ORNL/Sub/81-21099/1&06

26 FEBRUARY 1982

REPORT EBT-P010

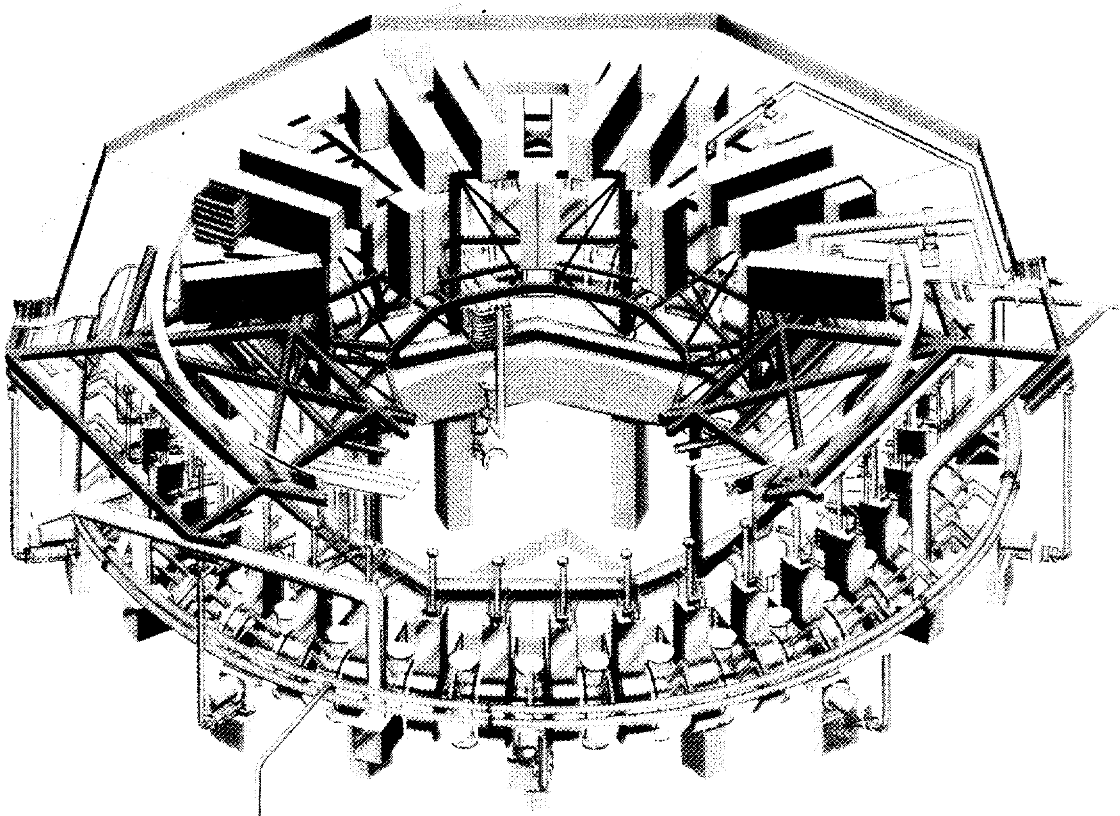
FUSION
ELMO BUMPY TORUS
ENERGY

Copy No. 3

Elmo Bumpy Torus Proof Of Principle

PHASE II — TITLE 1 REPORT

Volume VI INSTRUMENTATION AND CONTROL



MCDONNELL DOUGLAS ASTRONAUTICS COMPANY - ST. LOUIS DIVISION
Saint Louis, Missouri 63166 (314) 232-0232

MCDONNELL DOUGLAS
CORPORATION

PRELIMINARY DESIGN REPORT

INSTRUMENTATION AND CONTROL

VOLUME VI

PREPARED BY: R. J. Schmitt

R. J. Schmitt, Manager
EBT-P Instrumentation and Control

APPROVED BY: Harry F. Imster

H. F. Imster, Manager
EBT-P Engineering - MDAC

APPROVED BY: Roy J. DeBellis

R. J. DeBellis, Manager
EBT-P Project - MDAC

APPROVED BY: James D. Stout

J. D. Stout, Manager
EBT-P Engineering - ORNL

APPROVED BY: A. L. Boch

A. L. Boch, Manager
EBT-P Project - ORNL

Reference Index

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF PAGES

ii - xviii

1 - 330

A-1 - A-31

B-1 - B-3

C-1 - C-56

D-1 - D-5

E-1 - E-44

LIST OF FIGURES

LIST OF FIGURES (Continued)

FIGURE **PAGE**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF DRAWINGS

ACRONYMS, ABBREVIATIONS AND INITIALISMS

ADC	Analog-to-Digital Converter
ADL	ADA Design Language
A & E	Architect and Engineering
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
BDDB	Baseline Design Data Book
BIT	Built-In-Test
BPI	Bits Per Inch
CAMAC	Computer Automated Measurement and Control
CDR	Critical Design Review
CPU	Central Processor Unit
CRC	Cyclical Redundancy Check
CRT	Cathode Ray Tube
C/SCS	Cost/Schedule Control System
DA	Driver Amplifier
DAS	Data Acquisition System
DMA	Direct Memory Access
DPDT	Double Pole-Double Throw
DSV	Device State Vector
DTL	Diode/Transistor Logic
EBT-P	Elmo Bumpy Torus-Proof of Principle
EBT-S	Elmp Bumpy Torus-Scale
ECRH	Electron Cyclotron Resonance Heating
EDC	Experiment Director Console
EIA	Electronic Industries Association
EMI	Electromagnetic Interference
FED	Fusion Energy Division
FPA	Final Power Amplifier
GFECC	Global Field Error Correction Coils
GHe	Gaseous Helium
GN_2	Gaseous Nitrogen
HV	High Voltage

ACRONYMS, ABBREVIATIONS AND INITIALISMS (Continued)

HVAC	Heating, Ventilation, Air Conditioning
I & C	Instrumentation and Control
ICRH	Ion Cyclotron Resonance Heating
IDR	Interim Design Review
I/O	Input/Output
I/P	Current-to-Pressure
IPA	Intermediate Power Amplifier
ISA	Instrument Society of America
IVR	Induction Voltage Regulator
KSC	Kinetic Systems Corporation
LAM	Look-At-Me
LHe	Liquid Helium
LN_2	Liquid Nitrogen
LPA	Low Power Amplifier
MCC	Master Control Console
MDAC-STL	McDonnell Douglas Astronautics Company - St. Louis Division
MDC	McDonnell Douglas Corporation
MFE	Magnetic Fusion Energy
MOS	Metal Oxide Semiconductor
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
ORNL	Oak Ridge National Laboratory
ORVIP	Oak Ridge Valley Industrial Park
PC	Programmable Controller
PDR	Preliminary Design Review
PODI	Plasma Operation Device Instrumentation
QPC	Quench Protection Circuit
QPS	Quench Protection System
RAM	Random Access Memory
RF	Radio Frequency
RFP	Request For Procurement
SCC	Secondary Control Center (Console)

ACRONYMS, ABBREVIATIONS AND INITIALISMS (Continued)

SDN	Software Development Notebook
SHD	Serial Highway Driver
SOW	Statement of Work
SRD	Software Requirements Document
TBD	To Be Determined
TF	Toroidal Field
T/R/F	Transformer/Rectifier/Filter
TTL	Transistor/Transistor Logic
TVL	Toroidal Vessel/Limiter
UBC	Universal Block Channel
UPS	Uninterruptable Power Supply
WBS	Work Breakdown Structure

1.0 INTRODUCTION AND SUMMARY

This document, Vol VI - EBT-P Instrumentation and Control Title I Design Report, contains details of the EBT-P Title I Instrumentation and Control (I & C) System design. It is a self-contained document which can be read apart from the other volumes comprising the EBT-P Title I Report. This document is a contract deliverable and provides the necessary detail to support the I & C design contained in the EBT-P project Baseline Design Data Book (BDDB).

The following project personnel have contributed to this volume:

- R. J. Schmitt - EBT-P I & C System Design Manager
- T. L. Weaver - EBT-P I & C Plasma Heating Systems Design Engineer
- B. A. Boyd - EBT-P I & C Data Acquisition and Control System Design Engineer
- G. A. Schmidt - EBT-P I & C Designer and Unigraphics Specialist

1.1 I & C SYSTEM OVERVIEW

This system consists of the integral components and interfaces listed in Table 1-1. In the following sections of this report these components and interfaces are detailed using the format:

- Design Criteria
- Design Details
- Supporting Analysis
- System Cost Estimate
- Schedule Details

The I & C system is organized into three major subsystems.

- Data Acquisition System (DAS)
- Sensor and Control Elements
- Device Control and Interlock System

Table 1-1. EBT-P I & C System Contents

- Integral Subsystems

  - Facility Computer
  - Microprocessor/Data Acquisition Systems (DAS)
  - Programmable Controller/Interlock System
  - Master Control Console (MCC)
  - Secondary Control Centers (SCC)
  - Experiment Direction Console
  - Master Timer Subsystem
  - Key Interlock Subsystem

- Primary Interfaces

  - Magnet I & C Interface
  - Vacuum I & C Interface
  - Cryogenic Distribution I & C Interface
  - ECRH I & C Interface
  - ICRH I & C Interface
  - TVL I & C Interface
  - Device Utilities I & C Interface
  - Helium Refrigerator I & C Interface
  - Plasma Operation Device Instrumentation (PODI) I & C Interface

- Secondary Interfaces

  - Grounding System Interface
  - Research Diagnostics Computer Network Interface
  - Research Diagnostics Microprocessor Interface
  - Personnel Safety Interface

The DAS components include CAMAC hardware, microprocessor subsystems, the facility computer, various digital data communication links and a backup system. The CAMAC components provide the interface between the DAS and selected sensor elements. The DAS microprocessors are DEC PDP 11/23 units which are linked to the CAMAC dataway via CAMAC serial highway links. Each microprocessor is configured as a stand-alone unit with the following peripherals:

- 128 Kbyte MOS memory
- 10 Mbyte mini-Winchester disk unit with 1 Mbyte floppy disk backup
- CRT terminal with keyboard
- EIA serial interface unit (4 channel)

The function of the microprocessor unit is to buffer the data stream from the CAMAC unit and to transmit data in real-time to the facility computer. The buffer function is a backup measure to enable EBT-P device operation to continue in event of a facility computer malfunction. Additional backup capability is provided by a backup microprocessor dedicated to a CAMAC serial highway which interconnects all CAMAC crates in the DAS. This backup measure handles faults in other DAS microprocessors by providing an alternate link between the facility computer and the CAMAC subsystem.

The facility computer is a Harris System 135 unit, a 24-bit machine with the following peripherals:

— Slash 6 Central Processor Unit (CPU)
— 768 Kbyte MOS memory
— Five 80 Mbyte disk units
— Four 9-track tape units
— One 800 line/minute printer
— One Versatec printer/plotter
— Eight CRT/keyboard terminals
— High speed hardware floating point unit
— Thirty-two 19.2 Kbit/sec serial I/O ports

The Harris 135 is a virtual-memory machine which employs the VULCAN real-time multitask operating system software. The facility computer has four major functions:

- Data acqusition and buffering services
- Data file merge operations and archiving functions

- Formatting of data streams for the real-time CRT displays at the EBT-P Master Control Console (MCC)
- Communication with the EBT-P local computer network which links the EBT-P ORVIP site to the ORNL Y-12 facility

The design of the DAS is driven largely by the requirement to support the EBT-P device operation. The data communication paths and the facility computer application software are configured to provide the fastest possible response to operator commands issued at the MCC for data display services. A requested data display will start to be generated on an MCC CRT unit within one second following an operator command input.

The sensors and control elements constitute the second major I & C subsystem. The largest part of this volume deals with the design of this subsystem. Each sensor or control element together with its signal transmitter, field cabling and power supply (if required) is considered to be an individual data or control channel. Table 1-2 shows the number of such channels associated with various I & C system interfaces.

Table 1-2 I & C System Data/Control Channel Statistics

I & C Interface	Data Channels	Control/Interlock Channels
Magnets	480	180
Vacuum	243	723
Cryogenic	189	452
ECRH Tube/Supply	826	1844
ECRH Distribution	528	264
Toroidal Vesser/Limiter	234	468
ICRH	98	176
Device Utilities*	200	100
	2798	4207

A large portion (~80%) of the sensor and control elements have been selected from available industrial process control instrumentation product lines. The remainer consists of commercially-available laboratory-type instrumentation. This result derives from reliability and cost-effectiveness trade studies made during the Title I design effort. The typical data channel is an industrial two-wire current loop which produces a 4-20 ma. DC output current signal proportional to a changing input variable (temperature, flow, pressure, liquid level, etc.). The typical control channel transmits a two-state (binary, discrete) signal at 0 VDC and +24 VDC for operating DC relays associated with various control elements (valves, AC power relays, etc.). The use of current loop and 0/24 VDC discrete signal levels provides a high degree of noise immunity. In addition, the signal transmitters are of the isolating type to permit separate signal reference grounds to be used at each end of the data channel without causing a noise-producing ground loop to occur. The design of the data and control channels supports a baseline sampling rate of 1 sample/second/channel. Selected channels are designed with higher sampling capability (up to 1000 samples/second/channel for diamagnetic loop channels, for example). The baseline sampling rate is appropriate for a steady-state device such as EBT-P in which most parameters associated with device operation with and without plasma change on relatively long time scales (many seconds, minutes, hours). It should be noted that even at the baseline sampling rate, large amounts of device operation data will accumulate in a short period of time due to the large number of channels required to monitor device operation. About 30 Mbytes of data will be accumulated for each hour of device operation. Consequently off-line, post-test data compression tasks are an important facility computer data base management function.

The third major I & C subsystem is the device control and interlock subsystem. Critical control and interlock functions are provided by industrial-type programmable controller (PC) units, Allen-Bradley Model PLC-3 units. Note that the DAS microprocessors and the facility computers do not participate in the control and interlock tasks required to support EBT-P device operation. This is a deliberate design feature which derives from considerations of reliability and backup functions. Industrial PC units are designed for high-reliability control service and have designed-in features which permit easy implementation of backup function. In contrast, the DAS microprocessors are general purpose units, not especially designed for critical control functions requiring high reliability, but suitable and cost effective for data acquisition tasks required to generate data display and the device operation history. These observations are true of the facility computer also.

Each PC unit consists of three components:

- Remote PC Input/Output (I/O) Units
- PC Central Processor Unit (CPU)
- Local PC I/O Units

The remote I/O units are located outside the EBT-P Control Room in close proximity to the torus and other support systems in the Test Center Building, the Mechanical Equipment Building and on the outdoor Power Supply Pad. The PC processor and a given remote I/O unit are interconnected by a single coaxial or twisted, shielded pair conductor, usually in excess of 100 feet in length. Digital data are transmitted via these links. This design feature has important cost implications because the field cables which connect sensor and control elements to the remote I/O units are significantly shorter than would be required otherwise. Shortened field cables result in lower installation and materials costs and higher noise and ground-loop immunity. Thus, the typical data channel transmits analog data via two-wire 4-20 ma current loop over a distance of 50-100 feet into the remote I/O unit and digital data via a high speed digital link over a distance of 100-1000 feet to the PC processor unit located in the EBT-P Control Room.

The PC processor units are programmed to provide sequential control and interlock functions for the EBT-P device subsystems. All control signals originate at operator control and display panels located in the Control Room are processed by PC software and sent via the PC remote I/O units to the device control elements. Use of software for this function, instead of a strictly hardwired logic interlock approach, is cost-effective in a complicated device such as EBT-P with hundreds of discrete control elements. Software control implementation also permits rapid reconfiguring of the control and interlock subsystem as the EBT-P device is upgraded.

The PC local I/O units connect the PC processor units with the control and display panels. By locating the PC local I/O units in close proximity to these panels, the amount of cabling required in the Control Room is greatly reduced.

A key design element of the device control and interlock system is the concept of supervisory control by menu selection. The start-up, steady-state operation and shut-down control processes each require operator intervention at various points in these sequences. These "normal-operation" processes are controlled and interlocked by PC software which the operator "executes" by various switch selections made at the Master Control Consoles and Secondary Control Consoles located in the Control Room. These normal-operation processes occur on much longer time scales than the PC processor scan time (10-20 msec). A class of fault conditions exist for the EBT-P device which occur on significantly shorter time scales and which cannot be adequately handled by the PC processor. Hardwired interlock circuits are used for these conditions (e.g.; the TF coil quench protection circuits, the gyrotron power supply crowbar trigger circuits).

The concept of supervisory control by menu selection influences the design of the control and display panel layouts by allowing a reduction in the amount of "button-pushing" and "switch-flipping" required of the operators. In a completely hardwired control and interlock system there is a general one-to-one correspondence between control elements (valves, relays, etc.) and control panel switches and indicators. In a device with the complexity of EBT-P there would be several thousand switches and indicators with attendant implications for installation cost, reliability and inadvertant actuation. These difficulties are minimized in the design of the MCC control panels by using a relatively small number of "process select" switches instead of large arrays of switches and indicators each connected to a single control element. The operator at the MCC station controls device operation by selecting processes which are to be executed by the PC processor software. This software interlocks these processes and then outputs the proper sequence of control signals to the individual device control elements. This approach allows the operator to concentrate on the higher-level system aspects of device functionality and, in addition, minimizes the number of personnel required for device operation. The PC software continuously monitors the active device processes and grants or denies permission for execution of additional requested processes depending on the status of various control and interlock signals and on the values of various sensor inputs (temperature, pressure, flow rate, etc.).

Control activities are centered at the EBT-P Master Control Console. The various MCC stations contain the following components:

a) Panels containing process select switches
b) A CRT terminal connected to the facility computer

c) A touch-screen overlay for b) for communicating with the facility computer to request desired data displays
d) A CRT display connected to the PC subsystem with touch panel overlay.

In addition, the vacuum system MCC station contains a color TV monitor connected to the closed-circuit plasma TV system. This monitor is used by the operators to qualitatively adjust plasma operation based on plasma luminance and color features.

1.2 EBT-P CONTROL ROOM

Major portions of the I & C system are located in the EBT-P Control Room, 4000 ft^2 total floor space, on Level Two of the Test Center Building. The Control Room is divided into three areas:

- Computer Room - 800 ft^2 raised floor
- Main Control Area - 1500 ft^2 non-raised floor
- Secondary Control Area - 1500 ft^2 non-raised floor

The Computer Room contains two large mainframe computers, the Harris System 135 facility computer and the DEC VAX 11/750 research diagnostics main computer. The 11/750 unit is part of the EBT-P research diagnostics system. The Main Control area contains the MCC, the Experiment Direction Console and a number of research diagnostics control stations. The Secondary Control Area contains instrumentation racks required for intial Phase III device operation and space for ~40 additional racks required for subsequent device upgrade. A full-height wall, with glass panels from the four feet-to-ceiling level, isolates the blower noise in the computer room from the other parts of the control room. AC power cables and data communication cables are routed beneath the raised floor in the computer room. In the secondary control area cables are routed between the instrumentation racks via overhead busduct. A ramp is provided per building code regulations for access to the raised floor area.

1.3 I & C EQUIPMENT LAYOUT

Trade studies conducted during Title I has resulted in placing selected I & C components outside the Control Room. Rack-mounted equipment on level one of the Test Center Building consists of PC remote I/O units and CAMAC crates required to support the ECRH and ICRH plasma heating systems and the plant systems in the Mechanical Equipment Building. On level two, corresponding equipment is located on the north balcony to support the magnet, cryogenic distribution, vacuum and TVL cooling systems. The balcony is elevated eleven feet above the level of the second floor to eliminate interferences with research diagnostics equipment located along the north wall of the shield room. I & C components on the power supply pad are housed in weather-proof NEMA enclosures and support the I & C requirements of the ECRH and ICRH main power supplies. All of these remotely-located components are connected to Control Room equipment by a relatively few number of high speed digital communication links (CAMAC serial highways, PC remote I/O twisted shielded pair cables). This design feature greatly reduces the lengths of field cables in the EBT-P facility.

1.4 FACILITY GROUND SYSTEM

Several features have been included in the design of the facility ground system to support the I & C system. These include:

a) A main earth electrode installed beneath the Test Center Building to provide a "1-ohm ground".
b) A single-point isolated instrumentation ground system for the Control Room anchored on the main earth electrode.
c) A multiply-connected RF ground scheme for the Test Center Building.

The main earth electrode consists of 25 or more vertical ground rods (0.75 in. dia. x 10' long copper-clad steel) driven into the soil on 40' centers and interconnected via 4/0 bare copper cables. For typical soil resistivity conditions at the EBT-P site, the resulting DC resistance to earth is $\sim 0.75\ \Omega$. The tops of selected vertical ground rods are accessible in order to connect trunk grounding cables to the earth electrode. The Control Room single-point high quality isolated instrumentation ground is configured as a tree structure. This grounding subsystem is isolated from building structure, instrumentation racks, cable tray and the AC power system code ground (green wire) and provides a signal reference for I & C signal channels all of which terminate in the Control Room.

Because of the high power RF equipment located in the EBT-P facility, grounding design requires multiply-connected paths to the earth electrode to control the flow of high frequency current in the building structure and in the ground system. The structure of the Test Center Building is bonded with jumper straps at joints in the I-beam and sheet metal structure and multiple straps are provided to connect building structure to the earth electrode. Likewise, cable trays and busduct are multiply-connected to the building structure to drain high frequency currents to the earth electrode. Instrumentation rack frame structure is bonded together via jumper straps and then multiply-connected to the earth electrode.

1.5 FACILITY COMPUTER SOFTWARE

Software development is a significant part of the I & C Phase II effort and design factors have been included to provide a suitably tested and documented software package for the facility computer. Facility computer software is developed as modules (tasks) which manage communication to the microprocessors, correlate device operation data into a consistent data base, drive the MCC displays and manage communication with the research diagnostics main ORVIP computer. These tasks are written in a high-level programming language (FORTRAN, Pascal, Ada) and typically consist of fewer than 100 lines of code each. Facility computer tasks operate concurrently in the VULCAN system environment and use common blocks and message-forwarding tasks for intercommunication and synchronization functions. File management tasks format data structures into retrievable records and files of records and use the magnetic tape units to generate the device history archive.

1.6 MICROPROCESSOR SOFTWARE

Microprocessor software performs conversions of binary data to engineering units, data scaling and primary parameter extraction (e.g. conversion of differential presure data to flow rate in gallons/min). Microprocessor software tasks are modular, concurrently-operating entitites in an RSX-11M environment. Tasks are provided to format incoming device data streams into displays on Secondary Control Center CRT terminals. Other microproprocessor tasks synchronize data acquisition events with the I & C system Master Timer. Specialized tasks are executed by the microprocessors to provide back-up functions in event of a facility computer malfunction. These tasks are written in a high level programming language (FORTRAN, Pascal, Ada).

1.7 PROGRAMMABLE CONTROLLER CONFIGURATION

The I & C system programmable controller subsystem is an interconnected group of six Allen-Bradley PLC-3 units. Each unit typically contains a 32K word program storage memory and provides control and interlock functions for one of the I & C system interfaces. The PLC-3 units intercommunicate via the Allen-Bradley Data Highway for cross-interlock purposes. Serial digital links (EIA) are provided to connect the PLC-3 units to the DAS microprocessors and to various color graphic CRT terminals located in the MCC and the SCC stations. PLC-3 programming is done via a software control language which emulates relay ladder logic diagrams. PC software performs control signal output functions, input interlocking, data acquisition, data storage via tables in memory, data transmission to DAS microprocessors, data and control element status display and commnication with other PC units.

1.8 EBT-P FACILITY COMMUNICATION LINKS

The I & C System is provided with several communication links to external systems and facilities. These include:

a) Serial asynchronous (RS232) digital links between the facility computer and various CRT/keyboard terminals located in the ORVIP Administration Building.
b) A parallel digital link between the facility computer and the main research diagnostics computer at the ORVIP site.
c) A high speed serial link between the facility computer and various research diagnostics microprocessors.

Link a) provides the EBT-P staff with convenient access to the facility computer for application software development, post-test data processing tasks and retrieval of archived data from previous experiments. Three to six such links are envisioned presently, although the number could increase to twelve or more as Phase III progresses.

Link b) is the means provided to transmit device operation data to the research diagnostics computer network. Various experimentalists require these data to assist in processing plasma-related data. Presently, this link has a minimum 100 Kbyte/sec bandwidth.

Link c), in effect, provides the opposite function of link b), i.e. the former is the means used by the operation staff to obtain research diagnostics data needed for device operation. Presently, this link is a CAMAC serial highway which links one of the DAS PDP 11/23 microprocessors with the CAMAC crates associated with the various research diagnostics.

1.9 ORGANIZATION OF THIS VOLUME

The information presented in this introductory/summary section is expanded in more detail in the following sections of this volume. Section 2.0 describes the purpose and scope of the I & C Title I design effort and lays out the basic design guidelines listed in developing the I & C system design. Section 3.0 expands on the previous section by providing the detailed design criteria established for each I & C system component and interface. Section 4.0 is the main portion of this volume which contains the design description of the I & C system in a top-down format. Section 5.0 details a number of analyses which have been made to select among alternative design options uncovered during the Title I effort. Section 6.0 presents detailed schedule data for Phase II. Section 7.0 lists the reference cited in this volume. Appendices include:

- I & C Equipment List - Appendix A
- Instrumentation Rack Identification - Appendix B
- Software Requirements Document - Appendix C
- Cost Data - Appendix D (separately bound)
- I & C Title I Drawings - Appendix E

2.0 PURPOSE AND SCOPE

This volume details the EBT-P Instrument and Control (I & C) system Title I design. The design includes hardware and software components for the data acquisition computers and the I & C programmable controllers. The material in this volume supports the design details contained in the Title I engineering drawing package for the I & C system. The Title I design required a number of analyses to select among alternative approaches for several design details (see Sec. 5.0). Appendix A contains the I & C Equipment List. Appendix B lists the I & C instrumentation rack identification. The Title I software design details are presented in the form of a Software Requirements Document (Appendix C).

The volume incorporates the I & C design as presented at the Preliminary Design Review (PDR) held at MDAC-STL, 1-2 September 81. The PDR resulted in a number of design modifications which are included here.

The I & C Title I effort has proceeded by a strict top-down design methodology. The aim has been to perform the necessary analyses and trade-studies at a systems level, rather than at a detailed level, to minimize the effort devoted to dead-end approaches. Figure 2-1 shows the scope of the Title I/II design and the line of demarcation between these two phases.

The ISA process diagrams are schematics which identify the sensor and control elements of a given I & C interface. These diagrams are employed to derive the basic layouts of each data/control channel and to show the locations of important I & C components in the facility. As the Title I design progressed it became evident that the length and number of field cables could be greatly reduced by placing certain I & C I/O components at several remote locations in the facility. This decision, in turn, determines the cable routing details.

The next level of design detail involves the layout of the instrumentation rack front panels, both for control room racks and for those racks located remote from the control room. The layout of the Master Control Console (MCC) front panels are developed at this level of detail. The layout of the control room floor plan is developed next along with cable tray routing details within the control room.

The I & C Title I design effort is completed by development of equipment lists for each I & C integral subsystem and interface. The costs of equipment are obtained for vendor-supplied items via budgetary quotes while engineering estimating procedures are used to determine labor costs. Schedules for Phase II I & C activities have been developed during Title I. Finally, the I & C requirements for AC power, grounding and links to computer facilities remote from the ORVIP site are developed. The first two of these have been input to the A & E subcontractor in the facilities Title I/II effort. The third requirement has been coordinated with ORNL since the desired link will be one with the ORNL Y-12 DEC-10 facility.

The design of software required to support the I & C system is developed during Title I in a top-down fashion. Software block diagrams, timing constraints, data structures and display formats form important inputs to this design. The Title I software design criteria are detailed in the Software Requirements Document (SRD).

Figure 2-1. I & C Title I/II Design Detail Levels

Title I

Hardware	Software
• ISA Process Diagrams (Bubble Diagrams)	• Software Module Block Diagrams
• Data Channel Basic Layouts	• Timing Constraints
• Remote I/O Component Configuration	• Data Structures
• Cable Routing Details	• Display Formats
• Instrumentation Rack Front-Panel Layouts	• Software Requirements Document
• Control Room Cable Layouts	
• MCC Front-Panel Layouts	
• Control Room Equipment Floor Plan	
• Title I Equipment Lists	
• Title I Cost/Schedule Estimates	
• I & C System AC Power Requirements	
• Ground System Design Features	
• Facility Remote Communication Links	

Title II

Hardware	Software
• Revised ISA Process Diagrams	• Software Module Flow Diagrams
• Data Channel Two-Wire Diagrams	• Detailed Timing Diagrams
• Remote I/O Rack Internal Wiring Diagrams	• Data Structure Architecture Diagrams
• Field Cable Wire Bundle Schematics	• Display Format Detailed Diagrams
• Cable Connector/Receptacle Pin Assignments	• Software Specification
• Control Room Rack Internal Wiring Diagrams	
• Control Room Cable Wire Bundle Schematics	

I & C Title I/II Design Detail Levels

Title II	Hardware	Software

- MCC Mockup
- MCC Internal Wiring Schematics
- Procurement Quotation Packages-Long Lead
- Procurement Quotation Packages-Short Lead
- Specifications For Rack Wiring Installation
- Specification For Field Cable Fabrication
- Facility Computer Installation At MDAC
- Calibration Practices Document
- Detailed I & C Installation Work Flow Diagram
- Remote Communication Links Revised Design
- I & C Interface To Research Diagnostics
- Plan For Transition To ORVIP Site
- Specifications For I & C Sub-Assembly Fabrication

3.0 DESIGN CRITERIA

This section describes the criteria established during Title I for designing the EBT-P I & C system. Three groups of criteria are used corresponding to the three major sections of the I & C system itself, viz:

- Design criteria for the I & C interfaces to the EBT-P device and facility;
- Design criteria for the I & C integral subsystems;
- Design criteria for other I & C system design details.

Criteria in the last category are established for;

- Kirk key interlock subsystem;
- Interface between the I & C system and the facility grounding system;
- Interfaces between the I & C system and the EBT-P research diagnostics;
- Interfaces between the I & C system and remote computer facilities.

Table 3-1 lists the I & C design criteria contained in the ORNL Request for Procurement (RFP), UCC-ND RFP No. 22-80414. These criteria were supplemented by additional post-RFP design criteria which resulted from meetings between MDAC and ORNL personnel (see Table 3-2).

TABLE 3-1 RFP Design Criteria - I & C Related

1) 16 hours continuous operation in a 24-hour period with hydrogen plasma
2) Operation of each gyrotron tube shall be independent from operation of all others for control and optimization of microwave output
3) Capability shall be included for adjustment and optimization of any or all individual tube operating parameters independently of all others
4) Facility should be configured to minimize the number of required personnel
5) Facility should be configured to centralize operation at a master control console

TABLE 3-1 RFP Design Criteria - I & C Related (Cont'd)

6) Steady-state operation
7) Six 60 GHz gryotrons and two 28 GHz gyrotrons
8) Upgrade compatibility: ECRH, ICRH, ARE coils
9) Inter- and Intra-System interlocks required
10) A computer-controlled data acquisition system shall be provided for EBT-P machine data
11) Control scheme and grounding/shielding shall stress personnel and equipment safety
12) MCC shall be equipped with graphic or semi-graphic displays to provide facility status information
13) I & C system shall provide initial support for ICRH switchgear, power supplies, amplifiers
14) Device cooldown shall require less than seven (7) days

TABLE 3-2 I & C Design Criteria - Post-RFP

1) One full-time operator per gyrotron/power supply unit
2) Device DAS is non-network; research diagnostics DAS is networked
3) Operation and control of research diagnostics shall be centralized and located in the control room
4) DAS and control system backups required (alternate paths for data and control)
5) One gyrotron per power supply
6) Link required between the facility computer and the research diagnostics computer network
7) Control room floorspace required for research diagnostics main computer (ORVIP network node)

3.1 GLOBAL DESIGN CRITERIA

Specific design criteria are detailed below in sections 3.2 thru 3.4. In addition, a number of general design criteria are applied globally. These include:

1) Commercially-available (i.e.; "catalog") components are used, wherever possible, in preference to custom-designed equipment (i.e.; "buy" decisions are favored over "make" options).
2) Designs which tend to minimize the size requirements for the operations crew are favored.
3) Designs which minimize the amount of hand labor required for fabrication and/or installation are favored.
4) Designs which allow fabrication/checkout of sub-assemblies prior to installation are favored. This factor has schedule implications.
5) Designs which permit reconfiguration via software modifications, rather than by hardware re-design, are favored.
6) The I & C design shall contain features which permit centralized control (in the Control Room) of all device and facility operations.
7) The I & C design shall provide for interlocking of every control circuit in the device/facility.
8) Display of data via computer-driven CRT displays is favored over use of discrete display hardware (analog/digital panel meters, strip chart recorders, etc.).
9) All sensor signals shall be conditioned and delivered to the facility computer for archival storage at TBD intervals (typically once per second).
10) The status of all device/facility control elements (valves, set-points, etc.) shall be delivered to the facility computer for archival storage at TBD intervals (typically once per second).
11) Supervisory set-point control and "man-in-the-loop" control strategies are the baseline. Completely automatic control of a given EBT-P device/facility sub-system is not baselined, but is not excluded.
12) Designs are favored which minimize the amount of "button-pushing" required of an operator to control device/facility functions at the centralized Master Control Console (MCC).
13) The facility computer and the data acquisition system (DAS) design shall provide data displays in real-time to support device/facility operation.

14) Commercially-available I & C components are arranged in the following order of preference:

    — Industrial I & C components
    — Laboratory I & C components
    — Custom-built I & C components

15) Software-implemented interlock strategies generally are given preference over hardwired approaches unless one or more overriding factors require the latter.
16) Preference is given to I & C components which provide optical or other kinds of signal isolation (for safety reasons and for ground-loop disruption).
17) Designs are favored which minimize the length of field cables.
18) Designs are favored in which signals can be multiplexed over high speed fiber optic signal links.
19) Designs are favored which permit cost-effective backup features to be incorporated both for data acquisition and for control purposes.
20) Designs are favored which employ software-implemented computer input strategies (e.g.; touch panels) rather than conventional typewriter keyboards. This approach minimizes the amount of command strings (keystrokes) which an operator must memorize to communicate with the I & C computers.
21) Designs are favored which contain inherent expansion capabilities to handle planned upgrades of the EBT-P device/facility without costly re-design of the I & C system.
22) Cost-effectiveness is an important design criteria (i.e.; all things being equal, the low bidder is the winner).
23) The DAS (facility computer/microprocessors/CAMAC) shall not be involved in control/interlock functions. These functions shall be handled by the programmable controllers exclusively.

These global design criteria are influential in establishing specific design criteria described below. The I & C Title I design is almost entirely based on currently-available (mid-1981) components. Anticipation of future available components is minimized and occurs primarily for the DAS microprocessors. These components (specifically, packaged DEC PDP 11/23 microprocessor systems) are rapidly evolving such that, by the end of Title II (late

1982) it can be reasonably expected that increasingly more cost-effective microprocessor systems will become commercially-available. A similar situation exists for CAMAC modules, for programmable controller I/O modules and for digital data communication hardware. Consequently, it is likely that such equipment, selected in Title I, will be replaced by more cost-effective selections during Title II.

3.2 DESIGN CRITERIA FOR I & C INTERFACES

The EBT-P I & C system is unique in the sense that it contains interfaces to all device and plant systems, without exception. This situation arises because of the centralized control criteria and because of the criteria requiring archiving of all device/facility operational data (the "device history" design criterion).

3.2.1 Signal Channel Concept - The I & C interfaces are implemented via the concept of the "signal channel". Figure 3-1 shows, schematically, the generic components of the two basic types of signal channel, the "data channel" and the "control channel". The data channel links sensors built into the device/facility systems to the CAMAC equipment which functions as the "front end" for the DAS microprocessors. Similarly, the control channel links sensors and control elements to the programmable controllers which provide the necessary control/interlock functions. Information transmitted via data channels is sent to the facility computer in real time (i.e.; with minimal delay) where it is both archived and re-formatted for display at the MCC. Note that the data channel is essentially a one-way communication path from sensor to MCC display. By contrast, a given control channel is either a path from sensor element to PC (a status input) or is a path from PC to control element (a control output). A typical status input is a position sensor signal which gives the status of a valve (OPEN/CLOSED). A typical control output is a demand signal sent by the PC to a valve (DEMAND OPEN/DEMAND CLOSED). During Title I it became evident that several subsidiary categories are required to specify the variety of signal channels in the design (see Table 3-3).

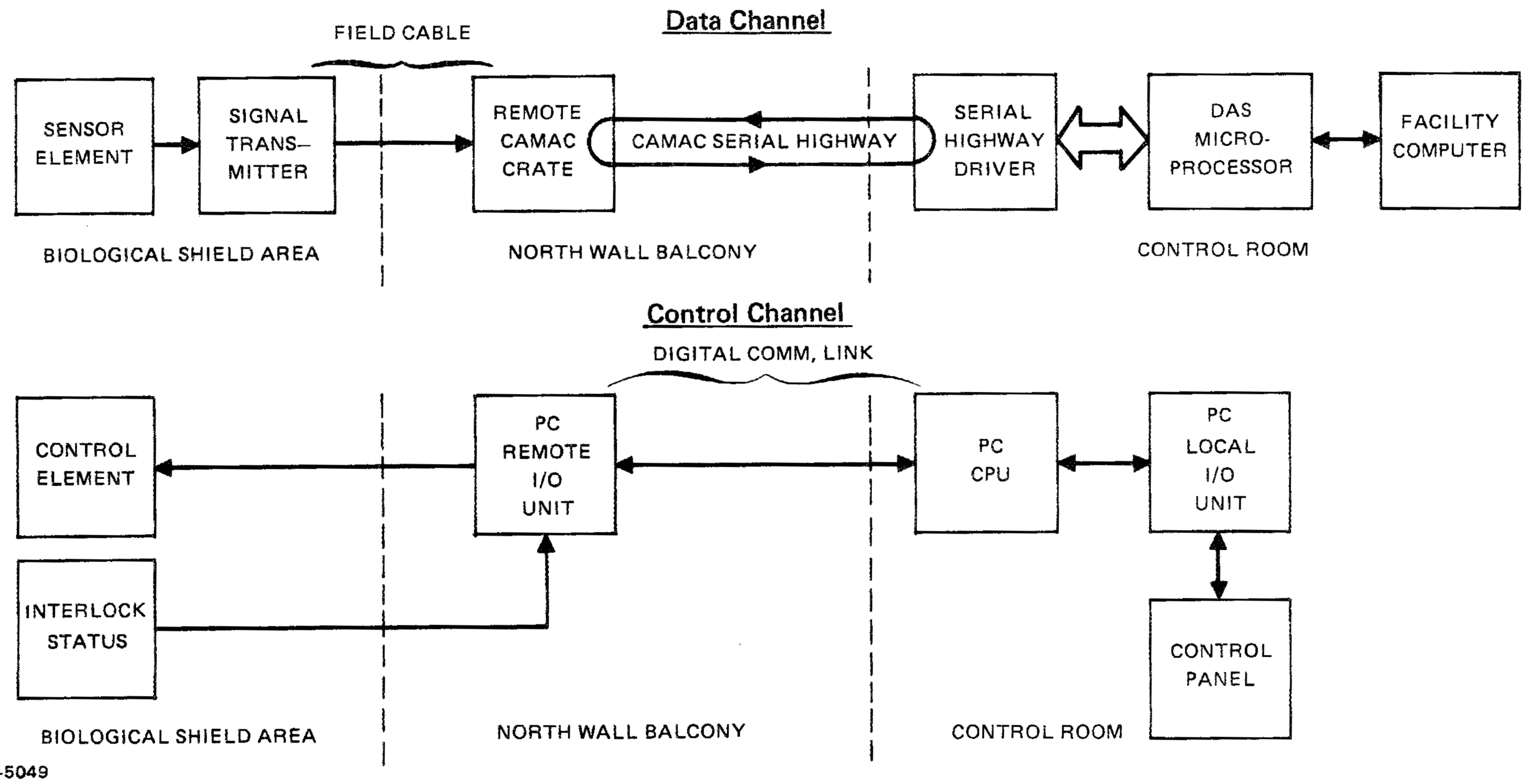


FIGURE 3–1 GENERIC SIGNAL CHANNEL BLOCK DIAGRAMS

Table 3-3. Signal Channel Definitions

Type Designation	Function
C	COMMAND OUTPUT
Q	DIAGNOSTIC INPUT
I	INTERLOCK/STATUS INPUT
O	OPERATING CONDITION-INTERLOCK INPUT
D	OPERATING CONDITION-DATA INPUT
F	WARNING/ALARM-INPUT
S	SETPOINT-OUTPUT

The specific design criteria for the generic signal channel are detailed next.

3.2.2 Sensors/Control Elements

- Specific Design Criteria

  - Sensors and control elements shall be compatible with the worst case EBT-P x-ray environment.
  - Sensors and control elements shall be fabricated of materials which will not perturb the EBT-P magnetic field.
  - Sensors and control elements shall be located such that the EBT-P fringe magnetic field will not degrade the function of these components.
  - Sensors and control elements shall operate normally in the microwave and RF EMI environment of the EBT-P device/facility.
  - Sensors shall be selected such that the re-calibration interval exceeds six (6) months.
  - Calibration techniques for sensors shall be either (in order of preference).

    a) In-place calibration, or
    b) Removal and calibration via bench set-ups.

- Organic components of control elements (e.g.; seals, potting) shall withstand the worse case EBT-P x-ray equipment for at least twelve (12) months.
- Hydraulic actuators shall not be used for control elements exposed to the EBT-P x-ray environment.
- Sensors/control elements requiring water cooling or attached to the EBT-P cooling systems shall be compatible with the EBT-P demineralized water cooling system.
- In those cases where sensors and/or control elements physically interface with research diagnostic access to the EBT-P plasma, the preferred solution shall be to relocate the former unless an excessive design impact thereby results.

• Implementation

- Vendor information on x-ray hardness of prospective sensors and control elements has been solicited during Title I.
- Material used to fabricate sensors and control elements have been screened by MDAC to determine susceptabilities to the EBT-P x-ray and magnetic environments.
- Sensors (e.g.; vacuum system ionization gauges) have been positioned such that the function of these components will not be degraded by the fringe magnetic fields.
- ORNL input has been obtained on research diagnostics envelopes and placement to resolve interferences with I & C system sensors/control elements.
- Pneumatic actuators are used exclusively.
- Flow, pressure, and differential temperature sensors and control valves selected for use in the toroidal vessel/limiter (TVL) cooling system have wetted parts fabricated of 304 stainless steel.
- Sensors have been selected such that RF filters can be inserted in the signal channel without degrading sensor function.

3.2.3 Signal Transmitters

- Specific Design Criteria

  - Signal transmitters shall be made compatible with the EBT-P worse case x-ray environment using minimal lead shielding.
  - Signal transmitters shall be located as close as practicable to sensor elements (i.e.; 72 inches or less).
  - For those sensors solidly grounded to the EBT-P device, isolating-type signal transmitters shall be used exclusively.
  - Signal transmitter output shall be two-wire 4-20 ma current loop signals with live zero level unless overriding considerations are present to choose otherwise.
  - Preference shall be given to signal transmitters having the smallest physical size to minimize the weight of lead shielding.
  - Signal transmitters shall be selected such that the re-calibration interval exceeds six (6) months.
  - Calibration techniques for signal transmitters shall be either (in order of preference).

    a) In-place calibration, or
    b) Removal and re-calibration via bench set-ups.

- Implementation

  - A survey of vendor-supplied industrial signal transmitters was made during Title I. The Analog Devices Model 2B52 has been selected as the best compromise.
  - Field transmitters required for use outside the concrete shield room are selected using cost-effectiveness criteria and are not required to meet x-ray hardness criteria.

3.2.4 Field Cables/Cable Trays/Cable Duct

- Specific Design Criteria

  — Field cables shall be selected that have materials compatibility with the EBT-P worst case x-ray environment.
  — Cable tray/duct shall be selected and positioned such that the EBT-P magnetic field is not perturbed.
  — Field cables/cable trays/cable ducts shall be positioned overhead at sufficient height above floor level such that personnel movement is not obstructed.
  — AC power cables shall not be routed in cable trays/cable duct carrying I & C system field cables.
  — Field cable shields shall be terminated such that signal return paths do not transmit common mode noise currents.
  — Twisted, shielded pair field cables with 100% shield coverage shall be the preferred type.

- Implementation

  — Field cables fabricated using cross-linked polyethylene insulation have been selected for x-ray hardness.
  — Cable trays/cable ducts have been positioned approximately 10 ft from the torus centerline to eliminate magnetic field perturbations and to provide personnel access to the EBT-P device.
  — Cable trays/cable ducts have been located at least eight (8) feet above floor level to prevent obstruction.
  — Field cable shield termination will be determined in the Title II design period when the final layout of the I & C signal channels has been established.

3.2.5 Remote I/O/Remote Instrumentation Racks

- Specific Design Criteria

  — Remote I/O designs shall be used whenever possible to minimize the length of field cables.
  — Remote instrumentation racks shall be located such that no physical interference occurs with research diagnostics equipment.
  — Remote I/O components shall be accessible for maintenance and/or replacement.
  — Remote I/O components shall be configured such that operation of these components is possible from the control room (e.g.; AC power ON/OFF).
  — Remote I/O components located outdoors shall be protected from environmental extremes.

- Implementation

  — Remote I/O components have been located in several areas of the EBT-P facility:

    a) On the North Wall Balcony in the Test Center Building, Level 2;
    b) On Level 1 of the Test Center Building (two locations);
    c) In the Mechanical Equipment Building (one location);
    d) On the Power Supply Pad (three locations).

  — Switches are located on control room panels to control AC power to these remote I/O components.
  — Remote I/O components in the Mechanical Equipment Building and on the Power Supply Pad (outdoors) are installed in weatherproof NEMA-4 enclosures. Heaters are installed in the outdoor NEMA-4 enclosures.

3.2.6 Digital Channel Links

- Specific Design Criteria

  — Both metallic and fiber optic digital links are permissable.
  — Fiber optic digital links are preferred to prevent hazardous voltages from entering the control room.
  — Bandwidth shall be sufficient to handle the maximum design data rates.
  — The digital data links shall be either of loop form (e.g.; CAMAC serial highway) or inherently bi-directional (e.g.; PC links between PC CPU and PC I/O units).

- Implementation

  — Digital channel links are of two types:

    a) Fiber-optic-implemented CAMAC serial highways;
    b) Digital links between PC remote I/O units and PC central processing units (CPUs).

  — The serial CAMAC fiber optic links isolate the control room components from all hazardous voltages.
  — The PC remote I/O modules handling binary signals (ON/OFF type) have 1500V rms optical isolation.
  — The PC remote I/O modules handling analog signals have thyristor over-voltage protection on the input conductors.

3.2.7 Control Room Instrumentation Racks/NEMA Enclosures

- Specific Design Criteria

  — A standardized instrumentation rack configuration shall be used except when overriding factors indicate otherwise in specific instances.
  — Cable routing design features shall be such that addition or removal of cables connected to these racks can be accomplished with minimal labor cost.

— Racks and NEMA enclosures shall be interfaced to the facility grounding system such that installed equipment functions properly.
— Racks and NEMA enclosures shall be interfaced to the facility grounding system such that personnel safety requirements are satisfied.
— Racks and NEMA enclosures shall be positioned such that adequate floor space is available for access to both front and rear entry points.
— Racks and NEMA enclosures shall carry suitable labels on the front panels to uniquely designate the rack/NEMA enclosure.
— Racks and NEMA enclosures greater than 72 inches in height shall be positioned preferentially near the walls of the control room unless overriding factors indicate otherwise.
— Racks and NEMA enclosures shall be positioned on the control room floor area in a functionally logical arrangement, preferably using the I & C interface schema.

- Implementation

— Standard ANSI 19 inch instrumentation racks are used in the EBT-P Control Room.
— Standard NEMA-12 enclosures are used in the EBT-P Control Room.
— Overhead cables trays/ducts with drop-down hardware are used to route I & C signal channel cables, AC power circuits and ground wires to the instrumentation racks and NEMA enclosures.
— AC power circuits are enclosed in steel cable ducts to prevent noise coupling to I & C signal channel cables.
— Instrumentation racks and NEMA enclosures are electrically isolated from the control room floor.
— The NEC AC power ground (green wire) is attached to the metal structure of each instrumentation rack and NEMA enclosure per code requirements.
— Multi-bay racks are provided with metal straps connecting individual rack frames.
— A secondary ground wire is attached to single/multi-bay racks such that the rack is electrically connected to the facility main ground electrode buried beneath the Test Center Building.

3.3 DESIGN CRITERIA FOR I & C INTEGRAL SUBSYSTEMS

The interface between the I & C signal channels and the I & C integral subsystem is located at the Data Acquisition System (DAS) microprocessors and at the programmable controller central processing units (PC CPUs). These components are located in the control room instrumentation racks and in the NEMA enclosures, respectively. This interface has both hardware and software aspects. The design criteria for the latter are detailed in the Software Requirements Document (SRD), Appendix C. This section concerns the design criteria related to the hardware aspects of the I & C integral subsystems.

The components comprising the I & C integral subsystems are:

- Facility Computer
- Microprocessor DAS
- Programmable Controller/Interlock Subsystem
- Master Control Console (MCC)
- Experiment Director Console
- Master Timer
- Secondary Control Subsystem

The specific design criteria for these subsystems are detailed next.

3.3.1 Facility Computer

- Specific Design Criteria
  - — The facility computer shall record the device operation history using the data supplied by the DAS microprocessors and the PC units.
  - — The facility computer shall support device operation by formatting selected parts of the data base into tabular and/or graphical displays for use by the operation crew at the Master Control Console (MCC) and at the Experiment Director Console (EDC).
  - — Data displays shall be generated with minimal delay (real-time response to operator demands).

- The facility computer shall not provide any control or interlocking functions for either the EBT-P device or facility.
- The facility computer shall contain an interface to the EBT-P research diagnostics computer network.
- The facility computer shall not require computer network assistance to perform its basic mission, i.e. to support the operation of the EBT-P device/facility operation via data acquisition, archiving and data display services.
- The facility computer shall have sufficient main memory and mass storage capacities to handle all anticipated data loads generated by EBT-P baseline and upgrade operation.
- The facility computer shall have sufficient reliability to operate without a dual-system backup.
- The facility computer shall require no more than 400 ft^2 of control room floor space.
- The facility computer shall support multi-user, multi-task real time operation.
- The facility computer shall be capable of unattended operation, i.e. a full-time computer operator shall not be required to support normal operational modes.

• Implementation

- The EBT-P computer is a Harris System 135 unit with 768K byte of main memory, 400M byte disk capacity and four 9-track magnetic tape units.
- The Harris VULCAN operating system is used to provide multi-user, multi-task real time capability.
- The H135 has thirty-two (32) serial I/O ports, each of which has 19.2K bit/sec capacity. Sixteen serial ports are required for the baseline EBT-P data loads.
- The H135 operates unattended on a three shift basis. Mounting and dismounting of magnetic tape reels is the typical task requiring operator intervention.
- MDAC-STL experience with H135 systems has shown that the expected failure rate is less than one hardware and one operating system fault per year of operation.
- The VULCAN system supports batch processing. This feature allows off-line data processing tasks to be queued for three shift service.

— A high speed (100K byte/sec) parallel interface connects the H135 system to the EPT-P research diagnostics computer network.
— The H135 system processes device/facility data streams via real-time, concurrently-executing programs (tasks).

3.3.2 Microprocessor/DAS Subsystem

- Specific Design Criteria

  — The microprocessor/DAS subsystem shall function as the interface between the facility computer and a selected group of device/facility sensors (Class A sensors).
  — The microprocessor units, in turn, shall employ CAMAC hardware as the basic interface to the Class A sensors.
  — The microprocessor units shall be identical in hardware and system software configuration.
  — The microprocessor units shall be configured as independent, stand-alone subsystems capable of operation completely independent of the facility computer.
  — The microprocessor subsystem shall function as a backup for the facility computer data archiving function.
  — The microprocessor subsystem shall contain backup features which will permit continual operation with one or more faulted microprocessor units.
  — The microprocessor units shall be located within the EBT-P Control Room.
  — The microprocessor units shall not be part of any critical control/interlock circuit upon which EBT-P device/facility operation is dependent.
  — The microprocessor/DAS subsystem shall provide electrical isolation to prevent hazardous voltages from entering the control room.

- Implementation

  — The EBT-P microprocessor units are PDP11/23 microprocessors with the following capabilities:

- 128K byte memory
- 10M byte Winchester disk
- 1M byte backup floppy disk
- Four 19.2K bit/sec serial data communication links
- One CRT/keyboard terminal.

— A backup CAMAC serial highway interconnects all CAMAC crates and provides an alternate path to the facility computer. This feature provides backup in the event of a fault in one or more microprocessor units.

— The PDP11/23 units use the RSX-11M operating system to provide multi-user, multi-task real-time computing capability.

— The PDP11/23 units and associated CRT terminals form a secondary display subsystem which provides backup for the facility computer and the MCC.

— Fiber-optic CAMAC serial highway links are used to provide electrical isolation between control room equipment and the EBT-P device/facility components.

3.3.3 Programmable Controller/Interlock Subsystem

- Specific Design Criteria

— All EBT-P device/facility control and interlock functions shall be provided by industrial programmable controllers (PC's).

— All control signals shall originate at control panels located in the EBT-P Control Room and shall be connected to the PC input/output (I/O) interface.

— All interlock signals shall be provided by either control element status indicators or by Class B sensors, both of which shall be connected to the PC I/O interface.

— The PC units shall maintain a continuous record of control and interlock element status and shall transmit these data to the facility computer upon demand.

— The PC units shall utilize CRT terminals to display control and interlock status information. These terminals shall be located at the MCC and at the secondary control consoles (SCC).

— Backup features shall be designed into the PC subsystem such that normal device/facility operation is not compromised by the failure of a single PC central processor unit (CPU).

— The PC CPUs shall be located in the EBT-P Control Room.
— PC I/O components shall be located in close proximity to control and interlock elements to minimize the lengths of field cables.
— The PC I/O interface shall provide suitable electrical isolation to prevent hazardous voltages from entering the EBT-P Control Room.

- Implementation

— The baseline PC unit is the Allen-Bradley PLC-3 series PC.
— Six PLC-3 units are used to control and interlock the EBT-P device/facility.
— Switch units are provided to connect portions of the PC I/O interface among the PLC-3 units. A faulted PC unit can be isolated from the PC I/O interface by means of these switches.
— Two types of electrical isolation are provided by the PLC-3 I/O modules:

a) Discrete (binary) I/O points are provided with optical isolator units with 1500V RMS standoff capability.
b) Analog I/O points are provided with thyristor over voltage protection at module input ports.

— The PLC-3 units contain several RS-232 ports for communicating with the micro-processors and with CRT display terminals.

3.3.4 Master Control Console (MCC)

- Specific Design Criteria

— Control of all EBT-P device/facility functions shall be centralized at the MCC, located in the EBT-P Control Room.
— The MCC control panels shall be designed to minimize the amount of "button-pushing" required of the operation personnel.
— The MCC stations shall contain two types of CRT displays:

a) CRT units driven by the facility computer

b) CRT units driven by the PC units

— The MCC stations shall be located in close proximity to each other on floor space not to exceed 400 ft^2 in total area.
— The MCC design shall be optimized to reduce the required number of operators to a practical minimum.
— The MCC shall be designed such that standard human factor recommendations are followed.
— The MCC design shall incorporate design features appropriate for a continuously manned control station.
— The MCC design shall incorporate design features which assist the requirements for MCC operator communication and cooperation.
— The MCC design shall contains standardized features to assist in cross-training MCC operators to operate several MCC stations.

• Implementation

— The EBT-P MCC design consists of sixteen standard 19" W x 48" H instrumentation racks.
— Seven operator stations are employed to provide centralized control of the following EBT-P systems:

a) Superconducting toroidal field magnets (1 station)
b) Cryogenic distribution (1 station)
c) Toroidal vessel/limiter cooling (1 station)
d) Vacuum system (1 station)
e) 60 GHz ECRH system (2 stations)
f) 28 GHz ECRH system (1 station)
g) ICRH system (1 station)

— The eighth MCC station is the Chief Operation Station.

- Each MCC station contains a CRT terminal operated by the facility computer and a CRT terminal operated by one of the PC units. The CRT units have touch-sensitive transparent overlay screens for operator communications with the facility computer and PC unit.
- Each MCC station contains two control panels. The number of switches on these panels has been minimized. No MCC control panel contains more than fifty (50) control switches.
- MCC control panels are designed to standard human factors recommendations appropriate for a 50TH percentile adult male operator.
- MCC control panel components are arranged such that logical flow of control operations occurs from left-to-right and from top-to-bottom.
- The MCC stations are designed to accommodate seated operators. Sufficient floor and leg space are available for operator convenience.
- The MCC stations are arranged in a floor plan which places operators sufficiently close together to permit oral communication in normal speaking tone and volume. MCC operators are able to view CRT displays at adjacent MCC stations with minimal physical discomfort.
- The MCC control panel components and CRT display formats are both standardized in physical arrangement and functionality such that operator cross-training is a simple and quick process.

3.3.5 Experiment Direction Console (EDC)

- Specific Design Criteria

  - The EBT-P EDC shall be located in close proximity to the MCC stations.
  - The EDC shall contain versatile CRT computer terminals driven by the facility computer.
  - The EDC shall provide graphical and tabular displays of all EBT-P device/facility signal channel data in response to operator demands.
  - The EDC shall not provide any control functions for the EBT-P device/facility.

- Implementation

  — The EDC is implemented using color graphics terminals connected to facility computer serial I/O ports.

3.3.6 Master Timer Subsystem

- Specific Design Criteria

  — The Master Timer shall provide the means to synchronize all EBT-P I & C system functions.
  — The Master Timer shall provide synchronization signals and time of day data to the facility computer, to the DAS microprocessors, to the PC units and to the research diagnostics microprocessors.
  — The synchronization signal shall have a nominal 0.1 sec resolution.
  — The internal clocks in the facility computer, DAS microprocessors, PC units and in the research diagnostics microprocessors shall re-synchronize themselves to the Master Timer at 10 minute intervals.

- Implementation

  — A crystal-controlled digital clock is used for the master timing function.
  — Parallel interfaces are used to interconnect the Master Timer to the I & C computers and to the research diagnostics microprocessors.
  — BCD-coded time-of-day signals (minutes, seconds, tenths of seconds) are provided by the Master Timer.
  — At each ten-minute re-synchronization point, the client processor clears the minutes, seconds and tenths of second registers and increments its "10-minute" register.
  — Between re-synchronizing points, the client processor can read the Master Timer BCD output directly, as required.

3.3.7 Secondary Control Center (SCC)

- Specific Design Criteria

  — The SCC shall provide the means to backup the control and display functions provided by the MCC and the EDC subsystems.
  — The SCC shall be located within the EBT-P Control Room.
  — The SCC shall be designed such that its operation is independent of the MCC stations and of the EDC. This criteria is necessary to remove the possibility that a fault in the MCC and EDC subsystems will degrade the operational capability of the SCC.
  — The SCC microprocessors shall provide data archiving backup for the EBT-P facility computer for limited periods of EBT-P operation.
  — The ECRH SCC units shall contain the necessary control panels and CRT displays to operate gyrotron tubes and power supplies. Control functions for the ECRH distribution system shall be centered at the ECRH MCC stations.
  — The ECRH SCC units shall consist of three (3) standard 19" W x 78" H instrumentation racks configured as a triple-rack unit.
  — The ECRH SCC unit shall be configured according to standard human factors recommendations appropriate for a continuously-manned control station.
  — Each ECRH SCC unit shall be designed according to the global design criterion requiring one continuously-present operator for each ECRH gyrotron/power supply unit.
  — The ECRH SCC configuration shall be designed such that additional such units can be added with mininal cost/schedule impact to handle anticipated Phase III upgrades. Sufficient control room floor space shall be pre-allocated to accommodate these upgrades.
  — The previously-stated specific design criteria for the ECRH SCC units shall be applied, mutatis mutandi, to the ICRH SCC units.

- Implementation

  — The SCC function is provided by the DAS microprocessor units and by secondary control panels attached to the PC I/O structure.

- — The microprocessor units and the secondary control panels are located within the EBT-P Control Room in standard 19 inch instrumentation racks. These racks are positioned around the periphery of the control room near the interior walls.
- — The microprocessor units contain sufficient disk storage capacity to backup the facility computer data archiving function for approximately one hour of device operation at the nominal per channel data rate (1 sample/channel/sec).
- — The SCC contains CRT terminals driven by the DAS microprocessors and by the PC units. These terminals operate independent of the MCC CRT terminals and of the EDC graphical display terminals. The SCC terminals provide data displays upon receipt of operator demands to enable device/facility operation to continue in event of failures in the facility computer, MCC and/or EDC.
- — The ECRH SCC triple-rack units are arranged in a general linear layout such that control panels and CRT-displays are positioned appropriate for the 50TH percentile adult male operator (seated).
- — The ECRH SCC units are designed according to requirements for a continously-present seated operator.
- — A general rectilinear arrangement is used for the ECRH SCC units reflecting the absence of a requirement for operators at these stations to be in continous visual and voice contact with each other.
- — The control room floor plan contains pre-allocated floor space for ECRH and for ICRH SCC upgrades.
- — A similar implementation corresponding to the ECRH SCC units has been provided for the ICRH SCC units.

3.4 SUPPLEMENTARY I & C DESIGN CRITERIA

The EBT-P I & C System has a number of interfaces which do not fall easily into the previously described categories of device/facility interfaces and I & C integral subsystems. These supplementary interfaces are:

a) The Kirk key interlock subsystem interface.
b) The I & C system interfaces to the facility grounding system.
c) The computer network interface.

d) I & C System interfaces to the EBT-P research diagnostics.
e) Personnel Safety interface

The specific design criteria for the supplementary interfaces follow.

3.4.1 Kirk Key Interlock Subsystem

- Specific Design Criteria

  — A Kirk key interlock system shall provide the primary level of interlocking for the EBT-P I & C System.
  — The Kirk key interlock system shall be designed such that supervisory personnel must perform a thorough "walk-around" through the EBT-P facility before device operation with plasma can be initiated.
  — MCC control panels shall be equipped with primary interlock Kirk key switches which must be locked into the "ON" position as a condition for control panel operation.
  — SCC control panels shall be equipped with primary interlock Kirk key switches which must be locked into the "ON" position as a condition for control panel operation.

- Implementation

  — Kirk key interlock transfer locks are located within the device shield room on both levels. A supervisor must perform a "walk-around" inspection in order to retrieve captive keys from these transfer locks.
  — The four maze entrances to the shield room contain gate locks with captive keys. These gates must be closed and locked by supervisory personnel in order to retrieve captive keys from these locks.
  — Cages located on Level One of the Test Center Building have gates with captive keys. These gates must be closed and locked by supervisory personnel in order to retrieve captive keys from these locks.

- The fence surrounding the Power Supply Pad has several gates each with a captive key. These gates must be closed and locked by supervisory personnel in order to retrieve captive keys from these locks.
- A central Kirk transfer lock is located in the EBT-P Control Room. Supervisory personnel must use the keys retrieved in the "walk-around" to release the keys required to unlock the MCC and the secondary control panels. The EBT-P device operation cannot be initiated until key switches on these control panels have been unlocked and set to the ON position.

3.4.2 Ground System Interface

- Specific Design Criteria
  - An isolated single point ground system shall be provided as required to support the EBT-P I & C system.
  - All I & C instrumentation racks/cable tray/bus duct shall be grounded per NEC code requirements (AC power system green wire).
  - All cable tray/bus duct/conduit shall be multiply-connected to the steel building structure to drain RF currents to ground.
  - The EBT-P device shall be multiply-connected to the facility ground system.
  - The facility ground system shall be designed such that the effective DC resistance to earth is $\leqslant 1$ ohm.

- Implementation
  - I & C instrumentation racks contain an isolated copper buss connected to the isolated single point ground subsystem to provide a high-quality signal reference path.
  - Instrumentation rack frames are electrically interconnected via metal straps and then connected to the facility ground earth electrode using 2/0 insulated copper cables.
  - The AC power system green wire is electrically connected to each I & C instrumentation rack.

— Remote I/O units and remote instrumentation racks contain isolated high quality ground subsystems for signal referencing purposes. Ground loops which can occur in these multiply-grounded signal channels are broken via isolation-type signal transmitters, optical isolation and/or via use of fiber-optic cables.

3.4.3 Computer Network Interface

- Specific Design Criteria

  — The EBT-P I & C system shall contain an interface to the research diagnostics computer network.
  — The basic function of the EBT-P I & C system, to support the operations of the EBT-P device/facility, shall <u>not</u> depend on the integrity of the computer network interface.
  — Computer network operations shall <u>not</u> compromise the basic function of the EBT-P I & C system.
  — EBT-P device/facility archival data shall be transmitted to the research diagnostics computer network with minimal delay.

- Implementation

  — The computer network interface links the Harris 135 facility computer to the main EBT-P research diagnostics computer, a VAX11/750 located in the EBT-P Computer Room at the ORVIP site.
  — The computer network interface is a parallel link with a 100K byte/sec or higher effective transmission rate.
  — The facility computer executes a data retrieval program in response to demands for transmission of archival data stored in the Harris 135 system.

3.4.4 Research Diagnostics Interface

- Specific Design Criteria

  — The EBT-P I & C system shall contain an interface to the research diagnostics.

— This interface shall link the Harris 135 facility computer to the research diagnostics microprocessor subsystem.
— The primary function of this interface shall be to provide research diagnostics data required for operation of the EBT-P device.

- Implementation

— The Harris 135 is linked to the research diagnostics via a PDP11/23 microprocessor unit using a 19.2K bit/sec serial digital link.
— The PDP11/23 communicates with the research diagnostics CAMAC crates via a dedicated CAMAC serial highway loop.

3.4.5 Personnel Safety Interface

- Specific Design Criteria

— X-ray monitors and appropriate alarm annunicators shall be provided to detect x-ray leakage from the biological shield pentrations.
— Microwave leakage shall be monitored near the gyrotron tubes.
— Rf leakage shall be monitored near the RF transmitter units.

- Implementation

— NaI (Tℓ) scintillation detectors (permanently installed) are used to monitor x-ray leakage from the four maze entrances in the biological shield.
— Portable x-ray survey monitors are used to locate small x-ray leakages at and around biological shield pentrations.
— Microwave horn/waveguide radiometers are used to detect leakage near the gyrotron output windows.
— Microwave dish antenna are used to detect millimeter wave leakage from the biological shield room.
— RF pickup loops are used to monitor leakage from the Final Power Amplifiers located in th ICRH screen room.

— RF pickup loops are positioned near the antenna tuning circuits to detect RF leakage.

4.0 DESIGN DESCRIPTION

This section contains details of the EBT-P I & C Title I design. This description follows the format of the previous section:

Section 4.1 - I & C Integral Subsystems Design Description
Section 4.2 - I & C Interfaces Design Description
Section 4.3 - Other I & C Design Details Description

This section concentrates on hardware details; details of I & C software requirements are found in Appendix C. Much of the design detail is arranged in tabular format (e.g.; Instrumentation Rack Identification, I & C Equipment List). These tabulations are accumulated and presented in the appendices since inclusion of these in this section would tend to divert the reader's attention from the design rationale, the essential content of this section.

Reference is made in this section to I & C engineering drawings which constitute the I & C Title I Drawing Tree. Table 4-1 shows the contents of this drawing tree. Several of these drawings have been included, on reduced scales, in this section.

The design detail has been developed during Title I using standard ISA process diagrams (called "bubble diagrams"). This format is a conventional, expressive and concise means for presenting important elements of design detail. Since some nomenclature and symbols may be unfamiliar, Table 4-2 is provided to define these symbols. In general, there is a one-to-one correspondence between the bubble symbols in a given process diagram and items on the corresponding equipment list.

Additional design detail is documented via several types of block diagrams (e.g.; signal channel diagrams, integral subsystems block diagrams). These block diagrams are schematic single-line figures which are used to show interconnections between major I & C components. The precise details of these links (e.g.; grounding, signal returns, shields, connectors, etc.) have not been developed during Title I. This level of detail will be developed in the Title II I & C effort using ISA standard two-wire schematics once ORNL-approval has been obtained for the basic link design.

Table 4-1. EBT-P I & C Title I Drawing Tree

Drawing No.	Title
70B378011	Control Room Floor Plan
70B378012	Wire Tray Routing/Penetrations - Control Room
70B378013	Instrumentation Rack Layouts - Control Room
70B378014	Master Control Console Layouts
70B378017	Test Support Area Floor Plans
70B378021	Wire Tray Routing - Test Support Building
70B378023	Basic Block Diagram
70B378024	Data Flow Logic Diagram

Table 4-2. ISA Nomenclature Used In This Section

ISA Symbols	Interpretation
FE	Flow Sensor
TDE	Differential Temperature Sensor
LE	Liquid Level Sensor
ZE	Position Sensor
PE	Pressure Sensor
TAH	Temperature Alarm, High Trip
FT	Flow Signal Transmitters
TDT	Differential Temperature Signal Transmitter
LT	Level Signal Transmitter
C	Command Output From PC
Q	Diagnostic Input To PC
I	Interlock/Status Input To PC
O	Operating Condition Interlock Input To PC
D	Operating Condition Data Input To μproc
F	Warning/Alarm Input To μproc
S	Setpoint Output From PC
SW	PC Software Interlock Point

Important elements of the I & C Title I design are contained in the layouts of the SCC instrumentation racks and of the MCC stations. This section describes the layout of these components from a frontal view showing arrangement of rack components and of switches and displays on individual control/display panels. Details of internal MCC and SCC wiring will be developed later during Title II work.

The I&C System Basic Block Diagram is shown in Figure 4.0-1. The EBT-P device/facility is represented here in terms of the various sensors and control elements. The DAS/CAMAC subsystem connects Class A sensors to the facility computer via CAMAC serial highways and numerous RS422 links. Similiarly, the PC-implemented control/interlock system links the Class B sensors and device/facility controls to the MCC and SCC control/display units. Paths are provided, in addition, for data to flow from the PC CPUs through the DAS microprocessor units to the facility computer. Data displays at the MCC statues are driven both by the facility computer and by the PC CPUs. Likewise, SCC data displays are driven by the DAS microprocessors and by the PC CPUs. Note that all control inputs pass through the PC local I/O units for interlocking purposes.

Table 4.3 supplies the cross-references between the three major I & C Work Breakdown Structure (WBS) elements and the relevant subsections of Section 4.0.

Table 4-3. I & C WBS Element/Section 4.0 Cross-Reference

I & C WBS ELEMENT	I & C TITLE I REPORT - APPLICABLE SECTIONS
3.5.1 Data Acquisition System	4.1.4, 4.1.5, 4.1.11, 4.3.2, 4.3.3
3.5.2 Device Instrumentation	4.1.1, 4.1.2, 4.1.3, 4.2.1, 4.2.2, 4.2.3, 4.2.4, 4.2.5, 4.2.6, 4.2.7, 4.2.8, 4.2.9
3.5.3 Safety Instrumentation	4.1.6, 4.1.7, 4.1.8, 4.1.9, 4.1.10, 4.3.1, 4.3.4

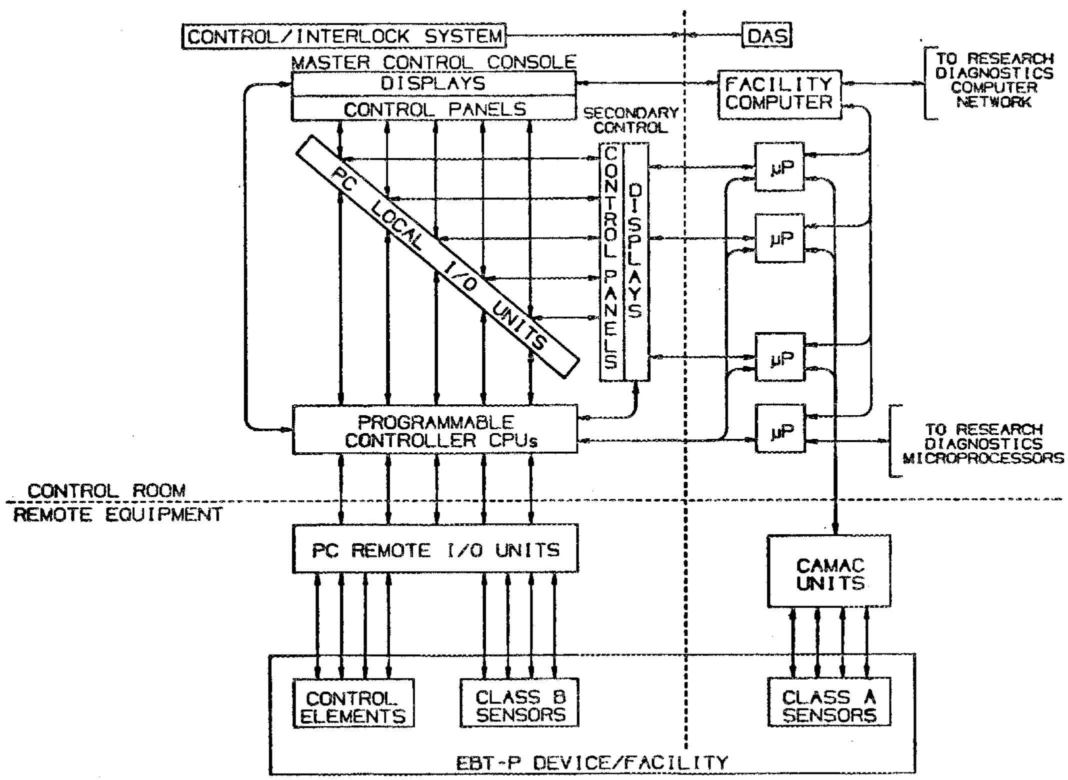


FIGURE 4.0–1 I&C SYSTEM BASIC BLOCK DIAGRAM

4.1 I & C INTEGRAL SUBSYSTEMS

This section contains design details for the I & C Integral Subsystems. The section begins with descriptions of the Control Room layout, field cable routing details and the layout of the North Wall Balcony equipment. The remaining subsections contain descriptions of the facility computer configuration, the DAS microprocessor subsystem, the PC control/interlock subsystem, the MCC configuration, the Secondary Control Center (SCC) layout, the key interlock subsystem, the Experiment Direction Console (EDC) and the Master Timer subsystem. The equipment list for the integral subsystems is contained in Appendix A. The field cable routing is included in this section, even though considered part of the I & C Interface, to unify the description of the I & C System as it relates to the EBT-P facility.

4.1.1 Control Room Layout - This layout is shown in Figure 4.1.1-1 (I & C Drawing No. 70B378011). The Control Room consists of two areas, the computer room and the device/facility control area. The computer room is an $\sim$ 800 ft^2 raised-floor area containing the Harris System 135 facility computer and the main research diagnostics computer. The latter is tentatively configured as a DEC VAX 11/780 system, although the exact configuration remains to be established. A full-height wall separates the two control room area and effectively isolates the larger portion of the control room from blower noise associated with the two large computers. Several windows are provided along with glass doors for personnel convenience. OSHA regulations require a ramp to provide access to the raised floor area.

The device/facility control area (non-raised floor area of $\sim$ 3500 ft^2) contains the EDC, the MCC, the SCC and floor space for twenty research diagnostic work stations. The MCC stations are arranged in a rectangular pattern. This arrangement centralizes the principal control area on $\sim$ 700 ft^2 and permits the MCC operations staff to interact efficiently with the Experiment Director. Also, this arrangement uses the available floor space in an efficient way. The MCC contains six stations for control of device systems (magnets, cryogenics, vacuum, 28 GHz ECRH, 60GHz ECRH and ICRH). Another MCC station is designated the Experiment Direction Console (EDC) and contains three substations (Chief Operator's Station, Experiment Director's Station and the Diagnostics Data Coordinator's

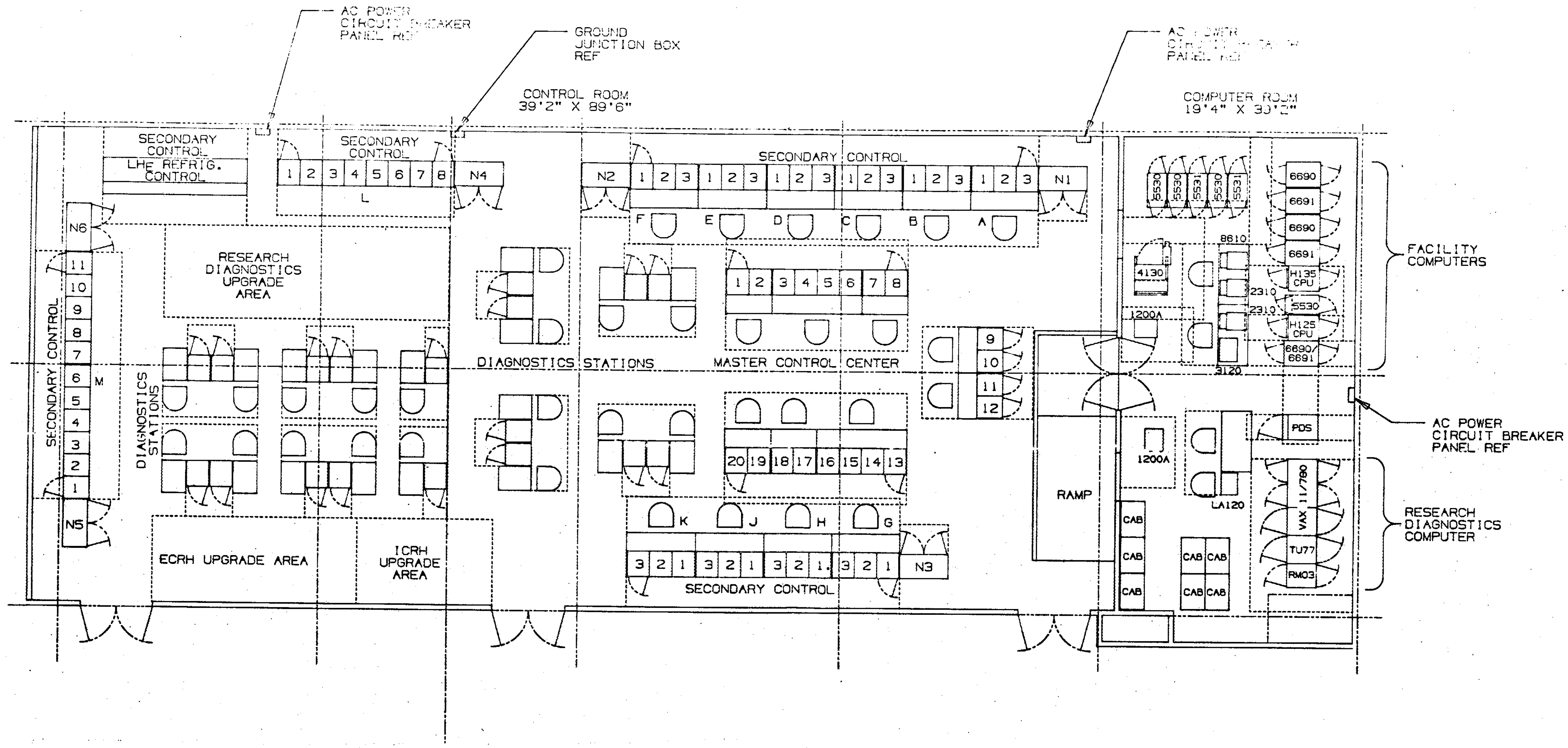


FIGURE 4.1.1–1 CONTROL ROOM LAYOUT

Station). Eight additional MCC stations are used to control important research diagnostics equipment.

The SCC components are located around the periphery of the device/facility control area. SCC units A, B, C, D, E and F are associated with the six 60 GHz gyrotron systems. Each gyrotron SCC unit consists of three instrumentation racks (standard 19"W x 78"H units). According to the present baseline,the ECRH SCC units are each continuously manned by an operator during normal EBT-P operations. Consequently, these SCC units are located as close as possible to the EDC/MCC area.

SCC units G and H are associated with the 28 GHz gyrotron systems, while units J and K are associated with the two 500 kW ICRH systems. Each of these units contain three standard instrumentation racks and are assumed to be manned by an operator during normal EBT-P plasma operations. Sufficient additional floor space is provided to accommodate two more ICRH SCC units required for planned Phase III upgrades.

A set of eight instrumentation racks (designated L-1 thru L-8) are provided to function as the SCC areas for the toroidal vessel/limiter (TVL) cooling system and for the device utilities system. These SCC units normally are not manned during EBT-P plasma operations.

A set of eleven instrumentation racks (designated M-1 thru M-11) function as the SCC areas for the vacuum system (M-1 and M-2), for the magnet system (M-3 thru M-9) and for the cryogenic distribution system (M-10 and M-11). These SCC units normally are not manned during EBT-P plasma operations.

The remaining SCC unit is the helium refrigerator local control console, a stand-up control unit containing a mimic display showing the flow paths associated with the refrigerator. This SCC unit normally is not manned during the EBT-P plasma operations.

The SCC area contains six NEMA-12 enclosures (designated N-1 thru N-6). These enclosures are 48"W x 72"H x 20"D units and contain the PC CPUs and PC local I/O units. PC hardware is configured to fit easily into NEMA-12-type enclosures and is relatively difficult to install in standard 19" instrumentation racks.

Twelve (12) research diagnostic work stations are positioned in the central part of the device/facility control area. Each of these stations consist of a table and a standard 19"W x 78"H instrumentation rack. Typically, the table supports a CRT/keyboard terminal while the rack contains microprocessor and CAMAC-related hardware. Sufficient additional floor space is provided to permit ten (10) new work stations to be added as new diagnostics are brought on line during Phase III.

Since the device/facility control area is a non-raised floor area, overhead cable duct is used to route ac power, grounding and I & C signal cables between the racks located therein (see Figure 4.1.1-2). These ducts are compartmentalized such that ac power conductors are isolated from I & C signal cables. Cabling routed to the computer room is placed beneath the raised flooring in that area.

4.1.2 Field Cable Routing - The layout of the field cables is shown in Figures 4.1.2-1 thru 4.12-4 (I & C Drawing 70B378021). The field cables are laid in ladder-type cable trays inside the Test Center Building and in the Mechanical Equipment Building. Those field cables which extend to the outdoor Power Supply Pad are laid in closed cable ducts with sealed covers. Note that these cable trays/ducts contain I & C system field cables (instrumentation cables) only and do not contain power cables (either ac or dc type). Power cables are routed separately away from the I & C field cables and generally follow the shortest path from power source to load.

Figure 4.1.2-1 shows the field cable trays on level 2 of the Torus Room. The cable trays here are configured in an octagonal pattern with three cable bridges to carry the cables through the thick concrete wall. The octagonal tray is 24" wide x 4" deep on the north, ease and west sides and 12"W x 4"D on the south side. The smaller size tray is used to reduce interference with assorted plumbing and structure which enters through the south wall of the concrete biological shield. The octagonal cable tray is positioned 109.25 inches above the horizontal midplane of the torus.

A cable bridge connects the octagonal cable tray to the cable penetration area on the north wall of the biological shield room. Another cable tray runs along the interior of the shield room at the 109.25 inch elevation and intersects the cable bridge. The field cables associated with various research diagnostics are laid in these cable trays. Cables laid in the octago-

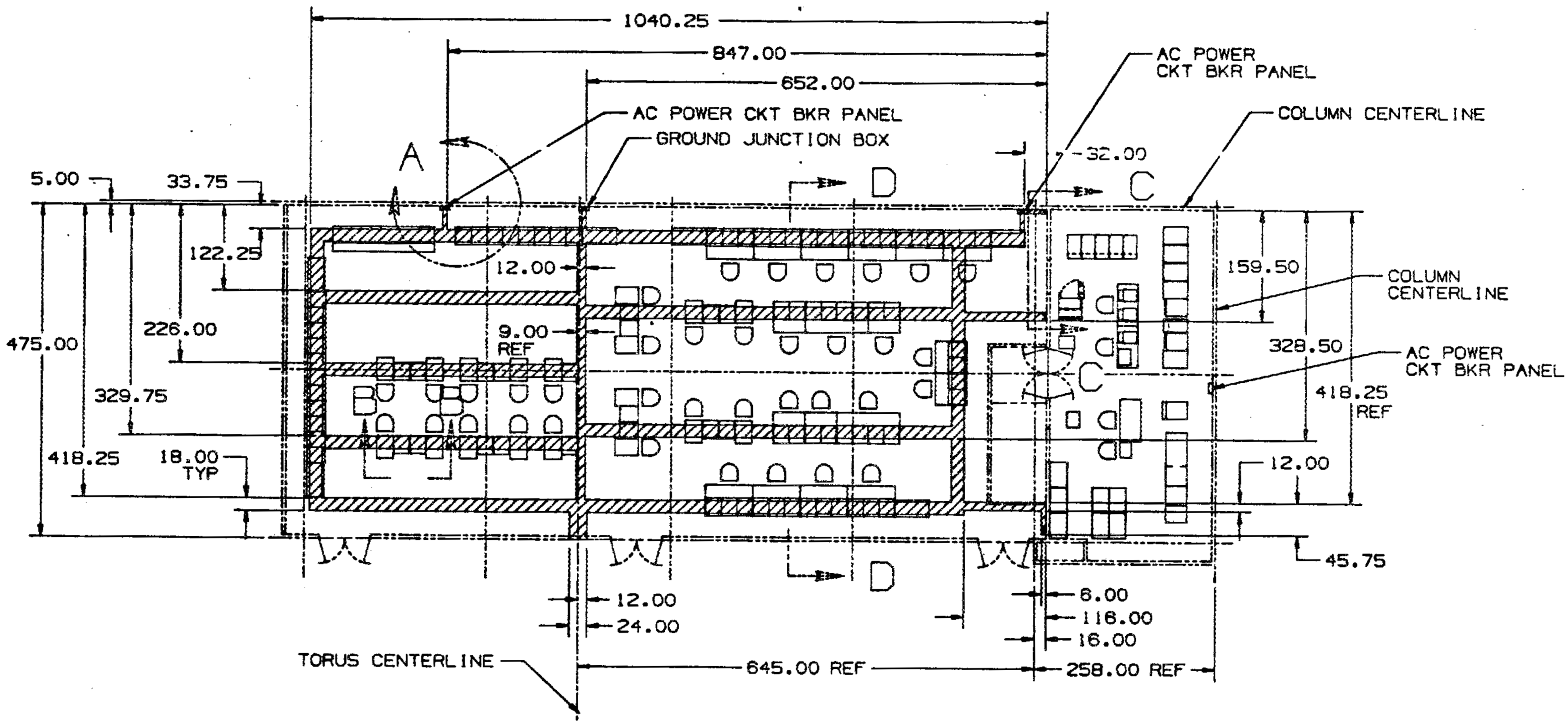


FIGURE 4.1.1–2 CONTROL ROOM CABLE TRAY ROUTING

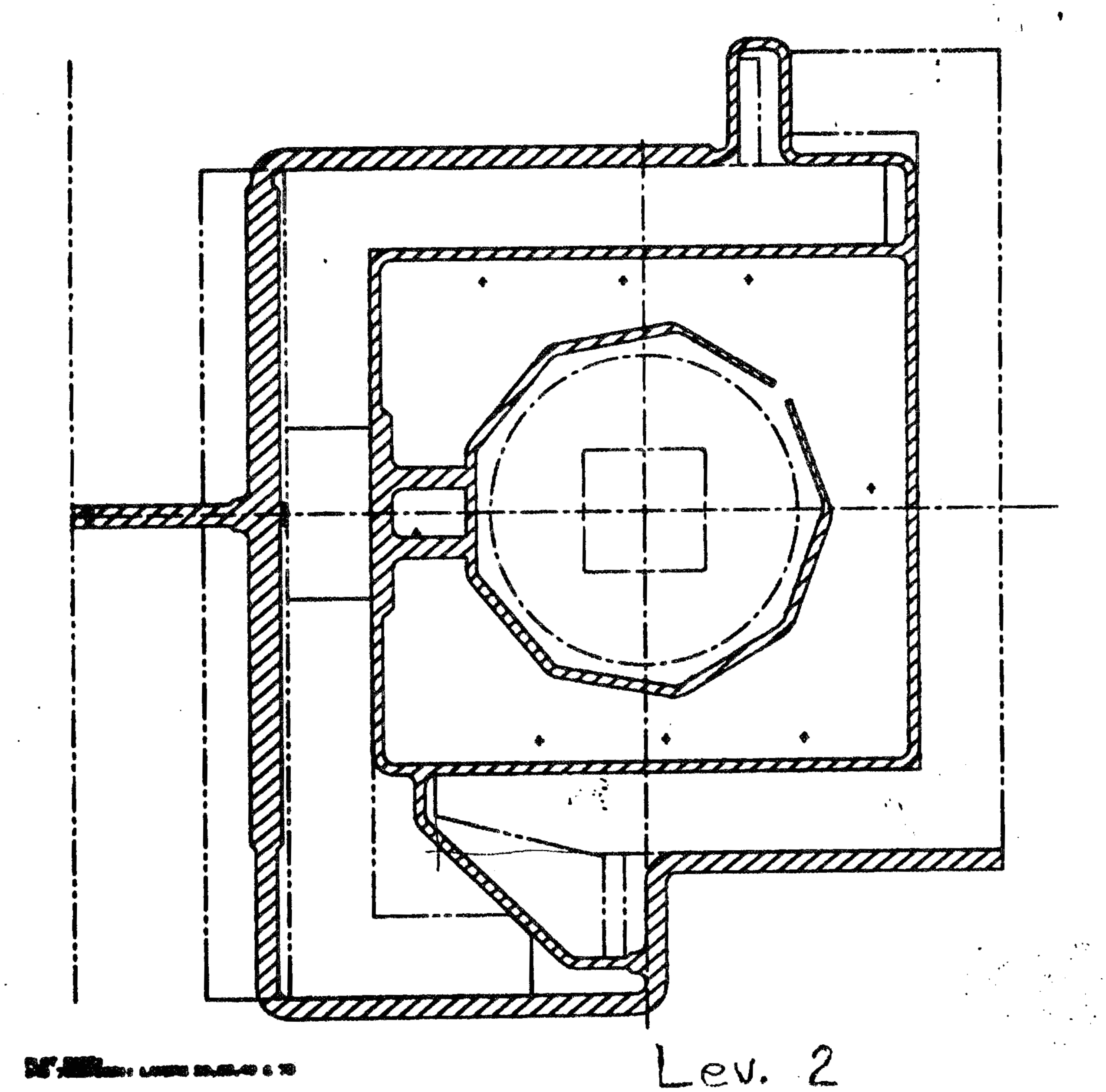


FIGURE 4.1.2–1 CABLE TRAY – TEST SUPPORT BUILDING – LEVEL TWO

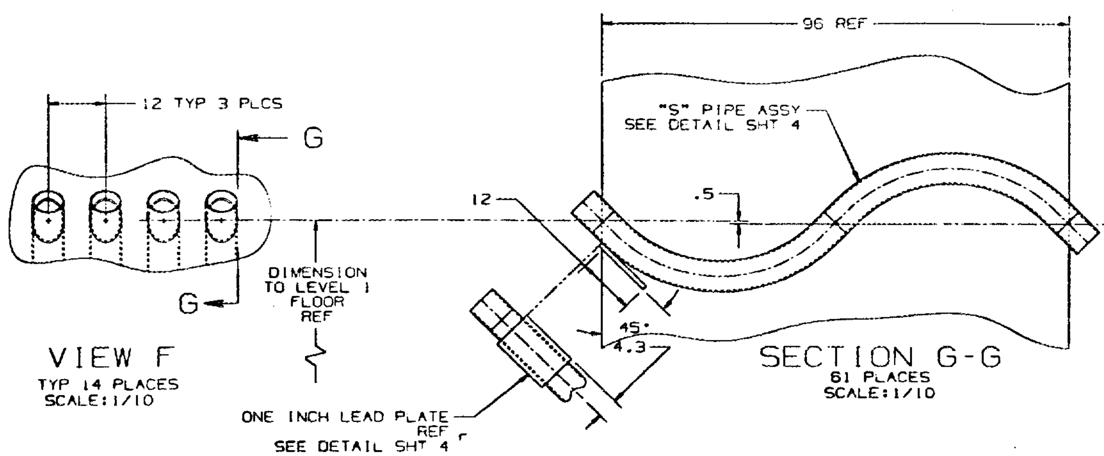


FIGURE 4.1.2–2 CABLE PENETRATION DUCT

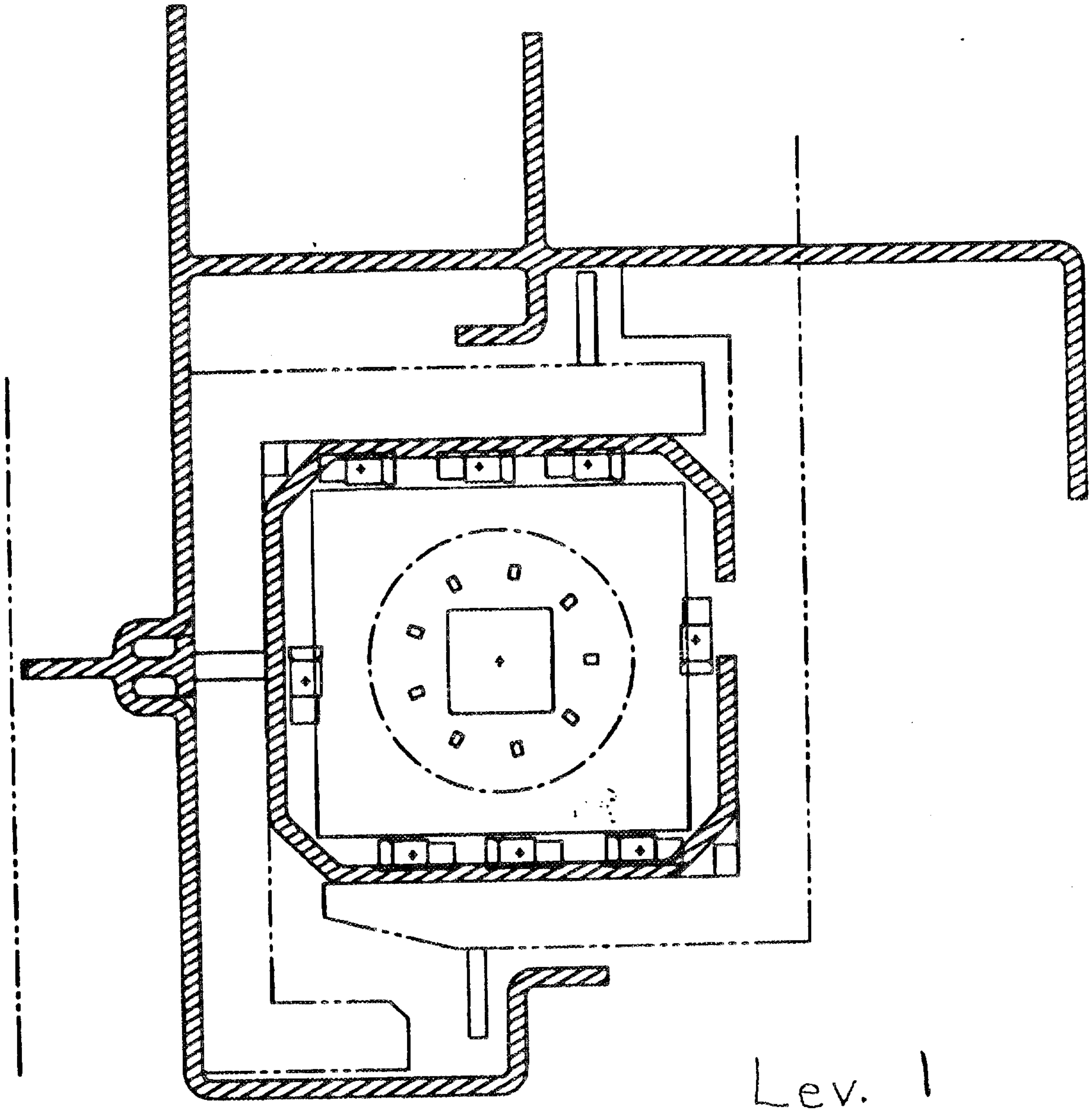


FIGURE 4.1.2–3 CABLE TRAY – TEST SUPPORT BUILDING – LEVEL ONE

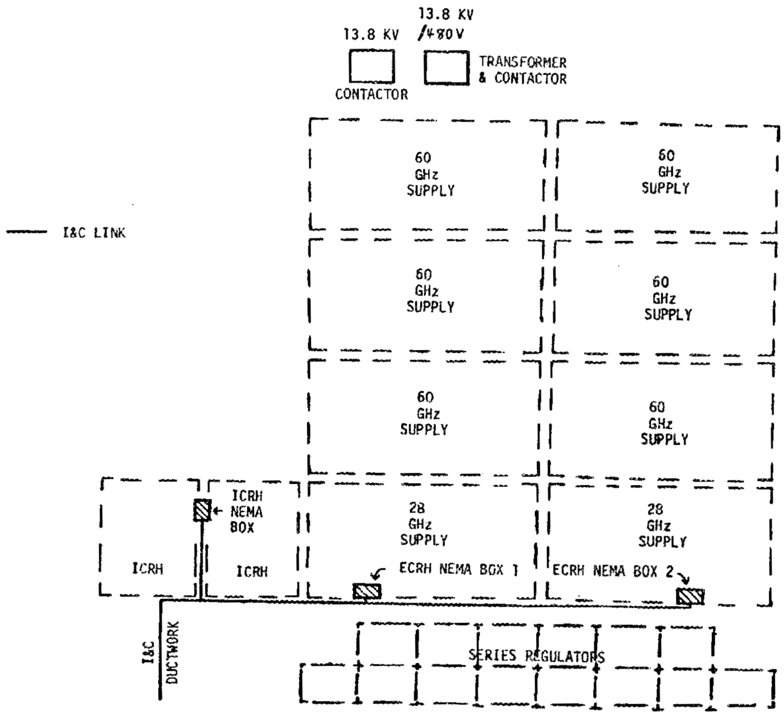


FIGURE 4.1.2–4 FIELD CABLE ROUTING – POWER SUPPLY PAD

nal tray exit the shield room via the cable bridge and the north wall cable ducts. Figure 2.1.2-2 shows these ducts, which are S-shaped 6.625 in. OD standard steel conduit permanently cast into the concrete wall. The S-shape provides an x-ray-tight cable penetration that does not require additional lead plugs to ensure x-ray tightness. Lead plugs are indesirable because of a potential photoneutron problem. Present estimates lead to eighteen of these ducts to handle cables on Level Two. Each duct is relatively loosely-packed with cables (~50% of the duct cross-sectional area contains cables) to ensure that cable pulling does not become a problem.

Cables exit the North Wall ducts and follow a large east-west cable tray that runs the length of the North Wall Balcony. Additional cable trays running along the exterior east and west walls of the Shield Room connect to the North Wall Balcony tray. These trays principally carry cables associated with various research diagnostics located along the exterior east and west walls. The North Wall Balcony cable trays carry cables to the instrumentation racks and NEMA-12 enclosures located on the balcony.

The field cables are carried into the Control Room via the North Wall Bridge which mates to the overhead cable tray layout inside the control room.

Figure 4.1.2-3 shows the cable tray layout in the Torus Room, Level 1. The main tray is located around the interior walls at 146 inches above floor level. This tray is a ladder type, 24"W x 6"D and carries I & C field cables associated with the gyrotron tubes and certain research diagnostics located on Level 1. A short bridge section carries these cables through a penetration ducts centered on the north wall of the concrete shield room and intersects a vertical cable chute located on the exterior side of the wall. This chute carries the cables upward to the North Cable Bridge on Level 2 and from there into the Control Room.

The short bridge on Level 1 intersects an east-west cable tray (Figure 4.1.2-2) which is routed eastward towards the ICRH area. This tray exits the Text Center Building and carries out to the Power Supply Pad. A north-south spur is provided which leads into the Mechanical Equipment Building. Note that these particular cable trays carry only a few cables, i.e., cables linking PC I/O units in the Mechanical Equipment Building and on the Power Supply Pad to PC processors located in the Control Room.

Figure 4.1.2-4 shows the cable duct routing on the Power Supply Pad. These ducts terminate at three NEMA-4 enclosures on the pad, each containing PC remote I/O hardware. Note that these ducts carry very few cables. An extensive cable duct layout is used to carry I & C field cables between the three NEMA-4 enclosures and power supply components located on the outdoor pad.

4.1.3 North Wall Balcony Layout - This layout is shown in Figure 4.1.3-1 (I & C Drawing No. 70B378019). The balcony is 96 inches wide and extends the length of the concrete shield north wall. Thirty (30) standard 19"W x 42"H instrumentation racks and fifteen (15) NEMA-12 enclosures are positioned on the balcony. This arrangement places these components approximately eleven (11) feet above the level of the second floor and eliminates conflicts between I & C components and research diagnostics equipment located outside the north wall.

Eleven (11) of these racks (designated R-1 thru R-11) contain ion gauge and thermal vacuum gauge controllers associated with the vacuum I & C interface (see Section 4.2.2 below). By locating these controllers on the balcony, the cable lengths required to connect the vacuum gauges is minimized (~ 100-125 ft.). If these units were located in the control room, longer cables would be required (~ 200-250 ft.) necessitating a customized controller design to handle the longer cables.

Two racks (designated R-14 and R-15) contain cryogenic I & C interface components (see Section 4.2.3 below).

Fifteen racks (designated R-16 thru R-30) contain magnet I & C interface components and the magnet system Quench Protection Circuits. Signal conditioners for strain gages and for resistance-type temperature sensors are also located in these racks.

Two racks (designated R-12 and R-13) contain CAMAC equipment and stepper-motor controllers for the remotely-adjustable limiter segments.

The NEMA-12 enclosures are fastened to the concrete wall using commercial cement anchors. NEMA units R-N1 and R-N2 contain PC remote I/O hardware associated with the TVL control/interlock system. NEMA units R-N3 thru R-N6 contain similar units for the

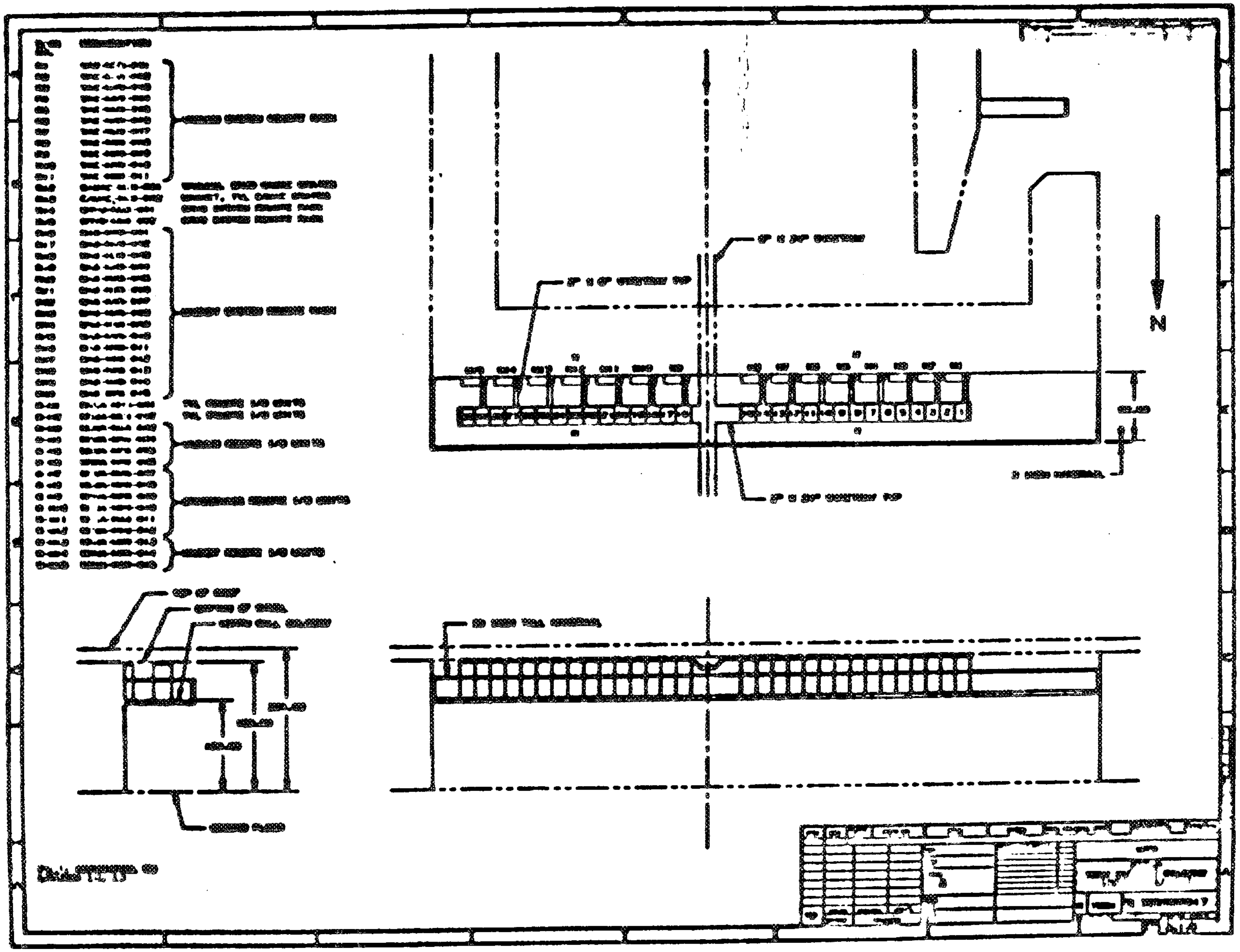


FIGURE 4.1.3–1 NORTH WALL BALCONY LAYOUT

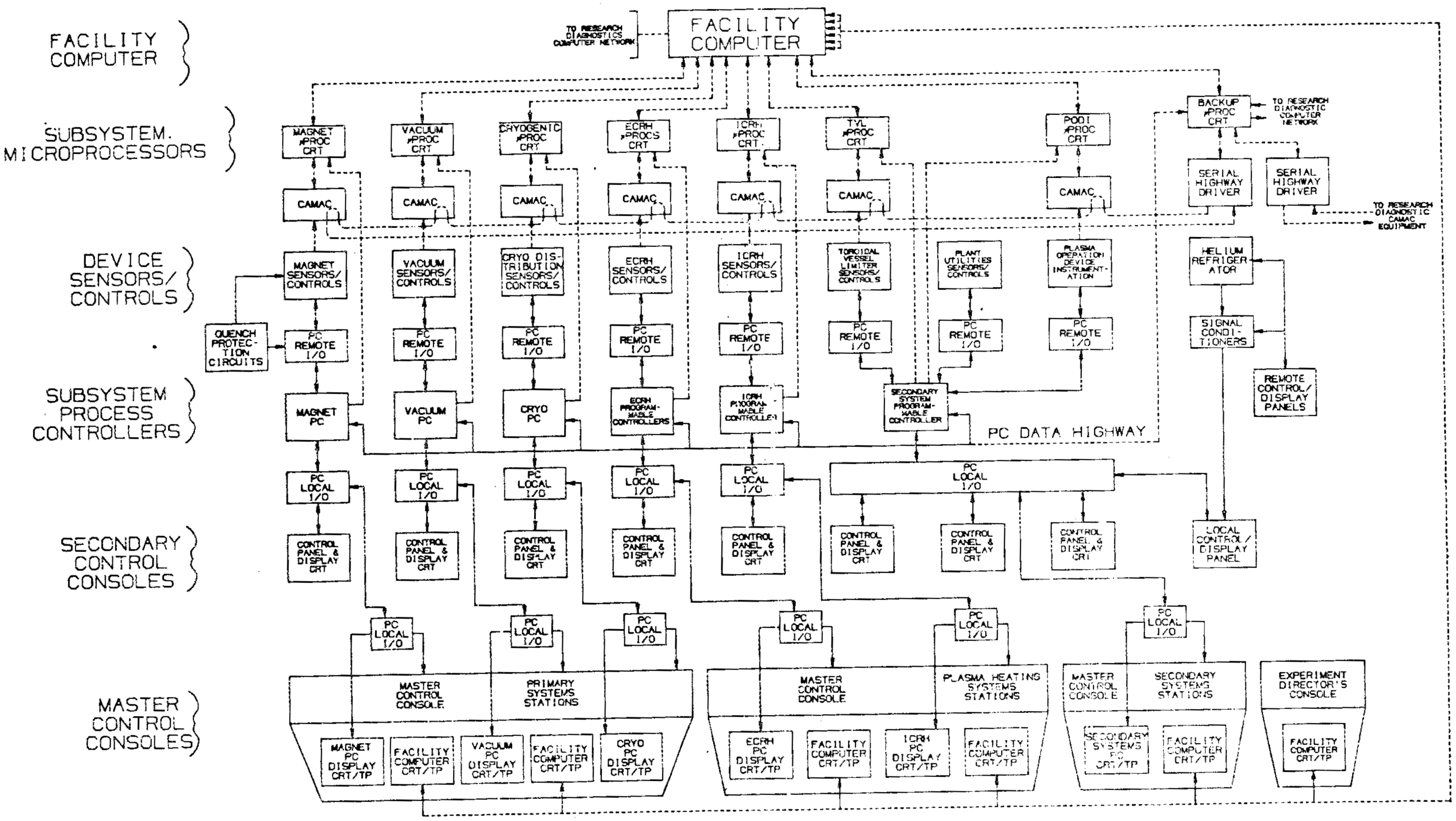
vacuum control/interlock system; NEMA units R-N7 thru R-N12 are associated with the cryogenic distribution control/interlock system; and NEMA units R-N13 thru R-N15 are associated with the magnet control/interlock system.

Overhead cable ducts are used to route ac power, grounding and I & C signal cables to balcony racks and NEMA-12 enclosures. All such units are provided with remote control relays such that ac power can be controlled from the Control Room SCC units. For normal EBT-P device operation there is no need for operator presence on the North Wall Balcony.

4.1.4 Facility Computer Configuration - The EBT-P I&C Master Diagram is shown in figure 4.1.4-1. This diagram shows the relationships between all elements of the I&C system, including both primary and secondary I&C; interfaces all processors: facility computer, microprocessors, and process controllers; and the Master Control Console and Secondary Control Console user interfaces. Figure 4.1.4-2 is the same diagram, but with the facility computer and its interfaces to the subsystem microprocessors and to the Master Control Console highlighted. The following paragraphs describe the facility computer hardware configuration and the implementation of its interfaces.

A Harris System 135 computer is used as the EBT-P facility computer. The System 135 is supplied by MDAC-St. Louis to the EBT-P Project at no cost to the Company and is dedicated to the exclusive use of the EBT-P Project during Phase II and for the duration of Phase III. The System 135 is now operating in the MDAC-St. Louis Missile System Development and Evaluation Facility (MSDEF). The unit currently has been on-line for 30 months during which it has been supporting both laboratory tests of missile guidance systems and complex missile guidance software development tasks. The System 135 is scheduled for replacement by a larger Harris System 800 computer in early 1982. The System 135 currently is maintained under a full-service factory maintenance contract and will remain so through the transfer to the EBT-P Project.

Figure 4.1.4-3 shows the facility computer hardware configuration. The major components are listed below:



SOLID LINE = CONTROL/INTERLOCK CHANNEL
DASHED LINE = DATA ACQUISITION/DATA DISPLAY CHANNEL

FIGURE 4.1.4–1 I&C SYSTEM MASTER DIAGRAM

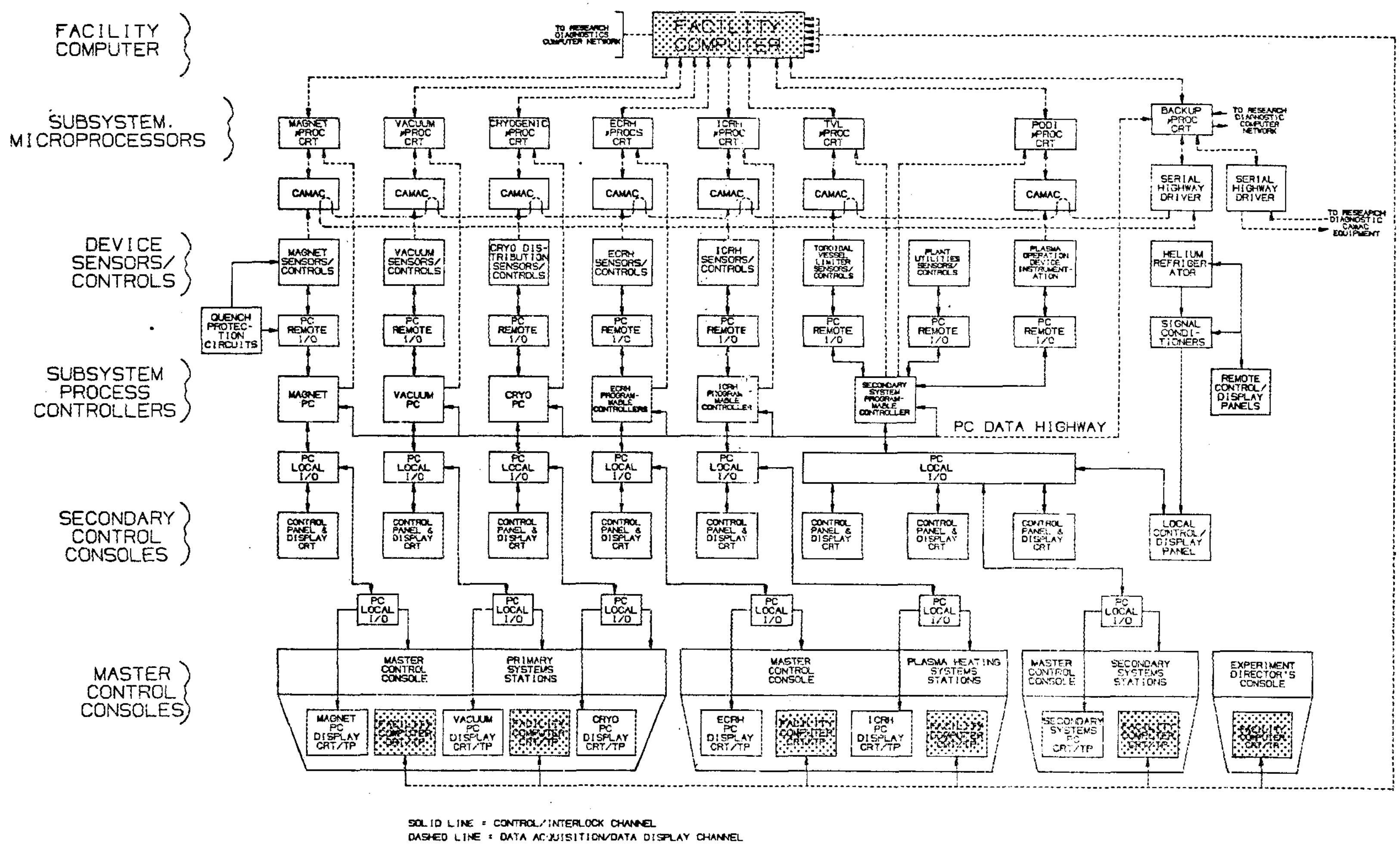


FIGURE 4.1.4–2 FACILITY COMPUTER COMPONENTS

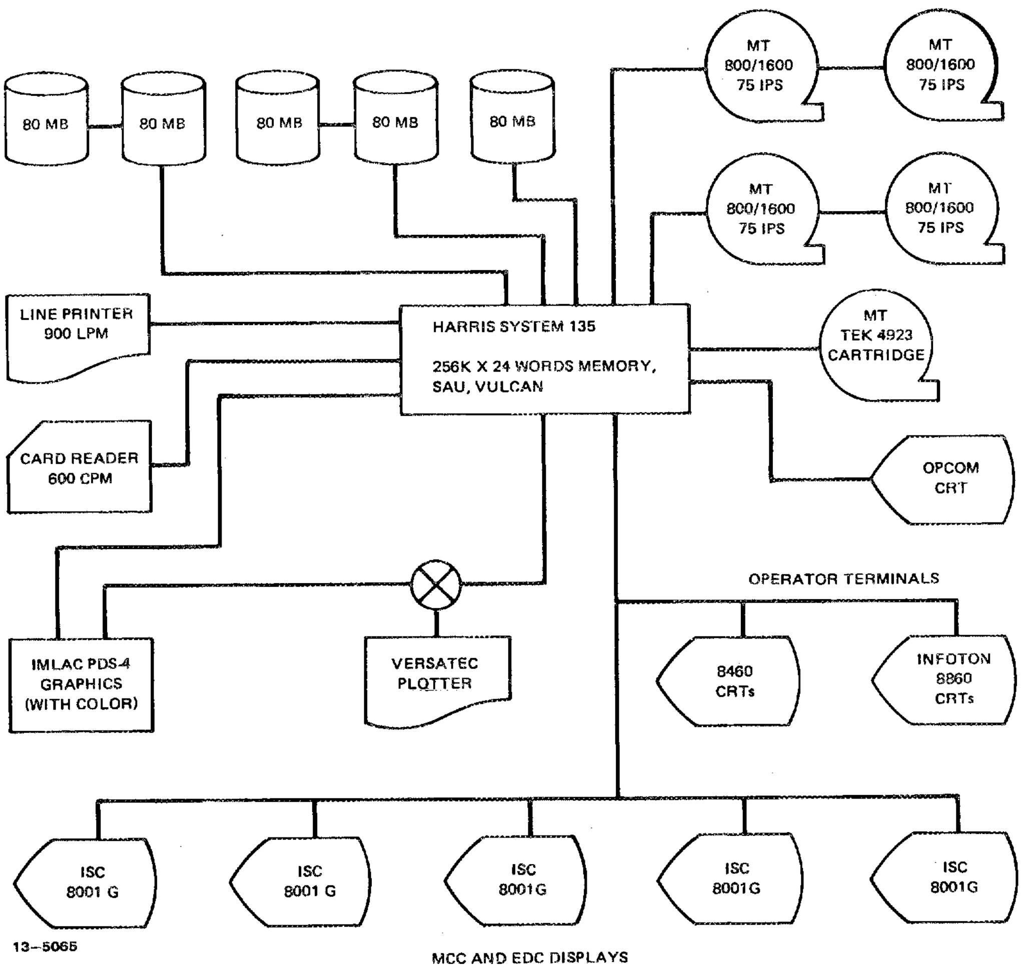


FIGURE 4.1.4–3 FACILITY COMPUTER HARDWARE BLOCK DIAGRAM

- Series 100 Central Processor Unit
  - 256-Kwords x 24 bit memory
  - Scientific Arithmetic Unit (Hardware floating point)
- Five Harris Model 5530/553 80-Mbyte disk drives
- Four Harris Model 6690/6691 Magnetic Tape drives (9 track, 800/1600 bpi)
- One Tektronix Model 4923 Cartridge Magnetic Tape Unit
- One Harris Model 2310 Operator Console (OPCOM)
- Three Harris Model 8430 DMACP I/O Multiplexers
- Four Harris Model 8610 CRT/Keyboard Terminals
- Two Infoton Model 8660 CRT/Keyboard Terminals
- One Harris Model 4130 Line Printer (900 lines/min)
- One Harris Model 3120 Card Reader (600 cards/min)
- One Versatec Model 1200A/Electrostatic Printer/Plotter (200 nibs per inch)
- One IMLAC Model PDS-4 Color Graphics Console Unit

Additional components which will be procured to augment the present configuration and provide the interface to the MCC facility computer displays and the microprocessor DAS systems include:

- Harris Model 8450 DMACP I/O Multiplexers
- ISC (Intecolor) Model 8001G Color Graphics Display Terminals
- Elographics Model E270 Transparent Touch Sensors with Controllers

The facility computer is responsible for the following functions:

- Collection of data from the subsystem microprocessors
- Processing and assembling that data into a working data base
- Display of all data, both current and historical on the MCC and EDC color graphic display screens
- Archival storage and management of the facility working and historical data bases
- Assignment of communications to alternate paths in case of data link failure
- Providing post-production analysis and graphical output of device subsystem data
- Providing a communication link for transmission of facility data to the research diagnostic computer and ultimately to the FED and MFE networks.

The design rationale for the performance of these functions explained in the following paragraphs.

Data collection from the various subsystem microprocessors is accomplished by the use of one or more EIA Standard RS-422 asynchronous serial data links operating at 19.2 Kbaud. The interface to the Harris System 135 is implemented via Model 8450 DMA Communications Processors. These are microprocessor controlled interfaces which can control up to 16 asynchronous ports. Two of these units will be purchased to replace the Model 8430 Communication Ports currently on the System 135. The DMACP units provide the intelligent interface to the microprocessor and display links required with a minimum of CPU overhead.

The estimated aggregate data rate from eight active subsystem microprocessors is 8192 bytes per second continuously during device operation. Each microprocessor is baselined to provide 1 Kbyte of data per second, although some subsystems may handle larger or smaller volumes. The 19.2 Kbaud data links allow for a maximum capacity of 1920 bytes per second each. If more data capacity is required for specific cases, two or more links may be used with particular microprocessors. This is a more cost effective approach, using available ports on the System 135 and microprocessors, than investing in high-speed synchronous links requiring additional interfaces.

The DMACP units in the System 135 receive data from the communication links and store it in memory via high-speed direct memory access (DMA). The memory region used to store the data is a monitor common block, where data may be accessed by various processing and display tasks. The software on the System 135 runs under the VULCAN Operating System. VULCAN is a multipurpose, multitasking system which is well suited for real-time data acquisition and processing. The EBT-P I&C software makes full use of the multi-tasking capabilities of VULCAN. For details of the software interface and task structure, see Appendix C, the Software Requirements Document.

Data processing capabilities of the facility computer include programs for analysis of device data and for assembling the data into a consistent working data base. Data records from the microprocessors are assembled into files containing a continuous time history of EBT-P device operation. The processing of this data includes reduction of data to engineering units in cases where this has not been done at a lower level, correlation of related data from different device subsystems, and selection of data and formatting for subsequent displays. Off-line facility computer processing includes data base management, editing of configuration files, data plotting, and transmission of data to the research diagnostic network. These processes are explained more fully as separate functions in subsequent paragraphs.

The **data display** function is done through color graphics terminals located in the Master Control Consoles and Experiment Direction Console. These terminals, composed of ISC Intecolor 8001G Graphics Terminals with touch panel input overlays and USgraphics "REACT!" firmware, provide the users with a window on the operation of the EBT-P device. There are six facility computer display stations in the MCC and two in the EDC at the Experiment Director's Station. These terminals provide the MCC and EDC users with access to any data contained in the facility computer working data base, either current or historical. The user interacts with the display via the touch panel overlay. No keyboards are needed for input to the facility computer. All inputs are done via menu-driven touch panel inputs. This ability satisfies a design criterion to avoid operator languages and operating system commands. The graphic firmware ("REACT!") effectively reduces the amount of communication between the computer and the terminal by storing the layout of the display page and relieving the computer from transmitting coordinate pairs for each point to be displayed. Details of the MCC layout and design rationale are given in Section 4.1.7. The details of the software requirements for facility computer display are given in Appendix C.

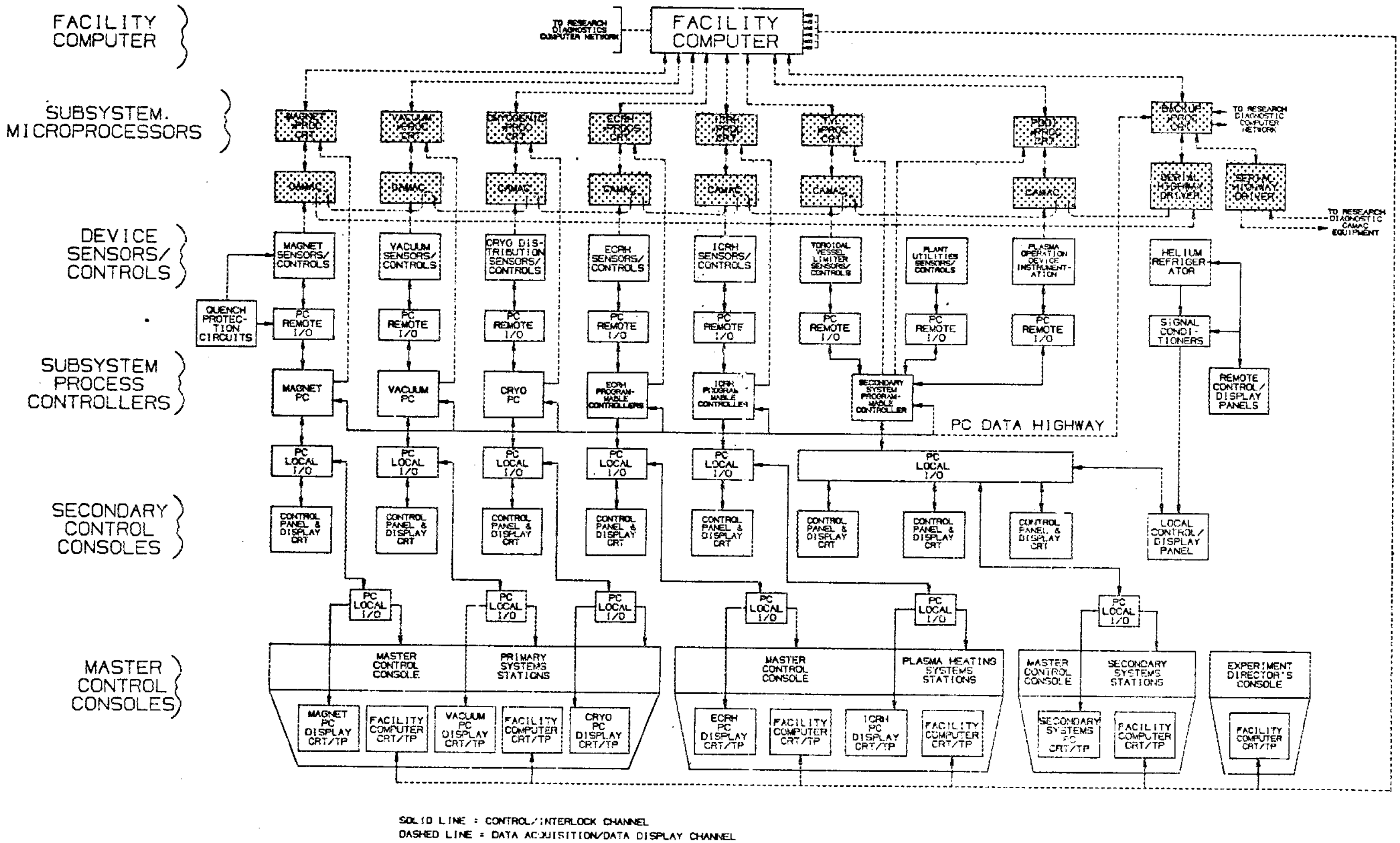
Archival storage and data base management are handled by the facility computer. The five 80-megabyte disk drives provide at least a one shift (8-hour) on-line storage capacity (nominally 236 Mbytes), in addition to program and configuration file storage. Archival storage of device data is done on 9-track 1600 BPI magnetic tape. A standard 2400 foot reel of tape has a capacity of approximately 46 megabytes. Working data are copyed to tape on a regular basis during device operation to provide backup for on-line files and to reduce the likelihood of saturating the 400 megabytes of on-line storage. Historical data may also be retrieved from magnetic-tape at any time for comparison with current data.

Communications redundancy is managed by the facility computer in concert with the microprocessors and process controllers. When the facility computer detects or is notified by a microprocessor of a communication failure from device sensors, the facility computer initiates communication over an alternate path to a CAMAC crate or process controller. The facility computer is connected to a backup microprocessor which has access to all device subsystem CAMAC crates via a backup serial highway. It also has access to the process controllers via a data highway link. These backup communication paths are discussed in the sections on the DAS microprocessor configuration (4.1.5) and the PC control/interlock subsystem (4.1.6).

Post-production analysis capability includes resources for graphical hardcopy of device data and development of special purpose analysis programs in FORTRAN (ANSI STD-1977) or Pascal. The graphical hardcopy is provided by the Versatec 1200A printer/plotter and its associated Versaplot software. Analysis programs may be developed at any of the facility computer alphanumeric terminals and incorporated into the operational software package accessable at the MCC and EDC terminals. This capability is provided to allow post-test analysis of any device data, either current or historical in the facility data base. Time history graphs of device parameters may be plotted, or parametric graphs of related device parameters. Recent data may also be compared on the same graph with historical data to detect changes in device operation.

A link to the research diagnostic computer is provided to transmit device data from the facility computer to the research diagnostic network. This link is implented as a high-speed parallel link interfaced through high-speed DMA interfaces in both computers. A Harris Model 046 buffered block channel is used in the Harris System 135. A data rate of approximately 100 Kbytes per second is anticipated, which is several times the aggregate real-time data acquisition rate of the microprocessors and facility computer. This data capacity allows large blocks of data to be transmitted quickly while device operation is taking place. The facility computer-to-network link is described in more detail in Section 4.3.2.

4.1.5 Microprocessor Subsytem Configuration - Figure 4.1.5-1 highlights the microprocessor subsystem of the DAS. Each microprocessor based system forms a link between the device subsystem sensors, including the PC sensors and controls, and the facility



SOLID LINE = CONTROL/INTERLOCK CHANNEL
DASHED LINE = DATA ACQUISITION/DATA DISPLAY CHANNEL

FIGURE 4.1.5–1 DAS MICROPROCESSOR COMPONENTS

computer. Each subsystem microprocessor is housed in the appropriate subsystem Secondary Control Console. There are nine microprocessor units supporting the following device subsystem or DAS functions:

- Superconducting Magnets
- Vacuum
- Cryogenic Distribution
- ECRH 28 GHz
- ECRH 60 GHz
- ICRH
- Toroidal Vessel/Limiters
- Plasma Operation Device Instrumentation (PODI)
- Backup of CAMAC Data Highway Unit

Each of the nine microprocessor systems is made up of essentially the same hardware configuration. This is done to assure commonality for spares, to make the operator interface identical from system to system, and to achieve commonality of software. The basic microprocessor configuration consists of the following components:

- Scientific Microsystems (SMS) Model DSX01172 Disk System consisting of:
  - LSI-11/23 Microprocessor CPU
  - KEF11-A Floating Point Option
  - Q-Bus Backplane
  - 128 Kbytes MOS Memory
  - DLV11-J 4-line Serial Interface
  - 10 Mbyte Winchester Disk
  - 1.2 Mbyte Dual-sided, Double-density Floppy Disk
- DEC VT100 Video Terminal with Digital Engineering, Inc. VT640 Retrographics Enhancement
- Kinetic Systems Corp. Model 2060 Serial Highway Driver with Model 1735 Fiber Optic U-Port Adapter
- Kinetic Systems Corp. Model 1500 Crate with Model 3952 Serial Crate Controller, Model 3935 Fiber Optic U-Port Adapter, and associated input modules.

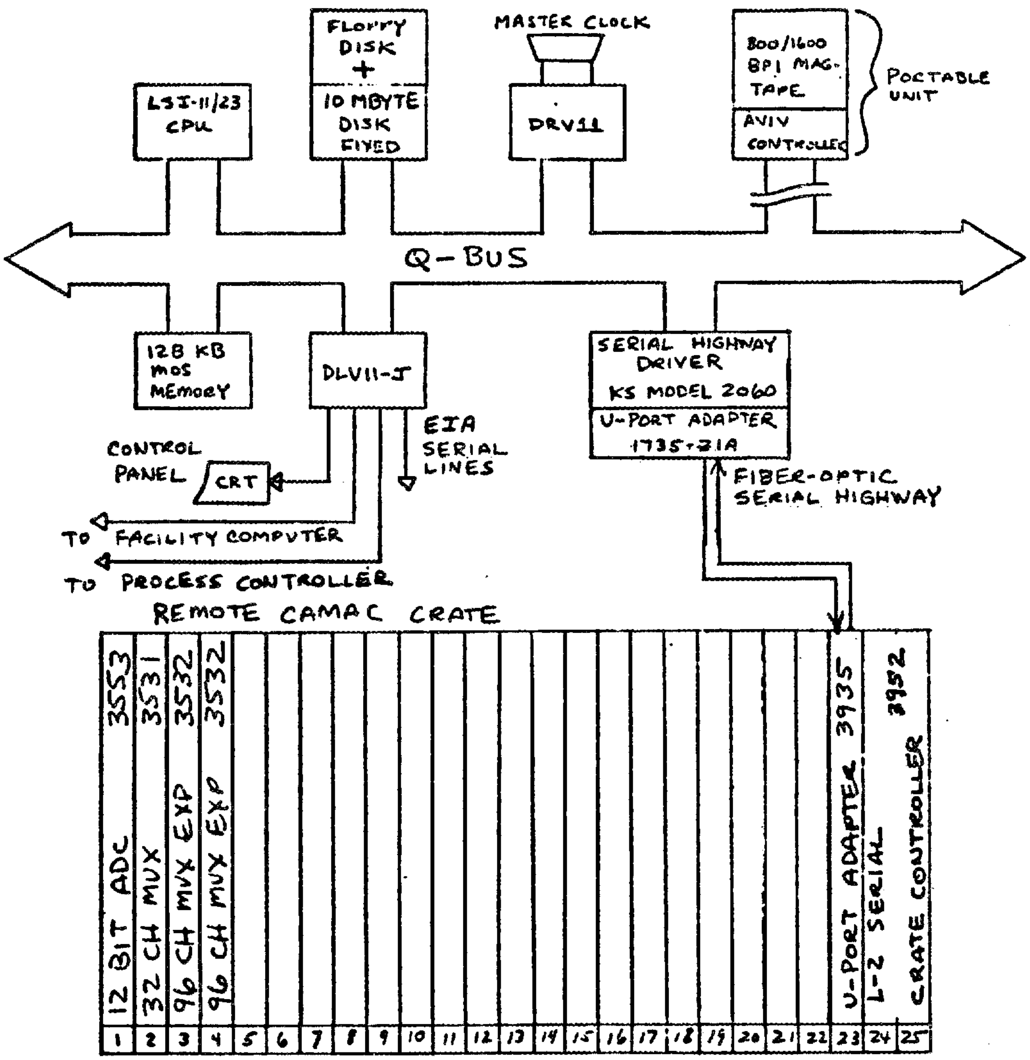


FIGURE 4.1.5–2 VACUUM MICROPROCESSOR/CAMAC CONFIGURATION

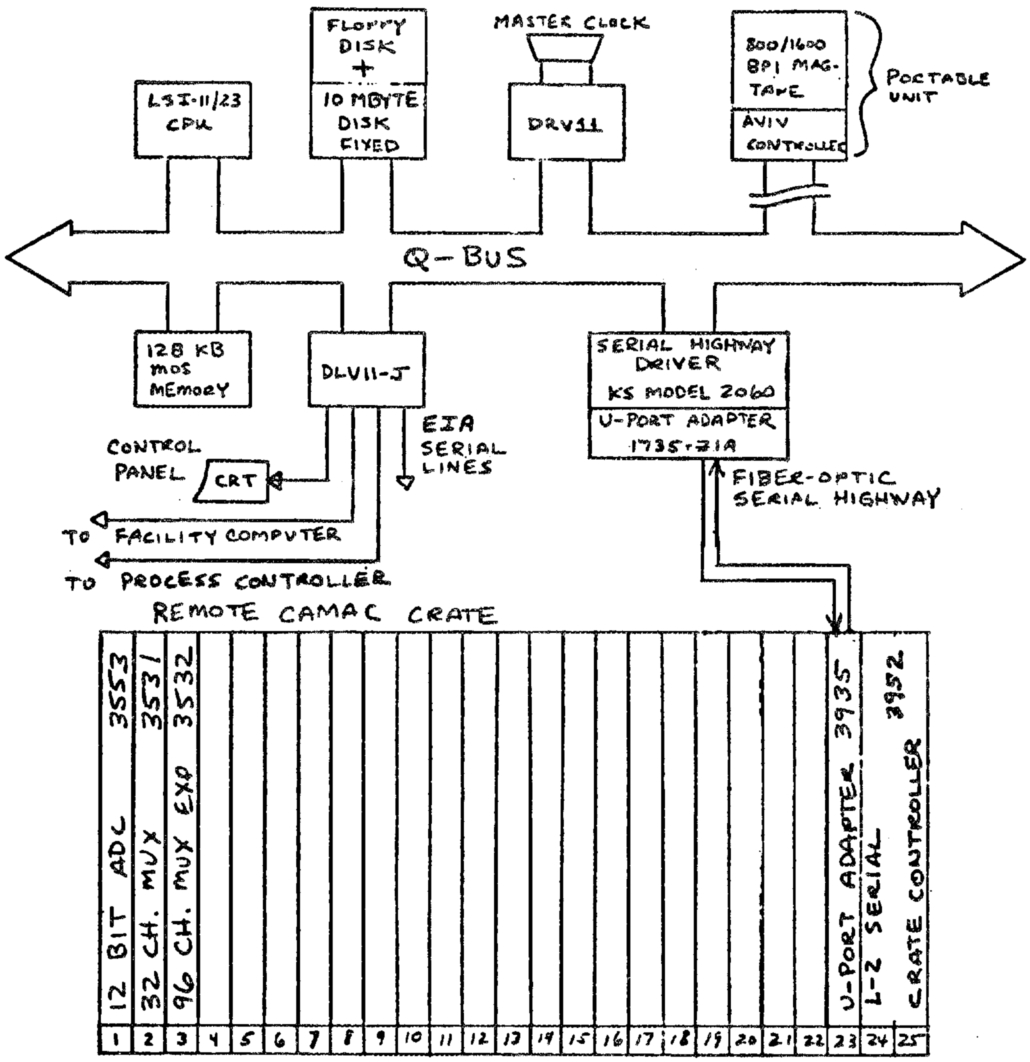


FIGURE 4.1.5–3 CRYOGENIC MICROPORCESSOR/CAMAC CONFIGURATION

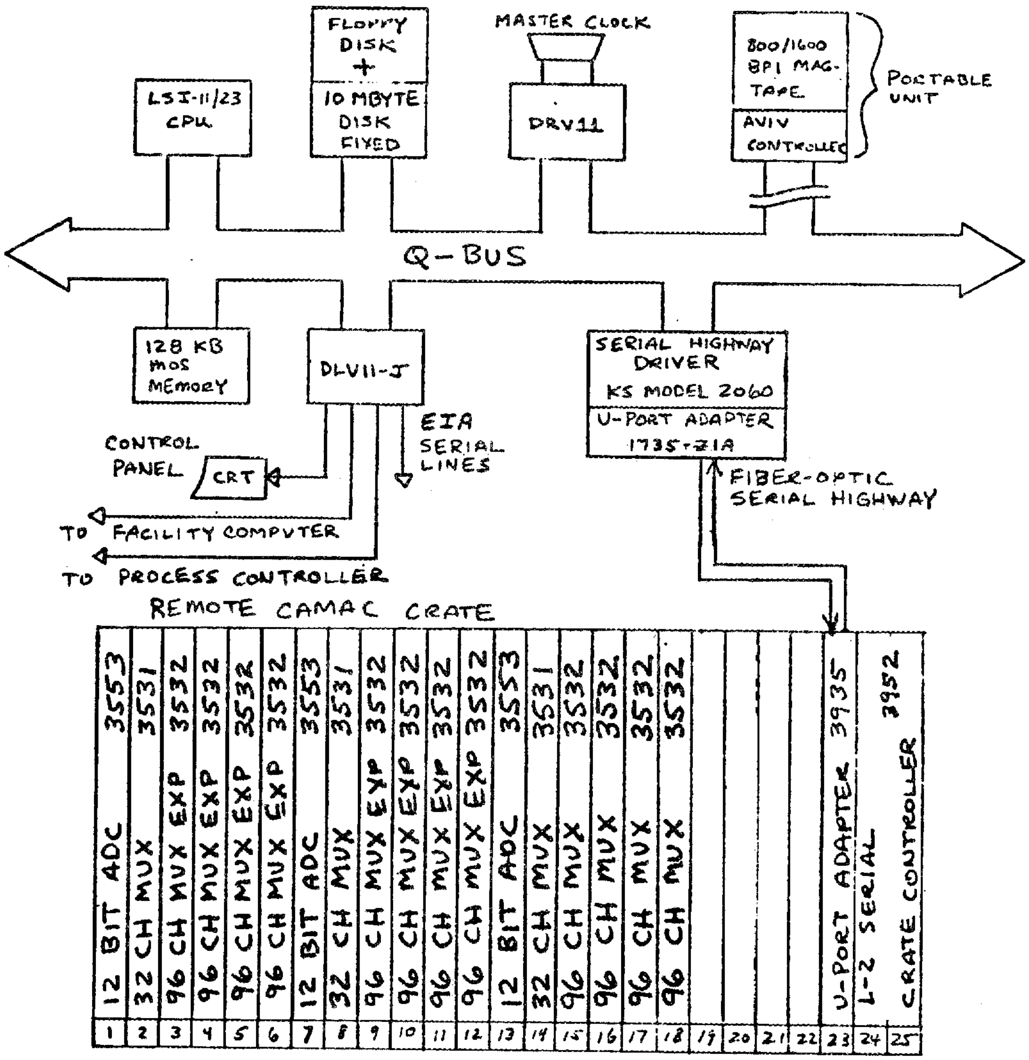


FIGURE 4.1.5–4 MAGNET MICROPROCESSOR CAMAC CONFIGURATION

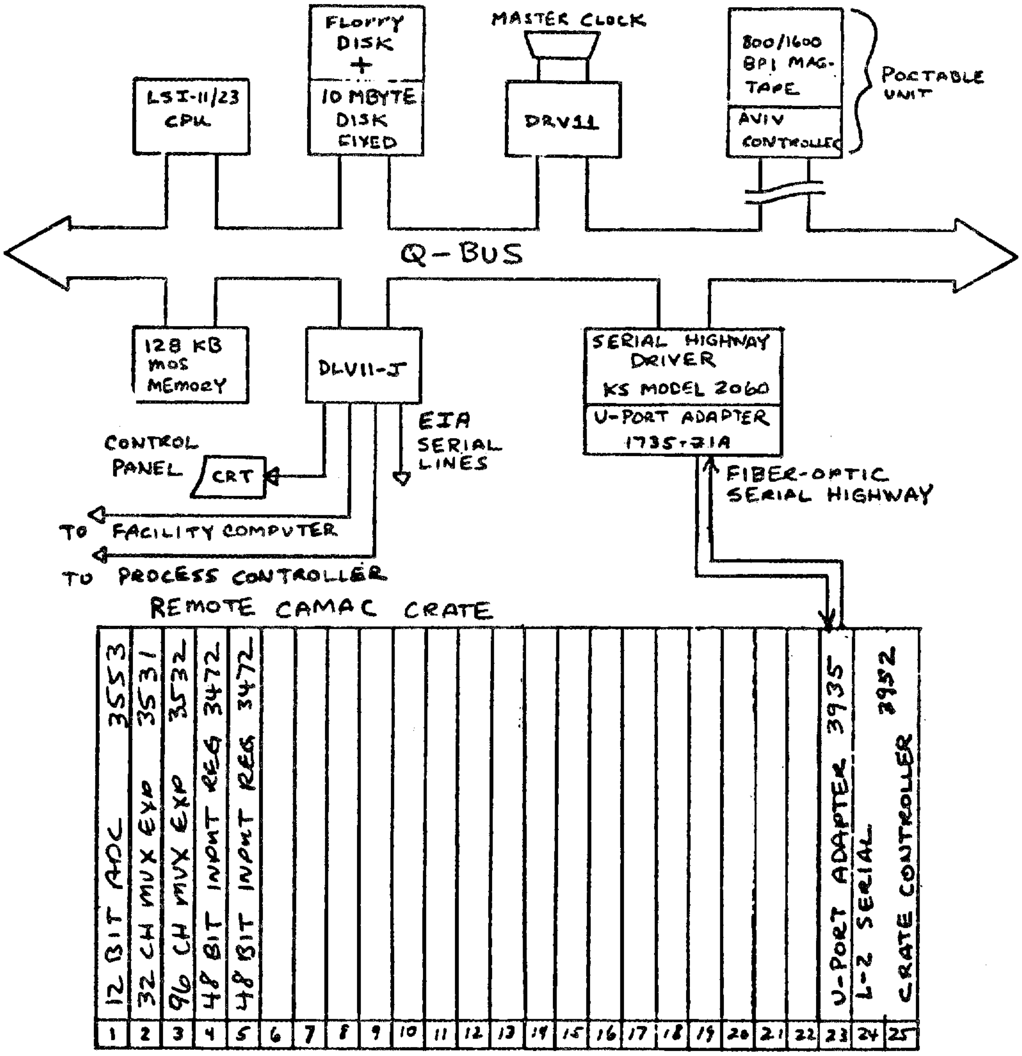


FIGURE 4.1.5–5 ECRH 28 GHz MICROPORCESSOR/CAMAC CONFIGURATION

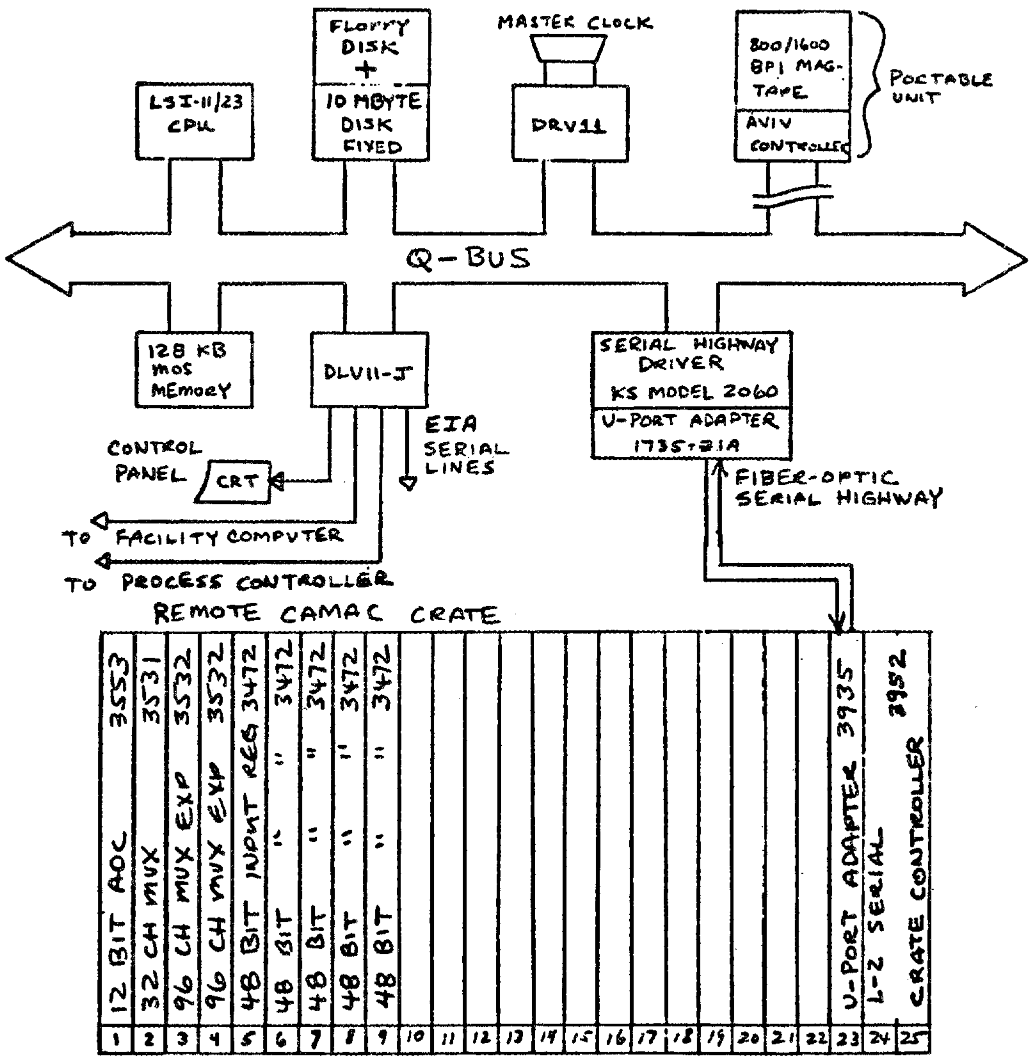


FIGURE 4.1.5–6 ECRH 60 GHz MICROPROCESSOR/CAMAC CONFIGURATION

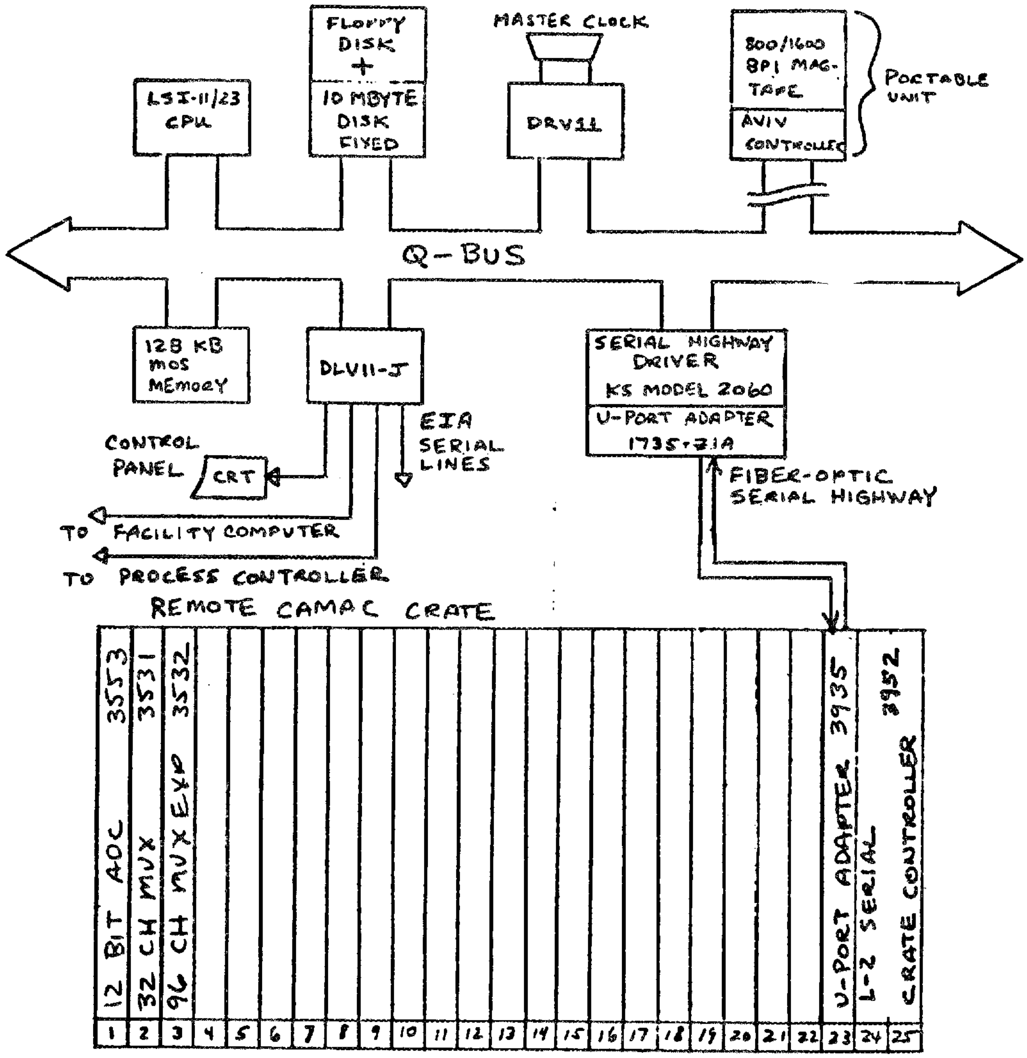


FIGURE 4.1.5–7 ICRH MICROPORCESSOR/CAMAC CONFIGURATION

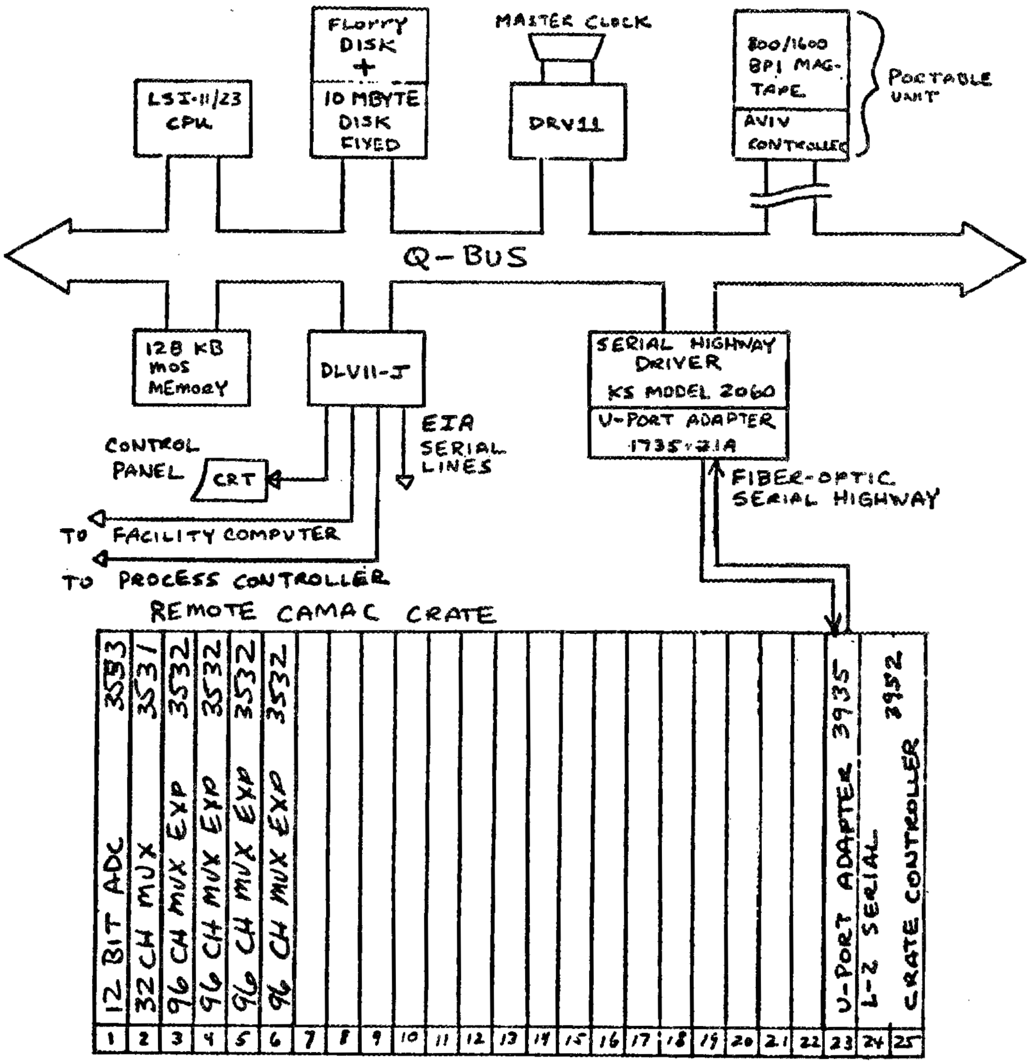


FIGURE 4.1.5–8 TOROIDAL VESSEL/LIMITERS MICROPROCESSOR/CAMAC CONFIGURATION

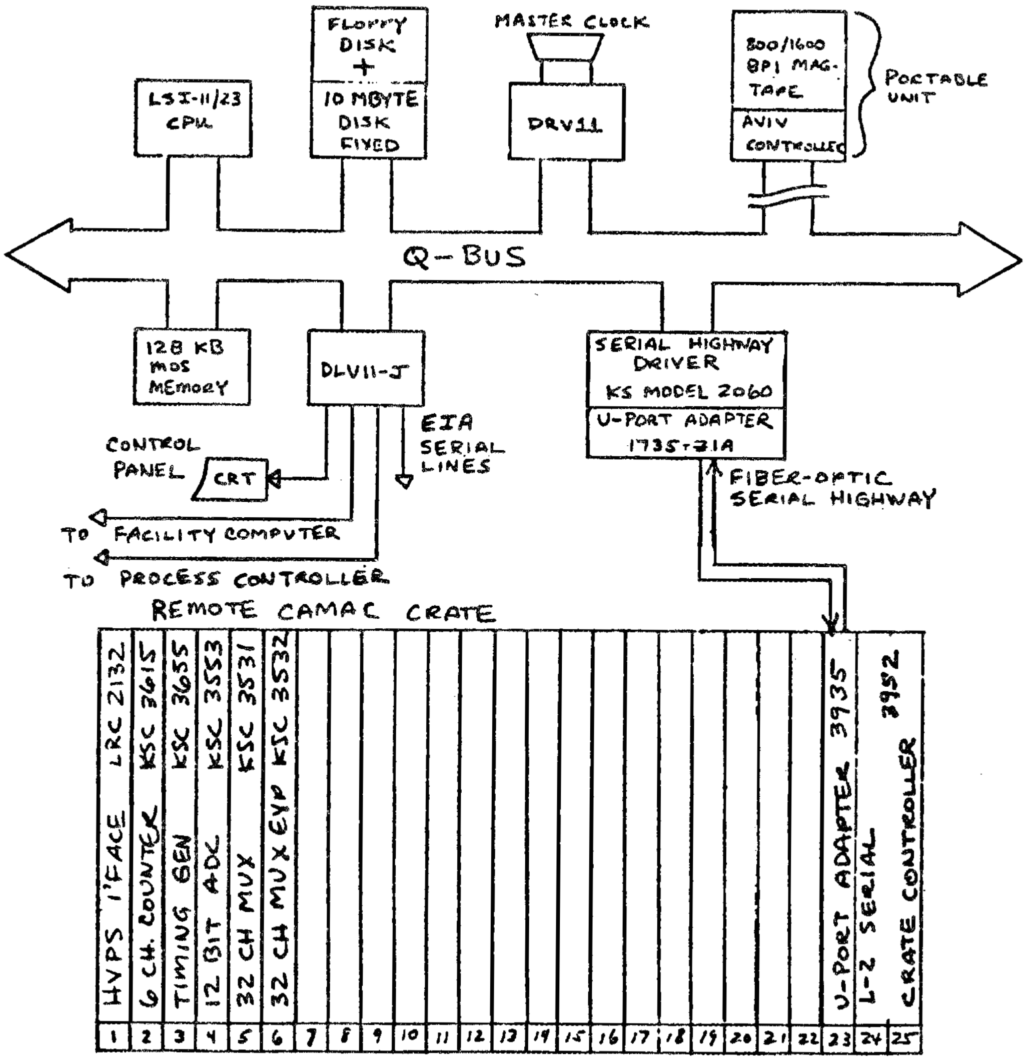


FIGURE 4.1.5–9 PODI MICROPROCESSOR/CAMAC CONFIGURATION

The input modules associated with each subsystem are detailed in Figures 4.1.5-2 through 4.1.5-9. The contents of each CAMAC crate are seen to be made up of various analog to digital converter modules, analog multiplexers, digital input modules, counters, and timers. Each CAMAC crate also has a controller, KSC Model 3952 Serial Highway Crate Controller (SCC), with U-port adapters to the primary and secondary fiber-optic serial highways. Each crate has a primary link to its associated microprocessor via the serial highway to the Model 2060 Serial Highway Driver (SHD). Each microprocessor controls its crate via the SHD with FORTRAN callable functions for serial highway commands. The Model 2060 operates at a 5 Mbit/sec data rate and uses direct memory access to move commands and data around the highway and in and out of the microprocessor memory as efficiently as possible. Each crate also has a secondary fiber-optic U-port for connection to a backup serial highway link. Discussions are currently taking place with Kinetic Systems and other CAMAC manufacturers to decide the best configuration for this backup loop. This issue will be resolved early in Title II.

As can be seen in the figures, each microprocessor has an interface to the Master Timer buss, a four-line serial interface, and a provision for a magnetic tape unit. The DRV11 16-bit parallel input interface connects each microprocessor to the time-of-day buss generated by the system master clock. These time data are used to synchronize all DAS microprocessors and to correlate all data accumulated in the facility computer to one clock. The details of the Master Timer subsystem and its operation are given in Section 4.1.11. The DLV11-J four-line serial interface is used to implement connections to the facility computer (19.2K baud, RS-422), to the process controllers (9600 baud RS-232) and to a black and white raster graphics CRT in the SCC (9600 baud, RS-232). One serial line remains uncommitted in each unit to serve as a spare, or to be used as a second link to the facility computer. The use of this second link would effectively raise the microprocessor-to-facility computer data rate to 38.4 Kbaud. The magnetic tape unit shown in the figures is a portable unit used for operating system software distribution and maintenance-type software and data archiving. This unit is not permamently attached to any of the microprocessors, but can be plugged into any of the units quickly to install software, or make a tape copy of programs and data on the microprocessor Winchester disk. This magnetic tape facility on the microprocessors provides a redundant link in the data chain from the device sensors to the facility computer data base.

The microprocessor subsystem has been designed to address the following basic functions:

- Data Acquisition
- Processing
- Display
- Storage
- Communications

The manner by which these functions are implemented by the microprocessor subsystem units is described in the following paragraphs.

Data acquisition tasks in each microprocessor perform data acquisition and the timing and synchronization necessary therefor. Tasks take data on a regular basis from sensors as specified in a configuration file. The tasks use vendor supplied software, e.g., CAMAC library routines, whenever possible. The tasks deposit their data records from sensors into a designated input data common block for access by other tasks.

The primary design criterion for data acquisition is to scan all device sensor and status inputs a nominal rates continuously during device operation. The nominal rate for microprocessor controlled channels is one sample per channel per second. However, the rate for specific channels may vary from 0.1 sample per second to over 100 samples per second.

The **processing** functions of the microprocessors include unit conversions, scaling and primary parameter extractions. These functions also manage communications with both the PC's and the facility computer. The microprocessors format data for display on the Secondary Control Console terminals. Synchronization of data acquisition events with the Master Timer is also done by each microprocessor. Utility functions available at each microprocessor during maintenance mode include:

- examination of currently stored data records
- transmission of records to the facility computer
- consolidation of storage and deletion of unnecessary data records
- graphical display and hardcopy of any currently stored data

- generation and modification of configuration files for subsequent production mode runs
- exercise of data acquisition tasks and sensors off-line for checkout and calibration
- exercise of the PC to microprocessor communication link
- exercise of total PC/CAMAC to microprocessor data acquisition subsystem in real-time using simulated inputs.

A major responsibility of the microprocessors in maintenance mode is to verify the proper operation of the data acquisition subsystem from sensors to microprocessor. Tasks, developed as maintenance mode tools, duplicate as closely as possible the tasks which operate in production mode. These tasks contain code to detect and report faults in the normal data acquisition process. It is not the responsibiity of these tasks to isolate or diagnose faults in the computer or I/O systems. Vendor supplied diagnostic software and normal operating system utilities are employed by the system managers in development mode for fault analysis.

The microprocessor data displays operate similarly to the MCC facility computer displays. Each microprocessor typically runs one display task which has access to all data currently in the microprocessor memory. Control of the microprocessor displays is menu oriented through the display control area of the screen. Actual control is via single keystroke commands rather than touch panel inputs. The structure of the typical display is based upon an expanded version of the RMDEMO task distributed with the RSX-11M operating system. The task is overlayed for each display page with resident common used to build continuously updated display pages of real-time data. As much as possible, each display task in each microprocessor consists of identical code, with only the page contents and format differing from subsystem to subsystem.

Microprocessor data storage. All data from CAMAC I/O systems and process controllers is buffered in main memory by data acquisition tasks for access by other tasks: display tasks, transmission tasks, storage tasks, etc. All data are recorded as records in a disk file for a period of not less than one hour, or until transmitted to the facility computer. The data are stored as records acquired coincident in time. The records may be grouped into files, but the files have no significance with respect to data base access. The basic unit of stored data is the record. A convenient representation of these records is a Pascal-type array of records. On demand, all records accumulated since the last demand are transmitted to the facility computer. Records are deleted as their age exceeds one hour. Additional in-memory buffers and common blocks may be used by tasks to manage data flow within the microprocessor, e.g., display buffers, transmit buffers, etc.

The microprocessor **communication function** is its most important role. There are three primary links to each device subsystem microprocessor and a secondary link involving the ninth backup microprocessor. The function of each link and its implementation are described below.

CAMAC I/O system to microprocessor link. Tasks in the microprocessor (data acquisition tasks) interrogate the CAMAC module registers in the various crates by means of serial data highway commands. The CAMAC crates are interfaced to the microprocessors by fiber optic serial data highways. Demand messages, look-at-me (LAM) signals, and controller-generated interrupt protocols are used as required, depending upon the specific application and data rate. Existing software resources furnished by the CAMAC vendors are used wherever possible to implement data acquisition.

Microprocessor to facility computer link. Tasks in the facility computer (data receiver tasks) command the microprocessors to transmit all data records recorded since the last transmission or start of production mode, at regular intervals, typically one to ten seconds. A task in each microprocessor responds to the command from the facility computer by transmitting a message consisting of zero or more data records. The microprocessor must respond within a pre-determined time inteval or the facility computer declares the microprocessor off-line. As microprocessors are declared off-line, the facility computer attempts to obtain data through the backup microprocessor by the same method. The backup microprocessor has an alternate path to the device subsystem CAMAC crates.

The message sent to the microprocessor has the following components: header, body and trailer. The header contains identification of the sending microprocessor, the time the data was transmitted, the number of records being transmitted, and any other information deemed necessary at the facility computer task level. The body contains the data records being transmitted. The trailer contains error detection data such as longitudinal parity codes, CRC codes, or others as appropriate.

Process controller to microprocessor link. A task in the microprocessor interrogates registers in the process controller at regular intervals, typically once per second, to collect data from PC sensors and control outputs. This link is implemented over a suitable hardware link compatible with the microprocessor and PC. Existing software resources in the PC are used to effect the transfer, i.e.; bus or highway functions, and message functions as appropriate. The data transmission does not cause the basic scan rate of the PC to be interrupted during data transfer. That is, I/O scanning, processing, and data transmission are performed concurrently by the PC. Transmission of data, setpoints, commands, or program changes to the PC by the microprocessor are not permitted during production mode. Maintenance mode utilities for modifying PC registers or program logic by microprocessor are available.

A **backup CAMAC serial highway** interconnects all device system CAMAC crates in the EBT-P test support area. This backup highway is connected to a backup microprocessor through an interface identical to the primary serial highway interfaces. This microprocessor contains or has access to copies of data acquisition tasks from all other microprocessors. It is able to access any CAMAC crate connected to an off-line microprocessor. This access is accomplished on command from the facility computer. The normal display processing and storage functions of the microprocessors will be sacrificed or degraded when operating in this mode. The backup microprocessor may be required to acquire data from more than one device system CAMAC crate. The communication link to the facility computer is identical to the primary links.

The backup microprocessor also has a communication link to the research diagnostics computer for backup of diagnostics processors. This hardware interface has yet to be defined, but it serves as an alternate path from the facility computer to the research diagnostics computer. The physical capability is provided to implement a direct link from device subsystems to research diagnostics. The software to support this link and its functionality will be determined during Title II. See also Section 4.3.3.

4.1.6 PC Control/Interface Subsystem Configuration - Figure 4.1.6-1 highlights the PC control/interface subsytem on the I & C master block diagram. The process controllers, along with their associated I/O structures, form the main link bewteen the EBT-P device subsystem sensors/controls and the operators at the MCC and SCC consoles. All control

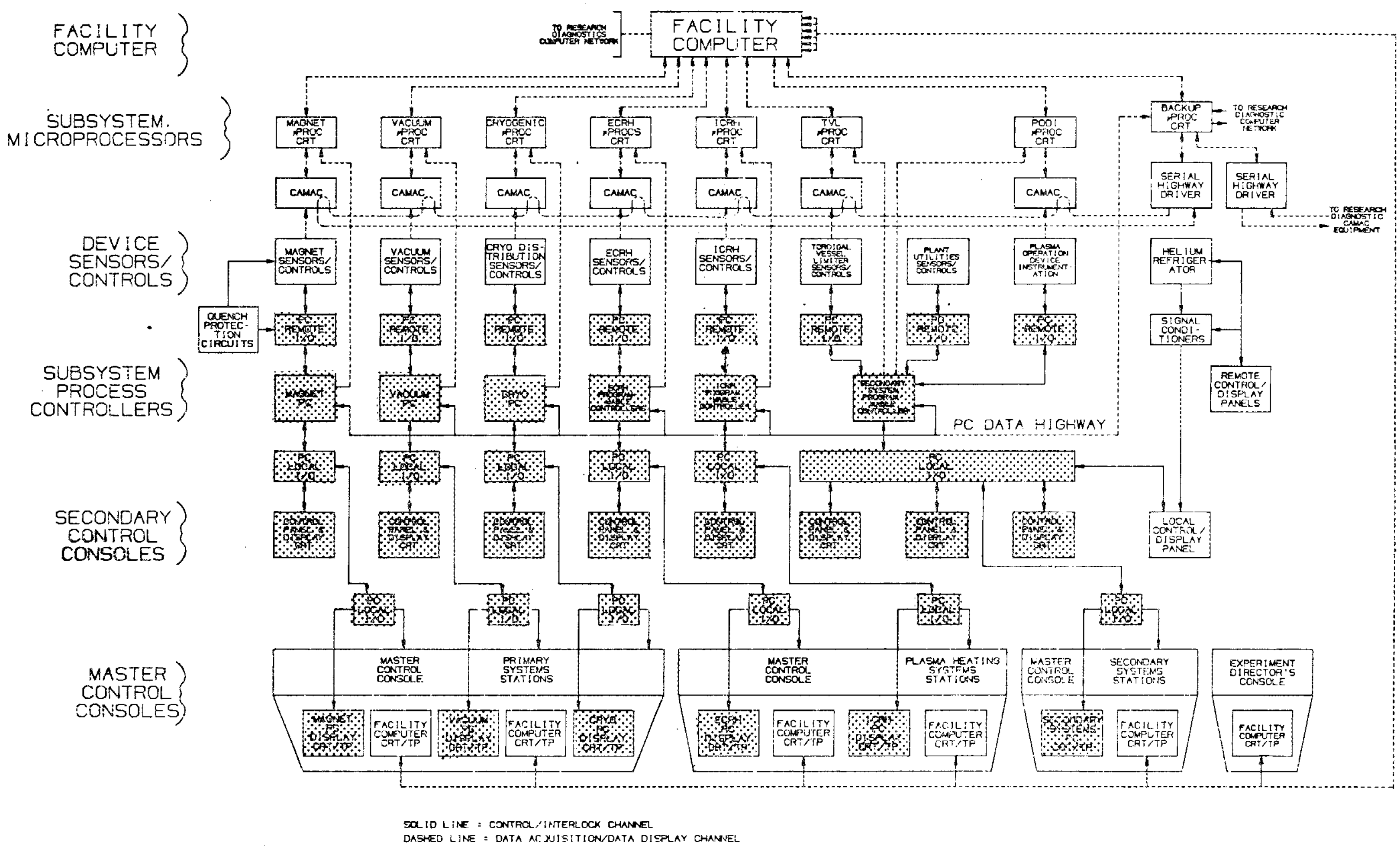


FIGURE 4.1.6–1 PROGRAMMABLE CONTROLLER COMPONENTS

signals originate at control panels which are wired to PC inputs. These control inputs are interlocked through the PC programmed logic. If and only if the PC logic allows a control output, the signal will pass through the PC remote I/O structure to the device subsystem control actuator. In order to complete the interlock loop, the bulk of device sensors are connected to PC remote input modules. These signals, both discrete (on/off, open/closed, etc.) and analog (voltages, pressures, etc.), are used to determine the validity of control inputs. Furthermore, the status of all control inputs and outputs is regularly transmitted to the associated subsystem microprocessor and continously displayed on dedicated color graphics display screens in the SCC and MCC panels.

There are seven process controllers comprising the control/interlock subsystem. They are:

- Superconducting magnet PC
- Vacuum PC
- Cryogenic distribution PC
- ECRH 28 GHz PC
- ECRH 60 GHz PC
- ICRH PC
- Secondary Subsystems PC

The standard process controller includes the following components:

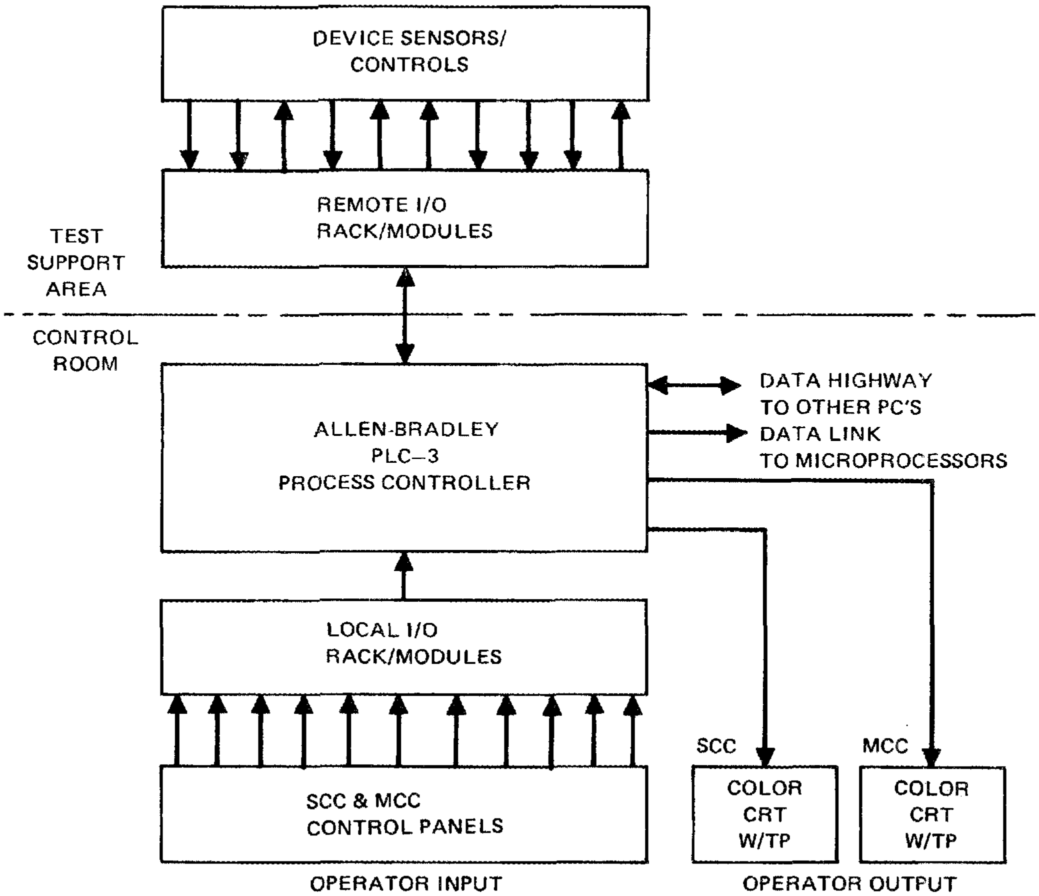
- Allen-Bradley (AB) Model PLC-3 Programmable Controller including:
  - 1775-A1 Main Chassis
  - 1775-L2 Main Processor with Level 2 Instruction Set
  - 1775-MR8 32K RAM Memory
  - 1775-S4 I/O Scanner Processor
  - 1775-DA Peripheral Processor
  - 1775-KA Communication adapter (Data Highway)
- AB Bulletin 1771 Universal I/O Equipment including:
  - 1771-A4 128 I/O Chassis Assembly
  - 1771-AS I/O Adapter Module
  - Appropriate Bulletin 1771 I/O modules

- PC Display Terminal including:
  - ISC Model 8001G Color Graphics Display Terminal
  - Elographics Model E270 Transparent Touch Sensor with Controller

Each process controller unit is composed of the mainframe processor including the chassis, CPU, memory and appropriate secondary processors and adapters as listed above. The I/O structure is logically separated into two components: local I/O and remote I/O. There is no electrical or hardware difference between the two. Local I/O consists of those I/O racks and modules located in the Control Room in close proximity to the PC mainframe. Remote I/O consists of I/O racks and modules located outside the Control Room: the Test Support Area, both Levels 1 and 2; the Mechanical Equipment Building; and the outdoor Power Supply Pad.

As with the microprocessor subsystem, each PC unit is configured similarly, with the only differences being in the quantity and location of the I/O equipment. Figure 4.1.6-2 is a functional block diagram of the basic PC configuration. At the top, device subsystem controls and sensors are connected to remote I/O modules. Sensor inputs and control outputs are communicated to and from the PC mainframe by the I/O scanner module in the PC chassis. The I/O scanner is connected to the I/O adapter modules in each local and remote rack. The total I/O capacity of the PLC-3 controller is 4096 inputs and 4096 outputs. Each I/O channel can be operated at a rated speed of 5 msec per I/O rack up to 5000 cable feet from the main processor. The data highway link to the other PC units is used to communicate interlock signals accross device subsystem boundaries. This facilitates, for example, interlocking of cryogenic distribution controls to vacuum system sensors and other multiple subsystem interlocks.

The link between the PC units and the associated microprocessor may be via serial RS-232C ports on a peripheral processor module, or via data highway, as is the PC to PC communication. The implementation of this link will be worked out during Title II. Local I/O is interfaced to the processor by the I/O scanner module exactly like the remote I/O. However, the local I/O consists only of input modules which sense the state of switches on the SCC and MCC control panels. There are no annunicators, indicators or panel meters controlled by local PC outputs. All PC operator output is directed to the two color graphic CRT terminals, one in the SCC and one in the MCC. These terminals are driven by serial



13–5046

FIGURE 4.1.6–2 BASIC PROCESS CONTROLLER CONFIGURATION

RS-232 lines (9600 baud) from the peripheral processor module in the PC chassis. Touch panel overlays provide the operator with control of the display format and content on each terminal. The terminals include intelligent graphics firmware for display page generation with little software overhead required by the PC. The current state of all PC inputs and outputs may be displayed on the display terminal screen during device operation.

Control programs in the process controllers use the status of input sensors and of contacts stored in memory to output control signals to the device. Unlike the single-function tasks in the facility computer and subsystem microprocessors, the PC control programs incorporate aspects of acquisition, processing, display, and communication, in addition to control. This is a characteristic of process controller relay ladder logic cyclic sequential programming. Normal modular programming techniques are not applicable. However, good PC programming is structured such to group distinct operations in an orderly logical sequence. The process controller subroutine and macro capabilities are used to modularize commonly used algorithms and processes as much as possible.

Within each process controller, input data flows from input modules to storage registers, where it is used to make process controller decisions. Control data flows from storage registers (both input data and output data) to the communication interface. Data also flows from registers to display output devices. Units of storage in the PC are individual registers, which are overwritten each scan and cyclic buffers which retain values from past scans.

Process controllers perform all processing required to solve logic necessary to control and sequence device systems. These also manage the transmission of data to the microprocessors and drive Secondary Control Console and Master Control Console displays. Utilities available through process controllers in maintenance mode include the ability to perform the following functions:

- examine process controller ladder logic programming
- exercise programming with outputs disabled
- examine input and output states for verification
- force inputs and outputs to a given state regardless of external conditions or programmed logic
- diagnose fault conditions in the PC I/O system.

These utility functions are performed with vendor-supplied software available with the PC.

Production mode processing in each PC includes the following functions:

- timing and sequencing of events
- interlock checking
- input data unit conversions
- parametric conversions (Δp to flow rate, for example)
- display generation
- data transmission
- output data scaling
- alarm generation and fault detection

Process controller Master Control Console users are not required to learn PC ladder logic programming. All interaction with PC is via hardware switches on each control panel for device control and via touch panel for display control. Data are displayed in a mix of graphical and textual elements. The user selects from a repertoire of display pages which vary in content and format. Displays are automatically updated as new data becomes available. Each MCC PC display only presents data from its specific system process controller. As control switches are actuated, the display acknowledges the command and confirms the action, regardless of the display format currently being viewed. Numeric inputs (setpoints, limits, etc.) are continuously displayed as they are being modified at a control panel. Alarm or warning messages override all other display formats.

The process controller displays are driven by message-generating logic in the PC. The displays are page-oriented similar to the facility computer displays. Touchpanel input soft keys are used for display control just as in the MCC facility computer displays. Regardless of the display format, all PC inputs and outputs are displayable at each device subsystem PC display. Alarms, warnings, cautions, etc., override all other display elements. Hardwired process control switches on control panels override soft switches on the touchpanel. When parameters are being set or modified, the control panel LOAD PARAMETER switch causes the current value of that parameter to be displayed. The control philosophy for EBT-P requires that the PC displays be the primary operator information feedback device.

Process controller SCC displays are identical to the MCC PC displays. Both units display the same data at the same time. Normally, display control resides in the MCC. However, by setting a hard switch on each MCC panel associated with a device subsystem, display control is transferred to a SCC display touchpanel. MCC display control has priority unless control is given to the SCC by MCC command.

There is no mass storage on PCs except for buffers maintained internally for logic control and display management. Data and status are transmitted to the microprocessors at regular intervals on demand. All PC data are recorded first by the associated microprocessor and then by the facility computer. Local storage of setpoint values in registers is done as a normal part of programming. These values remain in PC memory (as long as PC power is maintained) until changed by a user at a control panel.

Backup process controllers may exist which can be switched into the I/O channels previously connected to a malfunctioning process controller. These backup PC's contain or have access to the same process control logic as the primary PC. Each backup PC has a communication link to a microprocessor which is identical to the primary link. The communication software in the microprocessor detects when the primary PC is off-line and switch to the backup PC. The design of this backup function will be done during Title II.

The design of the PC control software includes the use of "man-in-the-loop" control techniques at a process level. Individual component control and sequencing is handled by PC logic. Annunciators and indicators are replaced by software generated displays wherever possible.

The process controller operational functions are listed below. All control functions are the responsibility of the process control software. These include:

- Sensing of interlocked inputs
- Output of control signals to actuators
- Input of setpoint values
- Display of alarms or exceptions
- Display of operating conditions

The PC logic software in each process controller addresses each of the control functions listed above. The value of each binary input point and each analog input is stored in a register for access by display and data transmission logic in the PC.

Input signals are classified according to the following categories:

- **INTERLOCK/STATUS INPUTS** are always discrete/binary signals. These are required by PC logic for decision making, interlocking of processes, action initiation or inhibition. They have no inherent good/bad meaning. Examples are on/off, enable/disable, open/closed, etc.
- **OPERATING CONDITION INPUTS** are always analog signals which indicate a range of possible values. These signals are required by PC logic for decision making. They have no inherent good/bad meaning. However, the PC may determine a fault condition if an operating condition input goes beyond a predetermined tolerance. Examples are: temperature, pressure, voltage, current, etc.
- **FAULT/WARNING/ALARM INPUTS** are always discrete/binary signals. These are predetermined at the source to indicate a fault, warning, or alarm condition. No additional logic is required in the PC to determine the meaning of the signal. Examples are: overvoltage warning, crowbar trip alarm, magnet quench alarm, etc.
- **DIAGNOSTIC INPUTS** may be either discrete or analog signals. These signals indicate status or operating conditions after a fault has occurred. They are only examined, displayed, and transmitted by the PC after a fault has occurred to aid in diagnosis of the fault.

Output signals are classified according to the following categories:

- **COMMAND OUTPUTS** are always discrete/binary signals. They indicate a particular command such as open valve, start pump, etc. The intended command output can only be activated when the proper sequence of interlocks has been asserted.
- **SETPOINT OUTPUTS** are always analog signals. They indicate a value of particular quantity to be set, such as power supply voltage level, heater current, etc. Due to the relatively high cost of analog output modules, these are used only for quantities which must be varied during production mode; constant setpoints are hardwired if possible.

Control panel switch inputs are considered to be interlock signals. Control panel indicators are not used unless necessary. Control panel switches on the Secondary Control Consoles (SCC) have a one-to-one correspondence with command output signals on the PC. The PC interlocks each function and performs the action only if appropriate. This provides component level control at the SCC. Control panel switches on the Master Control Console (MCC) correspond to processes in the PC logic. Assertion of an MCC switch causes a process involving a sequence of operations and components to be initiated or aborted. Little or no component-level control is provided at the MCC. This provides process-level control at the MCC. Numeric inputs at the MCC and SCC's are handled by a method which uses simple binary switches to increment and decrement selected PC registers. These switches are located in a specific numeric input cluster on each panel. Feedback of numeric values occurs on the PC CRT display. Other methods such as thumbwheels, keypads, and knob-controlled potentiometers are also used depending upon application requirements.

The control logic software treats all inputs and outputs as fail-safe in the unpowered state. External wiring is consistent with this requirement. Absence of an interlock input inhibits action, and likewise, absence of a command output inhibits action. Fault signals are treated such that the "OFF" state indicates fault, while assertion of the signal indicates "No Fault".

Process control initiated at the MCC is not allowed to proceed past a designated milestone or hold point until the next process is initiated at the MCC. Asserting multiple process switches in order to avoid anticipated operator action is not allowed.

4.1.7 Master Control Console (MCC) Configuration - The MCC layout is shown in Fig. 4.1.7-1. The MCC stations are arranged on a rectangular pattern. This configuration effectively organizes the operations crew into a centralized work group and efficiently utilizes control room floor space. The MCC is assembled for baseline Phase III operations from twenty (20) basic MCC units (see Figure 4.1.7-2). The typical MCC unit is a standard 19"W x 48"H rack and contains two components, a control panel and a color CRT terminal with a touch panel overlay.

The MCC design criteria requires centralized control and minimal control switches on the MCC control panels. The PC units are the means for achieving both of these ends. The

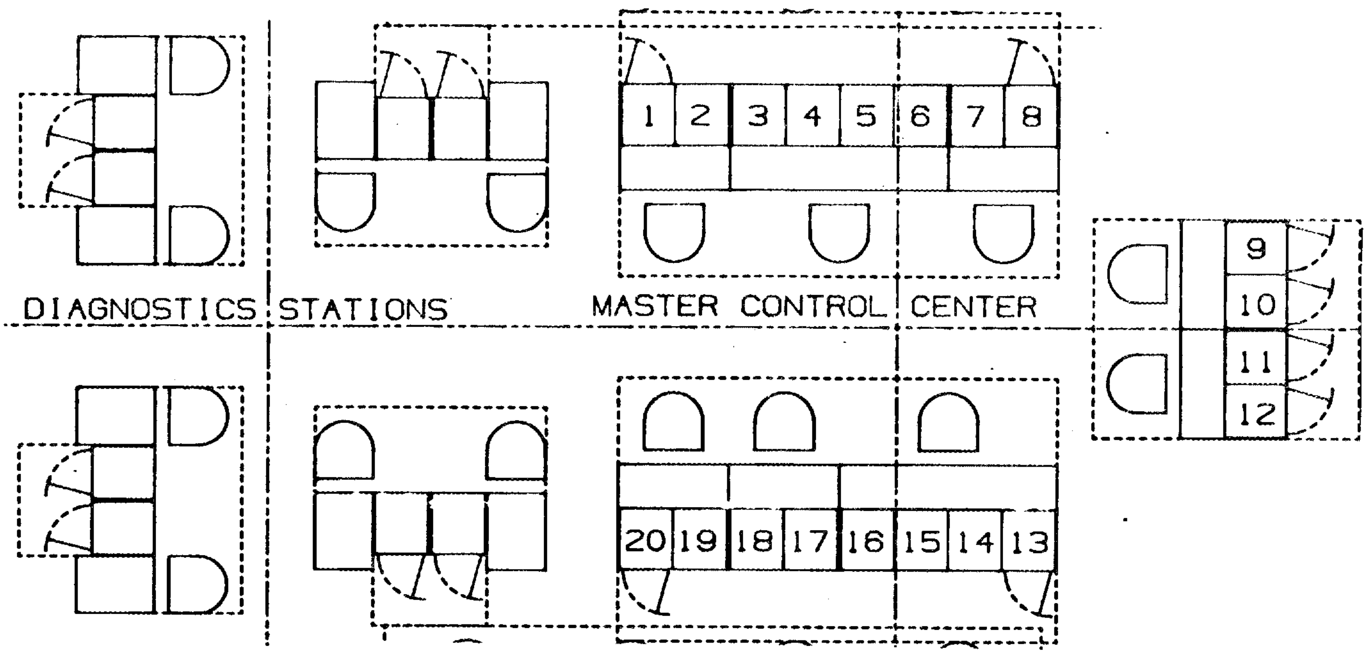


FIGURE 4.1.7–1 MASTER CONTROL CONSOLE PLAN VIEW

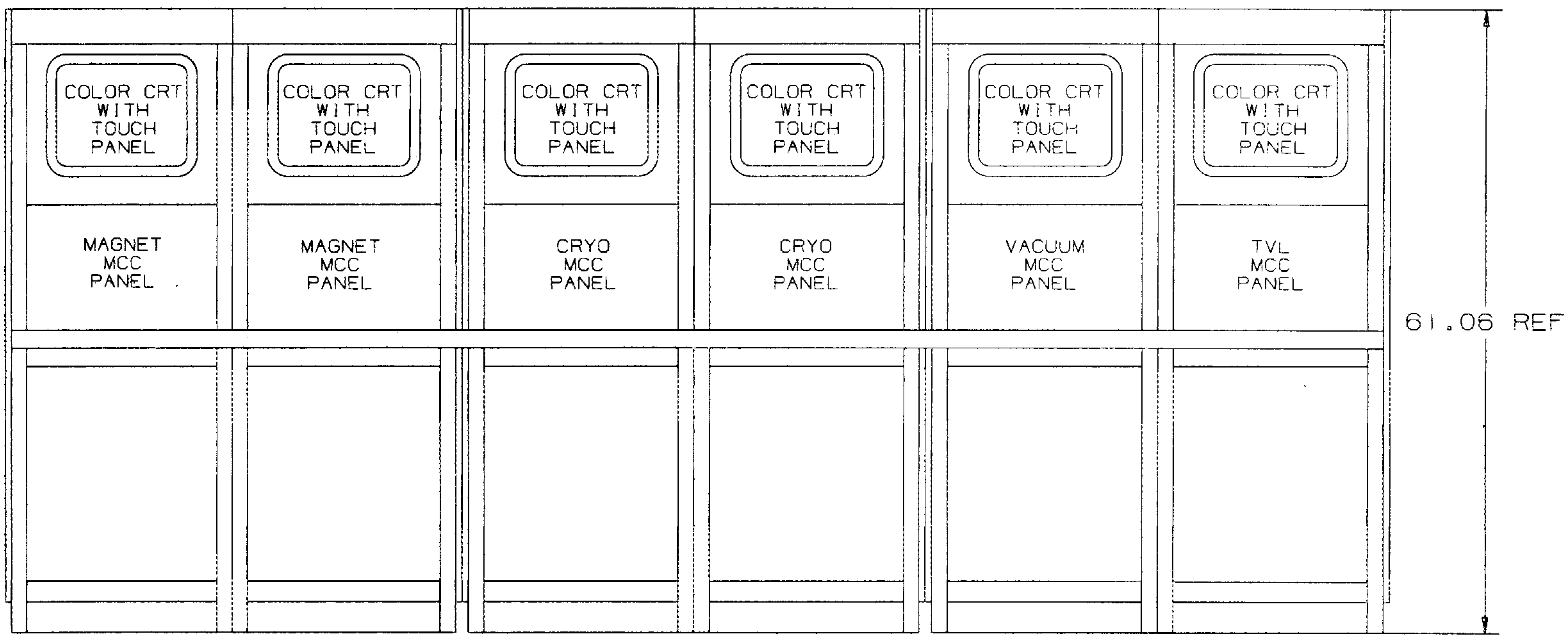


FIGURE 4.1.7–2 MCC STATION LAYOUT (TYPICAL)

switches on the MCC control panels interact with PC software to initialize, execute and abort control sequences that control and interlock pre-defined device processes (e.g. TF coil charging, torus vacuum pumping processes, etc.).

Data required to monitor these processes are fed back to the MCC color CRT terminals by the PC units and by the facility computer. There are no discrete, hardwired status indicators (analog panel meters, digital panel meters, illuminated status indicators, etc.) contained in the MCC stations. The rationale for this design approach is presented in Section 5.2.

MCC units are provided to control the primary EBT-P device systems:

MCC Station	Target System
MCC-1, MCC-2	Magnet System
MCC-3, MCC-4	Cryogenic Distribution System
MCC-5, MCC-6	Vacuum/TVL Systems
MCC-7, MCC-10	ECRH - 60 GHz System
MCC-11, MCC-12	ECRH - 28 GHz System
MCC-13, MCC-14	ICRH System
MCC-15, MCC-16	Chief Operator's Station
MCC-17, MCC-18	Experiment Director's Station
MCC-19, MCC-20	Diagnostic Data Coordinator's Station

MCC units 15 thru 20 are called the "Experiment Direction Console" and are described in Sec. 4.1.10. Figure 4.1.7-3 shows the first of two magnet system control panels (panel ID: PMCC-MAG-001 located at MCC station MCC-1). The main keyswitch is the first interlock for the magnet system. This keyswitch must be set to the ON position before any magnet system processes can be initiated. Four ac power switches are used to power-up various components of the magnet system. Another keyswitch is provided to override magnet system interlocks. In the OFF position, these interlocks are enabled; in the ON position the magnet system PC unit disregards certain normally-needed interlocks. Authorization to override is a prerogative of the EBT-P project supervision and is used only in extraordinary circumstances.

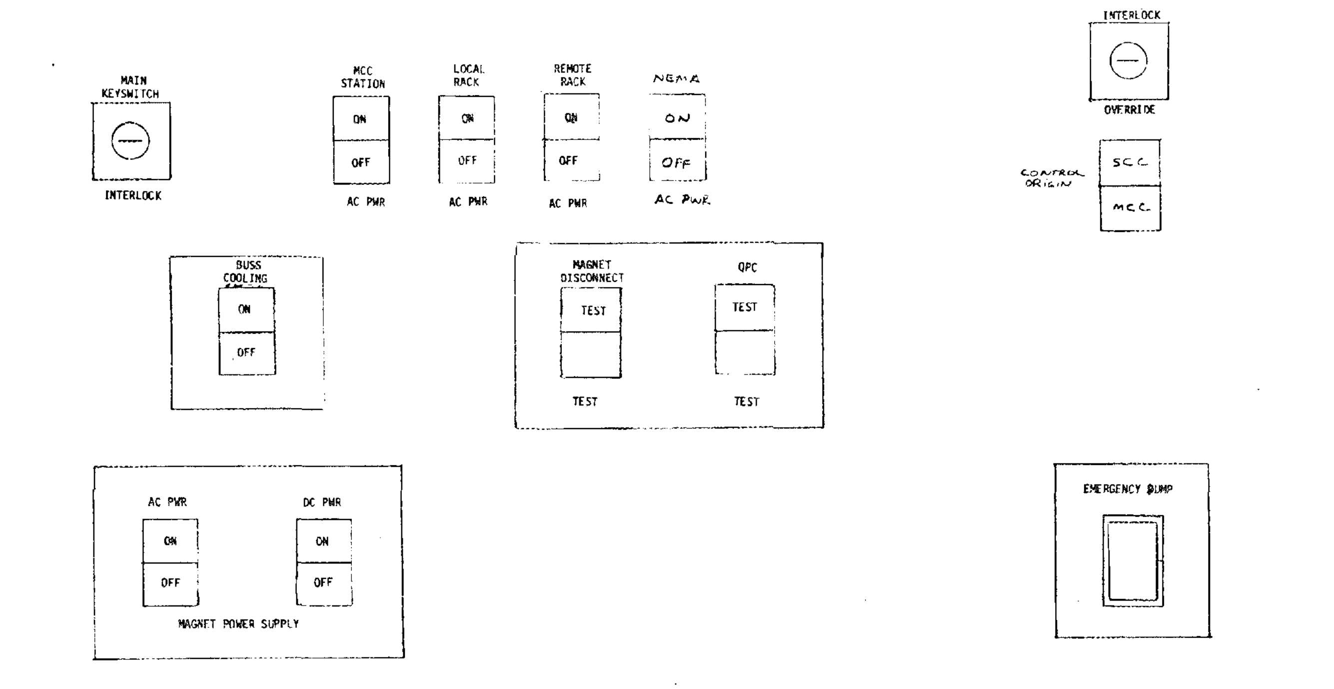


FIGURE 4.1.7–3 MCC CONTROL PANEL PMCC-MAG-001

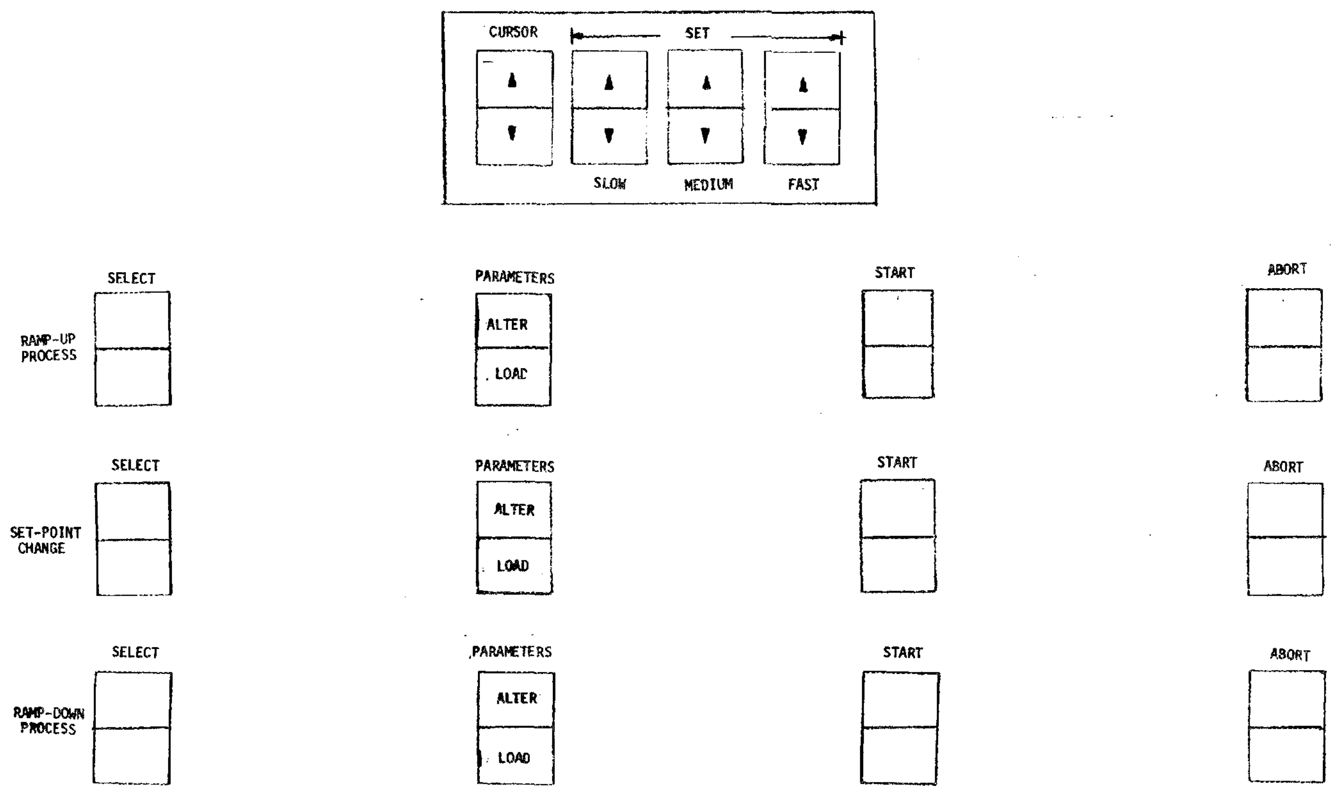


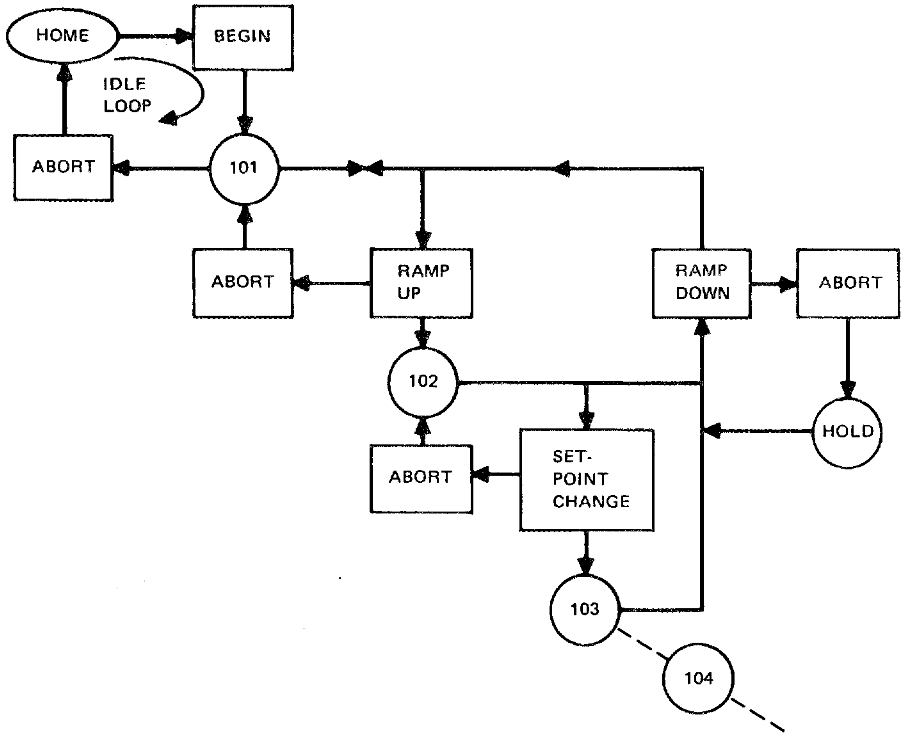
FIGURE 4.1.7–4 MCC CONTROL PANEL PMCC-MAG-002

A switch is provided to control water cooling to the magnet system buss bars. Two switches are available to test the magnet disconnect units and the magnet Quench Protection Circuits. These switches cause the magnet PC unit to execute pre-programmed control sequences which test these vital magnet system protection components. The results of these tests are displayed via the CRT units and error-conditions are flagged. Obviously these tests are performed only when the TF coils are uncharged.

Two switches are provided to initialize the magnet power supply. The first switch applies ac power to the power supply; the second switch is an enable input which permits the PC unit to output control signals to the power supply. Finally, an emergency dump switch is provided to allow the operator to manually initiate a magnet discharge process. This switch is covered with a transparent safety window which must be lifted before the switch is cycled. This measure prevents inadvertant actuation of this emergency switch.

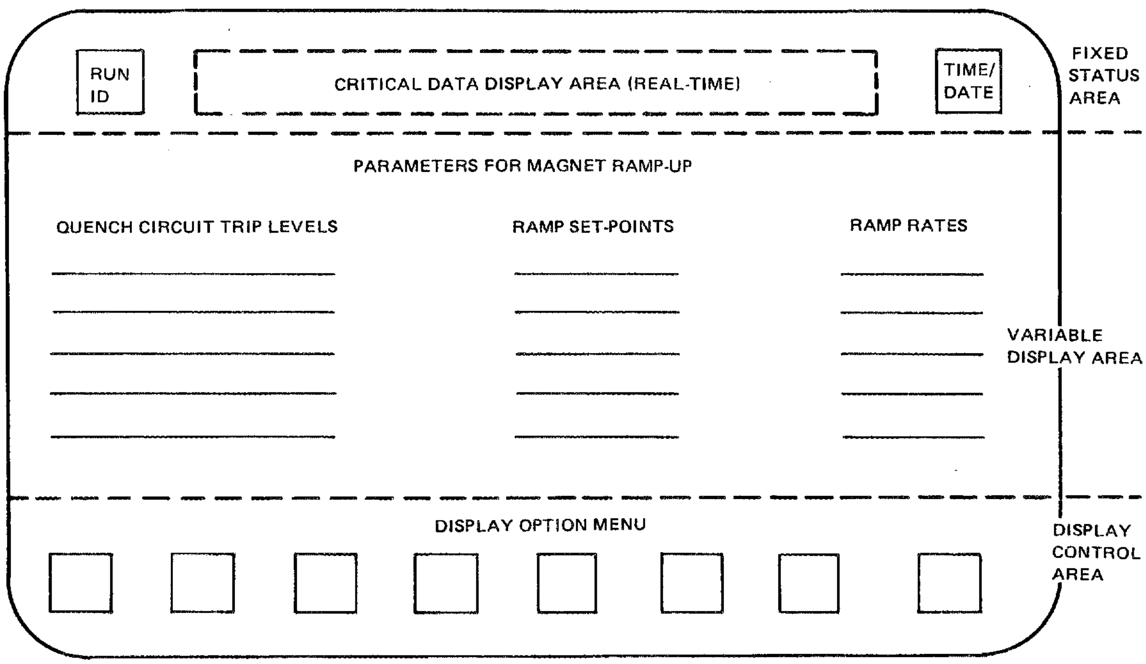
The second magnet system MCC control panel is shown in Fig. 4.1.7-4. Two groups of control switches are provided: a group of four switches located at the top of the control panel is used to set parameters for the various magnet system control processes, and another group of switches is provided to control the three magnet system processes (power supply ramp-up, output current set point change and the power supply ramp-down process). Each of these switches communicate with a distinct subroutine in the magnet PC unit. Each subroutine requires a number of parameters which the operator supplies prior to starting the execution of the process. The operation of the magnet system is visualized as a number of process control sequences which move the magnet system from one state to another. A flow diagram is used to show these operations (see Fig. 4.1.7-5). The circle symbols, e.g. 101 , represent definite magnet system states and are called "milestones". Each milestone is recognized by the magnet PC unit as a set of pre-defined values for a number of magnet system control and Class B sensor elements. The links between the milestones are the magnet system processes.

At initial MCC power-up, the magnet PC unit executes an "idle loop"; nothing happens since the PC unit is awaiting an operator command. At this point the operator has only one logical option, namely, to select the "ramp-up" process. If another selection is attempted, the PC unit flags this as an error. When the ramp-up process SELECT switch is actuated, the CRT unit displays the present parameters for this process (see Fig. 4.1.7-6).



13–5058

FIGURE 4.1.7–5 MAGNET SYSTEM PROCESS FLOW DIAGRAM



13–5050

FIGURE 4.1.7–6 MCC COLOR CRT DISPLAY-PAGE LAYOUT

These parameters include magnet charge-up rate (amps/min), final steady-state current to the magnets (which is proportional to the desired B-field level in the device) and the present trip thresholds for the QPC voltage sensors. If the operator desires to change these parameters, the PARAMETERS switch is moved to the ALTER position. This action causes a cursor to appear on the CRT display. The CURSOR switch is used to position the cursor next to the parameter to be changed. The operator next uses the SET switches to change the numeric value of the parameter to the desired value. When this "set" process is completed, the PARAMETERS switch is returned to the LOAD position to lock in the revised process parameters. The ramp-up process is initiated by actuating the START switch. As the ramp-up process proceeds, the CRT-display shows the real-time values of the relevant process variables, either numerically, graphically, or by both of these means. The operator can override the PC unit by using the ABORT switch. This switch is an input to an PC unit ABORT subroutine which returns the magnet system to milestone 102 in an orderly fashion.

The other magnet system MCC processes are parameterized and activated using the same approach described for the ramp-up process. The "set-point change" process permits the operator to change the magnet steady-state current set-point while the magnet system is operating. When this process is started, the PC unit ramps the power supply current up or down to achieve the new current setpoint. The "ramp-down process" permits the operator to discharge the magnets in a controlled manner such that a quench is not induced.

The cryogenic distribution system control is concentrated at MCC stations MCC-3 and MCC-4. Figures 4.1.7-7 and 4.1.7-8 show the MCC control panels. The cryogenic MCC CRT displays and control panels are configured in the same way as the corresponding magnet MCC components. This situation applies equally to the other MCC stations and is a delibrate design decision employed for two reasons:

a) To achieve a common MCC station design to reduce fabrication costs;
b) To enable operators to be cross-trained to operate several device systems without excessive difficulty.

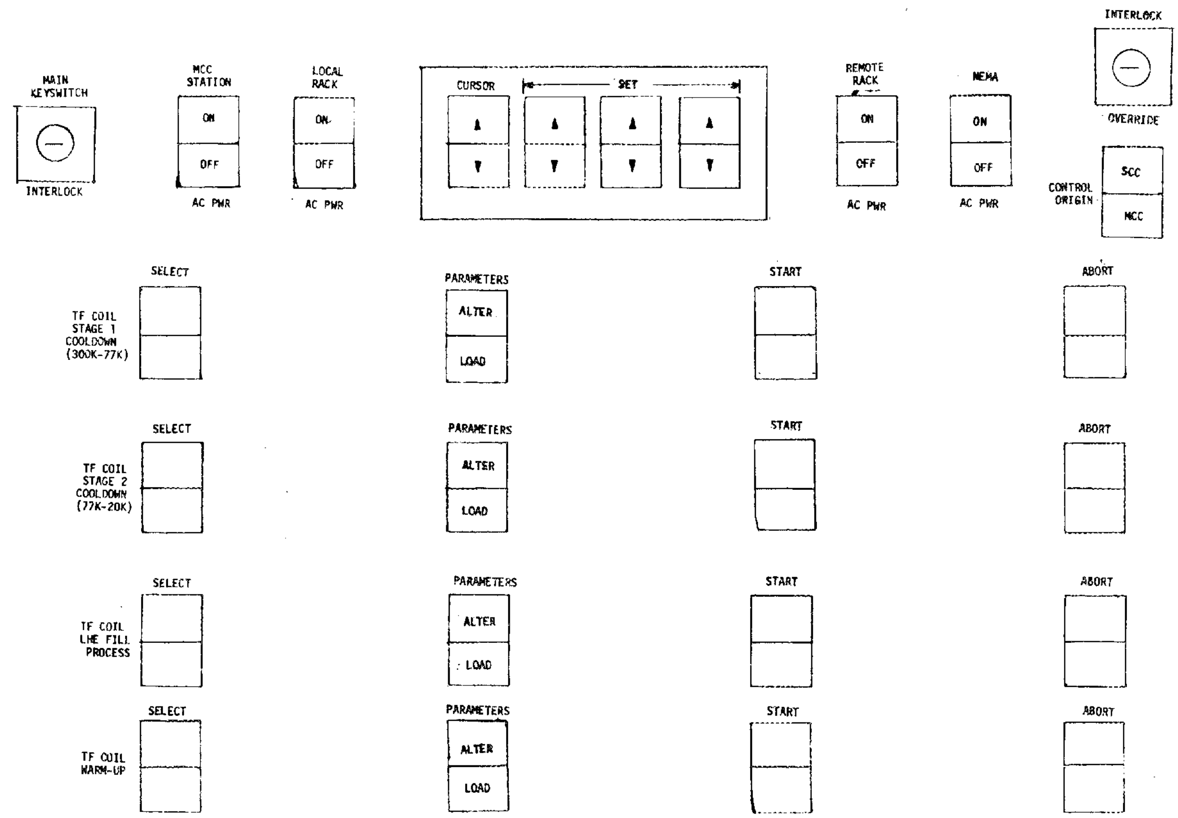


FIGURE 4.1.7–7 MCC CONTROL PANEL PMCC-CRYO-001

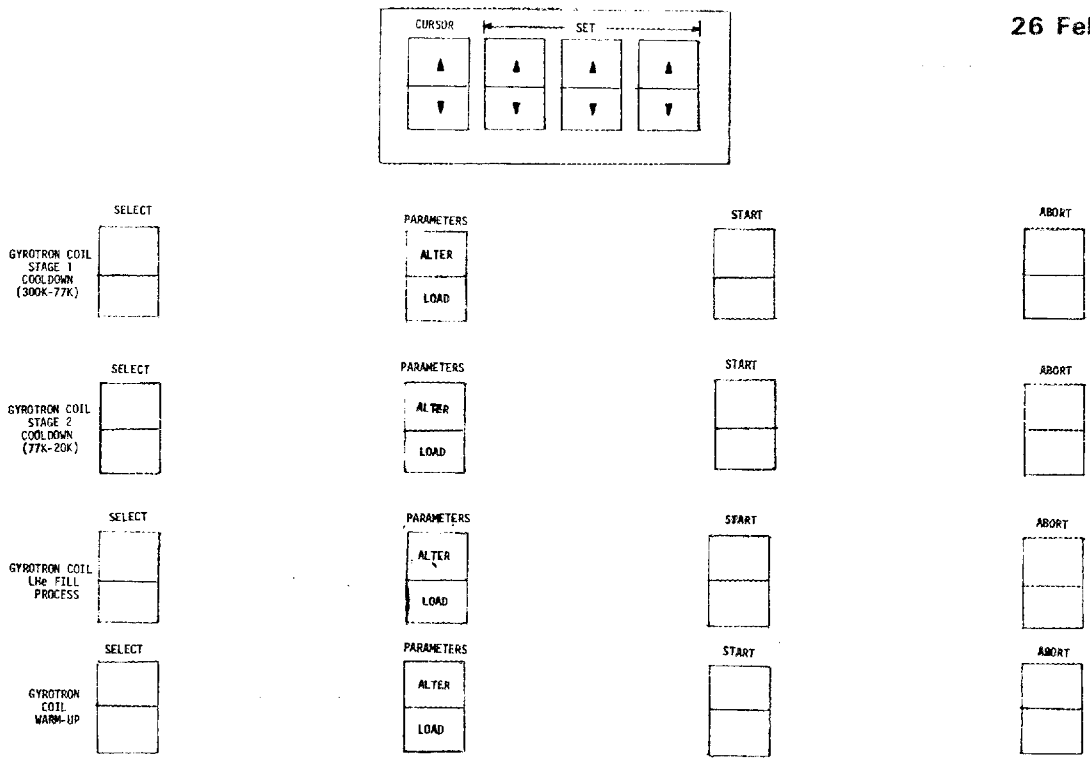


FIGURE 4.1.7–8 MCC CONTROL PANEL PMCC-CRYO-002

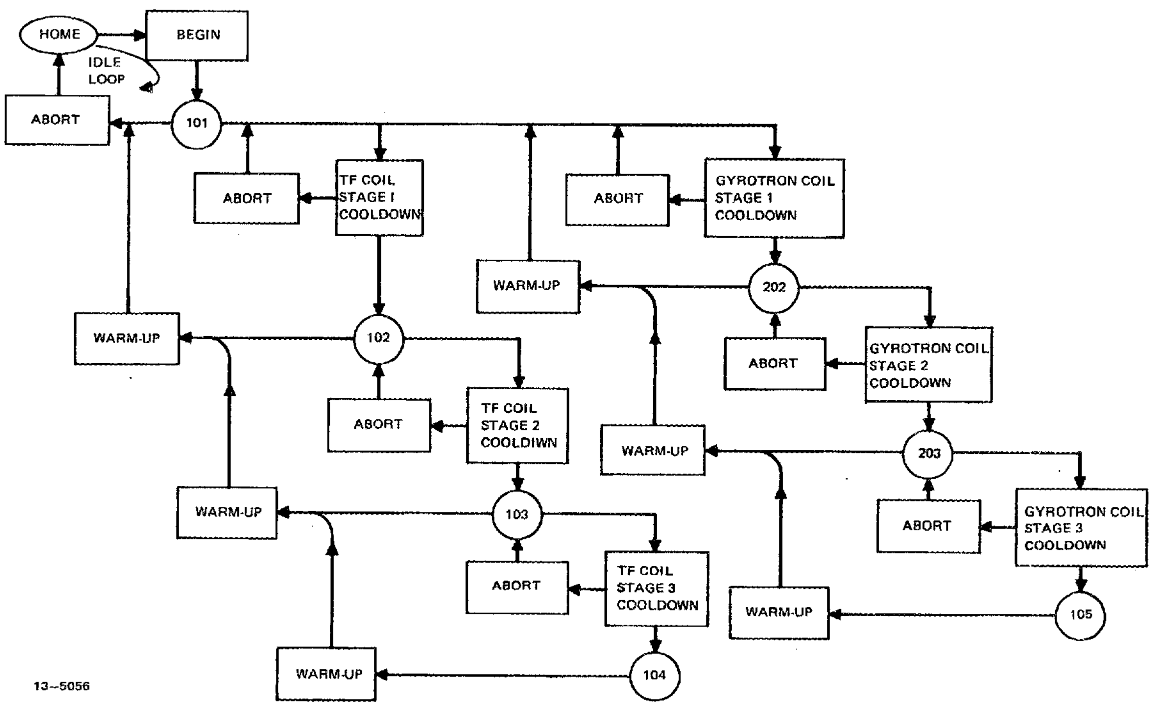


FIGURE 4.1.7–9 CRYOGENIC DISTRIBUTION SYSTEM PROCESS CONTROL FLOW DIAGRAM

Reason b) is the more relevant item for Phase III operations in which easy cross-training is expected to be an important factor in achieving the required device operation schedule milestones.

Figure 4.1.7-9 shows the process control flow diagram for the cryogenic distribution system. These processes are employed to control the LHe fill procedures for both the TF coil dewars and the 60 GHz gyrotron focus magnet dewars. Due to the design of the cryogenic distribution system (see Sec. 4.2.3) these two procedures can be operated concurrently (i.e. parallel operation). However, all thirty-six TF coil dewars must be filled simultaneously and all six gyrotron dewars must be filled simultaneously. Dewars cannot be filled singly since this would greatly increase the complexity and cost of the cryogenic distribution system.

The cryogenic distribution system processes are long-duration sequences probably requiring in excess of 24 hours to complete. An important issue involves the design of the PC software for these processes such that unattended operation can be achieved. In particular, the ABORT sequences are required to operate automatically to return the system to "safe" milestones when fault conditions are sensed by the PC unit. Capability for unattended operation is a present design criterion for the cryogenic distribution system.

The vacuum/TVL MCC unit is shown in Fig. 4.1.7-10. The two stations (MCC-5 and MCC-6) are standard design units and a color TV monitor associated with the PLASMA TV research diagnostic is installed here. This monitor displays plasma luminance and chromatic data and is used by the operator to assist to setting the device operation mode (C-, T- or M-mode).

The two vacuum/TVL MCC control panels are shown in Figs. 4.1.7-11 and -13. The layout and function of the various switches are similar to that previously-described for the magnet system. Figure 4.1.7-12 shows the process flow diagram corresponding to control panel PMCC-VAC-001 located at MCC station MCC-5. The processes control the pump-down sequences for the EBT-P toroidal vacuum vessel and the GH_2 backfill process. The latter process is used to establish and control plasma density. A SHUTDOWN process is used to provide an orderly means of returning the device to atmospheric pressure (by GN_2 backfilling). Milestone 206 represents conditions at the base pressure ($<10^{-7}$ torr) while

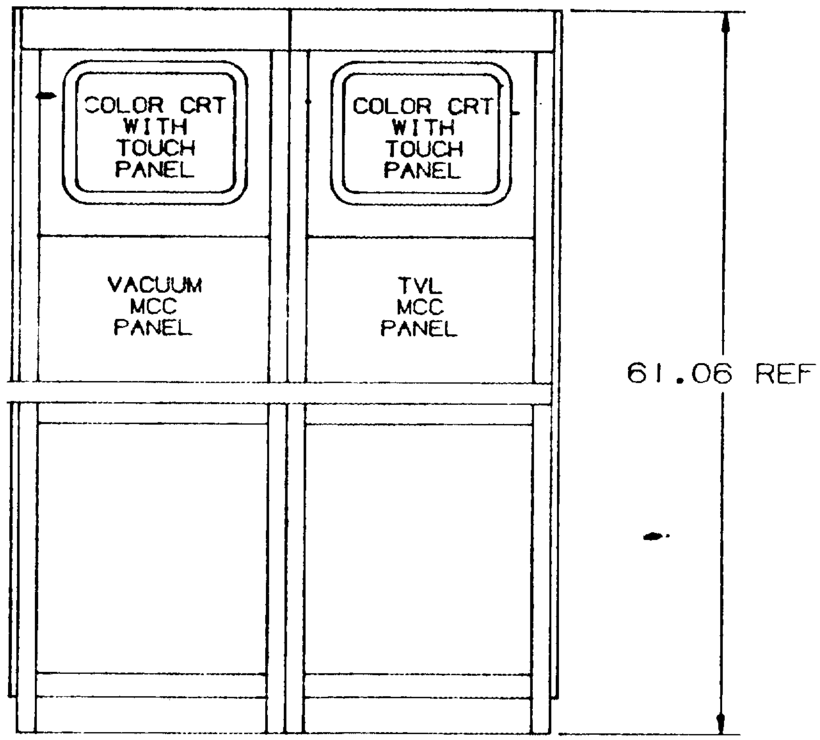


FIGURE 4.1.7–10 VACUUM/TVL MCC UNIT

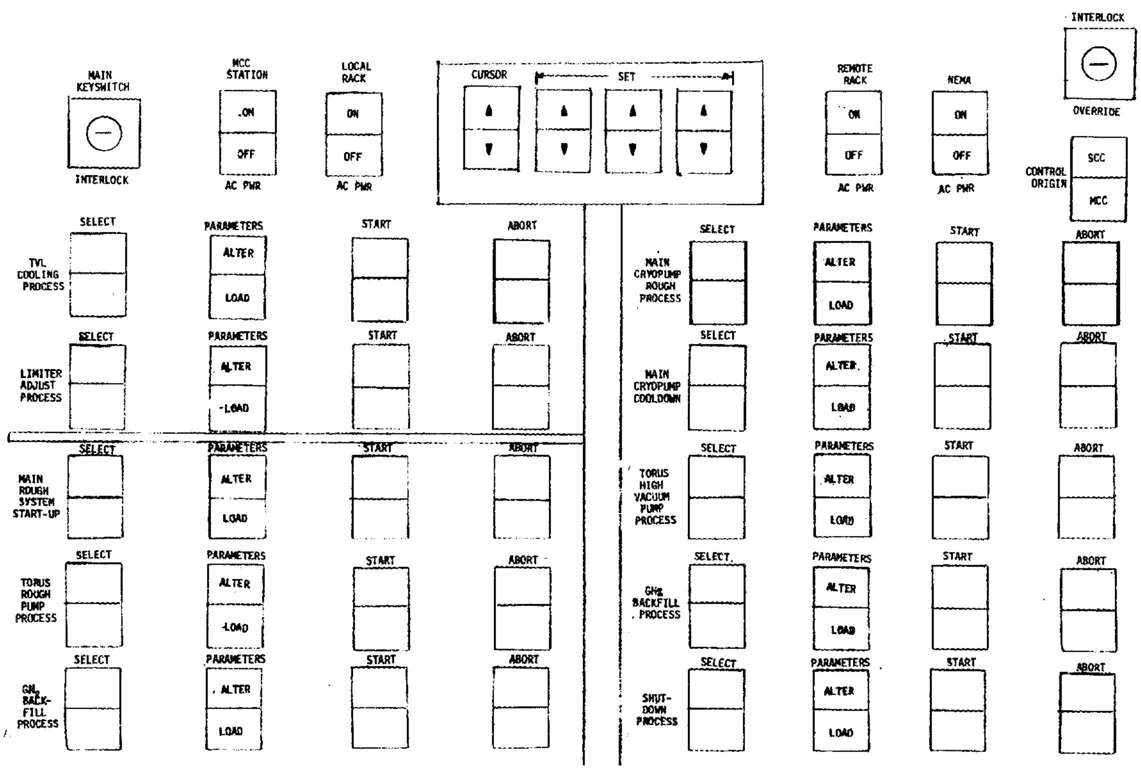


FIGURE 4.1.7–11 VACUUM/TVL MCC PANEL PMCC-VAC-001

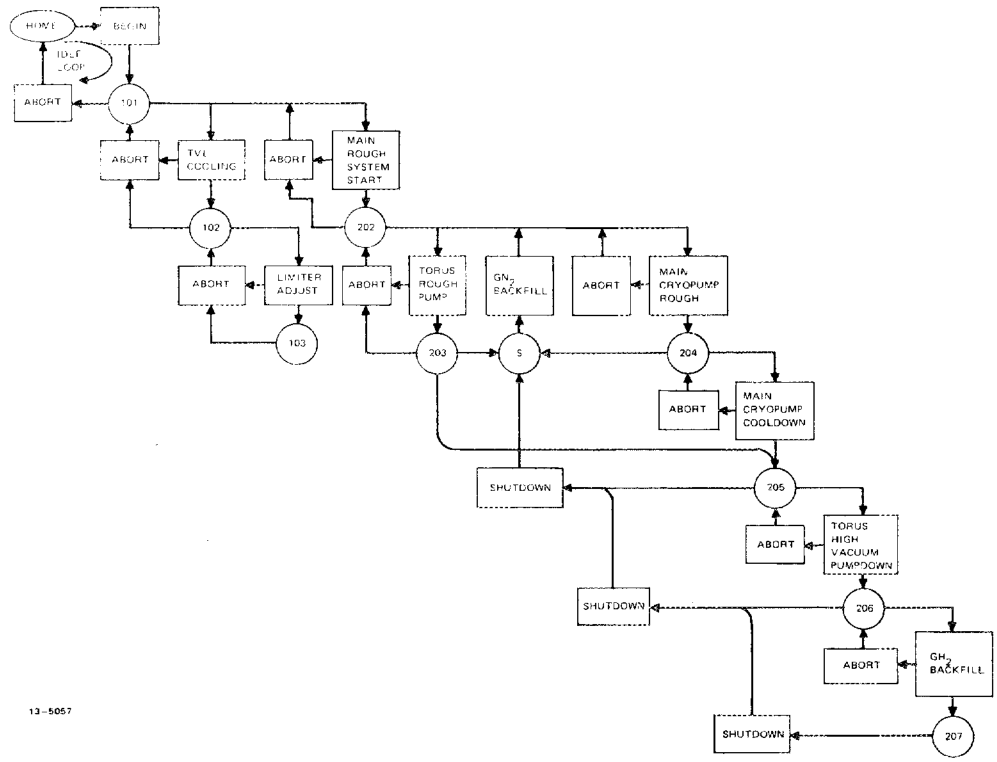


FIGURE 4.1.7–12 VAC/TVL MCC PANEL PMCC-VAC-001 FLOW DIAGRAM

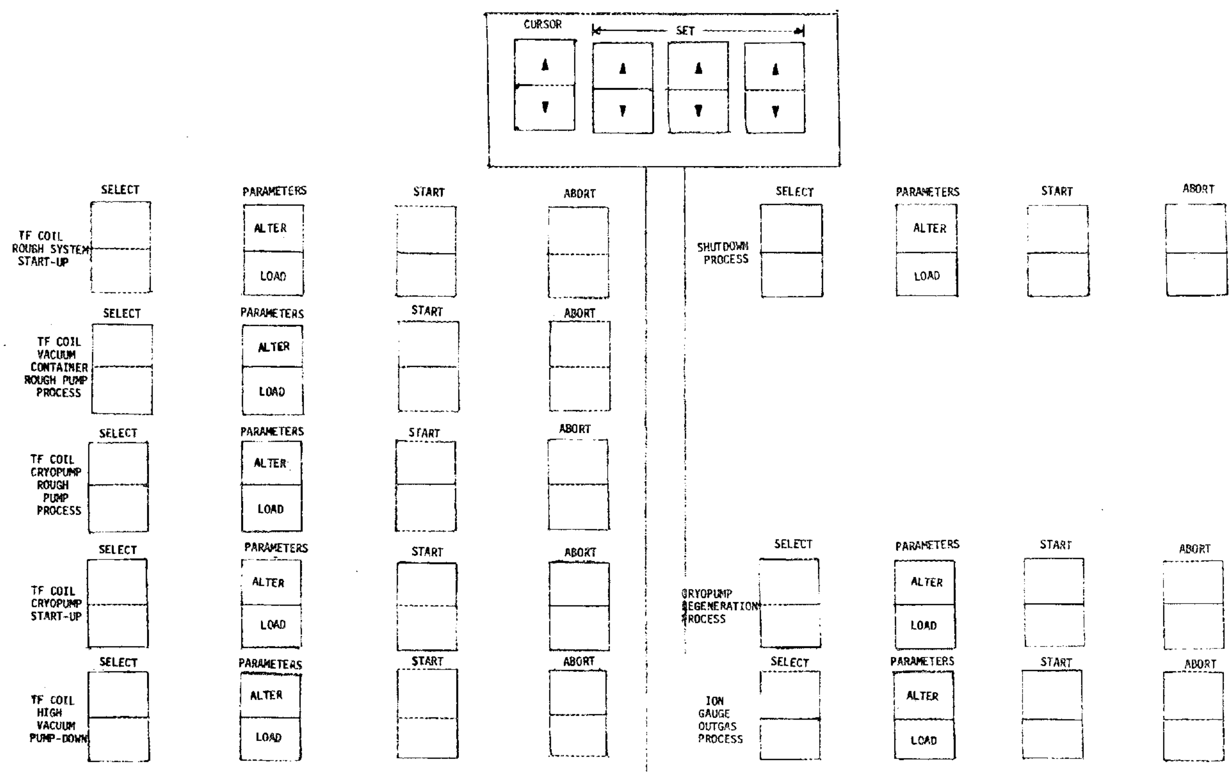


FIGURE 4.1.7–13 VACUUM/TVL MCC PANEL PMCC-VAC-002

milestone 204 represents conditions resulting from rough pump processes only ($\sim 10^{-3}$ torr).

Figure 4.1.7-14 shows the process flow diagram associated with control panel PMCC-VAC-002 (located in MCC station MCC-6). These processes inlcude:

- TF coil vacuum enclosure pumpdown processes,
- 60 GHz magnet vacuum enclosure pumpdown processes,
- Ion gauge outgas processes,
- Cryopump regeneration processes.

Milestone 205 represents the end point of the TF coil high vacuum pumpdown process (i.e.; $p < 10^{-6}$ torr) while milestone 203 is the end point of the TF coil rough pumping process ($p \sim 10^{-3}$ torr).

The ECRH 60 GHz MCC control panels are located on four MCC stations (MCC-7 thru MCC-10). These controls are used to adjust and balance the 60 GHz microwave power to the thirty-six device cavities. Figures 4.1.7-15 shows a generic ECRH MCC control panel layout which contains control switches attached to power balance processes, pulsed ECRH processes and the SHUTDOWN process. The process flow diagram corresponding to this control panel is shown in Fig. 4.1.7-16. The design of these ECRH MCC control panels at present is generic, rather than specific. This situation is due to the relatively undeveloped state of the ECRH distribution system design. As this subsystem design becomes better identified, these control panel layouts will be revised.

Note that the 60 GHz ECRH system is allocated four MCC stations. This feature is included due to the relatively large number of 60 GHz gyrotron sources (six) and to the presumed eventual complexity in the 60 GHz ECRH distribution system design. This number will be revised as the design proceeds in Title II. The 28 GHz ECRH distribution system is controlled via MCC stations MCC-11 and MCC-12 and the processes involved are identical to those shown in Fig. 4.1.7-15.

Two MCC stations are provided for the ICRH system, MCC-13 and MCC-14, both of which are standard MCC units. The single control panel, PMCC-ICRH-001 shown in Fig.

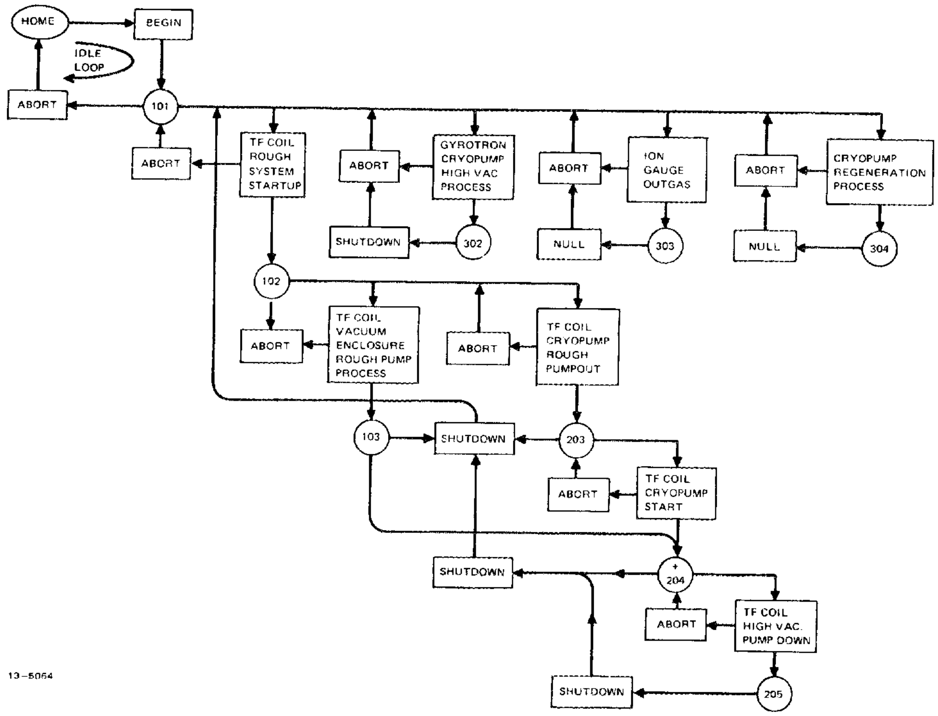


FIGURE 4.1.7–14 VACUUM/TVL MCC PANEL PMCC-VAC-002 PROCESS FLOW DIAGRAM

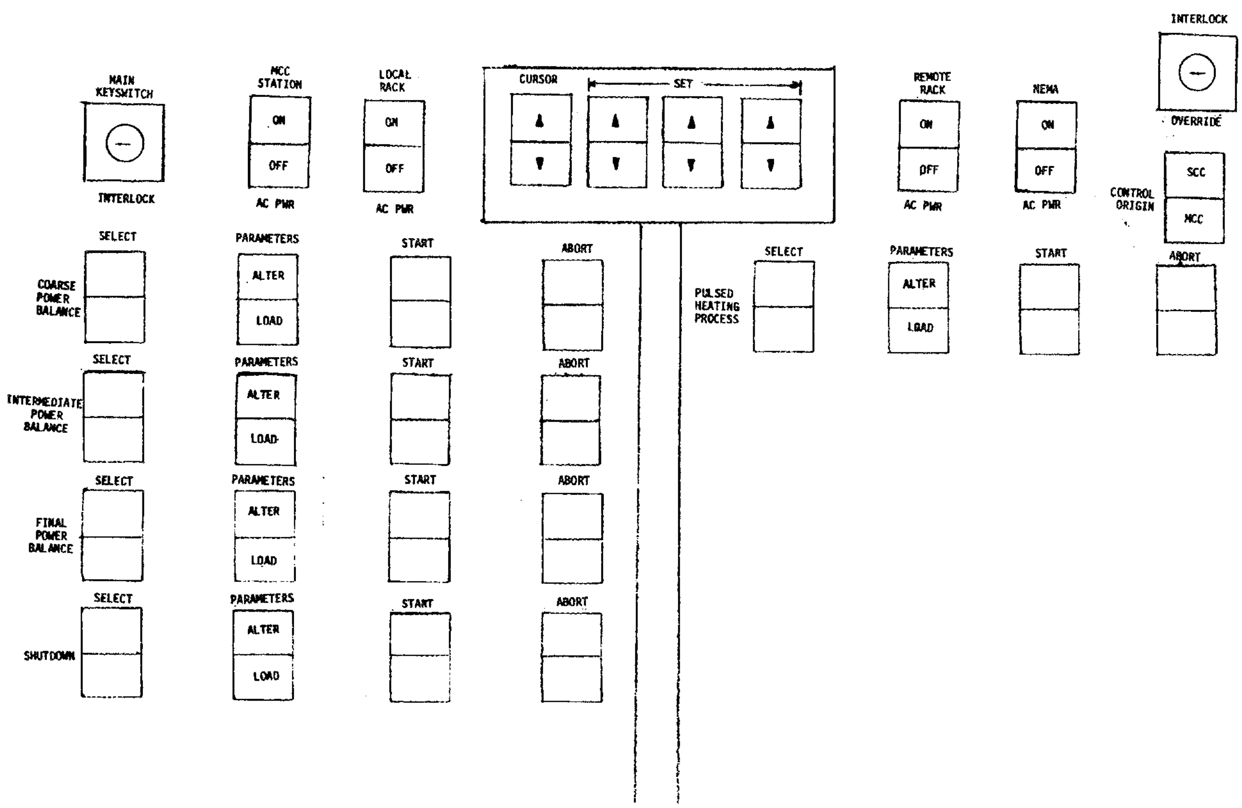


FIGURE 4.1.7–15 ECRH MCC CONTROL PANEL PMCC-ECRH-001/60

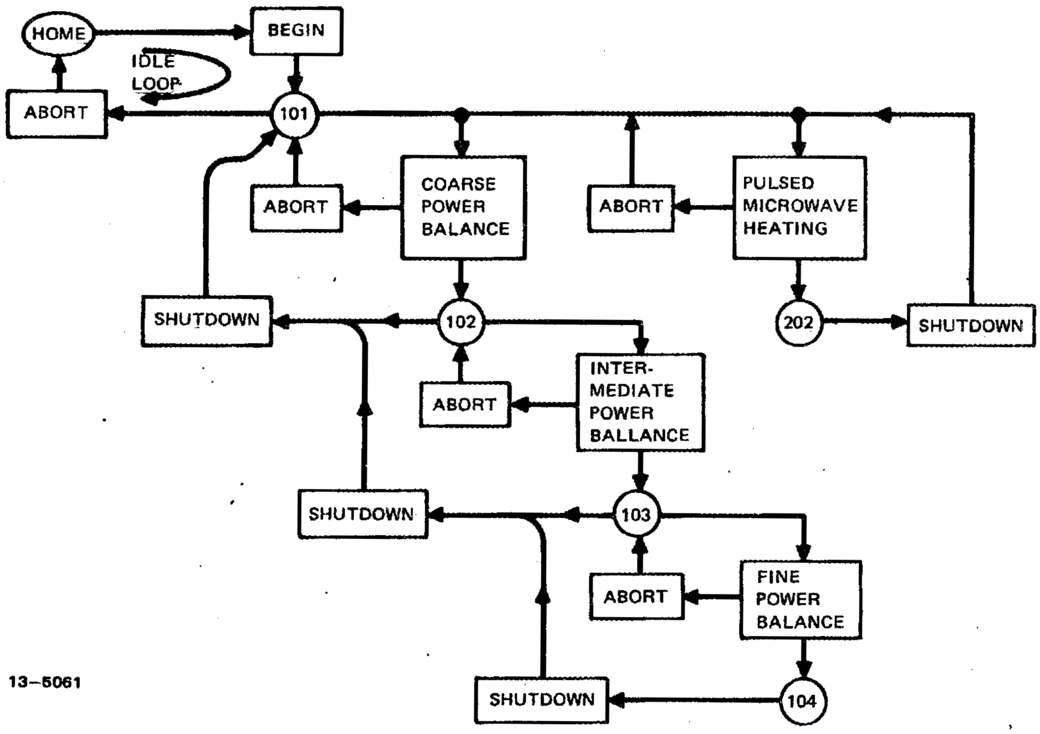


FIGURE 4.1.7–16 ECRH MCC PROCESS FLOW DIAGRAM

4.1.7-17, provides switches connected to four ICRH processes. These processes are used to tune the RF antenna systems, to control pulsed ICRH heating processes and to control the SHUTDOWN processes. Fig. 4.1.7-18 is the process flow diagram associated with the ICRH MCC station.

The design of any type of control panel arrangement is determined by a number of factors:

a) Human factors requirements,
b) Man-machine interface (ergonometric) factors,
c) Underlying hardware and software characteristics
d) Requirements dictated by the processes to be controlled.

Item a) involves physiological factors such as median operator seated height, arm reach, leg space requirements, tolerable range of head movement for eye direction and the relations of these factors to control station design. The MCC station design is compatible with these requirements. CRT display and control panels are positioned such that the 50th percentile adult male operator can see and reach these components from the normal seated position. In addition, the logical switch actuator sequences flow from left-to-right and from top-to-bottom in conformity with standard human factors recommendations. These switches are grouped into functional units by process and a standard scheme of switch positioning and labeling is enforced for each functional unit. The CRT display screens are located in close proximity to the MCC control panels such that operators receive data feedback due to switch actuating without the need to perform uncomfortable contortions to view the display screen. The MCC control panel design emphasis simplicity and uses the fewest possible switches to communicate with the PC control software.

Item b), the man-machine interface factors, are determined to a large degree by the choice of feedback data display technique. The MCC stations employ CRT displays with overlaying touch panels. This feature amounts to choosing a software-implemented display strategy rather than a conventional hardware approach. In effect, the operator is not faced with observing and comprehending a large assemblage of analog and digital data display components mounted on a large control panel. Rather, the operator "watches TV" in order to see the results of his control selections and to observe the on-going functions (processes) of the EBT-P device/facility. The operator uses the CRT display as a "window" through

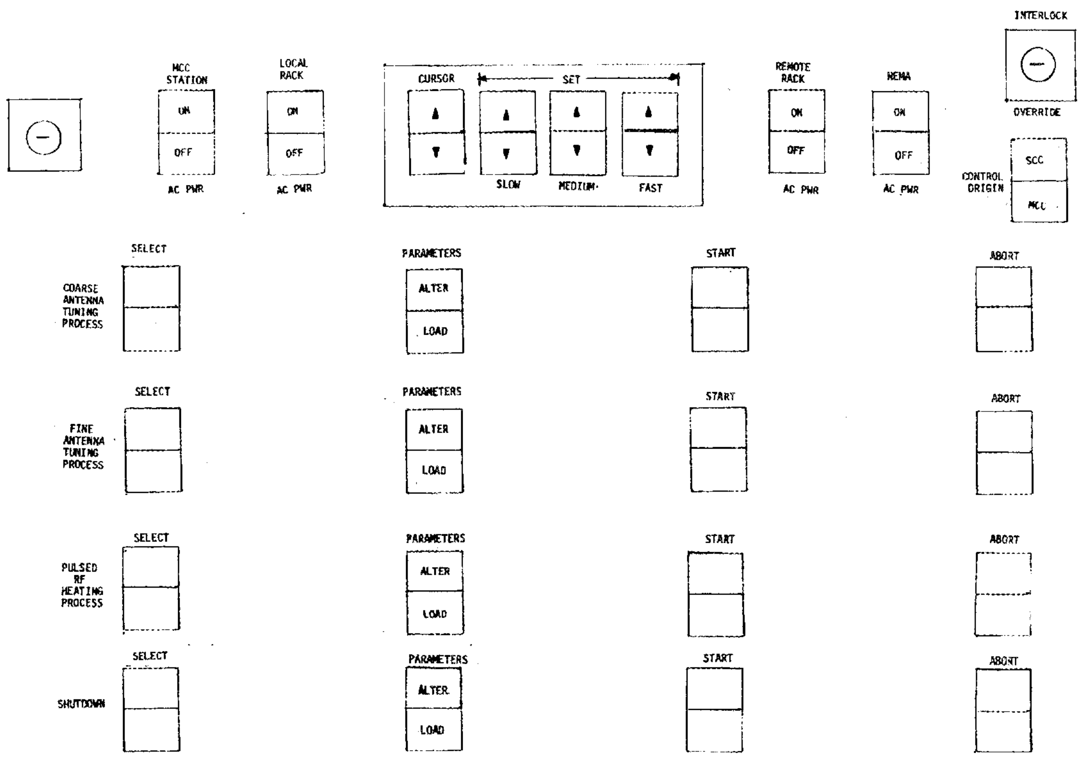


FIGURE 4.1.7–17 ICRH MCC PANEL PMCC-ICRH-001

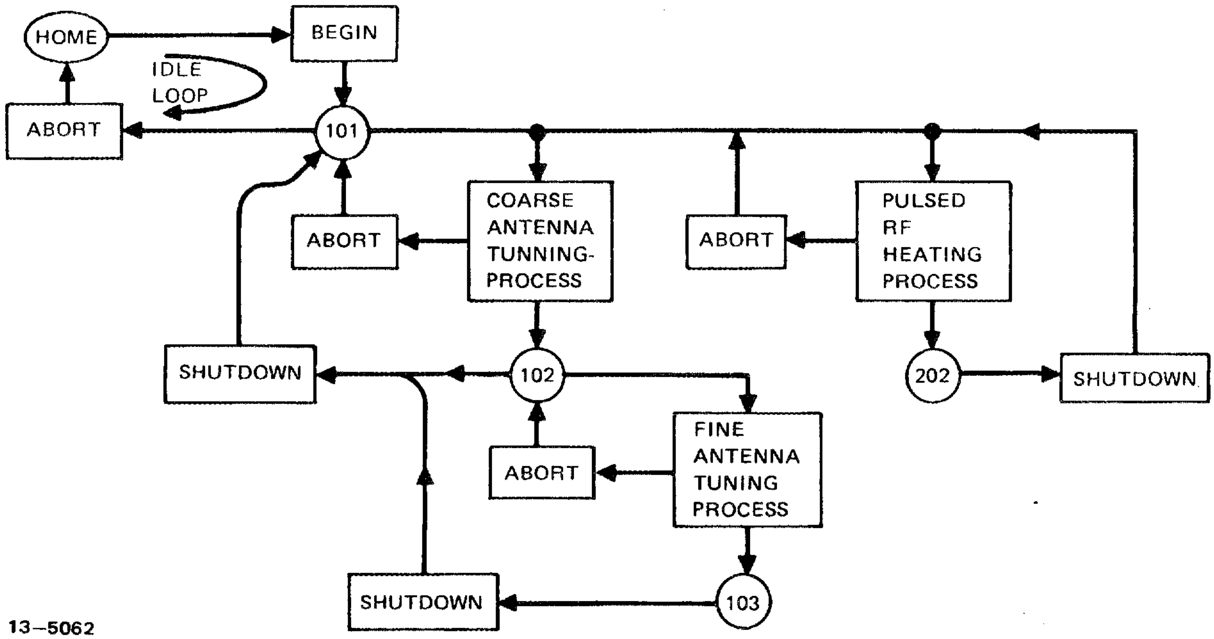


FIGURE 4.1.7–18 ICRH MCC PROCESS FLOW DIAGRAM

which he is able to see the processes as they are executed by the PC units. His window can be adjusted to view different parts of the process data display by the operator using his finger and the touch screen to request a particular view. The analogy of turning the pages of a book is also used to describe this type of man-machine interface. The MCC CRT displays also have a "zoom" capability, analogous to the function of a photographic zoom lens. This feature allows the operator to select a smaller portion of the process data display and "blow it up" such that the display fills the entire middle section of the CRT screen (see Fig. 4.1.7-6 where this area is called the "Variable Display Area").

Evidently, this type of man-machine interface design requires the operator to adopt a somewhat more sophisticated idea of the control/display functionality than is typical in the case of more traditional totally hardware-implemented approaches. He is aware that he is, in effect, "talking to a computer" but the normal awkwardness of this interface is reduced by using the color CRT displays and the touch panels. The operator becomes accustomed to pointing his finger to indicate his display requirements and is not burdened with the need to memorize command strings (sequences of typewriter keystrokes) in order to indicate his wishes to the PC unit.

Use of color is another important feature of the MCC man-machine interface. Color is used to supplement the digital and graphical information using easily-remembered color coding schemes, e.g. red for fault, yellow for caution, green for OK, etc. The MCC CRT displays also have blinking and reverse video capabilities which further enhance the operator's ability to rapidly comprehend the meaning of a given display.

Item c, the underlying hardware and software configuration of the EBT-P control/interlock system, has a crucial impact on MCC design since these characteristics make the man-machine interface, item b), possible. The CRT displays and touch screens truly are the crucial elements determining the MCC design. The CRT displays each contain a dedicated display microprocessor and the necessary firmware and memory to paint the required data displays onto the CRT screen. These embedded microprocessors have several functions:

a) To operate firmware-implemented graphics program which permit initial generation of MCC displays;

b) To store several displays in local memory such that there can be painted onto the CRT display with minimal delay (called "display paging");
c) To communicate with both the PC units and the facility computer for commands (i.e. "paint page 10 now") and for updated (real-time) process data to show the operator the present state of a given process.

The touch panels provide the means for easy operator interaction with the PC units and the facility computer. These units are simple, rugged and inexpensive substitutes for the usual ASCII keyboards used for man-machine interfacing to computers.

The MCC CRT units are instances where "bundled" microprocessors are introduced into the I & C system design without much fan fare. In fact, the total number of these "hidden" dedicated microprocessors likely will exceed 25 units at the conclusion of Title II design. A tally of computers of all types in the I & C system gives:

- One (1) facility computer (software-configured)
- Nine DAS microprocessors (software-configured)
- Four-to-eight PC units with microprocessor CPUs (firmware-configured)
- ~ Twenty-five dedicated display microprocessor (firmware-configured)

Item d), process intrinsic control requirements, influence the MCC design mainly regarding the relevant time-scales on which these processes naturally operate. All MCC-controllable processes are relatively slow control sequences which are capable of control on time-scales typical for human reaction. Even the pulsed plasma heating processses are in this category because parameters for the processes can be entered by the operator at his own pace and then executed via the START command. The PC unit handles the millisecond-scale requirements for these pulsed heating processes and outputs process status to the operator in real-time via the MCC CRT-displays.

All MCC-controllable processes are "well-behaved", repeatable processes which can be preprogrammed as executable control sequences, which typically is the forte of a PC unit. A possible exception may exist in the case of the ECRH gyrotron tube which, according to present practices, must undergo a "conditioning" process prior to running the tube up to full power level. Conditioning, presently, is a manual procedure and may be such even by the start of EBT-P Phase III operations. The process, therefore, may more properly be a manual SCC procedure requiring continual operator intervention. The design of the MCC and SCC subsystems supports this mode of operation with basic control/interlock services in response to operator inputs required for the gyrotron conditioning process. In addition, the ECRH PC units are capable of operation in a "learn" mode whereby the PC unit stores in memory the sequence of operator commands issued during the conditioning process. These stored tables can be transferred via the DAS system to the EBT-P facility computer for off-line analysis. The aim of this endeavor is to study the conditioning process to determine if well-behaved, repeatable features are present such that a PC control program could be developed to automatically control gyrotron conditioning. Possibly, this issue will be settled by the work done in the operations-funded microwave R & D program. If not, such a development definitely can be an adjunct to normal Phase III operations, possibly leading to a less operator-intensive control strategy for the ECRH system. A completely optimistic view would envision gyrotron conditioning as eventually evolving into a well-defined MCC process, controllable by one or two operators.

The Title I MCC design, therefore, emphasizes solutions to present design criteria while, concurrently, providing a hardware and software means to solve some of the more complicated EBT-P control tasks.

4.1.8 Secondary Control Center Configuration - The SCC consists of I & C equipment arranged along the walls of the Control Room (see Fig. 4.1.8-1). A total of 49 instrumentation racks (19" W x 78" H), six NEMA-12 boxes (4' W x 6' L x 20" D) and the helium refrigerator main control panel contain SCC equipment used to operate device systems and to provide a backup operation capability. The SCC is used as the device control center if faults occur in the facility computer, MCC and/or EDC units. The design of the SCC permits basic manual control functions to be performed by operators, in contrast to executing pre-programmed MCC sequences. In general, the 19" racks contain DAS microprocessor units, CRT displays and manual-type control panels. The NEMA-12 enclosures contain Allen-Bradley PLC-3 programmable controller units. Each rack has a rack power/control unit (RPCU).

A total of 18 instrumentation racks is dedicated to the 60 GHz ECRH system. Each 60 GHz gyrotron and power supply is allocated a three-rack SCC unit, Fig. 4.1.8-2. One of the

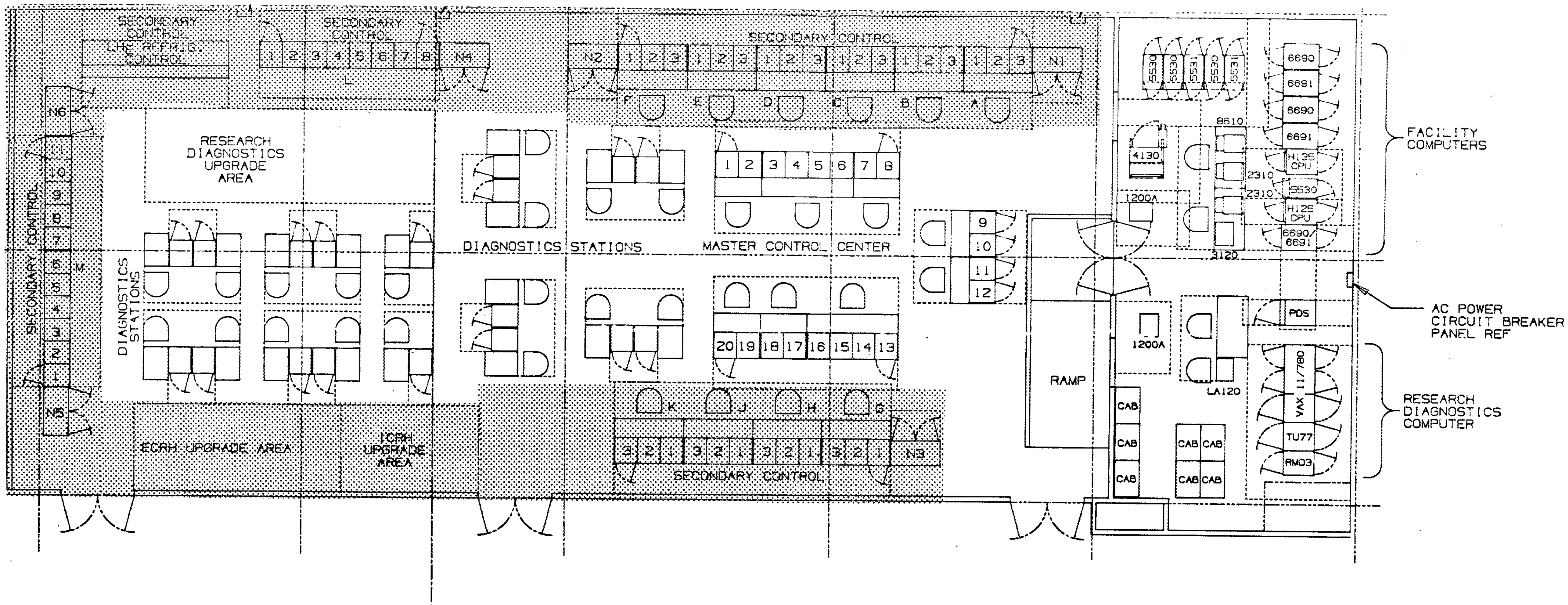
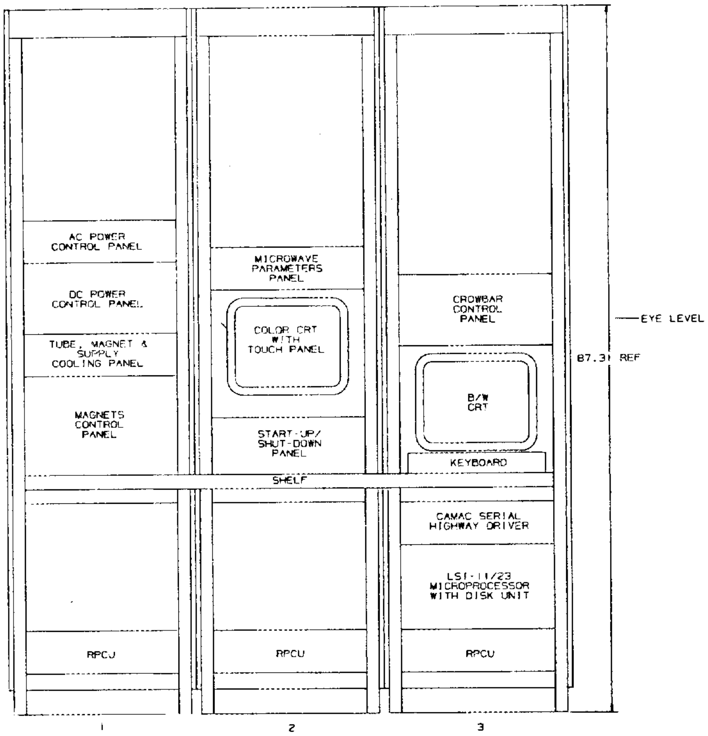


FIGURE 4.1.8–1 SCC FLOOR PLAN

six sets of racks contains the microcomputer. The design criteria for the ECRH system at present requires one full-time seated operator at each ECRH SCC station, i.e., these SCC stations are designed to support continuous, long-duration operator activity (at least one shift). The center rack contains the CRT terminals driven by both the ECRH DAS microprocessors and by the ECRH PC units. The left and right-hand racks contain control panels arranged to be easily accessible to a seated 50-th percentile adult male operator. The DAS ECRH microprocessor units are located in the left-hand racks. The CRT displays are arranged such that all software-generated touch-sensitive keys appear in the lower part of the screen within normal operator arm reach.

Figure 4.1.8-3 shows details of the type "-1" racks, the ECRH Power Supply and Cooling Rack. The AC and DC power control panels for the ECRH power supply, the cooling control panel (water and FC-75) for the gyrotron tube and power supply and the gyrotron magnet control panel. The controls are arranged according to functional group and are spaced such that confusion is avoided between similar-looking control subsystem (e.g., beam and gun power supplies). In addition, the control panels and CRT display units for the 60 GHz and 28 GHz gyrotron units are arranged in a similar manner such that operator cross-training is easier. All control elements on this rack are discrete momentary or alternate-action switches (e.g. Honeywell Microswitch AML series with rocker-type actuators). Numeric values are required for some control elements and are entered using LOAD switches in conjunction with the "numeric input cluster" on center rack (-2 units). The procedure used to enter numerics is identical to that described in conjunction with the MCC subsystem (see Sec. 4.1.7). The control switches are grouped such that normally the switches are operated in sequence from left-to-right. Load switches are placed lower on the panels than ON/OFF controls in order to highlight their special function. This arrangement is required because the load switches can be used with the START-UP/SHUT-DOWN panels on the center rack as well as with the detail control panels on which these are located.

The power control and cooling control panel drawings are self-explanatory. The larger Magnet Control Panel functions as follows. The Magnet Control Panel contains switches to turn on the gun magnet supply, the focusing magnet supply and the two collector magnet supplies. In the same row are the voltage LOAD switches for the gun and focusing magnet supplies main stages and for the two collector magnet supplies. The second row contains



A,B,C,D,E & F

FIGURE 4.1.8–2 ECRH 60 GHz SCC UNIT – TYPICAL

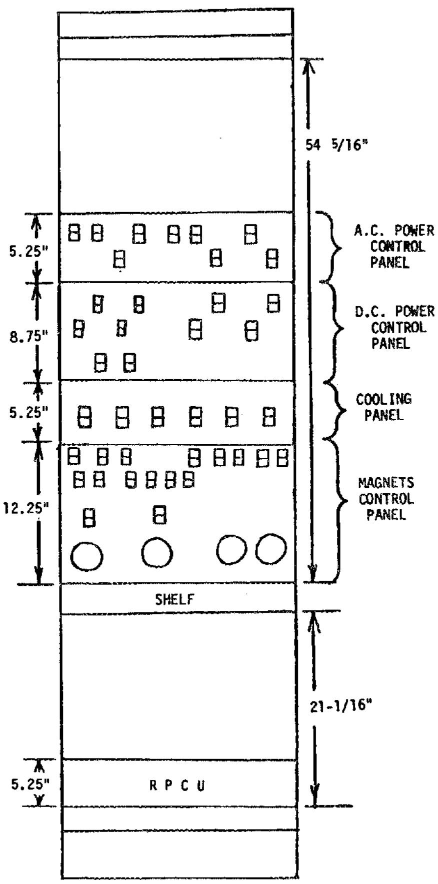


FIGURE 4.1.8–3 60 GHz EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 1

the voltage LOAD switches for the two gun magnet coils final stages and the four focusing magnet coils final stages.

The emergency off controls for each magnet set are in line with the switches above. The gun magnet set has an emergency off with a setable trip point and a manual trip. The focusing magnet set has a crowbar circuit with a setable trip point and a manual trip. The two collector magnet supplies are small and have fixed trip points and a manual trip.

The ERCH SCC type-2 rack, Fig. 4.1.8-4, contains the Microwave Parameters Panel, a color CRT unit with a touch panel, and the START-UP/SHUT-DOWN panel. The color CRT unit communicates with the ECRH PC subsystem while the other CRT unit is connected to the ECRH DAS microprocessor subsystem.

Controls for the devices which measure microwave parameters are located in the upper panel. The controls are an On/Off switch which controls the microwave frequency analyzer, an On/Off switch which controls the microwave leakage detector, and an On/Off switch for the tube VacIon pump. It is expected that the VacIon pump will be left to operate continuously.

When the EBT-P device is not running, the programming terminal on the type -3 rack can be used for entering control instructions (process sequences) into the ECRH PC units. Processes which do not change during a particular run on the device are programmed for interlock/control prior to start of device operation. Parameters which can change during a run are entered via the Numeric Input Cluster. The ECRH microprocessor units can be used to load tables of parameters into the PC units during maintenance mode (see Appendix C for the definition of these operational modes).

The Numeric Input Cluster is located on the Start-up/Shut-down panel. It operates as follows:

1. Switch the particular parameter load switch up to the "Load" position.
2. The current value appears on the color CRT.
3. Set the Increment/Decrement Switch.
4. Use the Slow, Medium, or Fast switches to set the desired value.

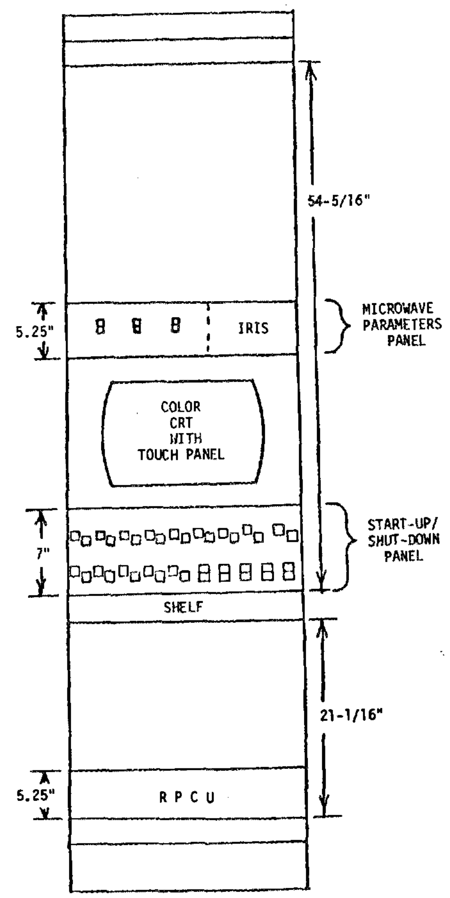


FIGURE 4.1.8–4 60 GHz EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 2

5. Switch the load switch back to its original position.
6. The new value will be stored in the subsystem PC and the subsystem will respond to the new entry according to instructions (e.g.; slew rate, sequencing) previously entered into the process controller.

The rest of the Start-up/Shut-down panel is used for a normal start-up or shut-down. For normal start-up, the switches are operated in sequence from left to right and top to bottom. Closing each switch allows the PC to start up several components according to the instructions in the PC program. Between the closing of one switch and the next, the PC informs the operator whether or not the system is ready for the next step. An out-of-order switch closure results in an error message.

To shut down the subsystem, the abort switches are operated in reverse order. If switches are opened out of order, the PC automatically shuts-down all following components in order to protect personnel and the device.

The term "abort" here means the reversal of a process. For instance, IVR unlock releases the IVR and allows it to rotate to a previously specified position. IVR abort returns the IVR to its "Off" position and locks it there.

Interaction between the Start-up/Shut-down panel and the Detail Control Panels is as follows. If it is desired to control each component separately, the 17th switch, the Start-up/Shut-down Panel Active/Inactive switch, is left in the "Inactive" position and the Detail Control Panels used thereafter. If "automatic" operation is desired, switch 17 is placed in the "Active" position and the Start-up/Shut-down Panel used. If it is desired to change from one mode to the other, switch 17 should be toggled; however, the PC will not allow the change of control to take place until all switches in the system receiving control are brought into agreement with the system relinquishing control. At all times the PC is guarding against inappropriate and harmful command sequences.

The Crowbars and Rack, shown in Figure 4.1.8-5, has only discrete controls. The Crowbar Control Panel is associated with the beam and gun supply crowbars. The first row contains switches which control the cooling water and heating air for the beam crowbar and the heating and cooling air for the gun crowbar. The second row contains the load switches for

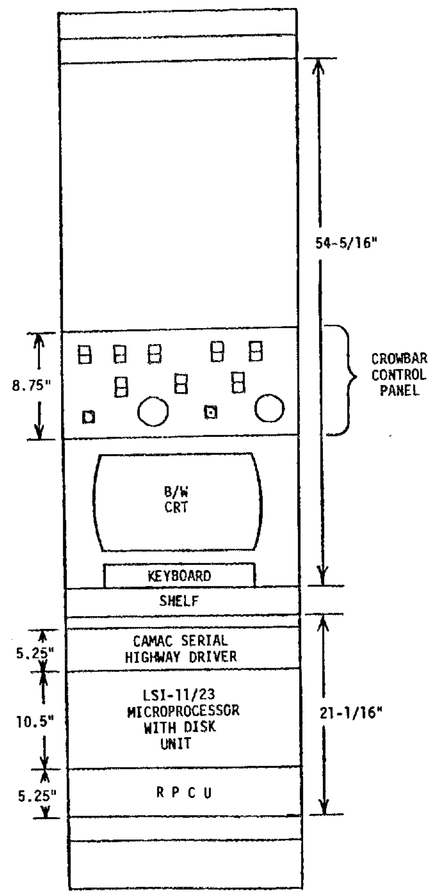


FIGURE 4.1.8–5 60 GHz EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 3

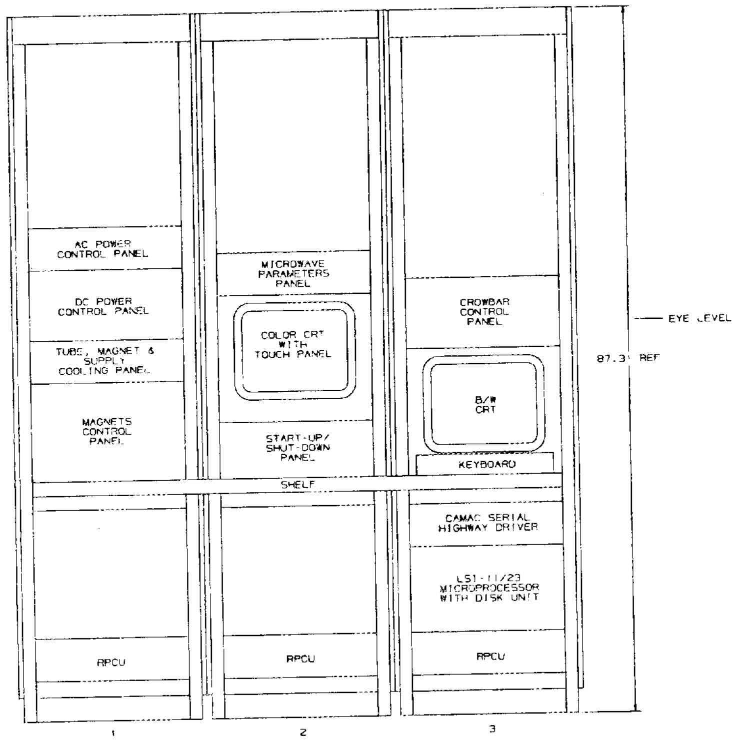
the beam and gun crowbar setpoints and, in the middle, the load switch for the body current setpoint. An excessive body current will trigger both crowbars. The third row contains coax receptacles to electrically trip the crowbars and manual trip buttons for the crowbars. The controls to manually trip the crowbars are enabled at all times that ECRH is operating.

Note that the SCC control panels contain illuminated switches only and that no hardware status indicators are provided (e.g. analog/digital panel meters, illuminated panel indicators, etc.). Status and process data displays are managed entirely by the CRT units. The trade study in Sec. 5.2 below gives the rationale for this approach.

The baseline SCC design contains six 60-GHz control consoles. Floor space has been allocated in the Control Room to accommodate up to five additional consoles to handle possible upgrades. Expansion beyond eleven 60 GHz units will require uses of control room floor space presently shown as research diagnostics upgrade area.

Six SCC racks are used to contain compoments associated with the two 28 GHz ECRH gyrotron and power supply units (see Figure 4.1.8-6). One of the two sets of racks contains the microcomputer. Figures 4.1.8-7, -8 and -9 show details of the control panel layouts, which are similar to those of the 60 GHz system for the reason mentioned above, namely, easy operator cross-training. As present plans do not call for additional 28 GHz gyrotrons during Phase III operations, no floorspace is required in the Control Room for additional 28 GHz SCC units.

Additional SCC racks are used to support the ICRH system (see Fig. 4.1.8-10). Two 500 kW ICRH transmitter systems are controlled from two SCC stations, each of which consists of three standard 19 inch racks. The design criteria for the ICRH system at present requires one full-time seated operator at each ICRH SCC station. The layouts of these SCC stations are designed to support continiuous, long-duration operator activity (at least on shift). Control panels and CRT displays are arranged to be easily accessible to the 50th percentile adult male operator. Note that the ICRH SCC stations are used normally to control the ICRH power supply and cooling system exclusively. Antenna tuning processes normally are controlled at the ICRH MCC station. Should the MCC station experience a



G, H

FIGURE 4.1.8–6 ECRH 28-GHz SCC UNIT – TYPICAL

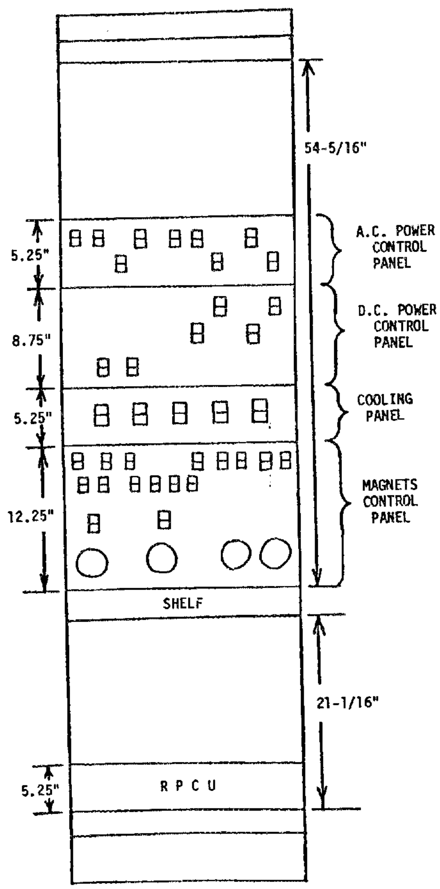


FIGURE 4.1.8–7 28 GHz EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 1

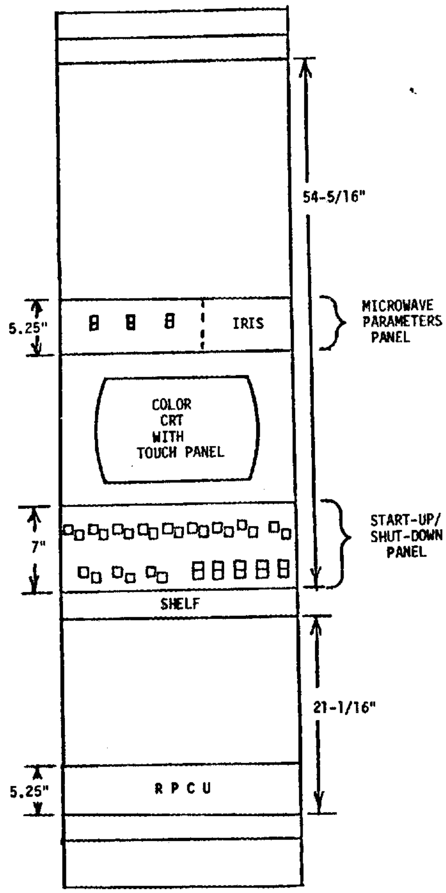


FIGURE 4.1.8–8 28 GHz EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 2

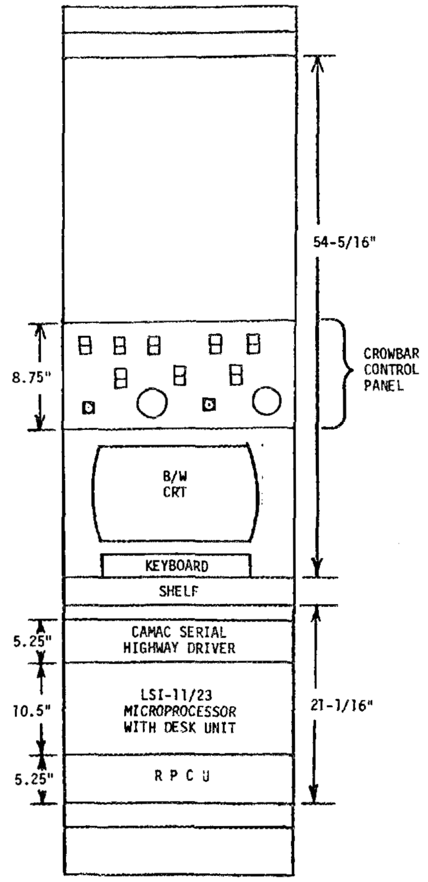


FIGURE 4.1.8–9 28 GHz EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 3

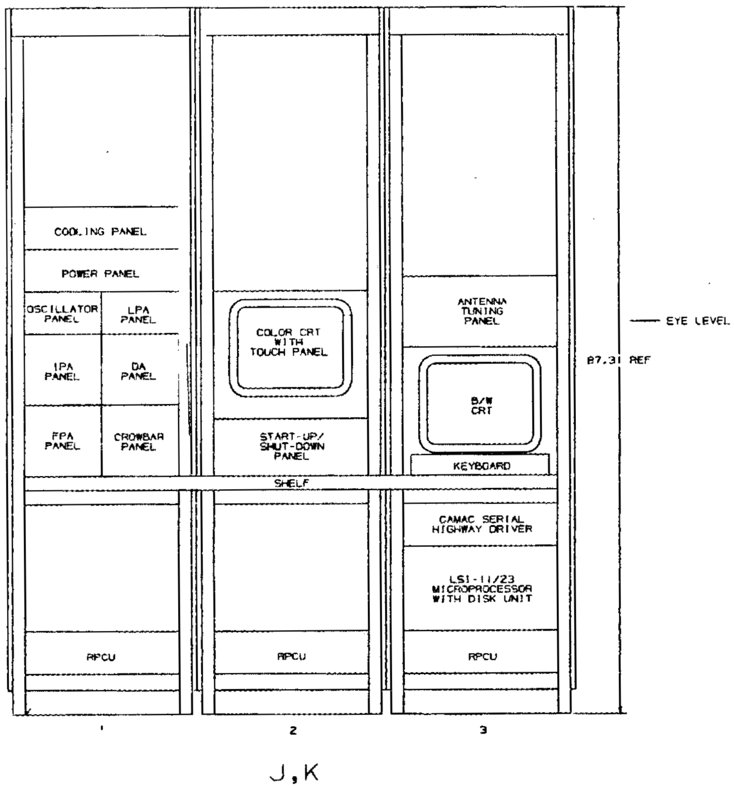


FIGURE 4.1.8–10 ICRH SCC UNIT – TYPICAL

fault, the ICRH SCC station backs-up the antenna tuning process. Floorspace has been allocated to accommodate two additional ICRH SCC units for anticipated Phase III upgrades.

The switches and controls on the ICRH Cooling and Transmitter Control Rack are diagrammed and labeled on Figure 4.1.8-11. The controls are arranged according to functional group but are spaced so as to avoid confusion between similar looking control systems. All controls of this rack are discrete switches. Some components require numeric inputs as well. Numeric values are entered by using the load switch associated with the component in conjunction with the Numeric Input Cluster on the center rack. The control switches for each component are grouped so that normally the switches are operated in sequence from left to right, ignoring level. Load switches are lower than on/off controls in order to highlight their special function. That is necessary because the load switches can be used with the Start-up/Shut-down panel on the center rack as well as with the detail control panels in which they are located.

Figure 4.1.8-12 shows the ICRH SCC center rack. It contains a color CRT with a touch panel and the Start-up/Shut-down panel. The color CRT displays parameters and the touch panel controls the display if the Master Control Console has relinquished control to the SCC. The parameters displayed on the color CRT are those accessible by the subsystem process controller. The ICRH Start-up/Shut-down panel operates in the same manner as that for the ECRH system. The ICRH SCC Numeric Instrument Cluster is identical to that for the ECRH SCC described above.

Figure 4.1.8-13 diagrams the panels in the rightmost of the ICRH SCC racks. The details of the antenna control panels are yet to be developed, however the general nature and approximate number of controls is well enough known to allow a space for the controls to be allocated. The black and white CRT displays information accessible by the ICRH microprocessor. The keyboard controls the display on the black and white CRT. When the device is not running, a programming unit can be used for entering control instructions (processes) into the process controller. Processes which do not change during a particular test run on the device (e.g.; slew rates, control sequences) are programmed in at that time. Parameters which can change during a run are entered via the Numeric Input Cluster.

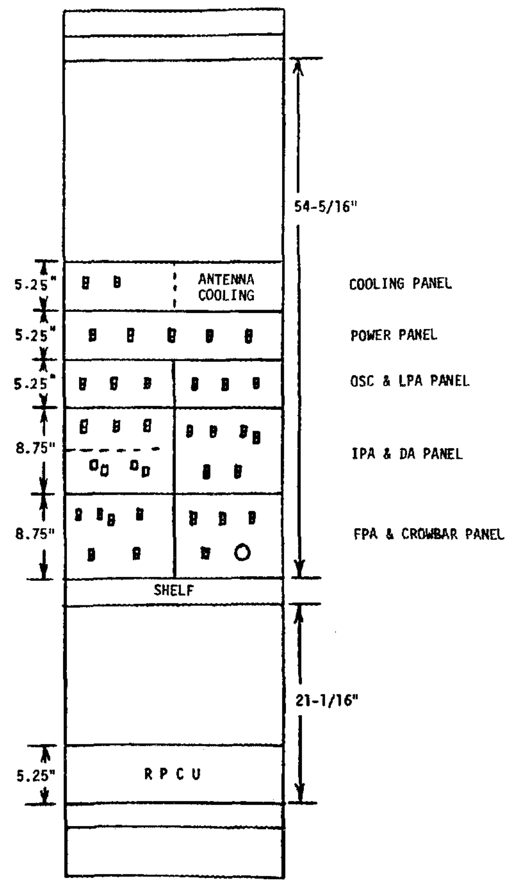


FIGURE 4.1.8–11 ICRH EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 1

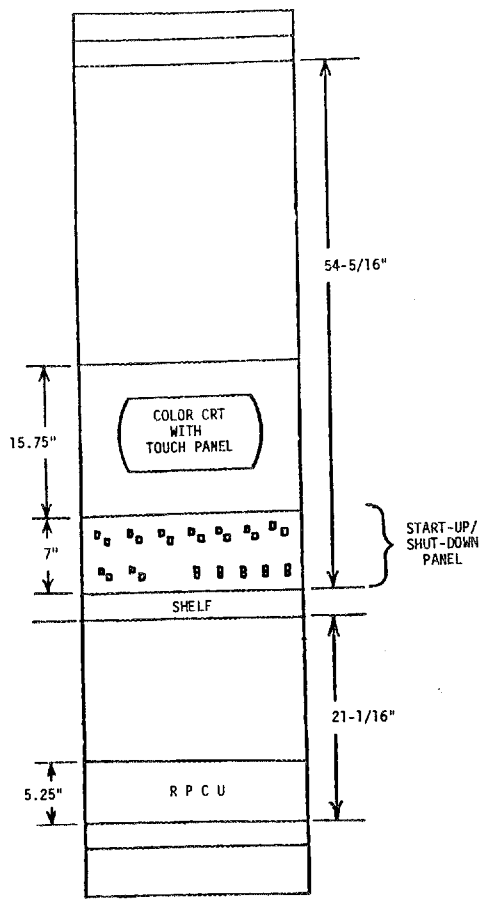


FIGURE 4.1.8–12 ICRH EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 2

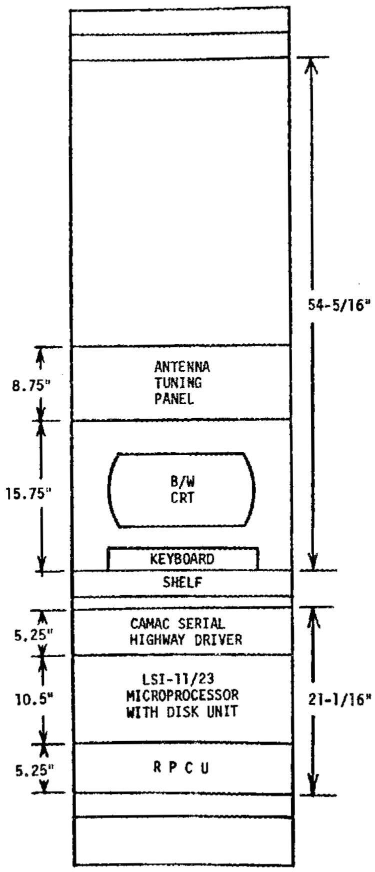


FIGURE 4.1.8–13 ICRH EBT-P CABINET CONFIGURATION AND PANEL LAYOUT – SECTION 3

The ECRH and ICRH SCC units contain sufficient space to accommodate storage oscilloscopes, transient digitizer display units and, if necessary, strip chart recorders. The ECRH SCC units also contain spectrum analyzer CRT displays to monitor gyrotron operating frequency. Gyrotron operating pressure is displayed at the ECRH SCC units at one second intervals. Gyrotron internal arcing causes outgassing and the tube pressure must be monitored closely before high voltage is again applied to the tube.

The SCC subystem contains three units which normally are not manned by operators. These are:

- The SCC L-unit (toroidal vessel/limiter and device utilities)
- The SCC M-unit (magnets, vacuum, cryogenic distribution)
- The helium refrigerator main control console.

Figure 4.1.8-14 shows the SCC L-unit, eight standard 19" W racks plus a NEMA-12 enclosure. Racks L-1 and L-2 contain the toroidal vessel/limiter (TVL) system SCC and are designed to accommodate a standing operator. However, the CRT/keyboard unit in rack L-1 accommodates a seated operator should extended periods of manned operation at this location be required. Two control panels are contained in rack L-2. The toroidal vessel panel (Fig. 4.1.8-15) contains six switches to supply AC power to the TVL cooling panels located near the EBT-P torus (see Sec. 4.2.6) and six switches to control the TVL cooling supply valves which apply cooling to the limiter segments. The limiter control panel (Fig. 4.1.8-16) contains switches associated with the twenty-four (24) stepper-motor-driven limiter segments. The ON/OFF switches are alternate-action units while the FWD/REV switches are momentary DPDT units. These switches, and all SCC switches, are split-lens illuminated units with either paddle-or rocker-type actuators. Honeywell Microswitch AML series switches are used as typical selections.

SCC racks L-3, L-4 and L-5 are associated with the device utilities I & C interface. Control panels are provided for the following subsystems:

- Facility primary ac power distribution
- Secondary ac power distribution
- Uninterruptable Power Supply (UPS)

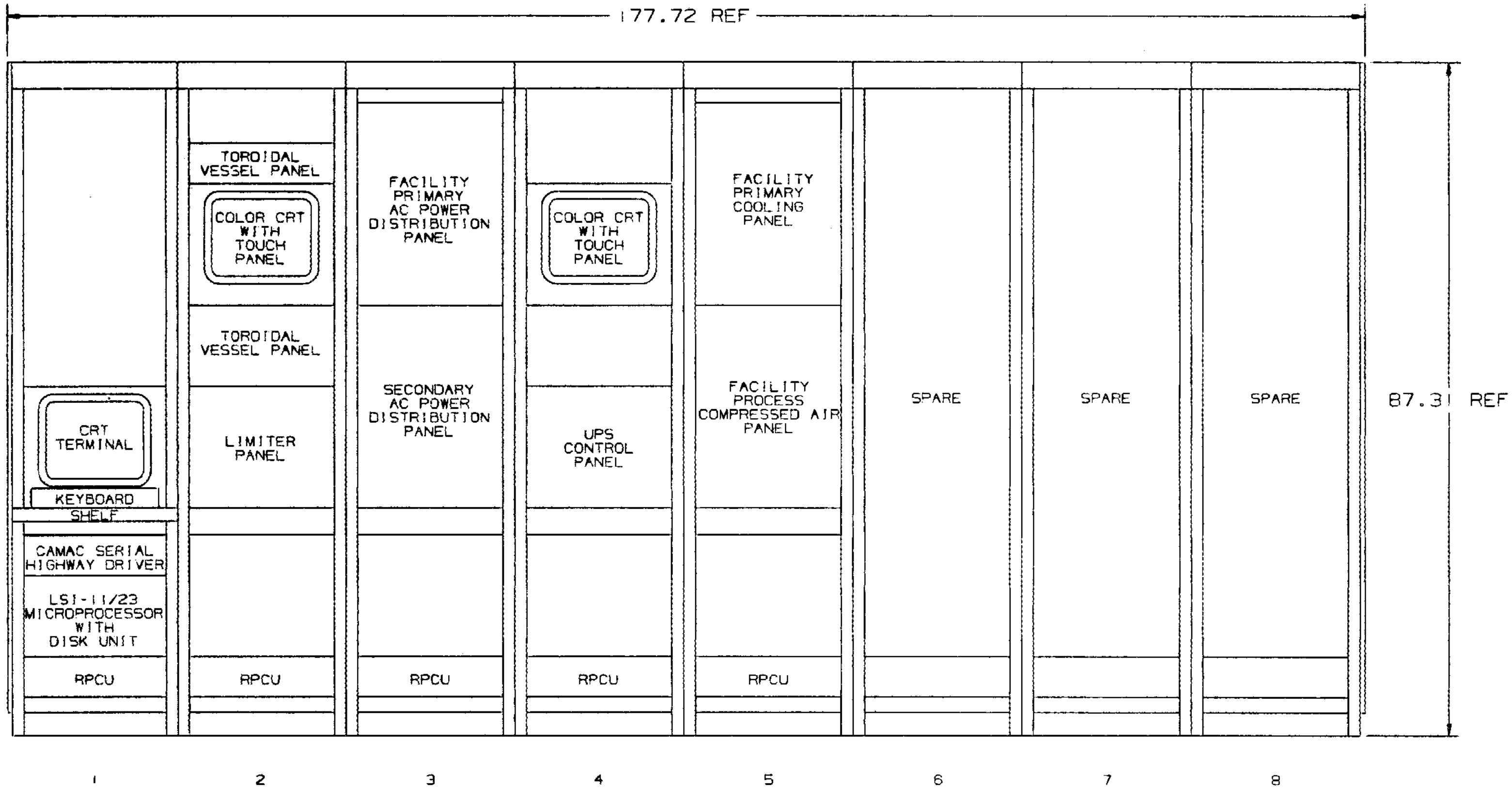


FIGURE 4.1.8–14 SECONDARY CONTROL CONSOLE L-UNIT

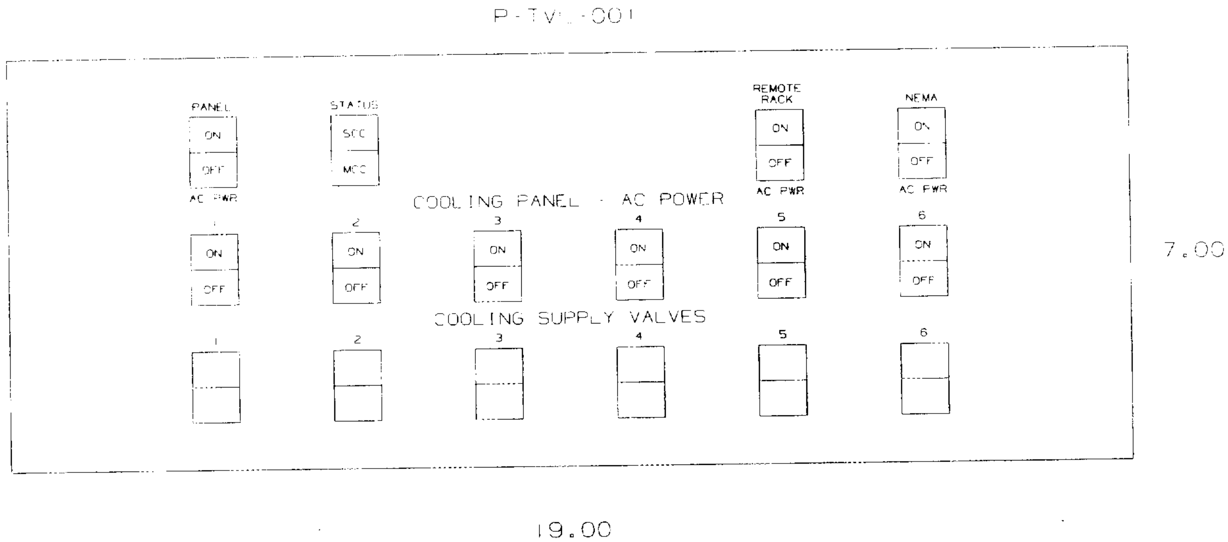


FIGURE 4.1.8–15 TVL SCC PANEL PSCC-TVL-001

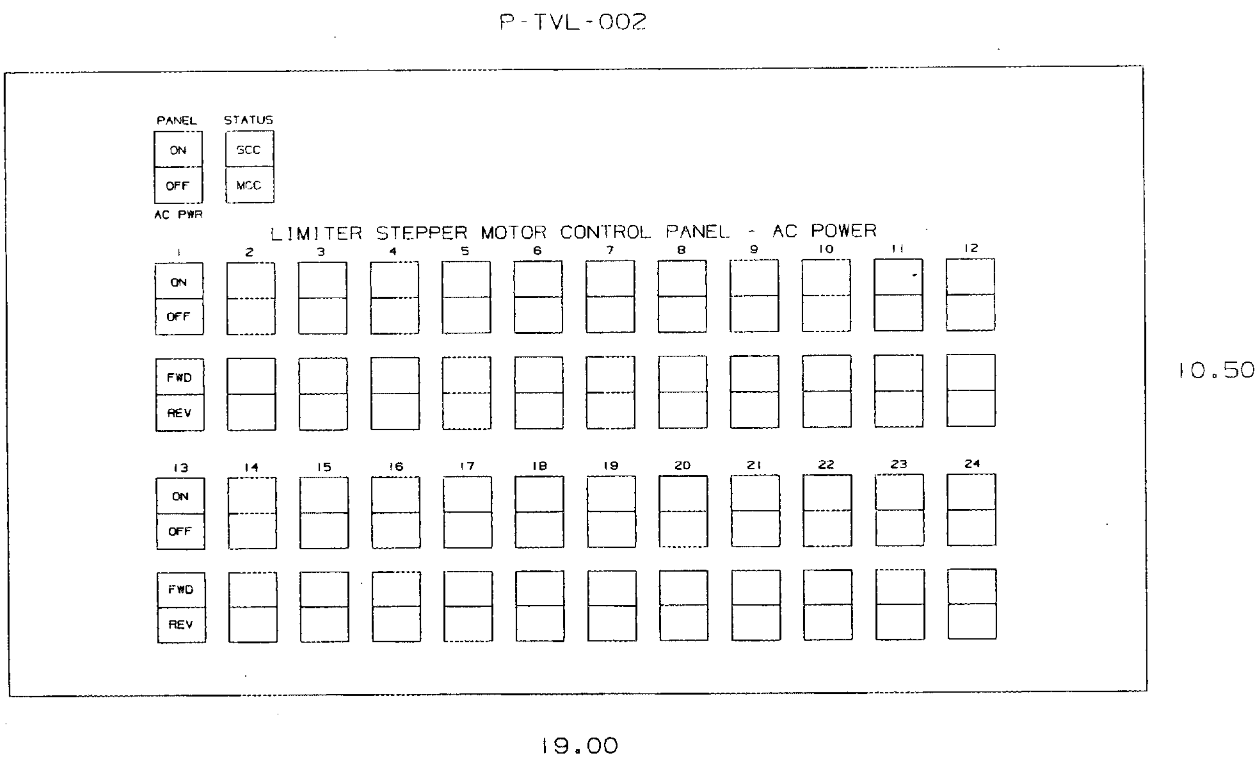


FIGURE 4.1.8–16 TVL SCC PANEL PSCC-TVL-002

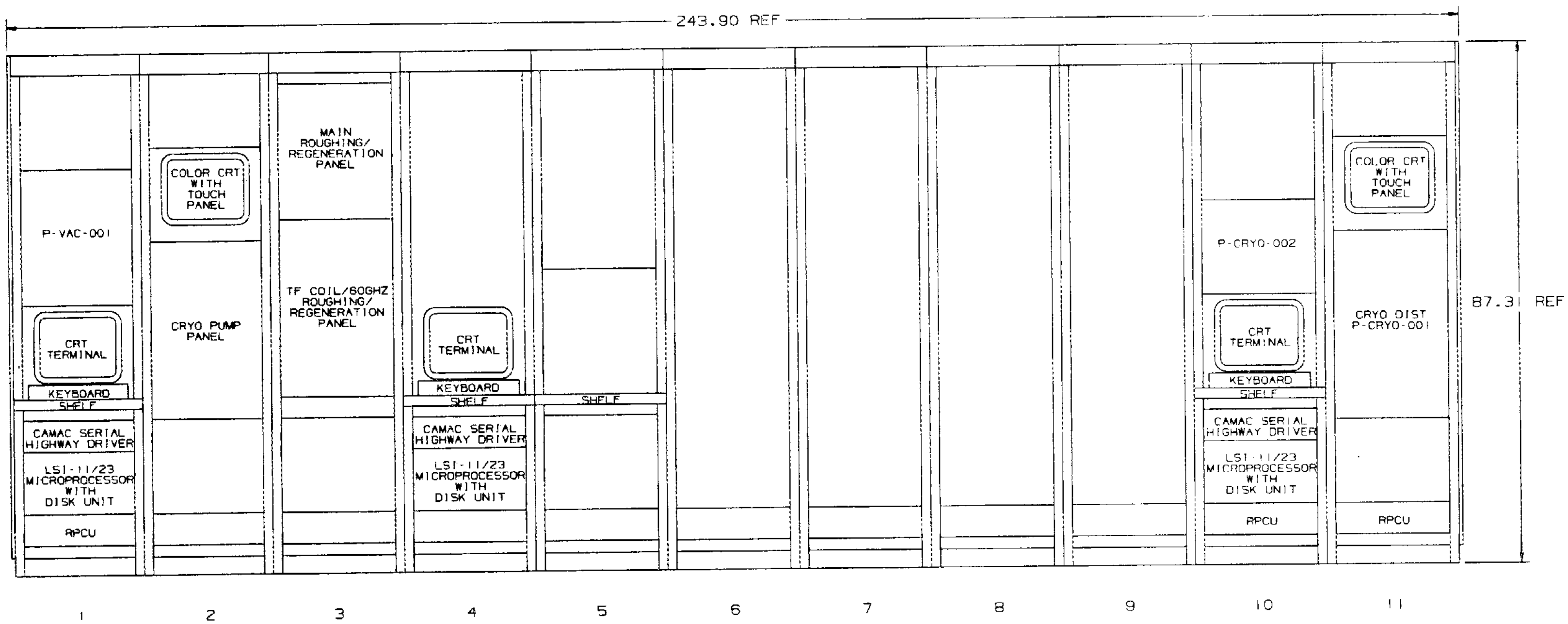
- Facility primary cooling
- Facility process compressed air

These control panels will be detailed during I & C Title II once the A & E subcontractor has established the detailed design for his side of the device utilities I & C interface. Racks L-6, L-7 and L-8 are spare units provided to handle expansion of the device utilities SCC subsystem.

Figure 4.1.8-17 shows the SCC M-unit, eleven standard 19" W racks and two NEMA-12 enclosures. Racks M-1, M2- and M-3 form the vacuum system SCC unit containing the four control panels, the vacuum system DAS microprocessor unit, a color CRT unit with touch panel and a black-and-white CRT unit with a keyboard. Figure 4.1.8-18 shows control panel P-VAC-001 at which control of the main cryopumps, the six 60 GHz gyrotron magnet cryopumps and the magnet cryopumps is centered. Switches are provided for cryopump ac power, for GHe valves and for the gate valves connecting the cryopumps to vacuum vessels (EBT-P torus and magnet vacuum containers). Control panel P-VAC-002 (Fig. 4.1.8-19) is associated with the main rough pump system. Switches are provided to control two LN_2 sorption pump units, to open and close the main torus roughing valve and to control the main cryopump regeneration valves. Panel P-VAC-003 (Fig. 4.1.8-20) is associated with the TF magnet roughing/regeneration system. Switches are provided to control a portable LN_2 sorption unit and to operate TF magnet roughing and GN_2 purge valves. Panel P-VAC-004 (Fig. 4.1.8-21) contain switches which control the ion gauge and thermal vacuum gauge units associated with the torus, with the TF coils, and with the 60 GHz magnets.

SCC racks M-4 thru M-9 are associated with the magnet system. The DAS microprocessor unit for the magnet system is installed in SCC rack M-4. A keyboard unit and a black/white CRT terminal are also placed in this rack and function as DAS microprocessor peripherals. Rack M-5 contains a color CRT terminal with touch panel overlay and is driven by the magnet system PC unit. Racks M-6 thru M-9 contains magnet system control equipment which will be identified during I & C Title II work.

SCC racks M-10 and M-11 are associated with the cryogenic distribution system. The DAS microprocessor for this sytem is installed in rack M-10 along with a black/white CRT ter-



M

FIGURE 4.1.8–17 SCC M-UNIT

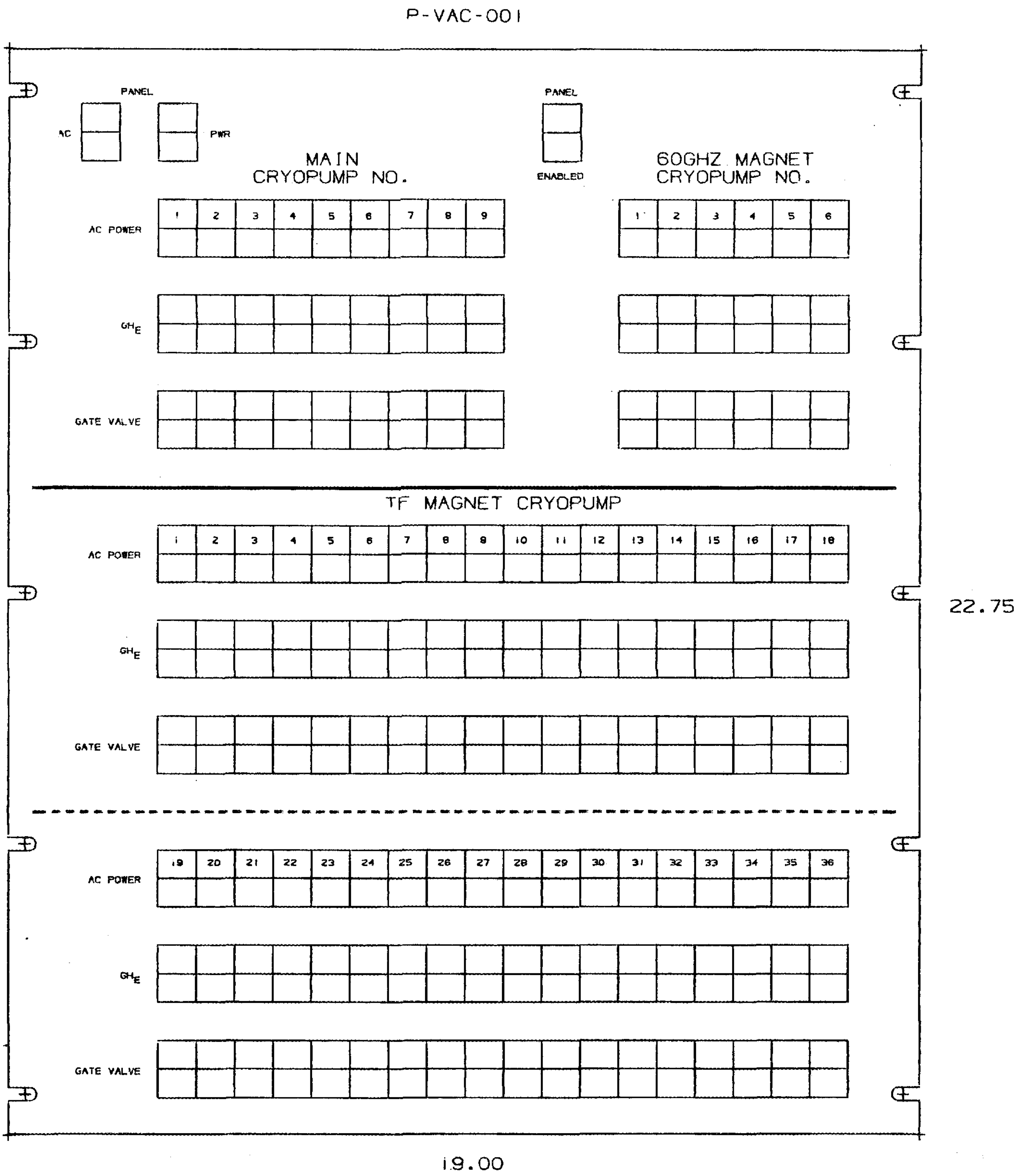


FIGURE 4.1.8–18 VACUUM SCC PANEL PSCC-VAC-001

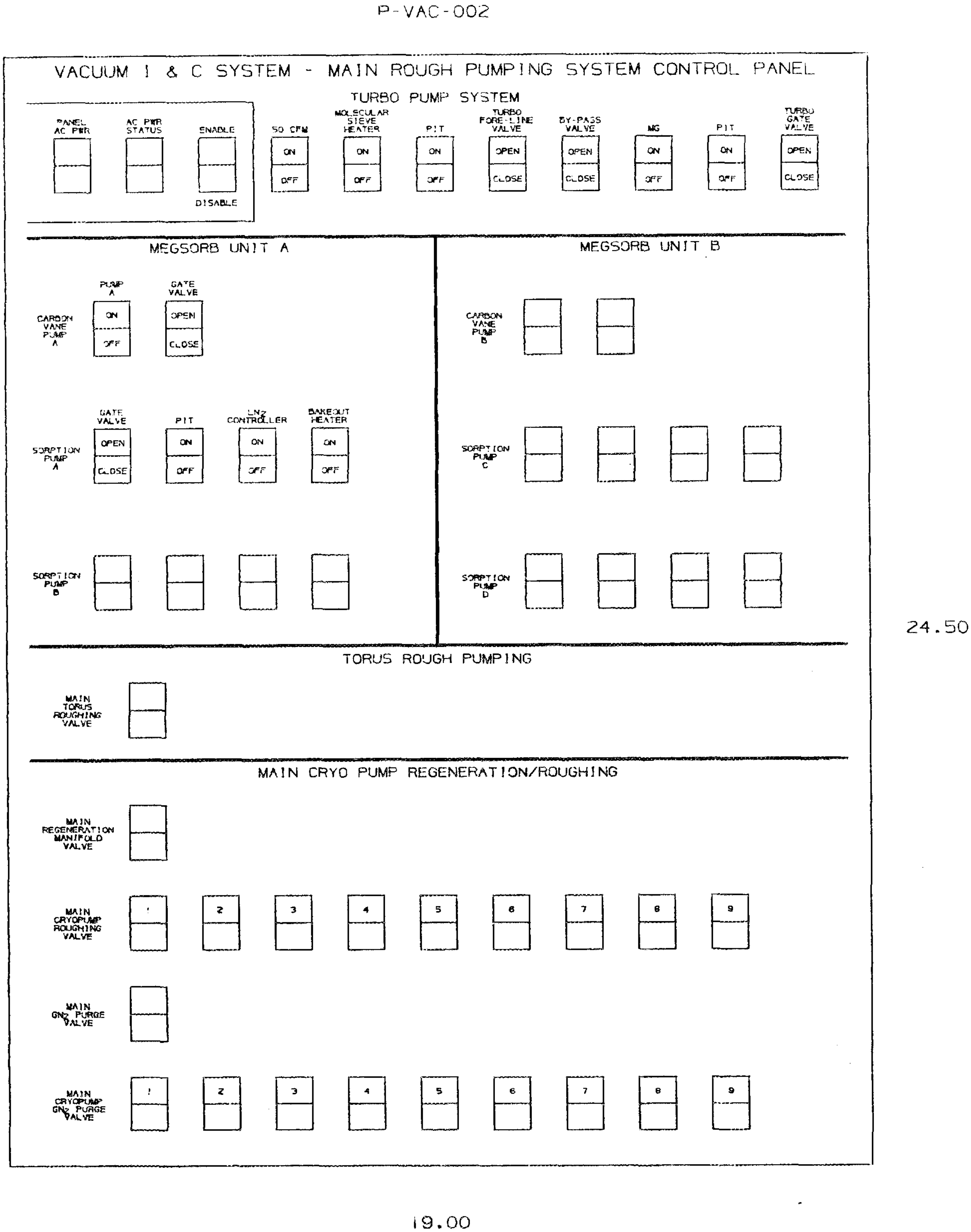


FIGURE 4.1.8–19 VACUUM SCC PANEL PSCC-VAC-002

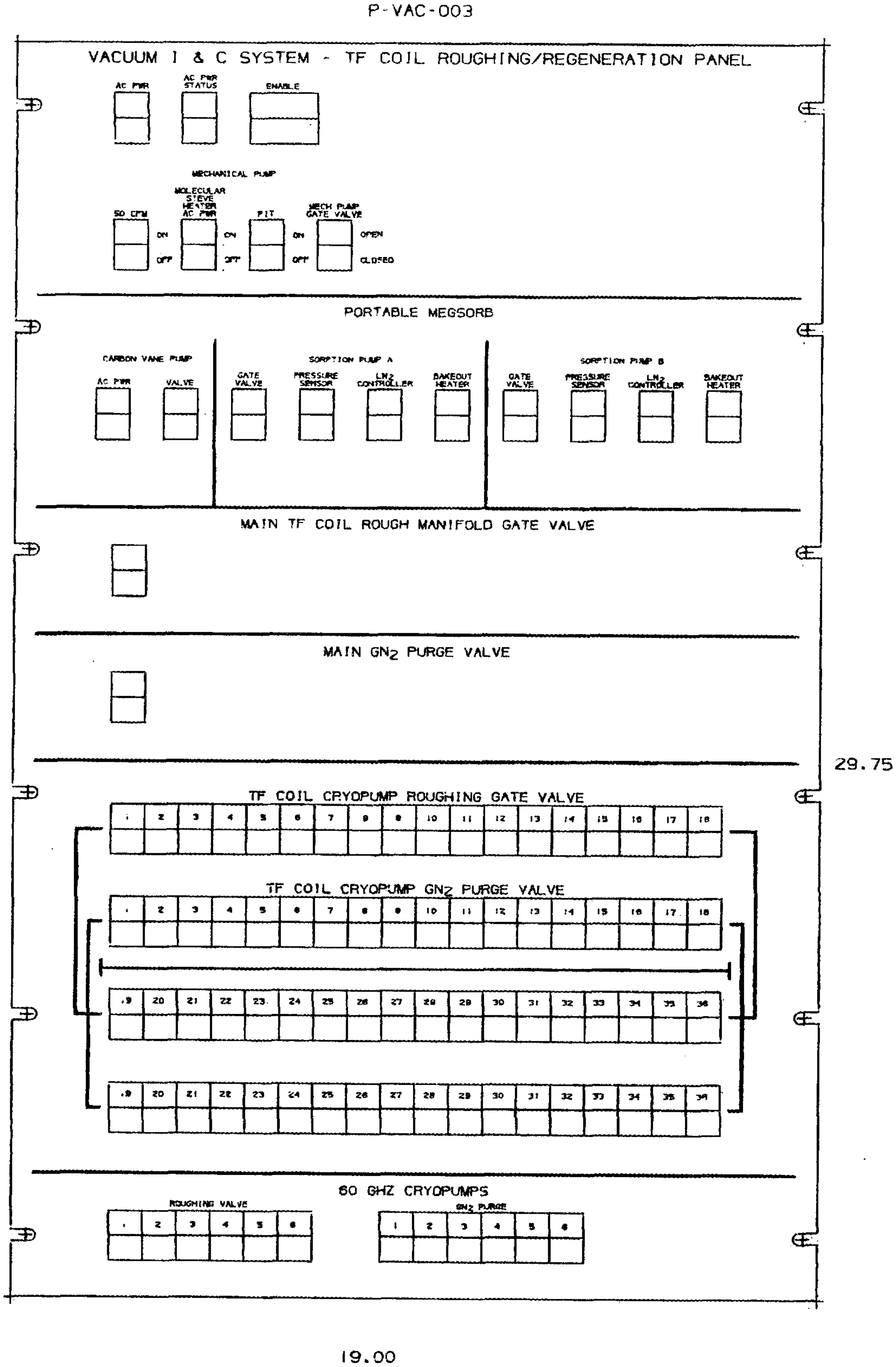


FIGURE 4.1.8–20 VACUUM SCC PANEL PSCC-VAC-003

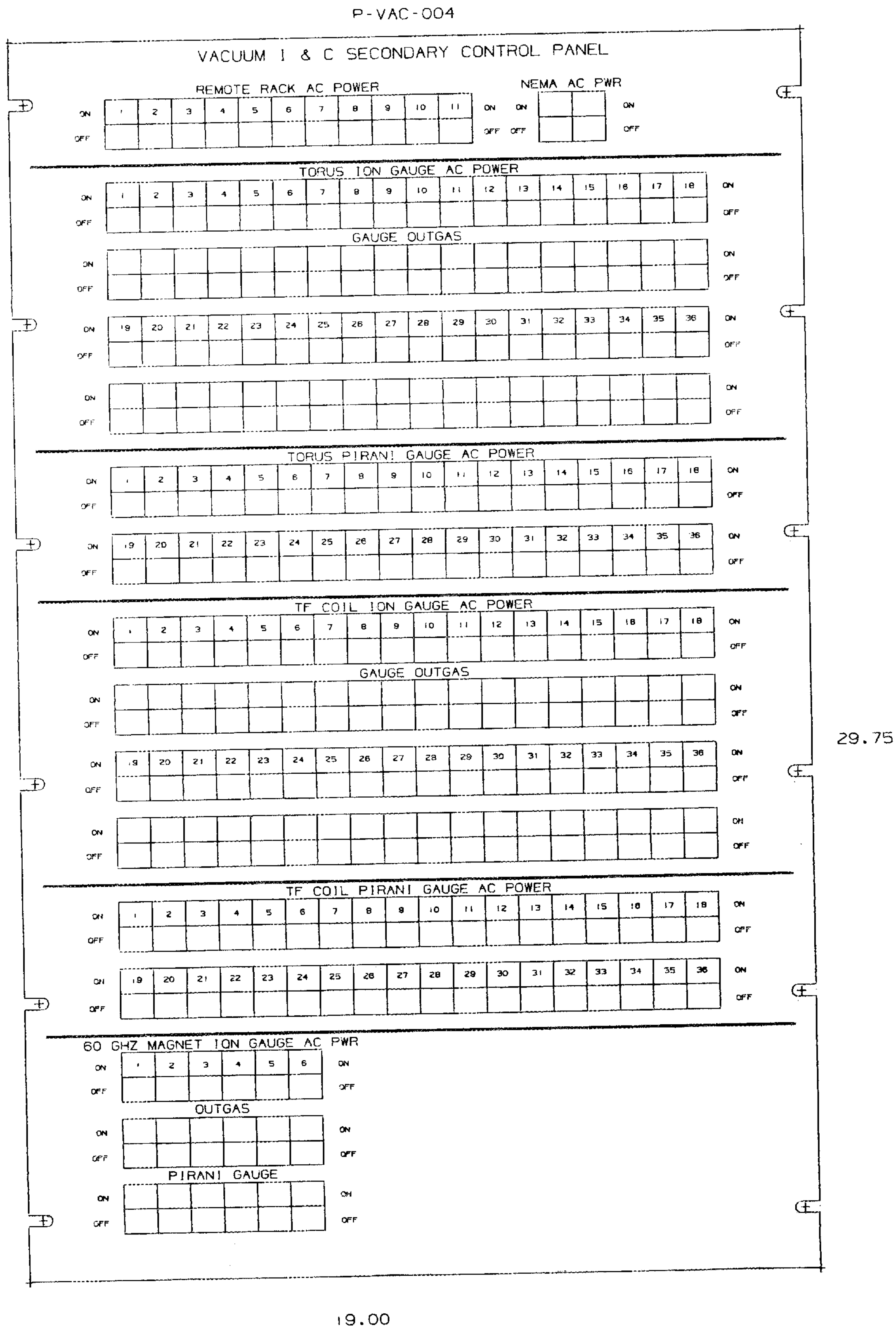


FIGURE 4.1.8–21 VACUUM SCC PANEL PSCC-VAC-004

minal. Rack M-11 contains the color CRT terminal with touch panel and is driven by the cryogenic distribution PC unit. Control panel P-CRYO-001 (Fig. 4.1.8-22) controls the LHe distribution system while P-CRYO-002 (Fig. 4.1.8-23) controls the LN_2 distribution sytem. LHe distribution controls are used to manually regulate the cooldown of TF magnets and 60 GHz gyrotron magnets from 300 K to 4.2 K. The present cryogenic distribution system design constrains the operator to cool all 36 TF magnets and/or all 6 gyrotron magnets together (see Sec. 4.2.3 below). Single magnets cannot be individually cooled.

Note that the SCC L- and M- units normally are unmanned. However, in event of an MCC fault, temporary operation at these SCC stations is possible with minimum operator inconvenience. Because of the arrangment of the SCC, this backup operation mode would require the operators to use the facility voice communication network to coordinate their activies, a measure not required during normal MCC- oriented operation.

The SCC subsystem contains two additional components:

- Helium refrigerator main control panel
- Six (6) NEMA-12 enclosures.

The refrigerator control panel is a stand-up control console containing a large minic diagram of the refrigerator plumbing. Under normal operating conditions, this control panel is unmanned. The helium refrigerator vendor will supply this component.

The NEMA-12 enclosures contain PC CPUs and PC local I/O units associated with various sytems:

NEMA Unit	System(s)
N-1, N-2	60 GHz ECRH
N-3	28 GHz ECRH, ICRH
N-4	Device Utilities, TVL
N-5	Vacuum, Magnet
N-6	Cryogenic Distribution

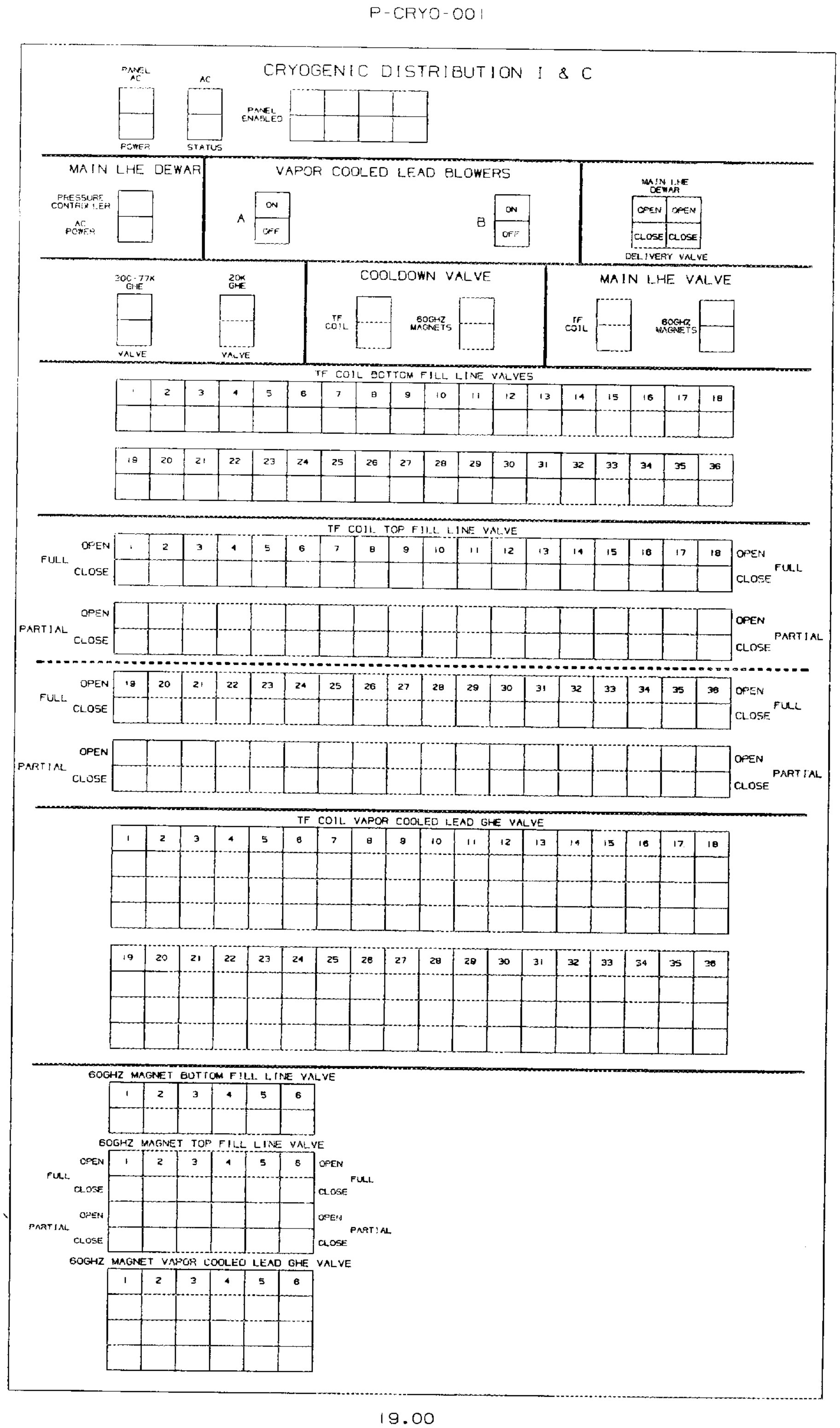


FIGURE 4.1.8-22 CRYOGENIC SCC PANEL PSCC-CRYO-001

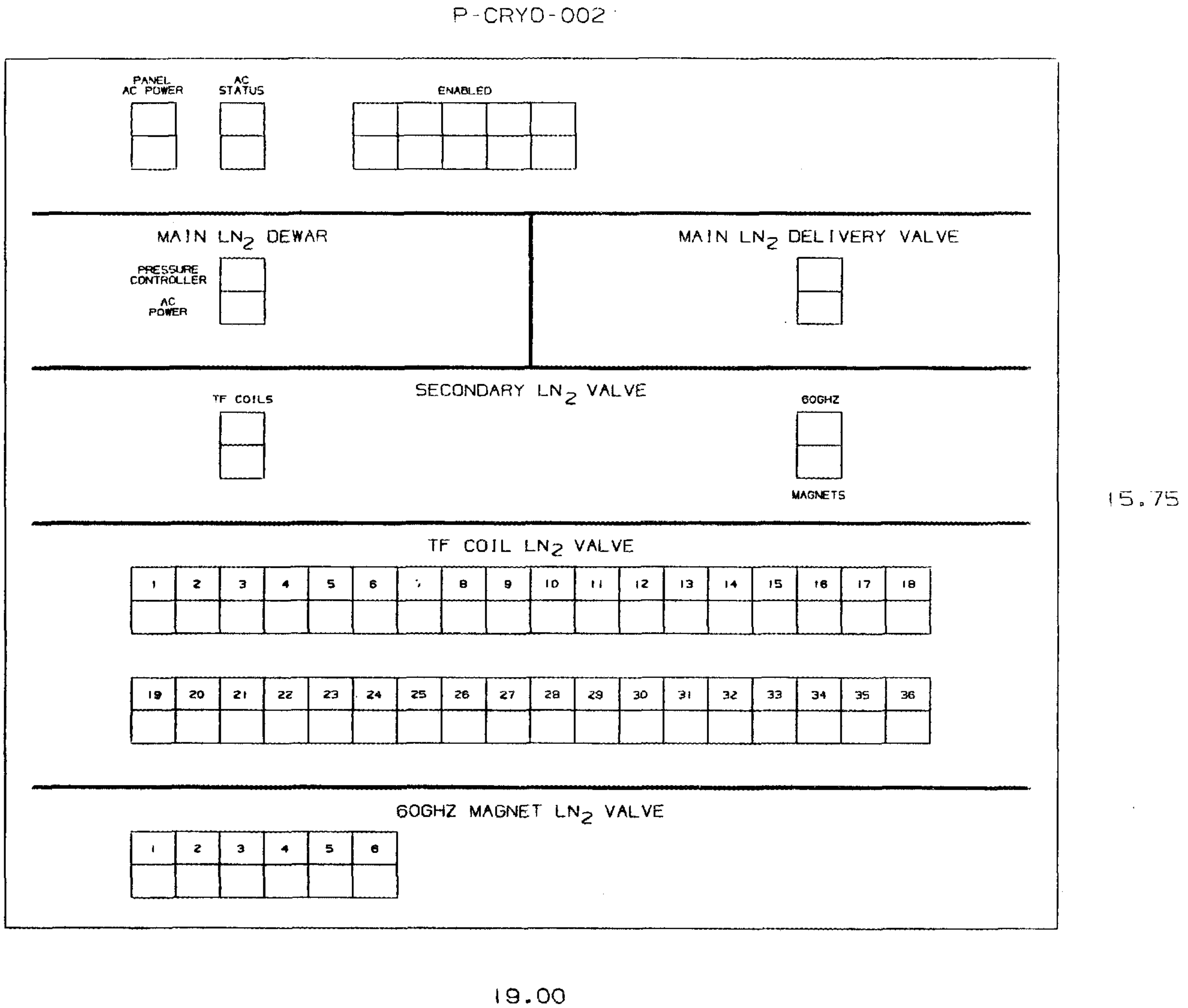
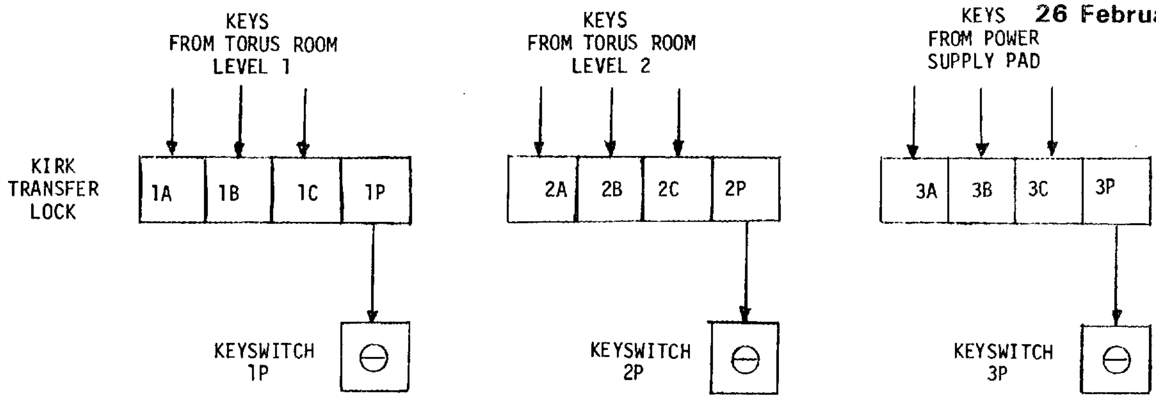


FIGURE 4.1.8–23 CRYOGENIC SCC PANEL PSCC-CRYO-002

NEMA units are used because PC hardware is not configured to easily fit into a standard 19" W instrumentation rack. Details of NEMA internal wiring will be developed in I & C Title II work.

4.1.9 Key Interlock Configuration - This subsystem is implemented using Kirk key interlock hardware and constitutes the primary level of interlocks for the EBT-P device/facility. The design of this interlock subsystem compels supervisory personnel to perform a walk-around tour of the Test Center Building, Mechanical Equipment and Power Supply Pad to insure that personnel are cleared from hazardous areas prior to device/facility start-up. This tour must be performed in a pre-defined sequence in order to successfully retrieve the necessary keys required to unlock various device control panels located at the MCC and SCC stations in the Control Room.

Figure 4.1.9-1 shows the layout of the Kirk key interlock subsystem. The Experiment Director or his designee is responsible for clearing personnel from the Torus Room (Levels 1 and 2) and from the Power Supply Pad. A total of nine keys are obtained via this walk around procedure as a result of locking various doors and gates. These keys are carried back to the Control Room to a Hoffman box located on the south wall of the Control Room and three keys (1P, 2P and 3P) are released from their respective Kirk key transfer locks. Keys 1P, 2P and 3P are inserted into three key switches also located in the Hoffman box (Fig 4.1.9-1). These key switches enable hardwired logic circuits located at several of the PC Remote I/O units. These logic circuits act as relays between various PC Remote I/O signal ports and selected device control elements. Figure 4.1.9-2 shows a preliminary logic for the Kirk key system. The check mark indicates those EBT-P device functions which must be inhibited when the three areas in the facility are occupied. Keys 1P, 2P and 3P are used to control the status of the hardwired logic units, schematically as shown in Fig. 4.1.9-3. For example, all three key switches must be in the "ON" condition in order to put the ECRH hardwired logic unit in the "GRANT" state whereby control signals can be passed from the ECRH PC to the ECRH power supplies. This arrangement eliminates all software links from the Kirk key interlock system, but requires the design of the hardwired logic units and associated field cables. The hardwired logic unit, like the PC units, are powered by the Uninterruptable Power Supply (UPS).



* NOTE: THIS EQUIPMENT IS LOCATED IN THE CONTROL ROOM, SOUTH WALL HOFFMAN BOX

FIGURE 4.1.9–1 KIRK KEY TRANSFER LOCK LAYOUT*

SAFETY ITEM / DEVICE FUNCTION	TORUS ROOM LEVEL 1 OCCUPIED	TORUS ROOM LEVEL 2 OCCUPIED	POWER SUPPLY PAD OCCUPIED
ECRH INHIBITED	✓	✓	✓
ICRH INHIBITED			✓
CRYOGENICS INHIBITED			
VACUUM INHIBITED			
MAGNET CHARGING INHIBITED	✓	✓	
WATER COOLING INHIBITED	✓	✓	

FIGURE 4.1.9–2 KIRK KEY INTERLOCK MATRIX – PRELIMINARY

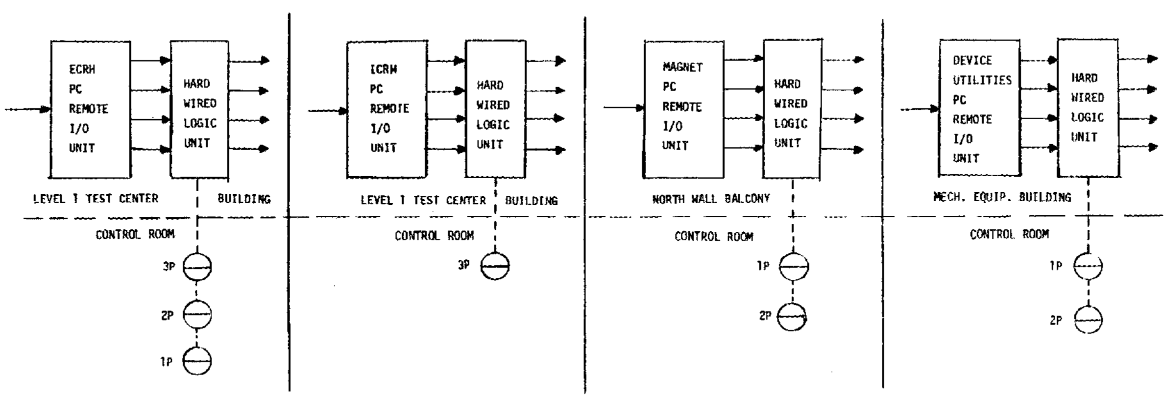


FIGURE 4.1.9–3 KIRK KEY INTERLOCK/PC INTERFACE

4.1.10 Experiment Direction Console - The EDC consists of six MCC-units:

• MCC-15, MCC-16	Chief Operator's Station
• MCC-17, MCC-18	Experiment Director's Station
• MCC-19, MCC-20	Diagnostic Data Coordinator's Station

Centralized control of device functions critical for plasma operation are centered at the EDC. The Chief Operator Station contains controls for regulating the flow of three bleed gases into the torus (typically H_2, D_2 and an inert gas) and is provided with CRT-displayed data derived from ion gauges, the diamagnetic loops, from the hard x-ray detectors and from the microwave interferometer diagnostic. MCC units 15 and 16 are identical to MCC unit 1 and 2 (Fig 4.1.7-2). Control of the Global Field Error Correction Coils is centered at the COS along with a display of toroidal plasma current as measured by the Rogowski coils.

The Experiment Director's Station (Fig. 4.1.10-1) contains two CRT color graphics terminals installed in a pair of slope-front consoles. These terminals are driven by the Facility Computer and have touch screen overlays to permit the operator to select a desired data display. The Experiment Director can access the entire device operation archive at his terminals

The Diagnostic Data Coordinator's Station is identical to the Experiment Director's Station except that the CRT terminals in MCC-19 and MCC-20 are driven by the Research Diagnostics Computer (a VAX unit). The three stations comprising the EDC are arranged in close proximity to enable these three operators to remain in close communication while an experiment is in progress. The Experiment Director, in addition, is sufficiently close to other MCC operators to permit close interaction. Similarly, the Diagnostic Data Coordinator is in close proximity to the experimentalists at other MCC stations responsible for operating the important research diagnostics. This arrangement also permits a single individual to perform EDC functions during device operation although three operators normally are involved.

The link between the Harris 135 facility computer and the research diagnostics main computer allows diagnostics data to be displayed on the EDC.

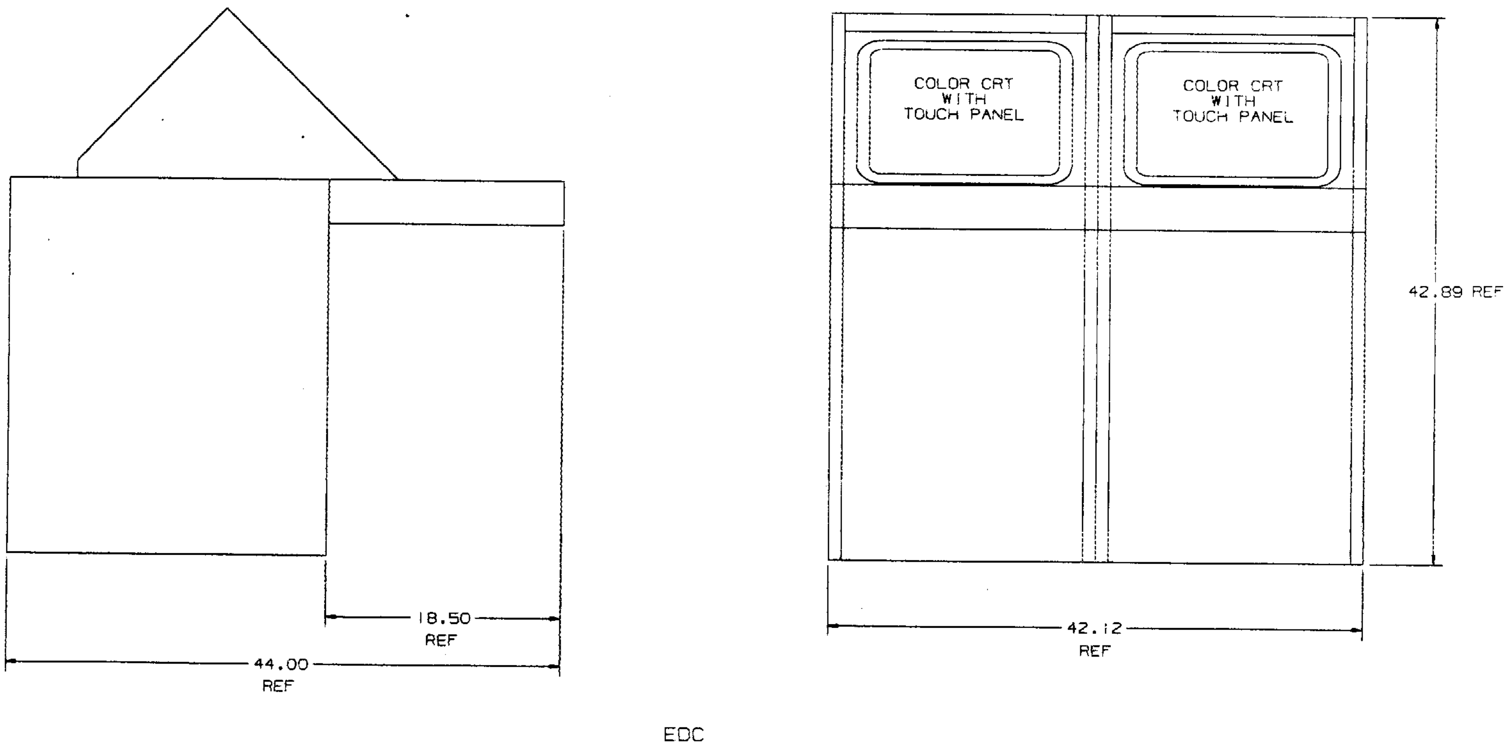


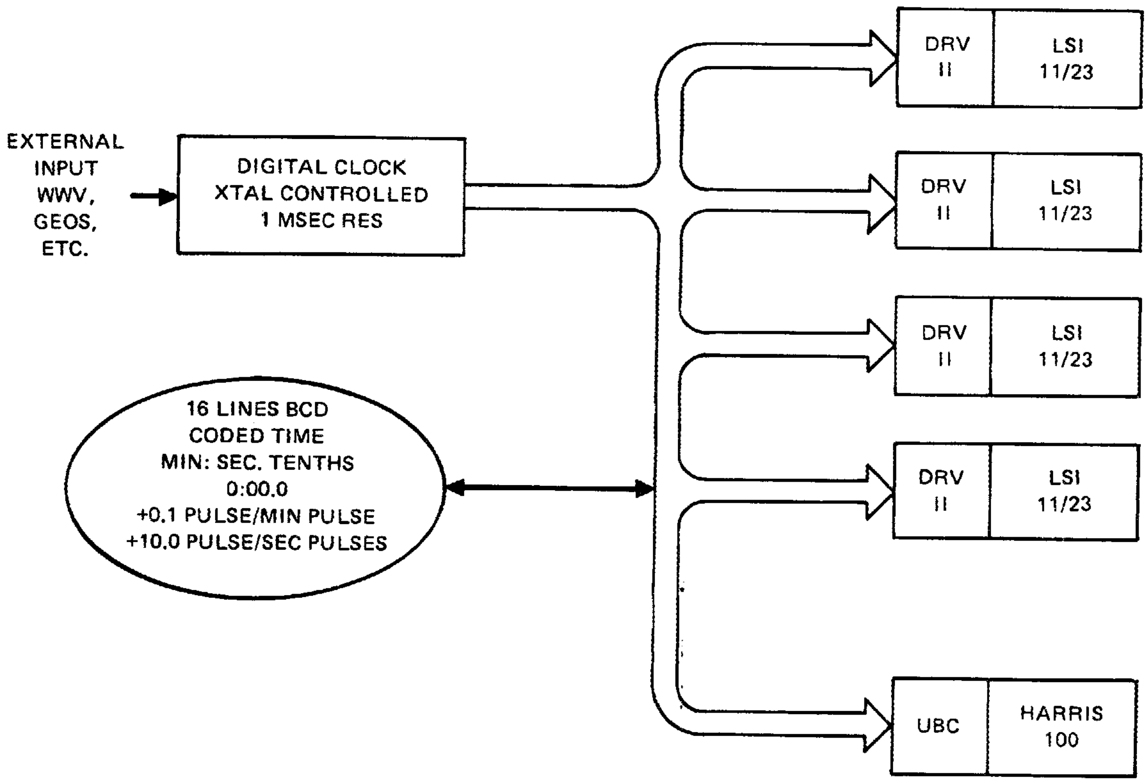
FIGURE 4.1.10–1 EXPERIMENT DIRECTION CONSOLE (TYP)

4.1.11 Master Timer Configuration - The Master Timer Unit is a specially designed digital clock with a 0.1 sec "tick". The clock is crystal-controlled temperature-regulated, and accumulates counts at the clock tick rate. The Master Timer will be set to real time and activated at a point in time during the Phase II system checkout period. From this time onward, the Master Timer operates in an uninterruptible mode to provide a continuous time base for the EBT-P facility. The Master Timer provides two basic types of time-reference data. The time of day is available to all computer tasks operating either in the facility computer, in device microprocessors, or in research diagnostic minicomputers. These tasks are able to read the Master Timer count at any time and include the count as part of a data packet. This facilitates time referencing of data in post-test off-line data processing tasks.

The Master Timer also provides its basic 0.1 sec "tick" signal to a number EBT-P device systems and research diagnostics. This signal is used to generate hardware interrupts in various microprocessors which will cause specific facility events (e.g.; pulsing ICRH power, pulsing ECRH power, synchronized scanning of several research diagnostics, etc.).

The Master Timer is based upon a Systron-Donner Model 8120 Time Code Generator. This unit generates a modulated IRIG B time code format in terms of hours, minutes, and seconds. In addition to the modulated code, the 8120 simultaneously generates a DC level shift output plus four precisely controlled pulse rates (1 pps, 10 pps, 100 pps, and 1000 pps). Updated time is supplied as parallel BCD outputs with DTL/TTL compatible logic levels.

The updated BCD output is distributed to all subsystem microprocessors and to the facility computer by a 16-line parallel buss available at various points in the control room. Also distributed with the current time buss are two pulse trains, one at a 10 pulse per second rate and one at a pulse each 10 minute interval. The 10 Hz signal is the basic heartbeat to which all events synchronize. The 10 minute pulse is used to synchronize the line clocks interval to the microprocessors and the facility computer. Figure 4.1.11-1 is a diagram of the master timer distribution scheme. Time values are interfaced to the microprocessors via DRVII parallel units and to the facility computer by a universal block channel (UBC) interface.



13–5063

FIGURE 4.1.11–1 MASTER TIMER BLOCK DIAGRAM

4.2 I & C PRIMARY INTERFACES

This section contains details of the interface between the I & C system and the EBT-P primary system. The description is presented in terms of the signal channel implementations for each interface. ISA process diagrams are employed to show the I & C components required for each interface and block diagrams are used to describe the connection of the signal channels to both the DAS CAMAC hardware and the PC remote I/O units. The components for these interfaces are contained in the I & C equipment list, Appendix A.

These interfaces are implemented using Class A and B sensors and various control elements. Class A sensors provide device operation data via the CAMAC units to assist in monitoring various processes in each primary system. The Class B sensors and the control elements provide the means to control and interlock primary system operations via the PC units.

4.2.1 Magnet I & C Interface - This interface, shown in Figures 4.2.1-1 thru 4.2.1-3 consists of the signal channels which appear in Table 4.2.1-1.

a) **Magnet temperature channels** - Each magnet is instrumented with six temperature sensors. The sensors monitor liquid helium bath temperature, nitrogen shield temperature, and vapor-cooled lead temperature. Each temperature sensor is connected to a dedicated signal conditioner. The conditioners are scanned sequentially at a rate of 20 channels per second or singularly, by the microprocessor based control unit (RIPDL). The control unit converts the data into a digital format and transmits it to the data acquisition system via an RS232 loop. One control unit is shared by both the temperature and strain conditioner systems.

b) **Magnet strain channels** - Strain in various areas of the magnet is sensed by nine strain gages per magnet. Six gages monitor the bobbin supports (two on each support), and three are mounted around the bobbin itself. Each gage is connected to a dedicated channel in the signal conditioner front end which is scanned by the common temperature/strain controller.

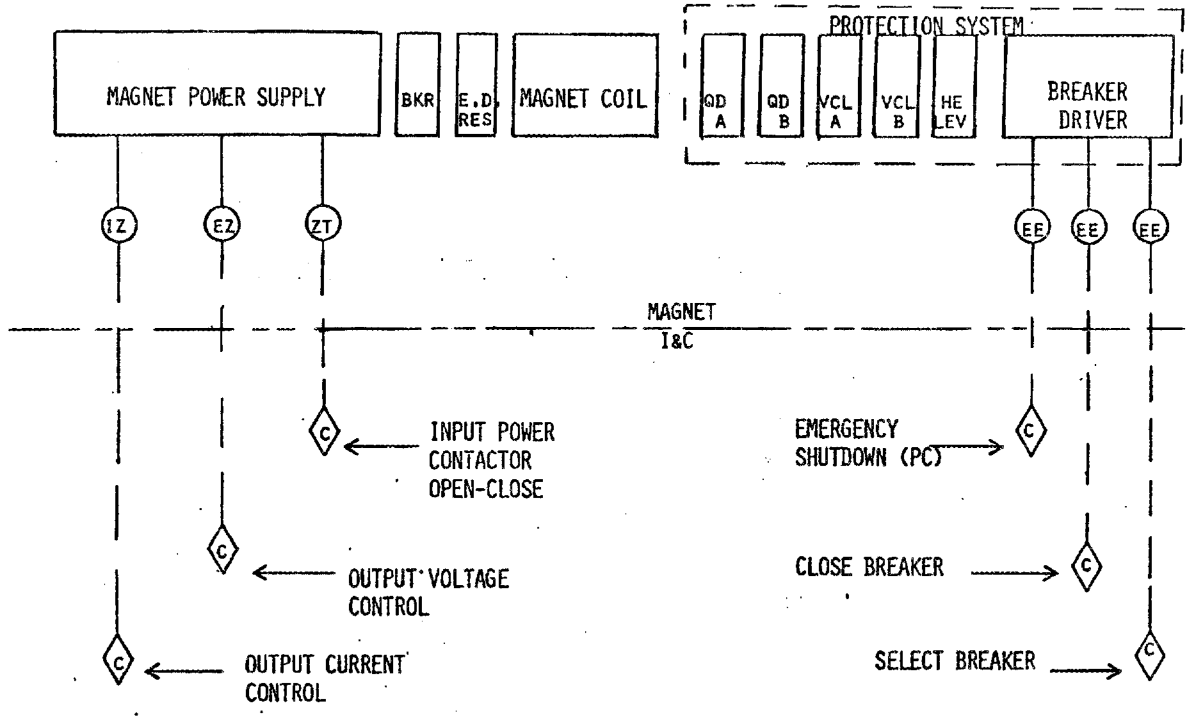


FIGURE 4.2.1–1 MAGNET SYSTEM I&C INTERFACE – CONTROL ELEMENTS

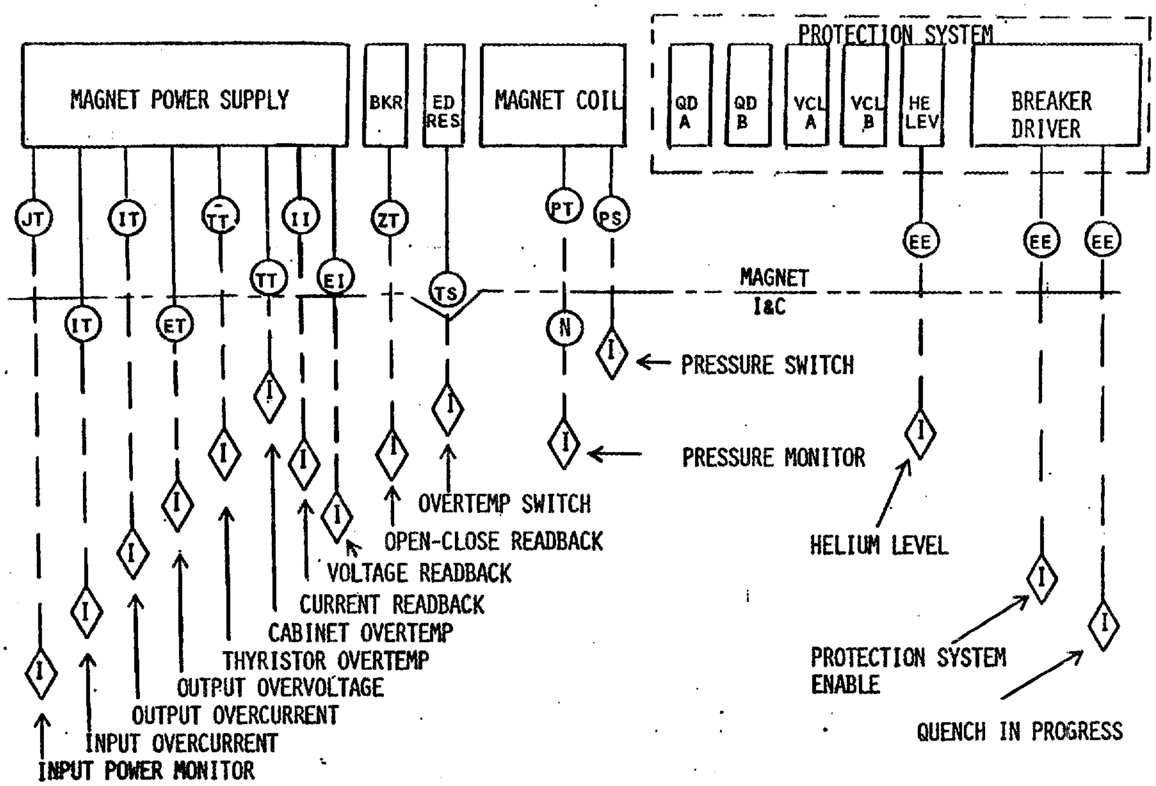


FIGURE 4.2.1–2 MAGNET SYSTEM I&C INTERFACE – INTERLOCKS

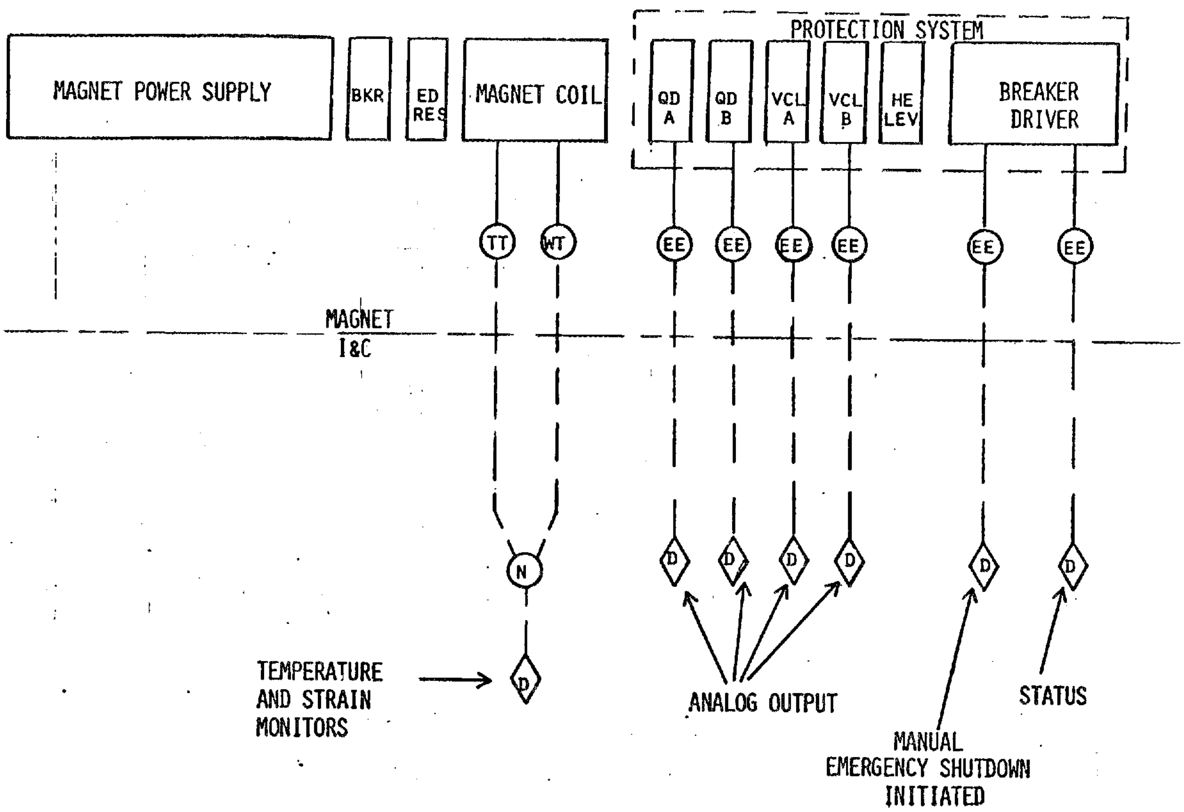


FIGURE 4.2.1–3 MAGNET SYSTEM I&C INTERFACE – CLASS A SENSORS

c) **Signal conditioners, temperature and strain** - Temperature measurements utilize two types of signal conditioners; one type is designed for type E thermocouple inputs, and the second for carbon glass resistor sensors. The thermocouple conditioners utilize a self-compensating circuit for termination offsets and switching circuits to connect each thermocouple output to the appropriate amplifier in the control unit. The carbon glass resistor sensors require and are provided with switched current levels. The current source voltage is monitored and fed to an amplifier in the control unit. Each resistor channel is individually excited and scanned.

The strain conditioner consists of a bridge completion network and excitation circuit for each gage. The output of each channel is multiplexed via switching circuits to an amplifier in the control unit. automatic zero and strain offset correction is done by the control unit.

d) **Magnet helium pressure** - Each magnet has a helium pressure transducer which provides data to the cryogenic system. The transducer output is input to a compatible Bell and Howell model 612400 signal conditioner. The signal conditioner transmits a 0 to 5 volt proportional signal directly to the process controller I/O.

e) **Magnet helium level** - Each magnet has a helium level indication. The system consists of a superconducting probe with a compatible excitation/conditioner. The excitation/conditioning for the probe is provided by a AMI model 130 A unit. To minimize power dissipation, the probe is excited and monitored for a short time out each cycle period. The sample time duty cycle is adjustable. The proportional analog output is sent to the process controller I/O.

f) **Magnet power supply channels** - The output voltage, current and their associated readbacks are interlocked with the process controller for control and feedback monitoring. The interfaces consist of two control interfaces, one for current and one for voltage; either mode can be selectively enabled. The output current and voltage are sensed by the magnet power supply circuitry and fed to the process controller for monitoring.

g) **Historical data channels** - The protection system outputs are sent to the data acquisition system for the purpose of data logging. The data includes quench detection analog outputs, vapor-cooled lead analog voltages, and vacuum switch discrete outputs. These data are provided for recognizing patterns the magnets may exhibit both during normal operation and emergency shutdown conditions.

h) **Control and interlock channels** - Interlock channels are provided to insure safe operation. These include dump resistor over-temperature, breaker open-closed readbacks, helium overpressure, magnet status readbacks, and quench in progress. Control channels consisting of both manual and programmable emergency shutdown circuits and individual breaker closing circuits are also provided.

Table 4.2.1-1 Magnet I&C Interface

FUNCTION	PROCESS CONTROLLER INPUT	PROCESS CONTROLLER OUTPUT	DATA ACQUISITION INPUT
Magnet P.S. - Power Failure	X		
Current Monitor - Input Overcurrent	X		
Current Monitor - Output Overcurrent	X		
Voltage Monitor - Output Overvoltage	X		
Temperature Transmit - Thyristor Overtemp	X		
Temperature Transmit - Cabinet Overtemp	X		
Position Transmit - Magnet P.S. Main Contactor		X	

Table 4.2.1-1 Magnet I&C Interface (Continued)

FUNCTION	PROCESS CONTROLLER INPUT	PROCESS CONTROLLER OUTPUT	DATA ACQUISITION INPUT
Current Transmit - Magnet P.S. Current Readback	X		
Voltage Transmit - Magnet P.S Voltage Readback	X		
Current Control - Magnet P.S. Current Control		X	
Voltage Control - Magnet P.S. Voltage Control		X	
Helium Pressure Switch	X		
Helium Pressure Monitor	X		
Helium Level Monitor	X		
Dump Resistor Overtemp	X		
Breaker Close (Steering Relay)		X	
Breaker Close (Make-Break Relay)		X	
Breaker Open-Close Readback	X		
Quench in Progress	X		
Emergency Shutdown		X	
Emergency Shutdown - Manual (Control Console)			
Status Readback			X

Table 4.2.1-1 Magnet I&C Interface (Continued)

FUNCTION	PROCESS CONTROLLER INPUT	PROCESS CONTROLLER OUTPUT	DATA ACQUISITION INPUT
Vapor Cooled Lead Monitors Analog Outputs			X
Quench Detectors Analog Outputs			X
Magnet Temperature			X
Magnet Strain			X

4.2.2 Vacuum I & C Interface - This section describes the vacuum I&C interface as it existed prior to the Vacuum System PDR. At that time cryopumps were baselined. Since then, turbomolecular pumps have been substituted for the cryopumps. The effect of this change on the I&C has not been accounted for in this document due to the time and cost involved in rewrite and making drawing changes. It should be noted, however, that this change will be reflected in all relevant Title II I&C drawings at the appropriate time.

This interface is composed of the five sections listed in Table 4.2.2-1. Each of these sections is described next.

a) Torus Section - The process diagram is shown in Figure 4.2.2-1. The dashed line (—– – —) shows the vacuum/I & C interface. Nine cryopumps are used to evacuate the EBT-P device and are located on the outboard ports of cavities 2, 5, 10, 14, 18, 20, 26, 30, and 34. These cryopumps are supplied with liquid helium (LHe) and liquid nitrogen (LN_2) from the cryogenic distribution system and return gaseous helium ($T<10K$) and nitrogen to the cryogenic distribution system. Each cryopump requires two vacuum-jacketed, long-stem cryogenic globe valves (designated NV30XX) with pneumatic two-position actuators. The pilot air valves are controlled (C) and software-interlocked (SW) by the vacuum system PC unit.

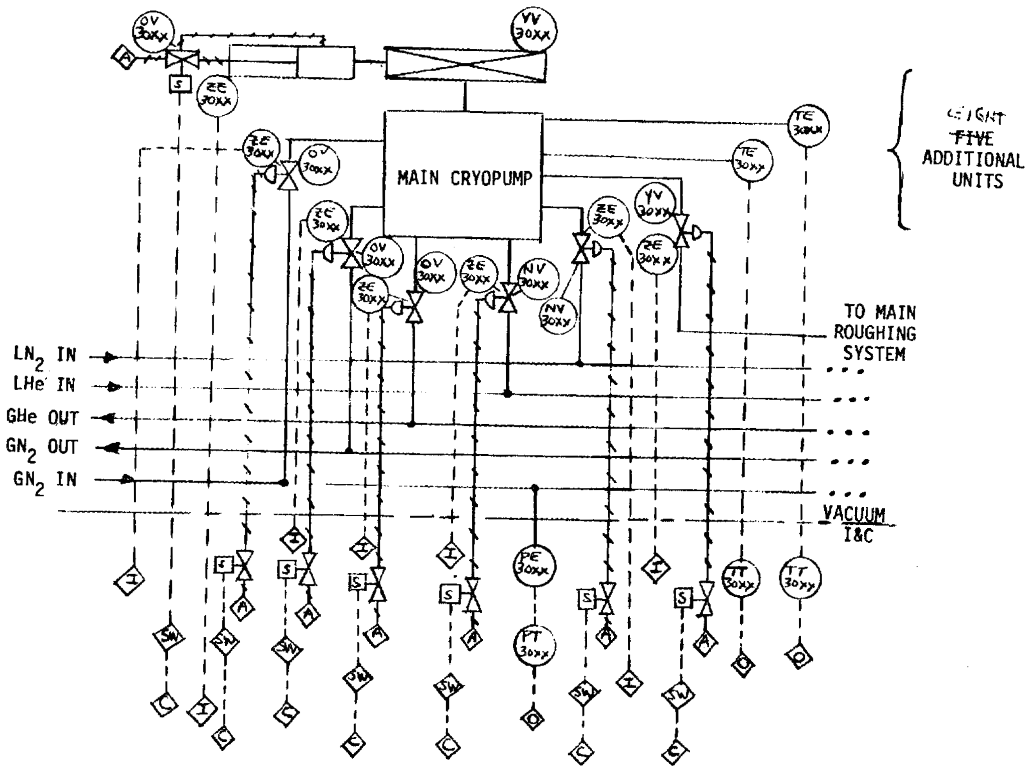


FIGURE 4.2.2–1 MAIN CRYOPUMP I&C INTERFACE

The main cryopumps each have a line connected to the torus rough pumping system (valve designation OV30XX) and a line connected to the gaseous nitrogen (GN_2) purge supply (valve designation YV30XX). The valves in these lines are provided with pneumatic two-position actuators which are controlled and software-interlocked by the vacuum system PC unit.

Table 4.2.2-1 Vacuum I & C Interface - Principal Sections

- Torus Section
  - Main Cryopumps (9)
  - Ion Gauges (36)
  - Thermal Vacuum Gauges (9)
  - Main Gate Valves (9)

- Torus Mirror Coils
  - Cryopumps (9)
  - Ion Gauges (36)
  - Thermal Vacuum Gauges (36)
  - Gate Valves (36)
  - Overpressure Switches (36)

- Gyrotron Tubes
  - Magnet Ion Gauges (6)
  - Magnet Thermal Vacuum Gauges (6)
  - Gate Valves (6)

- Rough/Regeneration Pumping System
  - LN_2 Sorption Pumps (4)
  - Turbomolecular Pump (1)
  - Mechanical Pumps (2)
  - Gate Valves (13)
  - Thermal Vacuum Gauges ($\sim$8)
  - LN_2 Fill Controllers (4)

Table 4.2.2-1 Vacuum I & C Interface - Principal Sections (Continued)

- Gas Bleed System
  - Regulators
  - Piezo Valves
  - Gas Flow Sensors

Each main cryopump has a main gate valve (designated YV30XX) for isolating the torus from the cryopump. This gate valve has an integral pneumatic cylinder, two-position actuator which is controlled and software-interlocked by the PC units. The cylinder actuator is equipped with OPEN/CLOSE limit switches (designated ZE30XX) which provide interlock input signals (I) to the PC unit.

Each main cryopump has an internal temperature sensors on the cryopanel surfaces (designated TE30XX). The temperature analog is converted into a 4-20 ma current signal by a signal transmitter (TT30XX) and sent as an operational input (O) to the PC unit.

Figure 4.2.2-2 shows more details of the PC remote I/O unit. Allen-Bradley components are specified. The control and interlock circuits for the gate valves and for solenoid valves in general employ 24 VDC signals. An isolated-output 24 VDC power supply provides the power for these circuits. Similarly, an isolated 24 VDC power supply is used to power the 4-20 ma current loop in the temperature sensor circuit. The link between the PC remote I/O unit and the PLC-3 programmable controller is a single twisted-pair cable.

b) Torus Mirror Coils - The thirty-six mirror coil vacuum containers connect via gate valves to the Mirror Coil Vacuum Manifold (see Figure 4.2.2-3). This manifold is pumped by four (4) LHe cryopumps which contain the same valves and instrumentation provided for the nine main cryopumps. Each of the four manifold cryopumps has a large gate valve to provide isolation from the manifold such that these cryopumps can be individually regenerated. Note that the manifold design requires that all 36 mirror coil vacuum containers be pumped simultaneously. This is a compromise designed to minimize the cost of the manifold.

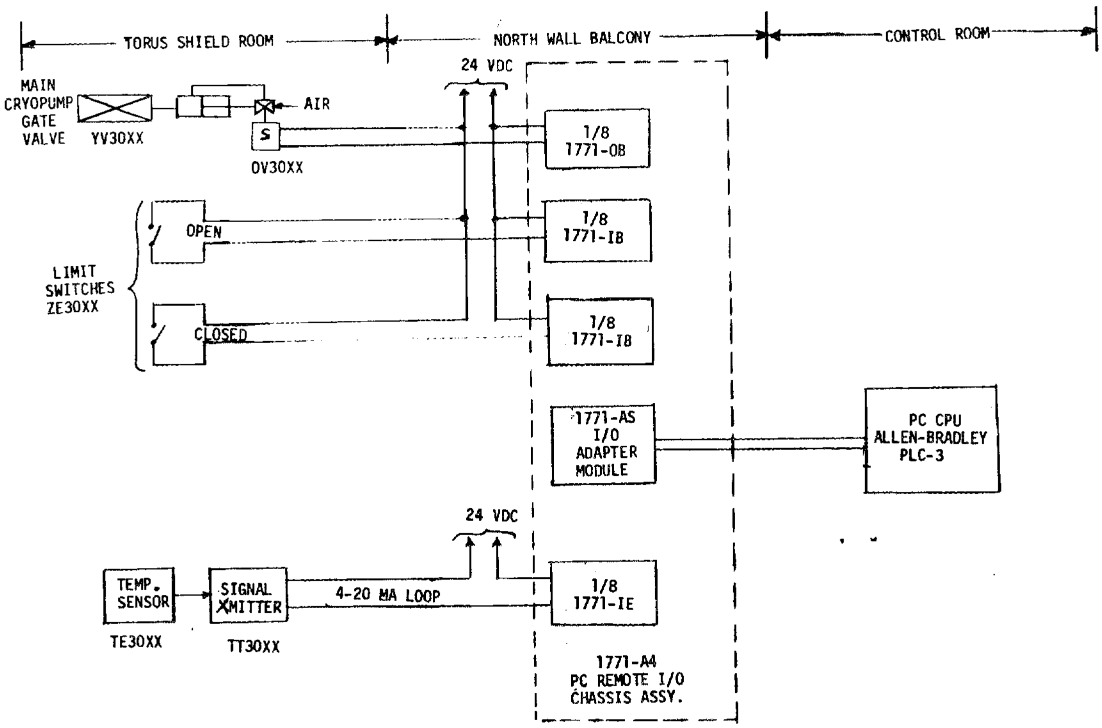


FIGURE 4.2.2–2 VACUUM I&C CHANNEL DIAGRAMS

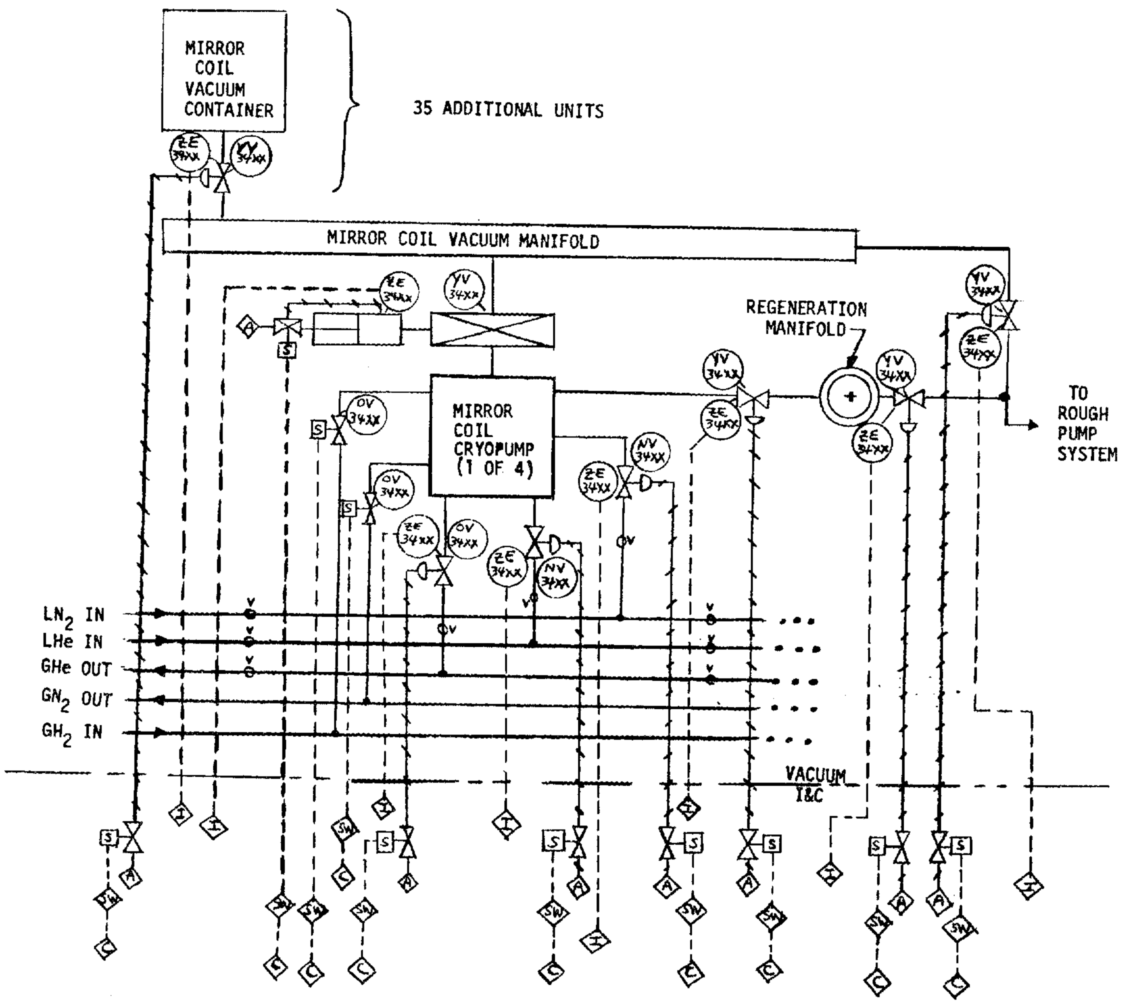


FIGURE 4.2.2–3 MIRROR COIL CRYOPUMP I&C INTERFACE

Two vacuum gauges (PE30XX) are attached to each mirror coil vacuum container, a hot-filament ionization gauge and a thermal vacuum gauge (thermocouple or thermistor type). The controllers for these gauges (PIT 30XX) are located in cabinets on the North Wall Balcony and provide operational status data (O) to the PC unit. Each controller has an over-pressure trip circuit (PSH 30XX) which provides interlock signals (I) to the PC unit. Hand-valves (HV 30XX) are provided such that the vacuum gauges can be changed without the need to backfill the mirror coil vacuum container. Note that the vacuum gauges and controllers are part of the I & C system equipment list.

Figure 4.2.2-4 shows additional details of the PC Remote I/O interface. The vacuum gauge controllers are equipped with remote control options such that gauge functions can be commanded from the EBT-P control room. The controllers produce analog output signals logrithmically related to pressure which are read by the Model 1771-IE modules.

c) Gyrotron Tubes - The 60 GHz gyrotron focus magnets are superconductive units enclosed in a Gyrotron Magnet Vacuum Container (see Figure 4.4.2-5). These containers are "permanently-pumped" units which are pumped to high vacuum ($\sim 10^{-5}$ torr) and sealed via a valve on the pumping port. A portable pumping unit is used to service these magnets. This minimizes the amount of permanently-installed pump plumbing required in the EBT-P facility.

d) Rough/Regeneration Pumping System - This system contains two sub-systems:

- Torus and main cryopump rough pumping subsystem;
- Mirror coil rough pumping subsystem

The rough pumping system provides two basic functions:

- Rough pumping services;
- Cryopump regeneration services.

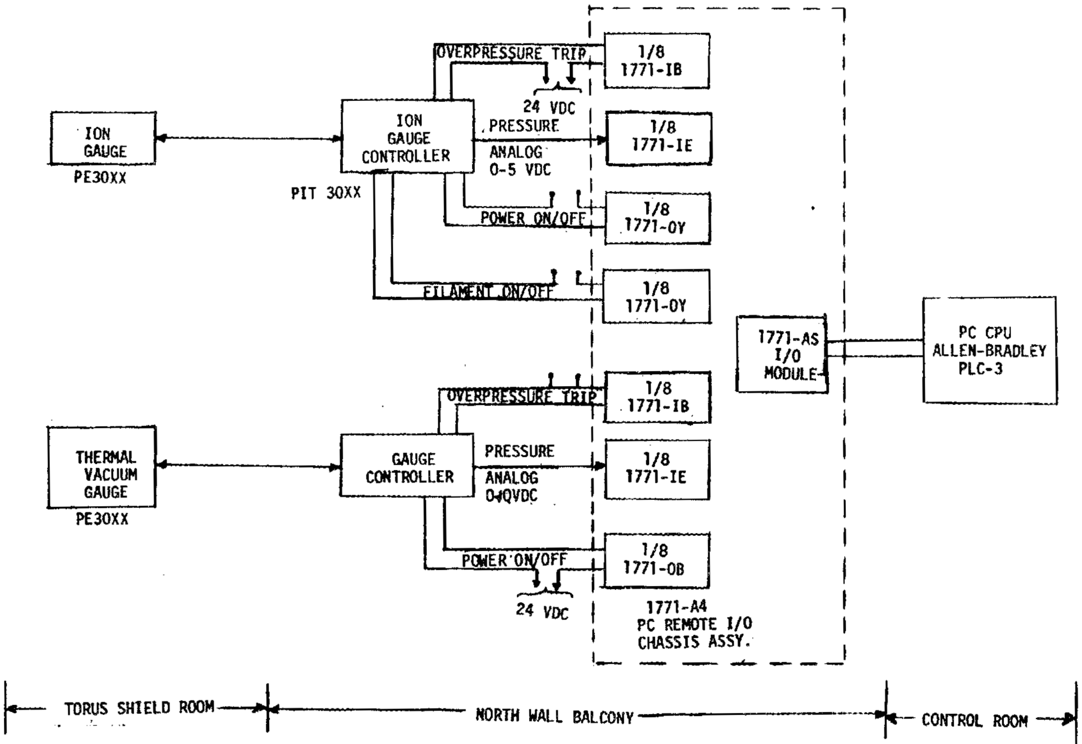


FIGURE 4.2.2–4 VACUUM GAUGE I&C CHANNEL DIAGRAM

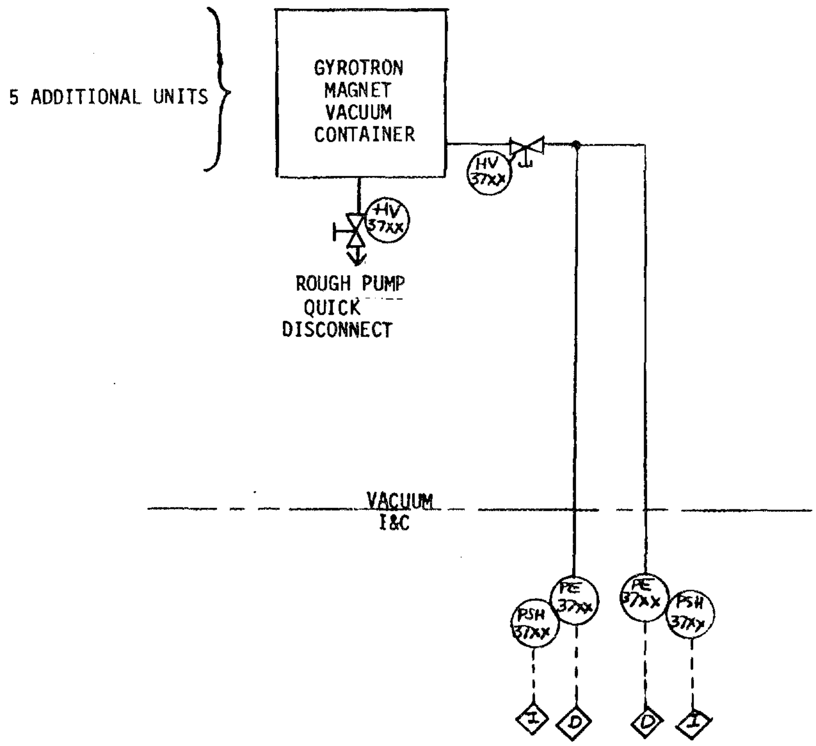


FIGURE 4.2.2–5 GYROTRON MAGNET VACUUM CONTAINER I&C INTERFACE

The torus and main cryopump rough pumping subsystem is shown in Figure 4.4.2-6. The components are:

- LN_2 cryosorption unit #1 consisting of sorption pumps A and B and carbon vane pump A;
- LN_2 cryosorption unit #2 consisting of sorption pumps C and D and carbon vane pump B;
- A single turbomolecular pump with mechanical forepump.

Figure 4.4.2-6 shows the principal control (C) inputs required, while Figure 4.4.2-7 shows the remainder of the I & C components for this system. The valves and manifolds are arranged such that the LN_2 cryosorption units and the turbopump subsystems are capable of independent connection to either the torus rough pump port or the main cryopump regeneration manifold. This isolation is required to permit the LN_2 cryosorption units to be independently regenerated while the EBT-P device is operational. This arrangement also permits simultaneous regeneration of one or more main torus cryopumps while the other main cryopumps continues to pump the torus.

Referring to Figure 4.4.2-7, instrumentation is provided to measure pressure (PE 33XX units), LN_2 level (LE 33XX units), motor speed (SE 33XX units) and to control the operation of AC power relay components (UY 33XX units). The water-cooling loop for the turbopump contains a low-flow interlock (FSL 33XX).

Figure 4.4.2-8 shows the mirror coil rough pumping subsystem. A toroidal manifold connects each of the mirror coil vacuum subsystems to a dedicated roughing subsystem. This subsystem contains an LN_2 cryosorption unit (sorption pumps E and F and carbon vane pump C) and a 50 CFM mechanical vacuum pump. The instrumentation for this LN_2 cryosorption unit is identical to that provided for the main cryopump roughing subsystem. In addition, the LN_2 cryosorption unit in Figure 4.4.2-8 can be detached from the mirror coil rough pump manifold and moved around the facility to service the gyrotron magnets.

e) Gas Bleed System - This system provides the means to control the pressure of bleed gases to the EBT-P device. The controller permits the pressure of one gas (usually H_2) to be controlled absolutely in terms of torr. One or two other gases (e.g., D_2 or an inert gas)

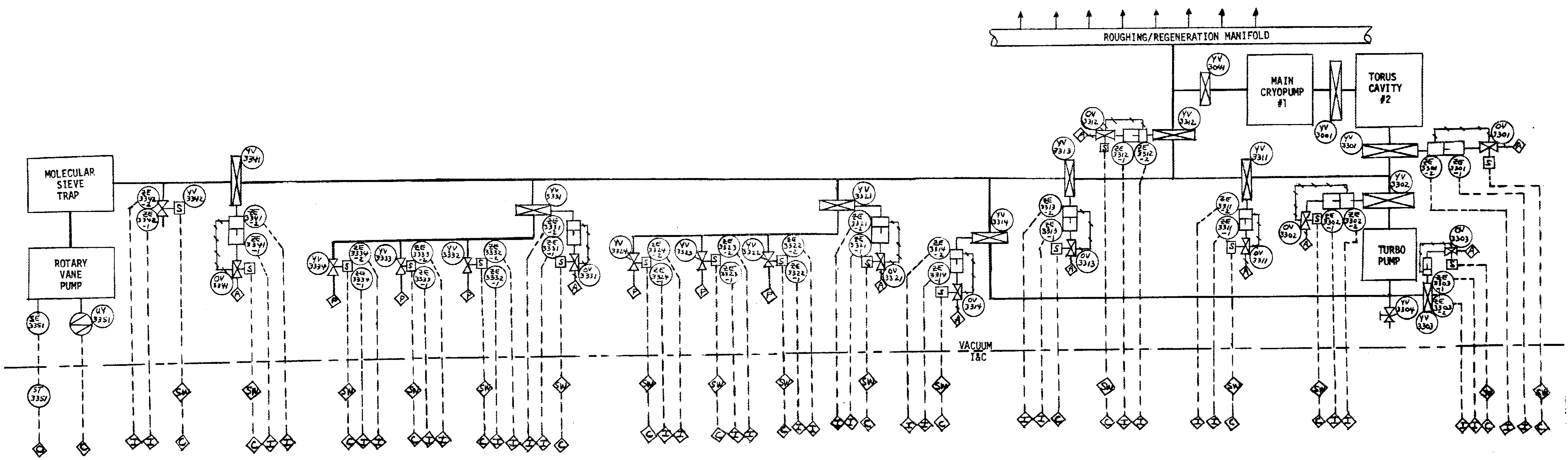


FIGURE 4.2.2-6 VACUUM/I&C INTERFACE - ROUGHING/REGENERATION SUBSYSTEM

FIGURE 4.2.2–6 VACUUM/I&C INTERFACE – SUBSYSTEM

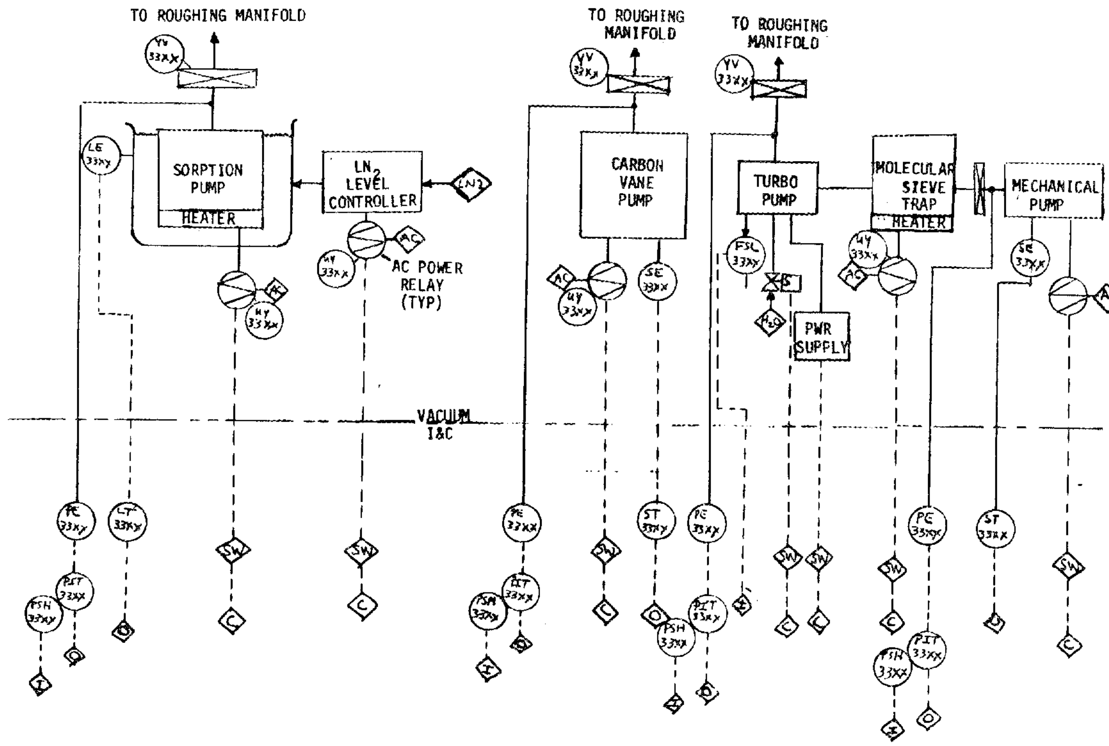


FIGURE 4.2.2–7 MAIN ROUGHING SYSTEM INSTRUMENTATION

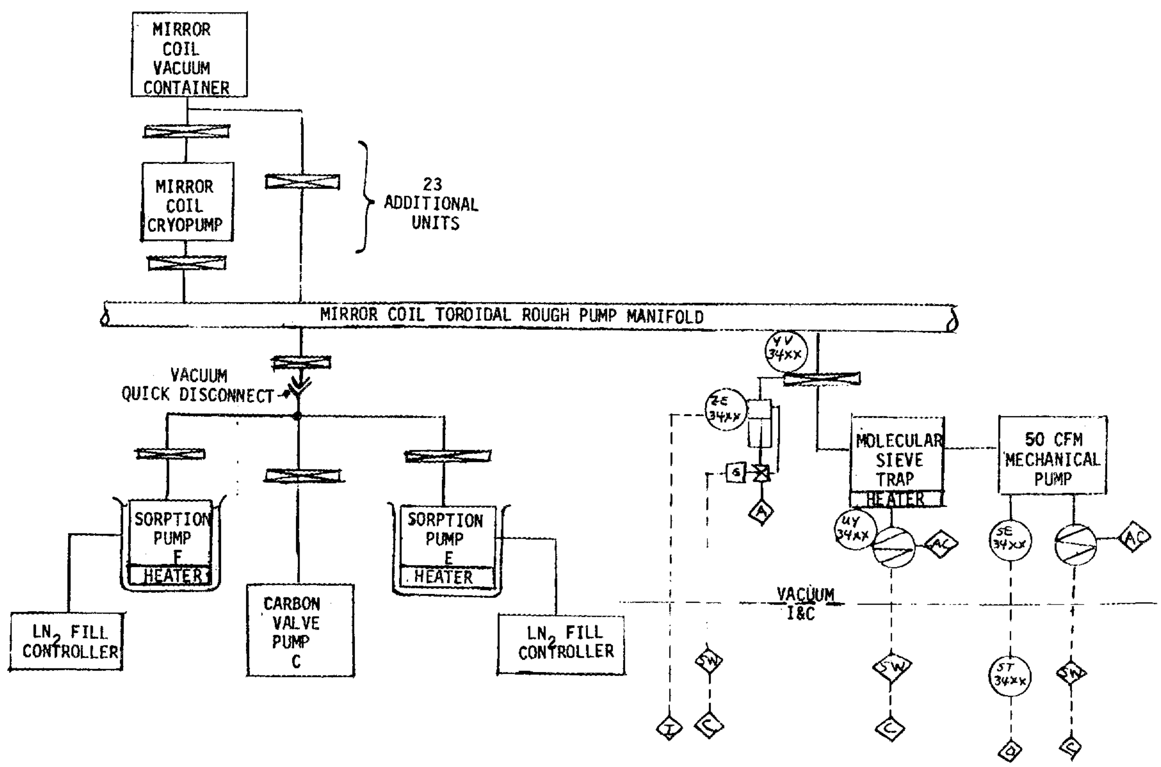


FIGURE 4.2.2–8 MIRROR COIL ROUGH PUMPING SUBSYSTEM

can be controlled such that the partial pressures are given fractions of the H_2 pressure. Magnetically-actuated proportioning valves are used to provide the control.

- Other Vacuum I & C Components - Each torus cavity (36 units total) is provided with a hot-filament ionization gauge. Nine ion gauges are interfaced to the PC remote I/O unit as indicated in Figure 4.2.2-4 and provide interlock input signals (I) for the vacuum PC processor. The remaining twenty-seven gauges are interfaced to the CAMAC I/O unit of the vacuum system DAS microprocessor. These gauges function as Class A sensors and provide operating condition data inputs (D) to the facility computer archive. The latter gauges are not involved in device control/interlock functions.

4.2.3 Cryogenic Distribution I & C Interface - This interface consists of two main subsystems:

a) Gaseous and liquid helium (GHe/LHe) distribution subsystem;

b) Gaseous and liquid nitrogen (GN_2/LN_2) distribution subsystem.

Figure 4.2.3-1 shows the interface to subsystem (a). This distribution subsystem contains the LHe Main Storage Dewar and associated vacuum jacketed cryogenic transfer lines which connect the Dewar to the thirty-six mirror coil LHe dewars and to the six 60 GHz gyrotron magnet LHe dewars. Flow controls for LHe transfer is provided by three long-stem vacuum-jacketed cryogenic transfer valves (NV4001, NV4002 and NV4003). These valves are equipped with limit switches (ZE40XX) to provide interlock inputs **I** to the cryogenic system programmable controller. All three valves in this subsystem are operated by pneumatic two-position actuators.

A secondary cryogenic distribution subsystem is used for initial cooldown of the LHe distribution subsystem. Valves NV4011 and NV4012 provide a path for GHe flow from the helium refrigerator cold box to the mirror coil LHe dewars. Cooldown from 300K to 77K is accomplished using this flow path. Similarly, valves NV4011 and NV4013 provide control of the 300K - 77K cooldown path for the gyrotron magnet dewars.

The next stage in the cooldown process is controlled by valve NV4021 which meters the flow of GHe (77K to 20K) from the helium refrigerator cold box. Valve NV4031 controls flow in an alternate path in order to cool the LHe flow path from the Main LHe Storage Dewar to the main LHe manifold.

A principal design goal is to minimize the heat load on the helium refrigerator due to the LHe distribution subsystem. As the valves are a major heat leak, the aim is to minimize the number of valves. This produces a constraint on the cryogenic distribution system, namely, that all thirty-six mirror coil LHe dewars must be cooled as a group. Individual mirror coil dewars cannot be cooled singly. Similarly, all six gyrotron magnet LHe dewars must be cooled as a group. All other cooldown schemes designed to circumvent this constraint result in additional valves and cryogenic plumbing and thereby increase both the heat load on the helium refrigerator and the capital cost of this equipment.

Figure 4.2.3-2 shows the I & C interface to the mirror coil LHe dewars. Two fill lines are provided, a "bottom-fill" line for the initial LHe fill process and a "top-fill" line for steady-state control of the LHe level in the thirty-six dewars. The bottom-fill line is controlled using a vacuum-jacketed, long-stem cryogenic valve operated by a two-position pneumatic actuator (NV4101). The top-fill line has a three-position valve (NV4151) which provides ON/OFF and a partially-open setting to control LHe steady-state level. The trade study outlined in Section 5.4 describes the rationale for the design of the top-fill valve control approach. A superconducting LHe level sensor (LE4101) provides a signal to the cryogenic system PC unit which executes a "time-proportioning" control algorithm and fully opens the top-fill valve (NE4151) for a period of time that is proportional to the error between the present LHe level and the desired LHe level setpoint. This procedure is repeated at a pre-specified interval (e.g.; every three minutes). During the interval between LHe replenishment, the top-fill valve is held slightly open to permit LHe to slowly dribble into the magnet dewar. This procedure is required to ensure that the top-fill line remains cooled to $\sim$ 4.2°K at all times, and to prevent the formation of superheated helium vapor upstream from the top-fill valve.

Three GHe vents are provided on each mirror coil dewar, a cold GHe vent and two vents through the vapor-cooled leads. The cold GHe is vented directly to the 10K GHe vent manifold and returns to the helium refrigerator cold box for re-liquifaction. The GHe flow

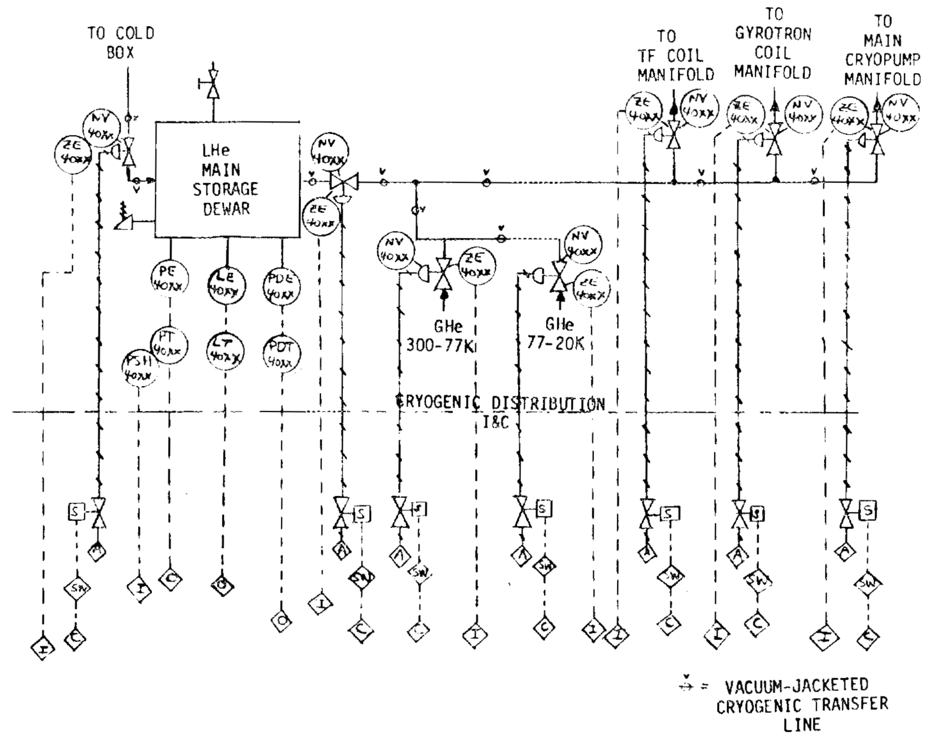


FIGURE 4.2.3–1 I&C INTERFACE – LHe DISTRIBUTION SYSTEM

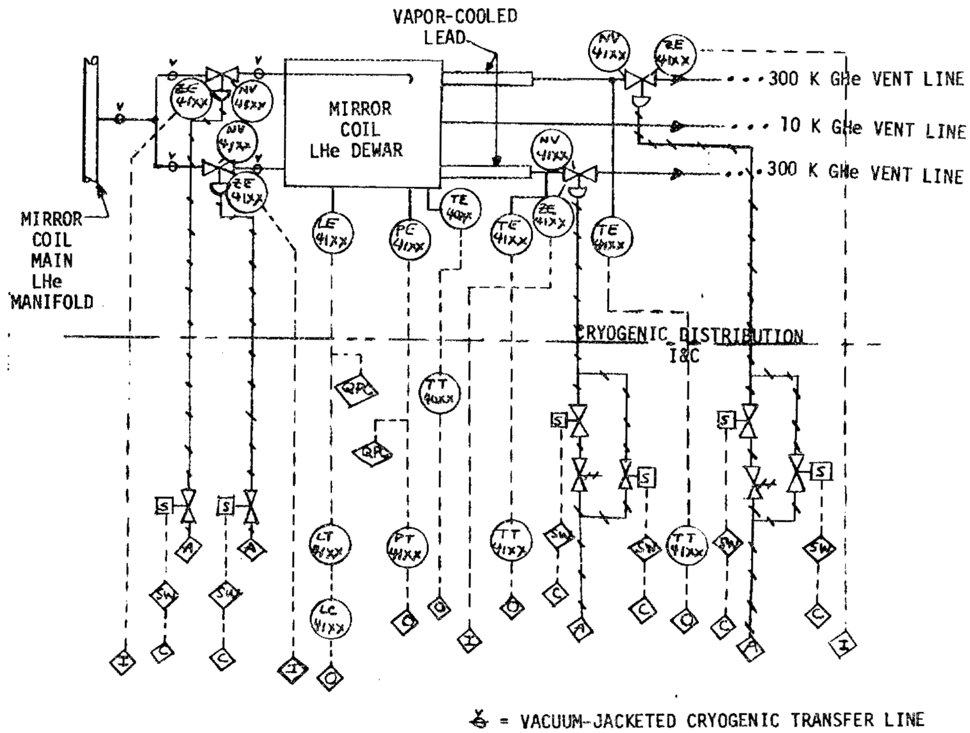


FIGURE 4.2.3–2 MIRROR COIL LHe DEWAR I&C INTERFACE

through the vapor-cooled leads results in two gas streams at temperatures near 300K. These gas streams are controlled by two globe valves (NV4101-1 and NV4101-2). These valves are positioned such that sonic flow conditions are achieved in each vapor-cooled lead vent line. The required Δp for sonic flow is provided by a pair of Roots blowers which maintains sub-atmospheric pressure in the 300K GHe vent system (see Figure 4.2.3-4). The sonic condition in the vapor-cooled lead GHe vents reduces the effects of pressure fluctuations in one dewar on the GHe flow from the other dewars.

A pair of temperature sensors (TE4101-1 and TE4101-2) are used to control the GHe vent valves. When the GHe gas stream becomes overheated, the cryogenic system PC unit opens the corresponding GHe vent valve in an effort to cool the overheated vapor-cooled lead. If this measure is ineffective, the magnet system Quench Protection Circuit (QPC) will initiate a magnet system shut-down.

Each mirror coil dewar has a pressure sensor (PE4101) which measures internal dewar pressure and provides input to the cryogenic system PC unit. This signal is provided as a display variable to enable the operator to monitor dewar pressure and to operate pressure relief valves as required. This function can also be performed automatically by the PC unit.

The LHe fill system I & C interface for the gyrotron magnet dewars is shown in Figure 4.2.3-3. A single top-fill line is the present baseline design. A three-position fill valve (NV4301) functions in the manner described previously to maintain LHe level setpoint. The GHe vent lines are identical in design to those provided for the mirror coil dewars. A pressure sensor (PE4301) is provided to sense overpressure conditions in the dewar.

Figure 4.2.3-4 shows the GHe return subsystem I & C interface. The 10K GHe streams from the magnet dewars are directed via a manifold to the helium refrigerator cold box. No additional instrumentation is required for this vent subsystem. The 300K GHe streams from the magnet dewars are collected in a manifold and directed to the first stage of the helium compressor. This manifold is maintained at a sub-ambient pressure ($\sim$5 psia) by a pair of Roots blowers such that sonic flow conditions exist across the control valves in the vapor-cooled lead lines. The blowers are provided in the ON/OFF start relays (YV42XX) and speed sensors (SE42XX).

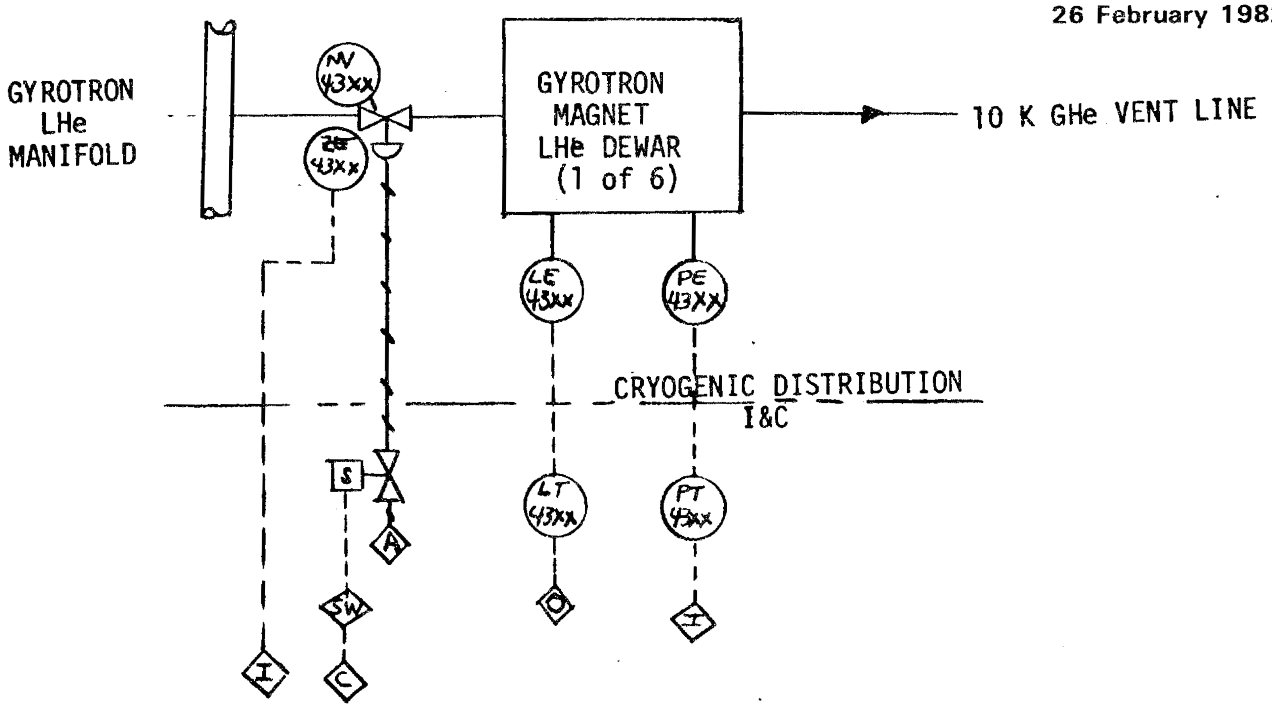


FIGURE 4.2.3–3 GYROTRON MAGNET DEWAR I&C INTERFACE

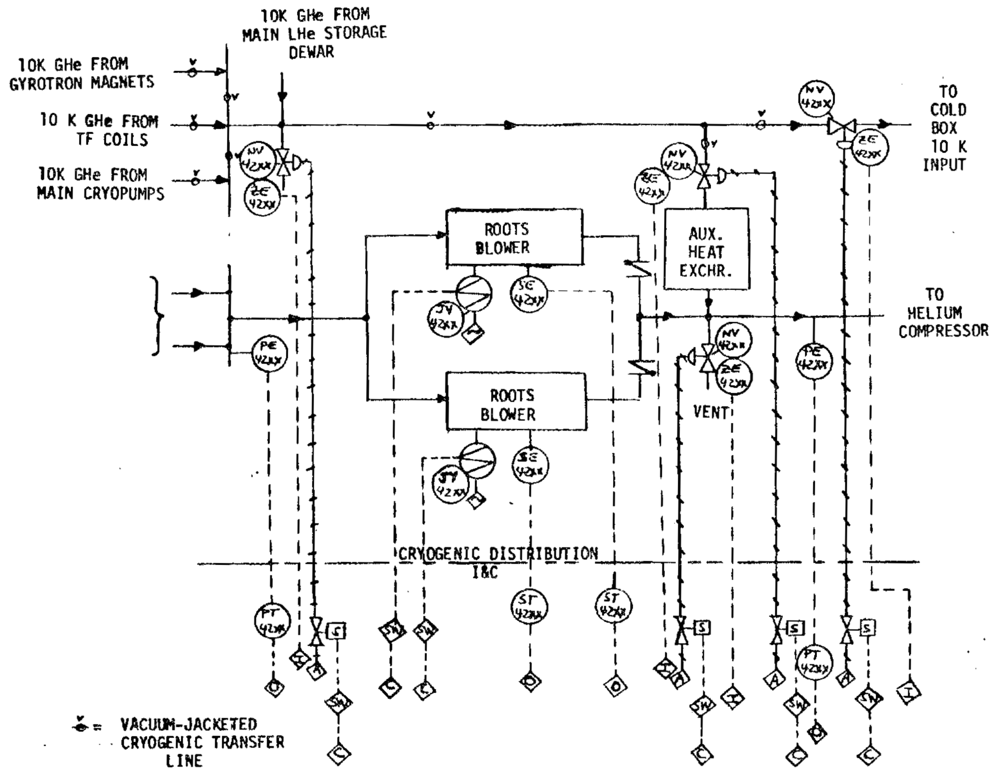


FIGURE 4.2.3–4 GHe RETURN SYSTEM I&C INTERFACE

The other major subsystem, the GN_2/LN_2 distribution subsystem, is shown in Fig. 4.2.3-5. A LN_2 Main Storage Dewar is filled via LN_2 delivery trailers and is provided with a LN_2 level sensors (LE4401) and a pressure control unit (PE4401, PIC4401 and YV4401). Flow of LN_2 is controlled by three valves (YV4402, YV4403 and YV4404). Two additional valves (YV4411 and YV4412) are used as service ports and emergency dumps on the LN_2 distribution mainfolds. Each input LN_2 shield has a temperature sensor (TE44XX) which provides a signal to the cryogenic system PC unit for control/interlock/display functions. A pair of pressure sensors (PE44XX) are used in the GN_2 vent mainfolds to detect flow blockage conditions.

The LN_2 distribution system has the same constraint mentioned above for the LHe system, i.e. that the thirty-six mirror coil LN_2 shields and the six gyrotron magnet LN_2 shields must be cooled together. Individual LN_2 shields cannot be cooled singly. The rationale here is as before, to minimize the numbers of cryogenic valves and lengths of LN_2 transfer line required for this subsystem.

Channel diagrams typically used for the cryogenic distribution system are shown in Fig. 4.2.3-6. The cryogenic-service valves require two-or-three-position pneumatic actuators and have associated limit switches to provide the PC unit with valve status information (OPEN/CLOSED).

The pressure, temperature and level sensor require signal transmitters producing 4-20 ma two-wire output current signals proportional to input millivolt levels. These transmitters are located close to the sensors in the protection zone (X-ray shadow) provided by the concrete support ring. These current signals are converted into voltage equivalents (2-10 volts) at the PC remote I/O modules located on the North Wall Balcony.

4.2.4 ECRH I & C Interface - This interface consists of the following components:

a) 28 GHz gyrotron tube I & C interface (Sec. 4.2.4.1)
b) 60 GHz gyrotron tube I & C interface (Sec 4.2.4.2)
c) 28 GHz gyrotron power supply I & C interface (Sec. 4.2.4.3)
d) 60 GHz gyrotron power supply I & C interface (Sec. 4.2.4.4)

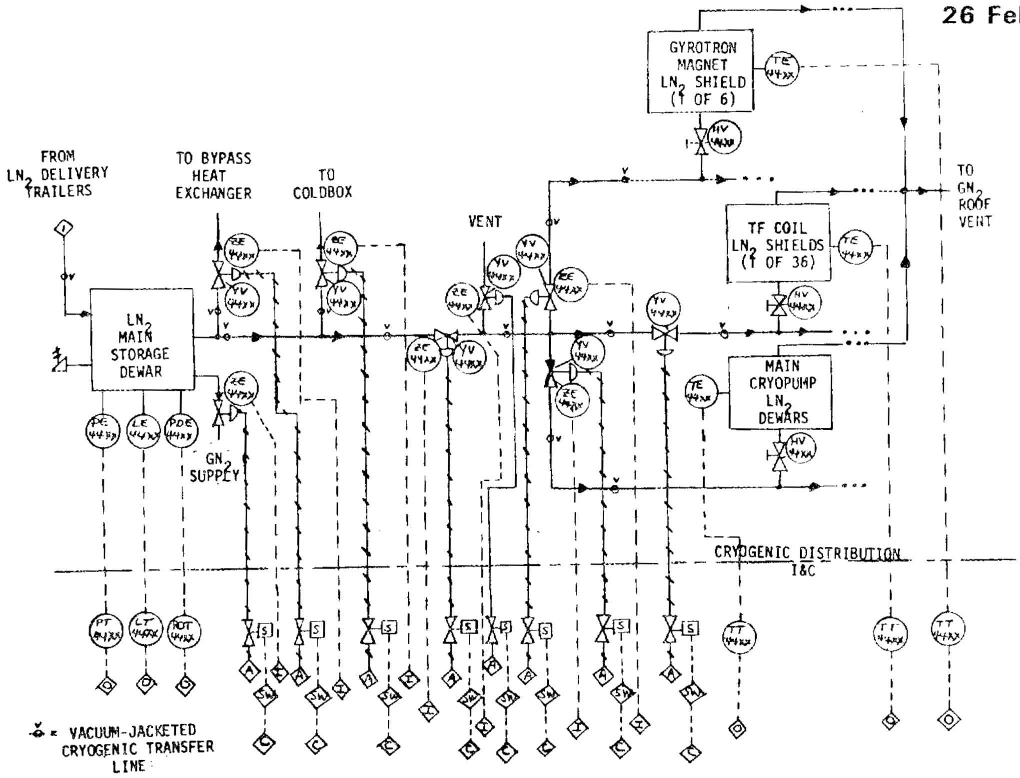


FIGURE 4.2.3–5 LN_2 DISTRIBUTION SYSTEM I&C INTERFACE

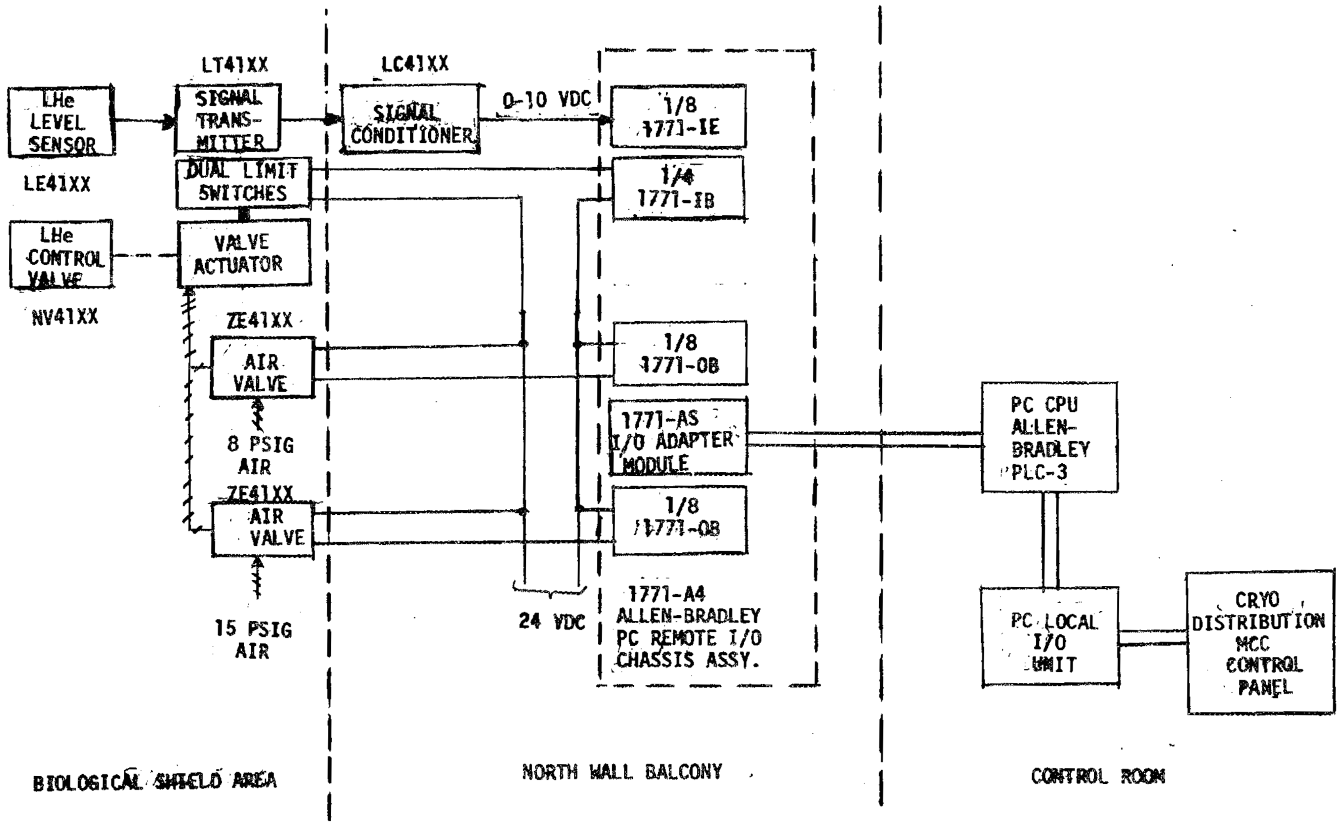


FIGURE 4.2.3–6 CRYOGENIC DISTRIBUTION CHANNEL DIAGRAM – LHe LEVEL CONTROL

e) 28 GHz distribution I & C interface (Sec. 4.2.4.5)
f) 60 GHz distribution I & C interface (Sec. 4.2.4.6)

The baseline EBT-P device design calls for two -28 GHz gyrotron tubes and six -60 GHz tubes. Each tube is powered by a separate ECRH power supply. The ERCH components contained in the Equipment List (Appendix A) reflect these numbers of gyrotrons and ECRH power supplies. Power supply and gyrotron tube conditioning operations are centered at the ECRH SCC units (see Sec. 4.1.8) and control of microwave power distribution to the plasma is centered at the ECRH MCC stations (see Sec. 4.1.7).

4.2.4.1 28 GHz Gyrotron Tube - Figure 4.2.4-1 shows a block diagram of the major components of a 28 GHz gyrotron tube. The diagram also shows the general physical relations between tube components and the direction of microwave power flow.

The gyrotron tube operates in a vertical orientation with the Oil Tank as its base. The Oil Tank/Pump serves the purposes of cathode cooling and high voltage stand-off. The Gun Cathode and Cathode Heater are immersed in the cooling oil. Above and around the cathode is the Gun Anode. The anode and its surrounding magnets are also located in the oil tank, however the gun magnets are water-cooled. The water-cooled Tube Body and its surrounding water-cooled Focusing Magnets are located above the gun. The top part of the tube itself is the Collector. The Collector is water-cooled and is surrounded by three air-cooled Collector Magnet Coils which are grouped into one single coil magnet and one double coil magnet. On the top of the collector are the beryllium oxide window and its seal. The window is cooled with FC-75 coolant and the seal is cooled with water.

The gyrotron has one accessory, the Vac-Ion pump. The Vac-Ion pump serves both to maintain the tube vacuum and to monitor the tube's internal pressure. It is designed for continuous operation and is left on even when the gyrotron is not in use.

Outside but associated with each gyrotron are the Microwave Leakage Detector and the Frequency Analyzer. Both of these units are part of the microwave system and output signals to the I & C system. The microwave leakage detector is located near, but be physically separated from the gyrotron. The frequency analyzer monitors the tube output via a

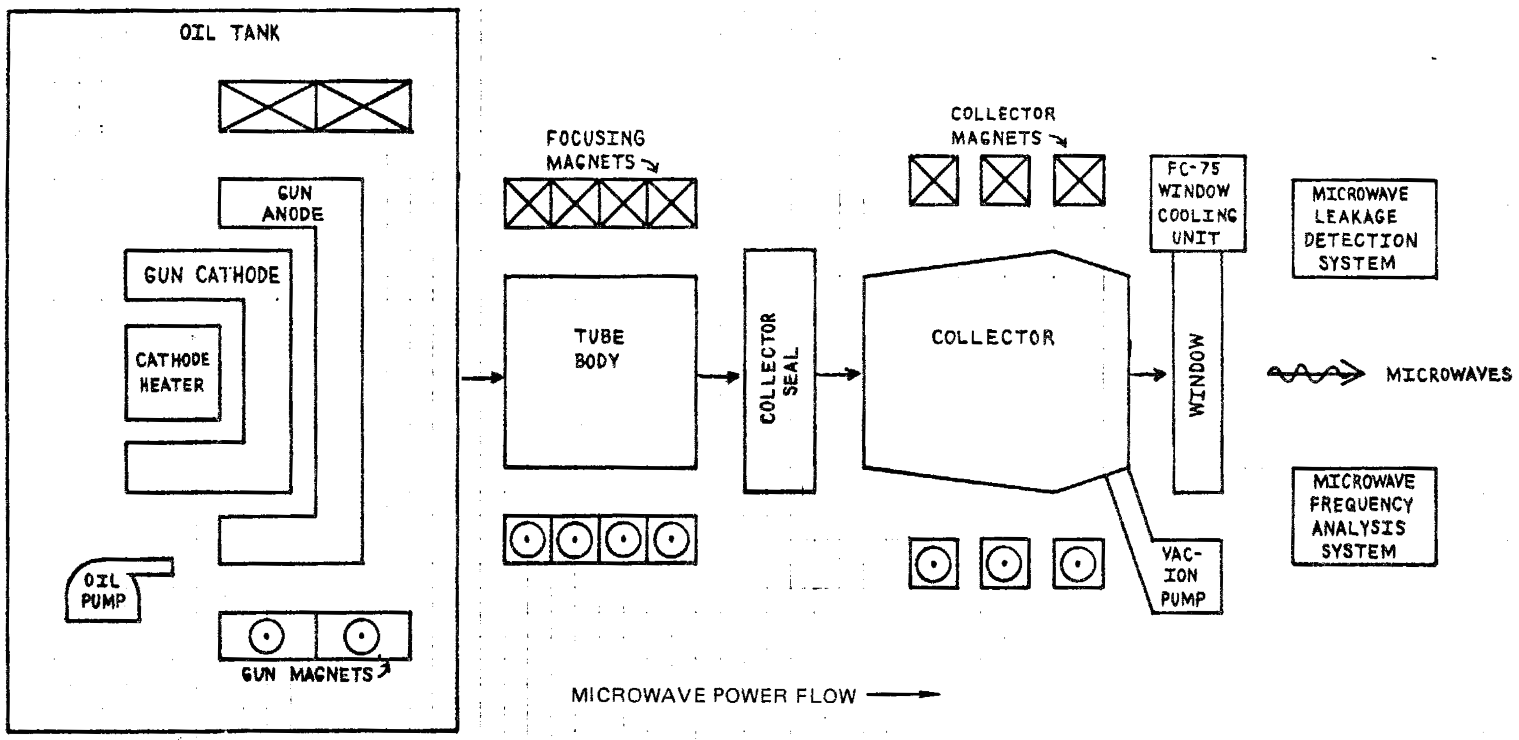


FIGURE 4.2.4-1 28 GHz GYROTRON TUBE—MAJOR COMPONENTS

dominant mode waveguide tap on the overmoded waveguide just outside the output window.

The instrumentation and control for each of the components shown in Fig. 4.2.4-1 are described in the following text and figures. The line labeled ECRH/I & C shows the interface between the ECRH system and the I & C system on each figure. Items above the line are to be part of and supplied with the ECRH system while items below the line are parts of the I & C Equipment List.

a) **Gyrotron Oil Tank/Pump** - The I & C signals to and from the Oil Tank/Pump are the following see Fig. 4.2.4-2:

Signal Name	Signal Type
Oil Level (LE)	Operating Condition - Data Input
Oil Flow (FS)	Interlock/Status Input
Oil Flow Rate (FE)	Operating Condition - Interlock Input
Oil Temperature (TS)	Interlock/Status Input
Oil Pump On/Off Status (ZE)	Interlock/Status Input
Oil Pump Control (C)	Command Output
Oil Pressure	Operating Condition - Data Input

Sensors for absolute temperature are used because the oil is circulated in an open system; differential temperature sensors would not be useful. Oil flow is monitored in three ways. A flow switch indicates to the PC interlock system that flow has been established. An oriface plate with a differential pressure flowmeter monitors the flow rate. Flow rate data is fed to the DAS. The combination of a flow switch and flow meter is used in all places where a liquid flow is monitored. The flow switch is part of the interlock system. The flowmeter data are available to the operators to backup the flowswitches, and in some cases the flowmeter data are used in conjunction with differential temperature monitors for the purpose of calorimetry. (See following sections on ECRH distribution system). Oil Pressure at the gyrotron indicates the pressure that the oil pump is working against and thus indicates whether or not the oil is actually flowing through the gyrotron.

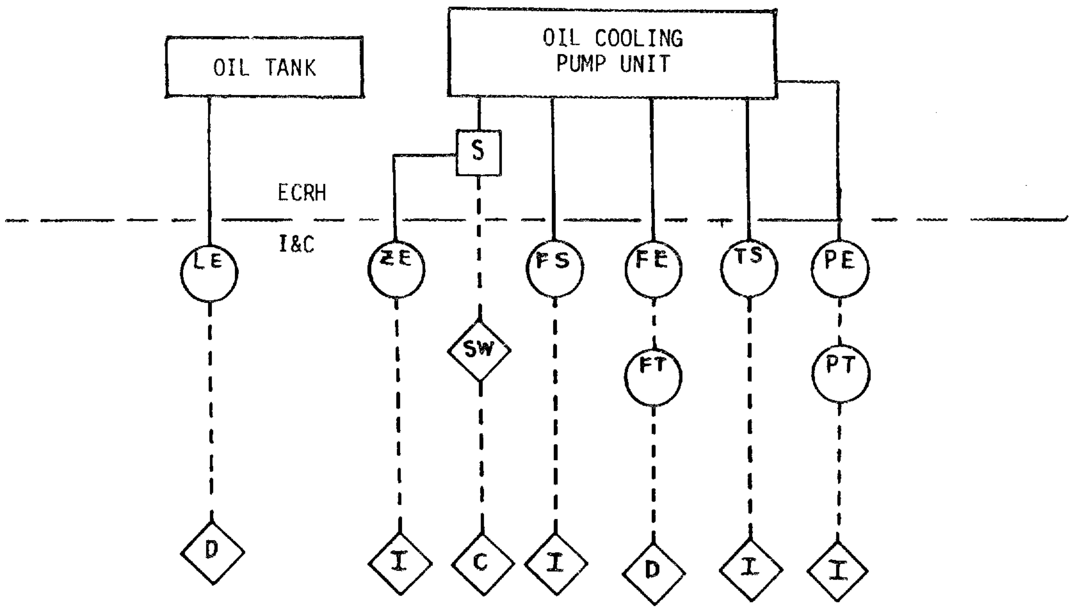


FIGURE 4.2.4–2 GYROTRON OIL-COOLING SYSTEM I&C INTERFACE

The oil pump has one monitor and one control. The pump is a single speed, immersible pump. Its control is a simple on/off signal and its monitor is a switch position monitor to indicate that power has been applied.

b) **Gyrotron Gun Cathode and Cathode Heater** - The Gun Cathode and Cathode Heater are presented here only for drawing consistency (Fig. 4.2.4-3). These have no monitors or controls and the monitors and controls for the power fed to them are discussed in the section on the 28 GHz power supply system I & C interface.

c) **Gyrotron Gun Anode and Gun Magnet** - The Gun Anode is shown for drawing consistency (Fig. 4.2.4-4). The Gun Magnet requires cooling water and electrical power. Cooling loop I & C consists of the following components:

Signal Name	**Signal Type**
Water Differential Temperature (TDE)	Operating Condition - Data Input
Water Flow Rate (FE)	Operating Condition - Interlock Input
Water Flow-Low (FSL)	Interlock/Status Input
Water Overtemp (TS)	Interlock/Status Input
On/Off Relay Status (ZE)	Interlock/Status Input
Control Valve (CV)	
Check Valve ( )	

The water differential temperature (ΔT) analog data are available to the operators for information and to backup the water overtemperature switch.

Water flow and flow rate are similar to the signals for the cathode oil cooling unit. Note that the flow switch and flow meter are at opposite ends of the loop with the flow switch at the outlet side. That insures that an indication of flow means the coolant is flowing through the component. The water cooling loops are shown separately for each coil for clarity. It is expected that these two parallel loops will actually be one series loop as on EBT-S.

The magnet system power I & C must meet the requirement for separate control of each

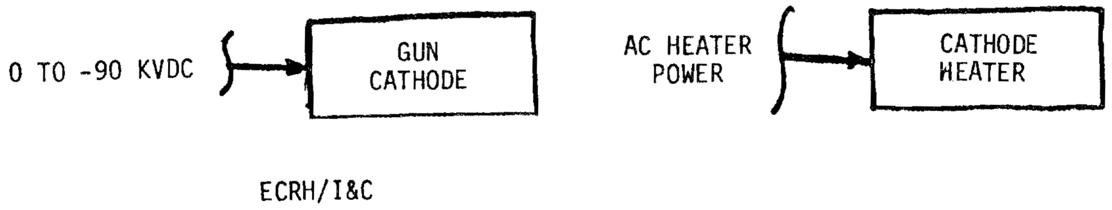


FIGURE 4.2.4–3 ECRH GUN CATHODE/HEATER I&C INTERFACE

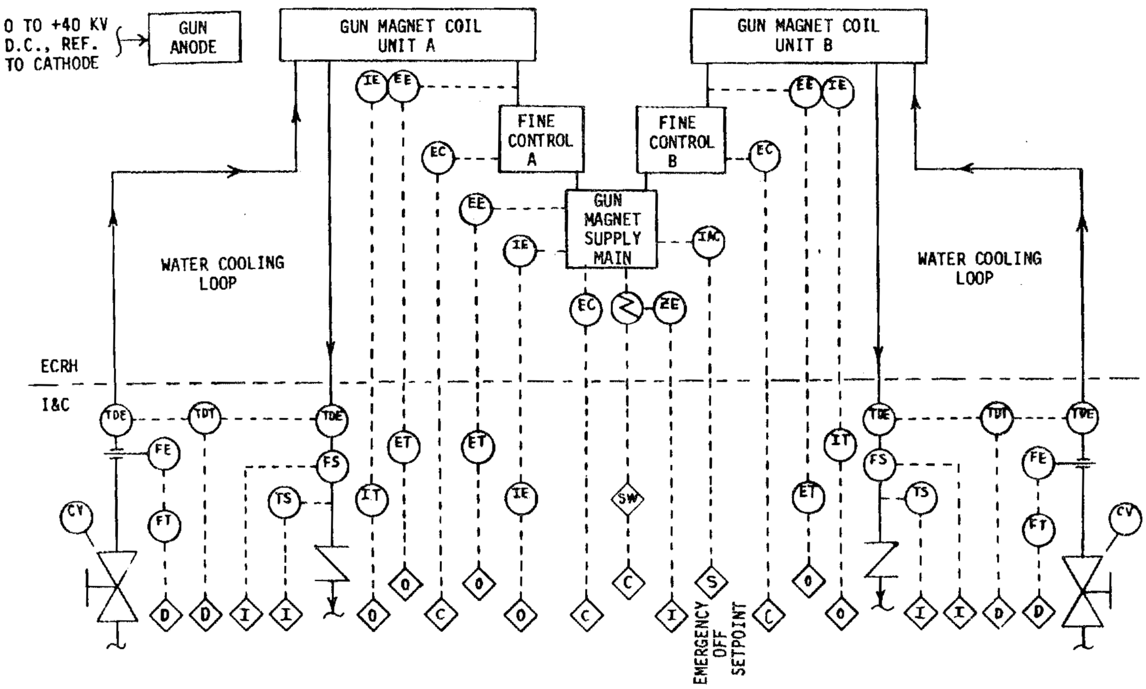


FIGURE 4.2.4–4 GUN MAGNET I&C INTERFACE

gun magent coil. The supply has a main stage and two fine control stages and the main stage has the following signals:

Signal Name	Signal Type
On/Off Control C	Command Output
Emergency Off Setpoint S	Setpoint - Output
Gun Magnet System Voltage Setpoint (EC)	Setpoint - Output
Gun Magnet System Voltage (EE)	Operating Condition - Interlock Input
Gun Magnet System Current (IE)	Operating Condition - Interlock Input

Each fine control stage has the following signals:

Signal Name	Signal Type
Gun Coil A (B) Voltage Setpoint (EC)	Setpoint Output
Gun Coil A (B) Voltage (EE)	Operating Condition - Interlock Input
Gun Coil A (B) Current (IE)	Operating Condition - Interlock Input

d) **Gyrotron Body -** The gyrotron tube body (Fig. 4.2.4-5) has no electrical connections that can be monitored. Under abnormal conditions, a large current could flow in the body. Such a current is detected by monitoring the difference between the input and output currents of the tube. This current is used by the crowbar trigger circuit, a hardwired unit supplied by the power supply vendor.

Because currents can flow in the tube body, it is necessary that the body be watercooled. This component has as the standard cooling loop instrumentation consisting of a flow switch, a flow meter, a ΔT, an overtemperature switch, an intake valve and a check valve.

e) **Focusing Magnet** - The instrumentation and control for the focusing magnet is identical to the gun magnet I & C except for the fact that there are four coils instead of two (Fig. 4.2.4-6). The only other difference between the two magnet systems is the power level.

f) **Gyrotron Collector** - Figure 4.2.4-7 shows the Gyrotron Collector I & C. The collector has a standard set of cooling loop instrumentation with one exception, the presence of an outlet control valve instead of a check valve. The exception is due to the large quantity of water which will flow through the collector.

The collector receives the entire beam current, therefore the collector current and voltage are monitored. Collector current data also goes to an ECRH subsystem, labeled CRB, which determines body current and outputs control signals to the beam and gun crowbars. The crowbar trigger circuits are supplied by the ECRH power supply vendor.

g) **Collector Magnets** - The collector magnets are low current devices which require only ambient air cooling (Fig. 4.2.4-8). Electrically the collector magnet coils are configured with one coil on one supply and two coils in series on the other supply. The supplies are single stage so each has only one set of voltage controls, voltage monitors and current monitors. Otherwise, the collector magnet I & C is similar to that for the other gyrotron magnet sets.

h) **Gyrotron Collector Seal and Gyrotron Output Window** - Figure 4.2.4-9 diagrams the instrumentation, control and cooling for the Gyrotron Output Window and the Collector Seal. The Collector Seal has no electrical connections. It is watercooled and utilizes a standard set of cooling loop instrumentation and controls. The Gyrotron Output Window has no electrical connections. It is cooled by FC-75 which, in turn, is watercooled. The FC-75 is circulated by a single speed pump through a cooling loop with the following instrumentation and control components:

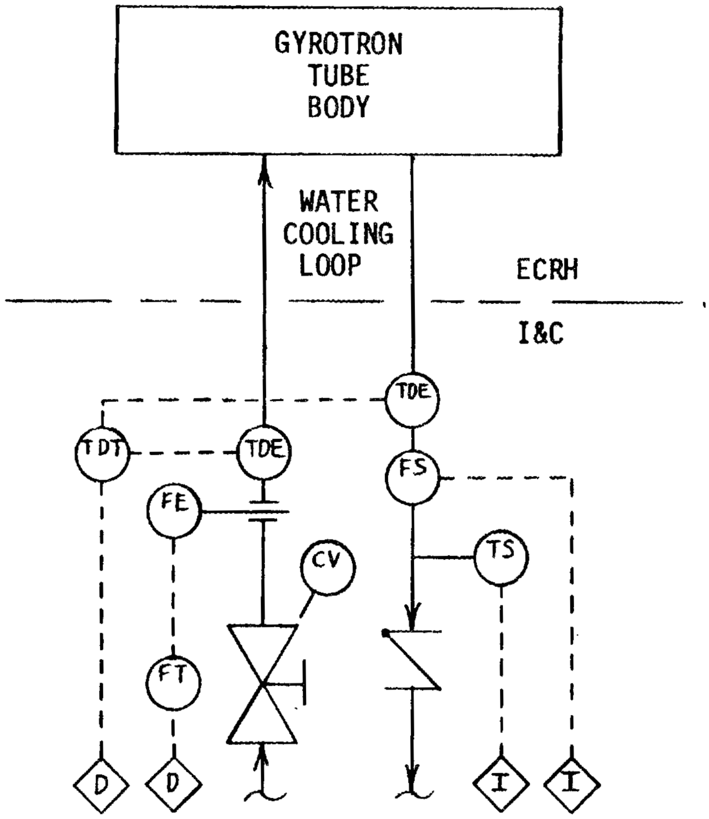


FIGURE 4.2.4–5 GYROTRON BODY I&C INTERFACE

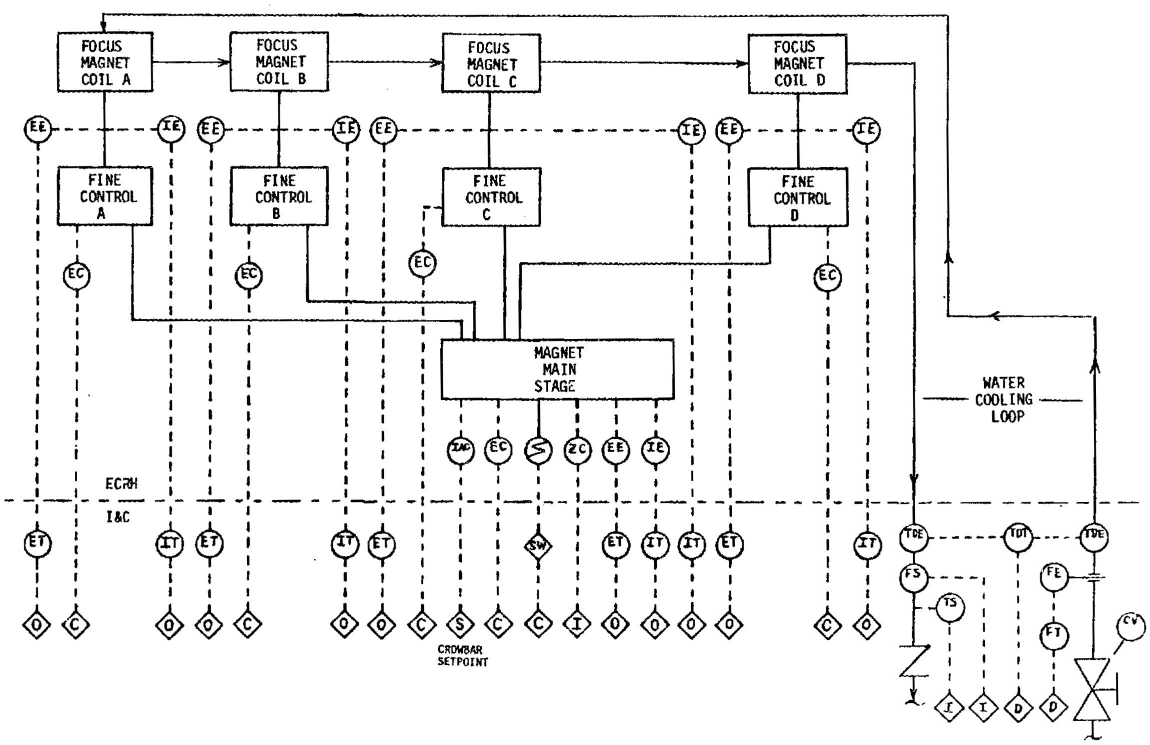


FIGURE 4.2.4–6 FOCUS MAGNET I&C INTERFACE

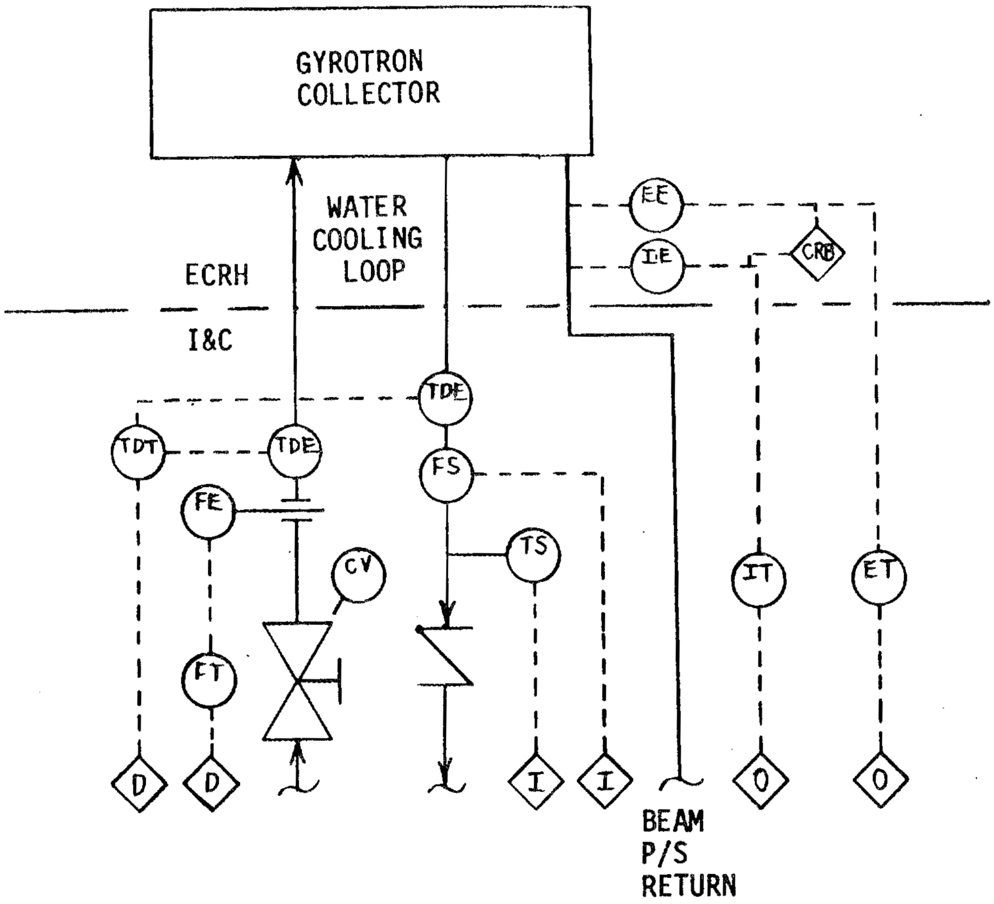


FIGURE 4.2.4–7 GYROTRON COLLECTOR I&C INTERFACE

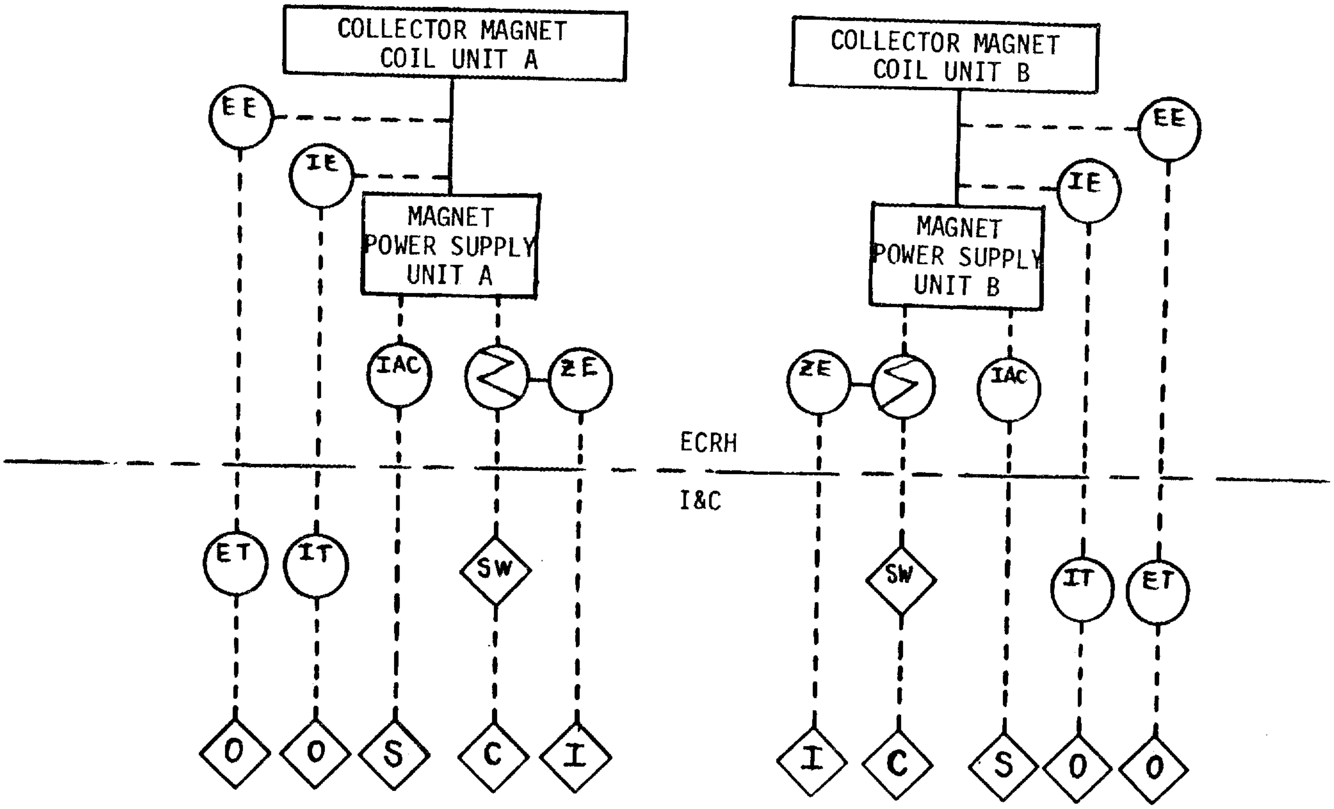


FIGURE 4.2.4–8 COLLECTOR MAGNET I&C INTERFACE

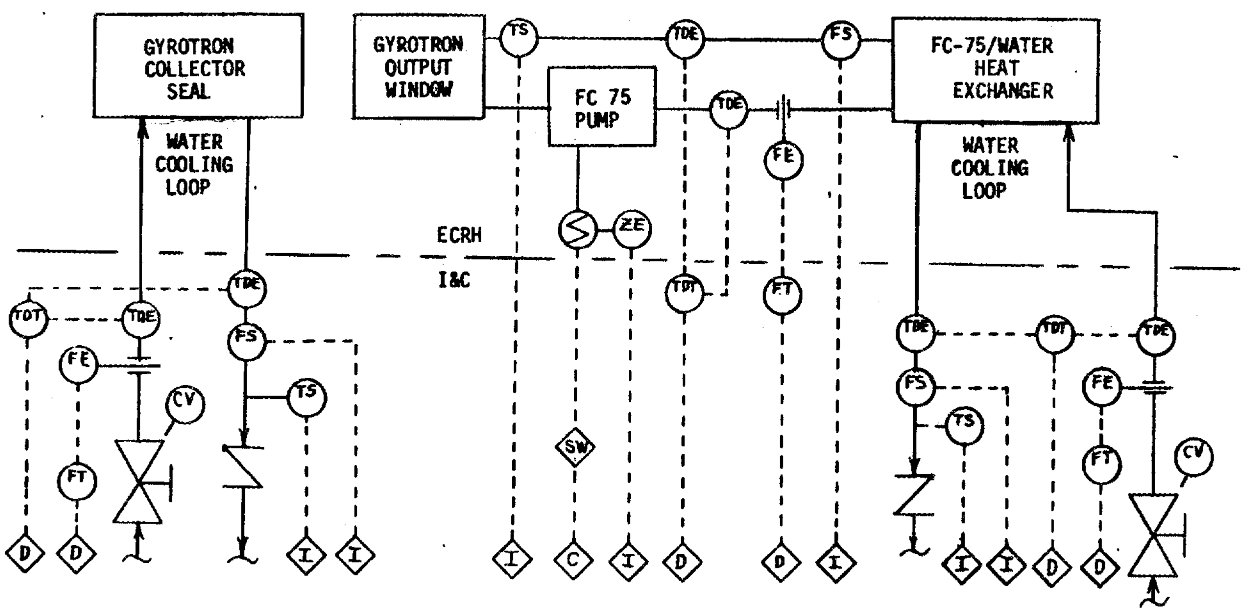


FIGURE 4.2.4–9 GYROTRON SEAL/WINDOW I&C INTERFACE

Signal Name	Signal Type
FC-75 Flow (FSL)	Interlock/Status Input
FC-75 Flow Rate (FE)	Operating Condition - Interlock Input
FC-75 ΔT (TDE)	Operating Condition - Data Input
FC-75 Temp Switch (TSH)	Interlock/Status Input
FC-75 Pump On/Off Status (ZE)	Interlock/Status Input
FC-75 Pump Control (C)	Command Output

Heat loss at the window is calculated from the FC-75 flow rate and ΔT. It is unnecessary to perform the same determination for the water in the FC-75/Water heat exchanger; it is only necessary to determine that the water is indeed cooling ther FC-75. Consequently, the water cooling loop for the heat exchanger has a standard set of cooling loop I & C which lacks the ΔT sensor and transmitter.

j) **Vac-Ion Pump, Leakage Detector and Frequency Analyzer -** The Vac-Ion Pump, Microwave Leakage Detector and Microwave Frequency Analyzer instrumentation and control components are diagrammed in Figure 4.2.4-10.

The Vac Ion Pump interfaces with the I & C system through a Vac Ion Pump Controller both of which are supplied by Varian, Inc. The Ion Pump Controller has the following instrumentation and control:

Signal Name	Signal Type
Gyrotron Tube Pressure (IE)	Operating Condition - Interlock Input
Vac Ion Pump On/Off Status (ZE)	Interlock/Status Input
Vac Ion Pump On/Off Control (C)	Command Output

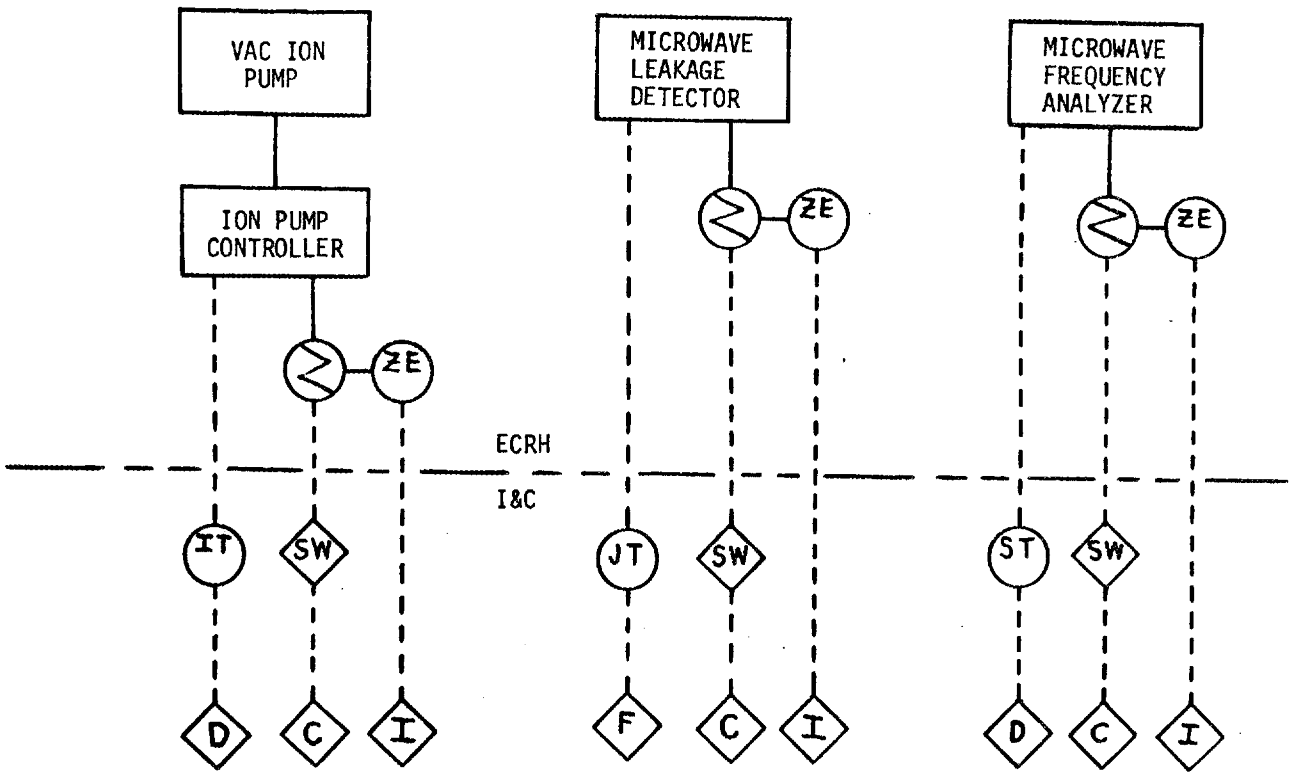


FIGURE 4.2.4–10 GYROTRON PUMP/LEAKAGE DETECTOR I&C INTERFACE

The Microwave Leakage Detector has the following instrumentation and control:

Signal Name	Signal Type
Microwave Leakage Warning (JT)	Warning/Alarm Input
Microwave Leakage Detector On/Off Status (ZE)	Interlock/Status Input
Microwave Leakage Detector Control (C)	Command Output

The Microwave Frequency Analyzer has the following instrumentation and control:

Signal Name	Signal Type
Frequency (ST)	Operating Condition - Data Input
Frequency Analyzer On/Off Status (ZE)	Interlock/Status Input
Frequency Analyzer On/Off Control (C)	Command Output

k) **Gyrotron Cooling Water** - All the gyrotron watercooled loops are fed from and return to a main manifold system (Fig. 4.2.4-11). Each set of gyrotron cooling loops receives its water from a supply manifold via a large three way valve and sends water to the return manifold via a similar valve. In parallel with a gyrotron cooling system there is a bypass loop which has pressure and flow characteristics similar to a gyrotron cooling system. The three way valves will have the following states:

Fully Closed
All water to Gyrotron
All water to Bypass

The operation of the two valves is synchronized and both are dampened to prevent a water hammer effect. The valves have the following instrumentation and control:

Signal Name	Signal Type
Water Feed Valve Position (ZE)	Interlock/Status Input
Water Feed Valve Control (C)	Command Output
Water Return Valve Position (ZE)	Interlock/Status Input
Water Return Valve Control (C)	Command Output

4.2.4.2 60 GHz Gyrotron Tube - Figure 4.2.4-12 shows a block diagram of the major components of a 60 GHz gyrotron tube. The diagram also shows the general physical relations between tube components and the direction of microwave power flow.

It will be noted that Figure 4.2.4-12 for the 60 GHz tube and Figure 4.2.4-1 for the 28 GHz tube are identical. Physically the two gyrotron tubes are so similar that the same description will almost completely characterize both. Because of the similarities, most of this description for the 60 GHz tube will be referenced to the 28 GHz description with the differences emphasized. In point of fact, the only difference between the 60 GHz and the 28 GHz tube that effects the I & C system is the fact that the 60 GHz gyrotron utilizes a superconducting focusing magnet instead of a normal magnet. This difference is discussed in subsection (e) below.

a) **Oil Tank/Pump, 60 GHz** - I & C, for this component, are identical to that for the 28 GHz Oil Tank/Pump. Reference Section 4.2.4.1 and Fig. 4.2.4-2.

b) **Gyrotron Gun Cathode and Cathode Heater, 60 GHz** - I & C, for these components, are identical to those for the 28 GHz Gyrotron Gun Cathode and Cathode Heater. Reference Section 4.2.4.1 and Fig. 4.2.4-3.

c) **Gyrotron Gun Anode and Gun Magnet, 60 GHz** - I & C, for these components, are identical to those for the 28 GHz Gyrotron Gun Anode and Gun Magnet. Reference Section 4.2.4.1 and Fig. 4.2.4-4.

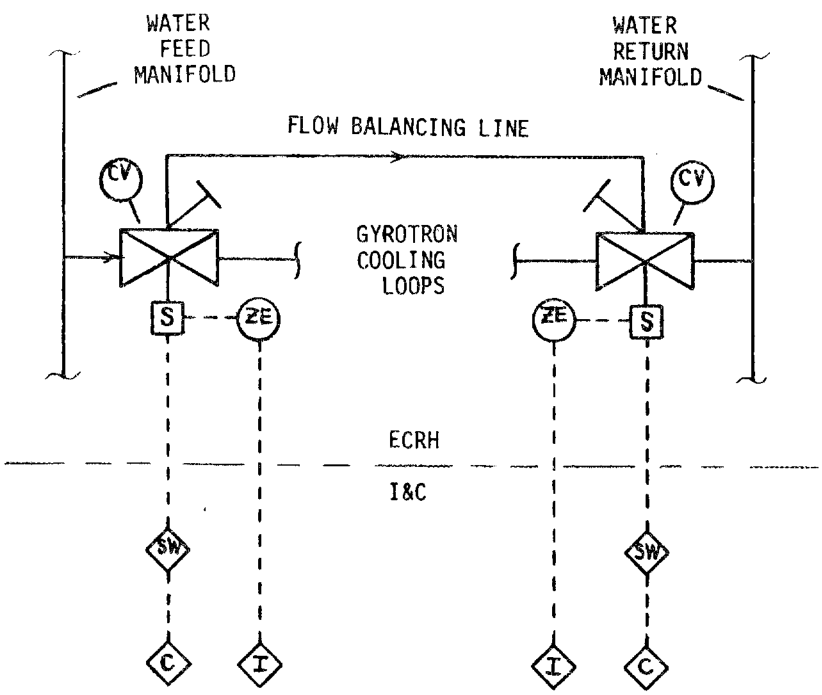


FIGURE 4.2.4–11 ECRH/I&C INTERFACE – MAIN GYROTRON COOLING LOOP

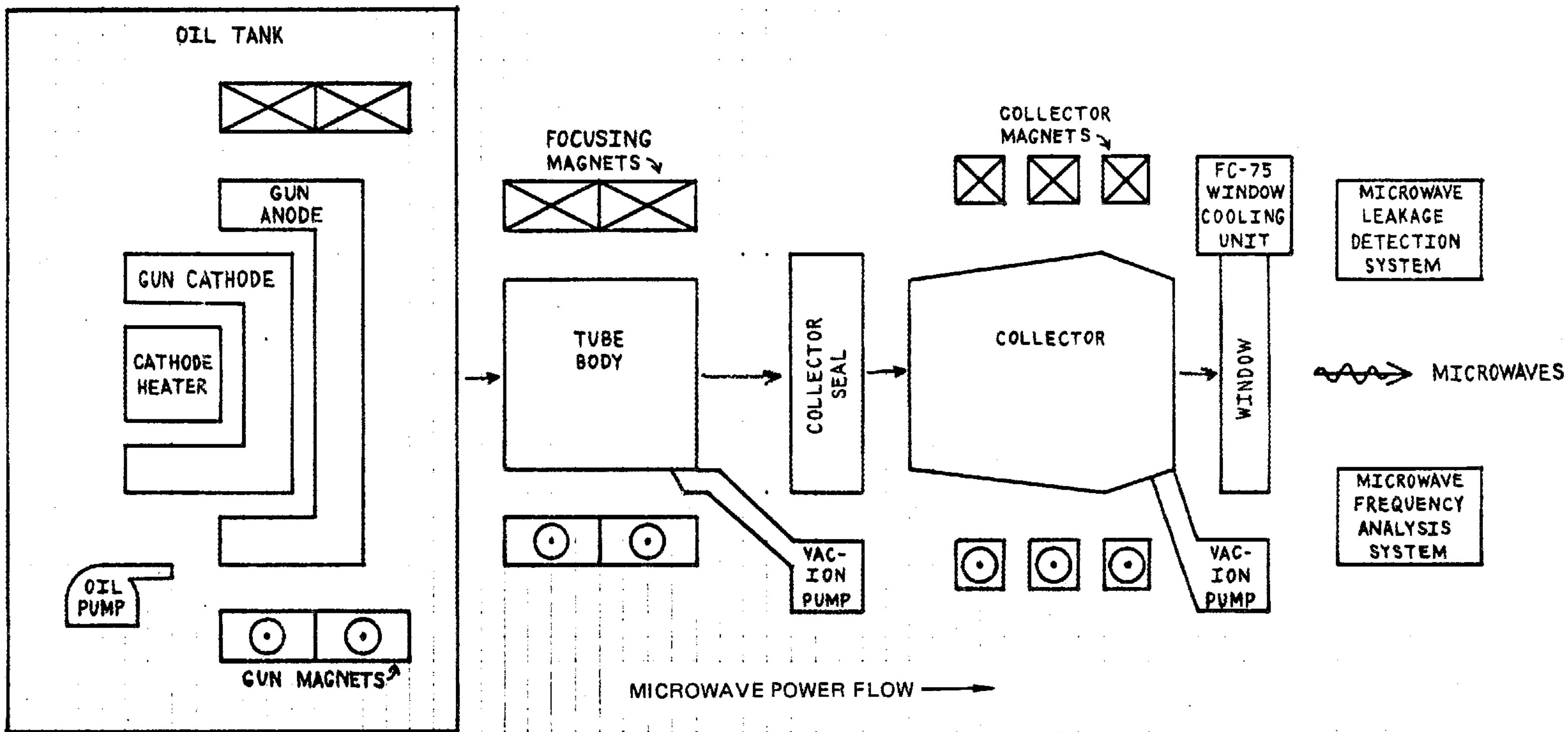


FIGURE 4.2.4–12 60 GHz GYROTRON TUBE – MAJOR COMPONENTS

d) **Gyrotron Body, 60 GHz** - I & C, for this component, are identical to that for the 28 GHz Gyrotron Body. Reference Section 4.2.4.1 and Fig. 4.2.4-5.

e) **Focusing Magnet Interfaces, 60 GHz** - Figure 4.2.4-13 diagrams the fact that the focusing magnet for the 60 GHz gyrotron interfaces with three components of the I & C subsystem. The superconducting magnet has interfaces with the ECRH the Vacuum, and the Cryogenics systems. The details of these interfaces are discussed in sections 4.2.2 and 4.2.3.

f) **Focusing Magnet, 60 GHz** - This interface involves only the power supplies required to operate the 60 GHz focus magnets and is similar to the corresponding 28 GHz interface (Fig. 4.2.4-14). The cryogenic and vacuum system intefaces to the 60 GHz focus magents are not part of this ECRH interface; rather the former interfaces are I & C/cryogenic and I & C/vacuum interfaces described in sections 4.2.3 and 4.2.2, respectively. Note that the magnet main stage is equipped with a crowbar set-point input channel. This set point is used by the focus magnet Quench Protection Circuit to operate the crowbar should quench occur.

g) **Gyrotron Collector, 60 GHz** - I & C for this component are identical to that for the 28 GHz Gyrotron Collector. Reference Section 4.2.4.1 and Fig. 4.2.4-7.

h) **Collector Magnet, 60 GHz** - I & C for this component are identical to that for the 28 GHz Collector Magnet. Reference Section 4.2.4.1 and Fig. 4.2.4-8.

j) **Gyrotron Collector Seal and Gyrotron Output Window, 60 GHz** - I & C for these components are identical to those for the 28 GHz Gyrotron Collector Seal and Gyrotron Output Window. Reference Section 4.2.4.1 and Fig. 4.2.4-9.

k) **Vac-Ion Pump, Microwave Leakage Detector and Microwave Frequency Analyzer, 60 GHz** - I & C for these components are identical to those for the 28 GHz gyrotron Vac-Ion Pump, Microwave Leakage Detector, and Microwave Frequency Analyzer. Reference Section 4.2.4.1 and Fig. 4.2.4-10.

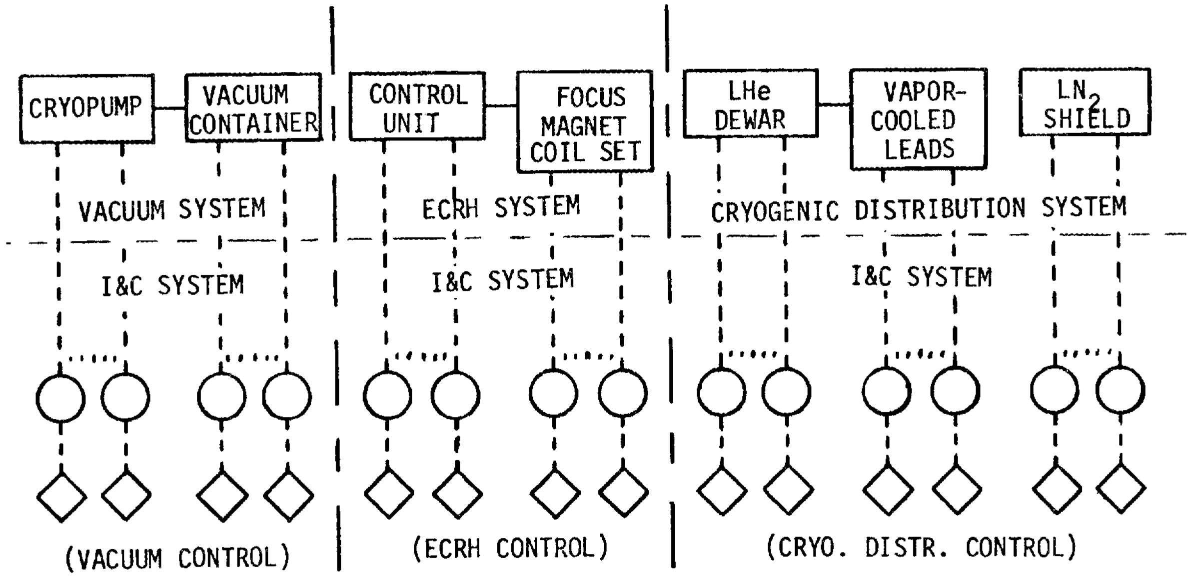


FIGURE 4.2.4–13 60 GHz FOCUS MAGNET I&C INTERFACE

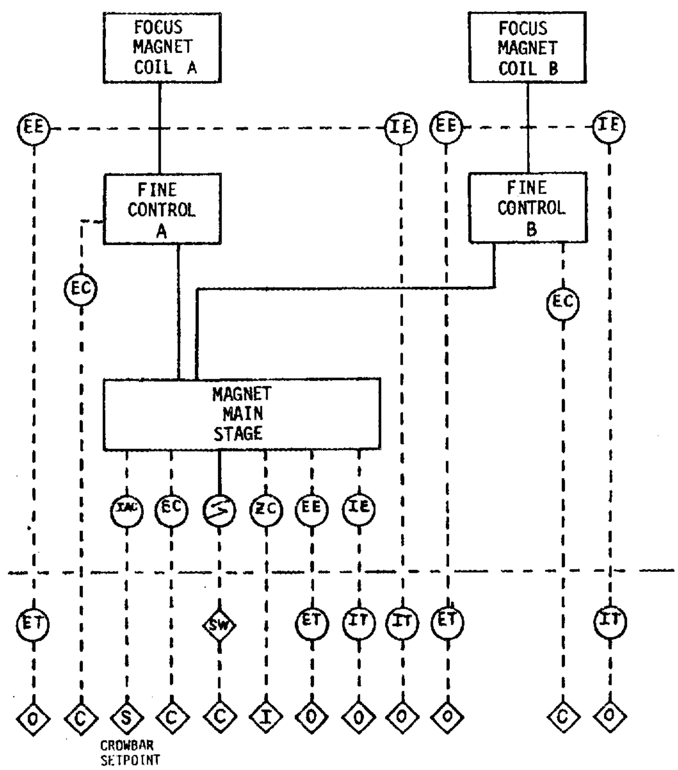


FIGURE 4.2.4–14 60 GHz MAIN FOCUS MAGNET I&C INTERFACE

l) **Gyrotron Cooling Loops, Water, 60 GHz** - I & C for this component are identical to that for the 28 GHz Gyrotron Cooling Loops. Reference Section 4.2.4.1 and Fig. 4.2.4-11.

4.2.4.3 Gyrotron Power Supply I & C, 28 GHz - A block diagram of the power supply for a 28 GHz gyrotron is presented in Figure 4.2.4-15. The power supply is divided into two main sections; that fed by 13.8 KV 3ϕ 60 Hz AC and that fed by the 460 V AC 3ϕ 60 Hz power. Only the gyrotron beam supply is powered from the 13.8 KV; the 460 V power is supplied to four systems: the gyrotron gun, the gyrotron cathode heater, the DC control power, and the AC control power. The high voltage busses feed two identical 28 GHz gyrotron supplies in the EBT-P facility. Only one supply is shown.

28 GHz Gyrotron Beam Supply - The gyrotron beam supply consists, in order from input to output, of a 3ϕ high voltage contactor, an induction voltage regulator, a 3ϕ high voltage vacuum interruptor, a transformer, rectifier and filter T/R/F assembly, and an ignitron-based crowbar circuit. The high voltage for the beam is produced in stages. The IVR takes the 3ϕ, 13.8 KV input and outputs a 3ϕ, 0 to 25 KV output. The transformer/regulator/filter is a 1:4 transformer and rectifier which takes the 0 to 25 KV 3ϕ power and outputs 0 to 100 KV DC power.

28 GHz Gyrotron Gun Supply - The gyrotron gun supply consists of a 3ϕ contactor, a 3ϕ Powerstat, a transformer/rectifier and filter assembly, an ignitron based crowbar circuit, and a series regulator tube. As with the beam supply, the task of producing the gun high voltage is divided between the power stat and the TRF. The details of that task will be determined by the power supply vendor.

Other Power Supply Branches - The remaining power supply branches are straightforward with one exception: the Automatic Gun Voltage Controller is not a basic branch. It is shown for consistancy with the detailed drawings which follow and is shown with the DC control power.

ECRH PS/I & C Interface Assumptions - Control of this high voltage power supply is accomplished at two levels. The first level is a set of hard-wired sensors and controls which are suppliied by the power supply vendor. The second level consist of the MDAC-supplied

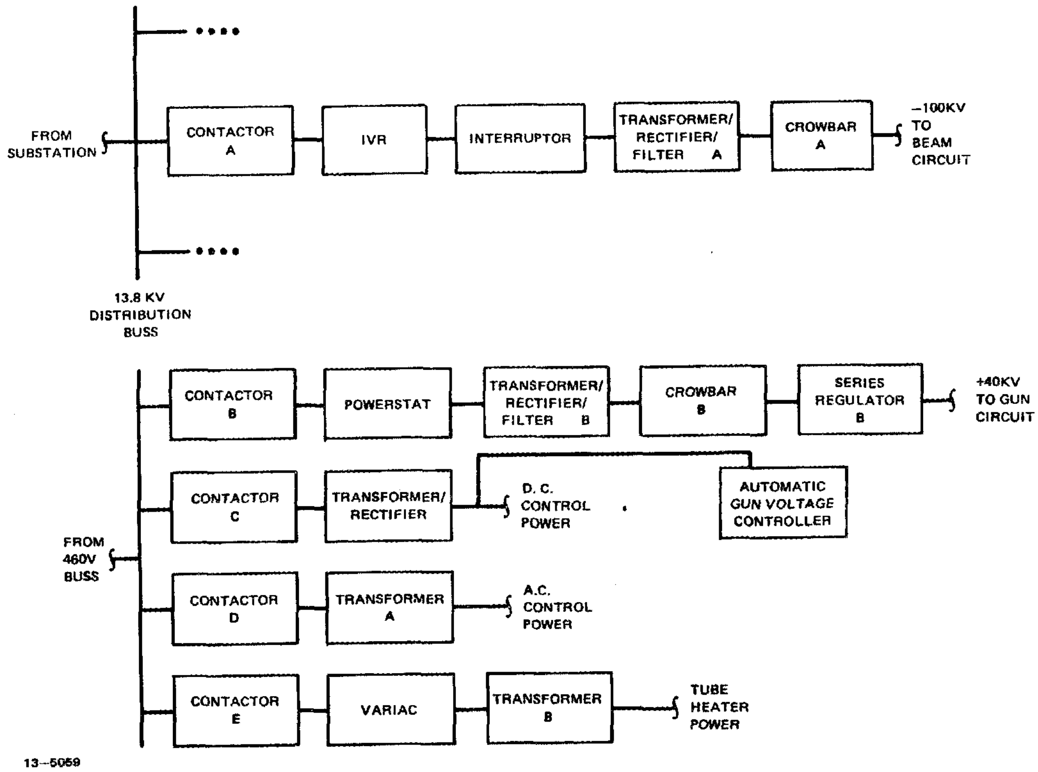


FIGURE 4.2.4–15 GYROTRON POWER SUPPLY BLOCK DIAGRAM – 28 GHz

process controllers. The reasons for the existance of each of the two levels are the following. The level of hard-wired controls exists because many of the emergency control features of a high voltage supply must operate on time spans on the order of microseconds. That can be best accomplished by dedicated, hard-wired controls. The level of process controller controls exists because normal start-up, operation and shut-down of the system can be controlled at a slower pace. The process controller per se is desirable because it allows sets of subsystems to be easily synchronized and it allows the operational control of the subsystems to be easily altered as the needs of the experiment change.

The presence of the two levels of control has allowed the gyrotron power supply I & C system to be designed according to the following criterion: All signals required by the P.C. are signals required by the hardwired control system. All control signal produced by the P.C. are used by the hardwired control system.

The above criteria allows the power supply vendor to design a fast and efficient hardwired power supply control system according to well-known principles. These controls responsible for personnel and equipment safety within a supply. The power supply vendor is required to condition some of the signals collected by the hard-wired system for transmission to the PC. The PC system integrates the operation of an individual supply with the rest of the EBT-P device/facility. It is responsible for overall normal operation of the power supply and is responsible for system safety interlocks and safety-and emergency-related shut-downs initiated outside the power supply. Control commands from the PC are accepted by the hard-wired control system provided by the vendor.

It will be noted in the following detailed diagrams, that the majority of the signal sensors and transmitters as well as the control actuators are the responsibility of the power supply vendor, as specified by the basic criterion of the power supply I & C design. It will also be noted that details of the hard-wired and PC control systems are not provided here. Only the signals to be used are shown. Details of the hard-wired control system are the responsibility of the power supply vendor. Details of the PC system consist largely of PC software and hardware (Sec. 4.1.6).

The set of instrumentation and control signals utilized in the power supply I & C system is one which is sufficient to locate and clear a fault at any major component. Redundancy in the fault-locating and clearing exists in that multiple sense points exist from input to output within a supply and multiple points exist at which a supply branch can be opened. As noted above, fault-clearing within a supply is performed by the hard-wired control system which is continuously monitored by the PC. Faults may be cleared by opening any of the contactors, via the modulating series regulator tubes or by operating the crowbar circuitry (designated CRB in the detailed drawings). All of the fault-clearing devices may be operated by the PC in the event of problems outside the supply which require its shutdown or if the hard-wired controls fail to operate.

All components which are temperature-sensitive are also monitored. In addition, all cooling loops have the standard instrumentation and control as defined in Section 4.2.4.1, unless specified otherwise.

The signals monitored are selected to be sufficient to characterize the power supply during normal operation, given that which is defined as "normal operation" may change as the EBT-P Phase III work progresses. It is recognized that this is an expensive system. A cost-benefit study will be used to guide the detail Title II design.

a) **13.8 KV Power Input and Contactor, 28 GHz Gyrgtron Supply** - Figure 4.2.4-16 shows components that are common to the entire ECRH system and components that are unique to each supply. The voltage and current sensors shown to the left of the 13.8 KV Distribution Buss appear on more than one drawing of power inputs, but for clarity only. There is actually only one set of 3ϕ input monitors for the entire ECRH system which indicate that input power is present and that no large current faults exist on the buss. The 13.8 KV Distribution Buss feeds high voltage power to both 28 GHz supplies and all (4 baseline, 6 upgrade) 60 GHz supplies.

The 13.8 KV Contactor is a 3ϕ contactor. It can be manually opened and closed and it can be solenoid-opened by the control system. The position sensors consist of two separate sensors for each phase; a sensor to record that the contact is open and one to record that is closed. Thus a positive indication will be given for each condition.

Following the contactor are voltage and current monitors for each phase. Those sensors indicate the presence of power and its state. The voltage and current are analog signals con-

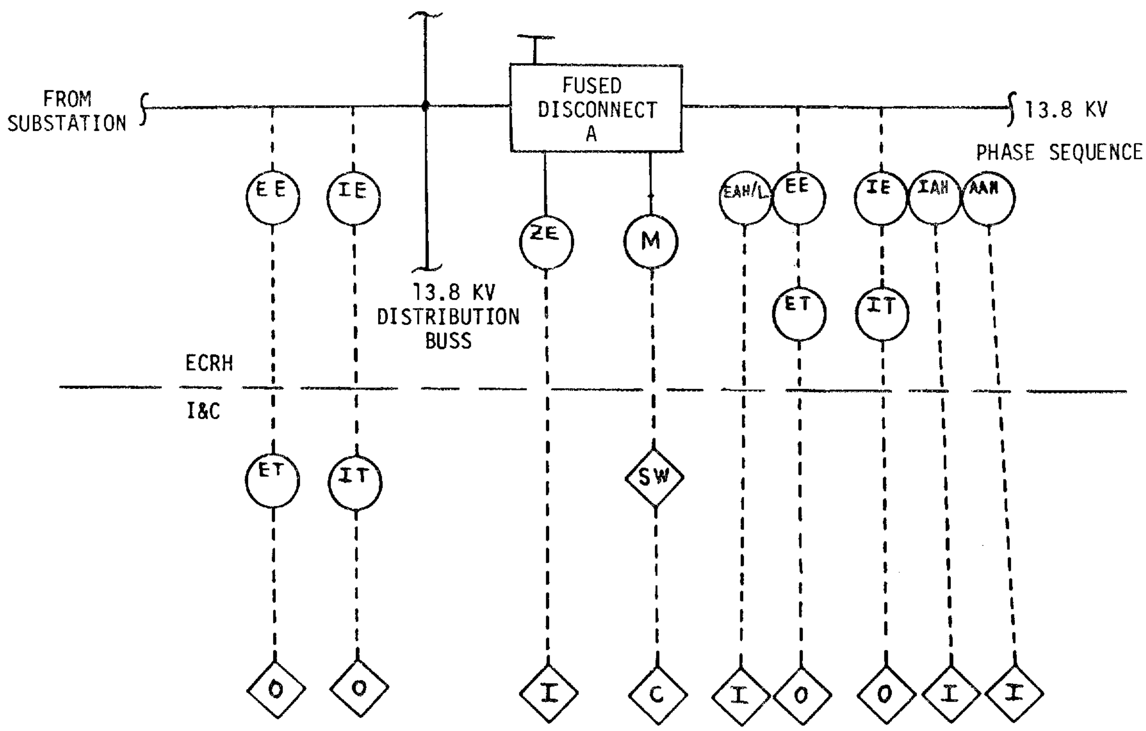


FIGURE 4.2.4–16 28 GHz POWER SUPPLY-FUSED DISCONNECT A I&C INTERFACE

verted to 4-20 ma signals and forwarded to the I & C system. The voltage exception signals are be a series of contact closures to indicate the following:

Voltage High Warning (3ϕ)	Interlock/Status Input
Voltage Normal (3ϕ)	Interlock/Status Input
Voltage Low Warning (3ϕ)	Interlock/Status Input

All parameter exception signals such as those above are used simultaneously by the hard-wired and PC control systems.

Current has five exception signals, produced by contact closures. Four of the signals are Current High Warning for each phase and neutral. The remaining signal is the warning signal from a hard-wired device to monitor for out-of-balance and reversed phases.

Each voltage and current Warning exception have an associated Caution exception. The Caution exception are generated by the PC from the analog signal.

b) **Induction Voltage Regulator I & C, 28 GHz** - Instrumentation and Control for the IVR are shown in Figure 4.2.4-17. An IVR is a type of variable, 3ϕ transformer filled with oil and dry nitrogen. Therefore, it is necessary to monitor the level and temperature of the oil, coil temperature, and pressure relief status.

Since the acceptable parameter ranges for the IVR are known and will not vary with the experiment, the vendor will provide both Warning and Caution signals for the oil level, oil temperature and coil temperature. Thus the IVR has the following I & C:

Signal Name	Signal Type
IVR Oil Level High Warning (LAH)	Interlock/Status Input
IVR Oil Level High Caution	Interlock/Status Input
IVR Oil Level Normal	Interlock/Status Input
IVR Oil Level Low Caution	Interlock/Status Input
IVR Oil Level Low Warning	Interlock/Status Input
IVR Oil Temp High (TAH)	Interlock/Status Input

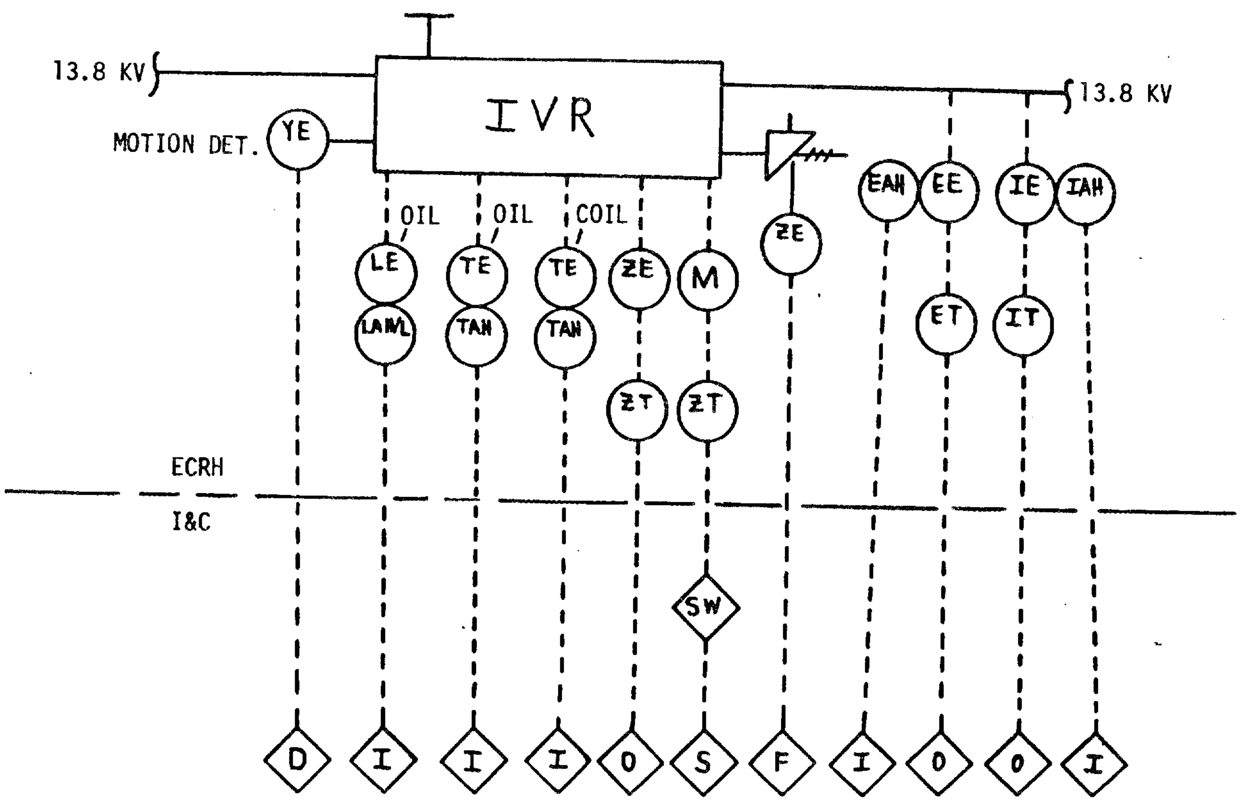


FIGURE 4.2.4–17 ECRH/I&C INTERFACE – INDUCTION VOLTAGE REGULATOR

Signal Name	Signal Type
IVR Oil Temp High Caution	Interlock/Status Input
IVR Oil Temp Normal	Interlock/Status Input
IVR Coil Temp High Warning	Interlock/Status Input
IVR Coil Temp High Caution	Interlock/Status Input
IVR Coil Temp Normal (TE)	Interlock/Status Input
IVR Position Monitor (ZE)	Operating Condition-Interlock Input
IVR Position Control S	Command Output
IVR Motion Up (YE)	Interlock/Status Input
IVR Motion Down (YE)	Interlock/Status Input
IVR Pressure Relief Status (ZE)	Interlock/Status Input

The following signals are monitored at the IVR output:

Signal Name	Signal Type
IVR Output Voltage (EE) (3 phase)	Operating Condition - Interlock Input
IVR Output Voltage High (EAH) Warning (3 phases)	Interlock/Status Input
IVR Output Current (IE) (3 phase + neutral)	Operating Condition - Interlock Input
IVR Output Current High (IAH) Warning (3 phase + neutral)	Interlock/Status Input

c) **Vacuum Interruptor I & C, 28 GHz Gyrgtron Supply-** The Vacuum Interruptor has the following I & C components (Fig. 4.2.4-18):

Signal Name	Signal Type
Interruptor Temp High Warning	Interlock/Status Input
Interruptor Temp High Caution	Interlock/Status Input
Interruptor Position Status (3 phase, open & closed)	Interlock/Status Input
Interruptor Position Control	Command Output

Following the interruptor are:

Signal Name	Signal Type
Interruptor Output Voltage (3 phase) (EE)	Operating Condition - Interlock Input
Interruptor Output Current (3 phase + neutral) (IE)	Operating Condition - Interlock Input

Note that the crowbar control circuit also has inputs (CRB) to the vacuum interruptor to deenergize the system after a crowbar firing, if necesary. Whether the interruptor opens is dependent upon which subsystems (beam, gun or body current sense) initiates a beam crowbar trip.

d) **Transformer/Rectifier/Filter I & C, Beam Supply, 28 GHz Gyrotron Supply** - Figure 4.2.4-19 shows the instrumentation on and following the Transformer/Rectifier/Filter unit for the beam. The beam T/R/F has the following I & C:

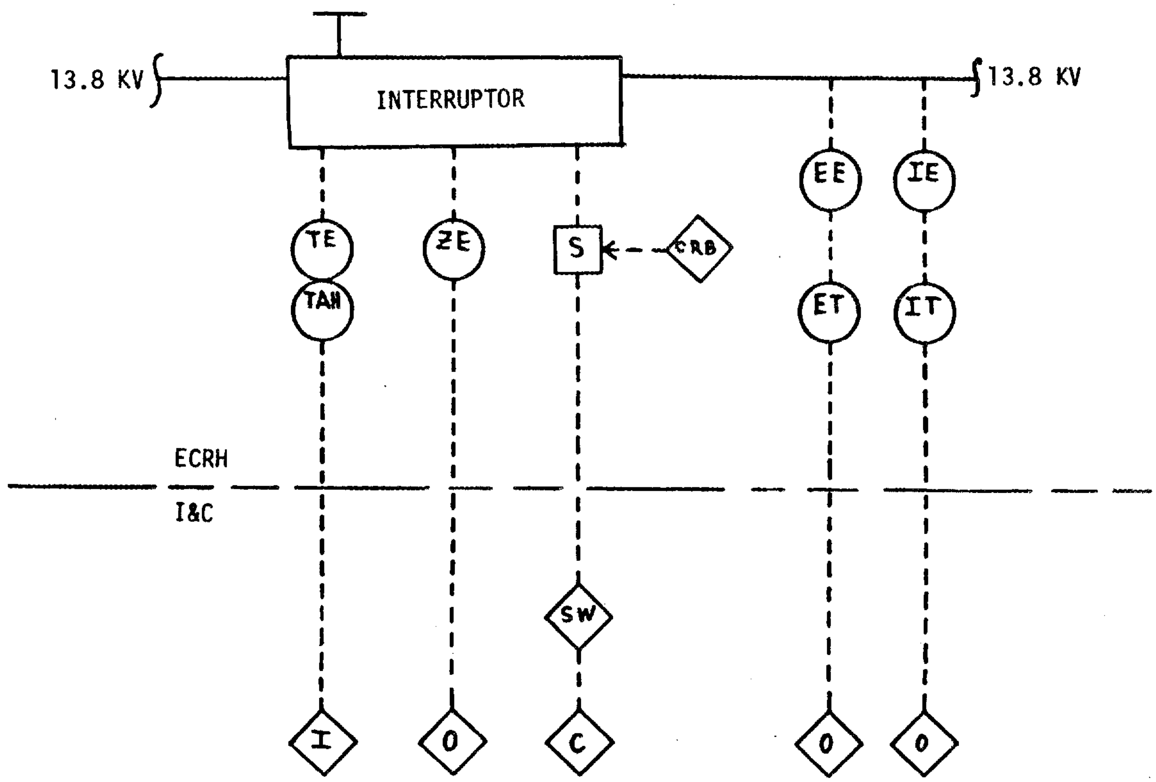


FIGURE 4.2.4–18 ECRH/I&C INTERFACE – VACUUM INTERRUPTOR

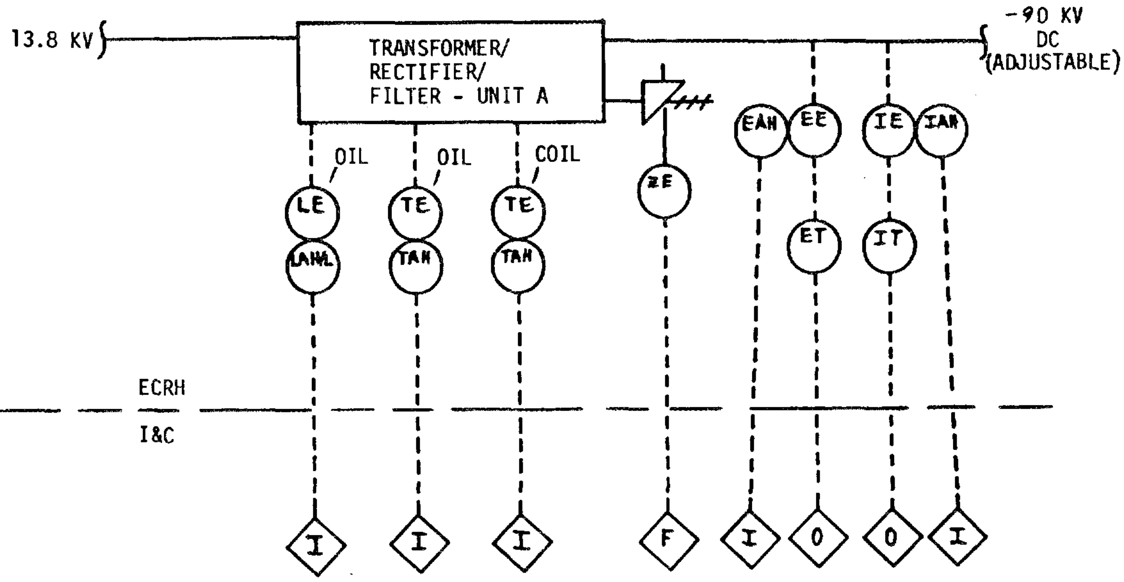


FIGURE 4.2.4–19 28 GHz POWER SUPPLY I&C INTERFACE – TRANSFORMER/RECTIFIER/FILTER – UNIT A

Signal Name	Signal Type
T/R/F Oil Level High Warning (LAH)	Interlock/Status Input
T/R/F Oil Level High Caution	Interlock/Status Input

Signal Name	Signal Type
T/R/F Oil Level Normal	Interlock/Status Input
T/R/F Oil Level Low Caution	Interlock/Status Input
T/R/F Oil Level Low Warning (LAL)	Interlock/Status Input
T/R/F Oil Temp High Warning (TAH)	Interlock/Status Input
T/R/F Oil Temp High Caution	Interlock/Status Input
T/R/F Oil Temp Normal	Interlock/Status Input
T/R/F Coil Temp High Warning (TAH)	Interlock/Status Input
T/R/F Coil Temp High Caution	Interlock/Status Input
T/R/F Coil Temp Normal	Interlock/Status Input
T/R/F Pressure Relief Status (ZE)	Interlock/Status Input

Following the T/R/F are:

Signal Name	Signal Type
T/R/F Voltage (EE)	Operating Condition - Interlock Input
T/R/F Voltage High Warning (EAH)	Interlock/Status Input

Signal Name	Signal Type
T/R/F Current (IE)	Operating Condition - Interlock Input
T/R/F Current High (IAH) Warning	Interlock/Status Input

e) **Beam Crowbar, 28 GHz Gyrotron Supply** - The last component in the 28 GHz beam supply is the Beam Crowbar Fig. 4.2.4-20. The local current sensing for the Crowbar is self-contained. The Crowbar also responds to commands from the Crowbar Trigger Circuit and the PC via the trigger circuit. The Crowbar Trip Setting is established by the PC. The Crowbar also sends status signals to the trigger circuit and the PC. Thus, its operation is integrated with the other supply crowbar, the contactors, the tube body current and, via the PC, with other parts of the EBT-P device.

The crowbar is based on an ignitron tube circuit. The ignitron requires cooling and it requires heating to maintain the proper internal mercury vapor pressure. The heating and cooling are both mediated by forced oil. The heating oil is warmed by electrically-heated air. The cooling oil is cooled by water.

The oil heating loop has an overtemp switch at the ignitron input to make sure that the oil is not overheated. At the outlet are temp switches to determine if the ignitron is within its operating temperature range. A flow switch determine that oil has flowed through the ignitron and a flow meter determine that oil has flowed through the heat exchanger and measures the flow rate. The oil pump is single speed with an on/off control and a switch position monitor. The air system has a single speed fan with an air flow switch to determine the presence of flow. The heating element has an on/off control and a current switch to determine the presence of heater current.

The oil cooling loop has standard cooling-loop instrumentation. The water loop has a solenoid controlled inlet valve, a check valve at the output and a flow switch at the outlet.

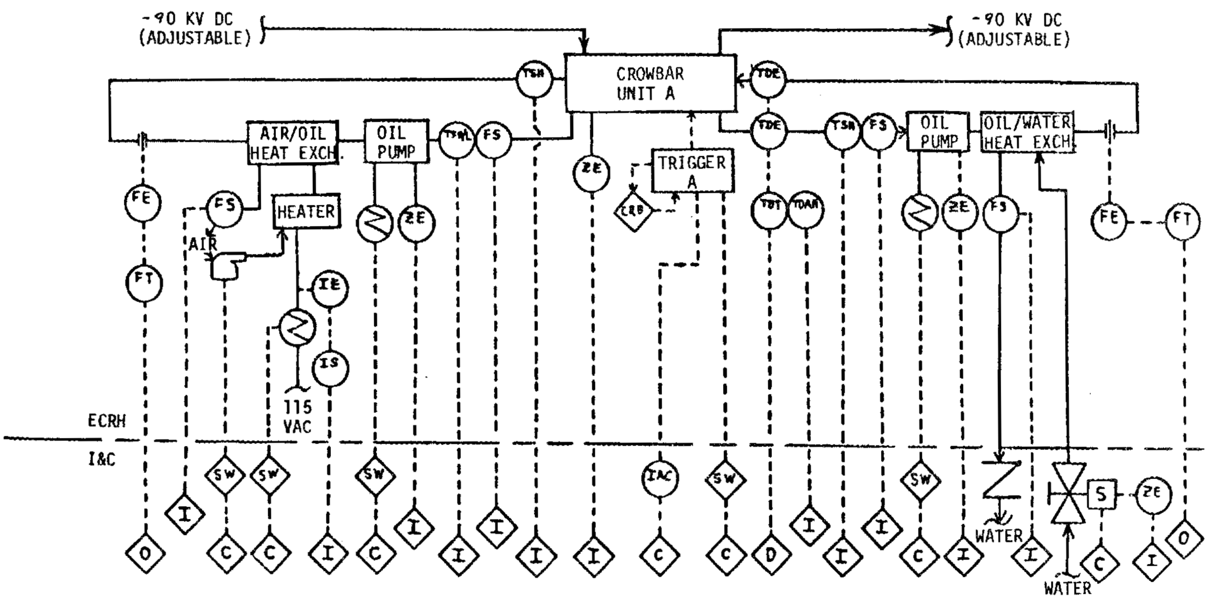


FIGURE 4.2.4–20 28 GHz POWER SUPPLY I&C INTERFACE – CROWBAR UNIT A

Summarized, the Beam Crowbar I & C are the following:

Signal Name	Signal Type
Beam Crowbar Status (ZE)	Interlock/Status Input
Beam Crowbar Setpoint Command	Command Output
Beam Crowbar Trip Command	Command Output
Heating Oil Pump On/Off Command	Command Output
Heating Oil Pump Status (ZE)	Interlock/Status Input
Heating Air Fan On/Off Command C	Command Output
Heating Air Flow	Interlock/Status Input
Heating Current On/Off Command C	Command Output

Signal Name	Signal Type
Heating Current Status (IE)	Interlock/Status Input
Heating Oil Flow (FS)	Interlock Status Input
Heating Oil Flow Rate (FE)	Operating Condition - Interlock Input
Heating Inlet Oil Temp High Warning	Interlock/Status Input
Heating Inlet Oil Temp Normal	Interlock/Status Input
Heating Outlet Oil Temp High Warning	Interlock/Status Input
Heating Outlet Oil Temp High Caution	Interlock/Status Input
Heating Outlet Oil Temp Normal	Interlock/Status Input
Heating Outlet Oil Temp Low Caution	Interlock/Status Input

Signal Name	Signal Type
Heating Outlet Oil Temp Low Warning	Interlock/Status Input
Cooling Oil Pump On/Off Command	Command Output
Cooling Oil Pump Status	Interlock/Status Input
Cooling Water Inlet Valve Command	Command Output
Cooling Water Flow (FS)	Interlock/Status Input
Cooling Oil Flow (FS)	Interlock/Status Input
Cooling Oil Flow Rate (FE)	Operating Condition - Data Input
Cooling Outlet Oil Temp High Warning	Interlock/Status Input
Cooling Oil Differential Temperature (TDE)	Operating Condition - Data Input
Cooling Oil Differential Temp High Warning	Interlock/Status Input

f) **460 V Power Input and Contactor I & C, 28 GHz Supply Gyrotron** - The instrumentation and control for the 460 V Power Input and Contactor, shown in Figure 4.2.4-21, are identical to the I & C for the 13.8 KV Power Input and Contactor, except for a change of signal names.

g) **Gun Powerstat I & C, 28 GHz Gyrotron Supply** - The instrumentation and control for the Gun Powerstat, shown in Figure 4.2.4-22, are identical to the I & C for the Beam IVR except for a change of signal names.

h) **Gun Transformer/Rectifier/Filter Unit I & C, 28 GHz Gyrotron Supply** - The instrumentation and control for the Gun T/R/F, shown in Figure 4.2.4-23, are identical to the I & C for the Beam T/R/F except for a change of signal names.

j) **Gun Crowbar I & C, 28 GHz Gyrotron Supply** - The Gun Crowbar and its instrumentation and control, shown in Figure 4.2.4-24 are similar to the Beam Crowbar

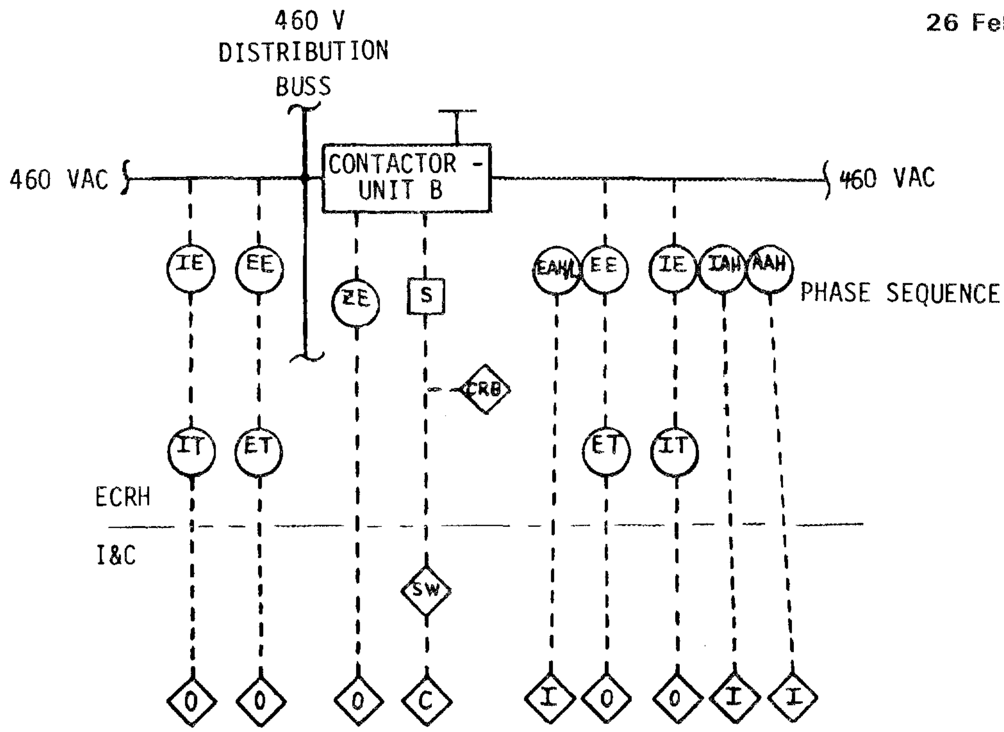


FIGURE 4.2.4–21 28 GHz POWER SUPPLY I&C INTERFACE – 460 VAC

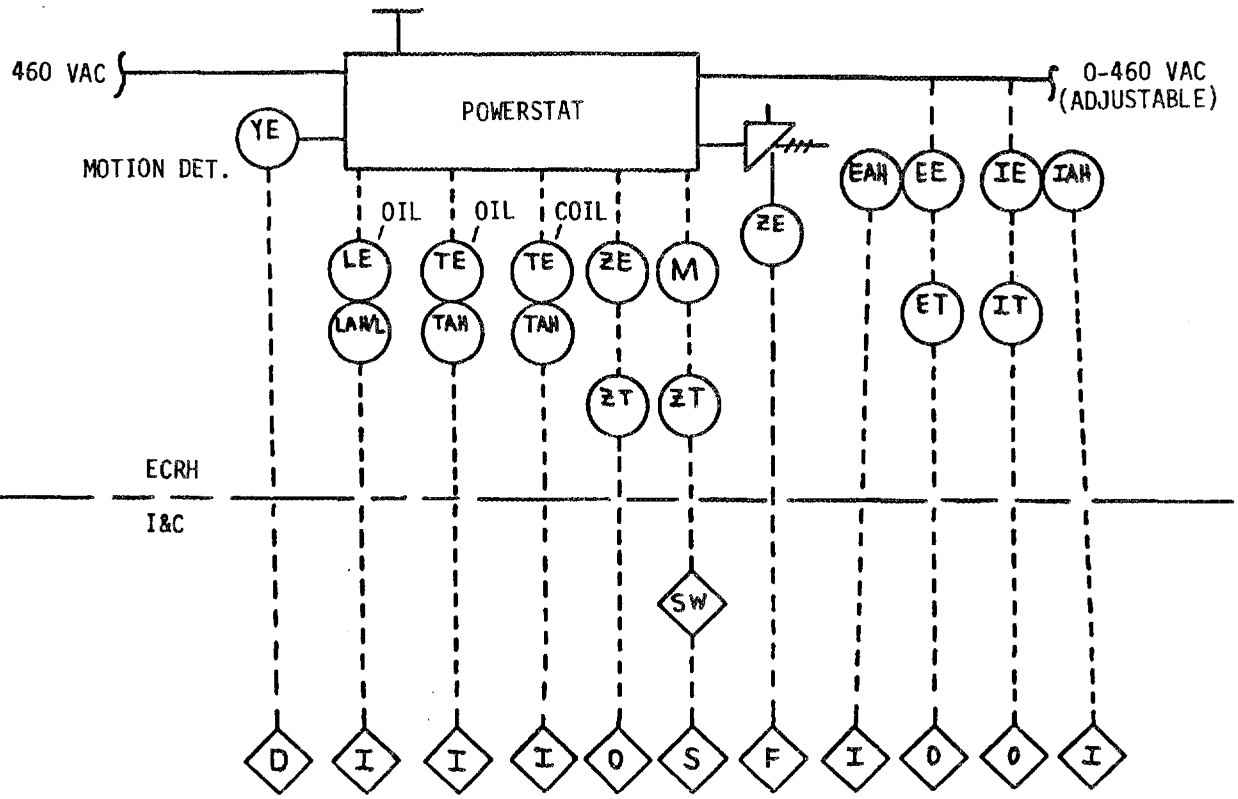


FIGURE 4.2.4–22 28 GHz POWER SUPPLY I&C INTERFACE – 460 VAC POWER STAT

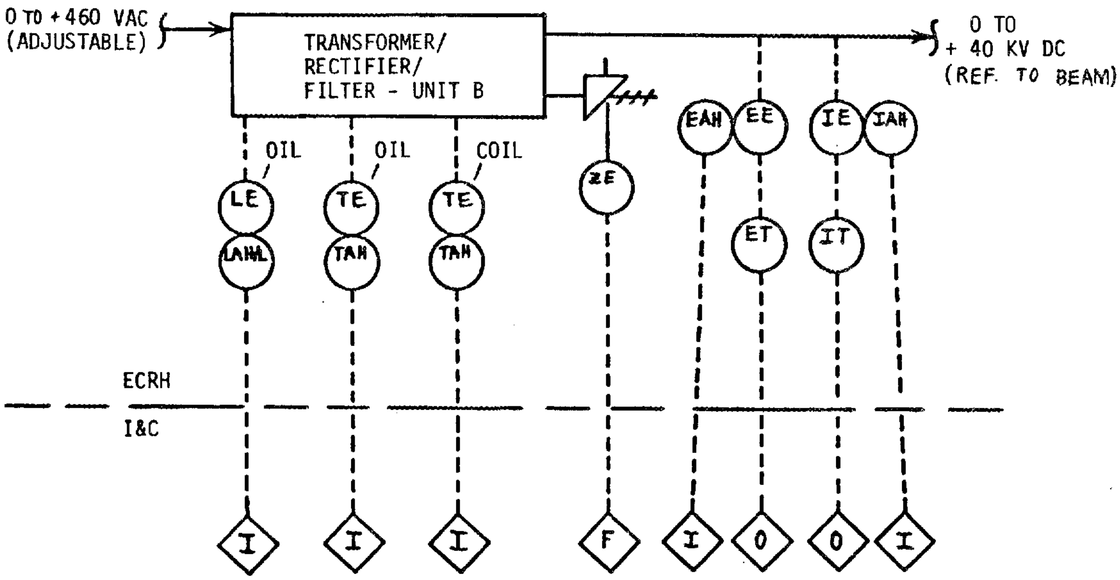


FIGURE 4.2.4–23 28 GHz POWER SUPPLY I&C INTERFACE – TRANSFORMER/RECTIFIER/FILTER – UNIT B

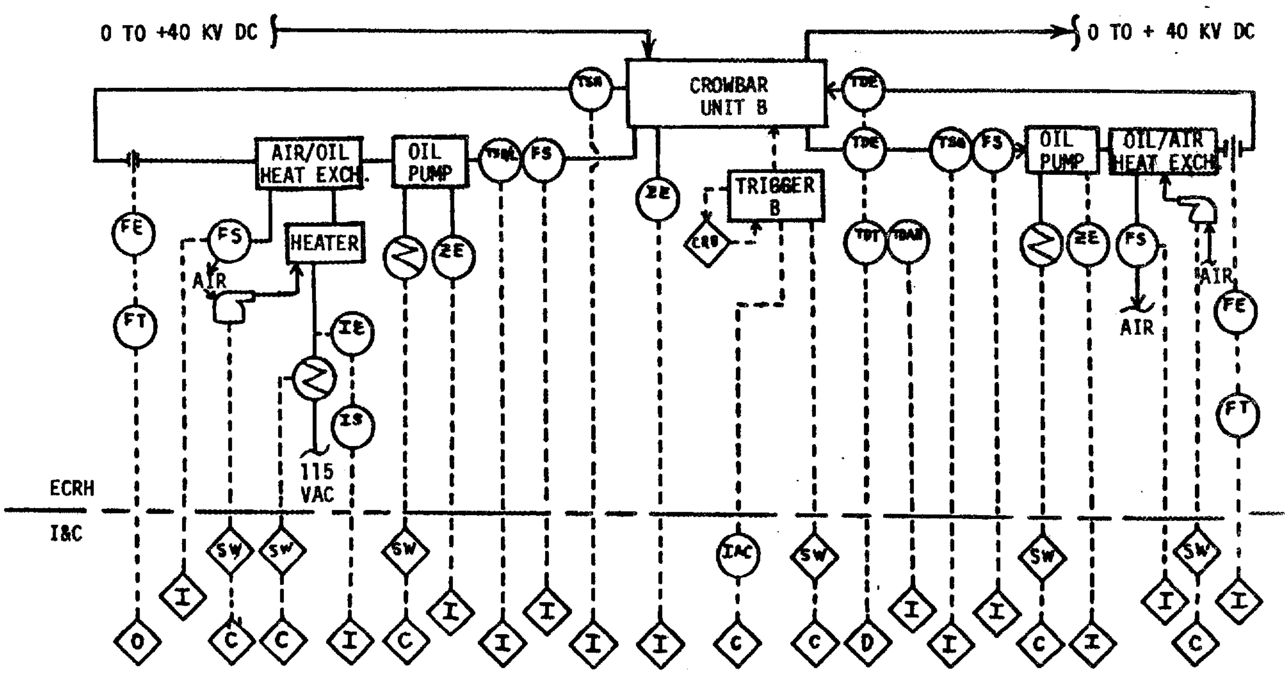


FIGURE 4.2.4–24 28 GHz POWER SUPPLY I&C INTERFACE – CROWBAR UNIT B

and its I & C. The I & C for the Crowbars and the heated oil loops in the two components are identical. The I & C for the two cooled oil loops themselves are also identical, however, instead of water cooling the oil, air cooling is used. The air loop has only a single speed fan and so requires only an On/Off command and outputs a Flow Status from the flowswitch.

k) **Gun Anode Series Regulator I & C, 28 GHz Gyrotron Supply** - Figure 4.2.4-25 shows the I & C for the Gun Anode Series Regulator and its Vac-Ion Pump. The Series Regulator is an air-cooled, voltage-controlled vacuum tube system. The Series Regulator tube requires control of its grid and screen voltages and the grid and screen voltages and currents are monitored. The Vac-Ion Pump and its I & C are identical to those used on the Gyrotron tubes. The air cooling has a single speed fan with an On/Off control, a flowswitch and a temperature switch to make sure the inlet air is not excessively hot.

The power leaving the Gun Anode Series Regulator is the final gun power. The voltage and current are monitored and a hard-wired device monitors voltage ripple and outputs a warning if the ripple is excessive.

In summary, the Gun Anode Series Regulator I & C signals are the following:

Signal Name	Signal Type
Series Regulator Tube Pressure (IE)	Operating Condition - Data Input
Vac Ion Pump On/Off Status (ZE)	Interlock/Status Input
Vac Ion Pump On/Off Command C	Command Output
Grid Voltage Control (EC)	Command Output
Screen Voltage Control (EC)	Command Output
Grid Voltage (EE)	Operating Condition - Data Input
Grid Current (IE)	Operating Condition - Data Input
Screen Voltage (EE)	Operating Condition - Data Input

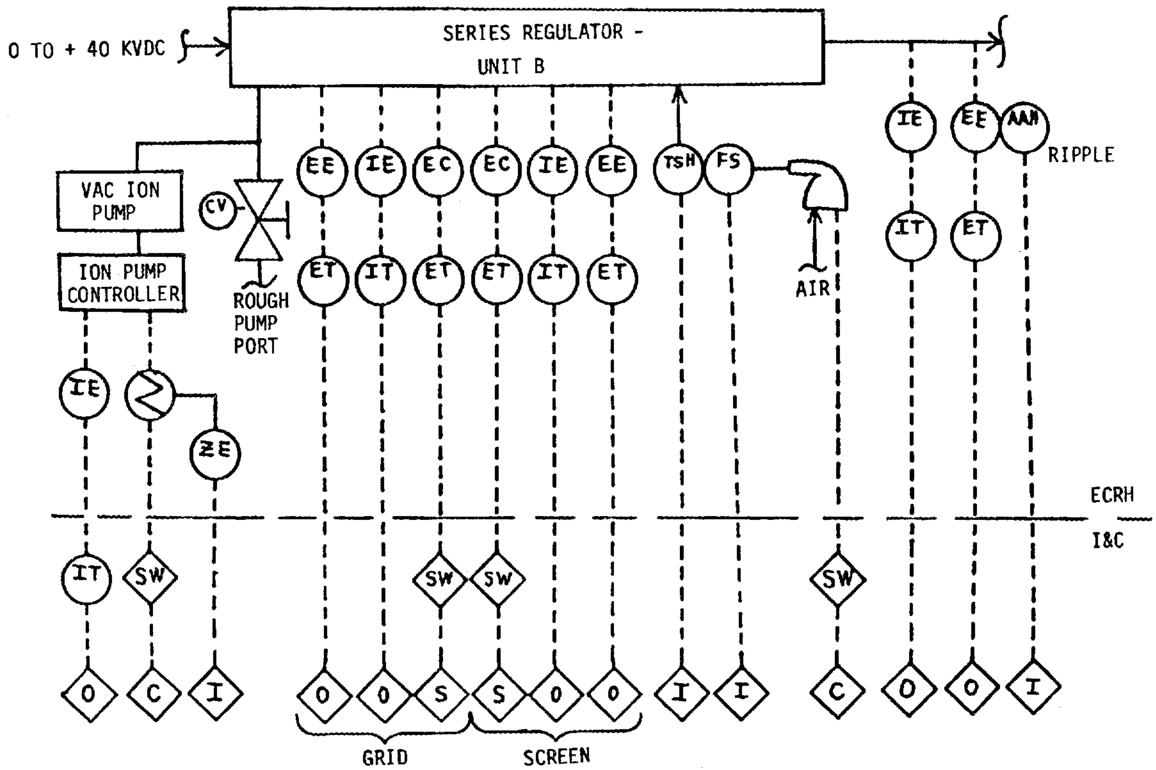


FIGURE 4.2.4–25 28 GHz POWER SUPPLY I&C INTERFACE – SERIES REGULATOR – UNIT B

Signal Name	Signal Type
Screen Current (IE)	Operating Condition - Data Input
Cooling Fan On/Off Command C	Command Output
Cooling Air Flow (FS)	Interlock/Status Input
Cooling Air Temp High Warning (TSH)	Interlock/Status Input
Cooling Air Temp High Caution	Interlock/Status Input
Cooling Air Temp Normal	Interlock/Status Input
Gun Voltage (EE)	Operating Condition - Data Input
Gun Current (IE)	Operating Condition - Data Input
Gun Voltage Ripple High (AAH)	Interlock/Status Input

l) **DC Control Power I & C, 28 GHz Gyrotron Supply** - DC Control Power, Figure 4.2.4-26, is a constant voltage on at all times any part of the supply is on. For that reason and to minimize possible outages of the DC Control Power, the power contactor is manual only. The DC Control Power I & C are the following:

Signal Name	Signal Type
DC Control Power Voltage (EE)	Operating Condition - Interlock Input
DC Control Power Current (IE)	Operating Condition - Interlock Input

m) **AC Control Power I & C, 28 GHz Gyrotron Supply** - AC Control Power, Figure 4.2.4-27, is identical except in name to the DC Control Power I & C.

n) **Gyrotron Heater Power I & C, 28 GHz Gyrotron Supply** - The Gyrotron Heater Power is a low voltage (0-15V) single phase AC power derived from the 460 V 3ϕ buss (Fig. 4.2.4-28). The gyrotron has stringent requirements for the power applied to it which nessitate a power contactor and a motor-controlled variac. The required system results in the following I & C signals:

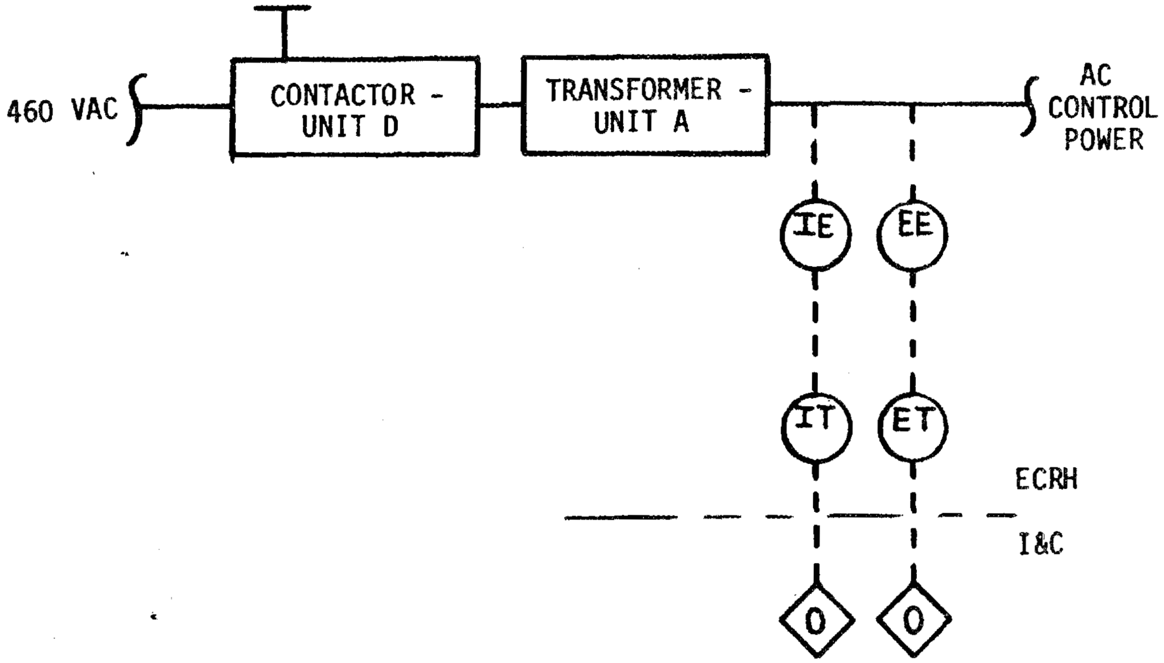


FIGURE 4.2.4–26 28 GHz POWER SUPPLY I&C INTERFACE – TRANSFORMER UNIT A

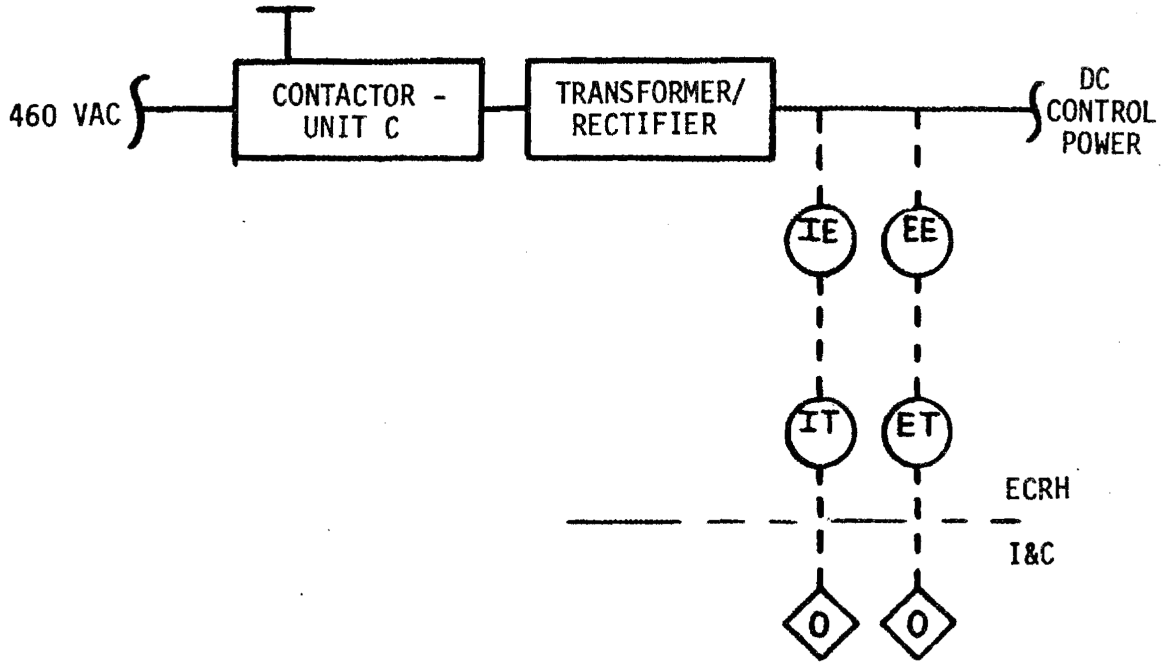


FIGURE 4.2.4–27 28 GHz POWER SUPPLY I&C INTERFACE – CONTACTOR UNIT C

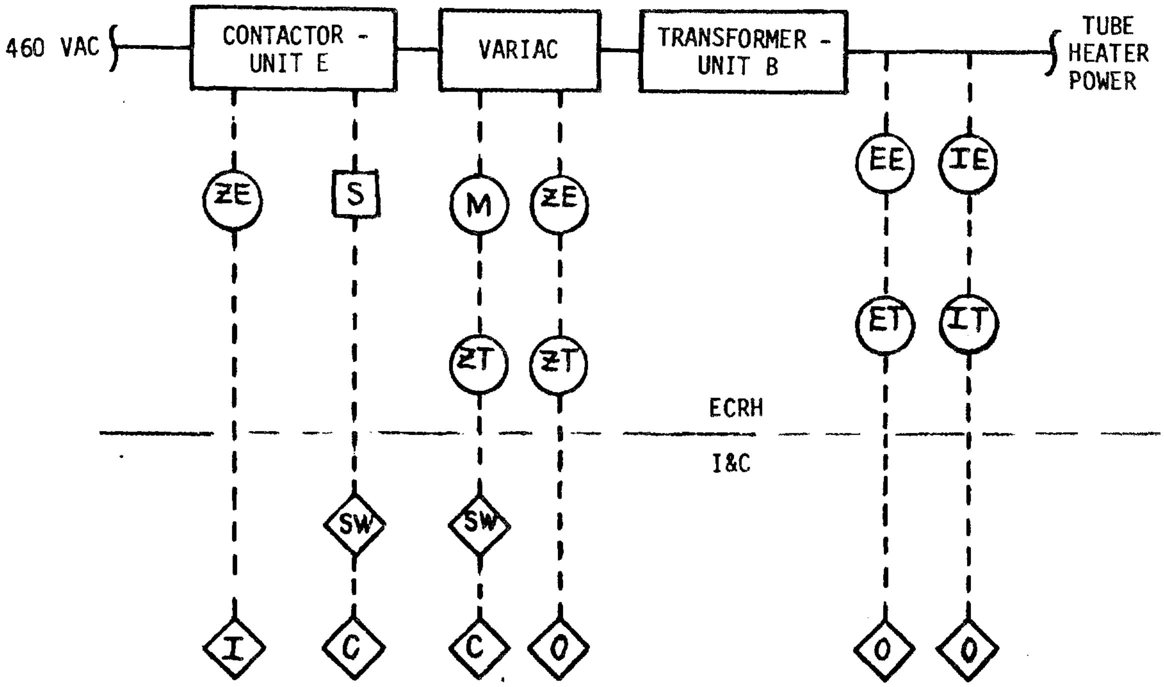


FIGURE 4.2.4–28 28 GHz POWER SUPPLY I&C INTERFACE – TRANSFORMER UNIT B

Signal Name	Signal Type
Heater Power On/Off C	Command Output
Heater Power Contactor Status (ZE)	Interlock/Status Input
Variac Montor Control Command S	Command Output
Variac Position (ZE)	Operating Condition - Data Input
Heater Voltage (EE)	Operating Condition - Data Input
Heater Current (IE)	Operating Condition - Data Input

o) **Automatic Gun Voltage Controller** - The Automatic Gun Voltage Controller has only one input and output that involve the I & C system (Fig. 4.2.4-29). The signals are the following:

Signal Name	Signal Type
Auto Gun Voltage Controller On/Off Command C	Command Output
Auto Gun Voltage Controller On/Off Status	Interlock/Status Input

4.2.4.4 Gyrotron Power Supply, 60 GHz - A block diagram of the power supply for a 60 GHz gyrotron is presented in Figure 4.2.4-30. To the I & C system, the 60 GHz supply is almost identical to the 28 GHz supply. The only difference is the presence in the 60 GHz supply of a series regulator following the Beam Crowbar.

a) **13.8 KV Power Input and Contactor I & C, 60 GHz Gyrotron Supply** - I & C for these components are identical to those for the 28 GHz 13.8 KV Power Input and Contactor.

b) **Induction Voltage Regulator I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Induction Voltage Regulator.

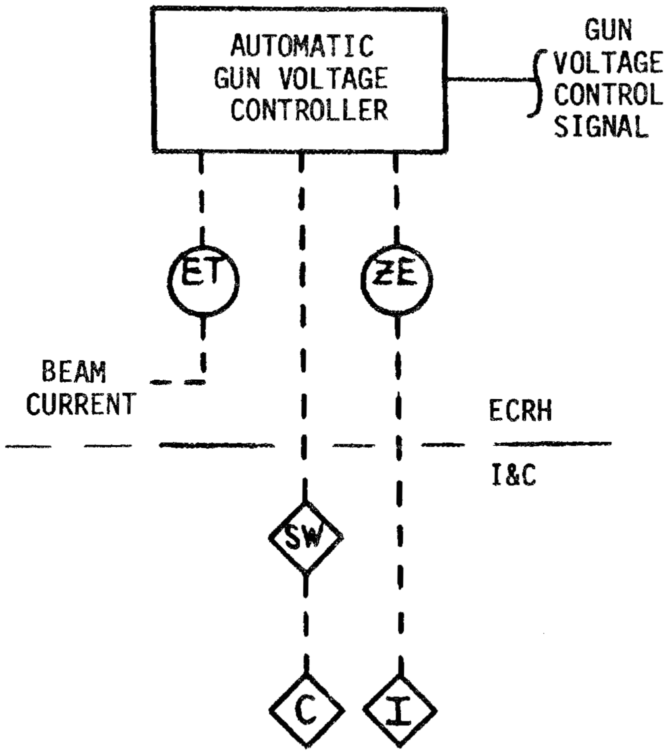


FIGURE 4.2.4–29 28 GHz POWER SUPPLY I&C INTERFACE – AUTOMATIC GUN VOLTAGE CONTROLLER

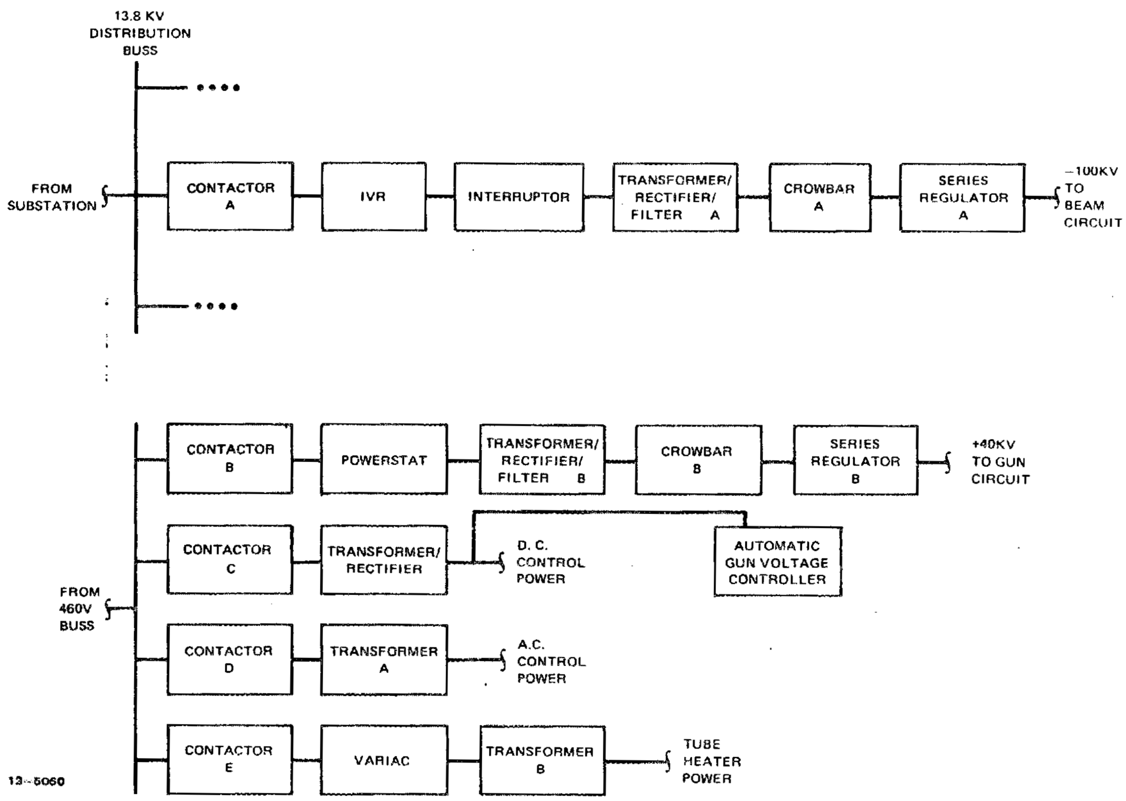


FIGURE 4.2.4–30 60 GHz GYROTRON POWER SUPPLY

c) **Vacuum Interrupter I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Vacuum Interruptor.

d) **Transformer/Rectifier/Filter I & C, Beam, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Beam Supply T/R/F.

e) **Beam Crowbar, I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Beam Crowbar.

f) **Beam Series Regulator I & C, 60 GHz GyrotronSupply** - Figure 4.2.4-31 shows the I & C for the 60 GHz Beam Series Regulator. The I & C for this Series Regulator similar to that of the 28 GHz Gun Series Regulator. The I & C for the two components are, in fact identical except that the 60 GHz Beam Series Regulator is water-cooled instead of air-cooled and it has a sulfur hexafluorine jacket. Consequently, the I & C signals for the Beam Series Regulator are the same as those previously defined except that the five cooling air signals are deleted and the following signals are added:

Signal Name	Signal Type
Cooling Water Flow (FS)	Interlock/Status Input
Cooling Water Flow Rate (FE)	Operating Condition - Interlock Input
Cooling Water Temperature High Warning (TS)	Interlock/Status Input
Signal Name	**Signal Type**
Cooling Water Temperature Normal	Interlock/Status Input
Cooling Water Differential Temperature (TDE)	Operating Condition - Interlock Input
Cooling Water Inlet Valve Command C	Command Output
Cooling Water Inlet Valve Position (ZE)	Interlock/Status Input
SF_6 Pressure (PE)	Operating Condition - Interlock Input

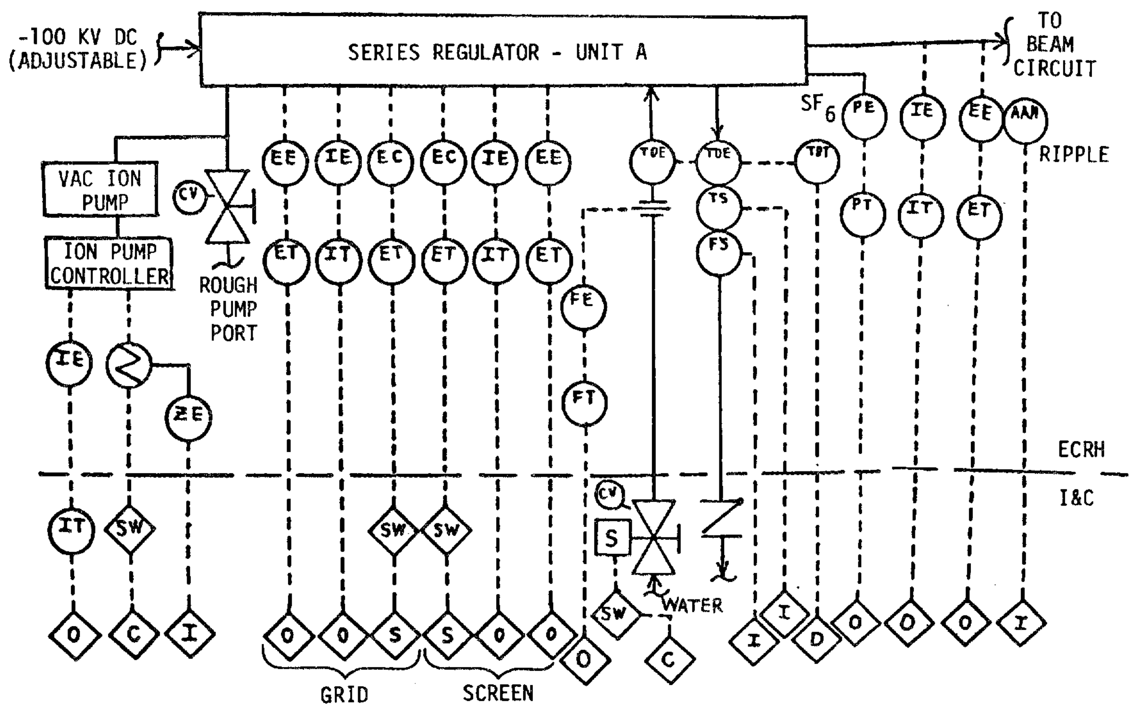


FIGURE 4.2.4–31 60 GHz POWER SUPPLY I&C INTERFACE – SERIES REGULATOR UNIT A

g) **460 V Power Input and Contactor I & C, 60 GHz Gyrotron Supply** - I & C for these components are identical to those for the 28 GHz Power Input and Contactor.

h) **Gun Powerstat I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Gun Powerstat.

i) **Gun Transformer/Rectifier/Filter Unit I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz T/R/F.

j) **Gun Crowbar I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Gun Crowbar.

k) **Gun Anode Series Regulator I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Gun Series Regulator.

l) **DC Control Power I & C, 60 GHz Gyrotron Supply** - I & C for this subsystem are identical to that for the 28 GHz DC Control Power.

m) **AC Control Power I & C, 60 GHz Gyrotron Supply** - I & C for this subsystem are identical to that for the 28 GHz AC Control Power.

n) **Gyrotron Heater Power I & C, 60 GHz Gyrotron Supply** - I & C for this subsystem are identical to that for the 28 GHz Gyrotron Heater Power.

o) **Automatic Gun Voltage Controller I & C, 60 GHz Gyrotron Supply** - I & C for this component are identical to that for the 28 GHz Automatic Gun Voltage Controller.

4.2.4.5 Gyrotron-to-Manifold Microwave Link I & C, 28 GHz System - The microwave distribution system receives no commands. It has only instrumentation which supports calorimetry measurements. Each cooling loop has a standard set of sensors, denoted by **I** , which will be discussed below.

Figure 4.2.4-32 shows on a block diagram of the microwave link between a gyrotron and the microwave manifold, the water cooling loops and instrumentation. Cooling water flow

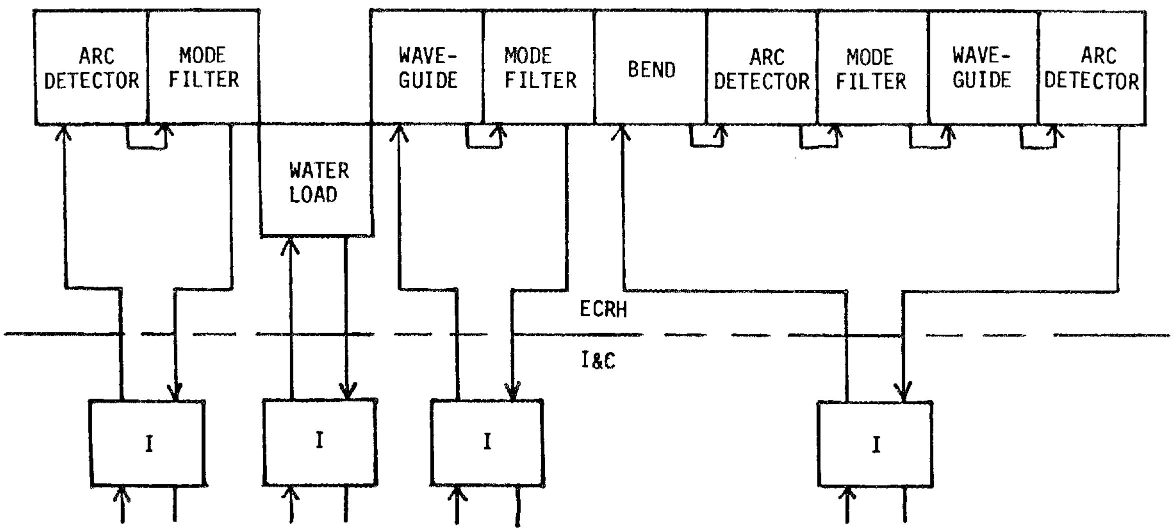


FIGURE 4.2.4–32 GYROTRON-TO-MICROWAVE MANIFOLD LINK

for the entire microwave distribution system is controlled by hand valves. EBT-P has two gyrotron-to-manifold links for the two 28 GHz gyrotrons. The waterload is used only to set up an experiment. It is capable of being moved in and out of the microwave path. Calorimetry will provide the means for determining gyrotron output, distribution system component heating and protection, and power delivered to the plasma. Means will be provided to reduce the transient effects of the multitime constant system to an acceptable level.

a) **Microwave Distribution Manifold I & C, 28 GHz System** - The 28 GHz Microwave Distribution Manifold has four cooling loops, each with standard instrumentation (I). See Fig. 4.2.4-33.

b) **Side Arm Couplers I & C, 28 GHz System** - There are 36 Side Arm Couplers for 28 GHz. For cooling, the couplers are grouped into nine groups of four with one set of standard instrumentation for each loop. (See Fig. 4.2.4-34). Calorimetry is performed in order to determine power delivered to the plasma. Power losses are determined by monitoring the water flow and differential temperature rise in each cooling loop. These data are forwarded to microprocessors in the DAS. The microprocessors compute the actual power loss.

4.2.4.6 Gyrotron-to-Manifold Microwave Link I & C, 60 GHz System - This link is identical to that for the 28 GHz system. The only difference between the two systems is the number of waveguide links. The 60 GHz system has four gyrotrons and hence four waveguide links in the baseline. It will have six waveguide links in the upgrade.

a) **Microwave Distribution Manifold I & C, 60 GHz System** - After the upgrade, the 60 GHz microwave manifold will carry power from six gyrotrons. Consequently for ease of performing calorimetry, the 60 GHz microwave manifold has twelve cooling loops, each with standard instrumentation (see Fig. 4.2.4-35).

b) **Side Arm Couplers I & C, 60 GHz** - Instrumentation for the 60 GHz Side Arm Couplers, is identical to that for the 28 GHz Side Arm Coupler.

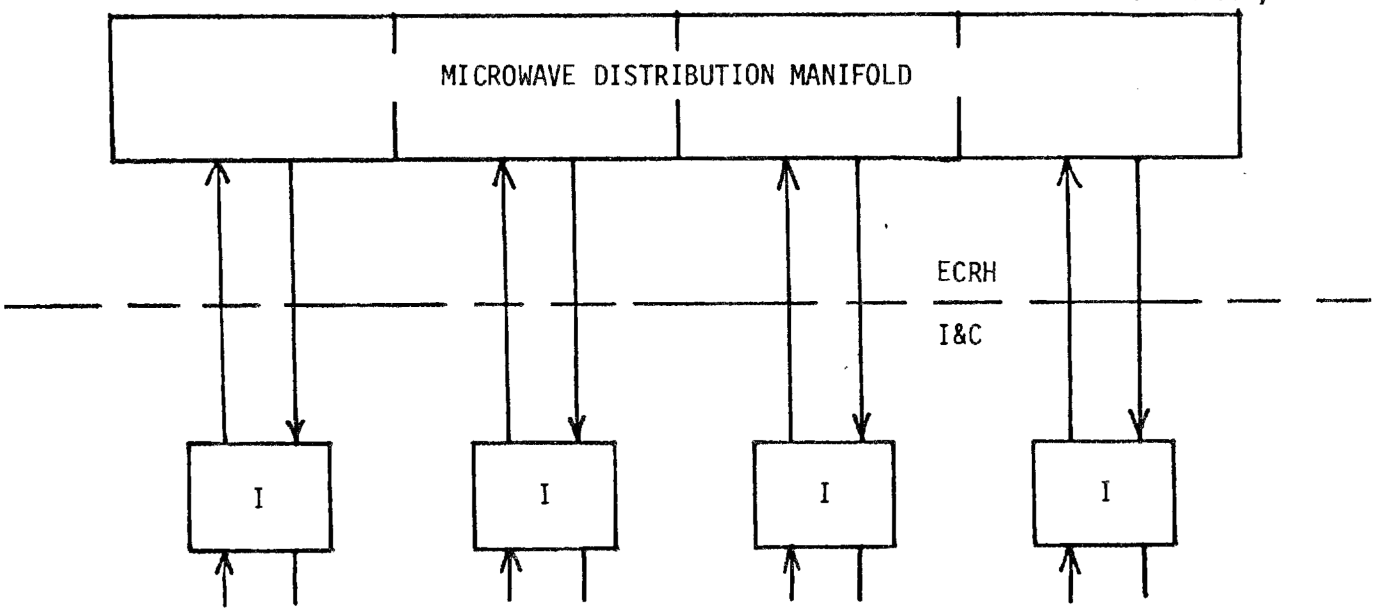


FIGURE 4.2.4–33 ECRH/IUC INTERFACE – TOROIDAL MICROWAVE MANIFOLD – 28 GHz

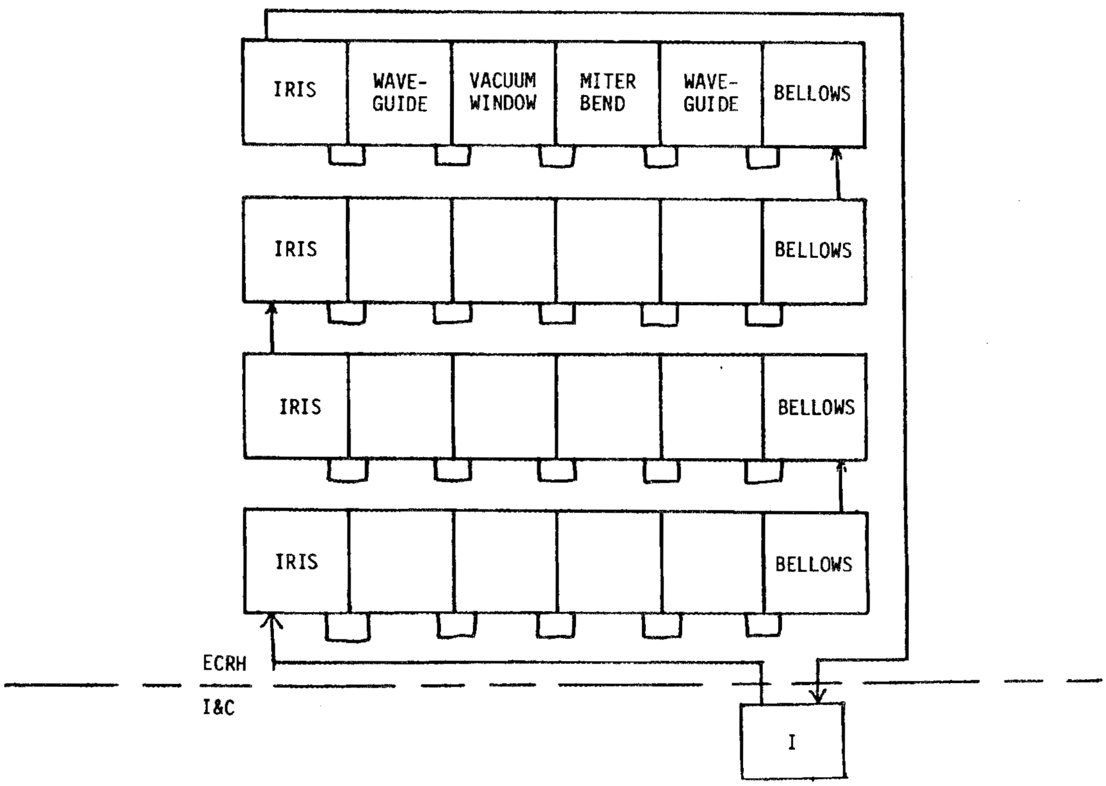


FIGURE 4.2.4–34 ECRH/I&C INTERFACE – SIDE-ARM COUPLER

c) Microwave Distribution System Cooling Loop Standard Instrumentation - The standard cooling loop instrumentation is diagrammed in Figure 4.2.4-36. It consists of the following signals:

Signal Name	Signal Type
Cooling Water Flow (FS)	Interlock/Status Input
Cooling Water Flow Rate (FE)	Operating Condition - Data Input
Cooling Water Temp High Warning (TS)	Interlock/Status Input
Cooling Water Differential Temperature (TDE)	Operating Condition - Data Input

As with other cooling loops, the flowmeter is on the inlet and the flowswitch on the outlet. The temperature switch is also on the outlet.

4.2.5 ICRH Transmitter Instrumentation and Control Interface - This section describes the design of the ICRH I & C interface. This interface is entered presently at the ICRH transmitter/power supply and does not consider the interface between the I & C system and the RF antenna tuning subsystem. The latter will be designed later during the Phase II effort.

4.2.5-1 ICRH Transmitter I & C - A block diagram showing the major components of one ICRH transmitter is presented in Figure 4.2.5-1. The transmitter has two main branches. One is the branch consisting of the amplitier/oscillator stages, the other is the high voltage power supply for the last two transmitter stages. The amplitier/oscillator branch consists, in order from input to output, of the Oscillator, the Low Power Amplifier, the Intermediate Power Amplifier, the Driver Amplifier, and the Final Power Amplifier. The Oscillator is a solid state signal generator, tunable over a 50-70 MHz range. The Low Power Amplifier is a solid state device which will receive the 0-1 mW Oscillator signal, amplify the signal by about 50 dB and output to the IPA. The Intermediate Power Amplifier is based upon a cathode driven Eimac 3CW5,000A7 triode. The triode is both forced air and water cooled. It utilizes separate power supplies for the anode and filament. The Driver Amplifier is based upon a cathode driven Eimac 4CW50,000E power tetrode. It is cooled

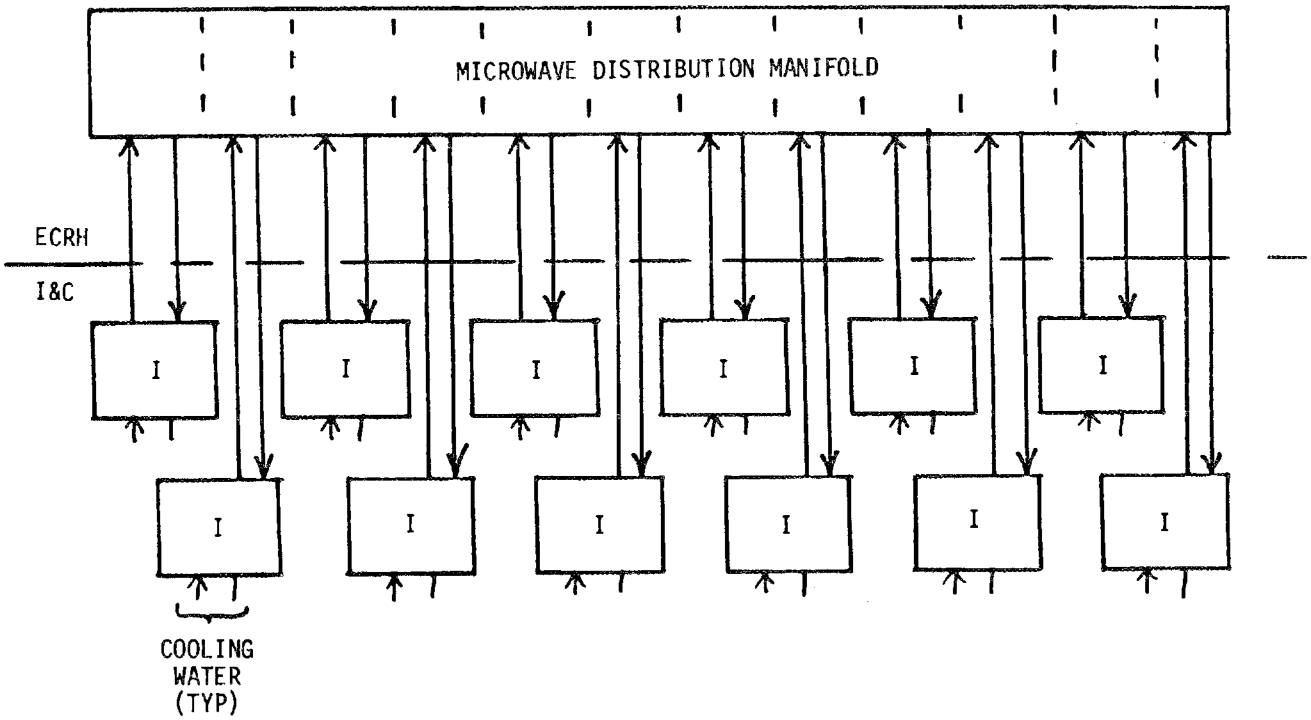


FIGURE 4.2.4–35 ECRH I&C INTERFACE – MICROWAVE DISTRIBUTION MANIFOLD – 60 GHz

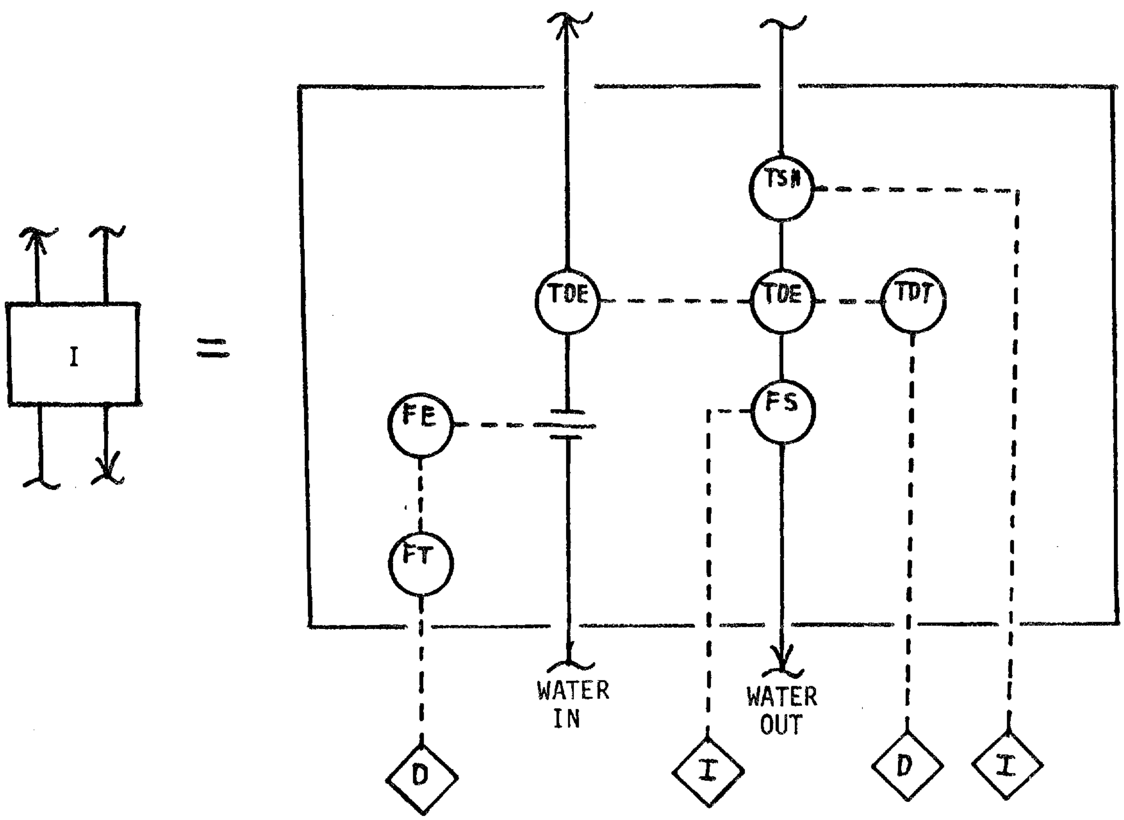


FIGURE 4.2.4–36 ECRH COOLING LOOP INSTRUMENTATION

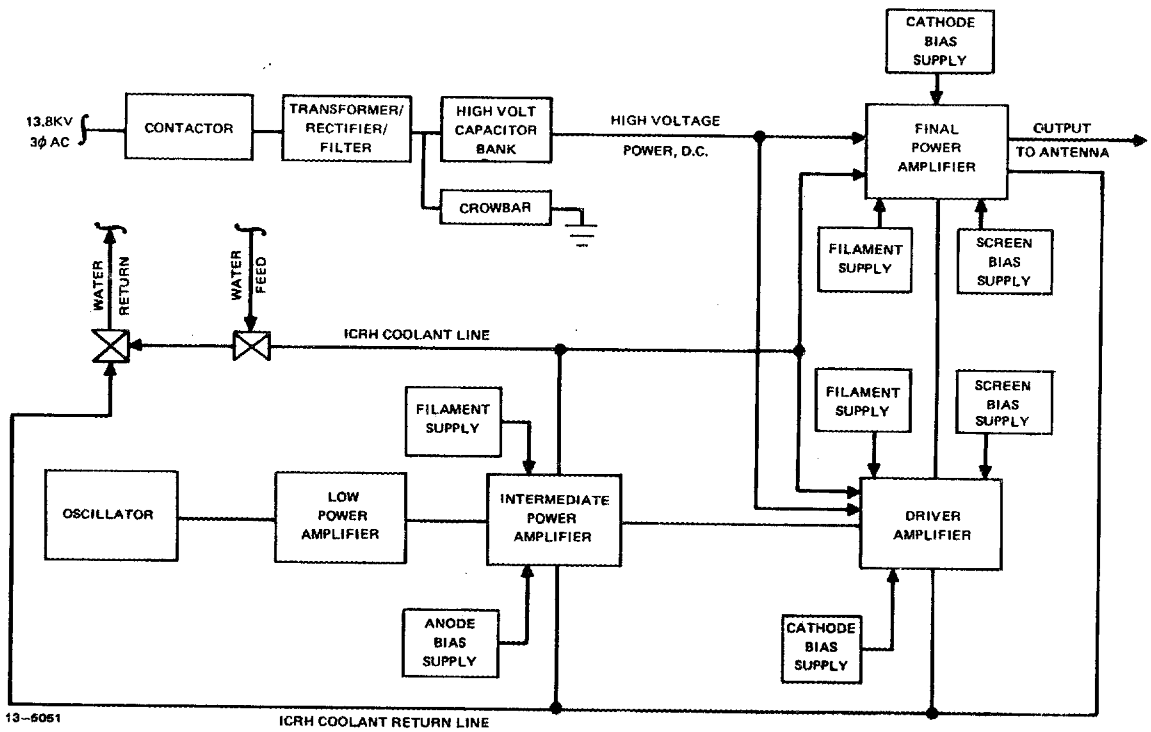


FIGURE 4.2.5–1 ICRH SYSTEM BASIC BLOCK DIAGRAM

with forced air and water. It makes use of separate supplies for the filament, screen and cathode.

The Final Power Amplifier is based upon a cathode driven Eimac 8973 power tetrode. The 8973 is forced air and water cooled and makes use of separate supplies for its filament, screen and cathode.

The high voltage power branch consists of an input Power Contactor, a Transformer/Rectifier/Filter, a Crowbar, and a high Voltage Capacitor Bank. The Power Contactor is a 3ϕ device for which the nominal load will be roughly 1400 KVA at 13.8 KV. The Transformer/Rectifier/Filter is based upon a Δ - Y to Y, oil filled transformer with a tap changing secondary, a rectifier and a parallel resistance/inductance filter. The Crowbar is a system based upon a GL37248 Ignition. Following the Crowbar is a high voltage ($\approx$ 16 KV) Capacitor Bank to further smooth the DC power.

The water cooling system is a fully-off or fully-on system with a flow balancing line to even the load on the pumps when the ICRH is not being cooled. The flow rate in individual cooling loops is controlled by hand valves.

The ICRH transmitters are based upon existing transmitters for which the control systems are supplied by the vendor. All sensors are supplied by the transmitter vendor. All control elements and control networks necessary to safely operate a transmitter as an independent unit are also provided by the vendor. The ICRH Process Controller receives data collected by the vendor supplied sensors. It handles all safety interlocking with the rest of the EBT-P device and controls the overall operation of the transmitters by sending commands to the vendor supplied, hardwired control network. The facility Data Acquisition System receives ICRH data from the vendor-supplied sensors.

Because of the redundant nature of the ICRH I & C system, the following drawings may appear to have components for which no controls are shown. In reality, such components are controlled automatically by the hardwired control system and it was deemed unwise to add the cost and complication of giving each item its commands individually from the process controller.

4.2.5-2 Input Power Contactor and Transformer/Rectifier/Filter I & C - The I & C for the Input Power Contactor and Transformer/Rectifier/Filter are shown on Figure 4.2.5-2.

The contactor receives only one command, the command to open. For safety reasons, closure is manual. The contactor produces a total of six discrete outputs by means of a separate sensor and output line for the open and closed states of each phase.

The T/R/F receives one set of commmands, those which control the steps of the tap changing mechanism. It produces outputs for tap state, oil level, oil temperature, coil temperature, and pressure status. Summarized, the Contactor and T/R/F signals are:

Signal Name	Signal Type
Input Contactor Open Cmd	Command Output
Input Contactor ϕA Open	Interlock/Status Input
Input Contactor ϕA Closed	Interlock/Status Input
Input Contactor ϕB Open	Interlock/Status Input
Input Contactor ϕB Closed	Interlock/Status Input
Input Contactor ϕC Open	Interlock/Status Input
Input Contactor ϕC Closed	Interlock/Status Input
T/R/F Tap Command	Setpoint Output
T/R/F Tap Position	Operating Condition/Interlock Input
T/R/F Oil Level High Warning	Interlock/Status Input
T/R/F Oil Level High Caution	Interlock/Status Input
T/R/F Oil Level Normal	Interlock/Status Input
T/R/F Oil Level Low Caution	Interlock/Status Input
T/R/F Oil Level Low Warning	Interlock/Status Input
T/R/F Oil Temp High Warning	Interlock/Status Input

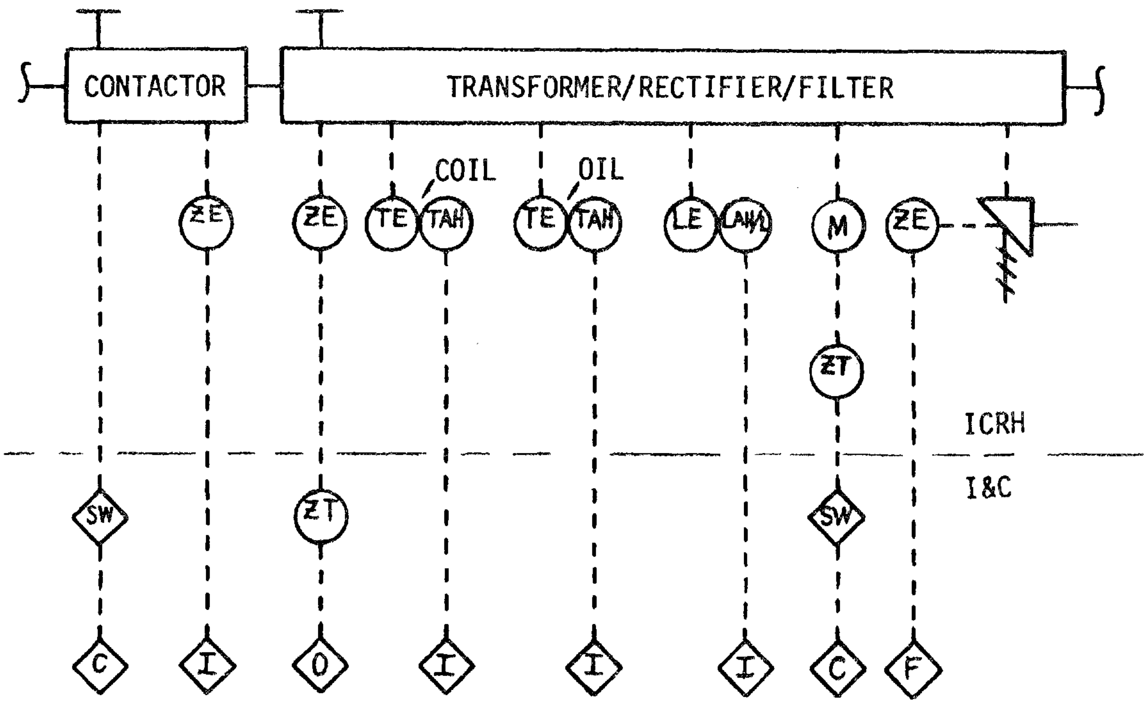


FIGURE 4.2.5–2 ICRH/I&C INTERFACE – TRANSFORMER/RECTIFIER/FILTER

Signal Name	Signal Type
T/R/F Oil Temp High Caution	Interlock/Status Input
T/R/F Oil Temp Normal	Interlock/Status Input
T/R/F Coil Temp High Warning	Interlock/Status Input
T/R/F Coil Temp High Caution	Interlock/Status Input
T/R/F Coil Temp Normal	Interlock/Status Input
T/R/F Pressure Relief Status	Primary Fault/Warning/Alarm Input

4.2.5-3 Crowbar and High Voltage Capacitor Bank - I & C - Figure 4.2.5-3 shows the I & C for the Crowbar and HV Capacitor Bank and it shows the air flow for the components. Both of these items are housed in the same enclosure.

The ignitron is air cooled and infrared lamp-heated. The crowbar has input lines to set the trip point and command a trip. It has output lines to indicate the crowbar status and the heater status.

The Cap Bank per se has no monitors or controls, however there are monitors for the input air temperature, the air flow and the output voltage.

A summary of the Crowbar and Cap Bank signals is as follows:

Signal Name	Signal Type
Crowbar Setpoint Cmd.	Setpoint Output
Crowbar Trip Cmd.	Command Output
Crowbar Status	Primary Fault/Warning/Alarm Input
Crowbar Heater Status	Interlock/Status Input
Cap Bank Air Temp High Warning	Interlock/Status Input

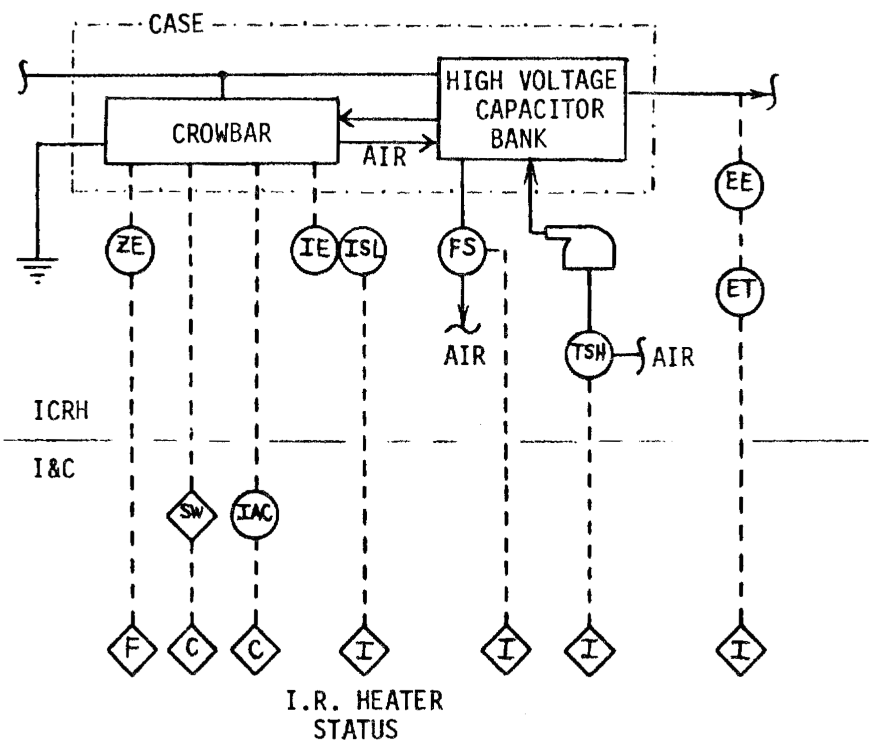


FIGURE 4.2.5–3 ICRH/I&C INTERFACE – CROWBAR UNIT

Signal Name	Signal Type
Cap Bank Air Temp High Caution	Interlock/Status Input
Cap Bank Air Temp Normal	Interlock/Status Input
Cap Bank Air Temp Flow	Interlock/Status Input
High Voltage	Operating Condition/Interlock Input

4.2.5-4 ICRH Cooling Water I & C - All the individual transmitter water cooled loops are fed from and return to a main manifold system (Fig. 4.2.5-4). Each set of transmitter cooling loops receives water from a supply manifold via a large three way valve and sends water to the return manifold via a similar valve. In parallel with a transmitter cooling system there is a bypass loop which has pressure and flow characteristics similar to a transmitter cooling system. The three way valves have the following states:

Fully Closed
All-water to transmitter
All-water to bypass

The operation of the two valves is synchronized and both are damped to prevent a water hammer effect.

The valves will have the following instrumentation and controls:

Signal Name	Signal Type
Water Feed Valve Position	Interlock/Status Input
Water Feed Valve Control	Command Output
Water Return Valve Position	Interlock/Status Input
Water Return Valve Control	Command Output

4.2.5-5 Oscillator and Low Power Amplifier I & C - The Oscillator and LPA have the I & C shown in Figure 4.2.5-5. The signals are the following:

Signal Name	Signal Type
Oscillator On/Off Cmd.	Command Output
Oscillator On/Off Status	Interlock/Status Input
Oscillator Frequency Cmd.	Setpoint Output
Oscillator Amplitude Cmd.	Setpoint Output
Oscillator Frequency	Operating Condition/Data Input
Oscillator Amplitude	Operating Condition/Data Input
LPA On/Off Cond	Command Output
LPA On/Off Status	Interlock/Status Input
LPA Phase Cmd.	Setpoint Output
LPA Amplitude Cmd.	Setpoint Output
LPA Phase	Operating Condition/Data Input
LPA Amplitude	Operating Condition/Data Input

4.2.5-6 Intermediate Power Amplifier I & C - Figure 4.2.5-6 shows the I & C for the IPA but not for its associated biasing and filament supplies; those are shown on Figure 4.2.5-7. The IPA itself has a number of inputs and outputs for which I & C are provided. The anode and screen have separate water cooling loops with hand-operated flow control valves. Cooling air is provided by a fan which is common to the IPA and Driver Amplifier, and air flow through both is monitored. Tuning of the amplifier output stage is accomplished by a motor-driven mechanical adjustment of the plate cavity. The cavity position and output current and voltage are also monitored.

In summary, the IPA I & C signals are the following:

Signal Name	Signal Type
IPA Air Flow	Interlock/Status Input
IPA Anode Water Flow	Interlock/Status Input

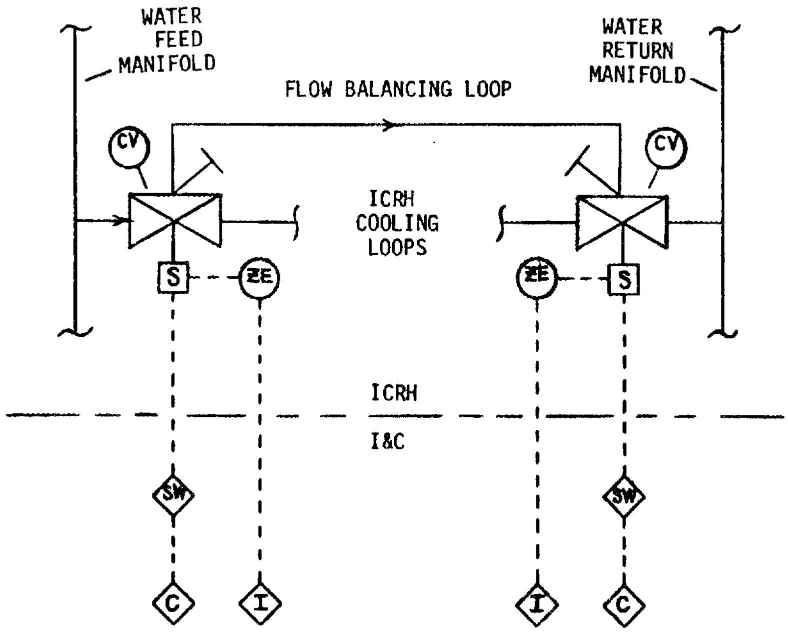


FIGURE 4.2.5–4 ICRH/I&C INTERFACE – COOLING SYSTEM DETAILS

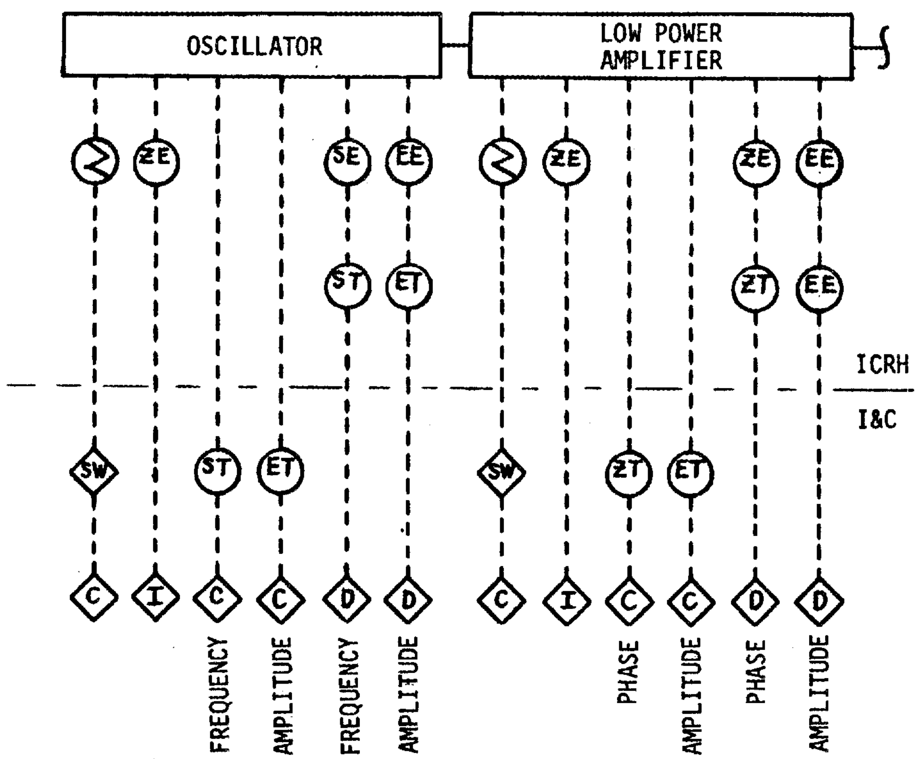


FIGURE 4.2.5–5 ICRH/I&C INTERFACE – OSCILLATOR/LOW POWER AMPLIFIER

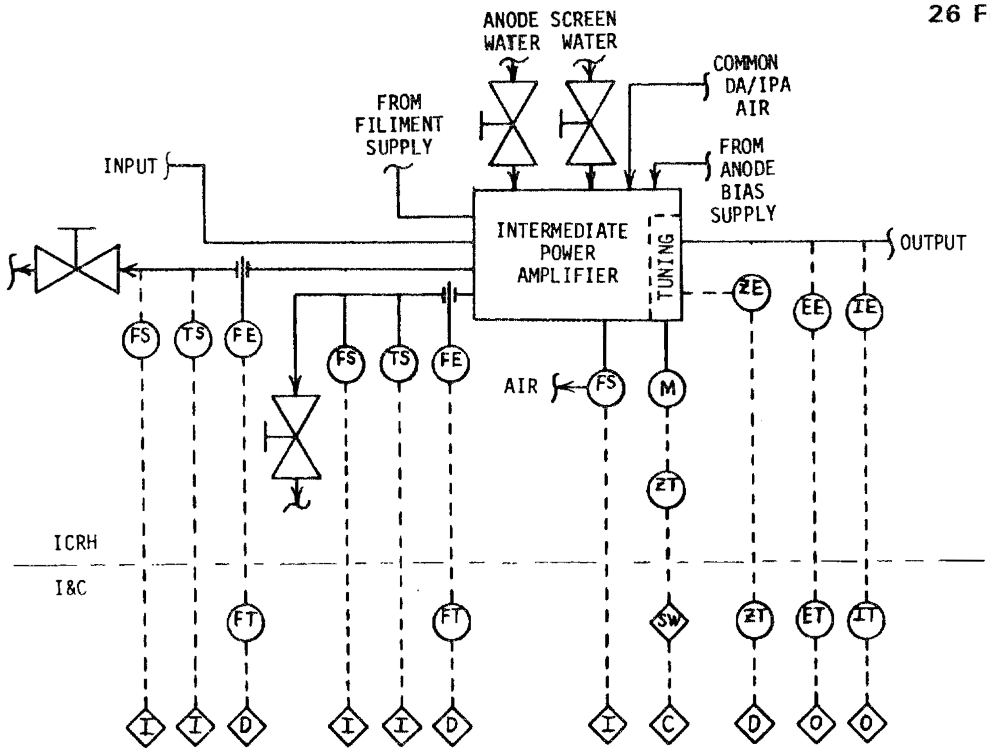


FIGURE 4.2.5–6 ICRH/I&C INTERFACE – INTERMEDIATE POWER AMPLIFIER

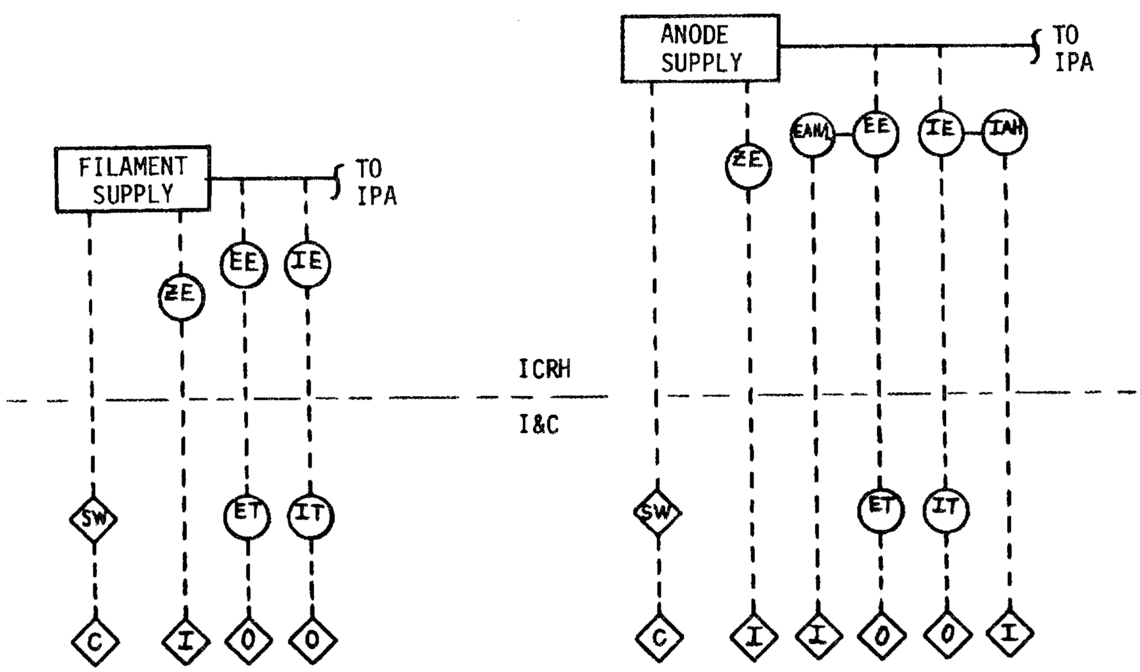


FIGURE 4.2.5–7 ICRH/I&C INTERFACE – FILAMENT/ANODE POWER SUPPLIES

Signal Name	Signal Type
IPA Anode Water Temp High Warning	Interlock/Status Input
IPA Anode Water Temp High Caution	Interlock/Status Input
IPA Anode Water Temp Normal	Interlock/Status Input
IPA Anode Water Flow Rate	Operating Condition/Data Input
IPA Screen Water Flow	Interlock/Status Input
IPA Screen Water Temp High Warning	Interlock/Status Input
IPA Screen Water Temp High Caution	Interlock/Status Input
IPA Screen Water Temp Normal	Interlock/Status Input
IPA Screen Water Flow Rate	Operating Condition/Data Input
IPA Output Tuning Control Command	Setpoint Output
IPA Output Tuning Cavity Position	Operating Condition/Data Input
IPA Output Voltage	Operating Condition/Interlock Input
IPA Output Current	Operating Condition/Interlock Input

4.2.5-7 IPA Anode and Filament Supplies I & C - The I & C for the IPA Anode and Filament Supplies are shown on Figure 4.2.5-7. To the I & C system, each supply has a command to turn it on and off and a monitor to give feedback as to whether or not a supply is on. Both supplies have output voltage and current monitors and the anode supply also has voltage and current exception warnings.

Summarized, the I & C signal are the following:

Signal Name	Signal Type
IPA Filament Supply On/Off Cmd.	Command Output
IPA Filament Supply On/Off Status	Interlock/Status Input
IPA Filament Supply Output Voltage	Operating Condition/Interlock Input
IPA Filament Supply Output Current	Operating Condition/Interlock Input
IPA Anode Supply On/Off Cmd.	Command Output
IPA Anode Supply On/Off Status	Interlock/Status Input
IPA Anode Supply Output Voltage	Operating Condition/Interlock Input
IPA Anode Supply Output Current	Operating Condition/Interlock Input
IPA Anode Supply Output Voltage High Warning	Interlock/Status Input
IPA Anode Supply Output Voltage Low Warning	Interlock/Status Input
IPA Anode Supply Output Current High Warning	Interlock/Status Input

4.2.5-8 Driver Amplifier I & C - Figure 4.2.5-8 shows the I & C for the DA but not for its associated biasing and filament supplies; those are shown on Figure 4.2.5-9.

The DA has a water cooling loop for the anode with hand-operated flow setting valves. Air cooling is provided by the common DA/IPA fan. Input and output stage tuning is accomplished in motor-driven cavities.

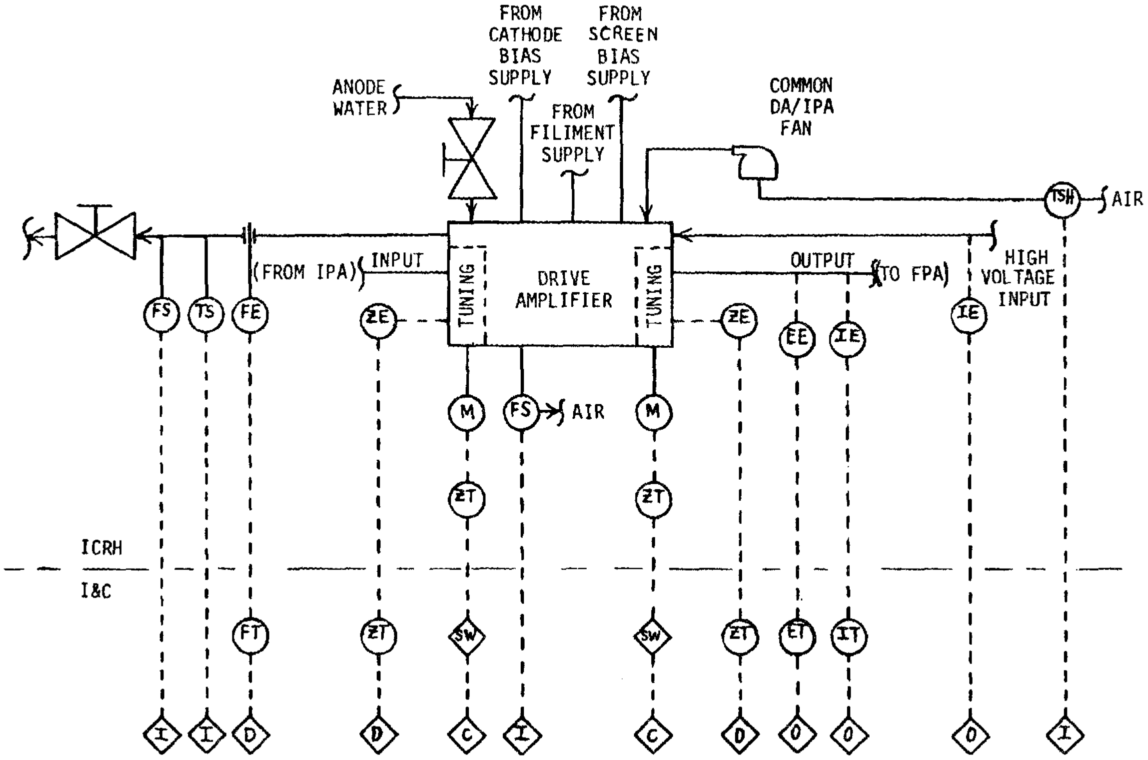


FIGURE 4.2.5–8 ICRH/I&C INTERFACE – DRIVE AMPLIFIER

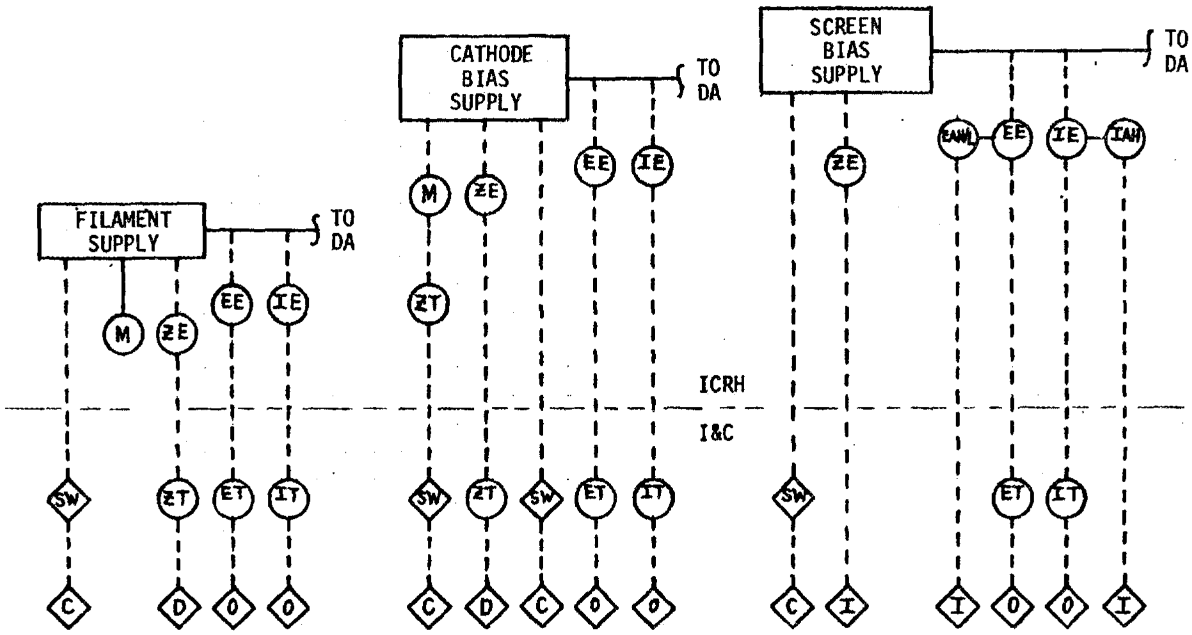


FIGURE 4.2.5–9 ICRH/I&C INTERFACE – BIAS SUPPLIES

The I & C signals here are:

Signal Name	Signal Type
DA/IPA Air Temp High Warning	Interlock/Status Input
DA/IPA Air Temp High Caution	Interlock/Status Input
DA/IPA Air Temp Normal	Interlock/Status Input
DA Air Flow	Interlock/Status Input
DA Anode Water Temp High Warning	Interlock/Status Input
DA Anode Water Temp High Caution	Interlock/Status Input
DA Anode Water Temp Normal	Interlock/Status Input
DA Anode Water Flow	Interlock/Status Input
DA Anode Water Flow Rate	Operating Condition/Data Input
DA Input Tuning Control Cmd.	Setpoint Output
DA Input Tuning Cavity Position	Operating Condition/Data Input
DA Output Tuning Control Cmd.	Setpoint Output
DA Output Tuning Cavity Position	Operating Condition/Data Input
High Voltage DA Current	Operating Condition/Interlock Input
DA Output Voltage	Operating Condition/Interlock Input
DA Output Current	Operating Condition/Interlock Input

4.2.5-9 DA Screen Bias, Cathode Bias and Filament Supplies I & C - The I & C for the DA Screen Bias, Cathode Bias and Filament Supplies are shown in Figure 4.2.5-9. The Screen Supply has on/off commands and monitors, the Cathode Supply has an on/off command, a setpoint control and a setting monitor, the Filament Supply has an on/off command and a setting monitor. All three supplies have output voltage and current monitors. The Screen Supply, which will not normally operate over a wide range, is also provided with voltage and current exception warnings.

In summary, the I & C signals are:

Signal Name	Signal Type
DA Filament Supply On/Off Cmd.	Command Output
DA Filament Supply On/Off Status	Interlock/Status Input
DA Filament Supply Output Voltage	Operating Condition/Interlock Input
DA Filament Supply Output Current	Operating Condition/Interlock Input
DA Cathode Bias Supply On/Off Cmd.	Command Output
DA Cathode Bias Supply Setting Control Cmd.	Setpoint Output
DA Cathode Bias Supply Setting Monitor	Operating Condition/Interlock Input
DA Cathode Bias Supply Output Voltage	Operating Condition/Interlock Input
DA Cathode Bias Supply Output Current	Operating Condition/Interlock Input
DA Screen Bias Supply On/Off Cmd.	Command Output
DA Screen Bias Supply On/Off Status	Interlock/Status Input
DA Screen Bias Supply Output Voltage	Operating Condition/Interlock Input
DA Screen Bias Supply Output Current	Operating Condition/Interlock Input

Signal Name	Signal Type
DA Screen Bias Supply Output Voltage High Warning	Interlock/Status Input
DA Screen Bias Supply Output Voltage Low Warning	Interlock/Status Input
DA Screen Bias Supply Output Current High Warning	Interlock/Status Input

4.2.5-10 Final Power Amplifier I & C - Figure 4.2.5-10 shows the I & C for the FPA but not for its associated biasing and filament supplies, those are shown on Figure 4.2.5-11.

The FPA has water-cooling loops for the anode, one filament connector and the screen, and the other filament connector. It also has forced air cooling from an FPA fan which cools both the tetrode tube and two of its supplies. Input tuning is accomplished with motor-driven coaxial shorts. Output tuning is accomplished by a motor-driven coaxial short and a motor-driven plate cavity element. Input HV current is monitored as are the final output voltage and current. A summary of the I & C signals is the following:

Signal Name	Signal Type
FPA Air Temp High Warning	Interlock/Status Input
FPA Air Temp High Caution	Interlock/Status Input
FPA Air Temp Normal	Interlock/Status Input
FPA Air Flow	Interlock/Status Input
FPA Anode Water Temp High Warning	Interlock/Status Input

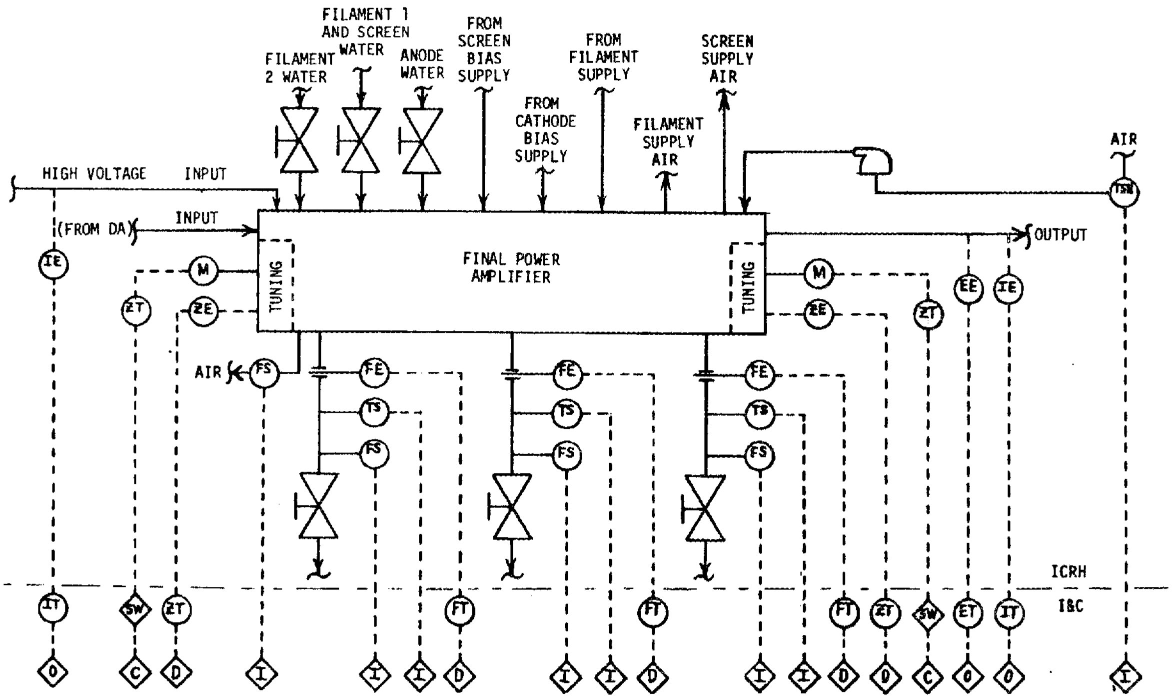


FIGURE 4.2.5–10 ICRH/I&C INTERFACE – FINAL POWER AMPLIFIER

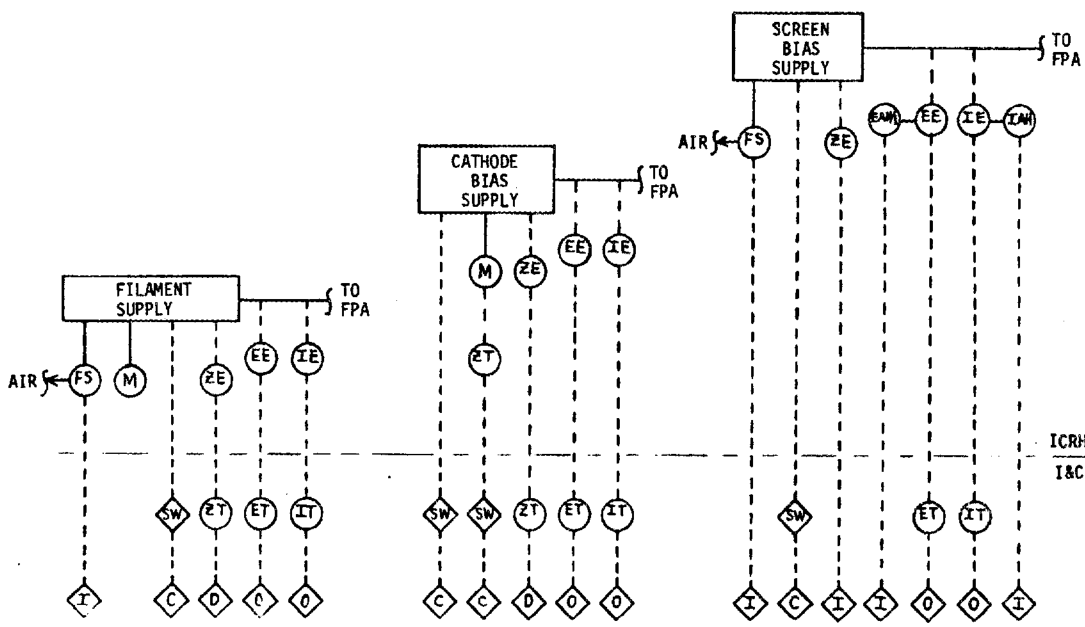


FIGURE 4.2.5–11 ICRH/I&C INTERFACE – BIAS SUPPLIES

Signal Name	Signal Type
FPA Anode Water Temp High Caution	Interlock/Status Input
FPA Anode Water Temp Normal	Interlock/Status Input
FPA Anode Water Flow	Interlock/Status Input
FPA Fil 1 & Screen Water Temp High Warning	Interlock/Status Input
FPA Fil 1 & Screen Water Temp High Caution	Interlock/Status Input
FPA Fil 1 & Screen Water Temp Normal	Interlock/Status Input
FPA Fil 1 & Screen Water Flow	Interlock/Status Input
FPA Filament 2 Water Temp High Warning	Interlock/Status Input
FPA Filament 2 Water Temp High Caution	Interlock/Status Input
FPA Filament 2 Water Temp Normal	Interlock/Status Input
FPA Filament 2 Water Flow	Interlock/Status Input
FPA Anode Water Flow Rate	Operating Condition/Data Input
FPA Fil 1 & Screen Water Flow Rate	Operating Condition/Data Input
FPA Filament 2 Water Flow Rate	Operating Condition/Data Input
FPA Input Timing Control Cmd.	Setpoint Output
FPA Input Timing Cavity Position	Operating Condition/Data Input

Signal Name	Signal Type
FPA Output Timing Control Cmd.	Setpoint Output
FPA Output Timing Cavity Position	Operating Condition/Data Input
High Voltage FPA Current	Operating Condition/Interlock Input
FPA Output Voltage	Operating Condition/Interlock Input
FPA Output Current	Operating Condition/Interlock Input

4.2.5-11 FPA Screen Bias, Cathode Bias, and Filament Supplies I & C - The I & C for the FPA Screen Bias, Cathode Bias and Filament Supplies is shown in Figure 4.2.5-11. It can be seen that the I & C of these FPA supplies are very similar to the corresponding I & C for the Driver Amplifier, presented in Section 4.2.5-9. The only difference between the two is the presence of cooling air in the FPA screen and filament supplies. A complete list of the FPA suplies I & C is the following:

Signal Name	Signal Type
FPA Filament Supply On/Off Cmd.	Command Output
FPA Filament Supply On/Off Status	Interlock/Status Input
FPA Filament Supply Output Voltage	Interlock/Status Input
FPA Filament Supply Output Current	Interlock/Status Input
FPA Filament Supply Air Flow	Interlock/Status Input
FPA Cathode Bias Supply On/Off Cmd.	Command Output
FPA Cathode Bias Supply Setting Control Cmd.	Setpoint Output

Signal Name	Signal Type
FPA Cathode Bias Supply Setting Monitor	Operating Condition/Interlock Input
FPA Cathode Bias Supply Output Voltage	Operating Condition/Interlock Input
FPA Cathode Bias Supply Output Current	Operating Condition/Interlock Input
FPA Screen Bias Supply On/Off Cmd.	Command Output
FPA Screen Bias Supply On/Off Status	Interlock/Status Input
FPA Screen Bias Supply Output Voltage	Operating Condition/Interlock Input
FPA Screen Bias Supply Output Current	Operating Condition/Interlock Input
FPA Screen Bias Supply Output Voltage High Warning	Interlock/Status Input
FPA Screen Bias Supply Output Voltage Low Warning	Interlock/Status Input
FPA Screen Bias Supply Output Current High Warning	Interlock/Status Input
FPA Screen Bias Supply Air Flow	Interlock/Status Input

4.2.5-12 Power Supply Pad Remote I & C - Instrumentation and Control for the ICRH on the power supply pad is diagrammed in Figure 4.2.5-12.

The I & C interfaces are located in three NEMA cabinets set on the power supply pad. The cabinet dedicated to ICRH interfaces is located in the circled area. The interface located in each NEMA cabinet is that between the I & C system supplied by MDAC and

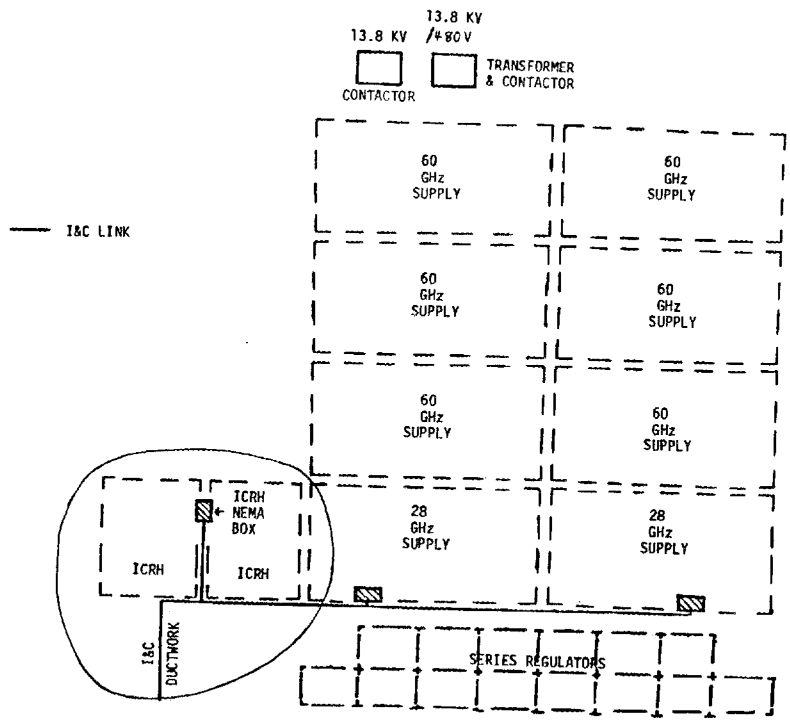


FIGURE 4.2.5–12 FIELD CABLE ROUTING – POWER SUPPLY PAD

the sensor and control wires supplied by the transmitter vendor. The transmitter vendor will design the wiring from sensors and controls to the NEMA cabinets.

Inside the NEMA cabinets are process controller and CAMAC remote I/O modules their power supplies and air temperature control equipment. Both the PC and CAMAC I/O modules operate with standard process control signals. Analog input signals operate from 4 to 20 ma current loops. Discrete are 0 or 24 volt levels. Control output signals are 0, 24 volt discretes and 4-20 ma analogs. As with ECRH, the PC handles all control outputs and all inputs on which automatic control is based. CAMAC handles input signals used for information only.

To connect the I/O modules to the rest of the I & C system, standard digital data highways are used. PC manufacturers produce isolated, shielded coaxial cable data highways, and the possibility of a fiber optic data link is being investigated. Fiber optic data links are used for the CAMAC data highway.

4.2.6 Torodial Vessel/Limiter I & C Interface - This interface consists of the following components:

a) Sensors and control/interlock elements associated with the cooling loops for magnet liner sections of the toroidal vessel;
b) Sensors and control/interlock elements associated with the cooling loops for the toroidal vessel microwave cavity sections;
c) Sensors and control/interlock elements associated with the limiter cooling loops;
d) Stepper-motor positioning units for selected limiter segments;
e) Thermocouple instrumentation on various TVL components.

The toroidal vessel has 540 associated cooling loops; the limiters have 144 loops (four limiter segments per EBT-P cavity). Twenty-four limiter segments are equipped with stepper motors to permit remote-controlled positioning operations.

A compromise approach is used for the design of this interface which provides for six fully-instrumented sectors and thirty standard sectors. Figure 4.2.6-1 shows the process diagram for the former. The fully-instrumented sectors contain the necessary instrumentation required to measure heat loads on all sector components (magnet liners, microwave cavities, limiters, microwave screens). In addition, the limiter segments in these six sectors are equipped with remotely-controllable stepper motor positioning equipment.

Figure 4.2.6-2 shows the process diagram for the thirty standard segments. Instrumentation is provided to measure the heat load on each limiter segment; coolant loops for other components are equipped with flow and temperature switches for interlock purposes.

The six fully-instrumented sectors are located symmetrically around the EBT-P device (cavities 1, 6, 12, 18, 24, 30). The principal function of the instrumentation on these sectors is to provide the means for experimentally determining the positions required of the limiter segments in order to balance the heat load around the torus. A possible scenario involves low power device operation with combined 28 and 60 GHz heating sources (~50 KW at each frequency) and the limiters in the thirty standard cavities withdrawn such that these do not function as true limiters. Next, the twenty four stepper-motor-driven limiter segments are adjusted such that the heat loads in the six fully-instrumented cavities are balanced. With the EBT-P device in the powered-down state, the remaining 120 limiter segments are manually re-adjusted to match the positions of the 24 special segments. This process is repeated until a balanced heat load state is achieved with all limiter segments positioned such that the magnet liner segments are properly protected (i.e., are in the shadow of a limiter segment).

The design of this interface is configured such that it is possible to assemble the majority of TVL I & C components in sub-assemblies. Figure 4.2.6-3 shows the position of TVL component mounting panels in relation to the EBT-P device. Twelve such sub-assemblies are needed, six panels carrying the limiter cooling loop instrumentation and six panels carrying other I & C hardware associated with the six fully-instrumented sectors. Those cooling loops with only flow and temperature switches do not require such sub-assemblies; rather these loops are supplied and drained by taps on six large cooling manifold positioned around the concrete support structure. These loops are connected by conventional plumbing techniques at the ORVIP site.

The TVL panels contain the major I & C components required for heat load measurement, namely differential temperature sensors and flow sensors. Figure 4.2.6-4 shows the signal channel layouts for these sensors and for the flow and temperature interlock switches. The ΔT sensors are provided with signal transmitter units located in close proximity to the TVL panels (see Section 5.3 which contains details of the trade study that establishes the need for these signal transmitters). As the signal transmitters contain integrated circuit components that are not x-ray hardened, these units are attached to the inner vertical surface of the concrete device support structure (see Figure 4.2.6-3). This positioning places the signal transmitters in an x-ray shadow region in which the x-ray flux rate is $\sim 10^{-3}$ of the typical rate within the shield room.

The TVL flow rate sensors are differential pressure units which measure the pressure drop across an orifice in the cooling loop. Flow rate is proportional to $\sqrt{\Delta p}$. These sensors are linear potentiometers (Vernitech Model 6100) which are powered by +24 Vdc and which do not require signal transmitters.

The ΔT and the Δp units are Class A sensors which are used to monitor, but not to control, the TVL cooling process. These sensors are handled by the DAS microprocessor/CAMAC integral subsystem. In contrast, the temperature and flow switches are part of the TVL interlock system (type I inputs) and are connected to the TVL remote I/O interface.

The TVL system requires a relatively small number of control elements. The large majority of valves in the TVL cooling system are manual hand valves. The exceptions are the six valves which are located between the main cooling input manifold and the six limiter cooling panels. These valves are equipped with pneumatic actuators which connect to the TVL PC remote I/O units. The limiters are critical device components which are highly stressed by the imposed heat loads and are susceptible to a major device fault condition, i.e., limiter burnthough. The six limiter valves have to be quickly cycled by the TVL PC unit should burnthough be detected to minimize damage to the toroidal vessel, i.e., flooding. The detection means are the vacuum system ion gauge overpressure interlocks which are sensed by the TVL PC I/O units.

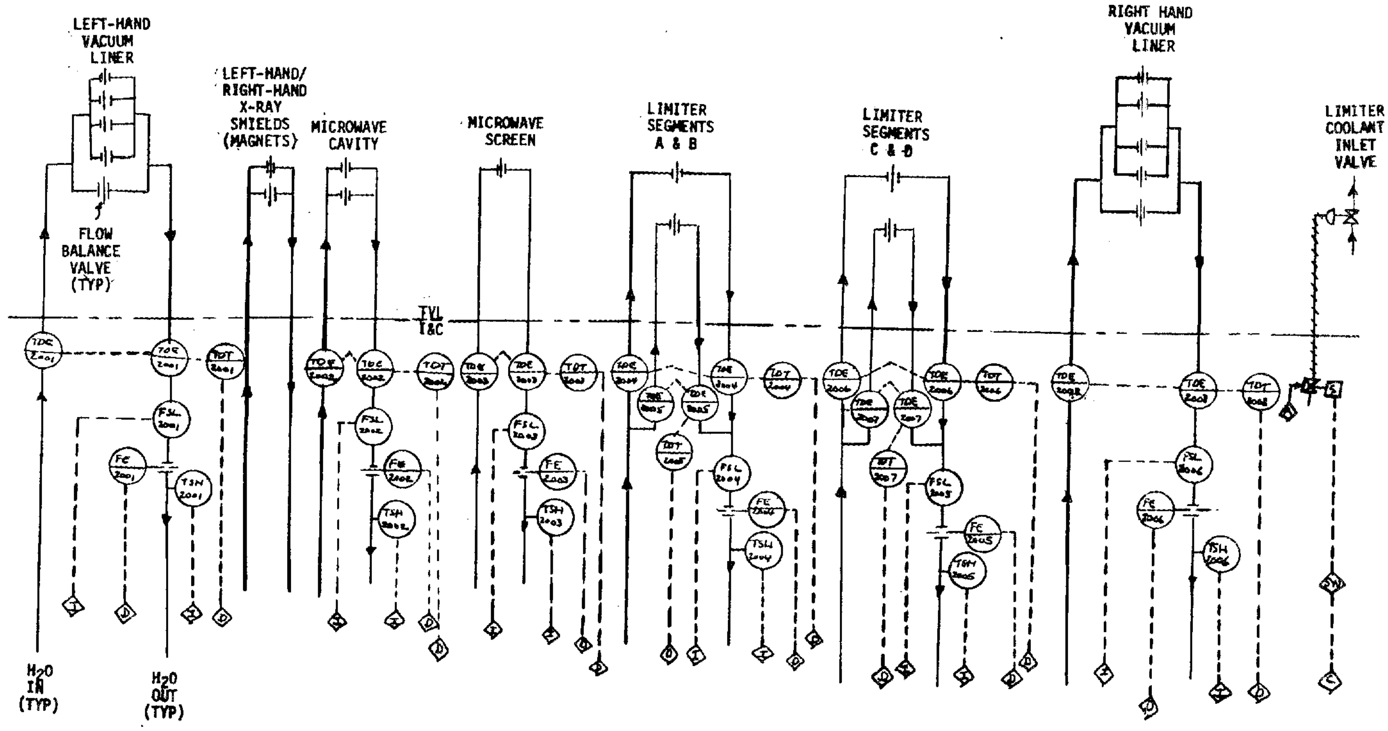


FIGURE 4.2.6–1 TVC FULLY INSTRUMENTED SECTOR – 1 OF 6

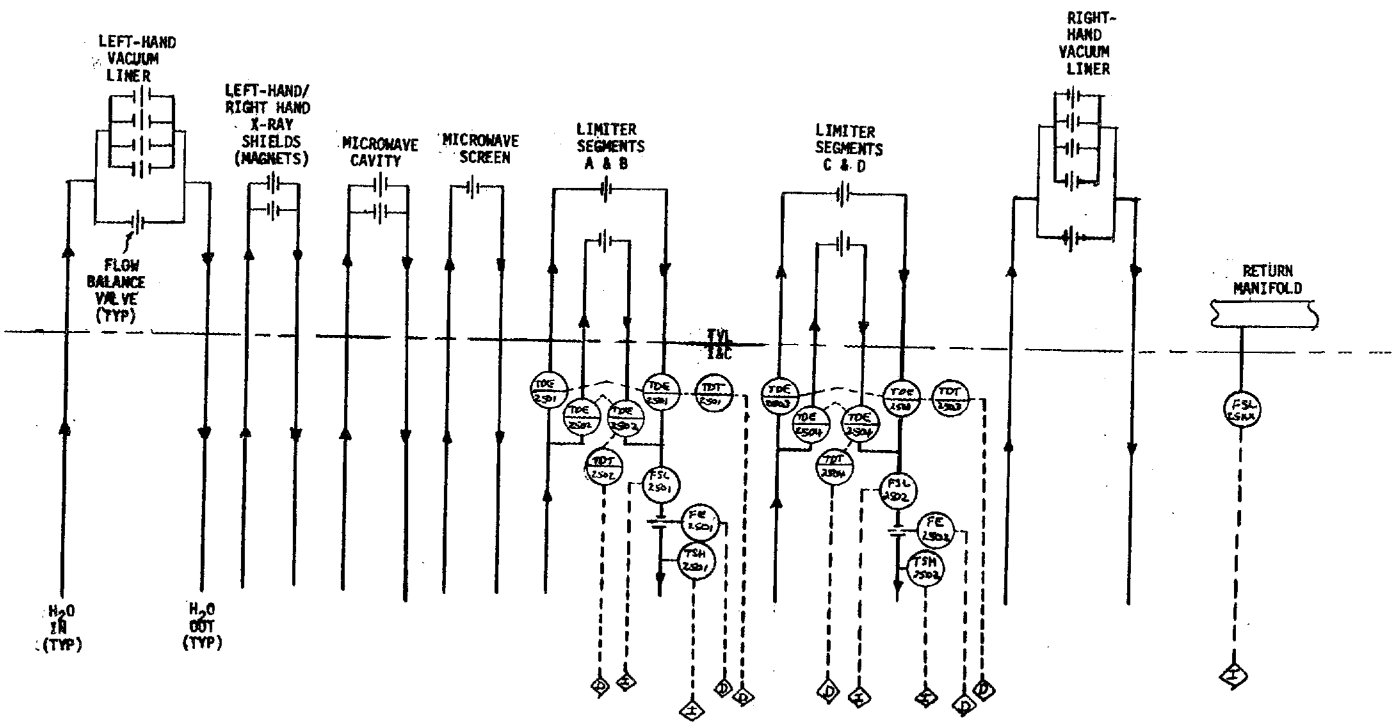


FIGURE 4.2.6–2 TVL STANDARD SECTOR – 1 OF 30

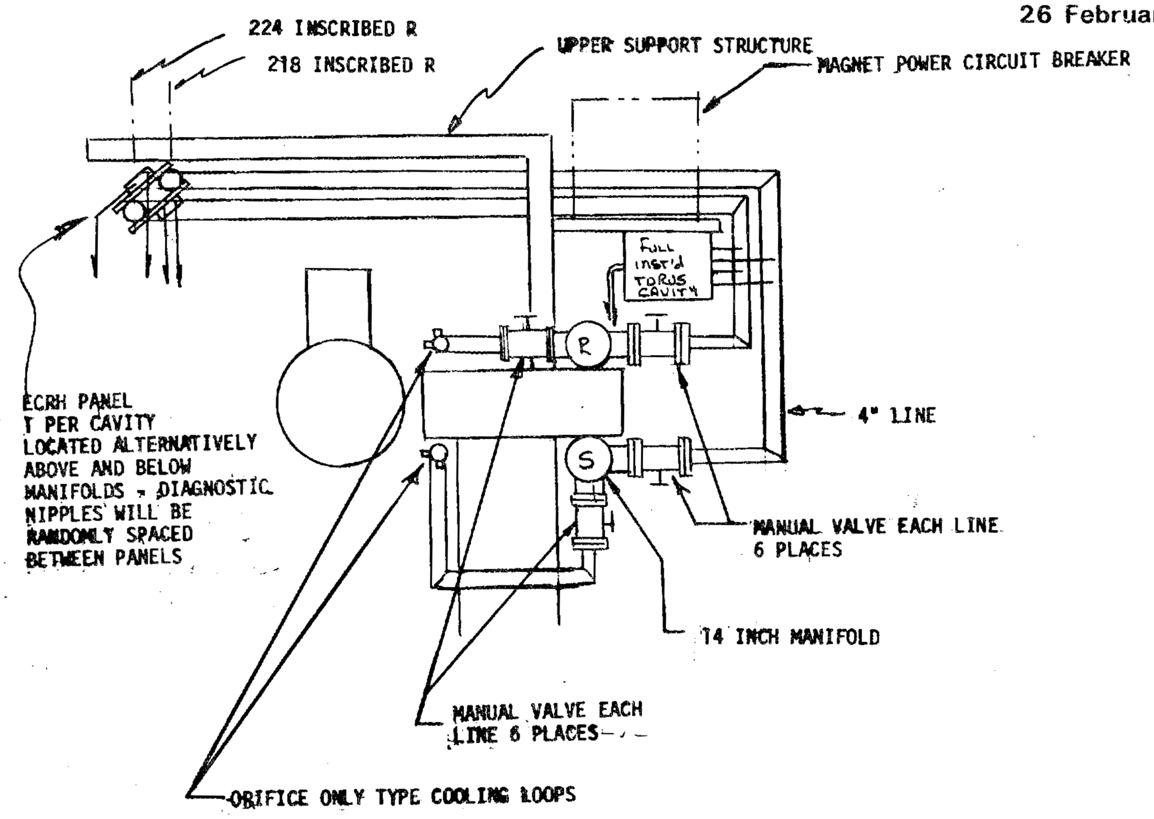


FIGURE 4.2.6–3 TVL COMPONENT MOUNTING PANEL LAYOUT

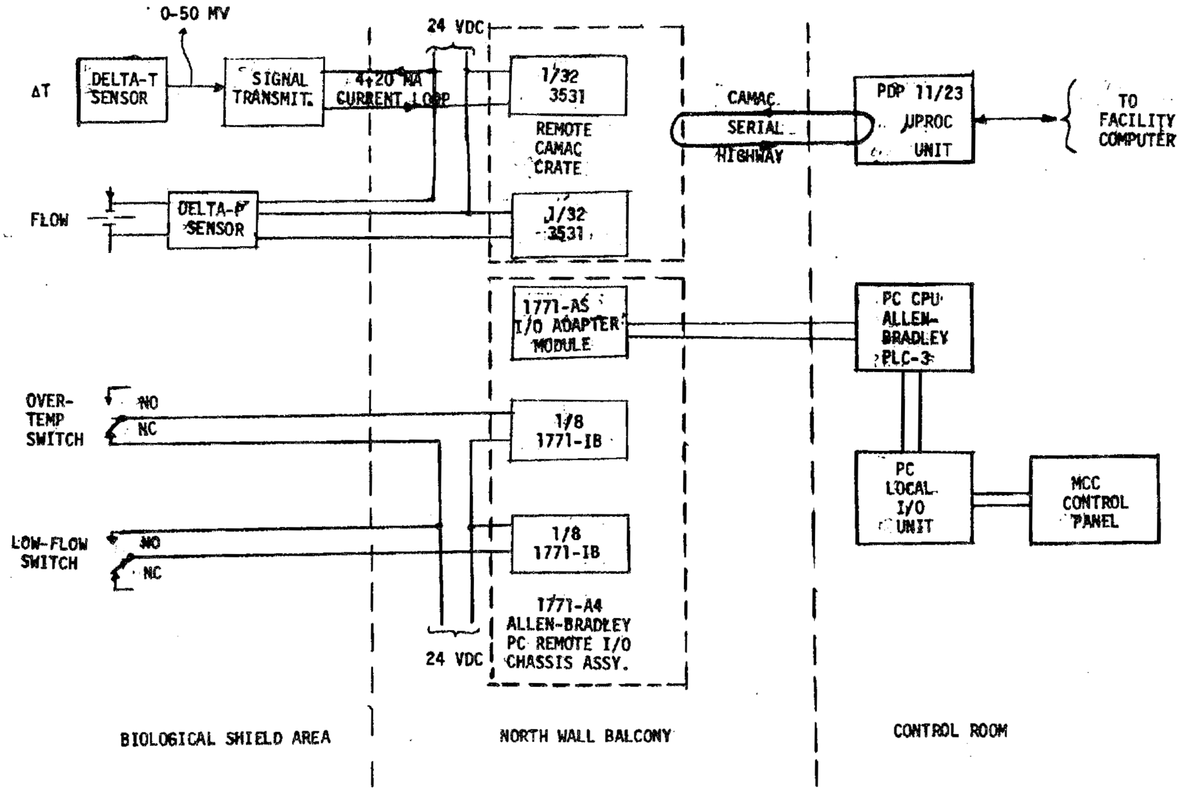


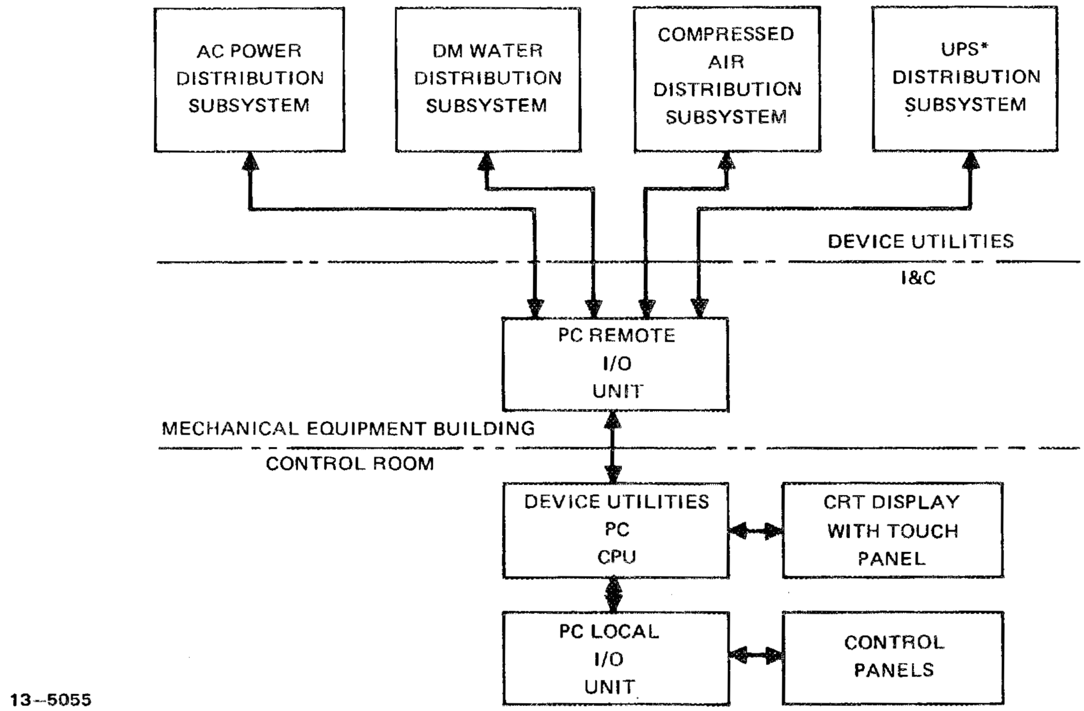
FIGURE 4.2.6–4 TVL DATA CHANNEL LAYOUT

The remaining TVL control components are twenty-four stepper-motor controllers. These units are controlled by the operator at the MCC station assigned jointly to the vacuum and TVL systems and are the means for remote adjustment of limiter position. Linear potentiometer position sensors are connected to each adjustable limiter and provide position feedback information via the DAS microprocessor/facility computer at the MCC CRT terminal. Operator demands to the stepper-motor controllers are directed to the TVL PC unit.

The final group of TVL instrumentation consist of thermocouple elements placed inside the EBT-P device on several limiter segments and on the interior surface of several magnet liners. The four limiter segments in device sector # 32 are provided with TCs buried within the limiter structures during the fabrication process. These sensors are arranged to measure temperature distributions on the limiters and magnet liners. These thermocouples are Class A sensors used to provide temperature distribution data to the facility computer archive via the DAS microprocessor/CAMAC interface. These data are not used for control/interlock purposes.

4.2.7 Device Utilities I&C Interface - This interface is shown in Fig. 4.2.7-1 in block diagram form. The details of this interface in terms of process diagrams and signal channel layouts will be developed during the EBT-P facilities Title II effort. The present concept calls for this interface to be made to the device utilities PC remote I/O unit located in the Mechanical Equipment Building. The PC CPU is located in the control room in a NEMA-12 enclosure (designated N4 on Drawing 70B378011). The control panels for the device utilities interface are located in 19 inch instrumentation racks (designated L-3 thru L-8). Device utilities status is displayed via one or more CRT units driven by the PC CPU. Touch panel interfaces are used to enable the operator to select various data display formats.

4.2.8 Helium Refigerator I&C Interface - This interface is shown in Fig. 4.2.8-1. The helium refrigerator is a self-contained system designed, fabricated and installed by a selected vendor per MDAC-STL specification. The refrigerator has two control centers, a remote center located in the mechanical equipment building in close proximity to the cold box, and local control center in the EBT-P control room (northwest corner). The latter unit contains a mimic display showing the internal flow paths and control elements of the



*UNINTERRUPTABLE POWER SOURCE

FIGURE 4.2.7–1 DEVICE UTILITIES I&C INTERFACE

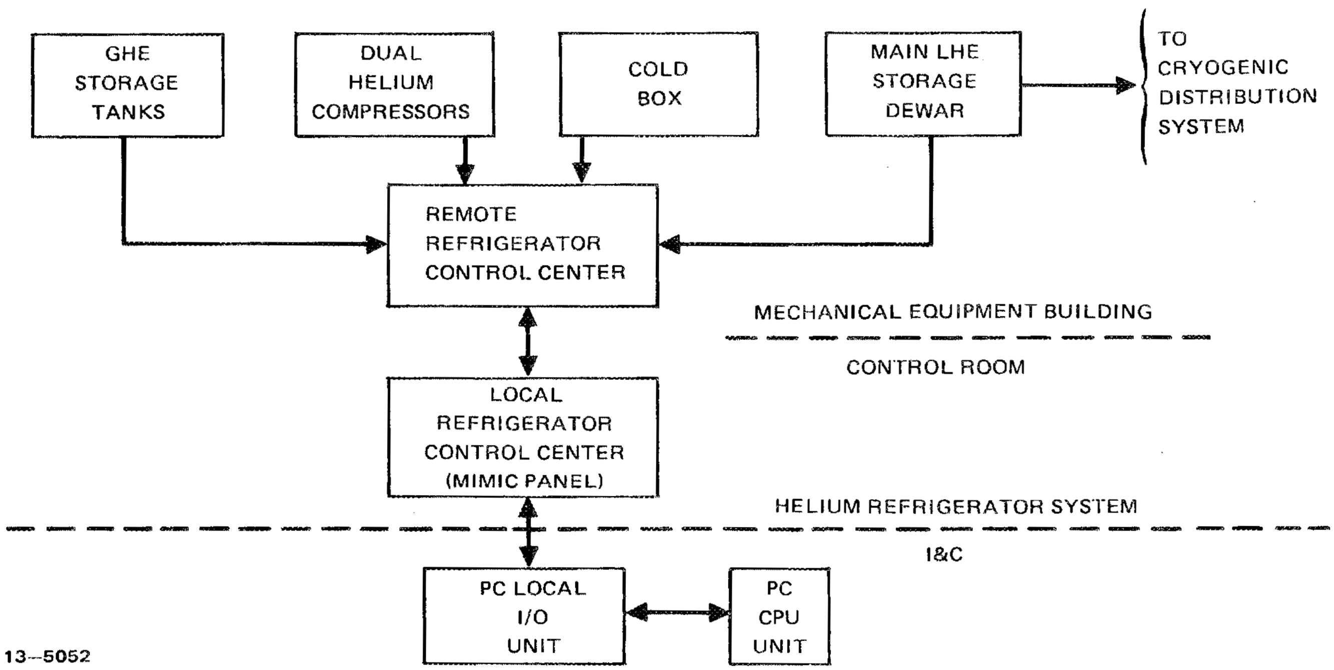


FIGURE 4.2.8–1 HELIUM REFRIGERATOR I&C INTERFACE

refrigerator. It is assumed that refrigerator operation will be unattended. The local control center is provided with an interface to the PC unit which handles device utilities. Refrigerator status information passes through this interface; the PC unit has no control function relating to refrigerator operation. The PC unit uses these status data to interlock other device processes which depend on refrigerator operation. The precise design details for this interface will be generated during I&C Title II after the helium refrigerator specification has been developed.

4.2.9 Plasma Operation Device Instrumentation (PODI) Interface - This interface consists of four parts:

a) Hard x-ray detector interface;
b) Diagnostic loop interface;
c) Global Field Error Correction Coil (GFECC) interface;
d) Plasma TV interface.

The PODI units are used by machine operators to monitor the state of the plasma and to aid in setting the desired operation mode (C-, T- or M-mode). The PODI is not, strictly-speaking, part of the I&C system as the PODI costs are allocated to operations budgets (WBS 6.X). However, the PODI interface is described in this volume of the Title I Final Report because of the tight interface between PODI and the I&C system.

Six NaI (Tℓ) scintillation detectors are provided to monitor the hard x-ray production due to the annulus. The detectors view the annulus through the bottom ports in cavities (TBD). Figure 4.2.9-1 shows the signal channel layout and the CAMAC interface. Single-channel CAMAC scalers are used in the pulse-counting mode. The output from these detectors are displayed in digital and/or graphical from via a CRT terminal connected to the PODI microprocessor unit (a PDP 11/23 system). Trend data can be viewed via this terminal while adjustments are made on GH_2 bleed pressure and microwave ECRH power level. These displays can be hard-copied using a Tektronic 4632 dry-silver copier attached to the CRT terminal video output port.

Figure 4.2.9-2 shows the signal channel layout for the diamagnetic loops. These units are identical in design and function to those used for EBT-S, but are adjusted in outer diame-

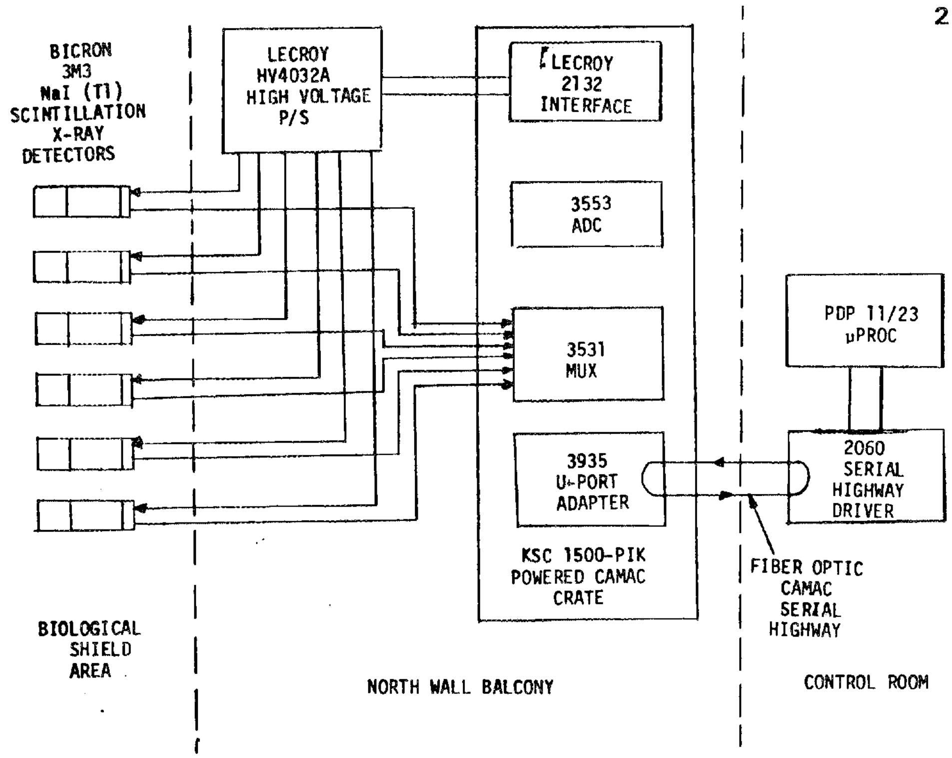


FIGURE 4.2.9–1 PODI – HARD X-RAY DETECTOR CHANNEL DIAGRAM

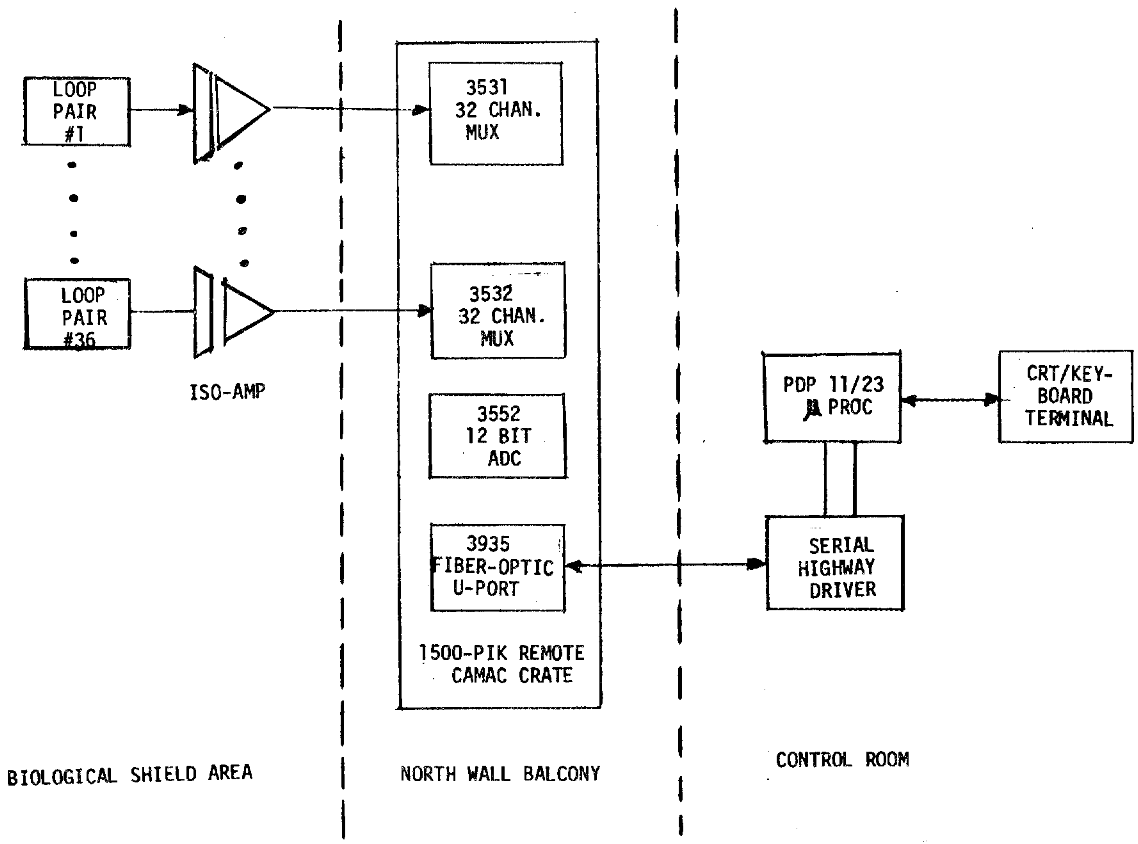


FIGURE 4.2.9–2 DIAMAGNETIC LOOP SIGNAL CHANNELS

ter and number of turns to handle EBT-P conditions. Each EBT-P microwave cavity section has a pair of loops attached to the main flanges (see Fig 4.2.9-3). The loop pairs are connected in series, electronally, and input to a differential-type isolation amplifiers. The iso-amps are positioned close to the loops in the protective zone (x-ray shadow) provided by the concrete support ring. The output of the iso-amp is a 0-10 volt signal which is input to a multiplexed CAMAC 12-bit analog-to-digital converter (ADC). Loop signals are processed by the PODI microprocesser unit (a PDP 11/23) and displayed via a CRT/keyboard unit. Trend data (integrated loop output) can be simulataneously displayed for four selected loop pairs via the CRT terminal.

This diamagnetic loop interface differs in several respects from the one used for EBT-S. First, this approach uses software integration methods whereas EBT-S uses hardwired analog integrators. The software approach is selected to capitalize on the capabilities of the PODI microprocessor and to reduce cost by eliminating the need for developing analog integrator circuits. Second, this approach does not use the elaborate EBT-S methods for reducing noise coupling to the loops. EBT-S mirror coils are low-inductance units driven by motor-generator sets (one set drives six series-connected EBT-S mirror coils). This arrangement results in current (and applied magnet field) fluctuations on the order of $\pm 0.1\%$ which appear as noise in the EBT-S loop signals. The EBT-S integrators have auxiliary circuits on the inputs to compensate for (buck out) these noise signals. By contrast, EBT-P provides a much more beneficent environment for the loop. The EBT-P mirror coils are high-inductance units series-connected ($\sim$ 36H) across a low-ripple, low-drift DC power supply. The result is a very "quiet" magnetic environment (fluctuation level $<$ 0.001% of applied field) which eliminates the need for compensation circuits on the iso-amps. This argument neglects, however, what can be called a second order effect which may be exhibited by the EBT-P mirror coils, namely flux-jump phenomena. The effects of flux-jumps are presently unknown and should be studied as part of the EBT-P magnet development program to determine whether the diamagnetic loops will be susceptable to noise pickup from this source.

The third PODI interface involves the global field error correction coil (GFECC) system. Four toroidal coils are used to null field errors in EBT-P (Fig. 4.2.9-4). The coils are fabricated of square copper tubing, six turns per coil. Because of the large major radius, these coils are designed as four 90° sections. At the joints between coil sections, the six turns are

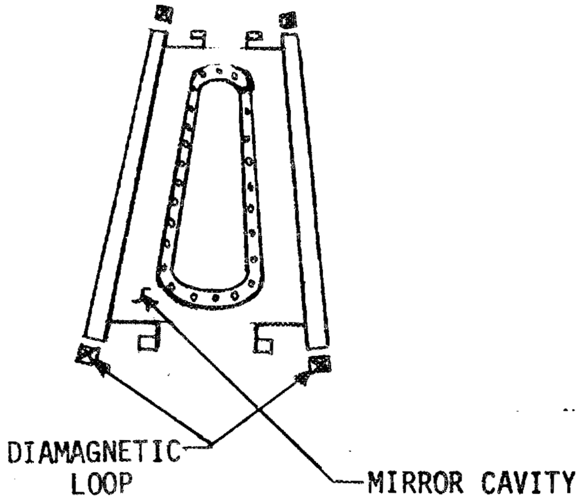


FIGURE 4.2.9–3 DIAMAGNETIC LOOP LOCATIONS

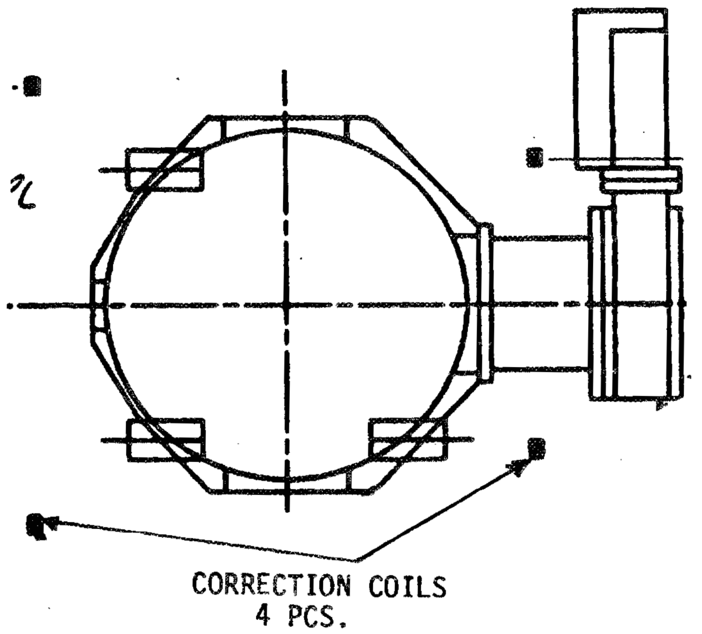


FIGURE 4.2.9–4 GLOBAL FIELD ERROR CORRECTION COIL LOCATIONS

series-connected via copper buses bars. These turns are also parallel-connected to the facility cooling system.

The signal channel layout for the GFECC system is shown in Fig. 4.2.9-5. The flow and overtemp switches provide interlock inputs (I) to the PC unit associated with the PODI system. Two DC power supplies are used to power the four correction coils, two coils in series across each supply. About 1400 amps are required to produce $5x10^{-3}$T at the center of the mirror coils. The output current from the DC power supply is controlled via a 3-turn potentiometer and the PC unit.

The plasma TV unit is located on cavity #7, Figure 4.2.9-6. The color TV camera is positioned outside the concrete shield and views the plasma via a periscopic optical transfer system. The camera is equipped with a telephoto zoom lens, automatic iris mechanism and remote controls. The control panel for the camera is located at diagnostic station #2 in the control room. Two color monitors are provided, one at the control panel and the other at the vacuum MCC station.

4.3 SECONDARY I & C INTERFACES

This section contains design details for three I & C interfaces:

- Grounding System Interface
- Research Diagnostics Computer Network Interface
- Research Diagnostics Microprocessor Interface

The first and third interfaces are required to support the I & C basic mission, viz EBT-P device/facility operation. The second interface is provided to support the needs of research diagnostic specialists for device operation data to assist in plasma parameters measurement.

4.3.1 Grounding System Interface - The EBT-P facility ground system provides three major services for the I & C system:

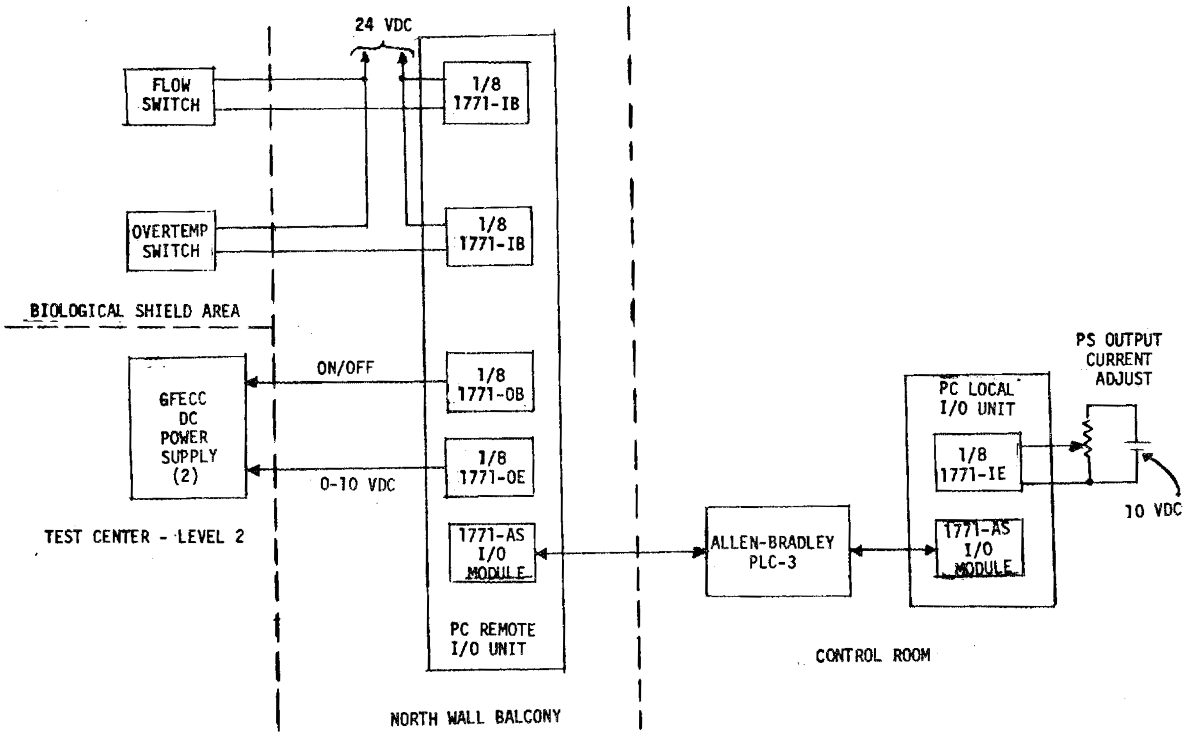


FIGURE 4.2.9–5 GFECC SYSTEM SIGNAL CHANNEL DIAGRAM

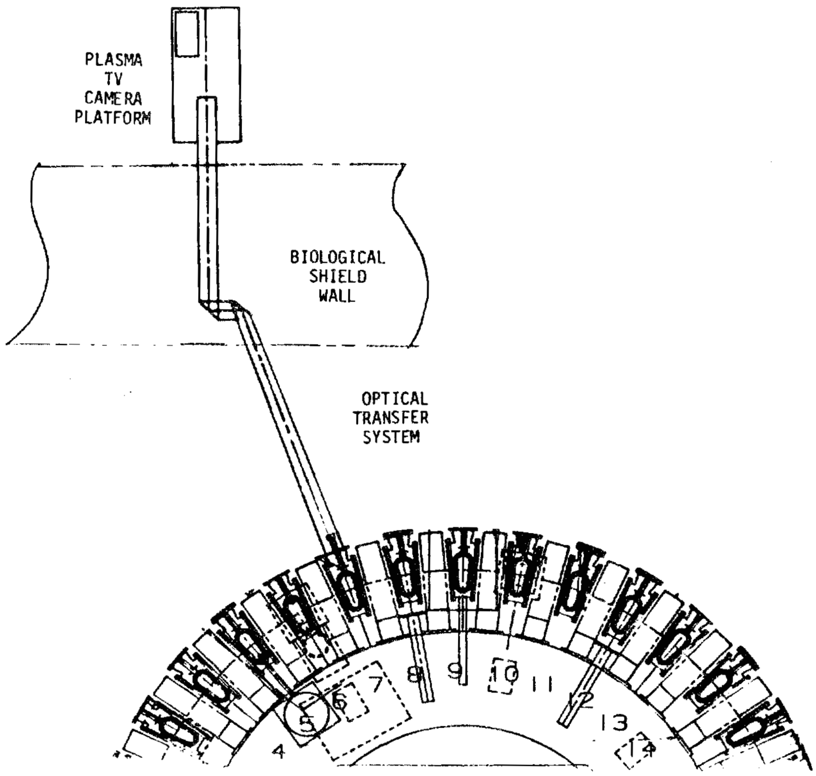


FIGURE 4.2.9–6 PLASMA TV SYSTEM BASIC DIAGRAM

a) A low-resistance connection to earth for low frequency (<100 KHz) signal referencing needs;
b) A means to provide a secure connection to earth for I & C-related components to minimize personnel safety problems;
c) A means to drain conducted RF noise to ground and thereby control a potentially important noise source for the benefit of the I & C system.

Item a) is based on the facility earth electrode subsystem, see Fig. 4.3.1-1. An array of vertical ground rods (copper-clad steel rods, 3/4 in. dia x 10 ft. long) is installed in the earth below the Test Center and the Mechanical Equipment Buildings. These rods are interconnected by buried horizontal bare 4/0 cables to form the earth electrode per sec. The design criteria requires that the DC resistance of the electrode be $\leqslant$ 1 ohm. The top of selected ground rods are accessable such that connections can be secured to the earth electrode for I & C grounding needs.

A number of connect points to the earth electrode are provided within the Test Center Building. On Level One, branch ground plates are located at several points inside the building (see Fig. 4.3.1-2). These plates are 4" x 6" x 0.5" thick copper plates attached to the building structure via insulated mounting spacers. These plates are connected to the earth electrode using insulated standard copper trunk cables (4/0 size). Branch cables are routed from the branch ground plates to various I & C components using insulated standard copper branch cables sized according to the design criterion.

Minimum wire cross section (in cmil) = length of branch cable in feet x500 cmil/ft.

This criterion limits the DC resistance between any two points to 20 milliohms.

A similar arrangement of branch ground plates is installed on Level Two of the Test Center Building, Fig. 4.3.1-3. In particular, a plate located along the north wall of the control room forms the basis of a ground structure resembling a tree. This tree forms an isolated single-point ground for the I & C equipment located in the Control Room. The tree is constructed using insulated standarded copper cable according to the design criterion stated above. The tree is distributed around the Control Room via the overhead cable ducts.

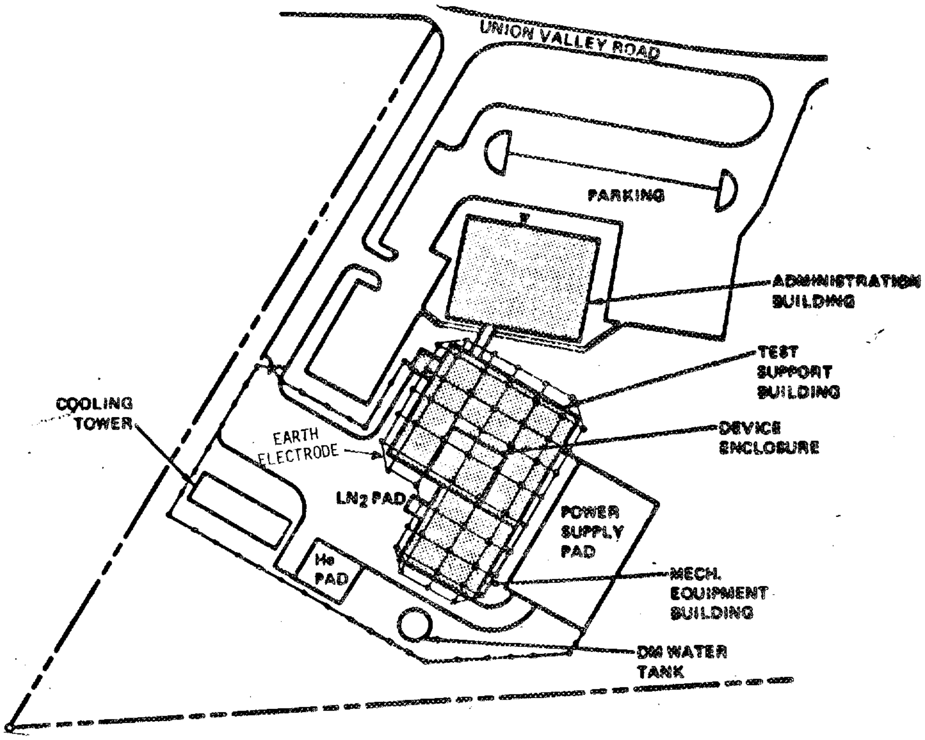


FIGURE 4.3.1–1 TEST SUPPORT BUILDING EARTH ELECTRODE

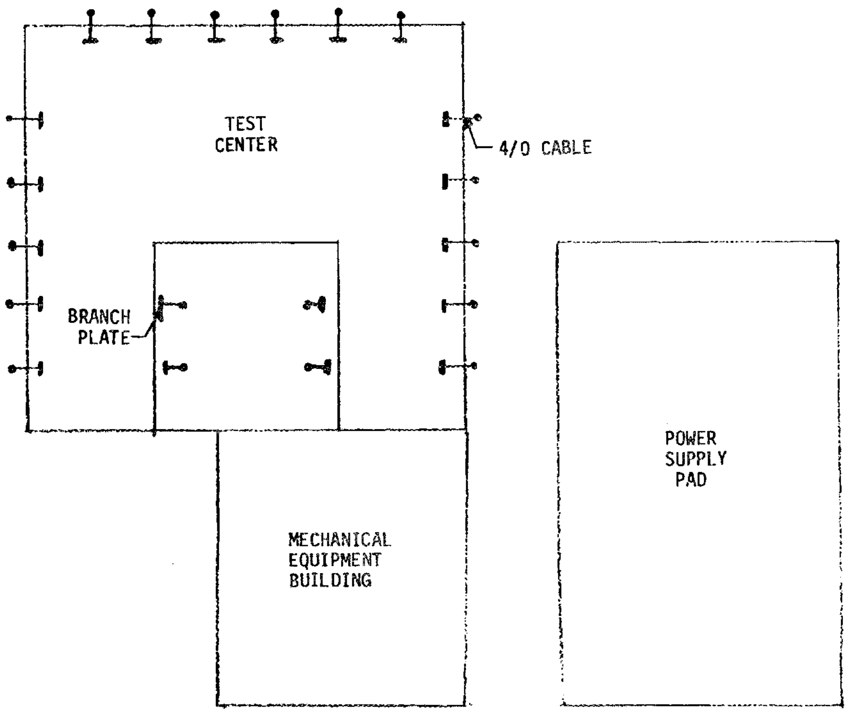


FIGURE 4.3.1–2 GROUND SYSTEM BRANCH PLATE LAYOUT – TEST CENTER – LEVEL ONE

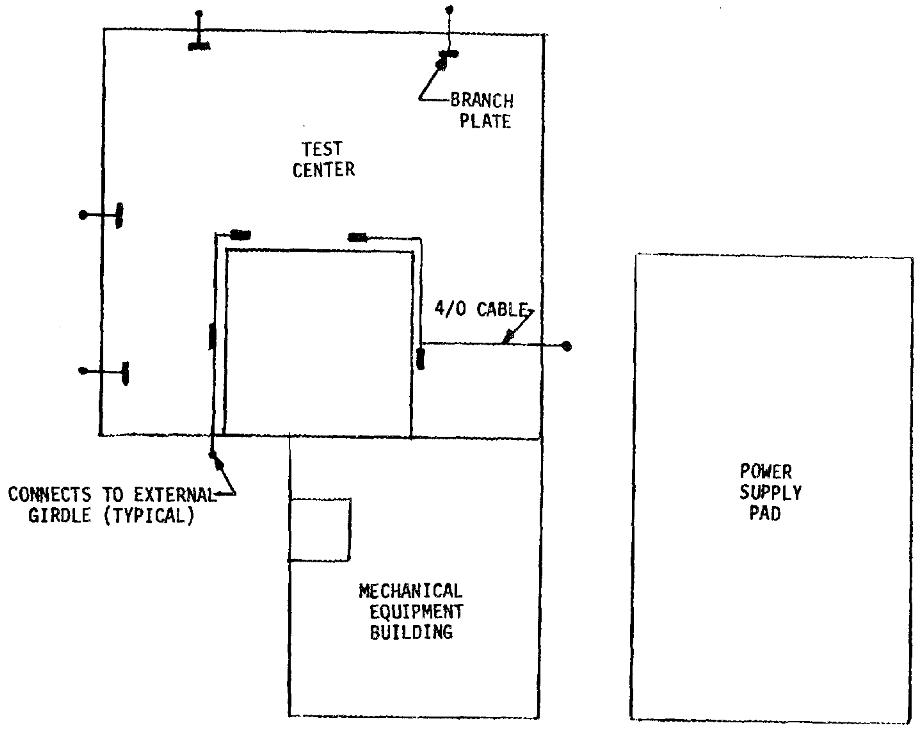


FIGURE 4.3.1–3 GROUND SYSTEM BRANCH PLATE LAYOUT – TEST CENTER – LEVEL TWO

Instrumentation racks and control consoles are configured such that the isolated single-point ground design is not compromised by short-circuit to rack frames (see Fig. 4.3.1-4). Each rack and console unit has an isolated buss bar (0.5" x 1.5" x TBD length) which is connected to the branch cables forming the tree. A typical connection for CAMAC units is shown in Fig. 4.3.1-5.

The Control Room ground tree structure is routed via the main cable bridge to the North Wall Balcony. The racks located on the balcony are configured with internal buss bars to implement a single-point isolated ground for I & C equipment installed there.

Further extension of the tree into the Torus Room is possible if a need arises. This issue will be settled during Title II design during which I & C signal channel grounding and shielding issues will be resolved on a channel-by-channel basis.

Note that branch ground plates are provided in the various laboratory areas on Level Two of the Test Center Building. These plates form the bases for isolated single-point grounding structures in these areas as the needs arise. Likewise, branch ground plates are installed such that research diagnostics equipment on Level Two have access to an earth electrode tie-in point.

Item b, personnel safety grounds, are implemented via two measures. Each I & C rack and control console is solidly grounded to the ac power distribution code ground (green wire). This connection is needed to satisfy National Electrical Code (NEC) requirements for personnel safety. In addition, each I & C rack and control console unit is connected to the earth electrode using a dedicated safety ground cable. This connection provides a backup for the green wire and is completely independent of the isolated single-point I & C ground connection, item a).

Item c, grounding for RF noise control, is a requirement which has been levied on the EBT-P facility design. The effective control of conducted RF noise requires a multiple-ground approach and is implemented as follows:

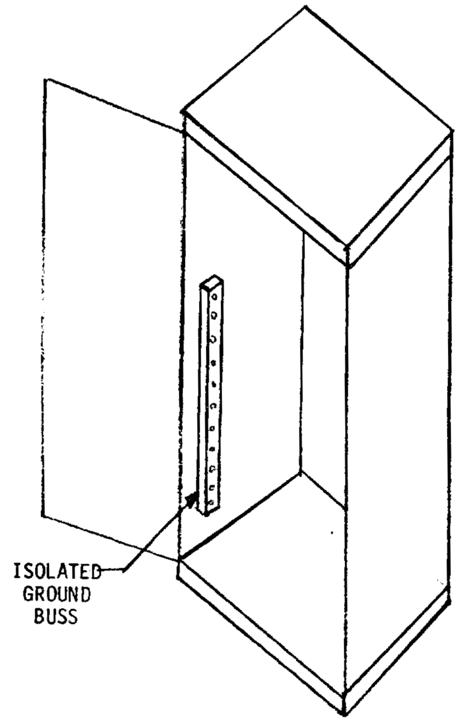


FIGURE 4.3.1–4 ISOLATED INSTRUMENTATION RACK GROUND BUSS

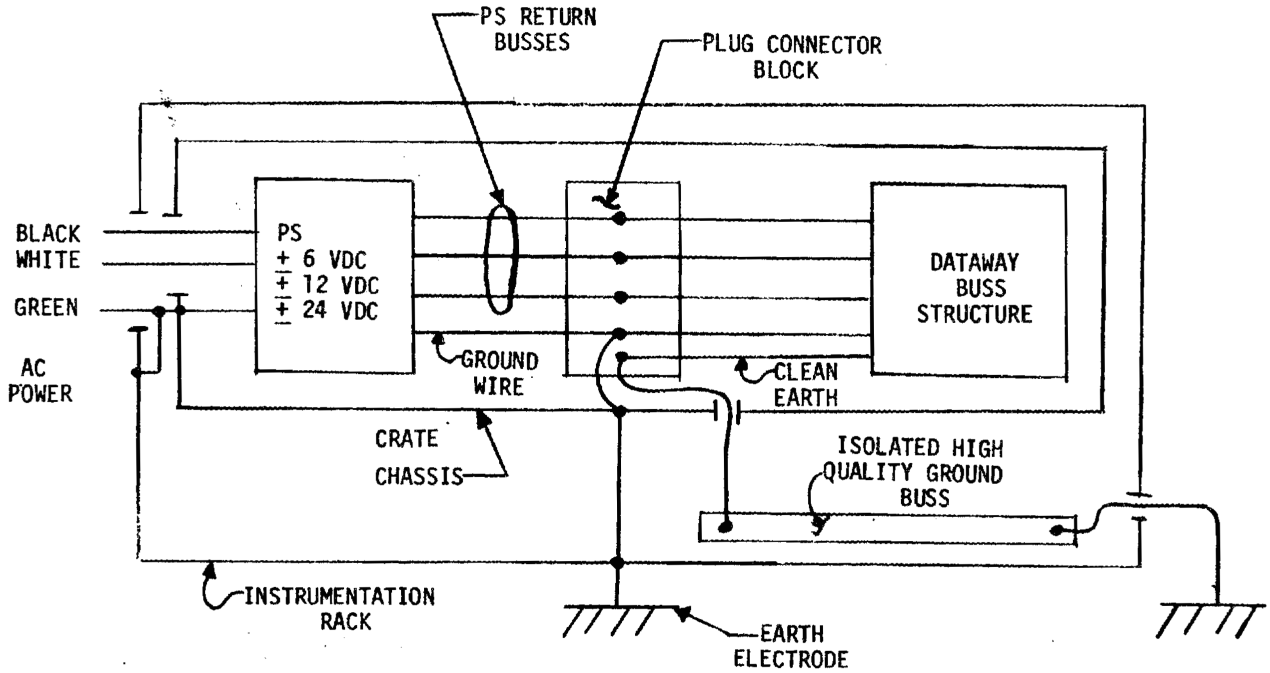


FIGURE 4.3.1–5 CAMAC CRATE GROUNDING CIRCUIT

1) Test Center Building structure components (I-beams, metal sidewall panels, metal flooring supports and roof panels) are electrically-bonded via direct welding and/or welded straps such that the entire structure is electrically continuous.
2) Test Center Building structure is connected to the earth electrode at numerous points to effectively drain RF noise currents to earth.
3) I & C cable trays and dusts are multiply-connected to the Test Center structure such that many paths exist to drain RF currents to earth.
4) Concrete rebar is welded into an electrically-continuous structure and solidly connected to the earth electrode.
5) The EBT-P device (TF coil structure and the main torodial vacuum vessel) is multiply-connected to the earth electrode via the rebar in the concrete support ring and via separate ground cables as required.

There are several additional issues involved in the design of the I & C grounding interface. First, a number of I & C sensors are unavoidably connected to the EBT-P device. These grounded sensors introduces the possibility of ground loops and require some means for ground loop disruption. The method selected as a result of a trade study performed in Title I (see Sec. 5.3) is to use an isolating-type signal transmitter to interface the sensor to either the DAS CAMAC system or to the PC I/O units. The isolating signal transmitter changes the sensor output to a 4-20 ma current signal for transmission to the CAMAC and PC I/O system.

Second, because of the connections between the grounding system and the I & C system, the latter becomes susceptable to faults which might introduce high current and/or voltage surges into the ground system. Faults in the magnet DC power supply or in the plamsa heating system power supplies are typical conditions which are of concern. Personnel safety is the first concern; equipment protection is secondary.

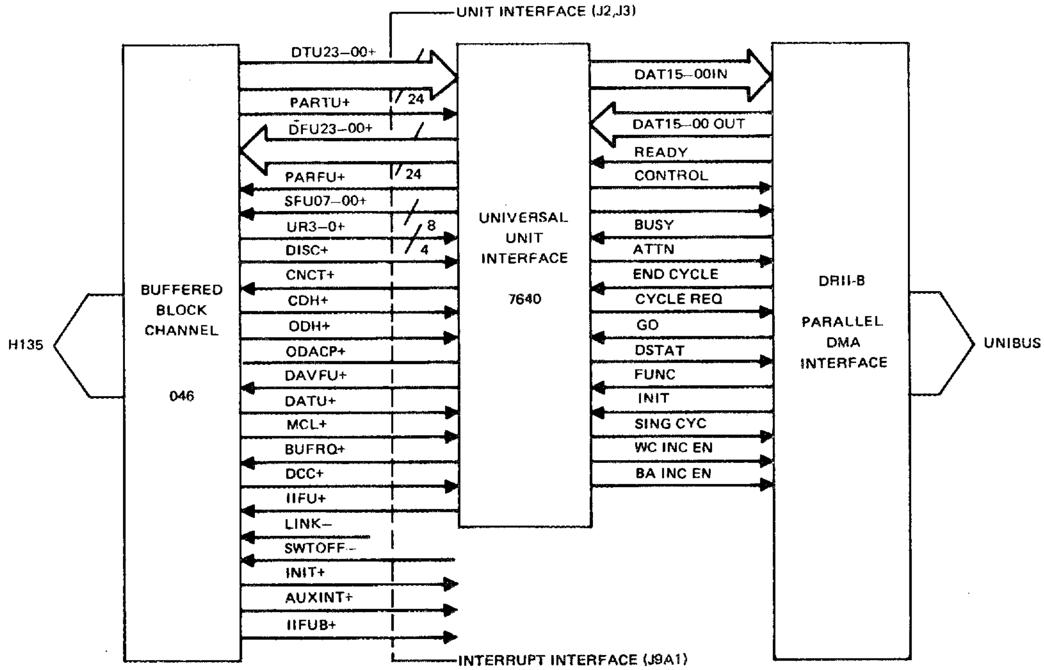
The design of the I & C system provides the means to insure personnel safety. The operating personnel in the Control Room are protected by the fiber optic CAMAC serial highway implementation between the remote CAMAC crates and the DAS microprocessors located in the Control Room. This protection strategy should be extended to the links between the PC remote I/O units and the PC CPUs located in the Control Room. At present fiber optic PC links are under development by Allen-Bradley, but are expected to be commercially-available before the start of Phase III operations.

While fiber optic links ensure personnel safety, it is possible that a severe fault might damage remote CAMAC and PC I/O hardware. This problem will be resolved in the I & C Title II work when the detailed design for the I & C signal channels is established.

4.3.2 Research Diagnostics Computer/Facility Computer Interface - A link between the facility computer (Harris System 135) and a research diagnostic computer is provided. This link is based upon high speed parallel DMA interfaces in both computers. Figure 4.3.2-1 is a diagram of a link between the Harris 135 and a DEC computer using a DR11-B Unibus interface. This concept is applicable to any PDP-11 series computer or to a VAX-11 computer. The interface to the Harris 135 computer is the same in any case. A model 046 buffered block channel (BBC) is connected to a model 7640 universal unit interface which is wired to accept a cable from the DR11-B.

This link is capable of operating at extremely high speed due to the DMA capabilities of both interfaces. The short cable lengths required due to the close proximity of the two computers will probably allow speeds approaching 1 Mbyte/sec between the two machines.

The facility computer software includes a task to transmit selected device data on demand to the research diagnostic computer. These data are only data in the work data base required by the research diagnostic network for correlation with experimental data on an immediate basis. All device history data are also available to the research diagnostic network via magnetic tape. A significant fraction of device data may be transmitted in real time. Data may be transmitted continuously during production mode operation or in blocks during maintenance mode. In either case, the type of data to be transmitted and the quantity must be entered by a user on a facility computer MCC terminal before the transmission can begin. An appropriate data receiver task in the research diagnostic computer completes the software link. The form of that task and what it will do with data received are not specified. The protocol and code for the transmission link are not specified. The basic unit of data transmitted is the record, as stored in the working data base or as received from the microprocessors.



13–5048

FIGURE 4.3.2–1 HARRIS 135 TO UNIBUS INTERFACE

4.3.3 Research Diagnostics/Microprocessor CAMAC Interface - It is anticipated that the research diagnostics interfaced to the EBT-P device will use microprocessor-based data acquisition systems similar to if not identical to the device subsystem microprocessors. The diagnostics, in general, will use CAMAC equipment as the primary data input and control interface. The device DAS design includes a provision for a link between the backup microprocessor and the research diagnostic CAMAC crates. This link is diagrammed in Figure 4.3.3-1.

The backup serial highway to the diagnostic crates is interfaced to the crates in the same manner as the device subsystem backup highway. This interface will be defined during Title II. The backup microprocessor is interfaced to the facility computer and to the research diagnostic computer via EIA RS-422 serial links at 19.2 Kbaud. These cross links allow redundant paths of communication in case of primary link failure. The links also provide for direct access from the research diagnostic computer to device data or from the facility computer to diagnostics data if the need should arise.

4.3.4 Personnel Safety Interface - This interface consists of three parts:

a) Hard x-ray monitors inside and outside of the biological shield room.
b) Microwave leakage detectors near the gyrotron tubes.
c) RF leakage monitors near the ICRH Final Power Amplifier screen room.

The RFP design criteria require ambient x-ray levels less than 0.25mrem/hr in unrestricted occupancy areas of the Test Center Building. The thickness of the concrete biological shield is determined by this criterion; however, leakage of x-ray could occur via various pentrations in the concrete shield and via the personnel access mazes.

Similarly microwave and RF ambient radiated power limits are established using Bureau of Radiological Health standards for microwave oven emission, ie. less than $5mW/cm^2$ at a point 5cm or more from the source.

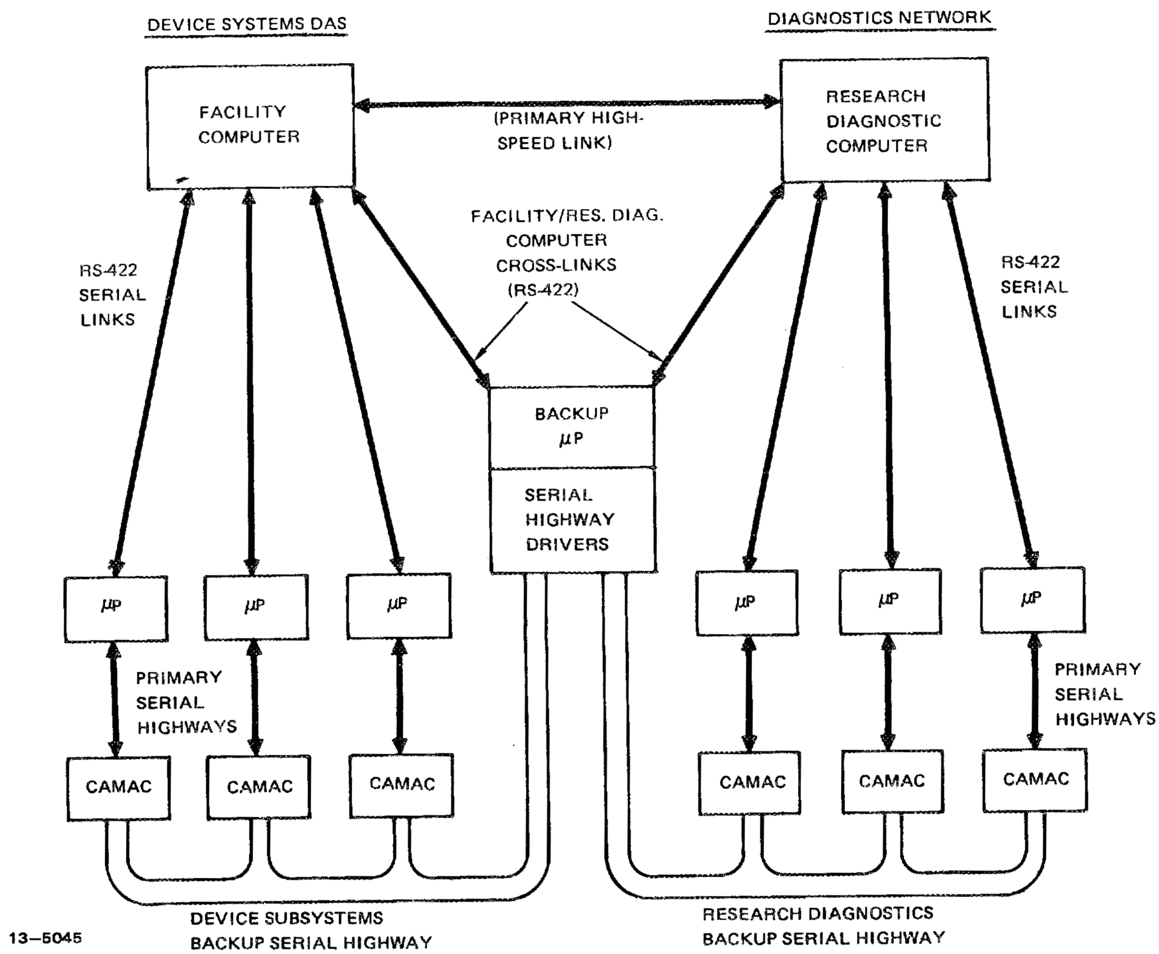


FIGURE 4.3.3-1 RESEARCH DIAGNOSTIC/MICROPROCESSOR INTERFACE

a) **Hard x-ray leakage** - In general, this source of leakage is monitored via ionization chamber detectors. Four such units are permanently positioned outside the two mazes on both levels of the Test Center Building. Scattered x-ray leakage which exits these mazes is monitored in this way.

The problem of monitoring x-ray leakage from penetrations in the concrete wall is more difficult because of possible collimation effects (beaming). Broad area x-ray survey methods probably will not suffice to locate beaming leaks. These require survey using hand-held detectors and careful survey of each penetration.

Another x-ray dose-rate monitor mounted inside the concrete shield room, positioned to view the entire EBT-P device. This unit is calibrated to read in rad/hr.

b) **Microwave leakage** - Millimeters wave radiometers are used to monitor this leakage source. Individual units are loacted close to the gyrotron output window. Survey units are located inside the Control Room on the north wall and are oriented to view the north wall of the concrete biological shield. These units may require additional microwave optics (plastic lenses or mirrors) to improve the field-of-view.

c) **RF leakage** - Pickup loops are located inside the ICRH screen room on Level One of the Test Center Building to monitor leakage from the RF transmitter. Additional loops are located inside the concrete biological shield room near the antenna tuning equipment. Two pickup loops are located on the north wall of the Control Room and are oriented to receive emission from the biological shield room.

Each of these monitor units is designed to operate from the Uninterruptable Power Supply (UPS). Calibrations are performed by the vendors to set the trip levels of these units at the proper values.

Provisions also are made to include closed-circuit TV cameras and monitors in the facility for monitoring those areas which contain personnel hazards. The use of cable TV hardware is a cost-effective means to accomplish this task.

5.0 SUPPORTING ANALYSES

This section documents several trade studies performed during the I & C Title I work. Alternative approaches were studied to:

a) Determine the baseline design approach for device control/interlock functions;
b) Determine the appropriate layout for the Master Control Console stations, and the Secondary Control Centers;
c) Determine the requirements for signal transmitters;
d) Determine the appropriate method for controlling liquid helium level in magnet dewars;
e) Determine the appropriate method for signal channel calibration;
f) Determine the I&C requirements for uninterruptable power supply support;
g) Determine a baseline device/facility start-up scenario;
h) Determine the optimal control room layout which satisfies the design criteria.

Additional analysis was done to determine the DAS signal channel timing requirements.

5.1 CONTROL/INTERLOCK METHODS STUDY

This analysis involves trade-offs between several alternative control/interlock methods:

a) Hardwired control/interlock logic;
b) Software control/interlock methods using general purpose microprocessors;
c) Software control/interlock methods using industrial programmable controllers;
d) Combinations of a), b), and c).

Option a) is not optimal for the complete EBT-P control/interlock system in view of design criteria requiring easy re-configuring of control/interlock logic during the normal periods of device operation. Nor does option a) allow easy re-configuring of this logic to handle planned upgrades of the device during Phase III operations. In addition, it is a difficult design into which to incorporate checkout and maintenance features which assist troubleshooting measures. Finally, a completely hardwired design requires development of unique logic circuits starting at the integrated circuit level, a task which would be beyond the budget resources of the I & C system.

Option b) has been used in other fusion projects (TFTR, MFTF) in the form of computer networks which handle both data acquisition and device control/interlock functions. This option has two drawbacks for use in the EBT-P I & C design:

1) General purpose computers typically function using operating system software and high level programming languages (BASIC, FORTRAN, PASCAL) which are not particularly optimal for control/interlock applications. A control/interlock program has to be developed essentially "from scratch" using various extensions (usually subroutine library packages such as the CAMAC FORTRAN subroutines) to fashion the desired logic. These programs communicate with an I/O interface, generally one which is custom-designed for a given application. The drawback with this approach is two-fold: the software tools are not optimized for control/interlock functions; and it is difficult to design in the necessary self-checking and maintenance features such that faulted portions of the system can be diagnosed and replaced without stopping the control/interlock program.

2) General purpose computers typically are not designed to the high-reliability standards required for critical control/interlock functions. Single-buss computers (e.g.; PDP series) are vulnerable to faults which bring down the entire internal computer communication link, i.e.; the single buss. Consequently, rather elaborate backup measures (e.g.; redundant processers) are required to give the necessary reliability. The quadruple-redundant Space Shuttle control system is a typical example of this approach.

Option c) provides the software flexibility of general purpose microprocessors with the reliability of a hardwired control/interlock design. Industrial PC units in reality are specially-packaged microprocessors which can be programmed using software tools that are optimized for control/interlock applications. These units have a drawback in terms of operating speed. The typical PC scan time varies from 1 to 100 msec per scan. Consequently, processes controlled by PC units tend to exhibit intrinsic time constants on the order of 0.1 second and longer. This is a severe drawback for PC control of a pulsed fusion device, but is much less of a problem for a steady-state device such as EBT-P. None of the normal processes which comprise EBT-P device operation have time constants shorter than ~ 100 msec. Note that the term "device operation" refers to non-plasma processes (e.g.; vacuum system pump-down, magnet LHe fill, LHe refrigerator operation, device cooling processes, magnet charging, etc.). The conclusion drawn is that the normal EBT-P device operation processes are amenable to control/interlock via PC units and that, in fact, this approach is the most cost-effective, especially when the costs of control/interlock software development are factored into the picture.

In reality, EBT-P does have associated fault conditions which exhibit time-constraints shorter than the typical PC scan time. These faults include:

a) Magnet quench;
b) ECRH power supply and gyrotron faults requiring crowbar triggering on microsecond time scales;
c) LHe refrigerator faults;
d) ICRH power supply faults.

These exceptions are handled by hardwired control/interlock logic circuits which function independent of the PC units. The function of the PC units, in handling these faults, is to monitor the hardwired logic and sense the operation of these circuits when these detect a fault. The PC units then initiate the required shut-down processes to assist in removing the fault (e.g.; shut down plasma heating sources when magnet quench is detected by the hardwired Quench Protection Circuits). Therefore, the selected approach is a combination of options a) and c).

5.2 CONTROL/DISPLAY PANEL METHODS STUDY

This study involves the basic trade-off between two generic approaches to control/display panel design:

a) Implementation using discrete control/display hardware (e.g.; manual switches, digital panel meters, analog panel meters, strip chart recorders, discrete illuminated status indicators, etc.).

b) Implementation via CRT displays with touch panel overlays.

A large variety of options can be envisioned using these two generic approaches. These are enumerated in Table 5-1 for both Master Control Console (MCC) and Secondary Control Center (SCC) applications. That both MCC and SCC implementations are considered is a reflection of the design criteria requiring that a backup means be provided for MCC functions such that EBT-P device operation will not be terminated by a fault in the MCC units. The SCC units provide this backup function.

The options given in Table 5-1 cover the gamut of present control and display technology. Option 1) is the completely hardwired control/display panel approach similar to the one used on EBT-S. The difference is that the switches and indicators of option 1) communicate with software residing in the EBT-P DAS microprocessors and PC units, while the EBT-S hard wired switches communicate directly with control elements (e.g.; power supply ON/OFF switch, valve actuator, etc.). For EBT-P the option 1) control switches cause preprogrammed software sequences to be selected and executed.

Table 5-1. Control/Display Panel Options

Option No.	Description
1	Hardwired control switches and indicators at both MCC and SCC.
2	Hardwired control switches at MCC and SCC, CRT display controlled by hardwired switches at MCC, hardwired indicators at SCC.
3	Hardwired control switches at MCC and SCC, CRT display controlled by touch panel at MCC, hardwired indicators at SCC.
4	Hardwired control switches at MCC and SCC, CRT displays controlled by hardwired switches at MCC and SCC.

Table 5-1. Control/Display Panel Options (Continued)

Option No.	Description
5	Hardwired control switches at MCC and SCC, CRT displays at MCC and SCC, CRT at MCC controlled by touch panel, CRT at SCC controlled by hardwired switches.
6	Hardwired control switches at MCC and SCC, CRT displays at MCC and SCC, display control by touch panel at MCC and SCC.
7	Touch panel process control input at MCC, hardwired control switches at SCC, CRT display controlled by touch panel at MCC, hardwired indicators at SCC.
8	Touch panel process and display control at MCC, hardwired control at SCC, CRT displays at MCC and SCC, hardwired display switches at SCC.
9	Touch panel process and display control at MCC, hardwired process control at SCC, CRT displays at MCC and SCC, touch panel display control at SCC.
10	Touch panel process and display control at MCC and SCC, CRT displays at MCC and SCC.

Option 10) represents another extreme offered by present control/display technology. The most relevant example of this approach, for EBT-P design purposes, is provided by the MFTF-B control/display system. The MFTF approach uses CRT displays exclusively for control/display functions and eliminates all hardwired control/display components. In place of these, the MFTF computers contain CRT display programs which paint the necessary control panel graphics onto the CRT terminals. MFTF operators interact with these "software-generated" control panels via touch panels and the software determines the meaning of the operator's finger placement on the touch panel.

The options 2) thru 9) each represent an intermediate position between the extremes delimited by options 1) and 10). In the trade study, option 1) was rejected since it does not effectively use the capabilities of the EBT-P DAS microprocessors and PC units to display device operation data via CRT terminals and thereby wastes the potentials of this hardware into which a considerable investment has been made already. This option also incurs a penalty in the form of substantial labor costs associated with wiring the discrete, hardwired control/display components.

Option 10) was rejected for EBT-P application because the cost of developing software for the "software-implemented" control panels was considered beyond the budgets allocated for EBT-P software development. Based on MFTF experience, a two to four man-year effort for this purpose would not be an unreasonable estimate. Additional microprocessor hardware could be required to implement option 10), further exascerbating the pressures on the I & C budget.

The issue, thus, involved a selection among options 2) thru 9). The trade study, considering the I&C hardware budget and software development costs, pointed to option 6) as the most cost-effective alternative. This option provides for the following control/display features:

a) Operators situated both at the MCC stations and at the SCC units control the operation of the EBT-P device via hardwired switches contained on various control panels. The MCC switches interact with PC software to parameterize, execute and abort sequences of control/interlock functions. In effect, by pressing a single "START" switch, the operator commands the PC unit to initiate a series of interlocked control functions required to perform a given well-defined EBT-P device process (e.g. main cryopump cooldown process).

The hardwired control switches at the SCC also control the operation of the EBT-P device by communicating with PC software. The principal difference, compared to MCC control switches, is that SCC control switches cause limited control actions to occur (e.g. "open main gate valve #8"). This limited function causes SCC control activities to be much more manual in nature than MCC control activities. This is an intentional design feature which provides the operator with two ways to perform a given device process, via programmed sequence or by completely manual means.

b) CRT displays are used exclusively at both the MCC stations and at the SCC units to provide operators with data necessary to monitor device processes. Option 6) completely removes the necessity for discrete, single-parameter display hardware (digital panel meters, analog panel meters, illuminated indicators, strip chart recorders) at the MCC and SCC areas. This design decision is the appropriate approach which effectively utilizes the capabilities of the facility computer, of the DAS microprocessors and of the PC units to drive CRT display terminals and, thereby capitalizes on the investment already made in this type of hardware to satisfy other I&C design criteria. In addition, the trade-off is made between the cost of installing hardwired discrete display components and the cost of developing software for the CRT displays. Two features make this tradeoff cost effective: 1) Common display software can be developed for the DAS microprocessors and for the PC-driven displays such that many CRT displays can be driven from one or two types of software packages. 2) Modifications of display formats is less costly via the software approach than by the discrete, hardwired avenue.

c) The CRT display units are controlled by touchpanel means at the MCC. This design feature of option 6) has the effect of removing the need for typewriter-form keyboards at the MCC area. This, in turn, means that operators are not required to memorize command stringes (typewriter keystroke sequences) in order to interact with the CRT display software. Instead, the operator is presented a CRT-displayed menu of display options. Selection of a particular display option requires only that the operator touch the surface of the touch panel at the appropriate position on the menu display.

This study was reported at the I & C PDR. Comments were received which indicated that option #10 should be reconsidered for the MCC stations. This issue will be reviewed in I & C Title II work with emphasis on the design and cost requirements for the necessary software effort involved in this option.

5.3 SIGNAL TRANSMITTER TRADE STUDY

This analysis is aimed at establishing the need, if any, for signal transmitters to provide the necessary accuracy, noise immunity and drift specifications for data transmitted via the EBT-P device signal channels. These signal transmitters would be used to condition low-level signals provided by certain sensor elements (e.g. differential temperature sensors). Typically these sensors are separated from remote CAMAC or PC I/O hardware by distances ranging from 50 to 200 feet. In general laboratory applications such distances would not ordinarily dictate a need for signal transmitters to condition millivolt-level signals. The nature of the EBT-P device/facility (megawatt level plasma heating power, high magnetic fields, high x-ray fluxes), however, may stretch the meaning of "ordinary laboratory environment" if one considers it such. In a completely conservative approach, the EBT-P facility would be considered more akin to an industrial environment, one in which the use of signal transmitters is virtually manditory, and the issue would be settled in favor of using signal transmitters without question and the accompanying costs would be considered unavoidable. This trade study reflects a pragmatic attitude and seeks to analyze the EBT-P low-level signal channel to ascertain the real issues involved in millivolt level signal transmission for this application.

The Title I design revealed requirements for large numbers of differential temperature sensors ("flow ΔTs"). About 450 of these sensors are required to aid in determining heat loads on various EBT-P components. Many of these units are located in close proximity to the EBT-P device, inside the concrete x-ray shield room. These units are available from Delta T Company and exhibit the following characteristics:

- Low-resistance sensor ($\sim 50\Omega$) composed of twenty (20) series-connected thermocouple elements;
- Typical 500 μV/F° differential sensitivity;
- Relatively slow response ($\sim$1 sec 10% to 90%);

- Sensor is electrically isolated from the ΔT housing (i.e. the sensor "floats" electrically)
- The housing is a soft-iron shield which is effective for electrostatic shielding, but somewhat less effective as a magnetic sheild.

Figure 5.3-1 shows a typical ΔT signal channel, minus the signal transmitter. This layout shows the signal channel termination as CAMAC hardware, a condition which is considered a requirement based on other design criteria which independantly determine the configuration of the DAS microprocessor/CAMAC subsystem. Three CAMAC modules are required:

- Model 3531 CAMAC Multiplexer
- Model 3532 CAMAC Multiplexer Expansion Unit
- Model 3553 CAMAC 12-Bit ADC Module

The design problem is complicated by the use of a differential input preamp in the 3553 module to handle a floating sensor. Such preamps are designed to handle grounded sensors at the input and to deliver output signals to grounded loads. Differential amplifiers, such as the unit used in the CAMAC 3553 module, require a DC return path from both input lines to the signal reference. This is manditory to prevent the preamp from becoming saturated by its own input bias current leakage. The trick is to provide this bias current return path for the floating sensor arrangement without degrading the preamp common-mode rejection capability.

Kinetic Systems recommends that 23.5KΩ resistors be placed between each preamp input line and signal return lead to drain the input bias currents. The next question involves the connection of the field cable shield. To provide a complete electrostatic shield around the ΔT sensor and the field cable, the cable shield should be connected to the ΔT sensor housing. This connection ties the cable shield to the EBT-P device and, hence, to the earth connection "A". The problem with this arrangement is that it violates a fundamental shielding guideline (see Morrison p-77), i.e., the potential difference between the shield

Reference 5-1 R. Morrison, <u>Grounding and Shielding Techniques in Instrumentation</u>, John Wiley and Sons, Inc, New York, 1967.

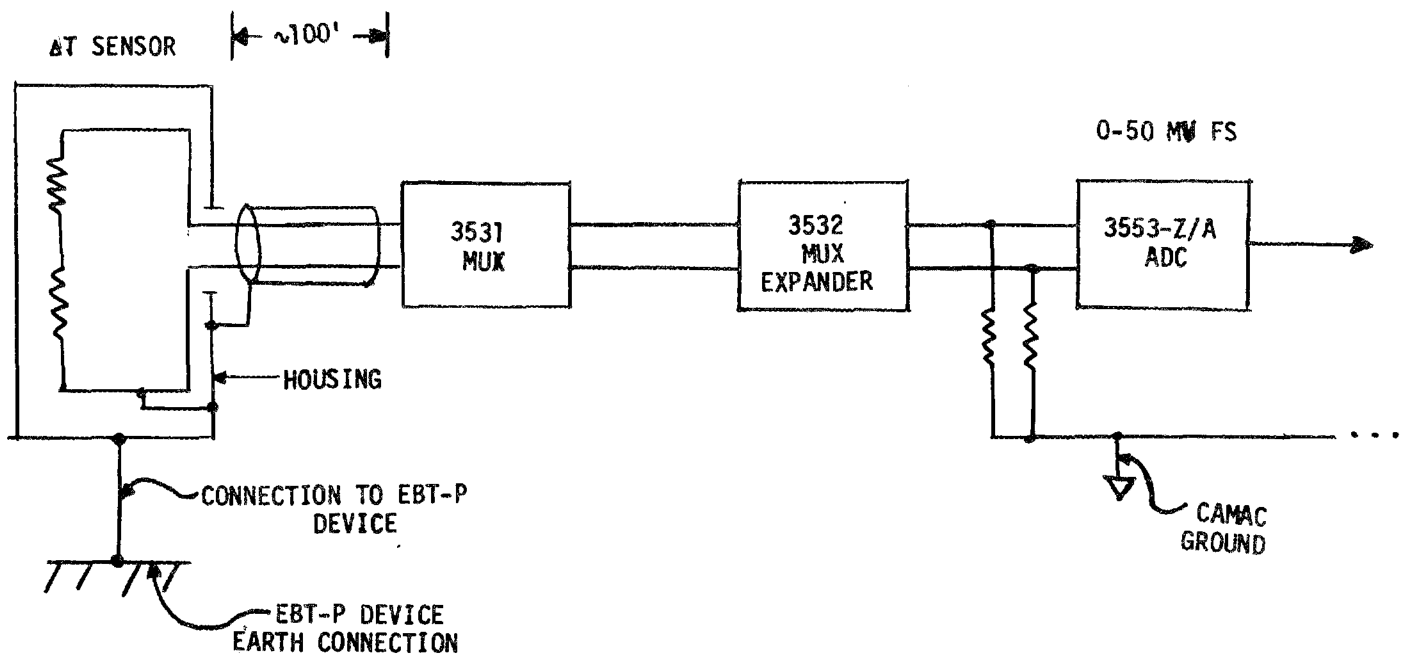


FIGURE 5.3–1 GROUND ΔT SENSOR CIRCUIT

and the signal conductors is undefined since the shield is not connected to the zero-signal reference point (the signal return reference provided by the CAMAC system). The only recourse is to connect one of the ΔT signal conductors to the shield (and thereby solidly grounding the sensor to earth connector "A") and to rely on the common-mode rejection capability of the pre-amp to eliminate the common-mode noise which now is solidly connected to the pre-amp input ports. The 23.5KΩ resistors should be eliminated since the pre-amp bias current has a drain path through the facility earth electrode now.

Use of an isolating-type signal transmitter can provide an alternative approach which will function with the floating ΔT sensor. This arrangement is shown in Fig. 5.3-2. The signal transmitter is located close to the ΔT sensor ($\sim$ 3 - 10 ft) and converts the millivolt signal from the ΔT sensor into a 4-20 ma current signal. This current signal is highly noise-immune and can be transmitted to the CAMAC unit using unshielded twisted-pair cabling. A small value resistor at the CAMAC input put converts the 4-20 ma current signal into a 2-10 volt signal.

This issue, therefore, cannot be settled on purely technical grounds since such would require an estimate of the EBT-P EMI environment. This estimate would necessarily be a very approximate one and likely would not decisively settle this issue. The issue can be advanced somewhat now by comparing costs. The signal transmitter option trades the need for CAMAC low level ADC units for signal transmitter units. The cost of the pre-amplifiers is $\sim$ \$45/channel compared to $\sim$ \$160/channel for signal transmitter units. The total cost delta is approximately (\$160-\$45) x 450 = \$52K. The decision, therefore, is to include the signal transmitter in the I&C equipment list.

5.4 LIQUID HELIUM LEVEL CONTROL STUDY

This study involves the design of the LHe level control subsystem and considers two alternatives:

a) Level control using proportional control techniques;
b) Level control using a variation of on-off control methods.

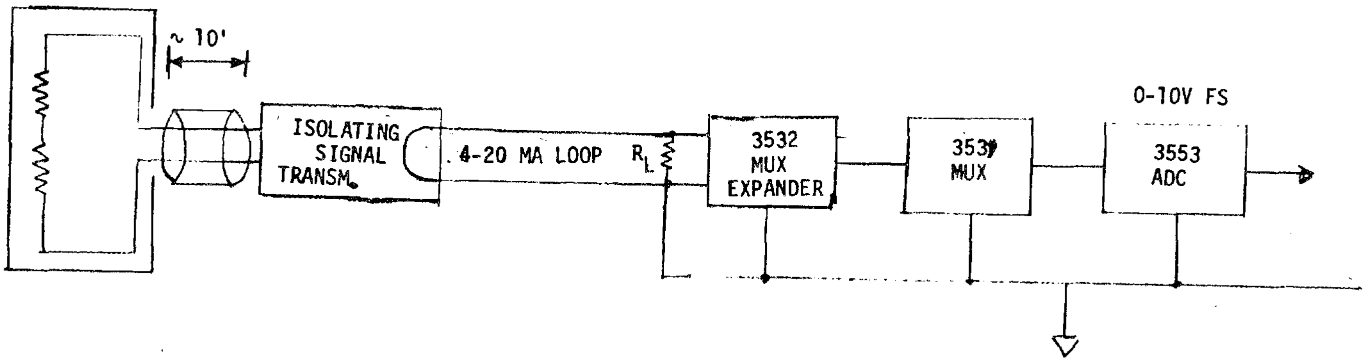


FIGURE 5.3–2 SIGNAL CHANNEL LAYOUT WITH ISOLATING SIGNAL TRANSMITTER

An ancillary issue involves the manner in which the selected control method should be implemented. The alternatives studied are:

1) Using a hardwired LHe level control approach;
2) Using the PC units to control LHe level.

The constraints imposed on the LHe fill system design have a significant impact on any type of level control methods trade-off. These constraints are:

- The fill lines of the thirty-six device magnets will be connected to a common LHe delivery manifold. This manifold will be fed with LHe from a single line to the main LHe storage drawer. All 36 magnet dewars will be filled simultaneously.
- Each magnet will have two (2) fill lines connected to the manifold. One fill line, the "bottom-fill line," extends far into the magnet drawer and will be used for the initial fill process. The second fill line, the "top-fill line", extends only slightly into the magnet stack and will be used for the LHe level control process.
- Long-stem cryogenic globe valves will be used to meter the LHe flow in each fill line. These valves will be operated by pneumatic actuators.
- A single superconductive-type LHe level sensor will be used in each magnet drawer to provide the signals for the LHe level controller.
- The steady-state heat leak into the magnet dewar (including x-ray heat loads) will be the only normal factor influential in determining LHe boil-off. Heaters submerged in LHe will not be available to assist the LHe level control process. Magnet quench is considered a fault condition over which the LHe level control subsystem has no control, except to close the LHe fill line valves upon command by the magnet QPC. The QPC, therefore, will override the LHe fill control subsystem if a quench occurs.

Figure 5.4-1 shows the process loop for a typical LHe fill line, while Fig 5.4-2 shows the baseline top-fill line arrangement. The LHe level sensor provides the level input to the controllers which processes this information into a 4-20 ma control signal for use by a current-to-pressure (I/P) converter. A 3-15 psig pneumatic control signal operates the valve actuator varying the flow of motor air to the actuator diaphram.

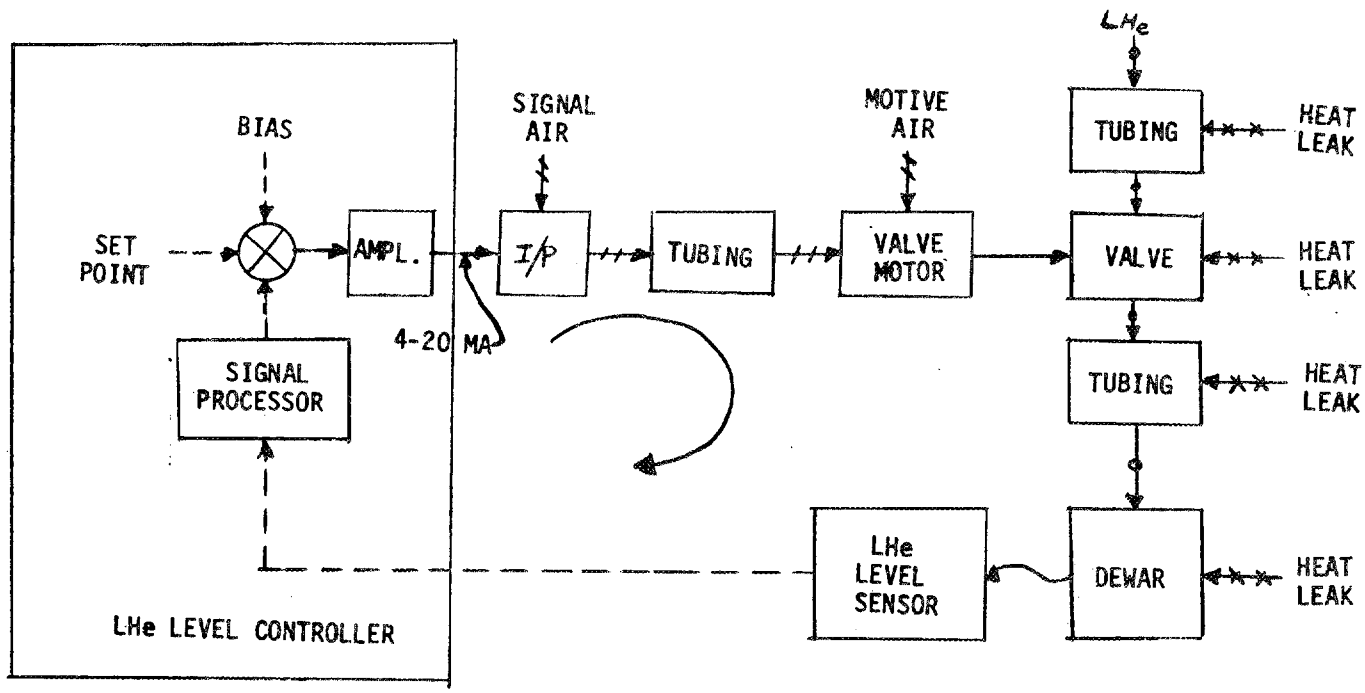


FIGURE 5.4–1 LHe LEVEL CONTROL LOOP – CONCEPTUAL LAYOUT

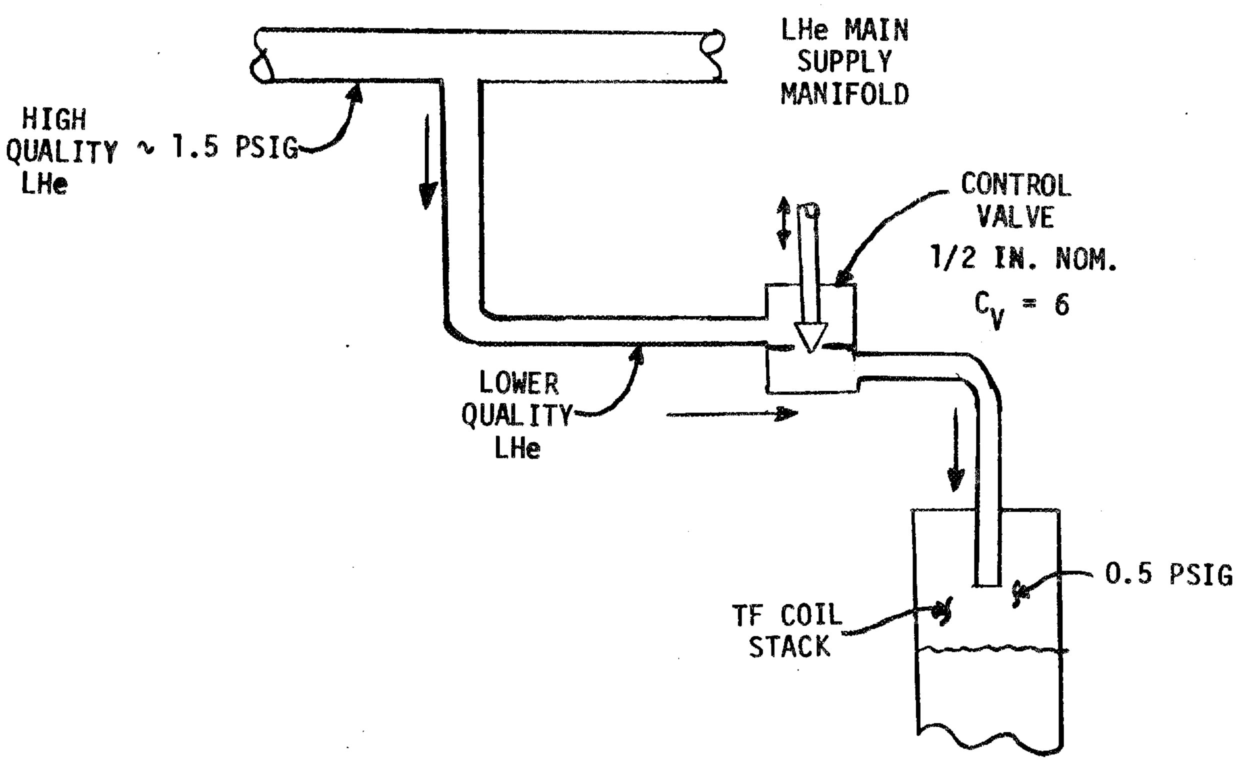


FIGURE 5.4–2 LHe CONTROL VALVE LAYOUT

This process loop would be conventional, except for the fact that the loop is required to control the flow of a boiling liquid. When the top-fill valve is completely closed, LHe trapped between the valve and the main LHe supply manifold will boil, providing lower quality LHe in this line. If the valve remains closed for a sufficiently long time, this line probably will fill completely with the vapor and could vapor-lock. It is common knowledge that flow of a cryogenic liquid should not be permitted to fall to zero during a transfer process. A trickle flow could be provided continuously, especially in a complex cryogenic distribution system, to minimize potential vapor-lock problems. This concern is definitely applicable to the top-fill line, but probably is not important for the bottom fill line since the latter is used only during the initial LHe fill process.

Next, the issue of proportional vs on-off control is faced. To proceed further in this study, additional features of the LHe fill system have to be specified. First, the steady-state rate of LHe level change is required. The following assumptions are made:

- The LHe level set-point will correspond to a TBD LHe level in the magnet stack (e.g. 10 inches below the top of the stack).
- The surface area of the LHe pool in the stack will be ~ 54 cm^2.
- The steady-state LHe boiloff rate will be 31 l/hr (8.6×10^{-3} l/sec).

Using these assumptions, the LHe level falls at ~ 1.6 mm/sec in the magnet stack. A proportional controller would be required to provide a continuous LHe flow at ~ 8.6×10^{-3} l/sec to tightly control the LHe level (~ ± 1-5 mm around the set point).

The next step is to select a long-stem cryogenic valve which can meter LHe at the required steady-state rates, assuming that tight level control is required. The smallest standard globe valve supplied by CVI was used as a typical selection. This valve is a nominal 0.5 inch model with $C_V = 6$. Assuming a ΔP of 1 psig across this valve (e.g. 1.5 psig in the LHe distribution manifold, 0.5 psig in the magnet dewar), this valve has a Q_{MAX} of ~ 1.0 l/sec. Clearly, this valve is grossly oversize for the present application and would require a highly non-linear flow transfer charactersitic to meter LHe at 8.6×10^{-3} l/sec. A tapered valve stem plug could be used to obtain a non-linear characteristic, and this approach requires additional cost to customize the valve plug.

Assuming that this analysis reasonably describes the actual conditions which the LHe fill system would encounter, the proportional level control approach appears inappropriate. This results primarily because the LHe level fill rate is very small and the present magnet stack is relatively long. An on-off control approach, under these conditions, appears easily capable of controlling LHe level to ± 1.0 cm at a selected set-point. In fact, a hybrid approach can be envisioned, namely, "time-proportioning" control. Figure 5.4-3 shows one implementation of this method using a controller which briefly switches the LHe probe ON at periodic intervals, samples the deviation from set-point (Δx_S), and calculates an OPEN duration for the LHe fill valve to raise the LHe level in the stack. Between these periodic "topping-off" intervals, the valve could remain cracked OPEN at the "dribble point" to keep the fill lines at or near 4.2°K. This hybrid approach is the method selected as a result of this study.

The ancillary question of implementing the time-proportioning control strategy was considered next. The straight-forward approach would provide thirty-six hardwired controllers, one for each magnet. The cost of this hardwire can be traded against the cost of hardware and software for the cryogenic system PC to handle this control task. The cost of PC I/O units to service the LHe level sensors is the same for both options because of the design criterion requiring all sensor outputs to be archived by the I&C system. The cost of PC I/O modules to output the 4-20 ma control signals for the I/P converter is the item which should be compared to the cost of the hardwired level controllers. These PC modules cost $\sim$ \$150 per output channel, while typical LHe level controllers are estimated at $\geqslant$\$500/unit. The trade-off favors the PC approach on the basis of hardware costs. The question of software cost will be defined in Title II at which time this study will be updated.

5.5 SIGNAL CHANNEL CALIBRATION STUDY

This analysis involves trade-offs between several alternative calibration methods:

a) Signal channel end-to-end calibration in place:
b) Calibration via bench methods.
c) Combinations of a) and b).

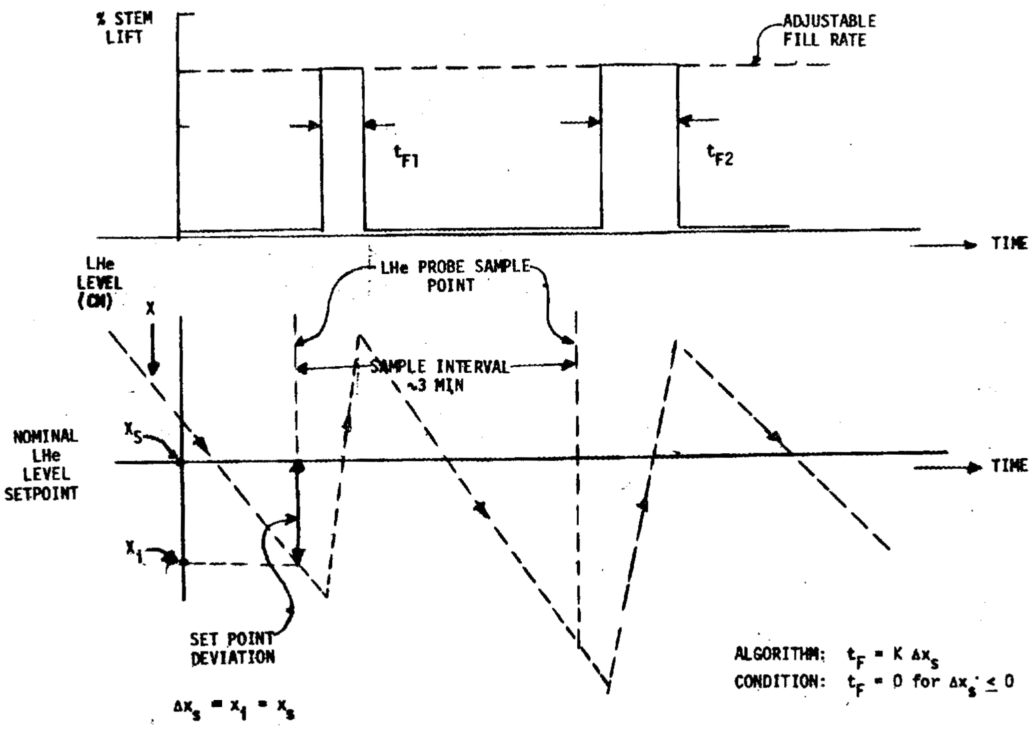


FIGURE 5.4–3 TIME PROPORTIONING CONTROL SCHEMATIC

The analysis is aimed principally at identifying methods to reduce the cost of signal channels recalibration during the Phase III operational period. In particular, the aim is to identify those signal channels for which either in-place calibration or built-in-test (BIT) methods can be designed. These methods reduce cost principally by eliminating the labor required to remove signal channel components for bench calibration and later re-installing either the same components or using spares.

Table 5-2 lists the calibration method applicable to each type of EBT-P signal channel. The "in-place" method utilizes a process variable (e.g. torus vacuum system pressure) and a single calibrated sensor to transfer a calibration to a number of other sensors without the need to change the sensors and signal transmitters from the normally installed configuration. The "bench" method requires a calibration fixture into which one or more sensors of a particular type are installed. Typically, a set of spare calibrated sensors would be substituted for those sensors requiring re-calibration. "Bench" re-calibration of the signal transmitters normally would not require removal of the unit. An appropriate calibrated millivolt or current source would be used for signal transmitter re-calibration.

Examination of Table 5-2 shows that relatively few signal channels can be calibrated via the "in-place" method at a reasonable cost. The vast majority of sensors require the bench/substitution method, a situation which is somewhat troublesome in the case of the differential temperature sensors. The problem is two-fold:

a) The number of ΔT sensors is large;
b) Removing and re-installing these sensors is a significant maintenance cost since four fittings are involved for each ΔT sensor.

Table 5-2 - SIGNAL CHANNEL CALIBRATION METHOD SUMMARY

CHANNEL TYPE	CALIBRATION METHOD		NUMBER OF CHANNELS
	SENSOR	SIGNAL TRANSMITTER	
• PRESSURE-VACUUM-TORUS	IN-PLACE	IN-PLACE	36

Table 5-2 - SIGNAL CHANNEL CALIBRATION METHOD SUMMARY (Continued)

CHANNEL TYPE	CALIBRATION METHOD		NUMBER OF CHANNELS
• PRESSURE-VACUUM-MAGNET VACUUM CONTAINER	BENCH/ SUBSTITUTION	BENCH	42
• DIFFERNTIAL TEMPERATURE-WATER	BENCH/ SUBSTITUTION	BENCH	~450
• PRESSURE-WATER	IN-PLACE	IN-PLACE	~15
• LEVEL (LHe)	BENCH/SUBSTITUTION	BENCH	~46
• LEVEL (LN_2)	BENCH/SUBSTITUTION	BENCH	2
• FLOW-WATER	BENCH/SUBSTITUTION	N/A	
• TEMPERATURE-TORUS WALL AND LIMITERS	N/A (NON-REMOVABLE)	BENCH	~100
• STRAIN	N/A (NON-REMOVABLE)	BENCH	~180
• TEMPERATURE-MAGNET INTERNAL	N/A (NON-REMOVABLE)	BENCH	~334

Experience with ΔT sensors indicates, however, that a re-calibration interval of twenty-four (24) months is reasonable. This fact makes the cost of this particular re-calibration task source affordable.

A number of sensors will not be re-calibratable because these are not removable (e.g. internal magnet strain and temperature sensors). The usual approach would be to provide redundant sensors in these cases. However, additional magnet sensors increase the heat leak into the LHe dewar.

5.6 UNINTERRUPTABLE POWER SUPPLY SUPPORT FOR THE I&C SYSTEM - This analysis involves tradeoffs between UPS capacity/cost issues and the requirements for I&C system functioning during major fault occurences. Although a spectrum of faults can be analyzed, this study concentrated on the complete power outage fault. It is assumed that the EBT-P device/facility is operating normally with plasma when the power outage occurs. The outage immediately causes the following events:

a) ECRH and ICRH power supplies are crowbarred. Plasma heating power falls to zero in 50 μsec or less.
b) The magnet power supply output current falls to zero in 100 msec or less.
c) The helium refrigerator compressors cease functioning in 1 sec or less.
d) The main water circulation jumps in the device utilizes systems cease functioning in 1 sec or less.
e) Facility HVAC utilities cease functioning in 1 sec or less.
f) Facility emergency lighting switches ON within 2 sec.
g) The TF magnet Quench Protection Circuit (QPC) starts to dump stored energy from the magnets within 0.5 sec or less.

Figure 5.6-1 shows the sequence of EBT-P devices processes occurring after a primary power outage. At one second following the outage, the following processes have been completed:

- Main cryopump GHe valves are closed.
- TF magnet LHe fill valves are closed.
- 60 GHz magnet LHe fill valves are closed.
- 60 GHz cryopump GHe valves are closed
- GH_2 bleed valve is closed.
- 28 and 60 GHz PC units initiate emergency shut-down processes.
- Primary coolant pumps are disconnected from the AC power system.
- UPS has switched to battery operation.

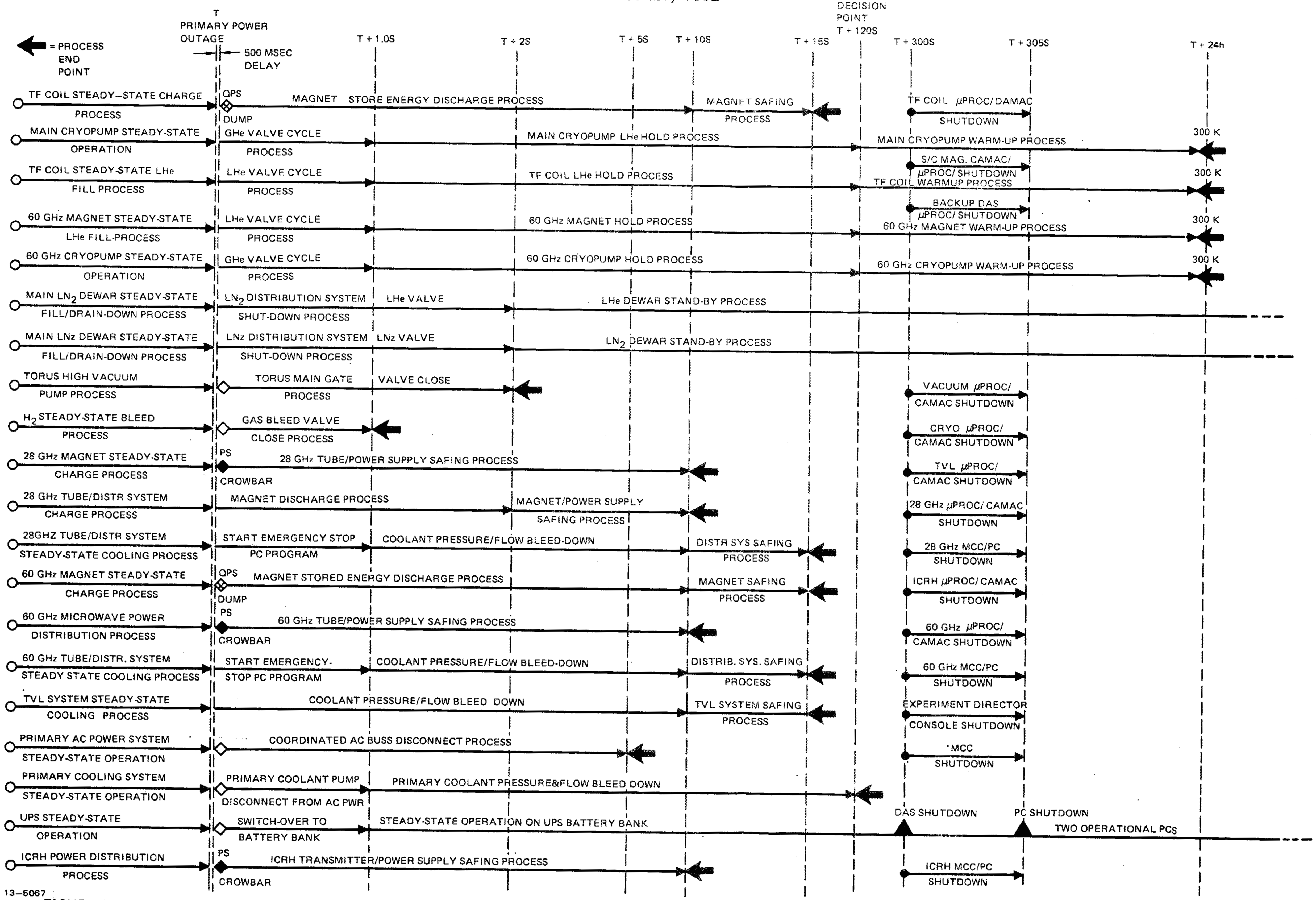


FIGURE 5.6–1 EBT–P PRIMARY POWER OUTAGE – PROCESS SEQUENCE DIAGRAM

The issue is to determine which I&C components need to be powered by the UPS at this point in the shut-down process. Figure 5.6-2 shows the results of the analysis. At the one second point, the facility computer and the MCC plasma heating stations are the only I&C components without power since these are not backed up by the UPS. Since the facility computer does not perform any vital control function, the normal power-fail software/hardware is allowed to bring the facility computer to a powered-down state. Likewise, the plasma heating MCC units control the microwave and RF distribution processes which cease immediately at the instant of the outage. Consequently, there is no reason to back up these MCC units via the UPS.

Referring again to Figure 5.6-1, two seconds after the outage the following processes have been completed:

- The LHe Main Dewar has been isolated from the cryogenic distribution system.
- The LN_2 Main Dewar has been isolated from the cryogenic distribution system.
- The main cryopump gate valves are cycled to the closed position.

The UPS loads remain as these were at the 1 sec point (Figure 5.6-2). Five seconds following the outage, the disconnects in the primary AC power distribution system have cycled to return this system to its initial unpowered configuration.

At the ten second point following the outage, the following processes have been completed:

- The stored energy in the TF magnet system is zero.
- The 28 GHz gyrotron tube/power supply safing procedure has been completed.
- The coolant pressure in the 28 GHz gyrotron collector cooling system has bled down to near zero and flow has ceased.
- The stored energy in the 60 GHz focus magnet has been reduced to zero.
- The 60 GHz gyrotron tube/power supply safing procedure has been completed.
- The coolant pressure in the 60 GHz gyrotron collector cooling system has bled down to near zero and flow has ceased.
- The coolant pressure in the TVC cooling system has bled down to near zero and flow has ceased.
- The ICRH transmitter/power supply safing procedure has been completed.

FIGURE 5.6-2. I&C UPS SUPPORT REQUIREMENTS TIME FOLLOWING PRIMARY POWER OUTAGE

I&C COMPONENT	1 SEC	15 SEC	300 SEC	24 HR
• FACILITY COMPUTER	N	N	N	N
• MCC MAGNET STATION	Y	Y	N	N
• MCC CRYO STATION	Y	Y	N	N
• MCC VACUUM/TVL STATION	Y	Y	N	N
• MCC 60 GHZ ECRH STATION	N	N	N	N
• MCC 28 GHZ ECRH STATION	N	N	N	N
• MCC ICRH STATION	N	N	N	N
• SCC MAGNET STATION	Y	Y	Y	Y
• SCC VACUUM STATION	Y	Y	Y	N
• SCC TVL STATION	Y	Y	Y	N
• SCC DEVICE UTILITIES STATION	Y	Y	Y	N
• TF MAGNET QPS	Y	Y	N	N
• 60 GHZ GYROTRON MAGNET QPS	Y	Y	N	N
• DAS μPRUC - MAGNET	Y	Y	N	N
• DAS μPVOC - CRYO	Y	Y	N	N
• DAS μPVOC - VACUUM	Y	Y	N	N
• DAS μPVOC - TVL/DEVICE UTILITIES	Y	Y	N	N
• DAS μPVOC - 60 GHZ ECRH	Y	Y	N	N
• DAS μPVOC - 28 GHZ ECRH	Y	Y	N	N
• DAS μPVOC - ICRH	Y	Y	N	N
• PC UNIT - MAGNET	Y	Y	Y	Y
• PC UNIT - VACUUM	Y	Y	Y	N
• PC UNIT - TLV/DEVICE UTILITIES	Y	Y	Y	N
• PC UNIT - 60 GHZ ECRH	Y	Y	N	N
• PC UNIT - 28 GHZ ECRH	Y	Y	N	N
• PC UNIT - ICRH	Y	Y	N	N
• HELIUM REFRIGERATOR LOCAL CONTROL PANEL	Y	Y	Y	Y
• EXPERIMENT DIRECTORS CONSOLE	Y	Y	N	N
• SCC 60 GHZ ECRH	Y	Y	N	N
• SCC 28 GHZ ECRH	Y	Y	N	N

The UPS loads are identical to those at the 1 sec point.

Fifteen (15) seconds after the power outage, the following processes have been completed:

- The TF magnet safing procedure is complete.
- The 28 GHz distribution system safing process is complete.
- The 60 GHz gyrotron focus magnet safing procedure is complete.
- The 60 GHz distribution system safing process is complete.
- The TVL cooling system safing process is complete.

The UPS loads remain the same as those at the 1 sec point. A decision point is reached at the 120 sec point following the power outage. Project management then chooses between two alternatives:

a) Continue the flow of LHe and LN_2 to the TF coils and to the 60 GHz gyrotron focus magnets anticipating a return of primary power.
b) Start the magnet warm-up process.

Presumably, the project management will have been in contact with local power utility supervisors in an effort to learn the cause of the outage and the prospects for early resumption of service. If a long duration outage seems likely, the warm-up process would start around the 300 sec point. Simultaneously, the I&C equipment listed in Figure 5.6-2 (t = 300 sec) would be powered down. As a result, the only I&C equipment on the UPS are those PC components associated with the cryogenic, vacuum, TVL/device utilities and helium refrigerator systems. These components require UPS support because a) the toroidal vessel is still under vacuum and b) the LHe and LN_2 main storage dewars still contain large quantities of cryogenic liquids. It is likely that the PC units associated with the vacuum and TVL/device utilizes system can be powered down within 15 minutes following the outage, leaving only the cryogenic system PC unit requiring UPS support.

Assuming that this scenario reasonably describes the UPS requirements for the primary power outage fault, two estimates are needed:

- Estimate of UPS peak power requirement,
- Estimate of UPS battery unit capacity requirement.

The I&C loads on the UPS distribution system are shown in Figure 5.6-3. The estimate peak power requirement is ~ 20KVA, the principal uncertainty arising from the estimated PC load requirements. The largest part of this load is shed within 5 minutes following the outage. The charge supplied by the battery bank during this period is approximately (neglecting inverter efficiency).

$$\frac{20\ \text{KVA}}{120\text{V}} \times \frac{5\ \text{min}}{60\ \text{min/hr}} = 14\ \text{amp hr}$$

The sustained load on the battery bank is due to the cryogenic system PC unit. The estimated power requirement for this unit is 120 VAC @ 10 amps. Therefore, each 24 hours of operation will require 240 amp-hr of battery capacity.

5.7 DEVICE POWER-UP SEQUENCE STUDY

This analysis is aimed at deriving a basic operation sequence to be used as the framework for developing the device control and interlock logic. This logic ultimately will be implemented in the Title II PC software design. The most fundamental control/interlock process is the device power-up sequence which begins with a completely non-functioning state and proceeds through various subsystem processes leading to device operation with plasma.

The device power-up sequence is conveniently displayed via a process "waterfall" diagram, Fig. 5.7-1. The starting conditions are:

1) LN_2 main storage dewar empty.
2) LHe main storage dewar empty.
3) LHe refrigerator in the stopped state.
4) ECRH and ICRH plasma heating systems not operating.

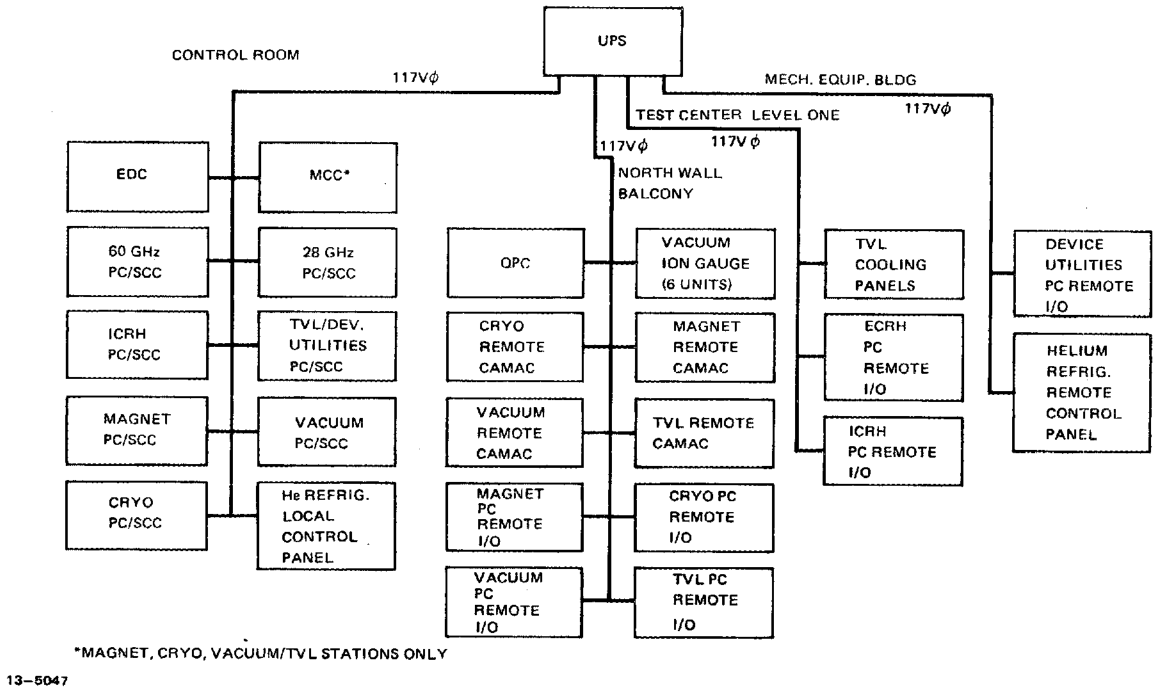


FIGURE 5.6.–3 UPS LOAD DISTRIBUTION DIAGRAM

5) TF magnets at ambient temperature; magnet vacuum at 760 torr.
6) Toroidal vessel at ambient pressure.

The power-up sequence begins with two processes,

- LN_2 Main Storage Dewar Fill.
- Helium refrigerator compressor start-up.

LN_2 fill typically requires 8-16 hours, while the compressor start up requires ~ 2-8 hours.

The next process is the helium refrigerator start up procedure, requiring perhaps 24 hours. Following successful start-up, the LHe Main Storage Dewar fill process is initiated. Assuming a 500 l/hr liquification rate and a 20,000 liter dewar, approximately 40-50 hours are required to fill the dewar. An ~ 100 hour period (Hold A) is indicated in Fig 5.7-1 during which the LHe Main Storage Dewar fill process operates and fills the dewar to ~ 90% capacity.

At the end of Hold A, several processes are initiated:

- LHe Main Dewar steady-state drain-down and fill-up process,
- TF magnet vacuum enclosure pump down,
- 60GHz focus magnet vacuum enclosure pump down,
- TVL cooling system checkout process,
- ECRH distribution system cooling checkout process.

The pump down processes are the pacing items and probably will require 24-48 hours to reach the 10^{-5} torr level.

Four processes are started next:

- Main cryopump start-up process,
- TF magnet cool-down process,
- 60GHz gyrotron focus magnet cool-down process.
- Toroidal vessel rough pump process.

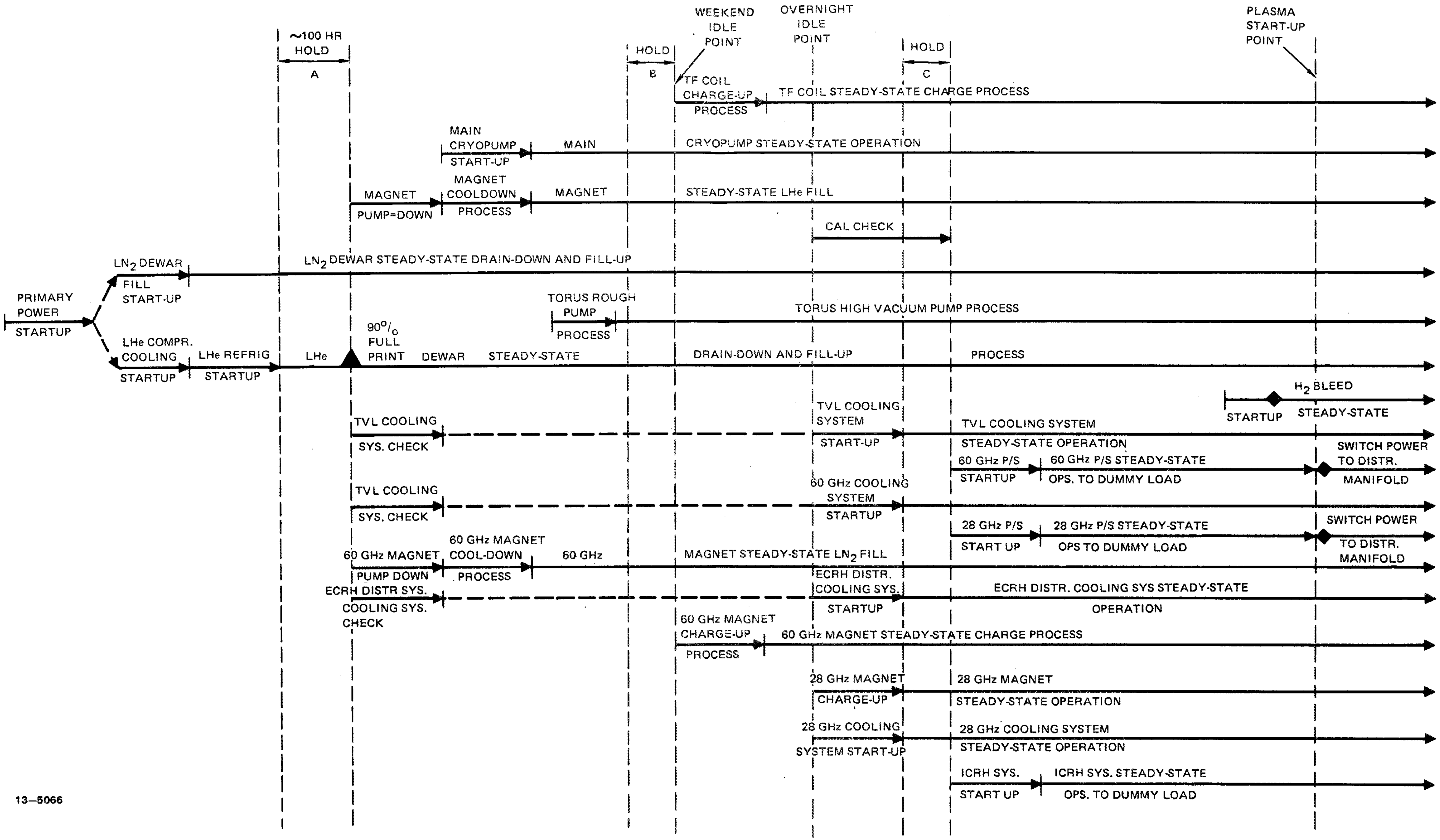


FIGURE 5.7–1 EBT-P ZERO-ZERO START-UP DIAGRAM

The TF magnet cool-down process is the pacing item, possible requiring ~ 72 hours depending on the guidelines used to control thermal stresses in the cold mass and coil pack. These three processes next transition into three steady-state LHe fill processes for the magnet dewars and the main cryopumps and the toroidal vessel high vacuum pump process.

These steady-state processes carry the start-up procedure through the "weekend idle point" (Hold B). This milestone represents a partially active state (or partially shut-down stage depending on point-of-view) for the EBT-P device/facility. The magnets are operating at 4.2°K (uncharged) and the EBT-P toroidal vessel is idling at the baseline pressure ($\sim 10^{-7}$torr).

Two processes are started next:

- TF magnet charge-up process,
- 60GHz focus magnet charge-up process.

These processes require ~ 10-120 minutes and transition to steady-state magnet charge processes. In so doing, the start-up process moves through the "overnight idle point." From this milestone, five new processes are initiated:

- TVL cooling system start-up,
- 60GHz water-cooling system start-up,
- 28 GHz water-cooling system start-up,
- 28 GHz focus magnet charge-up process (normal magnet),
- ECRH distribution system cooling start-up.

Completion of these processes brings the start-up procedure to another milestone, Hold C, a TBD interval probably not exceeding 30 minutes in duration.

Hold C terminates with the initiation of three new processes:

- 60 GHz ECRH power supply start-up,
- 28 GHz ECRH power supply start-up,
- ICRH power supply start-up.

These processes involves gyrotron tube conditioning tasks and RF antenna impedance matching tasks (no plasma in the device, gyrotron output power fed to dummy loads). These procedures probably will require 30-120 minutes to finish.

The final procedure in the device/facility start-up sequence is the GH_2 bleed process which increases the toroidal vessel pressure to $\sim 10^{-5}$ torr. At a TBD point following start of the steady-state GH_2 bleed process, ECRH and/or RF power is fed to the torus and the "plasma start-up" milestone is achieved.

During Title I this baseline start-up process was used as a framework for developing the MCC process flow diagrams (see Sec. 4.1.7). This work will continue in Title II during which these processes will be further analyzed into PC-implemented control/interlock sequences operated via MCC control panel switches.

5.8 DAS TIMING STUDY

This analysis considers the data transmission requirements of the digital data links between the DAS microprocessor and the Harris System 135 facility computer. It establishes the suitability of using asynchronous serial data links operating at 19.2K bit/sec rates to handle the anticipated requirements of Phase III operation.

The specific design criteria for these links are:

a) The link shall have a data transmission rate sufficient to introduce not more than 1.0 sec delay in transmitting data from a given Class A sensor to the facility computer I/O port.
b) The link shall have a data transmission rate sufficient to support the basic 1 sample/channel/sec data rate required for the Class A sensors.

Figure 5.8-1 shows the timing diagrams for the link between the DAS microprocessors and the Harris 135 facility computer. This link is an EIA asynchronous serial link operating at 19.2 kbit/sec. This timing diagram considers the typical communication task, viz to transmit a 1 Kbyte data block. Four steps are required:

LSI-11/23 TIMING TO ACQUIRE, STORE AND TRANSMIT
1K BYTES TO FACILITY COMPUTER:

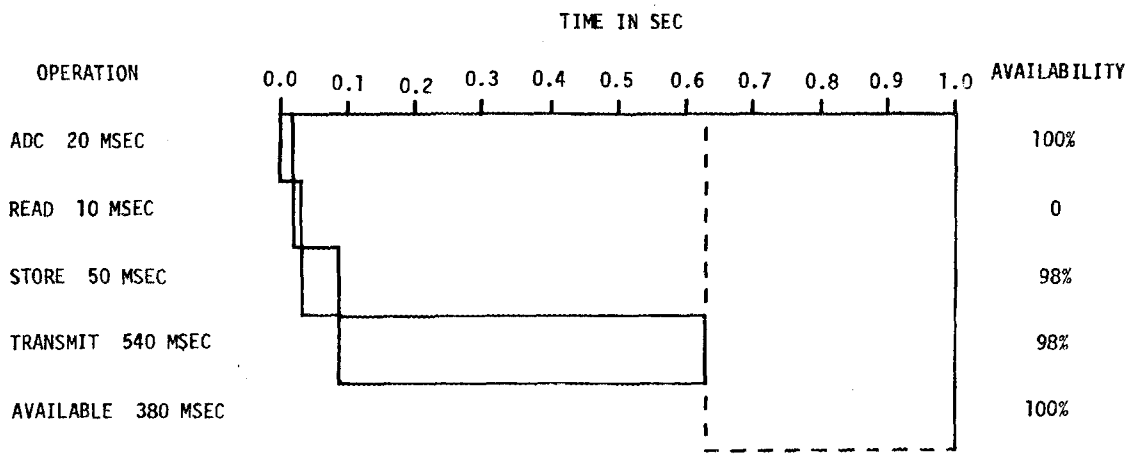
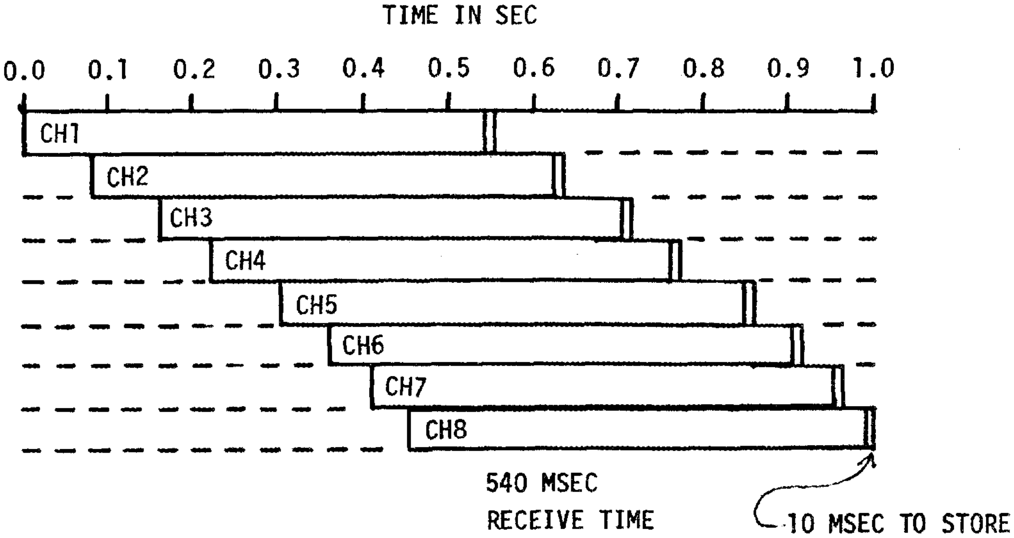


FIGURE 5.8–1 MICROPROCESSOR TIMING

HARRIS S135 TIMING TO RECEIVE 1K BYTES FROM
EACH OF EIGHT MICROPROCESSORS, AND STORING
IT EACH SECOND:



PROCESSOR AVAILABILITY USING 1 CHANNEL = 98%
TOTAL AVAILABILITY USING 8 CHANNELS = 85% WORST CASE

FIGURE 5.8–2 FACILITY COMPUTER TIMING

a) A 20 msec interval is required for the CAMAC ADC module to fill the 1 Kbyte buffer.
b) A 10 msec interval is required to move the 1 Kbyte block from the CAMAC buffer to the DAS microprocessor memory.
c) A 50 msec interval is required to copy the 1 Kbyte block to the DAS microprocessor Winchester disk unit. This procedure ensures that a retrievable copy of the block exists should the buffer became corrupted during transmission from the DAS microprocessor to the facility computer.
d) A 540 msec interval is required to transmit the 1 Kbyte block to the facility computer.

The total time required for this task is 620 msec and easily fits into the 1 sec time slot reserved for this task (derived from the 1 sample/channel/sec design criterion). Note that the demands on the DAS microprocessor due to this task are extremely slight, i.e. the microprocessor availability is ~98% while this task executes. This is due largely to the slowness of the serial link (19 kbit/sec) compared to the basic microprocessor CPU cycle (~2 μsec/cycle). In the RSX-11M operating system environment, the DAS microprocessor can manage several other concurrent tasks while the basic data transmission task is executing. For instance, a display refresh task can be executed by the DAS microprocessor to service one of the SCC CRT displays concurrent with the data transmission task.

In addition, the Harris 135 facility computer capability allows numerous such data transmission tasks to be executed concurrently using only a small percentage of available CPU capacity (see Figure 5.8-2). For example, six data transmission tasks require only about 10% of the facility computer capacity for concurrent execution.

5.9 CONTROL ROOM LAYOUT STUDY

This study involves an analysis of control station layouts which satisfy the design criteria for the EDC, MCC and SCC (see Sec 3.0). A conventional link analysis technique is used to qualitatively arrive at a layout which is compatible with the given control room dimensions. The term "link" refers to the connections between the members of the device operations crew, and includes primarily verbal and visual links between these individuals.

Figure 5.9-1 shows the individual control stations (box symbols) and the device operations crew (circle symbols). The design criteria requiring operators at each SCC station for the 6-60 GHz gyrotrons, for the 2-28 GHz gyrotrons and for the two ICRH SCC stations have been used. Similarly the placement of operators at the MCC stations reflects the design criteria requiring centralized control of all device systems at a location within the control room.

The huge number of links possible between 24 operators has been considerably reduced already in Fig 5.9-1 by means of engineering decisions based on knowledge of those systems which are hardware close-coupled and of those which are uncoupled. For instance, there is no important hardware coupling between the individual 60 GHz gyrotron tubes and power supplies. In fact a design criteria requires that these units be uncoupled and independently controllable. Consequently, there is no compelling reason to consider verbal and/or visual links among operators **1** thru **6** for the purpose of this analysis. If these gyrotrons are hardware-coupled at all, these links will likely occur via the 60 GHz microwave distribution system. This coupling is controlled by the MCC 60 GHz operator **15** who has control over both the output microwave power delivered by each 60 GHz gyrotron and the power balancing control elements built into the 60 GHz distribution system. This same reasoning is applied to the SCC stations association with the 28 GHz system and with the ICRH system.

This next step in this analysis is to employ the design criteria to rank the importance of each link. The key member of the operation crew is the Experiment Director in whom the authority and responsibility for device operation solely resides. This factor, together with the design criteria requiring centralized control, gives rise to the links rated "9" to indicate that verbal and visual contact via these links is absolutely required. The Experiment Director delegates his authority and responsibility to the six MCC operators primarily by verbal communication.

The Experiment Director also is connected by a rank "9" link to the Diagnostics Data Coordinator (DDC). The DDC is responsible for the coordinated operation of the six main research diagnostics indicated in Fig. 5.9-1 and for evaluation of plasma measurements during a run via quick-look data. The Experiment Director and the DDC jointly direct the operation of the EBT-P device during a given experimental run.

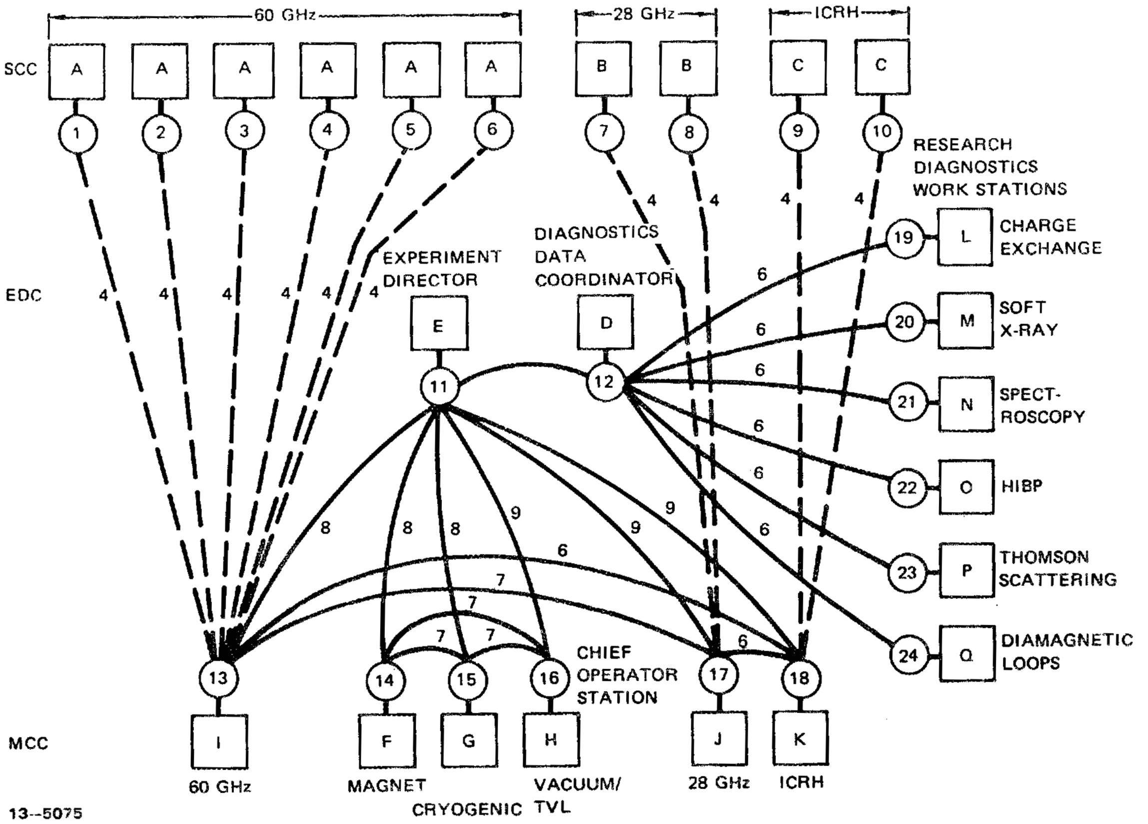


FIGURE 5.9–1 EBT-P CONTROL SYSTEM LINK DIAGRAM

The links rated "7" connect MCC operators who control systems with important hardware interconnections. A rating of "7" is applied to the link between the MCC 60 GHz and MCC 28 GHz operators because their systems are close-coupled via the plasma heating process itself. A visual/verbal link here is desired for normal device operation. A somewhat weaker link between the MCC ECRH operators and the MCC ICRH operator is given a rating of "6". A visual/verbal link here is "provided" rather than "required" or "desired" to indicate that this link likely will be less utilized than the rank "9" and rank "7" links.

The possible links between the three MCC device systems operators and the three MCC plasma heating operators are not shown for sake of clarity and are not likely to be heavily used because these groups of systems are not hardware close-coupled. These links are rated "5".

The remaining links in Fig 5.9-1 connect MCC and SCC operators and are shown as dashed lines to indicate secondary importance insofar as visual/verbal contact requirements are concerned. In fact, these links exist and are implemented by the PC units and the DAS microprocessors associated with the various device systems. Communication on these links is via the CRT terminals located at the MCC and SCC stations and is in the form of status displays provided for the operator at his request. Thus, the 60 GHz MCC operator can inquire concerning the status of an individual 60 GHz gyrotron tube and/or power supply by using his CRT display and touch panel. Normally, this MCC operator treats the gyrotron/power supply as a "black box" which converts DC power into microwaves and over which he has a limited control capability (e.g. he can adjust the microwave output power level as part of his ECRH distribution balancing process). Thus, there is a split-function control strategy used for the gyrotrons; the SCC operator controls and monitors some of the functions while the MCC operator controls other gyrotron functions and also balances the microwave power to the 36 device sectors.

The control room layout described in Section 4.1.1 (Fig. 4.1.1-1) is derived from the link diagram using two basic criteria:

a) Minimize the number of crossing links
b) Minimize or optimize the lengths of the most important links.

The simplest arrangement satisfying these criteria is the rectangular MCC layout with the EDC, DDC and Chief Operator's console placed side-by-side. This untangles most of the links and makes each rank "9" link of nearly equal length. The SCC units are most logically located close to an interior wall because these units are tall instrumentation racks. According to human factors recommendations, these should not be positioned in the center of a control room since these would form visual obstructions if so located. The control room layout is completed by positioning the normally unmanned SCC stations near the interior walls at the west end of the control room. This arrangement opens up a large portion of the center area of the control room to accommodate equipment associated with the research diagnostics work stations.

6.0 SYSTEM SCHEDULES

This appendix contains details of the plan for the EBT-P I & C Title II and Tasks 3 & 4 work. The plan is described in terms of scheduled tasks and forms the basis of the C/SCS model for Title II and Tasks 3 & 4. The information contained in this section is a contract deliverable called out in the UCC-ND SOW.

Table 6-1 lists the significant milestones for the I & C Title II and Tasks 3 & 4. The plan calls for completing major I & C sub-assembly work at MDAC-STL facilities before December 1983, the completion date for transition to the ORVIP site. The intent is to reduce the amount of base-level wiring that is required during the installation period at the ORVIP site.

Table 6-1. I & C Title II Task 3 & 4 Milestones

- Sept 81 — Start I & C Title II
- April 82 — I & C Interim Design Review
  Receive ORNL Approval for Long-lead/Advance Procurement
- Nov 82 — I & C Critical Design Review
- Dec 82 — Start I & C Task 3 Procurement & Fabrication
- June 83 — Start Transition to ORVIP Site
- Dec 83 — Complete Transition to ORVIP Site
- Feb 85 — Start I & C Pre-operational Testing
- May 85 — Start Phase III Operations

This section is divided into two parts. Section 6.1 discusses general schedule details for Title II and Tasks 3 & 4. Section 6.2 concentrates on the near term Title II work and describes the tasks required to accomplish the CDR milestone.

6.1 BASELINE SCHEDULE

Figure 6-1 shows the general details of the I & C Title II and Task 3 & 4 schedule. Title II effort involves five parallel tasks:

a) The Title II detailed design tasks;
b) Development of the MCC mockup;
c) The Interim Design Review (IDR) initiating long-lead procurement tasks;
d) Installation of the Harris 135 facility computer at MDAC-STL;
e) Preliminary software development.

Tasks a) are enumerated in Section 6.2. The MCC mockup is an inexpensive wooden assembly which serves as a design tool to work out man-machine interface (ergonometric) design details. To maintain the Phase II schedule, it is necessary to obtain ORNL approval to initiate advance procurement of several I & C components:

- Facility computer DMACP I/O multiplexer
- One or more DAS microprocessor units/software
- One or more CRT terminals/software
- Selected CAMAC hardware/software
- One or more programmable controller (PC) units/software
- Selected data communication hardware

This equipment is needed to ensure that the software development tasks maintain schedule.

The Harris 135 computer will be re-installed in a new location at MDAC-STL and dedicated exclusively to EBT-P software development work (starting in July 1982). This work initially will support the Title II design and, at the start of Task 3, will support the detail software development coding tasks and various acceptance tests for I & C sub-assemblies.

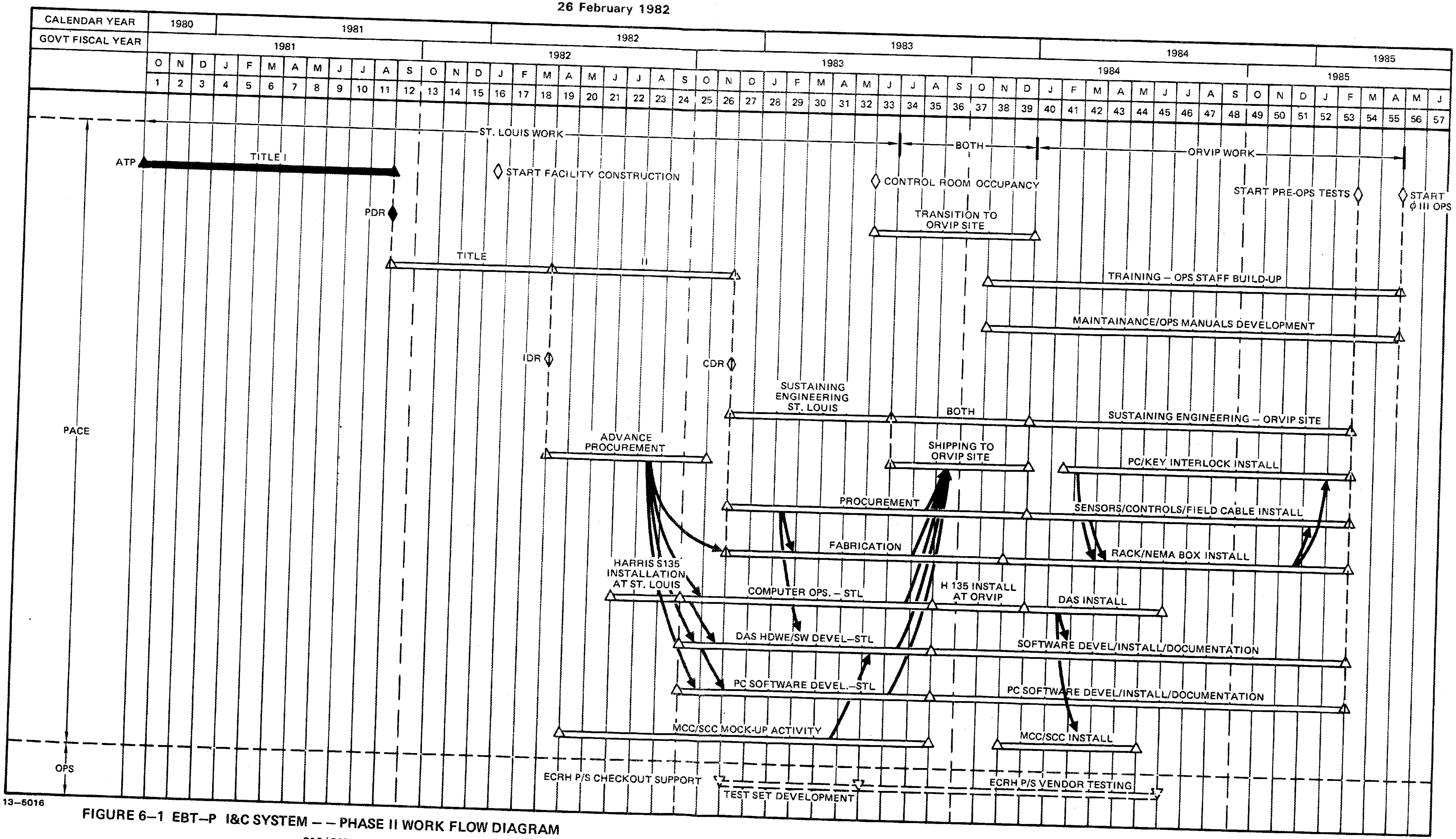


FIGURE 6–1 EBT–P I&C SYSTEM – – PHASE II WORK FLOW DIAGRAM

Upon achieving the CDR milestone, three concurrent tasks will commence (initiating the Task 3 effort):

a) Release of I & C procurement packages to vendors approved by ORNL at CDR;
b) Release of fabrication/assembly subcontracts to vendors approved by ORNL at CDR;
c) Production of software modules (detailed code generation).

Figure 6-2 shows the work flow involved in accomplishing tasks a) and b). MDAC-STL Procurement Support Group handles the detailed procurement work in support of the I & C group. The present plan calls for vendors to ship components to MDAC-STL for receiving inspection (generally consisting only of parts type and count verification using the Purchase Order specification details as the guide). Concurrently, MDAC-STL Procurement issues subcontract awards for I & C fabrication/assembly work. Current plans call for three subcontracts:

- Subcontract A
  - Cooling panel sub-assembly work
- Subcontract B
  - Instrumentation rack wiring installation
  - Secondary control panel wiring assembly
  - MCC control panel wiring assembly
  - Field cable assembly
  - Instrumentation racks final assembly
  - MCC stations final assembly
- Subcontract C
  - NEMA enclosure wiring installation
  - Assembly of PC hardware in the NEMA enclosures

These assemblies are delivered to MDAC-STL for acceptance testing although it is possible that selected testing can be better accomplished at the vendor's site in certain instances.

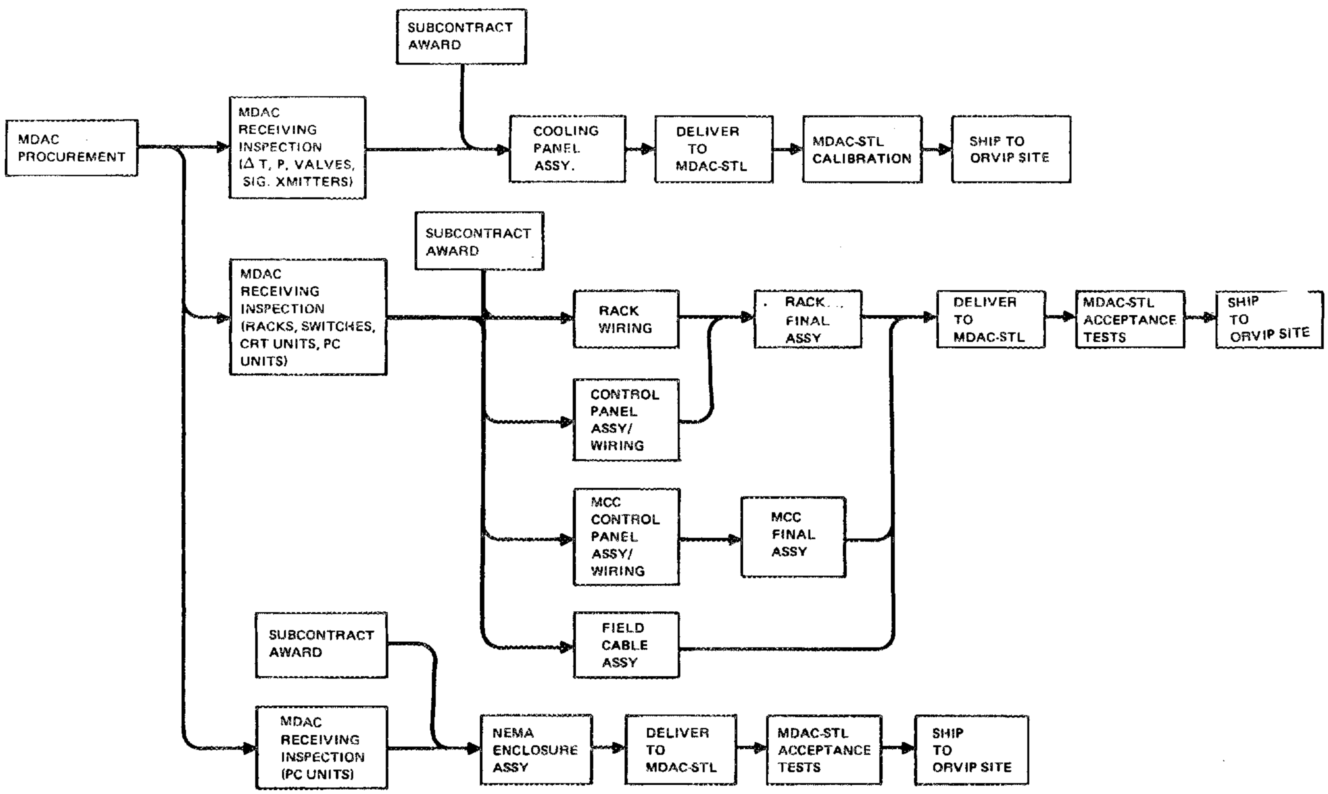


FIGURE 6-2 I&C TASK 3 FABRICATION/ASSEMBLY WORK FLOW DIAGRAM

Acceptance testing methods are tailored to the requirements of the individual subassemblies. The cooling panels contain differential temperature, flow and flow metering components together with associated plumbing and signal transmitters. These panels are delivered to the MDAC-STL calibration laboratory and undergo flow tests and sensor/signal transmitter transfer function calibrations.

The instrumentation racks containing DAS microprocessor equipment are subjected to system software/hardware verification tests at MDAC-STL appropriate for such equipment. These tests include verification of data communication links between the Harris 135 facility computer and the DAS microprocessor unit. Upon successful completion of these tests, the I & C group starts tasks directed at building the CAMAC "front-ends" for the DAS microprocessors. This work involves additional testing to verify the proper function of CAMAC serial highways. CAMAC diagnostic software is used to support these tests.

The MCC stations are subjected to tests which require establishing links to the facility computer and to the PC I/O structure. Software modules developed at the start of Title III are used to support these tests and check out the function of the MCC control panels and of the MCC CRT terminals.

The field cable acceptance tests generally involve basic electrical continuity checks, electrical isolation tests, verification of correct wire labeling and verification of proper pin-out if a cable connector has been specified.

NEMA enclosure acceptance tests involve verification of proper wiring between PC I/O module screw terminals and fan-out barrier terminal straps.

Present schedule milestones require transition to the ORVIP site to start in June 1983 and to be completed by December 1983. The key task, besides effective coordination at both ends of the road, is supported by MDAC-STL Shipping Dept., which assumes responsiblity for disassembly and packaging at MDAC-STL and for transportation logistics.

The I & C Task 4 work at the ORVIP site involves nine tasks:

1) Installation of the Harris 135 facility computer
2) Installation of the DAS microprocessors and CAMAC hardware
3) Continued software development, installation and documentation
4) Instrumentation rack and NEMA enclosure installation
5) MCC installation
6) Sensor/control element/field cable installation
7) Operator training and staff build-up
8) Development of operations and maintenance procedures/documentation
9) I & C pre-operational testing

These tasks have imbedded sub-tasks which essentially repeat a selected number of acceptance tests accomplished at MDAC-STL. The purpose is to detect any anomalies which may have occurred in shipment to the ORVIP site. The main thrust of these tasks is to move the I & C system to the pre-operations testing start milestone (February 1985) without schedule slippage such that the I & C system does not fall on the critical path during the last twelve months of Phase II. This requirement is especially important because much of the sensor/control element installation is paced by other device system installation work (e.g.; TF coils, toroidal vessel, vacuum, cryogenics) and occurs late in Phase II.

6.2 I & C TITLE II TASK DETAILS

A detailed breakdown of the I & C Title II tasks is shown in Table 6-2. Each task in this list forms the basic input to the C/SCS model for I & C Title II via the work/planning package methodology.

The task breakdown calls for development of a set of hardware procurement specifications and for several software specifications. The hardware specifications are developed in standard MDAC-STL format tailored for "best commercial practice" procurement. Military specifications are not invoked. A large portion of the I & C equipment is specified by part number; detailed specifications are not required for these components. The software specifications use MDAC-STL standard practices for software development. (Appendix C).

Table 6-2. Title II I & C Tasks

I. DAS

- Hardware Detailed Design
  - Facility Computer
  - Microprocessor Units
  - CAMAC Front-End
  - MCC CRT Terminals
  - Data Links
  - Master Timer
  - Computer Room Floor Plan

- DAS Software Specification
  - Facility Computer Tasks - Modules
  - Microprocessor Tasks - Modules
  - Software-Implemented Communication Paths
  - Data Structure Definition - Common Areas
  - Data-Base Record/File Definition
  - Programming Language Trade Study
  - CRT Display Page Definitions
  - Operator Software Interface Definition - Monitor Console Routines
  - Software Documentation Methods Definition
  - Software Maintenance Methods Definition
  - Software Training Methods Definition

- DAS Procurement Package
  - Microprocessor Units
  - CAMAC Hardware
  - CRT Display Units
  - Data Communications Hardware
  - Master Timer Unit

- DAS Advance-Procurement Package
  - Facility Computer DMACP I/O Multiplexer
  - One or More Microprocessor Units
  - Selected CAMAC Hardware
  - One or More CRT Display Units
  - Selected Data Communications Hardware
  - Software Packages Required for these hardware items

- Facility Computer Re-Installation at MDAC-STL
  - Harris 135 System Required by EBT-P in June 1982
    - Software Design Verification Studies
    - Basic Timing Studies
    - Timely Transition to Title III Activities
    - Preparation for Title III Software Development Work
  - Install in MDAC-STL, Building 101
  - Set-Up Typical Microprocessor Link
  - Set-Up Typical MCC CRT Terminal Link

- Other DAS Tasks
  - MCC Mockup
    - Verify CRT Terminal Ergonometrics
    - Verify Control Panel Ergonometrics

II. I & C INTERFACES

- Detailed Hardware Design For Interfaces To
  - Magnet System
  - Cryogenics Distribution System
  - Vacuum System
  - Toroidal Vessel/Limiter Cooling System
  - ECRH System
  - ICRH System
  - Helium Refrigerator System
  - Device Utilities System

- Plasma Operation Device Instrumentation
- Plant Systems

- Procurement Packages For
  - Sensor Elements
  - Control Elements
  - Signal Transmitters
  - Field Cable Assemblies
  - Sub-Assemblies
  - Instrumentation Rack Wiring Installation
  - NEMA-12 Enclosure Wiring Installation
  - MCC Control Panel Fabrication
  - Secondary Control Panel Fabrication

III. CONTROL/INTERLOCK/SAFETY SUBSYSTEM

- Hardware Detailed Design
  - PC Remote I/O Units
  - PC Local I/O Units
  - PC CPU System
  - PC Driven CRT Display Units
  - PC Data Communication Links
  - Key Interlock Subsystem

- PC Subsystem Software Specification
  - PC Software Interlock Logic Definition
  - PC Sequential Control Logic Definition
  - PC Data Structure Definition
  - CRT Display Page Definition
  - Operator Software Interface Definition
  - Software Implemented Backup Design Definition
  - Software Documentation Methods Definition
  - Software Maintenance Methods Definition
  - Software Training Methods Definition

- Procurement Packages For
  - PC Hardware
  - CRT Display Units
  - PC I/O Module Wiring Installation
  - Key Interlock Hardware

- PC Advance-Procurement Package
  - One or More PC Units
  - One or More CRT Display Units
  - Software and Programming Units

IV. OTHER I & C INTERFACES

- Hardware Detailed Design
  - Electrical Grounding Interface
  - Link To Research Diagnostics Computer Network
  - Link To Research Diagnostics Microprocessors

- Software Specification
  - Communications Task - Computer Network Link
  - Communications Task - Research Diagnostics Microprocessor Link

APPENDIX B

I&C SYSTEM EQUIPMENT RACK DESIGNATIONS

DESIGNATIONS	CONTENTS
ECRH-60L-001	AC POWER/DC POWER CONTROL PANELS FOR 60GHZ GYROTRON NO. 1
ECRH-60L-002	MICROPROCESSOR/CRT TERMINALS FOR 60GHZ GYROTRON NO. 1
ECRH-60L-003	CRYOGENICS/COOLING/MAGNET CONTROL FOR 60GHZ GYROTRON NO. 1
ECRH-60L-004	
ECRH-60L-005	60GHZ GYROTRON NO. 2
ECRH-60L-006	
ECRH-60L-007	
ECRH-60L-008	60GHZ GYROTRON NO. 3
ECRH-60L-009	
ECRH-60L-010	
ECRH-60L-011	60GHZ GYROTRON NO. 4
ECRH-60L-012	
ECRH-60L-013	
ECRH-60L-014	60GHZ GYROTRON NO. 5
ECRH-60L-015	
ECRH-60L-016	
ECRH-60L-017	60GHZ GYROTRON NO. 6
ECRH-60L-018	
ECRH-28L-001	AC POWER/DC POWER CONTROL PANELS FOR 28GHZ GYROTRON NO. 1
ECRH-28L-002	MICROPROCESSOR/CRT TERMINALS FOR 28GHZ GYROTRON NO. 1
ECRH-28L-003	WATER COOLING/MAGNET CONTROL FOR 28GHZ GYROTRON NO. 1
ECRH-28L-004	
ECRH-28L-005	28GHZ GYROTRON NO. 2
ECRH-28L-006	
ICRH-LCL-001	ICRH TRANS. SYS. NO. 1 INPUT STAGE CONTROLS

DESIGNATIONS	CONTENTS
ICRH-LCL-002	ICRH TRANS. SYS. NO. 1 MICROPROCESSOR/CAMAC/CRT ANNUCIATOR
ICRH-LCL-003	ICRH TRANS. SYS. NO. 1 FPA/ANTENNA TUNING CONTROLS
ICRH-LCL-004	
ICRH-LCL-005	ICRH RF TRANSMITTER NO. 2
ICRH-LCL-006	
TVL-LCL-001	TVL COOLING SYS. MICROPROCESSOR/CAMAC/CRT DISPLAY
TCL-LCL-002	TVL COOLING SYS. CONTROL PANEL/CRT ANNUCIATOR-SECONDARY CONTROL
BOP-LCL-001	PRIMARY/SECONDARY AC POWER DISTRIBUTION PANEL
BOP-LCL-002	UPS CONTROL/CRT ANNUCIATOR
BOP-LCL-003	FACILITY PRIMARY COOLING/COMPRESSED AIR CONTROL
BOP-LCL-004	SPARE
BOP-LCL-005	SPARE
BOP-LCL-006	SPARE
VAC-LCL-001	VACUUM SYS. MICROPROCESSOR/CAMAC/CRT DISPLAY
VAC-LCL-002	VACUUM SYS. CONTROL PANELS/CRT ANNUCIATION-SECONDARY CONTROL
MAG-LCL-001	
MAG-LCL-002	
MAG-LCL-003	
MAG-LCL-004	MAGNET SYSTEM RACKS
MAG-LCL-005	
MAG-LCL-006	
MAG-LCL-007	

DESIGNATIONS	CONTENTS
CRYO-LCL-001	CRYO. DISTRIBUTION SYS. MICROPROCESSOR/CAMAC/CRT DISPLAY
CRYO-LCL-002	CRYO. DISTRIBUTION SYS. CONTROL PANELS/CRT ANNUCIATOR-SECONDARY CONTROL
N1	ECRH 60GHZ PROGRAMMABLE CONTROLLERS
N2	ECRH 60GHZ PROGRAMMABLE CONTROLLERS
N3	ECRH 28GHZ/ICRH PROGRAMMABLE CONTROLLERS
N4	BOP/TVL COOLING PROGRAMMABLE CONTROLLERS
N5	VACUUM/MAGNET PROGRAMMABLE CONTROLLERS
N6	CRYO. SYS. PROGRAMMABLE CONTROLLERS

APPENDIX C
SOFTWARE REQUIREMENTS DOCUMENT

C.1 INTRODUCTION AND JUSTIFICATION

C.1.1 Purpose Of This Requirement

This Software Requirements Document (SRD) is being supplied as an Appendix to the EBT-P Instrumentation and Control Title I Report. This document describes the requirements for software to be used in support of the EBT-P device Data Acquisition System (DAS) and the EBT-P device Control and Interlock System.

The need for software development and this requirements document is predicated on the assumption that EBT-P instrumentation and control shall be done by automated data acquisition computers and process controllers. All software to be developed as a part of the EBT-P DAS and control system is described in this SRD.

While this document forms an Appendix to the I & C Title I Report, it duplicates some hardware and software description given in the main body of the report. This is done to insure that this SRD is a self-contained description of the software requirements.

C.1.2 Scope Of Applicability

This document is intended to serve as a source document for reference to EBT-P software. Accordingly, the intended readers of this document include any scientific, engineering, and management personnel who require information regarding the operation, function, structure, environment, development schedule or other characteristics of the EBT-P software.

This document is applicable to all software which shall execute in the EBT-P DAS computers and process controllers. This includes software for the DAS microprocessors and the EBT-P Facility Computer. Not included in this software requirement is software for EBT-P research diagnostic processors and computers.

Application software developed by MDAC is included in the scope of this SRD as well as purchased software such as operating systems, display firmware and libraries, data acquisition libraries, and other packaged software elements furnished with hardware items.

C.1.3 Applicable Documents

Documents which describe the requirements of the EBT-P device and the instrumentation system supported by the software described herein are:

- EBT-P Phase II Request for Proposal, UCC-ND RFP No. 22-80414.
- EBT-P Phase II Proposal-Alternate Site, MDC Report E2229
- EBT-P Baseline Design Data Book, MDC Report E2325.
- EBT-P I & C Title I Report (this document forms Appendix C).

Documents which specify or describe hardware or other software with which the EBT-P software must interface include:

- Modular Instrumentation and Digital Interface System (CAMAC), IEEE Std. 584-1975.
- Serial Highway Interface System (CAMAC), IEEE Std. 595-1976.
- Block Transfers in CAMAC Systems, IEEE Std. 683-1976.
- Multiple Controllers in a CAMAC Crate, IEEE Std. 675-1979.
- Subroutines for CAMAC, IEEE Std. 758-1979.
- USA Standard Code for Information Interchange (USASCII), ANSI-X3.4-1968.
- Flowchart Symbols and their use in Information Processing, ANSI-X3.5-1970.
- Interface between Data Terminal Equipment and Data Communications Equipment Employing Serial Binary Interchange, EIA RS-232-C.

The MDC Corporate Control Procedure which is applicable to this software development effort is:

- Software Management and Control, CP 8.250AE, 15 Dec 1980.

C.1.4 Establishment Of Need

This software is required to meet the need for a computer-controlled data acquisition system (DAS) for EBT-P machine data. Related requirements for graphic or semi-graphic displays of facility status information also establish the need for this software development. These needs are detailed in Section 6 of the EBT-P Reference Design Criteria of the EBT-P Phase II RFP.

C.1.5 General Description Of The Needed Software

The software described in this document will perform the following functions with regard to EBT-P device operation:

- Data Acquisition
- Processing
- Data and Status Display
- Data Storage
- Interprocessor Communication
- Device Control and Interlocking

To accomplish these basic functional elements, programs will be written to perform each of these functions on each component processor in the DAS and control system. The processor components are:

- Harris Model 135 (SLASH 6) Facility Computer.
- DEC LSI-11/23 Microprocessors.
- Allen-Bradley PLC-3 Process Controllers.

In addition, each processor component is associated with peripheral equipment specifically intended to aid the accomplishment of the six basic functions. Those peripheral components which will require software development for EBT-P include:

- Data acquisition systems (CAMAC).
- Graphics displays (Black & White and Color CRT terminals).

- Touchpanel screen overlays.
- Communications interfaces.
- Master timer distribution network.

The processing components of the DAS and control system form a hierarchy as diagrammed in Figure C.1.5-1. Each processor will require software to control the flow of data with respect to some or all of the peripheral components. Each processor will have some degree of responsibility for each of the six basic functional elements. A detailed description of the functional requirements is given in Section C.5 of this SRD.

C.1.6 Feasibility Studies

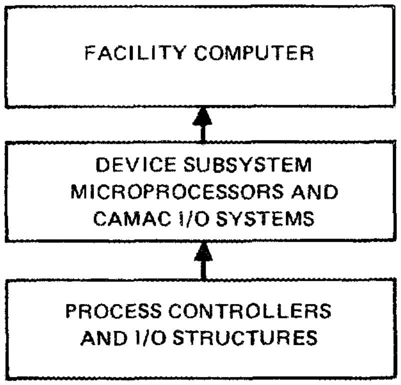
The proposed software for the EBT-P DAS and control system has been evaluated considering the following:

- Timeliness
- Technological feasibility
- Capability
- Major risks

The results of these studies are summarized here.

With regard to timeliness, a thirty-month development period is anticipated with an April 1985 finish date. Development will begin on the facility computer (supplied by MDAC-STL) when moved from its current location to the EBT-P DAS development lab in mid to late 1982. Advance procurement of one microprocessor and PC unit will also be requested at that time. The goal is to use the actual operational hardware for software development. Thus, no cross-compilers or other emulation software will be required. Similarly, portability of the finished software is not an issue.

The technical feasibility of this software is assured by using proven system software products at all levels. All operating system software, program development utilities, and file management software will be used as supplied on the microprocessors and facility computer. Special device drivers or other system level programs will not be developed. The pro-



13–5054

FIGURE C.1.5–1 I&C PROCESSOR HIERARCHY

cess controllers will be programmed in industry standard ladder logic using software development utilities supplied with the PC. The timing constraints for real-time data acquisition and communication software have been found not to be critical, with enough margin for specific cases to exceed the baseline data rate of one sample per channel per second if required. Concurrency of function will be achieved using the multitasking capabilities of the VULCAN and RSX-11M operating systems. Specific functions will be performed using special purpose library routines for data acquisition (CAMAC), graphical display, and data communication wherever possible. In summary, technical feasibility of this software is assured by the large degree of dependence on proven vendor-supplied system software and application libraries.

The baseline software package will have the capability to support the initial EBT-P Phase III operations. The software will be designed to have a high degree of expandability to handle foreseen upgrades to the EBT-P device. The expansion capability of the hardware is also appreciable.

No significant risks are seen in the EBT-P software development due to the use of proven system software and application libraries, use of the target operational hardware for software development, and the thorough software testing to be done before the EBT-P device becomes operational.

C.2 MANAGEMENT INFORMATION

C.2.1 Acquisition Method or Plan

C.2.1.1 Method of Acquisition

Software for the EBT-P DAS and control system will be developed in-house by members of the EBT-P Instrumentation and Control (I & C) group. No application coding will be performed by groups outside MDAC-STL or by other software groups within MDC. However, this in-house coding will be highly dependent upon software components supplied by vendors for use with specific processors and peripheral hardware. Software purchased will be in the form of "off-the-shelf" libraries and modules, which are known to be compatible with system software supplied with the processors. Software items to be purchased include:

- RSX-11M multitasking operating system
- Fortran IV/RSX compiler and object time system
- Pascal compiler and object time system
- CAMAC interface driver
- CAMAC support library
- Graphics firmware for color CRT terminals

Software items which are supplied as part of a hardware package or are to be considered as imbedded software are:

- Process Controller operating and program development firmware
- VULCAN operating system, utilities, and languages for the Harris facility computer
- Plotting software for the facility computer
- Communications drivers for the various interprocessor links
- RSX-11M utilities and program development tools for the microprocessors
- Diagnostic programs furnished with each processor

These purchased and imbedded software items will form an integral part of the application software package developed in-house by the EBT-P I & C group.

C.2.1.2 Responsible Group and Staff

Raymond J. Schmitt has overall responsibility for the EBT-P I & C system which includes the DAS and control systems. He will function as the software development program manager as defined in CP 8.250-AE Section D.5.

Bruce A. Boyd will have responsibility for the software design, development, and testing in detail. He will direct the efforts of two to four programming specialists who will be assigned to the project during Task 3.

C.2.2 Funding and Manpower

See Appendix D.

C.2.3 Milestone and Review Schedule

See Section 6.0.

C.2.4 Software Deliverables

A checklist of specific software items to be developed is given in this section. The basic element of deliverable software is the task. A task is defined to be an executable load module which performs or supports one of the six basic functional elements listed in section C.1.5.

The software package residing on any of the microprocessors or the facility computer shall be a collection of tasks together with common blocks for communication of data among tasks. This collection of tasks shall exist in the environment of the multitasking operating system on the processor, either RSX-11M or VULCAN.

The control programs running on the process controllers cannot be divided into distinct tasks performing separate functions due to the sequential logic of the PC. However, various elements in the control programs will be involved in execution of the same six functions as the tasks in the computers.

The checklist of software deliverables to be developed follows:

I. FACILITY COMPUTER

A. REAL-TIME TASKS (Production Mode)

1. Production Mode Supervisor
2. Touch Panel Input Interpreter
3. Display Formatters
4. Display Outputters
5. Data Receiver (from Microprocessor)
6. Data Transmitter (to Research Diagnostics)
7. Data Base Builder
8. Data Processors
9. Data Recorder
10. Data Retriever

B. OFF-LINE TASKS (Monitor and Maintenance Modes)

1. Monitor Mode Supervisor
2. Pre-production Preparation Tasks
3. Post-production Processors
4. Data Base Managers
   a. Archiver
   b. Retriever
   c. Lister
   d. Editor
   e. Plotter
5. System Component Verifiers
   a. Calibrators
   b. Exercisors
6. Data Transmitter (to Research Diagnostics)

II. MICROPROCSSOR DATA ACQUISITION SYSTEMS

A. REAL-TIME TASKS (Production Mode)

1. Production Mode Supervisor
2. Keyboard Input Interpreter
3. Display Formatters
4. Display Outputters
5. CAMAC Data Acquisition Controllers
6. PC Data Receiver
7. Data Transmitter (to Facility Computer)
8. Data Processors
9. Data Recorder
10. Data Retriever

B. OFF-LINE TASKS (Monitor and Maintenance Modes)

1. Monitor Mode Supervisor
2. Pre-production Preparation Tasks
3. Storage Manager and Consolidator
4. System Component Verifiers
   a. Calibrators
   b. Exercisors
5. Process Controller Access Task

III. PROCESS CONTROLLERS

One production mode program in each, which addresses the following functions:

1. Control Output
2. Input Interlocking
3. Data Acquisition
4. Data Collection
5. Data Transmission to Microprocessor

6. Data and Status Display
7. Communication With Other PC's

C.3 ENVIRONMENT AND INTERFACE REQUIREMENTS

This section of the SRD introduces the general environment within which the EBT-P DAS and control software is to operate. It identifies the users, operators, and maintenance personnel, the required operating systems and the system interfaces.

The physical environment for the software will be composed of the EBT-P facility computer, the subsystem DAS microprocessors and the subsystem process controllers (PC's). These components will be located in the EBT-P control room.

The facility computer shall be located in a separate enclosed, raised floor area at one end of the control room proper. Terminal access to the facility computer will be provided within the computer room as well as at access points in the control room and the EBT-P administration building. Facility computer data display terminals will be located in the Master Control Consoles (MCC) within the control room.

The subsystem microprocessors will be housed in racks adjacent to their associated secondary control console racks. Terminal access to the microprocessors will be provided by black and white raster refresh graphics terminals located in the rack with the processor. CAMAC data acquisition equipment will be located in racks on a balcony above the test support area suspended from the biological shield wall.

The subsystem process controllers will be located in NEMA cabinets adjacent to the associated subsystem secondary control consoles. A portable programming terminal will be available for programming access to any of the PC's. PC color graphics display terminals will be located in both the secondary and master control consoles in the control room. Remote I/O equipment will be located in NEMA boxes on the same balcony as the DAS CAMAC equipment.

C.3.1 User Environment

The users of this software will be the scientific, engineering, and technical staff who have responsibility for the operation of the EBT-P device before, during, and after production experimental operation. User interfaces to the software will be provided through the control panel and display hardware of the Experiment Director's Console, the Master Control Console, and the Secondary Control Consoles. The components which make up each of these consoles and the role of the user at each are described in the following paragraphs.

Experiment Director's Console (EDC). The EDC will consist of a console containing two color graphic display stations connected to the facility computer. The Experiment Director will, through these two display terminals, have access to all EBT-P device and facility data and status which is being gathered by the facility computer. His role will be to monitor this flow of data in order to make decisions concerning the operation of the device with respect to fulfillment of current experimental objectives. He will make those decisions known by requesting operators at MCC stations to initiate processes which control machine operation. The EDC will not contain any control switches which initiate or affect processes in the PC's. The experiment director will control the format and content of data displayed on his display screens by touch panel inputs.

Master Control Consoles (MCC). There will be several MCC stations, each corresponding to one or more of the primary or secondary device subsystems:

- Magnet Control Station
- Cryogenic Distribution Control Station
- Vacuum and Toroidal Vessel/Limiters Control Station
- 60 GHz Microwave Heating Control Station
- 28 GHz Microwave Heating Control Station
- RF Plasma Heating Control Station

At each of those stations will be located one or more facility computer display terminals (similar to EDC displays), one or more PC color graphic display terminals, and appropriate control panels. The facility computer displays will provide access to all data being collected by the facility computer. The MCC user can look at trends, compare current data with that from previous production runs, or see how a particular subsystem is affectng overall device operation at a facility computer terminal. The PC displays will provide the MCC users with live real-time status from each PC associated with a particular device subsystem. The control panels will contain switches which provide access to the processes controlled by each PC. The user may initiate, abort, or hold processes by actuating these switches.

Secondary Control Consoles (SCC). There are also several SCC stations, again containing computer, PC, and instrumentation hardware for each of the device subsystems. In particular, the SCC's are directly associated with the microprocessor data acquisition computers and terminals; the process controllers; local I/O and displays; and with the secondary subsystem control panels. The user at the microprocessor terminal has access to all data being collected by the microprocessor, both from the associated CAMAC I/O system and the associated PC. This data can be displayed on the microprocessor terminal in graphical form while it is being collected and transmitted to the facility computer. The user will also have access to any data stored by the microprocessor within the last hour of operation. The user will be able to exercise limited control over data acquisition during production, and have full access to data acquisition parameters during maintenance mode. The PC color graphic display terminals located in the SCC stations will mimic the corresponding displays in the MCC stations. Control panels in the SCC stations will provide process control as in the MCC, and individual component control. Individual device components such as pumps, valves, and power supplies, will be controllable by SCC control panel switches, subject of course to PC controlled interlocks.

C.3.2 Operational Environment

The operators of the EBT-P DAS and control system will be the members of the I & C group as defined in Section C.2.1.2. Thus, the same team which develops the software will have responsibility for operating and maintaining it after acceptance. Members of this group will also become the DAS system managers, who will have responsibility for any system level software maintenance.

The operational environment is physically similar to the user environment. Operational access to the DAS processors includes operating system access at several terminals in the computer room and control room. In particular, the system operators and managers will have access to the facility computer OPCOM terminal, and will be able to access the facility computer directly at MCC and EDC display stations via a removable keyboard. This ability will aid both the development and maintenance of display software which uses those terminals. In addition, the system managers will insure that the facility computer production mode software is enabled and active at each MCC and EDC station before the start of each EBT-P device operational cycle.

At the SCC microprocessors, individual users will be able to initialize and start (bootstrap) their systems. However, only the system managers will be able to override the normal monitor mode procedures in order to access the software at the system level. Except for occasional development mode software maintenance, the microprocessors will be "operator-less" machines.

The DAS operators and system managers will also have access to the process controller programming terminal which will be shared by all the PC's. The programming terminal will be physically transported from PC to PC. It will be individually connected to each PC for programming and maintenance. It shall not be possible to change the programmed logic of a PC when this terminal is not connected. Furthermore, only the system managers will have access to the keys which allow read/write access to the PC program memory.

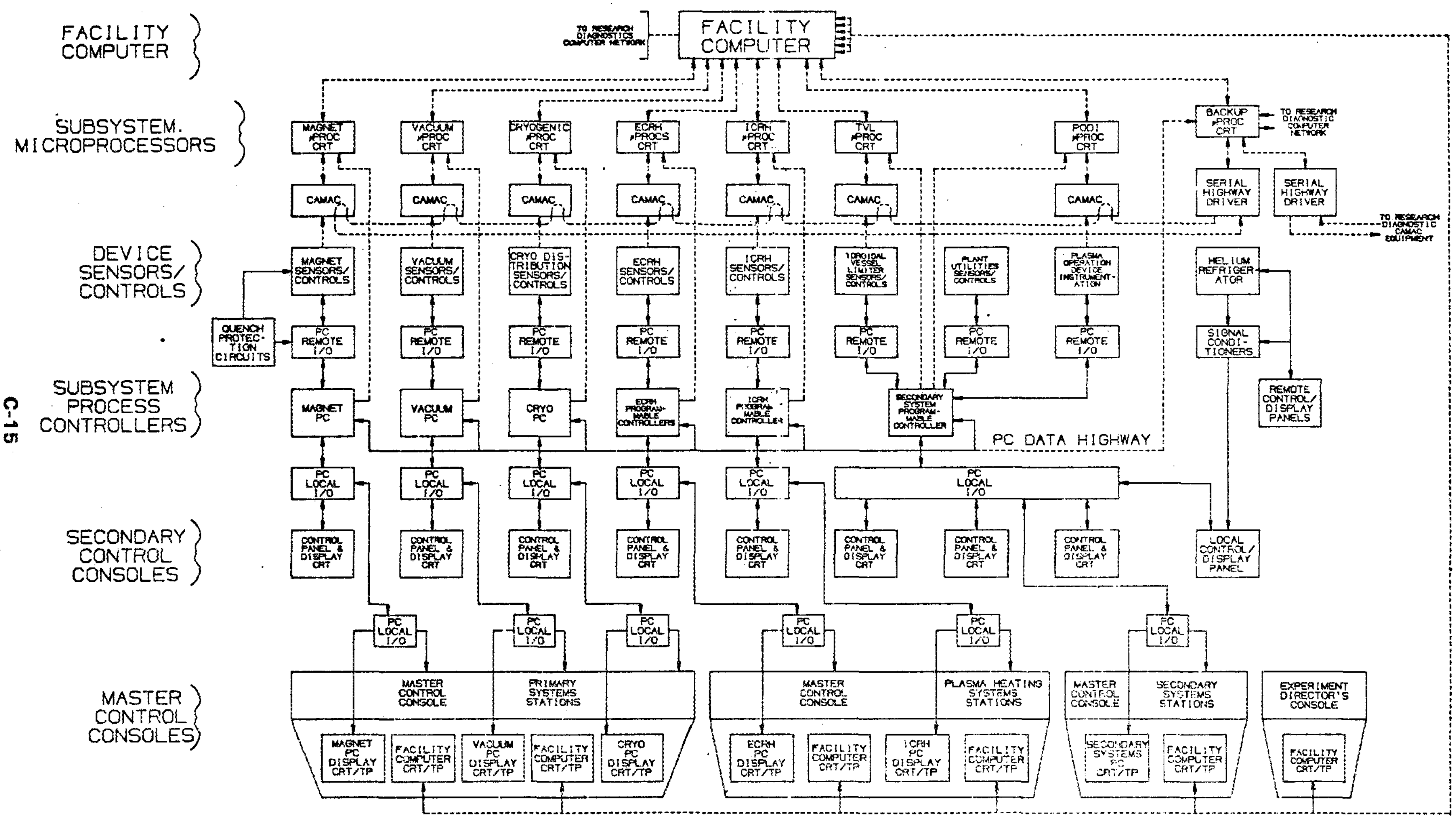
C.3.3 System/Subsystem Environment and Interface Requirements

This section provides a narrative overview of the total system in which the proposed software is required to operate. Figure C.3.3-1 is the master block diagram of the EBT-P I & C systems. The major components of the I & C system which relate to this SRD are:

- Facility Computer
- Subsystem Microprocessors
- Subsystem Process Controllers

Each of those processor components provides both a hardware and software environment for the application software to be developed. The software environment is also shaped by

FIGURE C.3.3–1 I&C SYSTEM MASTER BLOCK DIAGRAM



SOLID LINE = CONTROL/INTERLOCK CHANNEL
DASHED LINE = DATA ACQUISITION/DATA DISPLAY CHANNEL

the interfaces between the processor components. The following sections describe the hardware and software environments.

C.3.3.1 Hardware Characteristics and Constraints

One of the major design goals of this software development is to reduce or eliminate the impact of the transition from development to operation. Accordingly, one of the primary constraints on hardware is to use the actual operational hardware for all phases of software development.

The first software development will begin on the facility computer when it is transferred to the EBT-P project in late summer 1982. The Harris 135 (SLASH 6) Facility Computer is being supplied to the project as contractor furnished equipment. The facility computer consists of the following hardware components:

- Central Processor Unit
    - 256-Kwords x 24 bit memory
    - Scientific Arithmetic Unit (hardware floating point)
- Five Harris Model 5530/5531 80-Mbyte disk drives
- Four Harris Model 6690/6691 Magnetic Tape drives (9 track, 800/1600 bpi)
- One Tektronix Model 4923 Cartridge Magnetic Tape Unit
- One Harris Model 2310 Operator Console (OPCOM)
- Three Harris Model 8430 DMACP I/O Multiplexers
- Four Harris Model 8610 CRT/Keyboard Terminals
- Two Infoton Model 8660 CRT/Keyboard Terminals
- One Harris Model 4130 Line Printer (900 lines/min)
- One Harris Model 3120 Card Reader (600 cards/min)
- One Versatec Model 1200A Electrostatic Printer/Plotter (200 nibs per inch)
- One IMLAC Model PDS-4 Color Graphics Console Unit

Software development will begin with those tasks and modules which will support the hardware listed above. This will most likely include the supervisor tasks and data base management tasks.

Facility computer items for which advance procurement will be sought include:

- One Harris Model 8450 DMACP I/O Multiplexer
- One ISC (Intecolor) Model 8001G Color Graphics Display Terminal
- One Elographics Model E270 Transparent Touch Sensor with Controller

This equipment will be used to support development of microprocessor to facility computer communication tasks, MCC and EDC color graphics display tasks, and MCC and EDC touch panel input tasks.

Advance procurement of one microprocessor unit with a CAMAC I/O interface, and one process controller unit with local and remote I/O will also be sought. These units will be identical to the operational configuration and be used for initial program development. The standard microprocessor configuration consists of the following components:

- Scientific Microsystems (SMS) Model DSX01172 Disk System consisting of:
  - LSI-11/23 Microprocessor CPU
  - KEF11-A Floating Point Option
  - Q-Bus Backplane
  - 128 Kbytes MOS Memory
  - DLV11-J 4-line Serial Interface
  - 10 Mbyte Winchester Disk
  - 1.2 Mbyte Dual-sided, Double-density Floppy Disk
- DEC VT100 Video Terminal with Digital Engineering, Inc. VT640 Retrographics Enhancement
- Kinetic Systems Corp. Model 2060 Serial Highway Driver with Model 1735 Fiber Optic U-Port Adapter
- Kinetic Systems Corp. Model 1500 Crate with Model 3952 Serial Crate Controller Model 3935 Fiber Optic U-Port Adapter, and associated input modules.

The standard process controller includes the following components:

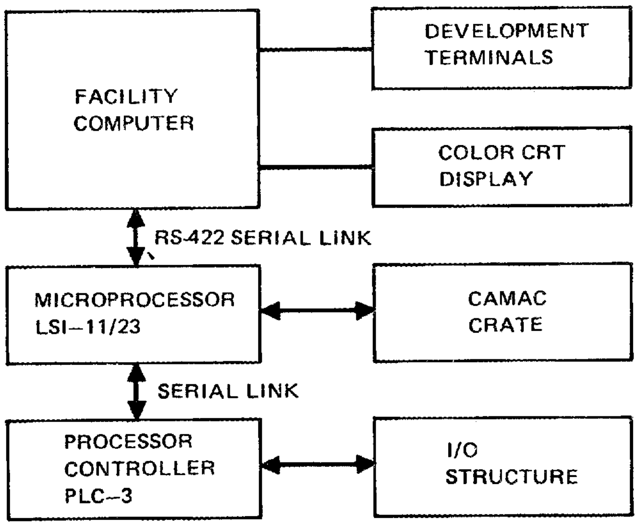
- Allen-Bradley (AB) Model PLC-3 Programmable Controller including:
  - 1775-A1 Main Chassis
  - 1775-L2 Main Processor with Level 2 Instruction Set
  - 1775-MR8 32K Ram Memory
  - 1775-S4 I/O Scanner Processor
  - 1775-DA Peripheral Processor
  - 1775-KA Communication adapter (Data Highway)
- AB Bulletin 1771 Universal I/O Equipment including:
  - 1771-A4 128 I/O Chassis Assembly
  - 1771-AS I/O Adapter Module
  - Appropriate Bulletin 1771 I/O Modules
- PC Display Terminal including:
  - ISC Model 8001G Color Graphics Display Terminal
  - Elographics Model E270 Transparent Touch Sensor with Controller

A software development facility based upon this initial hardware will be assembled as shown in figure C.3.3-2. This development facility will duplicate one leg of the total DAS and control system of Figure C.3.3-1. Even though constrained by the limited amount of hardware, software development will proceed to a very mature level using this development facility. Final development using full hardware will be limited to specific subsystem detailed programming and configuration file generation.

C.3.3.2 Software Characteristics and Constraints

The proposed software will be designed to take advantage of existing system and utility software whenever possible. Therefore, the software components with which the EBT-P software must interface should be viewed as adjuncts to the application package rather than as constraints.

Another design criteria for the facility computer and microprocessor based software is to use the multiprogramming and multitasking characteristics of the host operating systems to the fullest. Accordingly, the problems of scheduling and priority arbitration will be de-



13–5053

FIGURE C.3.3–2 PROGRAM DEVELOPMENT FACILITY CONFIGURATION ferred to the operating system rather than be addressed within the application programs. Programs will be written as tasks which perform one particular function only. Communication among tasks will be handled by memory resident common blocks and system communication services. This task-structured approach is consistent with the VULCAN and RSX-11M operating systems, with the use of the Pascal language, and with a top-down development approach.

A checklist of software components assumed to form the program development environment on each processor and peripheral is given below.

I. FACILITY COMPUTER

- A. VULCAN Multi-purpose, Multi-programming Virtual Memory Operating System.
- B. FORTRAN IV (ANSI 1977 Std.) Compiler and Libraries.
- C. PASCAL-P4 (University of Colorado) Compiler and Libraries.
- D. Versaplot Graphics Software for the Versatec 1200A Printer/Plotter.
- E. Additional Utilities and Libraries for:
  1. Text Editing.
  2. Screen Formatting.
  3. Storage Management.
- F. Computer diagnostics.

II. MICROPROCESSORS

- A. RSX-11M V3.2 multi-tasking Operating System.
- B. FW Driver for the Scientific Microsystems Floppy/Winchester Disk Drive Unit.
- C. FORTRAN IV/RSX Compiler and Object-time System.
- D. PASCAL-2 Compiler, Debugger, Profiler, and Utilities (Oregon Software).
- E. CAMAC Support (Kinetic Systems Corp.)
  1. RSX Driver for CAMAC Serial Highway Driver Unit.
  2. FORTRAN Subroutine Support.
- F. FORTRAN Subroutine Support for Allen-Bradley PLC-3 Data Highway.

III. PROCESS CONTROLLERS

A. Allen-Bradley (AB) Bulletin 1775-L2 PLC-3 Level 2 Instruction Set.
   1. Relay Equivalents.
   2. Timers and Counters.
   3. Data Manipulation.
   4. Program Control.

B. AB Bulletin 1770-T4 Industrial Terminal Firmware for Program Development.

IV. MISCELLANEOUS

A. REACT! Graphic Firmware for ISC Color Graphic Terminals (US graphics).

C.3.4 Development Support Interfaces and Requirements

No special interfaces are required for the development of this software. As described in Section C.3.3.1, the actual operational hardware will be used for software development. The single line development facility will be used for early development in St. Louis. After transition to ORVIP, the remainder of the operational hardware will be installed so that final software development may proceed on the full operational configuration.

C.3.5 Training Requirements

Training for members of the development team in the use of VULCAN, RSX-11M, and the PC logic programming will commence at the beginning of Task 3. Training in the use of the special purpose drivers and libraries will take place on an as-needed basis as development proceeds. Prior experience of all development team staff with FORTRAN, PASCAL, and multitasking operating systems in general is assumed.

EBT-P operations crew training will be provided by MDAC-STL during late Task 4. This training will cover the use of the application software developed. Training in the use of languages, operating systems, and diagnostics not specifically required for EBT-P device operation will not be included. Staff supplied by both MDAC-STL and ORNL will operate and maintain this software during Phase III Operations. Key MDAC personnel will remain as part of the Phase III staff to provide continuity in software operation and maintenance.

C.4 POLICIES AND CONSTRAINTS

C.4.1 Standard Practices, Policies, and Procedures

A Software Engineering Practices Manual (MDC M1.016 - AEB) is in the process of being prepared by the MDAC-STL Computer Systems and Software Engineering Department (E415), which includes members of the EBT-P I & C group. When completed and approved as a corporate standard, this document will govern the development of all deliverable software produced by MDAC-STL. Until that time, and probably throughout the development of EBT-P DAS and control software, the development team will follow certain practices proposed in the draft of the Software Engineering Practices Manual; they include:

- Establishment of a Software Development Notebook for each task to be developed.
- Use of structured walkthroughs (peer reviews) for all software components at the following stages of development:
  - — Completion of software component design.
  - — Completion of coding, i.e.; after successful compilation.
  - — Completion of a successful test sequence.
- Use of a program design language such as Ada Design Language (ADL) during the software design phase.
- Adherence to a programming and coding standard to promote program uniformity, readibility, and understandability.

The goal of such recommended practices is to insure that the software is developed in an orderly fashion, is self-documenting, and achieves the goals of the structured, modular, top-down design philosophy described below in Section C.4.2.

There are no known specific exceptions to the recommended practices described above with respect to the EBT-P software. However, exceptions will be taken when rigid compliance with a practice would compromise a functional requirement or restrict EBT-P device operational capability. Possible exceptions will be determined on a case by case basis by the software development program manager, at the request of a structured walkthrough team.

C.4.2 Approach Requirements and Constraints

C.4.2.1 Development Philosophy

The proposed software shall be developed using a structured top-down approach. This structured modular design will start with an end-to-end overall description or specification of a program. The specification will then be analyzed into a number of component parts. Each of the component subfunctions will be given its own precise end-to-end subspecification until such a level is reached that the collection of final specifications can be coded without functional ambiguity.

The basic element of the EBT-P software will be the task. A task is an independent unit of executable code which performs one of the six functions listed in section C.1.5. At each processor component of the DAS and control system, development will begin with the specification of each task. These task specifications shall be decomposed into subspecifications of subroutines, procedures, and functions to support the tasks. In practice, coding and even testing of top level components may proceed while specification and design of lower level components are taking place.

This technique will provide a way to control program complexity in a disciplined, systematic way. With complexity under control, the probability of producing a correct design will be greatly enhanced. By using a program design language, such a design will be ready for coding immediately after design conclusion. Subfunctions, to be detailed at the next level down, may be programmed as blocks of temporary code or dummy "stubs". These will be simple procedures which merely supply or test interfaces at the current level. The task will be executed and tested within the capability of the dummy stubs. As development progresses, the stubs will be replaced using later-level designs for those intended subfunctions.

Review of each level of software design by the members of the software development term will insure that the best designs are being used. In addition, the regular structured walkthroughs will enhance communication between development team members so as to avoid duplication of effort as lower levels of the development hierarchy are reached.

C.4.2.2 Development Constraints

This section discusses some of the major constraints on the development of the EBT-P DAS and control software. These constraints address the following development issues:

- Design and development media
- Programming languages
- Use of available subroutines
- Processor memory size

These issues are considered in the following paragraphs.

The primary software development tools will be the CRT terminals associated with each processor. Program designs shall be entered into each target computer using the program design language. Each task design will be editted by the program designer much like a coded program. When the design is complete, and approved by a walkthrough team, the design will be translated into code, again using a text editor and CRT terminal. Program listings shall be generated regularly during the coding process and maintained in the software design notebook associated with each task. Working copies of development software shall be kept on magnetic disk to make up a software development library. Backup copies of all development files, both design and code, shall be kept on magnetic tape for the facility computer and floppy disk for the microprocessors.

The programming languages to be used for this software development are restricted to FORTRAN, Pascal and Ada. Facility computer software shall be written using either the Harris FORTRAN 77 compiler or the Harris Pascal-P4 compiler. The choice of FORTRAN or Pascal may be made at the programmers discretion. However, Pascal is preferred due to its structure, and its resemblance to the Ada design language to be used. If an Ada compiler becomes available during the early program design phase it may also be used for facility computer software development. Microprocessor software shall be written using the DEC FORTRAN IV/RSX compiler and object time system or the Oregon Software (OMSI) Pascal-2 compiler. Again the choice is made at the developer's discretion. In general, Pascal procedures may call FORTRAN subroutines, but the software developed for EBT-P shall be constrained to use a single language for each task. Tasks which must interface with existing FORTRAN subroutines for data acquisition or other libraries will normally be written in FORTRAN. Tasks which stand alone, such as data processors, will be written in Pascal.

As stated in section C.3.3.2, the proposed software will be required to utilize existing libraries and modules furnished by vendors for interfaces to peripheral hardware. Modules with functionality similar to furnished software are not to be developed, nor are existing modules to be modified without the approval of the software development program manager. This requirement is intended to limit the development of system level assembly language modules. All program interfaces to hardware registers or system data bases shall be done via furnished software or operating system service routines. No assembly language coding shall be done without approval of the software development program manager.

Program size is not normally a constraint in a virtual machine such as the Harris 135 or in an LSI-11/23 processor running RSX-11M. In non-real-time environments, the program swapping algorithms are sufficiently efficient to avoid degradation of system performance. However, real-time production mode tasks in the facility computer and microprocessors shall be designed so that all production mode tasks may concurrently be memory resident. In particular, data acquisition and communication tasks shall be fixed in memory to avoid compromise of the data throughput of each processor.

Commonality of code shall be a goal in the design of software modules for each processor. Once a module or task has been designed to perform a given function in a processor, that design shall be used to perform that function in all processors of the same type. All microprocessor data acquisition tasks shall be composed of the same code; all data display tasks in the facility computer shall use the same code; and all process controllers shall use the same sequence of instructions to scan and interpret touch-panel inputs. This commonality of design and code shall be carried through the development of all common function tasks. Differentiation of specific functional requirements shall be done by a configuration file in each processor which contains subsystem and processor specific execution parameters for each task.

C.4.3 Priorities and Phasing

Software for all components of the DAS and control system shall be developed concurrently, consistent with the top-down development approach. Design of the top level tasks in each processor shall be complete and structured walkthroughs of each task design shall be held before coding begins on each processor. Design walkthroughs shall be held in the following order:

1. All facility computer top level task designs
2. All microprocessor top level task designs
3. All PC top level logic designs

As the level of design becomes more detailed, priority shall be given to the highest level component undefined on the highest level processor. As much as possible, design and coding should progress in parallel on each processor with development at approximately the same level of detail on each.

C.4.4 Performance Requirements

C.4.4.1 Reviews and Approvals

Software development reviews shall generally coincide with the scheduled views of the EBT-P device hardware design. In particular, the progress in software development shall be presented at the regularly-scheduled Quarterly Project Review. This procedure is appropriate for the Title II period and will be augmented during Tasks 3 and 4 by scheduled reviews specifically devoted to the software development effort. Schedule milestone for these dedicated software reviews will be developed during I & C Title II work in which the detailed C/SCS model for I & C Tasks 3 and 4 will be produced. The schedule for Tasks 3 and 4 software review will be presented at I & C CDR for UCC-ND approval.

Within the software design team (the I&C group), the reviewing format shall consist of the structured walkthroughs. There shall be three walkthroughs of each task developed for each processor:

- Design walkthrough
- Code walkthrough
- Test walkthrough

The **design walkthrough** is based upon the assumption that the functional requirement of the task has been correctly stated. The function of the walkthrough is to examine and verify the correctness of the proposed solution to the problem stated in the task's functional requirements.

The **code walkthrough** reviews the code of the program, i.e. the program listing. The walkthrough should expose existing or potential bugs in the code: syntax errors and logic errors.

Test walkthroughs are conducted to ensure the adequacy of test data for the program, not to examine output from a test run. The test participants should agree that proposed test runs will adequately exercise the task and verify its correctness for a sufficiently wide range of data and operating conditions.

The members of a walkthrough team are the software developers themselves. The programmer responsible for a particular software component will be the presenter and the other members of the team shall be the reviewers. Only when a software component has been accepted by the walkthrough team will it progress to the next level of development and become eligible for project acceptance and release.

C.4.4.2 Performance Measures

The performance of the software developed shall be evaluated with respect to achievement of the following criteria:

- Compliance with the EBT-P I&C design criteria as detailed in section 3.0 of the Title I Report.
- Compliance with software design criteria as detailed in section C.5 of this SRD.
- Compliance with the other requirements with regard to environment, interfaces, policies, constraints, and acceptance as described in the remainder of this SRD.
- Compliance with cost and schedule constraints

C.4.5 Documentation and Reporting Requirements

Progress on the software development effort shall be reported through the EBT-P project regular monthly reports and quarterly review process. The status of all software deliverables shall be reported including the number of design, code, and test walkthroughs successfully conducted for each component.

Documentation of the development process and the software itself shall be maintained in software development notebooks for each component task. The software development notebook (SDN) shall contain the following sections:

1. Requirements
2. Functional Description
3. Detailed Design
4. Code
5. Test Plan
6. Test Results
7. Problem Reports and Log
8. Change orders and Log
9. Miscellaneous

The SDN shall be maintained as a group of text files on the development processor and as a physical notebook containing printouts of those files and applicable manually-produced documents. At the conclusion of the development process, the SDN shall serve as the source document for each component task.

C.5 FUNCTIONAL REQUIREMENTS

C.5.1 Functional Overview

C.5.1.1 Structure

The structure of the DAS software shall be modular with respect to function. The smallest modular unit addressed in this document is the task. No task will perform more than one of the following functions:

- Data Acquisition
- Processing
- Display
- Storage
- Communication
- Control

Multiple functions shall be managed by multitasking. Communication between tasks shall be handled by common blocks, system message facilities, and system flags. Large functional requirements shall be divided into multiple tasks.

Data acquisition tasks shall take data from sensors and place it in a common block. Processing tasks shall take data from a common block, process it and place it in a common block. Display tasks shall take data from a common block and cause it to be displayed on a display device. Storage tasks shall take data from a common block and store it on a disk or tape. Communication tasks shall receive data from a communication line and place it in a common block, or take data from a common block and transmit it over a communication line.

Control tasks, which reside only in process controllers, shall use the status of input sensors and contacts stored in memory to output control signals to the device. Unlike the single-function tasks in the facility computer and subsystem microprocessors, the PC control tasks will incorporate aspects of acquisition, processing, display, and communication, in addition to control. This is a characteristic of process controller relay ladder logic cyclic sequential programming. Normal modular techniques will not be applicable. However, good PC programming shall be structured so as to group distinct operations in an orderly logical sequence. If a process controller with subroutine or macro capabilities is used, these facilities shall be used to modularize commonly used algorithms and processes as much as possible.

C.5.1.2 Data Flow

Data shall flow up the hierarchy of DAS processors from sensors to microprocessor, from sensors to PC, from PC to microprocessor, from microprocessor to facility computer, and from facility computer to research diagnostics computer. At each interface communication will be managed by the higher level system:

- Sensors shall be controlled by a microprocessor or PC
- Each PC shall be interrogated by a microprocessor
- Each microprocessor shall be interrogated by the facility computer.

The only exception to this rule will be the facility computer to research diagnostic computer link which shall be controlled by the facility computer, on user demand.

Within the process controller, input data shall flow from input modules to storage registers, where it will be used to make process control decisions. Control data shall flow from storage registers to output modules. Data communicated to the microprocessor shall flow from storage registers (both input data and output data) to the communication interface. Data will also flow from registers to display output devices. Units of storage in the PC may be individual registers, which are overwritten each scan, or cyclic buffers which will retain values from past scans, depending upon the specific application.

Within each microprocessor data shall flow:

- From sensors in CAMAC crates to common blocks via data acquisition tasks.
- From a PC communication link to common blocks via receiver tasks.
- From common blocks to the same or different common blocks via processing tasks.
- From common blocks to disk via storage tasks.
- From common blocks to a display device via display tasks.
- From common blocks to a communication link via transmission tasks.

Data will not be stored permanently on disk, but reside there until transmitted or until one hour elapses, whichever is longer. All data will be kept for at least one hour.

Within the facility computer data shall flow:

- From microprocessor communication links to a common block via communication tasks.
- From common block to common block via processing tasks.
- From common block to display via display tasks.
- To/from common blocks from/to disk via storage tasks.
- To/from common block from/to magnetic tape via storage tasks.
- From disk or common block to a diagnostics computer communication link via communication task.

Data may flow directly from disk to tape or other mass storage device for the purpose of archival storage or data base management. Real-time data shall flow through common blocks for access by multiple tasks. Manipulation of filed data will not normally require access by other tasks during transfer, and therefore need not flow through common blocks.

C.5.1.3 Operating Modes

The four major software operating modes shall be:

1) Development Mode
2) Monitor Mode

Production mode will be divided into three normal phases and a fourth abnormal phase:

I. Startup Phase
II. Operation Phase
III. Shutdown Phase
IV. Transitional Phase.

The phase will affect operation at the PC and microprocessor levels. At the PC it shall affect the order in which operations occur and the timing of input and output events. At the microprocessor it will affect data rates and quantities of sensors which are scanned. During startup and shutdown, milestones of device condition shall be established; these will serve as stable states where the device can be brought in case of abnormality. During operation phase, the experiment director shall decide whether progress toward shutdown milestones or regression to a startup milestone takes place. In many cases these decisions will be reversable. Transitional phase will be the period between normal operations and the establishment of one of these stable states. Transitional phase will be used to diagnose problems, restore operation, or shut down operation during abnormal conditions.

Tasks executing during production mode will be:

- Data Acqusition Tasks
- Display Tasks
- Communication Tasks
- Data Storage Tasks
- Data Processing Tasks (Limited)
- Control Tasks (PC only)

The display tasks executing in the facility computer and microprocessors will have multiple page structures accessible to the user at each terminal. At facility computer MCC terminals, any data or status from any system shall be available at all terminals. At the microprocessor SCC terminal, data and status from the specific system only will be available at the terminal. At the conclusion of shutdown phase, monitor mode shall return control to the user for possible entry to maintenance mode.

C.5.1.4 Security and Protection

Basic security will be provided by the lack of outside access permitted. The device microprocessors, PC's and facility computer will not be truly networked. No access shall be permitted to data from communication links except that access predetermined by communication tasks and configuration files. There will be duplication of data at all levels for at least one hour. There shall be one hour data storage on the microprocessors of both PC and CAMAC data. There will be long-term (of indeterminate length) data storage on the facility computer. All PC's and microprocessors shall operate independently of each other. There shall be no control of data acquisition or device processes from the facility computer. Data acquisition parameters shall be preset by the configuration file. Process control will be preset by stored logic in each PC which will not be modifyable under normal operating conditions by control panel contacts. Terminal access under monitor, maintenance, and production modes will not require logging onto system. Certain operations which allow modification to data or configuration files will require an access code. Development mode will require logging on by a system manager.

C.5.2 User Requirements

This section details the requirements upon the software as imposed by the user's point of view. There are four user interfaces:

- Facility Computer via MCC terminals.
- Process Controllers via MCC terminals.
- Microprocessors via secondary control console terminals.
- Process Controllers via secondary control console terminals.

Facility Computer Master Control Console terminal users shall not be required to learn any computer languages or command input syntax. All user interaction via shall be touchpanel, using software generated "keypads" and "buttons". Data displayed on the color CRT terminals shall be presented in a mix of graphical and textual elements. The user may select from a repertoire of display pages which vary in content and format. Displays shall be automatically updated as new data becomes available. When modifying data or configuration files in maintenance mode, the user shall always be able to return to last unmodified state. All MCC terminals shall have identical characteristics regardless of position.

Process Controller Master Control Console display users shall not be required to learn PC ladder logic programming. All interaction with PC shall be via hardware switches on each control panel for device control and via touch panel for display control only. Data displayed shall be a mix of graphical and textual elements. The user may select from a repertoire of display pages which vary in content and format. Displays shall be automatically updated as new data becomes available. Each MCC PC display shall only display data from its specific system process controller. As control switches are actuated, the display must acknowledge the command and confirm the action, regardless of display format currently being viewed. Numeric inputs (setpoints, limits, etc.) must be continuously displayed as they are being modified at a control panel. Alarm or warning messages shall override all other display formats.

Microprocessor Secondary Control Console terminal users shall not be required to learn computer languages or operating system commands. All interaction shall be via conversational monitor tasks using keystroke or English-like commands. Data displayed on the terminal shall be a mix of graphical and textual elements. The user may select from a repertoire of display pages which will vary in content and format. Displays shall be automatically updated as new data becomes available. When modifying configuration or other files in maintenance mode, the user shall always be able to return to last unmodified state. Data from both the CAMAC I/O system and the PC I/O system shall be accessible at the microprocessor level. A continuously updated trend-showing graphic of multiple channels shall be available, e.g., stripchart mode. A multiple bar chart display shall be available for comparison of data from sensor groups. The current time and date shall be continuously displayed. Data acquisition parameters shall be modifyable in real-time (data rate, sensors being scanned, etc.).

Process Controller Secondary Control Console display requirements are identical to those of the MCC PC displays. Both displays shall display the same data at the same time. The MCC display control shall have priority unless control has been given to subsystem panel by MCC command.

C.5.3 Operational Requirements

C.5.3.1 Data Acquisition

The primary design criterion for data acquisition is to scan all device sensor and status inputs at nominal rates continuously during device operation. The nominal rate for microprocessor controlled channels shall be one sample per channel per second. However the rate for specific channels may vary from 0.1 sample per second to over 100 samples per second.

Data acquisition tasks in each microprocessor shall perform only data acquisiton and the timing and synchronization necessary therefor. Tasks shall take data on a regular basis from sensors as specified in the configuration file. The tasks shall use vendor supplied software, e.g., CAMAC library routines, whenever possible. The tasks shall deposit their data records from sensors into a designated input data common block for access by other tasks.

The process controllers shall scan input modules and store all data in designated holding registers. This data shall be transmitted to the associated microprocessor on demand at least once per second. The communication task in the microprocessor shall place the data in the input common block. Data acquired from the process controller shall include the state of output control points as well as input points.

C.5.3.2 Processing

The primary design criterion for data processing is to perform all calculations necessary to control the EBT-P device and to determine the device state vector in real-time. The device state vector (DSV) shall be composed of those parameters which characterize the state of the EBT-P device in time. Enough processing capability shall be provided to determine the DSV locally without recourse to outside network computing. The processing load breakdown by component is described in the following paragraphs:

The facility computer shall have the processing responsibility to manage communication with the microprocessors, to correlate data into a consistent data base, to drive the master control console displays, and to manage communication with the research diagnostic computer. The facility computer software shall include, but is not limited to, the following utility functions during maintenance mode:

- examination of DSV files after a production run
- graphical display and hardcopy of selected data in the working data base
- archival storage and retrieval of data base files
- generation of directories of data base files
- consolidation of facility computer mass storage
- generation and modification of the facility computer configuration file
- exercise of single or multiple subsystem components from PC to microprocessor to facility computer
- transmission of DSV data base files to the research diagnostic computer network.

Microprocessors shall perform unit conversions, scaling and primary parameter extractions. They shall also manage communications with both the PC's and the facility computer. The microprocessors shall format data for display on the secondary control console terminals. Synchronization of data acquisition events with the master timer shall also be done by each microprocessor. Utility functions available at each microprocessor during maintenance mode shall include:

- examination of currently stored data records
- transmission of records to the facility computer
- consolidation of storage and deletion of unnecessary data records
- graphical display and hardcopy of any currently stored data
- generation and modification of configuration files for subsequent production mode runs
- exercise of data acquisition tasks and sensors off-line for checkout and calibration
- exercise of the PC to microprocessor communication link
- exercise of total PC/CAMAC to microprocessor data acquisition subsystem in real-time using simulated inputs.

Since a major responsibility of the microprocessors in maintenance mode will be to verify the proper operation of the data acquisition subsystem from sensors to microprocessor, the functionality of the tasks used must be considered. These tasks, developed as maintenance mode tools, shall duplicate as closely as possible the tasks which operate in production mode. These tasks shall contain code to detect and report faults in the normal data acquisition process. It shall not be the responsibility of those tasks to isolate or diagnose faults in the computer or I/O systems. Vendor supplied diagnostic software and normal operating system utilities shall be employed by the system managers in development mode for fault analysis.

Process controllers shall perform all processing required to solve logic to control and sequence device systems. They shall also manage the transmission of data to the microprocessors and drive secondary control console and master control console displays. Utilities available through process controllers in maintenance mode shall include the ability to perform the following functions:

- examine process controller ladder logic programming
- exercise programming with outputs disabled
- examine input and output states for verification
- force inputs and outputs to a given state regardless of external conditions or programmed logic
- diagnose fault conditions in the PC I/O system.

These utility functions shall be performed with vendor supplied software available with the PC.

Production mode processing in each PC shall include the following functions:

- timing and sequencing of events
- interlock checking
- input data unit conversions
- parametric conversions (Δp to flow rate, for example)
- display generation
- data transmission
- output data scaling
- alarm generation and fault detection

C.5.3.3 Display

The primary design criterion for data display is to display, in real-time, selected device parameters with minimum latency or delayed response. Latency is defined as a lack of currency of the data being displayed. A display with minimum latency does a good job of displaying what is happening to the device now. Response time is defined as the ability of the display hardware and software to respond to a user command. A display with good response time does not make the user wait after entering a command.

The facility computer MCC terminals will provide access to any data from all device subsystems. The subsystem microprocessor displays and process controller displays will provide display of the individual subsystem data and status. Data displayed at all terminals shall be presented in a mix of graphical and textual elements, as appropriate to the specific application.

All displays will consist of three distinct areas:

- Variable status and data area
- Fixed status area
- Display control area

These display areas are described in the following paragraphs. A typical display format made up of the three areas is shown in Figure C.5.3.3-1.

The **variable status and data area** will be used for general purpose data display. The content and format shall be variable as selected by soft keys in the display control area or by keyboard command. The content of the area shall consist of both graphical and textual elements and may include one or more of the following:

- lists
- tables
- bar graphs
- line graphs

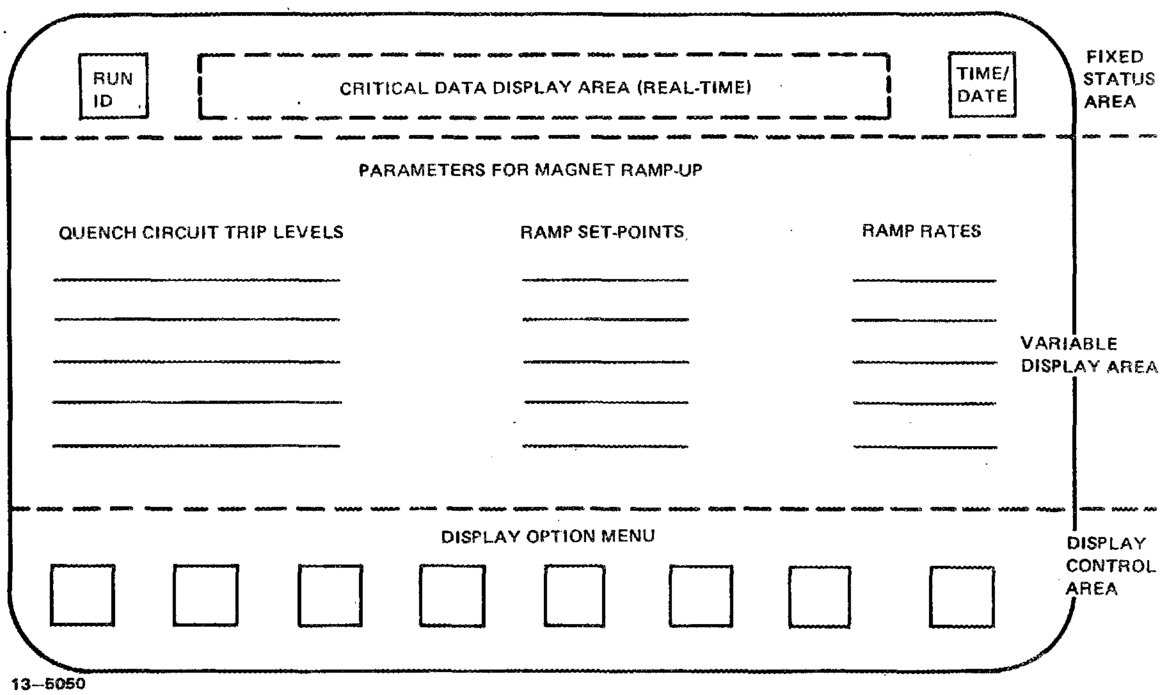


FIGURE C.5.3.3–1 MCC COLOR CRT DISPLAY-PAGE LAYOUT

- "thermometer" graphs
- special symbols and graphics

The displays in the variable area shall be page oriented, with each page consisting of a preset form. The display elements placed here shall be suitable for video hardcopy or photographic reproduction. The area of the screen devoted to variable data shall occupy the center of the screen from the bottom of the fixed area to the top of the control area. The size of the variable area will be determined for each display task by the sizes of the other two areas.

The **fixed status area** shall contain higher priority information than the variable data area. The content shall include alarms, caution, warning and error messages. High priority data and status may also be displayed here numerically. The content of the fixed area shall not be altered dynamically while the production mode display task is running. The format and content of the fixed area will not change when variable area pages are selected. The soft keys or keyboard commands shall not affect this area. Each display task shall define the size of its fixed status area which may include only, one line or as much as 50% of the screen area in size. The fixed area shall be located at the top of the display screen including the first line of the display. Fixed area text shall not scroll off the top as new information is added. The data displayed here shall occupy fixed positions which are directly addressed by the display software. Use of color, reverse video, blinking, and special characters are recommended for emphasis. A dashed or dotted line may be used to delimit the fixed area if space allows.

The **display control area** shall exist on displays controlled by touchpanel overlays and displays controlled by keyboard or keypad inputs. On touchpanel controlled displays it shall contain soft keys to be touched by the operator to effect changes in the variable data area. On keyboard controlled displays it shall contain instructions for keys to be depressed to effect changes. The keys (both soft and hard) will be used for display page selection and format control. The content of the control area shall, in general, change as new pages are selected to present different command options. The selection of commands and display page options shall be menu driven. The user shall progress through increasing levels of detail until the page content and format selection process is complete. The development of the variable data area being defined should progress in stages as commands and options are entered. Thus, the development of a display page should be considered as an interactive process. Some keys may be active for all pages of a particular display task, for example: NEW PAGE, REPAINT SCREEN, CLEAR, RETURN TO START, etc. The size of the screen area used for the control area may vary from page to page and may include all of the screen not in the fixed data area, depending upon the content of the variable data display area.

The following paragraphs describe the requirements for display software at each of the component display stations:

- MCC Facility Computer Displays
- SCC Microprocessor Displays
- MCC Process Controller Displays
- SCC Process Controller Displays

The **MCC facility computer displays** shall be based upon a multiple page structure. Each display task in the facility computer shall display data and status from one device subsystem. Each task shall generate multiple pages relating to its particular device subsystem. The display pages shall be selectable via soft keys in the display control area. Other soft keys shall control the content of each selected display page. The displays shall be dynamic, changing as new data are available and responding to user input as appropriate. Display tasks on the facility computer shall make use of memory common regions as appropriate. In particular, formatting tasks may be used to build screen pages which are continuously updated and used by display tasks on an as-needed basis. In addition to the single-subsystem display tasks described above, special display tasks shall be developed which have access to data from multiple device subsystems. These tasks will be used to display correlated device data to the experiment director or MCC operators.

The **SCC microprocessor data displays** shall operate similarly to the MCC facility computer displays. Each microprocessor will typically run one display task which has access to all data currently in the microprocessor memory. Control of the microprocessor displays shall be menu oriented through the display control area of the screen. Actual control shall be via single keystroke commands rather than touch panel inputs. The structure of the typical display task shall be based upon an expanded version of the RMDEMO task distributed with the RSX-11M operating system. The task shall be overlayed for each display page with resident common used to build continuously updated display pages of real-time data. As much as possible, each display task in each microprocessor shall consist of identical code, with only the page contents and format differing from subsystem to subsystem.

The **MCC process controller displays** will be driven by message generating logic in the PC. The displays can be page oriented similar to the facility computer displays if the logic permits. Touchpanel input soft keys shall be used for display control just as in the MCC facility computer displays. Regardless of the display format, all PC inputs and outputs must be displayable at each device subsystem PC display. Alarms, warnings, cautions, etc., must override all other display elements. Hardwired process control switches on control panels shall override soft switches on the touchpanel. When parameters are being set or modified, the control panel LOAD PARAMETER switch shall cause the current value of that parameter to be displayed. The control philosophy for EBT-P requires that the PC displays be the primary operator feedback device.

The **secondary control console PC displays** shall mimic the MCC displays. Normally, display control shall reside in the MCC. However, by setting a hard switch on each MCC panel associated with a device subsystem, display control can be transferred to a SCC display touchpanel.

C.5.3.4 Storage

The primary design criterion for data storage is to record the device state vector so as to provide a continuous history of EBT-P device operation.

All microprocessors shall have a one hour data buffering capacity in case of facility computer or data link failure. The facility computer shall have a one shift (8-hour) data capacity on disk during normal operation without copying data to magnetic tape or transmitting data to another site. The primary on-line storage medium shall be hard magnetic disk. The primary archival (off-line) storage medium shall be 9-track 1600 BPI magnetic tape. Any previously recorded data shall be available for access by the facility computer. The organization of data records as they progress through the DAS hierarchy is shown in Figure C.5.3.4-1.

Process controller data storage. There shall be no mass storage on PC's except for buffers maintained internally for logic control and display management. There shall be no data latency constraints imposed on the PC's. Data and status will be transmitted to the microprocessors at regular intervals on demand. All PC data will be recorded first by the associated microprocessor and then by the facility computer. Local storage of setpoint values in registers will be done as a normal part of programming. These values will remain in PC memory (as long as PC power is maintained) until changed by a user at a control panel.

Microprocessor data storage. All data from CAMAC I/O systems and process controllers will be buffered in main memory by data acquisition tasks for access by other tasks: display tasks, transmission tasks, storage tasks, etc. All data will be recorded as records in a disk file for a period of not less than one hour, or until transmitted to the facility computer. The data shall be stored as records acquired coincident in time. The records may be grouped into files, but the files will have no significance with respect to data base access. The basic unit of stored data will be the record. A convenient representation of these records will be a Pascal-type array of records. On demand, all records accumulated since the last demand shall be transmitted to the facility computer. Records shall be deleted as their age exceeds one hour. Additional in-memory buffers and common blocks may be used by tasks to manage data flow within the microprocessor, e.g., display buffers, transmit buffers, etc.

Facility computer data storage. All data from microprocessors and PC's will be stored by the facility computer. Data receiver tasks will place the data in a common block for access by other tasks. All data will be copied from the common block to disk files by storage tasks. These disk files will constitute the facility computer working data base. At a given point in time, the working data base will consist of:

- Data from the current device operation shift.
- Other data which has not yet been copied to magnetic tape.
- Historical data which has been retrieved from magnetic tape for access.

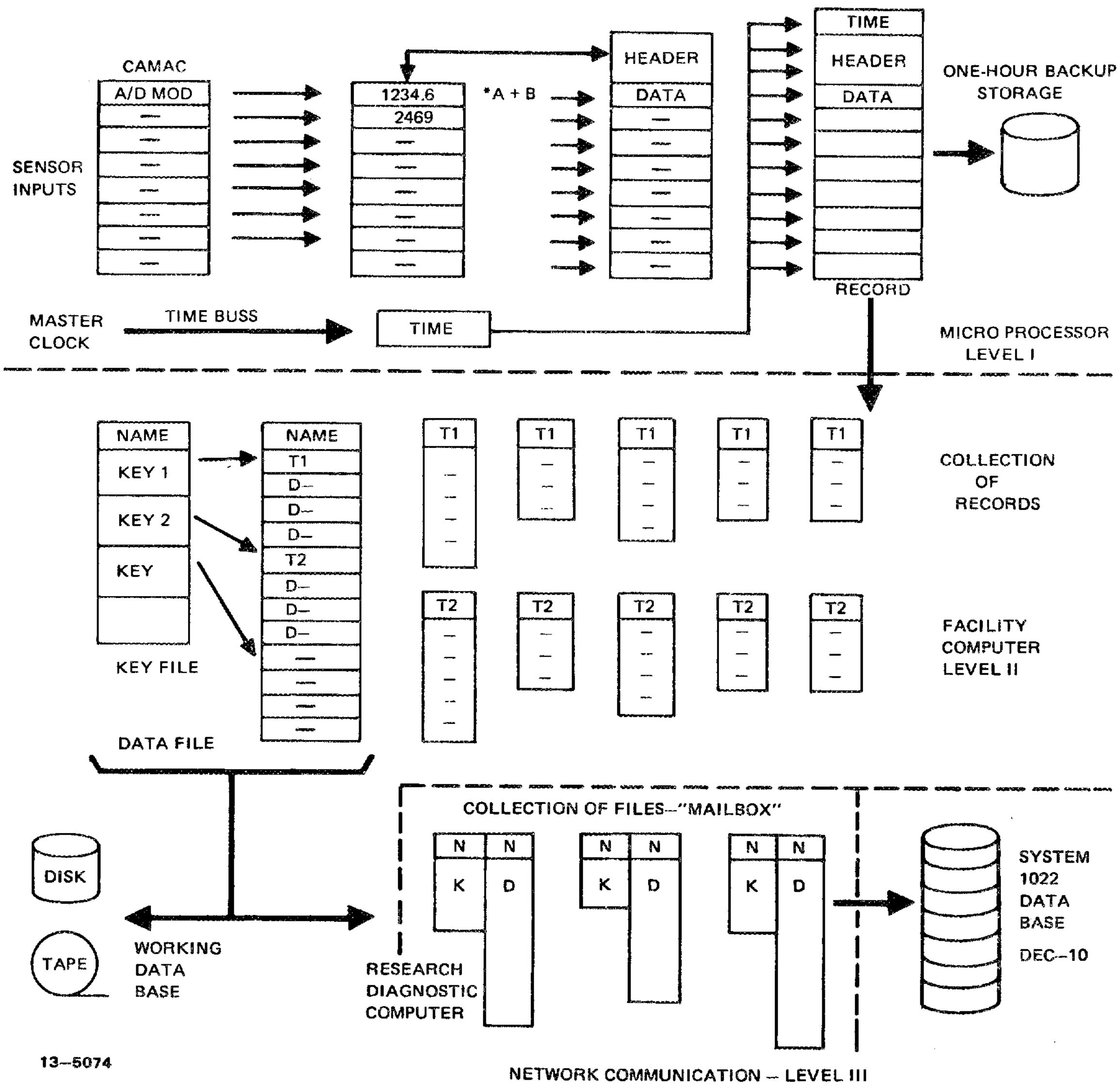


FIGURE C.5.3.4–1 EBT-P DATA ORGANIZATION

Each data file shall consist of records received from the microprocessors gathered together into files organized by time. Each file shall collect data records for a fixed interval of time. The name of the file shall indicate the time at which the file was opened. Keys within each file shall point to records from each microprocessor and from specific data acquisition intervals. Keys within each record shall point to particular data elements from distinct sensors and device components. In addition to the main input buffer fed by data receiver tasks, other buffers (common blocks) may be used by tasks to facilitate management of data flow to displays, communication links, processing tasks, etc.

C.5.3.5 Communication

The primary design criterion for interprocessor communication is that device data shall be transmitted up through the DAS hierarchy in the following manner:

- From sensors
- To I/O system (CAMAC or PC)
- To microprocessor
- To facility computer
- To research diagnostic computer
- To network for subsequent correlation with diagnostic data and analysis by researchers.

The facility computer and DAS will be capable of operating and monitoring device function indefinitely without access to the FED network. The network protocol chosen for research diagnostics communication will not impact the DAS facility computer, microprocessors or process controllers. Data will flow automatically from PC to microprocessor to facility computer. Data shall not flow automatically from the facility computer to the research diagnostic computer, but only on command from a user at a facility computer MCC terminal.

Process controller to microprocessor link. A task in the microprocessor shall interrogate registers in the process controller at regular intervals, typically once per second, to collect data from PC sensors and control outputs. This link shall be implemented over a suitable hardware link compatible with the microprocessor and PC. Existing software resources in the PC shall be used to effect the transfer, i.e.; bus or highway functions, and message functions as appropriate. The codes and protocols to be used are not specified, subject to those available on the specific PC selected. The data transmission mode selected shall not cause the basic scan rate of the PC to be interrupted during data transfer. That is, I/O scanning, processing, and data transmission shall be performed concurrently. This requirement also precludes the use of "one character per scan" type protocols. Transmission of data, setpoints, commands, or program changes to the PC by the microprocessor will not be permitted during production mode. Maintenance mode utilities for modifying PC registers or program logic by microprocessor are permitted but not required.

CAMAC I/O system to microprocessor link. Tasks in the microprocessor (data acquisition tasks) shall interrogate the CAMAC module registers in the various crates by means of serial data highway commands. (The CAMAC crates will be interfaced to the microprocessors by fiber optic serial data highways). Use of demand messages, look-at-me (LAM) signals, and controller generated interrupt protocols is encouraged but not required, depending upon the specific application and data rate. Existing software resources furnished by the CAMAC vendors shall be used wherever possible to implement data acquisition.

Microprocessor to facility computer link. Tasks in the facility computer (data receiver tasks) shall command the microprocessors to transmit all data records recorded since the last transmission or start of production mode, at regular intervals, typically one to ten seconds. A task in each microprocessor shall respond to the command from the facility computer by transmitting a message consisting of zero or more data records. The microprocessor must respond within a pre-determined time interval or the facility computer will declare the microprocessor off-line. As microprocessors are declared off-line, the facility computer will attempt to obtain data through a backup microprocessor by the same method. The backup microprocessor shall have an alternate path to the device subsystem CAMAC crates.

The message sent to the microprocessor shall have the following components: header, body and trailer. The header shall contain identification of the sending microprocessor, the time the data was transmitted, the number of records being transmitted, and any other information deemed necessary at the facility computer task level. The body shall contain the data records being transmitted. No data record need be transmitted if none are available. A status record may be sent instead to indicate the reason no records are available. The trailer may contain error detection data such as longitudinal parity codes, CRC codes, or others as appropriate. The code to be used is not specified, however serial ASCII seven-bit plus parity code is preferred. This code may be generated and displayed directly by a terminal for testing.

Facility computer to research diagnostics computer link. A task shall exist in the facility computer to transmit on demand selected device data to the research diagnostic computer. This data shall be only that data in the working data base required by the research diagnostic network for correlation with experimental data on an immediate basis. All device history data shall be available to the research diagnostic network via magnetic tape and this shall be the normal mode of data transmission. The physical link between the facility computer and research diagnostic computer is not specified. However, the capacity of the link shall not be less than the aggregate data rates of all facility computer input links. This will insure that a significant fraction of device data may be transmitted in real time. Data may be transmitted continuously during production mode operation or in blocks during maintenance mode. In either case, the type of data to be transmitted and the quantity must be entered by a user on a facility computer MCC terminal before the transmission can begin. An appropriate data receiver task shall exist in the research diagnostic computer. The form of that task and what it will do with data received are not specified. The protocol and code for the transmission link are not specified. The basic unit of data transmitted shall be the record, as stored in the working data base or as received from the microprocessors.

Alternate communication links. The communication links and software support described up to this point are the primary communication paths. Secondary or alternate paths exist for some of the links. The software requirements for alternate communication links are as follows.

Backup process controllers may exist which can be switched into the I/O channels previously connected to a malfunctioning process controller. These backup PC's shall contain or have access to the same process control logic as the primary PC. A communication link to a microprocessor shall exist for each backup PC which is identical to the primary link.

The communication software in the microprocessor shall detect when the primary PC is off-line and switch to the backup PC.

A backup CAMAC serial highway shall exist which interconnects all device system CAMAC crates in the EBT-P test support area. This backup highway will be connected to a backup microprocessor through an interface identical to the primary serial highway interfaces. This microprocessor shall contain or have access to copies of data acquisition tasks from all other microprocessors. It will be able to access any CAMAC crate connected to an off-line microprocessor. This access will be accomplished on command from the facility computer. The normal display processing and storage functions of the microprocessors will be sacrificed or degraded when operating in this mode. The backup microprocessor may be required to acquire data from more than one device system CAMAC crate. A communication link to the facility computer identical to the primary links shall exist.

The backup microprocessor shall also have a communication link to the research diagnostics computer for backup of diagnostics processors. This hardware interface is not defined, but it shall also serve as an alternate path from the facility computer to the research diagnostics computer. The physical capability will be provided to implement a direct link from device subsystems to research diagnostics. The software to support this link is not specified and is not required by this document; however, it is not prohibited.

C.5.3.6 Control

The primary design criterion for EBT-P device control software is to control all EBT-P device subsystems by operator inputs and process control logic implemented interlocks. The design of the control software will include use of "man-in-the-loop" control techniques at a process level. Individual component control and sequencing will be handled by PC logic. Annunciators and indicators shall be replaced by software generated displays wherever possible.

The process controller operational requirements are specified below. All control functions shall be the responsibility of the process control software. These include:

- Sensing of interlocked inputs
- Output of control signals to actuators
- Input of setpoint values
- Display of alarms or exceptions
- Display of operating conditions

The PC logic software in each process controller shall address each of the control functions listed above. The value of each binary input point and each analog input shall be stored in a register for access by display and data transmission logic in the PC.

Input signals will be classified according to the following categories:

- **INTERLOCK/STATUS INPUTS** are always discrete/binary signals. These are required by PC logic for decision making, interlocking of processes, action initiation or inhibition. They have no inherent good/bad meaning. Examples are on/off, enable/disable, open/closed, etc.
- **OPERATING CONDITION INPUTS** are always analog signals which indicate a range of possible values. These signals are required by PC logic for decision making. They have no inherent good/bad meaning. However, the PC may determine a fault condition if an operating condition input goes beyond a predetermined tolerance. Examples are: temperature, pressure, voltage, current, etc.
- **FAULT/WARNING/ALARM INPUTS** are always discrete/binary signals. These are predetermined at the source to indicate a fault, warning, or alarm condition. No additional logic is required in the PC to determine the meaning of the signal. Examples are: overvoltage warning, crowbar trip alarm, magnet quench alarm, etc.
- **DIAGNOSTIC INPUTS** may be either discrete or analog signals. These signals indicate status or operating conditions after a fault has occurred. They are only examined, displayed, and transmitted by the PC after a fault has occurred to aid in diagnosis of the fault.

Output signals will be classified according to the following categories:

- **COMMAND OUTPUTS** are always discrete/binary signals. They indicate a particular command such as open valve, start pump, etc. The intended command output can only be activated when the proper sequence of interlocks has been asserted.
- **SETPOINT OUTPUTS** are always analog signals. The indicate a value of a particular quantity to be set, such as power supply voltage level, heater current, etc. Due to the relatively high cost of analog output modules, these should be used only for quantities which must be varied during production mode; constant setpoints should be hardwired if possible.

Control panel switch inputs will be considered to be interlock signals. Control panel indicators shall not be used unless necessary. If used, they shall considered command outputs, e.g., "Turn on power indicator". Control panel switches on the secondary control consoles (SCC) shall have a one-to-one correspondence with command output signals on the PC. The PC shall interlock each function and perform the action only if appropriate. This requirement provides component level control at the SCC. Control panel switches on the master control consoles (MCC) shall correspond to processes in the PC logic. Assertion of an MCC switch will cause a process involving a sequence of operations and components to be initiated or aborted. Little or no component-level control shall be provided at the MCC. This requirement provides process-level control at the MCC. Process-level control switches duplicating MCC switches may be provided at the SCC's. The MCC switches shall have priority over the SCC switches unless SCC control is granted by an additional MCC switch. Numeric inputs at the MCC and SCC's may be handled by a method which uses simple binary switches to increment and decrement selected PC registers. These switches shall be located in a specific numeric input cluster on each panel. Feedback of numeric values shall occur on the PC CRT display. Other methods such as thumbwheels, keypads, and knob controlled potentiometers may be used depending upon application requirements.

The control logic software shall treat all inputs and outputs as fail-safe in the unpowered state. External wiring shall be consistent with this requirement. Absence of an interlock input shall inhibit action, and likewise, absence of a command output shall inhibit action.

Fault signals shall be treated such that the "OFF" state shall indicate fault, assertion of the signal shall indicate "No Fault".

Process control initiated at the MCC shall not be allowed to proceed past a designated milestone or hold point until the next process is initiated at the MCC. Asserting multiple process switches in order to avoid anticipated operator action shall not be allowed.

C.6 ACCEPTANCE AND EVALUATION CRITERIA

C.6.1 Competing Characteristics

This section includes a list of factors or features that compete for development resources. These factors have been listed in order of importance in meeting the EBT-P DAS and control software technical requirements.

The following factors are viewed as being extremely important to the overall success of the software developments effort:

- Lack of vulnerability to operator or input error
- Maintainability
- Documentation readability

The next group of factors are viewed as important, but have alternate solutions besides software development. For example, program size constraints can be relaxed by the addition of more memory in specific cases.

- Execution speed
- Growth potential
- Program size

The last group of important factors includes cost and scheduling criteria. The major consideration here is that program specification, design, and implementation objectives do not exceed the funding and time resources of the project.

- Time to develop
- Cost to develop
- Cost to operate

Finally, a factor is listed which is of no importance to this software development effort.

- Portability and machine independence

C.6.2 Acceptance Requirements And Criteria

C.6.2.1 Demonstration Configuration

The demonstration configuration of the DAS and control hardware and software will be the full operational configuration from sensors and I/O systems through the facility computer, MCC and EDC as diagrammed in Figure C.3.3-1. The testing of the software and its various hardware interfaces will be part of Tasks 4 and 5: pretesting, systems checkout, and pre-operational testing. These three test phases are described in sections 8.5.2 through 8.6.2 of the EBT-P Phase II proposal (MDC report E2229).

C.6.2.2 Testing Requirements and Criteria

Testing of individual tasks and the modules which compose them will be done as part of the normal software development process and be reviewed by structured walkthroughs. This testing will constitute the pretesting phase for EBT-P software. This testing shall be performed as soon as practical after task coding is complete. The goal of pretesting is to verify that systems, including software, satisfy all applicable functional specifications. Successfully completed pretesting will insure maximum success during subsequent Task 5 pre-operational testing and checkout.

Additional tests following task-by-task functional testing will verify the integrity of the entire I&C system. Tests applicable to the software development effort, which will be included in overall I&C pretesting include:

- functional checkout of computers individually and integrated via their digital links;
- bi-directional verification of the computer and Master Control Console (MCC) links;
- verification that personnel safety interlock control panel will terminate ECRH or ICRH operations if one or more applicable personnel safety or key interlocks are not satisfied;
- functional verification of the links between the various Process Controllers, MCC's, and the computers;
- functional verification of interlocks implemented by the various PC's;
- verification of software to display magnet, vacuum, cryogenics, microwave and rf operations status utilizing surrogate sensor test signals;
- checkout of all MCC controls and links and displays
- functional verification of start-up diagnostic devices.

The next phase of testing will be systems checkout to be done in Task V after all systems are installed and interconnected. This checkout shall be accomplished system by system to confirm the mutual compatibility of directly interconnected systems, that no damage has been incurred to systems after pretesting during the continuing installation of other systems, and that the functional integrity of each system is still satisfactory.

Following checkout, pre-operational testing will also be performed in Task V. This might also be identified as "all systems" tests. The objective of pre-operational testing is to verify while performing in an operational mode that all systems are mutually compatible and satisfy functional specification requirements. Any interference, or "cross talk", between independent or isolated systems will be identified and resolved during these tests. The pre-operational tests formally demonstrate the satisfactory design, fabrication, installation, and integration of the EBT-P device and supporting facilities, including software.

C.6.2.4 Test Result Documentation

The results of each software component functional test shall be documented in each task's software development notebook. Following software pretesting software discrepancies shall be noted in a software maintenance notebook which contains the following information:

- Symptoms of the discrepancy
- Identification of the processor and software component manifesting the symptoms
- Diagnosis of the problem
- Action required or taken

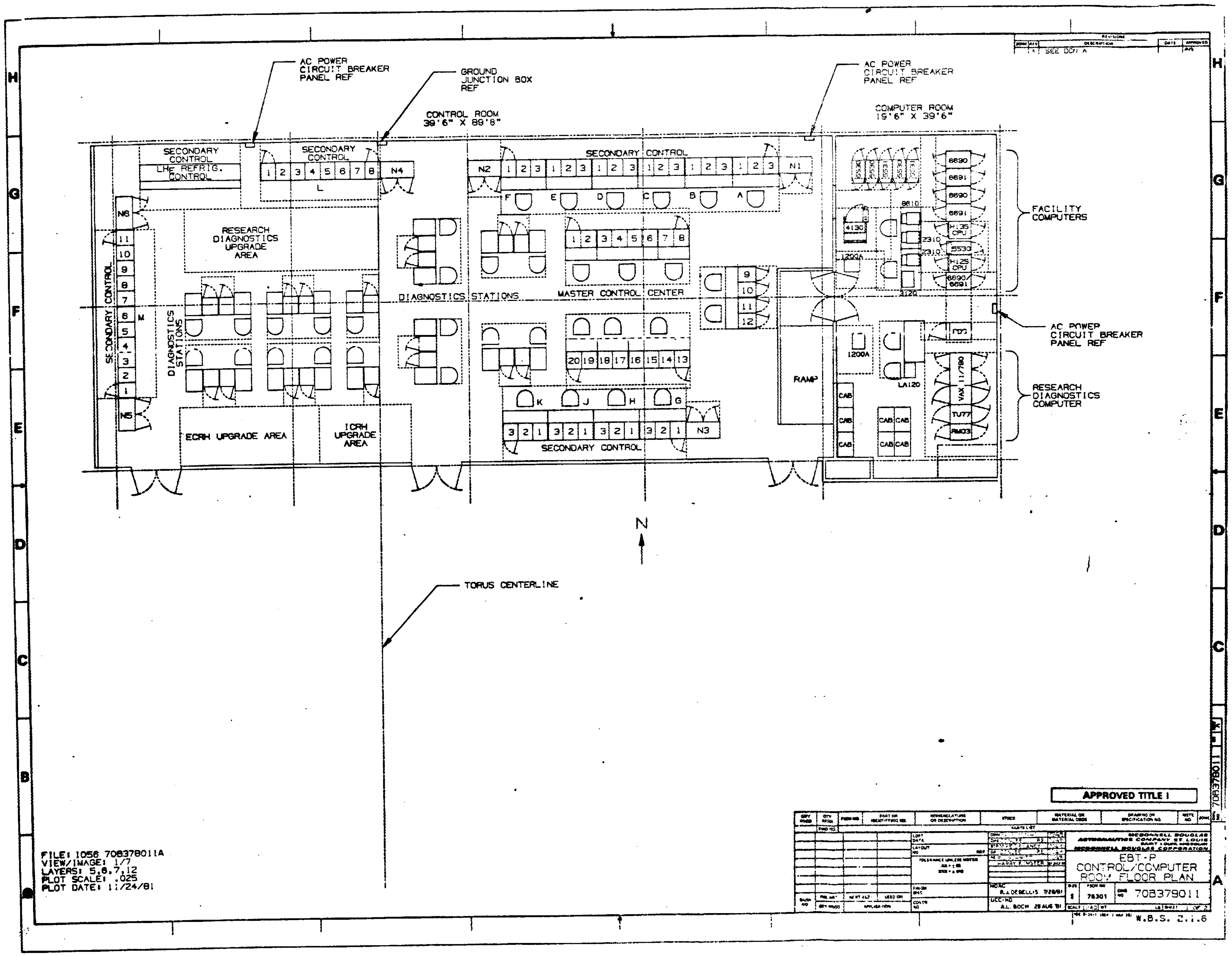
A copy of each software discrepancy report will also be filed in the applicable task's software development notebook.

C.6.3 Quality Assurance Requirements

The EBT-P project quality assurance plan is outlined in Appendix E of Volume I of the EBT-P Phase II proposal (MDC E2229). The applicability of this plan to the software development effort will be determined during Title II.

APPENDIX E

I&C TITLE I DRAWINGS


AC POWER CIRCUIT BREAKER PANEL REF
GROUND JUNCTION BOX REF
CONTROL ROOM 39'6" X 88'8"
AC POWER CIRCUIT BREAKER PANEL REF
COMPUTER ROOM 19'6" X 39'6"
SECONDARY CONTROL
LHE REFRIG. CONTROL
SECONDARY CONTROL
SECONDARY CONTROL
RESEARCH DIAGNOSTICS UPGRADE AREA
FACILITY COMPUTERS
DIAGNOSTICS STATIONS
MASTER CONTROL CENTER
SECONDARY CONTROL
DIAGNOSTICS STATIONS
AC POWER CIRCUIT BREAKER PANEL REF
RAMP
RESEARCH DIAGNOSTICS COMPUTER
ECRH UPGRADE AREA
ICRH UPGRADE AREA
SECONDARY CONTROL
N
TORUS CENTERLINE
APPROVED TITLE I
FILE: 1056 708378011A
VIEW/IMAGE: 1/7
LAYERS: 5,6,7,12
PLOT SCALE: .025
PLOT DATE: 11/24/81
EBT-P
CONTROL/COMPUTER
ROOM FLOOR PLAN
708378011
W.B.S. 2.1.6

RACK NO.	DESIGNATION	CONTENTS
A-1	ECRH-60L-001	AC POWER/ DC POWER CONTROL PANELS FOR 60GHZ GYROTRON NO. 1
A-2	ECRH-60L-002	MICROPROCESSOR/ CRT TERMINALS FOR 60GHZ GYROTRON NO. 1
A-3	ECRH-60L-003	CRYOGENICS/ COOLING/ MAGNET CONTROL FOR 60GHZ GYROTRON NO. 1
B-1	ECRH-60L-004	
B-2	ECRH-60L-005	60GHZ GYROTRON NO. 2
B-3	ECRH-60L-006	
C-1	ECRH-60L-007	
C-2	ECRH-60L-008	60GHZ GYROTRON NO. 3
C-3	ECRH-60L-009	
D-1	ECRH-60L-010	
D-2	ECRH-60L-011	60GHZ GYROTRON NO. 4
D-3	ECRH-60L-012	
E-1	ECRH-60L-013	
E-2	ECRH-60L-014	60GHZ GYROTRON NO. 5
E-3	ECRH-60L-015	
F-1	ECRH-60L-016	
F-2	ECRH-60L-017	60GHZ GYROTRON NO. 6
F-3	ECRH-60L-018	
G-1	ECRH-28L-001	AC POWER/ DC POWER CONTROL PANELS FOR 28GHZ GYROTRON NO. 1
G-2	ECRH-28L-002	MICROPROCESSOR/ CRT TERMINALS FOR 28GHZ GYROTRON NO. 1
G-3	ECRH-28L-003	WATER COOLING/ MAGNET CONTROL FOR 28GHZ GYROTRON NO. 1
H-1	ECRH-28L-004	
H-2	ECRH-28L-005	28GHZ GYROTRON NO. 2
H-3	ECRH-28L-006	
J-1	ICRH-LCL-001	ICRH TRANS. SYS. NO. 1 INPUT STAGE CONTROLS
J-2	ICRH-LCL-002	ICRH TRANS. SYS. NO. 1 MICROPROCESSOR/CAMAC/CRT ANN.
J-3	ICRH-LCL-003	ICRH TRANS. SYS. NO. 1 FPA/ ANTENNA TUNING CONTROLS
K-1	ICRH-LCL-004	
K-2	ICRH-LCL-005	ICRH RF TRANSMITTER NO. 2
K-3	ICRH-LCL-006	
L-1	TVL-LCL-001	TVL COOLING SYS. MICROPROCESSOR/ CAMAC/ CRT DISPLAY
L-2	TCL-LCL-002	TVL COOLING SYS. CONTROL PANEL/CRT ANN.-SEC. CONTROL
L-3	BOP-LCL-001	PRIMARY/ SECONDARY AC POWER DISTRIBUTION PANEL
L-4	BOP-LCL-002	UPS CONTROL/ CRT ANNUNCIATOR
L-5	BOP-LCL-003	FACILITY PRIMARY COOLING/ COMPRESSED AIR CONTROL
L-6	BOP-LCL-004	SPARE
L-7	BOP-LCL-005	SPARE
L-8	BOP-LCL-006	SPARE
M-1	VAC-LCL-001	VACUUM SYS. MICROPROCESSOR/ CAMAC/ CRT DISPLAY
M-2	VAC-LCL-002	VACUUM SYS. CONTROL PANELS/CRT ANN.-SEC. CONTROL
M-3	MAG-LCL-001	
M-4	MAG-LCL-002	
M-5	MAG-LCL-003	
M-6	MAG-LCL-004	MAGNET SYSTEM RACKS
M-7	MAG-LCL-005	
M-8	MAG-LCL-006	
M-9	MAG-LCL-007	
M-10	CRYO-LCL-001	CRYO. DISTRIBUTION SYS. MICROPROCESSOR/ CAMAC/ CRT DISPLAY
M-11	CRYO-LCL-002	CRYO. DISTRIBUTION SYS. CONTROL PANELS/CRT ANN.-SEC. CONTROL
N-1		ECRH 60GHZ PROGRAMMABLE CONTROLLERS
N-2		ECRH 60GHZ PROGRAMMABLE CONTROLLERS
N-3		ECRH 28GHZ/ ICRH PROGRAMMABLE CONTROLLERS
N-4		BOP/ TVL COOLING PROGRAMMABLE CONTROLLERS
N-5		VACUUM/ MAGNET PROGRAMMABLE CONTROLLERS
N-6		CRYO. SYS. PROGRAMMABLE CONTROLLERS

RACK NO.	DESIGNATION	CONTENTS
MCC-1	MCC-ICRH-001	ICRH SYSTEM
MCC-2	MCC-ICRH-002	ICRH SYSTEM
MCC-3	MCC-ECRH-001	
MCC-4	MCC-ECRH-002	
MCC-5	MCC-ECRH-003	ECRH-60GHZ SYSTEM
MCC-6	MCC-ECRH-004	
MCC-7	MCC-ECRH-005	ECRH-28GHZ SYSTEM
MCC-8	MCC-ECRH-006	ECRH-28GHZ SYSTEM
MCC-9	MCC-MAG-001	MAGNET SYSTEM
MCC-10	MCC-MAG-002	MAGNET SYSTEM
MCC-11	MCC-CRYO-001	CRYOGENIC DISTRIBUTION SYSTEM
MCC-12	MCC-CRYO-002	CRYOGENIC DISTRIBUTION SYSTEM
MCC-13	MCC-VAC-001	VACUUM/TVL SYSTEMS
MCC-14	MCC-VAC-002	VACUUM/TVL SYSTEMS
MCC-15	MCC-COS-001	CHIEF OPERATOR'S STATION
MCC-16	MCC-COS-002	CHIEF OPERATOR'S STATION
MCC-17	MCC-EDS-001	EXPERIMENT DIRECTOR'S STATION
MCC-18	MCC-EDS-002	EXPERIMENT DIRECTOR'S STATION
MCC-19	MCC-DDC-001	DIAGNOSTIC DATA COORDINATOR'S STATION
MCC-20	MCC-DDC-002	DIAGNOSTIC DATA COORDINATOR'S STATION

A | SEE DCN A

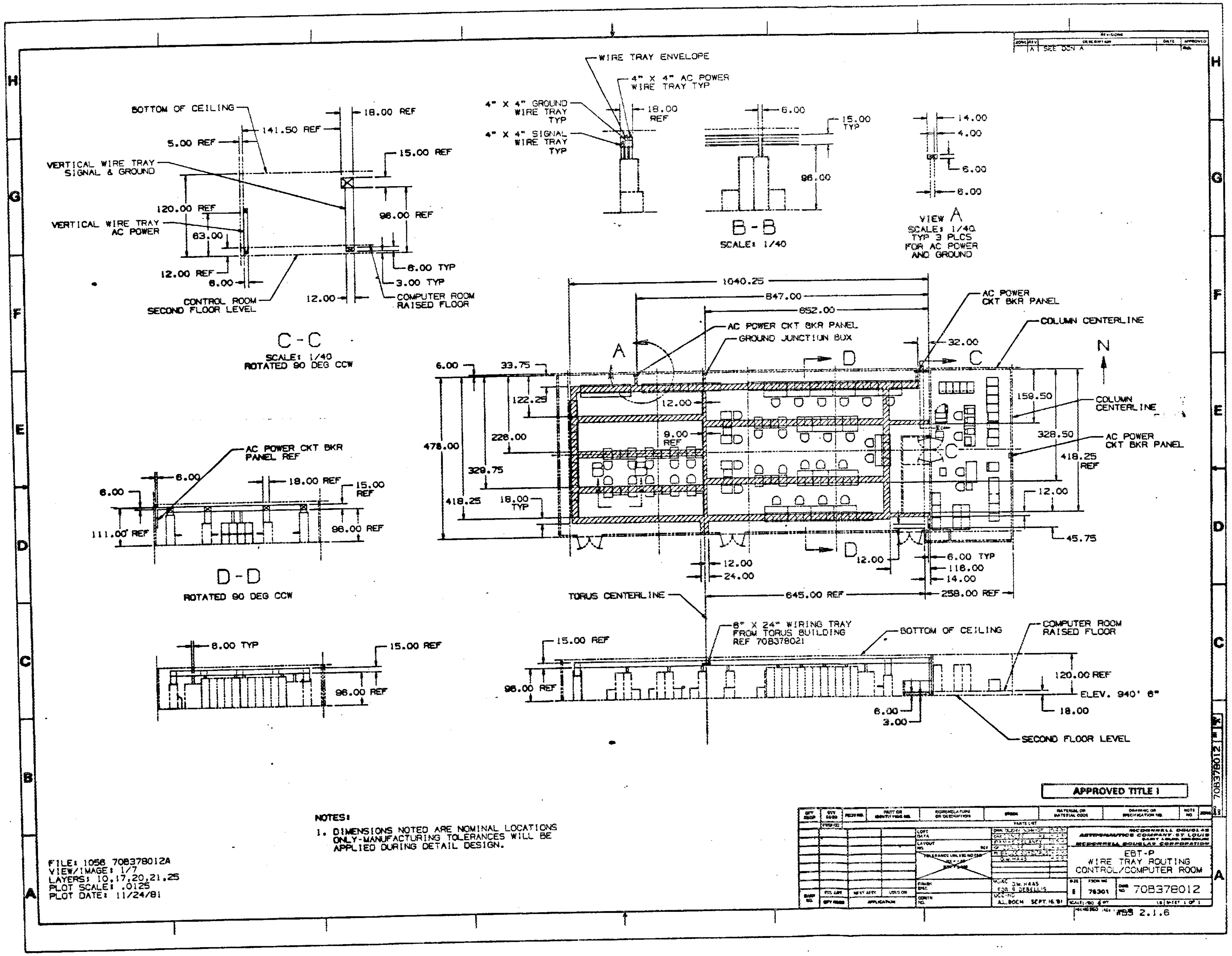
FILE: 1056 70B378011A
VIEW/IMAGE: 1/6
LAYER: 9
PLOT SCALE: 1
PLOT DATE: 11/24/81

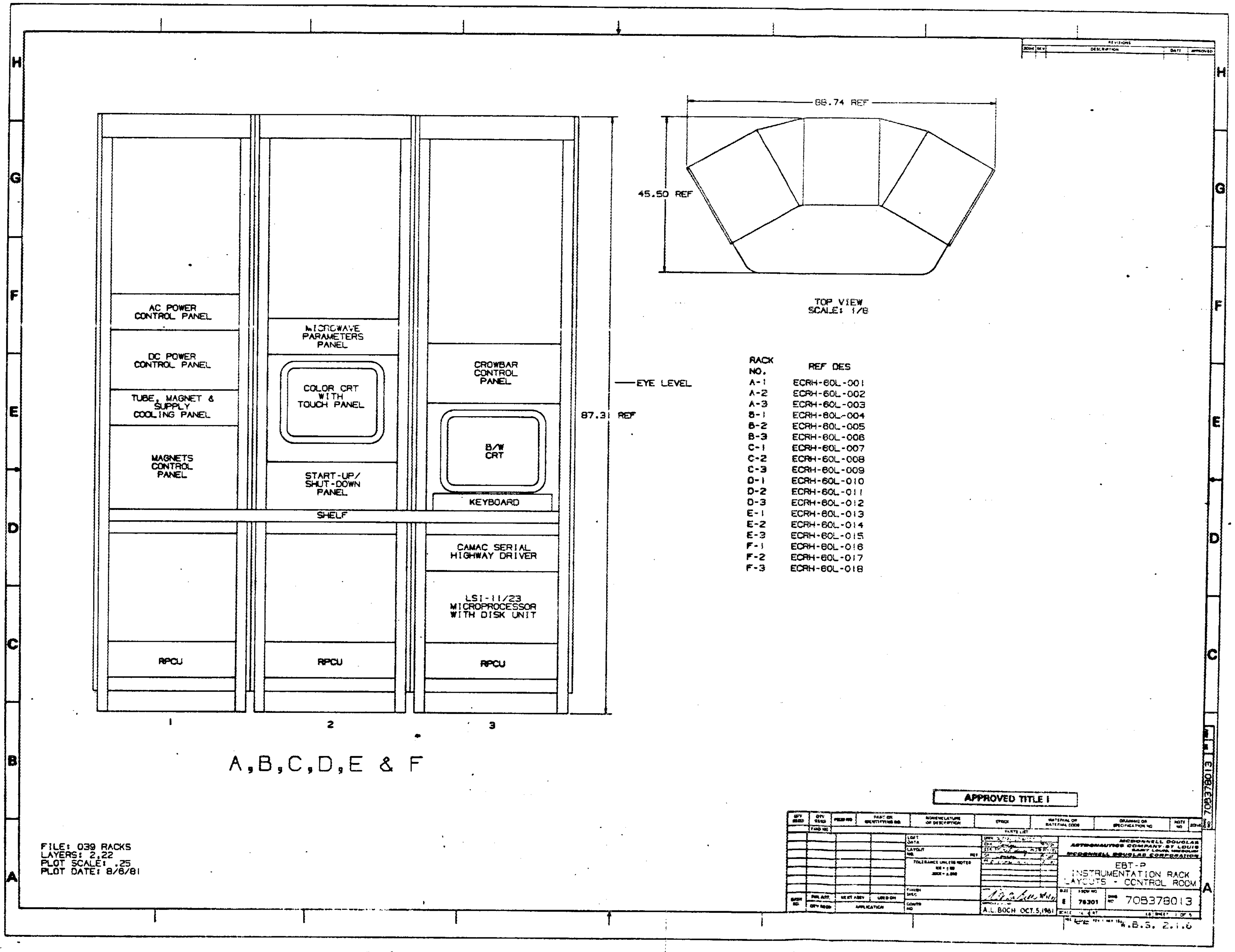
APPROVED TITLE I

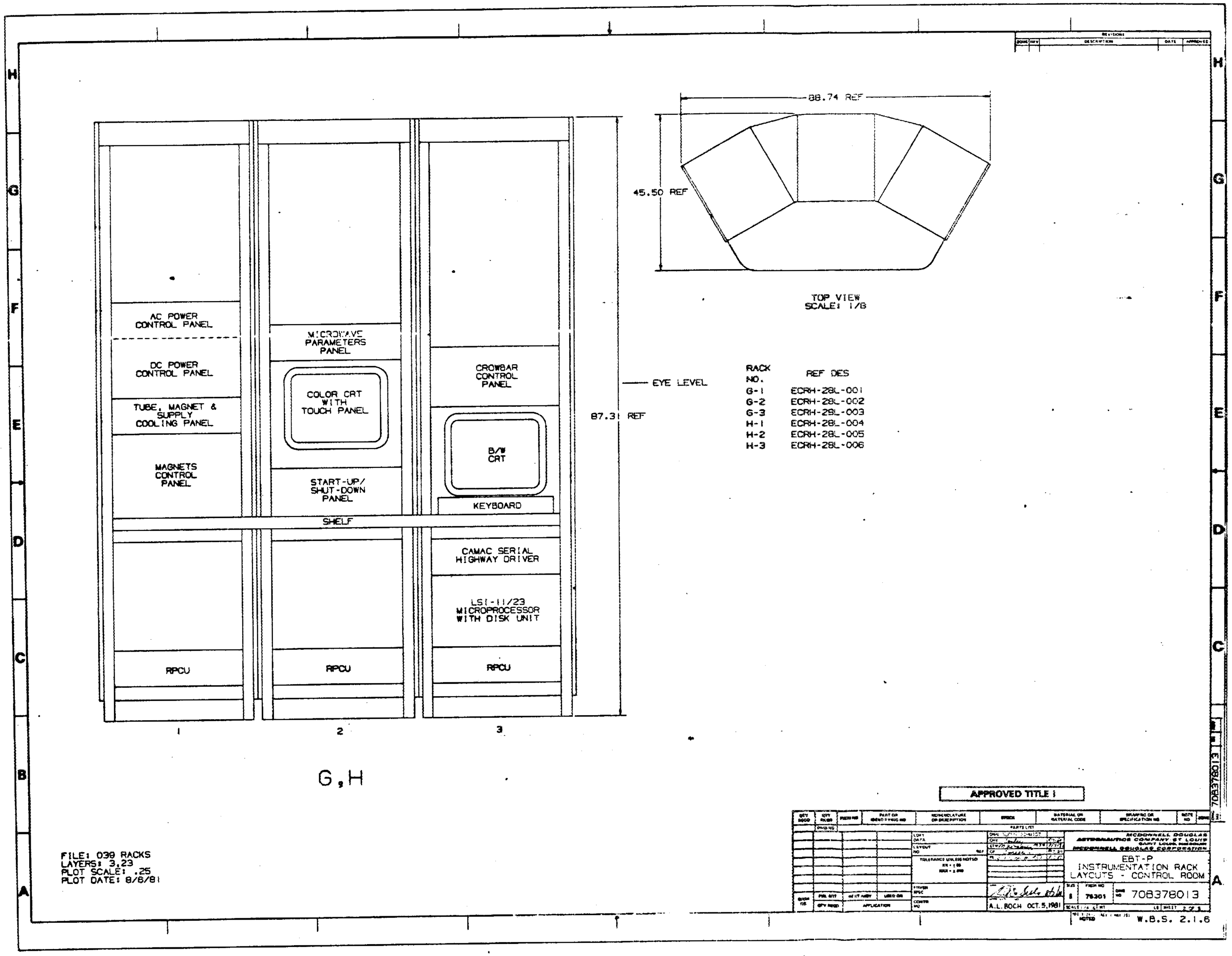
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION

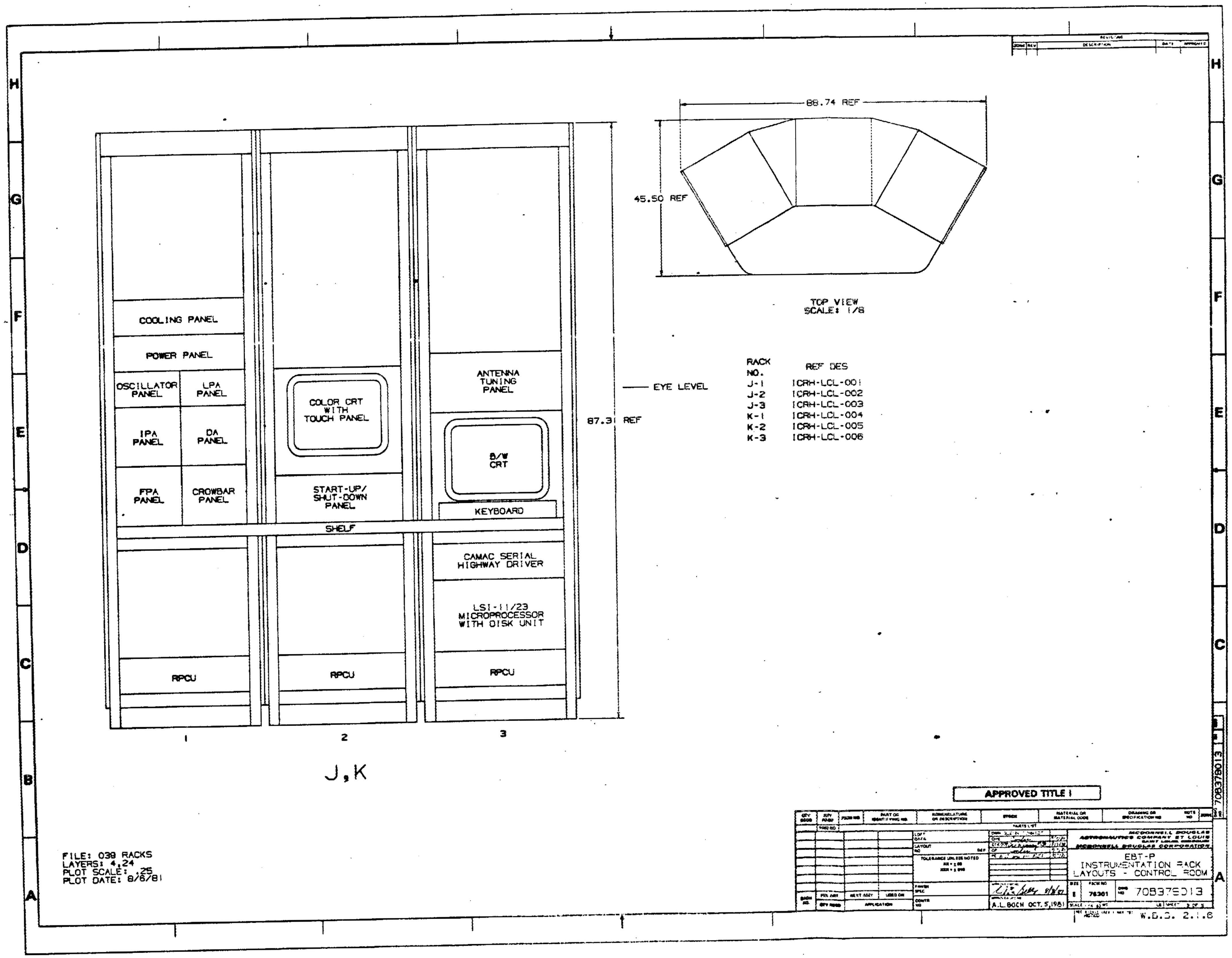
EBT-P
CONTROL/COMPUTER
ROOM FLOOR PLAN

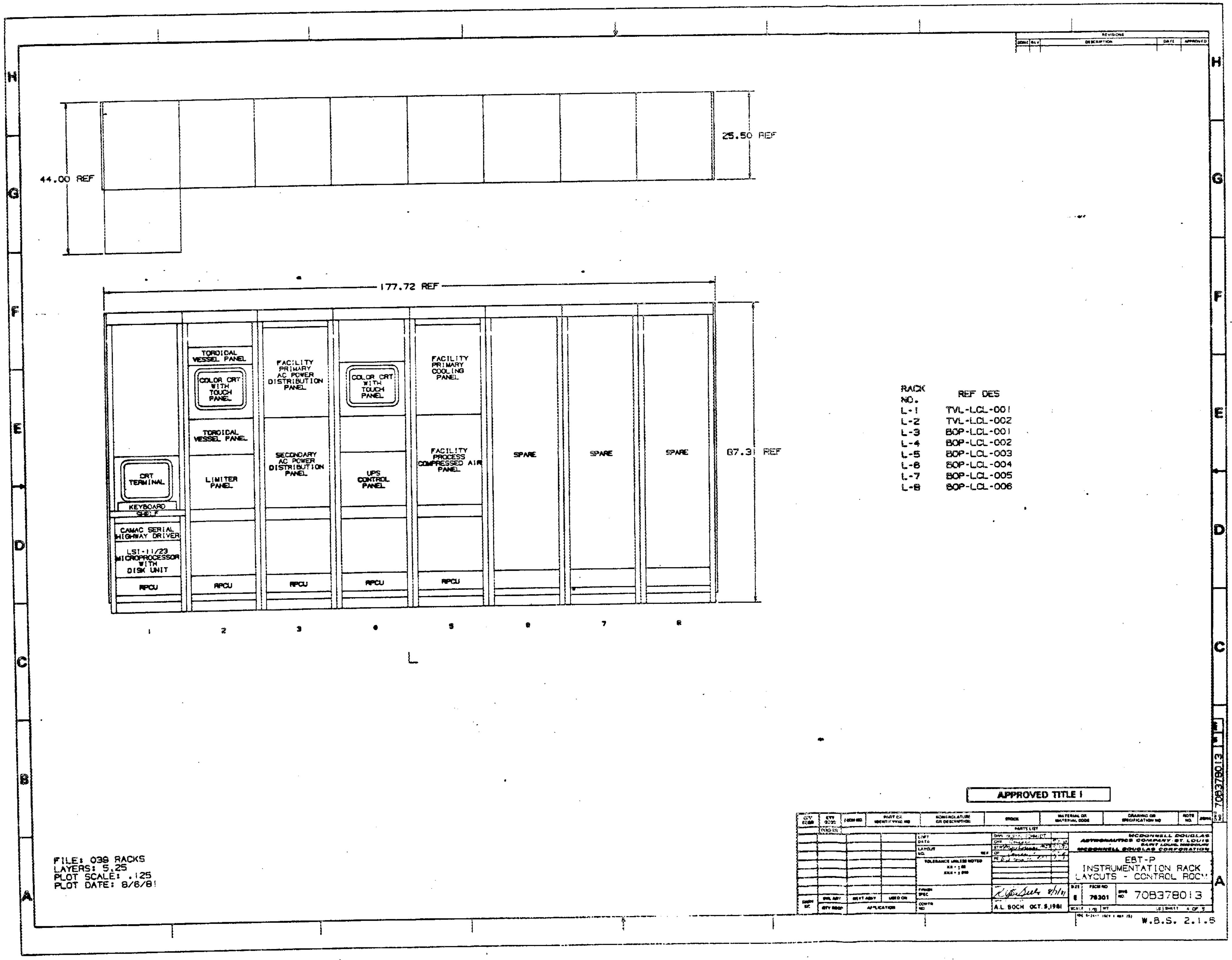
R.J. DEBELLIS 7/28/81
A.L. BOCH 28 AUG '81
FSCM NO 76301
DWG NO 70B378011
W.B.S. 2.1.6

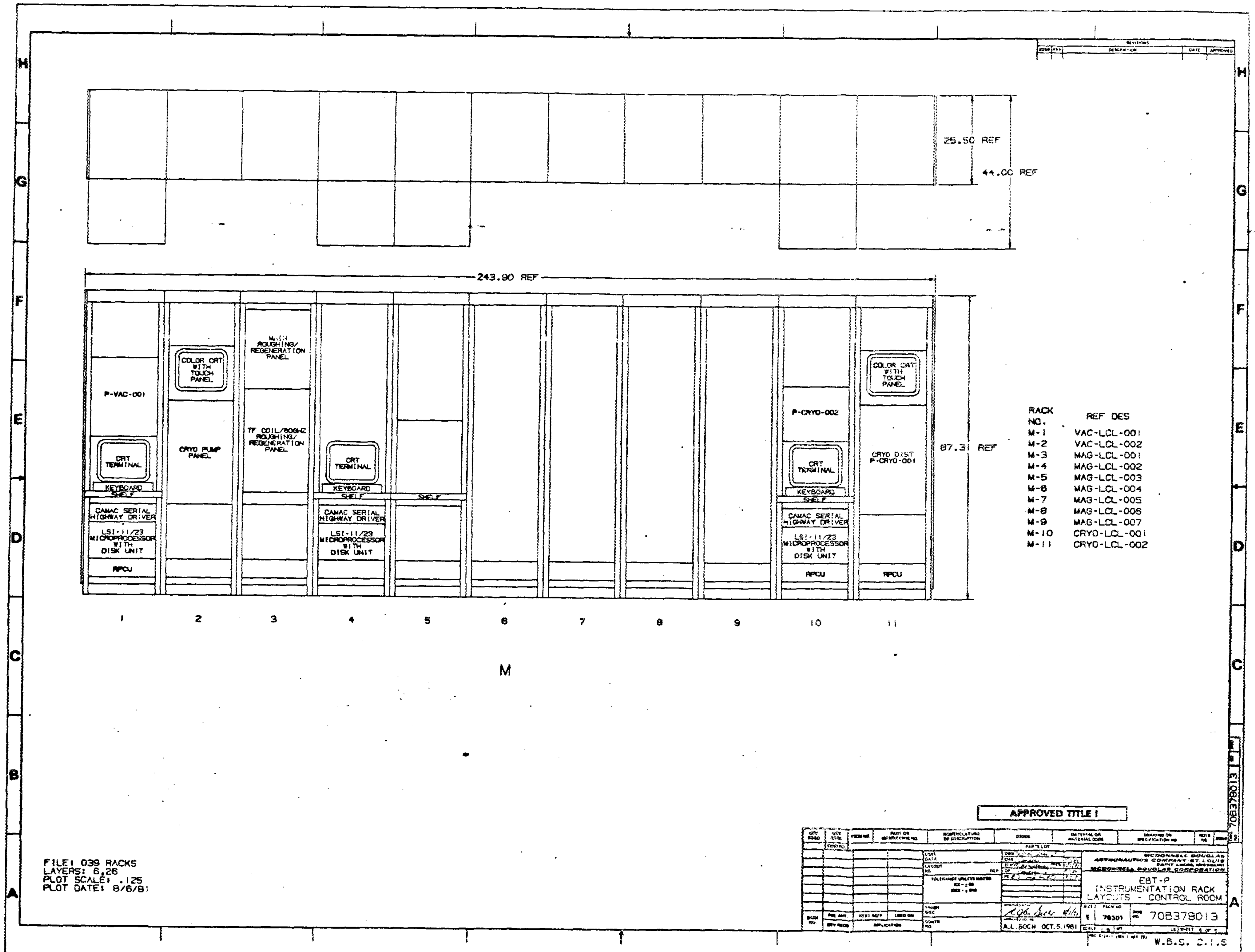

WIRE TRAY ENVELOPE
4" X 4" AC POWER WIRE TRAY TYP
4" X 4" GROUND WIRE TRAY TYP
4" X 4" SIGNAL WIRE TRAY TYP
BOTTOM OF CEILING
VERTICAL WIRE TRAY SIGNAL & GROUND
VERTICAL WIRE TRAY AC POWER
CONTROL ROOM SECOND FLOOR LEVEL
COMPUTER ROOM RAISED FLOOR
C-C
SCALE: 1/40
ROTATED 90 DEG CCW
B-B
SCALE: 1/40
VIEW A
SCALE: 1/40
TYP 3 PLCS
FOR AC POWER AND GROUND
AC POWER CKT BKR PANEL
GROUND JUNCTION BOX
COLUMN CENTERLINE
AC POWER CKT BKR PANEL REF
D-D
ROTATED 90 DEG CCW
TORUS CENTERLINE
8" X 24" WIRING TRAY FROM TORUS BUILDING REF 70B378021
ELEV. 940' 6"
SECOND FLOOR LEVEL
NOTES:
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY-MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
FILE: 1056 70B378012A
VIEW/IMAGE: 1/7
LAYERS: 10,17,20,21,25
PLOT SCALE: .0125
PLOT DATE: 11/24/81
APPROVED TITLE I
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
EBT-P
WIRE TRAY ROUTING
CONTROL/COMPUTER ROOM
76301
70B378012
WBS 2.1.6

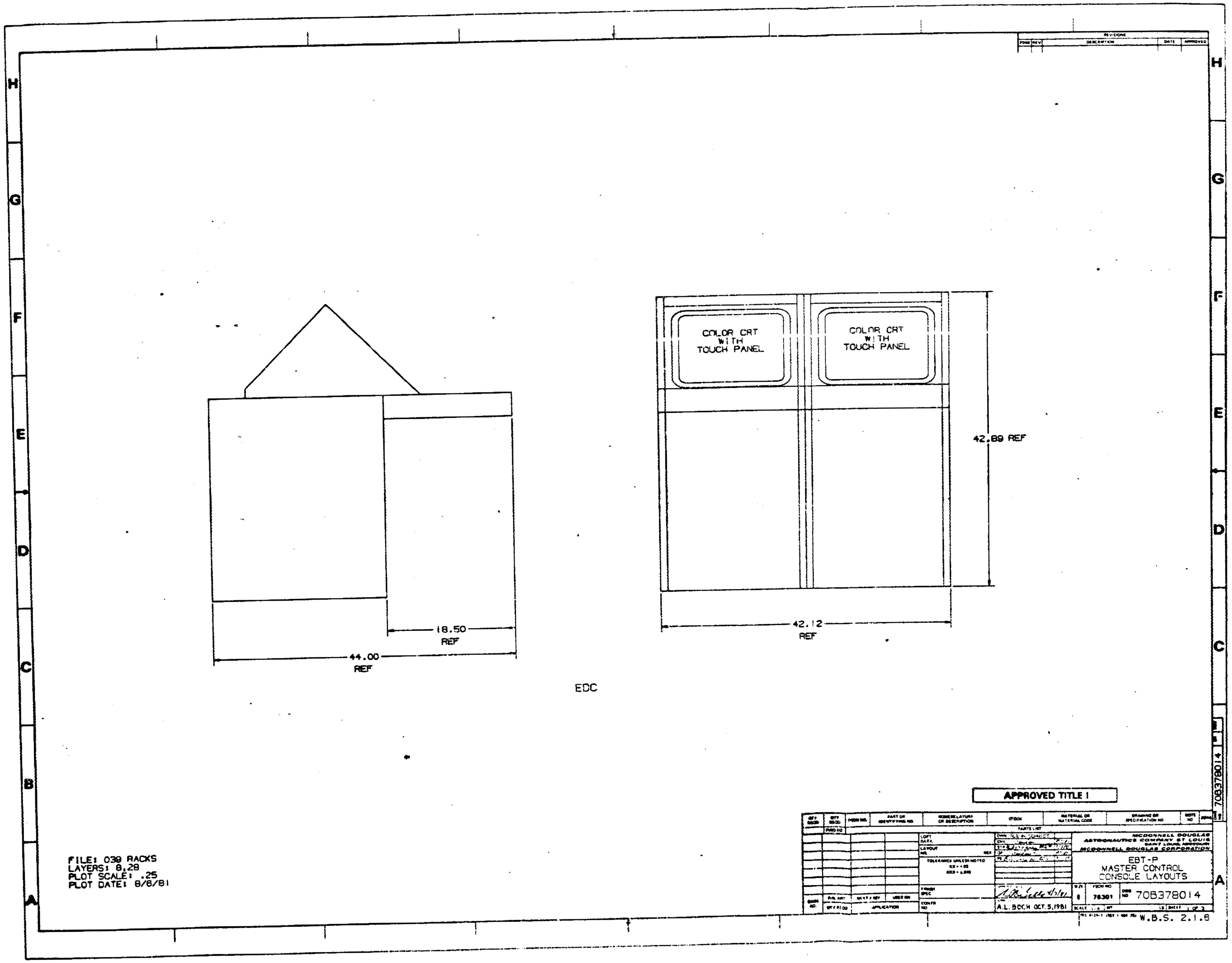

AC POWER CONTROL PANEL
DC POWER CONTROL PANEL
TUBE, MAGNET & SUPPLY COOLING PANEL
MAGNETS CONTROL PANEL
MICROWAVE PARAMETERS PANEL
COLOR CRT WITH TOUCH PANEL
START-UP/ SHUT-DOWN PANEL
SHELF
CROWBAR CONTROL PANEL
B/W CRT
KEYBOARD
CAMAC SERIAL HIGHWAY DRIVER
LSI-11/23 MICROPROCESSOR WITH DISK UNIT
RPCU
RPCU
RPCU
1
2
3
A,B,C,D,E & F
EYE LEVEL
87.31 REF
88.74 REF
45.50 REF
TOP VIEW
SCALE: 1/8
RACK NO.
REF DES
A-1 ECRH-60L-001
A-2 ECRH-60L-002
A-3 ECRH-60L-003
B-1 ECRH-60L-004
B-2 ECRH-60L-005
B-3 ECRH-60L-006
C-1 ECRH-60L-007
C-2 ECRH-60L-008
C-3 ECRH-60L-009
D-1 ECRH-60L-010
D-2 ECRH-60L-011
D-3 ECRH-60L-012
E-1 ECRH-60L-013
E-2 ECRH-60L-014
E-3 ECRH-60L-015
F-1 ECRH-60L-016
F-2 ECRH-60L-017
F-3 ECRH-60L-018
FILE: 039 RACKS
LAYERS: 2,22
PLOT SCALE: .25
PLOT DATE: 8/6/81
APPROVED TITLE I
EBT-P
INSTRUMENTATION RACK LAYOUTS - CONTROL ROOM
76301
70B378013
A.L. BOCH OCT.5,1981

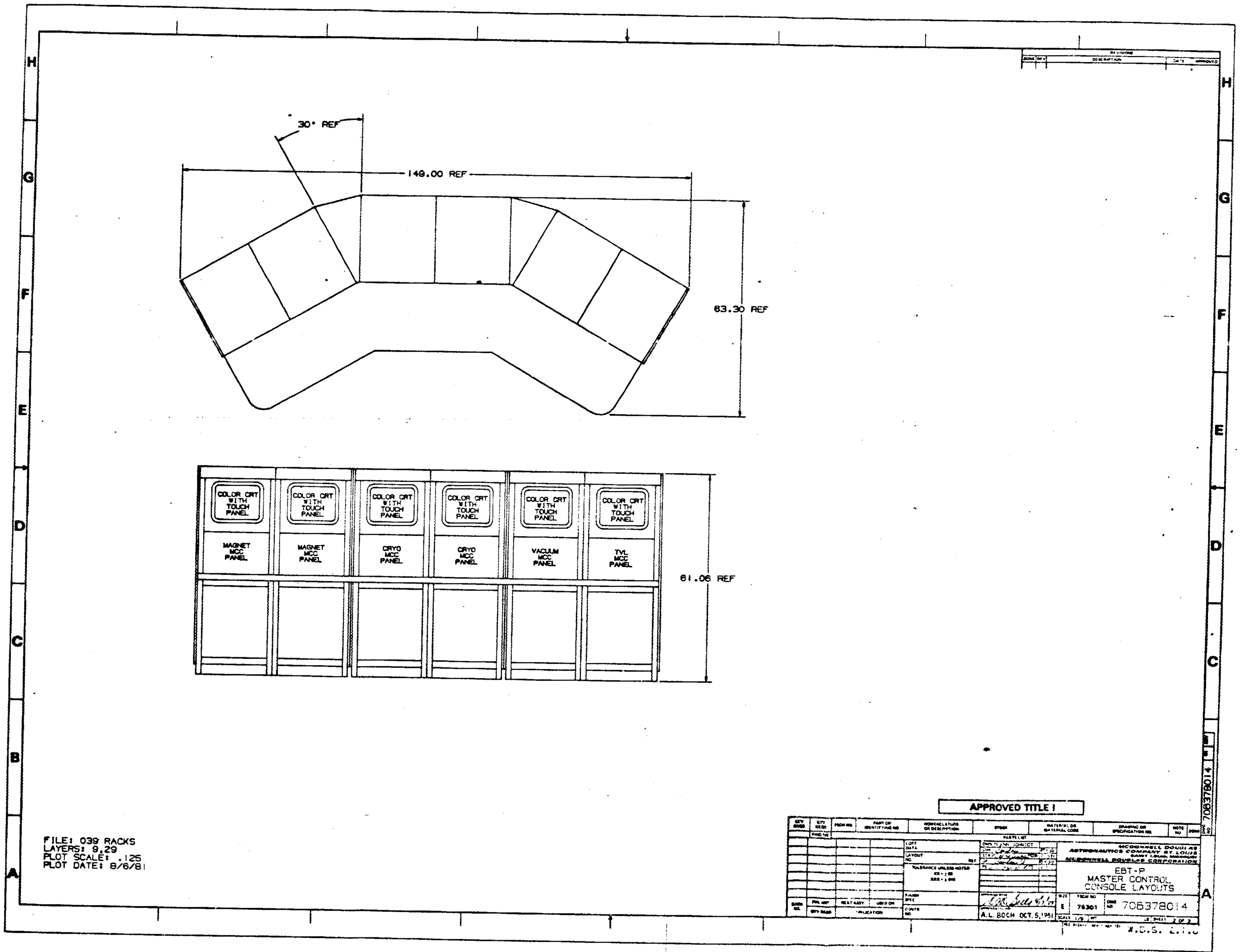

88.74 REF
45.50 REF
TOP VIEW
SCALE: 1/8
AC POWER CONTROL PANEL
DC POWER CONTROL PANEL
TUBE, MAGNET & SUPPLY COOLING PANEL
MAGNETS CONTROL PANEL
MICROWAVE PARAMETERS PANEL
COLOR CRT WITH TOUCH PANEL
START-UP/ SHUT-DOWN PANEL
CROWBAR CONTROL PANEL
B/W CRT
KEYBOARD
SHELF
CAMAC SERIAL HIGHWAY DRIVER
LSI-11/23 MICROPROCESSOR WITH DISK UNIT
RPCU
RPCU
RPCU
1
2
3
EYE LEVEL
87.31 REF
RACK NO.
REF DES
G-1 ECRH-28L-001
G-2 ECRH-28L-002
G-3 ECRH-28L-003
H-1 ECRH-28L-004
H-2 ECRH-28L-005
H-3 ECRH-28L-006
G,H
FILE: 039 RACKS
LAYERS: 3,23
PLOT SCALE: .25
PLOT DATE: 8/6/81
APPROVED TITLE I
EBT-P
INSTRUMENTATION RACK
LAYOUTS - CONTROL ROOM
A.L. BOCH OCT. 5,1981
76301
708378013
W.B.S. 2.1.6

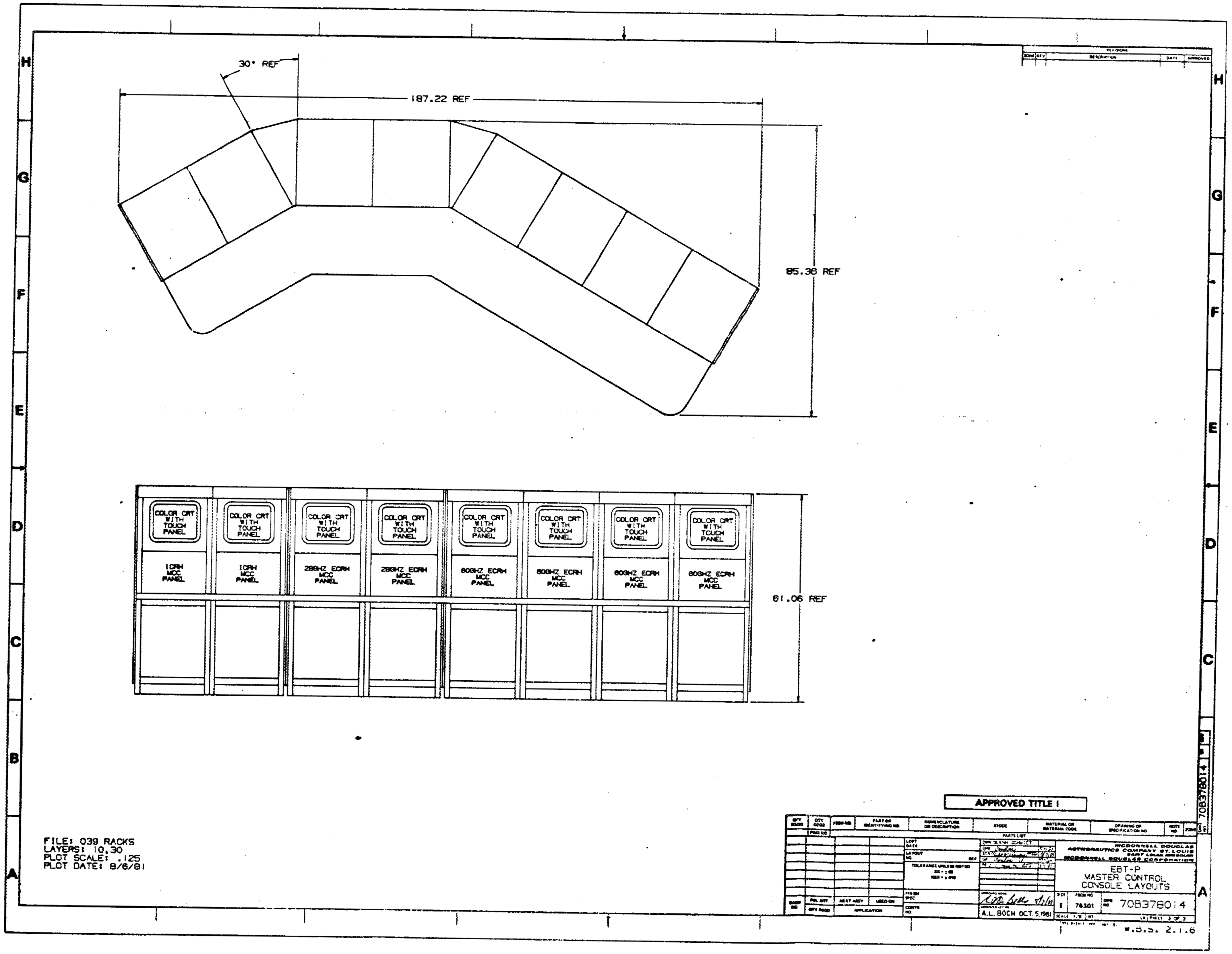

88.74 REF
45.50 REF
TOP VIEW
SCALE: 1/8
COOLING PANEL
POWER PANEL
OSCILLATOR PANEL
LPA PANEL
IPA PANEL
DA PANEL
FPA PANEL
CROWBAR PANEL
COLOR CRT WITH TOUCH PANEL
START-UP/ SHUT-DOWN PANEL
ANTENNA TUNING PANEL
B/W CRT
KEYBOARD
SHELF
CAMAC SERIAL HIGHWAY DRIVER
LSI-11/23 MICROPROCESSOR WITH DISK UNIT
RPCU
RPCU
RPCU
1
2
3
J,K
EYE LEVEL
87.31 REF
RACK NO.
REF DES
J-1 1CRH-LCL-001
J-2 1CRH-LCL-002
J-3 1CRH-LCL-003
K-1 1CRH-LCL-004
K-2 1CRH-LCL-005
K-3 1CRH-LCL-006
FILE: 039 RACKS
LAYERS: 4,24
PLOT SCALE: .25
PLOT DATE: 8/6/81
APPROVED TITLE I
EBT-P
INSTRUMENTATION RACK
LAYOUTS - CONTROL ROOM
76301
70837SD13
A.L. BOCH OCT. 5, 1981
W.B.S. 2.1.6
70837SD13

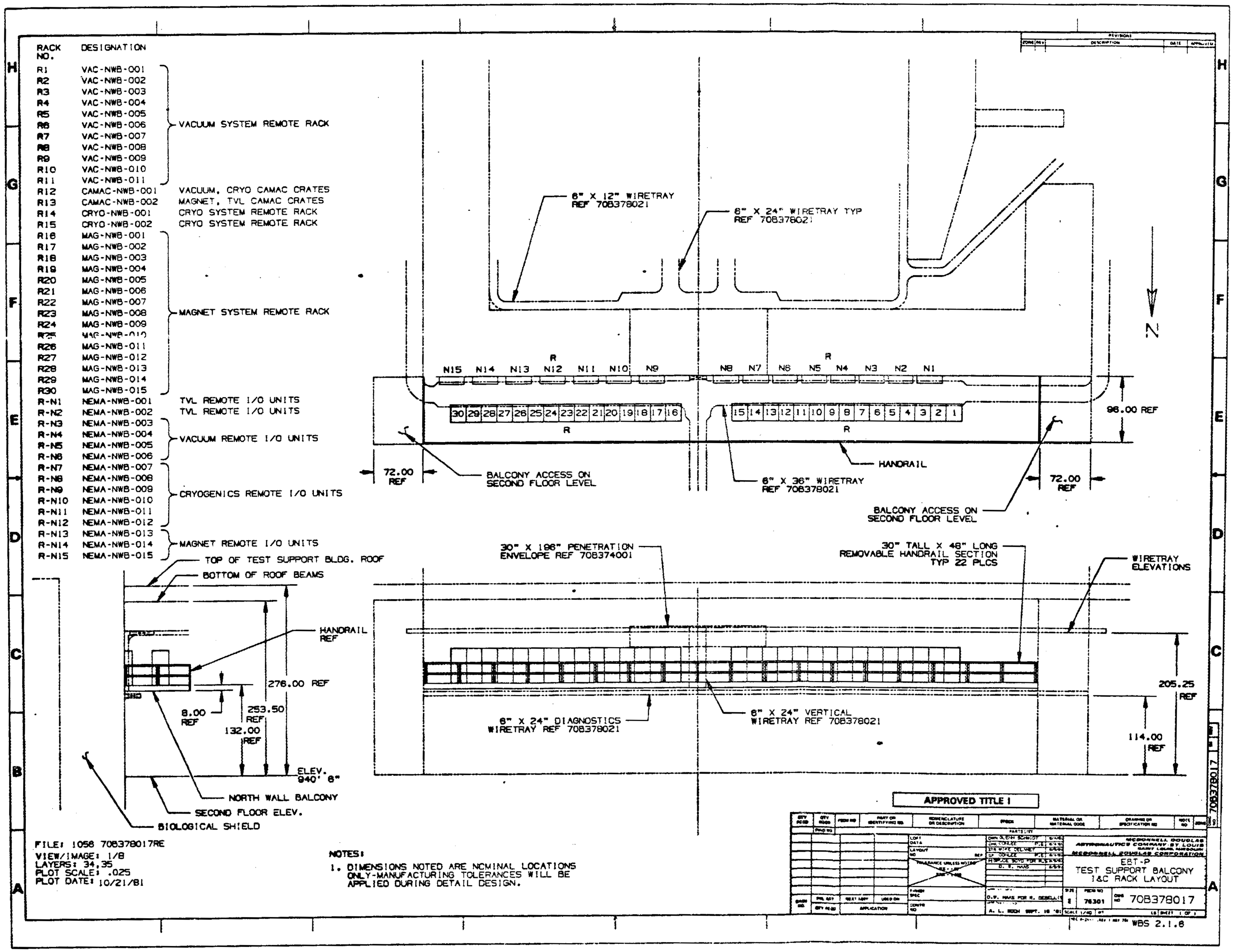

44.00 REF
25.50 REF
177.72 REF
87.31 REF
TOROIDAL VESSEL PANEL
COLOR CRT WITH TOUCH PANEL
TOROIDAL VESSEL PANEL
LIMITER PANEL
FACILITY PRIMARY AC POWER DISTRIBUTION PANEL
SECONDARY AC POWER DISTRIBUTION PANEL
COLOR CRT WITH TOUCH PANEL
UPS CONTROL PANEL
FACILITY PRIMARY COOLING PANEL
FACILITY PROCESS COMPRESSED AIR PANEL
SPARE
SPARE
SPARE
CRT TERMINAL
KEYBOARD SHELF
CAMAC SERIAL HIGHWAY DRIVER
LSI-11/23 MICROPROCESSOR WITH DISK UNIT
RPCU
RPCU
RPCU
RPCU
RPCU
1
2
3
7
L
RACK NO. / REF DES
L-1 TVL-LCL-001
L-2 TVL-LCL-002
L-3 BOP-LCL-001
L-4 BOP-LCL-002
L-5 BOP-LCL-003
L-6 BOP-LCL-004
L-7 BOP-LCL-005
L-8 BOP-LCL-006
FILE: 039 RACKS
LAYERS: 5,25
PLOT SCALE: .125
PLOT DATE: 8/6/81
APPROVED TITLE I
PARTS LIST
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
INSTRUMENTATION RACK
LAYOUTS - CONTROL ROOM
76301
70B378013
A.L. BOCH OCT. 5,1981
W.B.S. 2.1.5

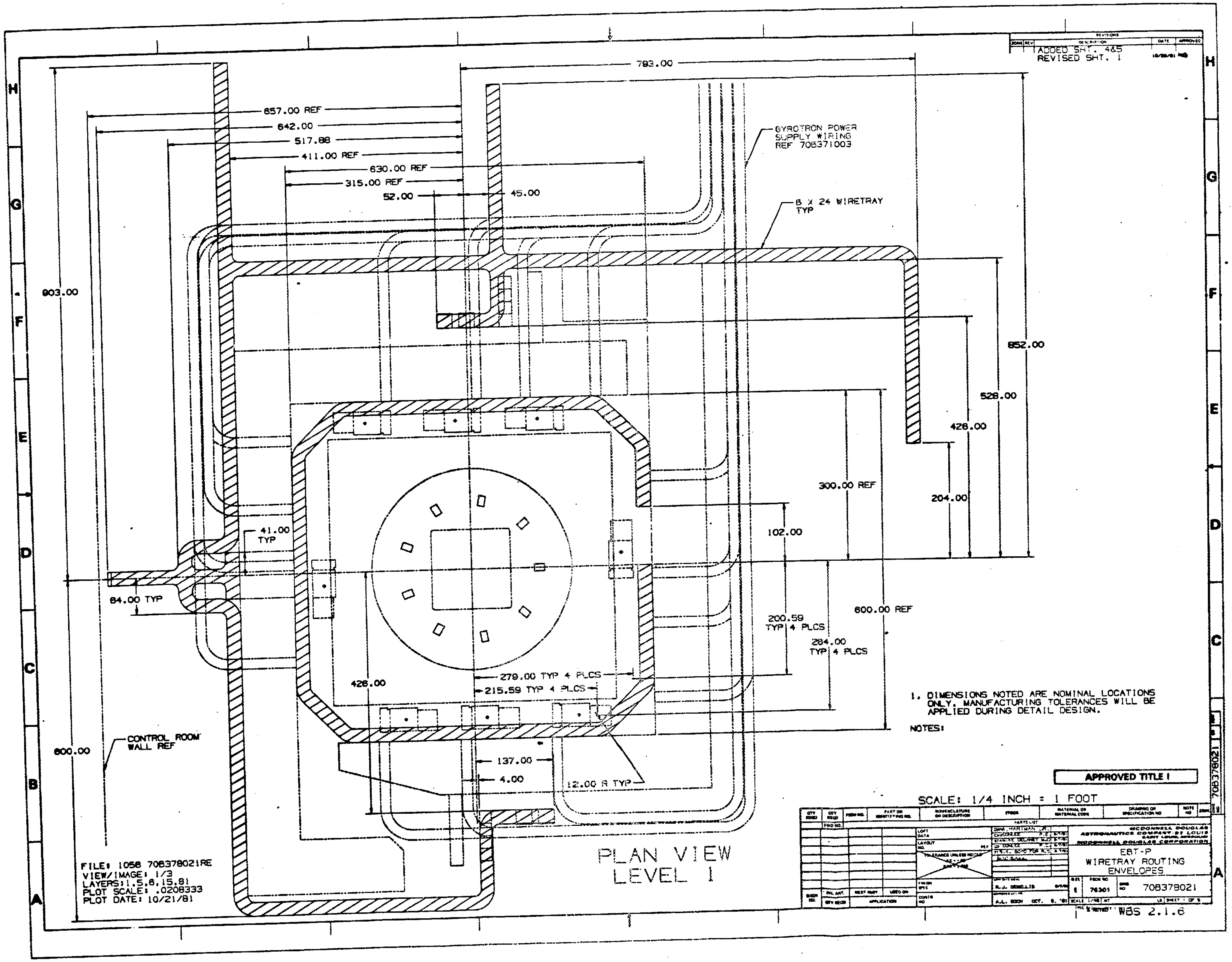

25.50 REF
44.00 REF
243.90 REF
87.31 REF
P-VAC-001
CRT TERMINAL
KEYBOARD SHELF
CAMAC SERIAL HIGHWAY DRIVER
LSI-11/23 MICROPROCESSOR WITH DISK UNIT
RPCU
COLOR CRT WITH TOUCH PANEL
CRYO PUMP PANEL
ROUGHING/ REGENERATION PANEL
TF COIL/60GHZ ROUGHING/ REGENERATION PANEL
SHELF
P-CRYO-002
CRYO DIST P-CRYO-001
1
2
3
4
5
6
7
8
9
10
11
M
RACK NO.
REF DES
M-1 VAC-LCL-001
M-2 VAC-LCL-002
M-3 MAG-LCL-001
M-4 MAG-LCL-002
M-5 MAG-LCL-003
M-6 MAG-LCL-004
M-7 MAG-LCL-005
M-8 MAG-LCL-006
M-9 MAG-LCL-007
M-10 CRYO-LCL-001
M-11 CRYO-LCL-002
FILE: 039 RACKS
LAYERS: 6,26
PLOT SCALE: .125
PLOT DATE: 8/6/81
APPROVED TITLE I
PARTS LIST
TOLERANCE UNLESS NOTED
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
INSTRUMENTATION RACK
LAYOUTS - CONTROL ROOM
76301
708378013
A.L. BOCH OCT. 5, 1981
W.B.S. 2.1.5

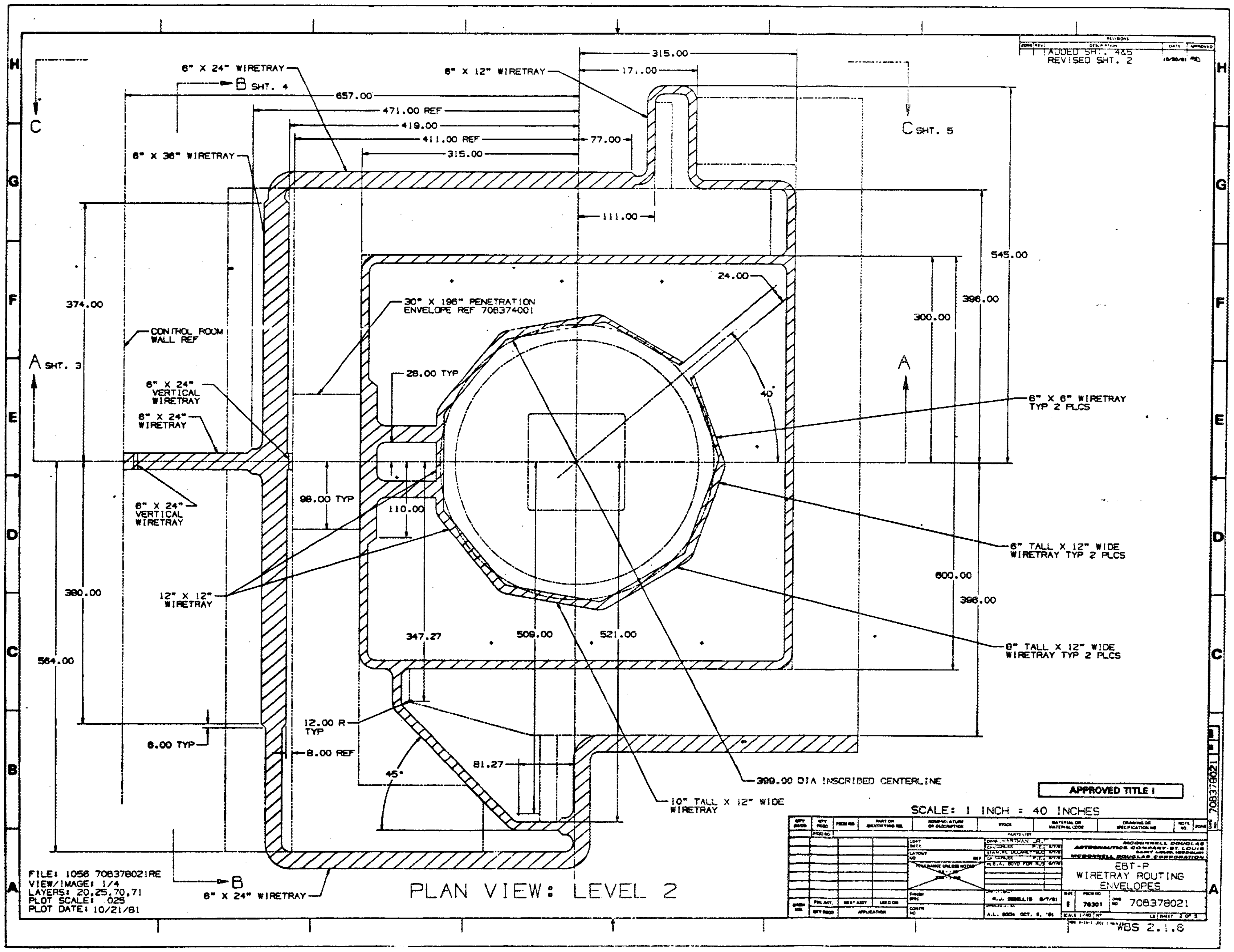

COLOR CRT
WITH
TOUCH PANEL
COLOR CRT
WITH
TOUCH PANEL
42.89 REF
18.50
REF
44.00
REF
42.12
REF
EDC
FILE: 039 RACKS
LAYERS: 0,28
PLOT SCALE: .25
PLOT DATE: 8/6/81
APPROVED TITLE I
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
MASTER CONTROL
CONSOLE LAYOUTS
A.L. BOCH OCT. 5, 1981
76301
70B378014
W.B.S. 2.1.6

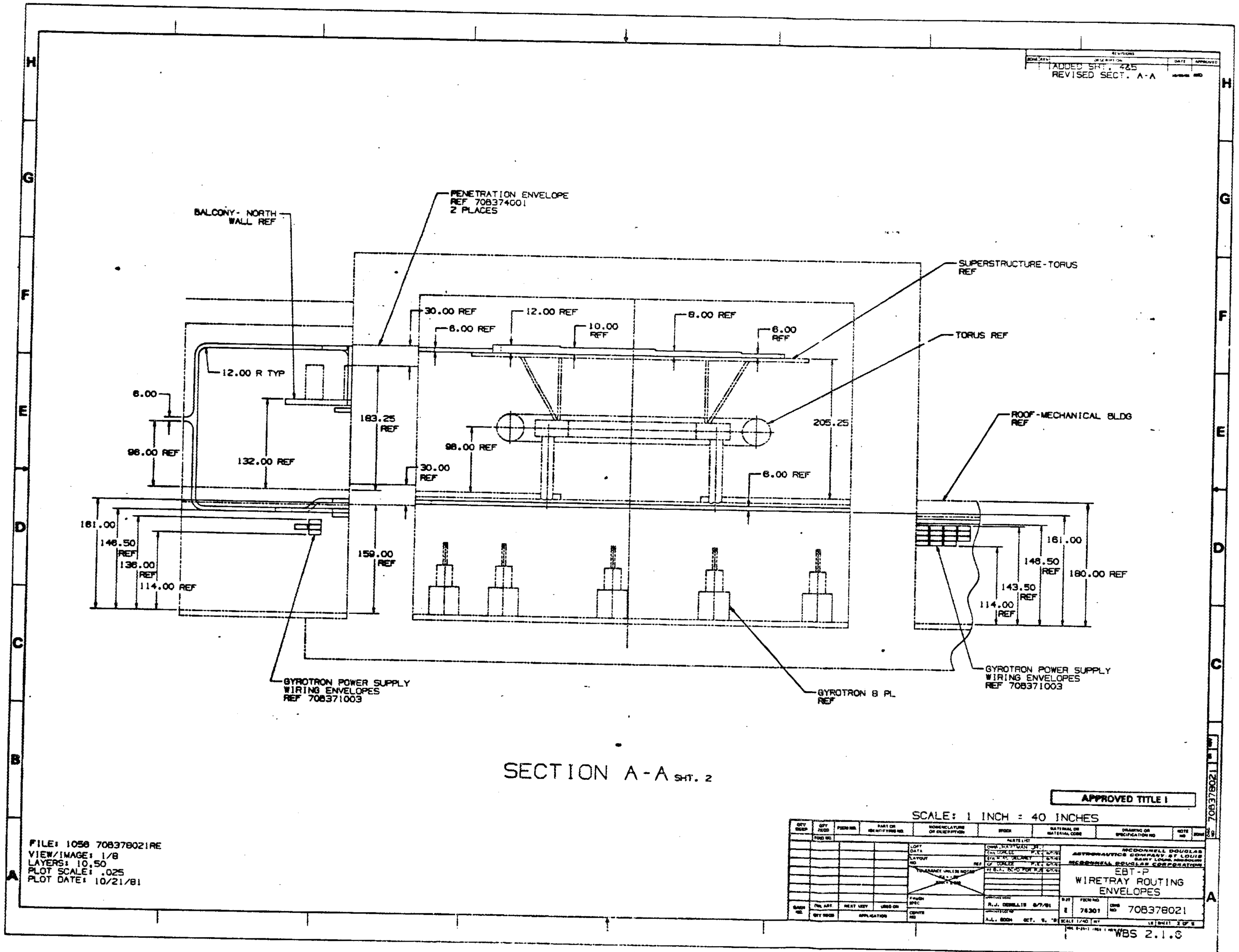

30° REF
149.00 REF
83.30 REF
COLOR CRT WITH TOUCH PANEL
MAGNET MCC PANEL
MAGNET MCC PANEL
CRYO MCC PANEL
CRYO MCC PANEL
VACUUM MCC PANEL
TVL MCC PANEL
61.06 REF
FILE: 039 RACKS
LAYERS: 9,29
PLOT SCALE: .125
PLOT DATE: 8/6/81
APPROVED TITLE I
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
MASTER CONTROL
CONSOLE LAYOUTS
A.L. BOCH OCT. 5, 1981
E
76301
70637801 4
SHEET 2 OF 3

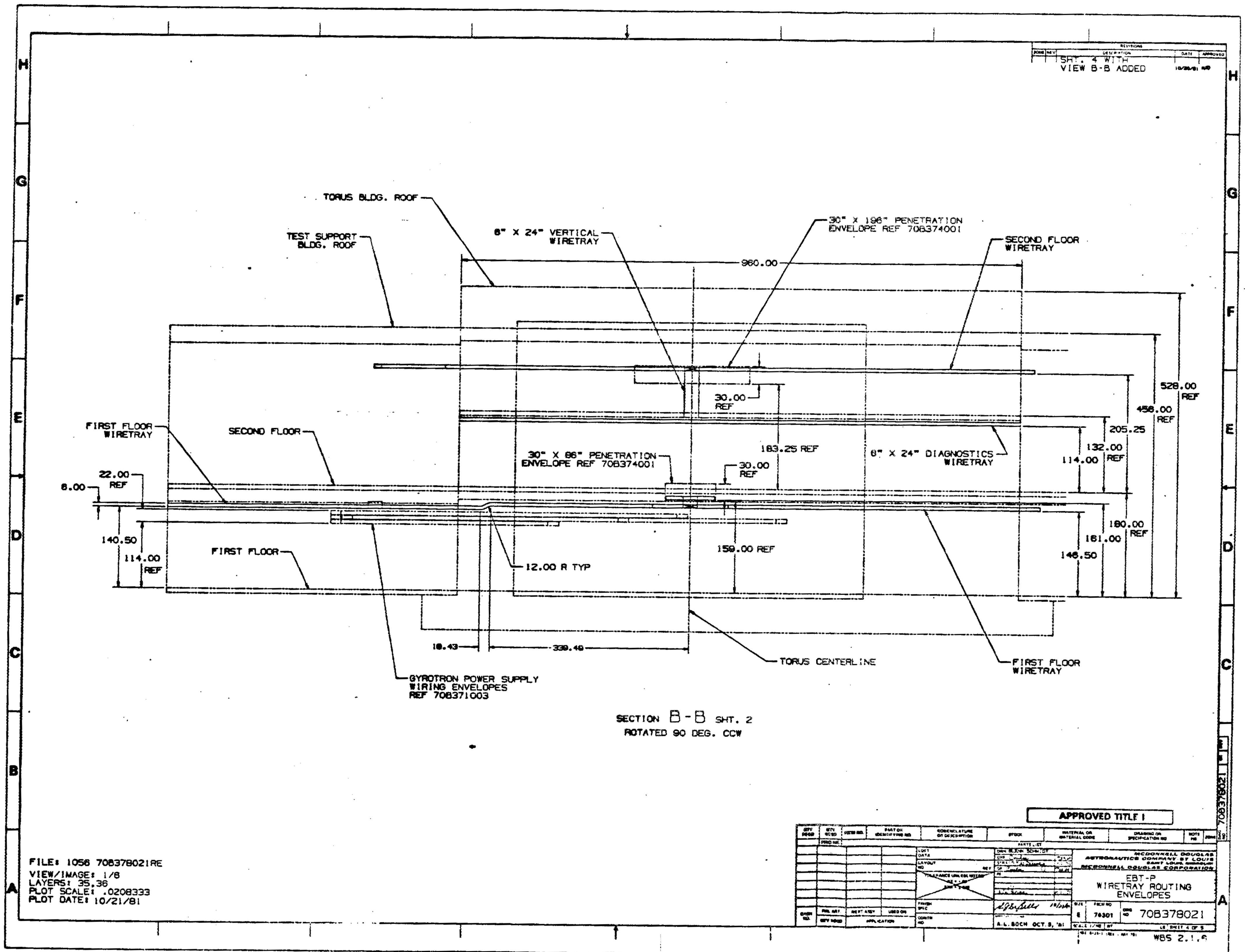

30° REF
187.22 REF
85.38 REF
COLOR CRT WITH TOUCH PANEL
ICRH MCC PANEL
ICRH MCC PANEL
28GHZ ECRH MCC PANEL
28GHZ ECRH MCC PANEL
60GHZ ECRH MCC PANEL
60GHZ ECRH MCC PANEL
60GHZ ECRH MCC PANEL
60GHZ ECRH MCC PANEL
61.06 REF
FILE: 039 RACKS
LAYERS: 10,30
PLOT SCALE: .125
PLOT DATE: 8/6/81
APPROVED TITLE I
PARTS LIST
TOLERANCE UNLESS NOTED
DWN GLENN SCHMIDT
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
SAINT LOUIS MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
MASTER CONTROL
CONSOLE LAYOUTS
A.L. BOCH OCT. 5,1981
76301
70B378014
SCALE 1/8
SHEET 3 OF 3
W.B.S. 2.1.6

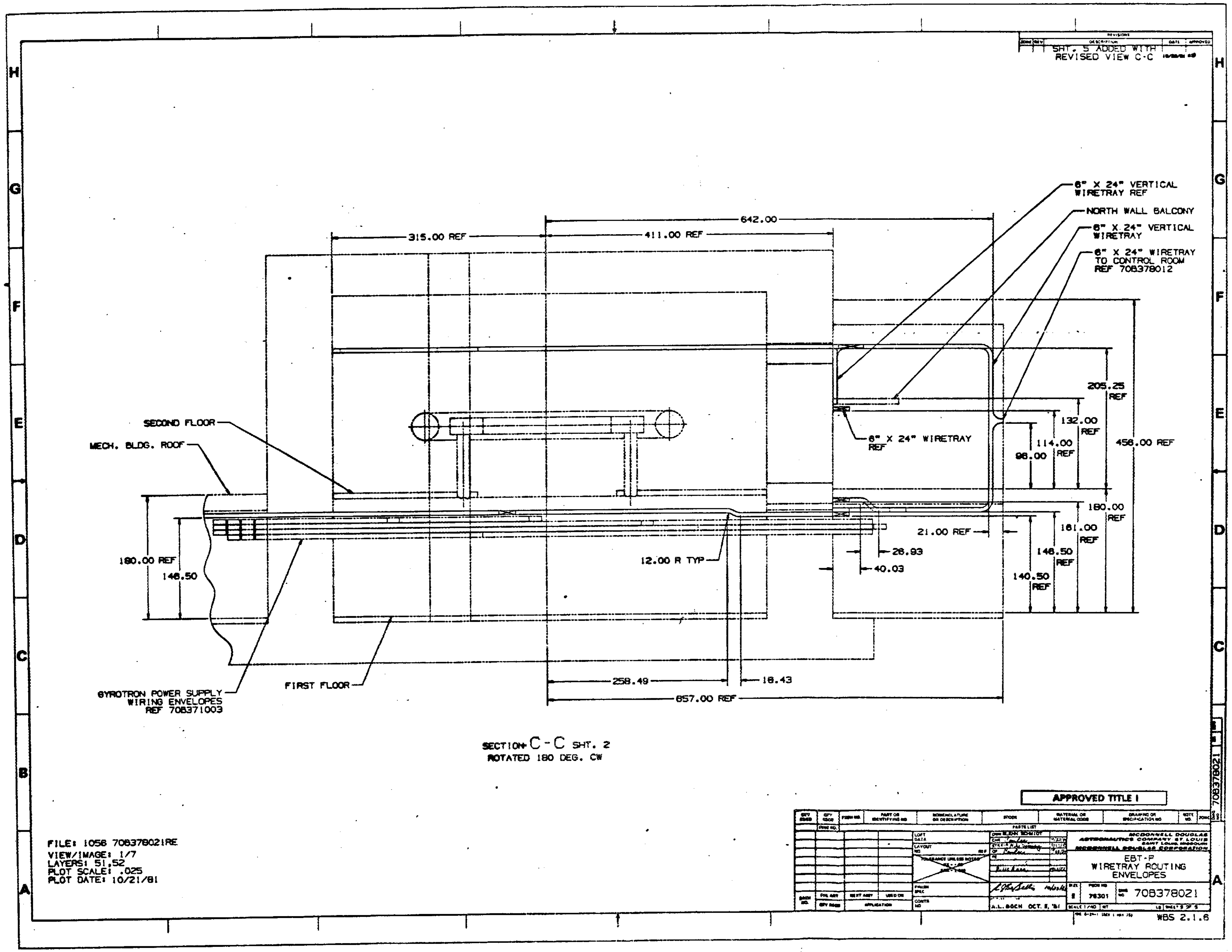

RACK NO. DESIGNATION
R1 VAC-NWB-001
R2 VAC-NWB-002
R3 VAC-NWB-003
R4 VAC-NWB-004
R5 VAC-NWB-005
R6 VAC-NWB-006
R7 VAC-NWB-007
R8 VAC-NWB-008
R9 VAC-NWB-009
R10 VAC-NWB-010
R11 VAC-NWB-011
VACUUM SYSTEM REMOTE RACK
R12 CAMAC-NWB-001 VACUUM, CRYO CAMAC CRATES
R13 CAMAC-NWB-002 MAGNET, TVL CAMAC CRATES
R14 CRYO-NWB-001 CRYO SYSTEM REMOTE RACK
R15 CRYO-NWB-002 CRYO SYSTEM REMOTE RACK
R16 MAG-NWB-001
R17 MAG-NWB-002
R18 MAG-NWB-003
R19 MAG-NWB-004
R20 MAG-NWB-005
R21 MAG-NWB-006
R22 MAG-NWB-007
R23 MAG-NWB-008
R24 MAG-NWB-009
R26 MAG-NWB-011
R27 MAG-NWB-012
R28 MAG-NWB-013
R29 MAG-NWB-014
R30 MAG-NWB-015
MAGNET SYSTEM REMOTE RACK
R-N1 NEMA-NWB-001 TVL REMOTE I/O UNITS
R-N2 NEMA-NWB-002 TVL REMOTE I/O UNITS
R-N3 NEMA-NWB-003
R-N4 NEMA-NWB-004
R-N5 NEMA-NWB-005
R-N6 NEMA-NWB-006
VACUUM REMOTE I/O UNITS
R-N7 NEMA-NWB-007
R-N8 NEMA-NWB-008
R-N9 NEMA-NWB-009
R-N10 NEMA-NWB-010
R-N11 NEMA-NWB-011
R-N12 NEMA-NWB-012
CRYOGENICS REMOTE I/O UNITS
R-N13 NEMA-NWB-013
R-N14 NEMA-NWB-014
R-N15 NEMA-NWB-015
MAGNET REMOTE I/O UNITS
6" X 12" WIRETRAY REF 708378021
6" X 24" WIRETRAY TYP REF 708378021
N
N15 N14 N13 N12 N11 N10 N9
N8 N7 N6 N5 N4 N3 N2 N1
30 29 28 27 26 25 24 23 22 21 20 19 18 17 16
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
96.00 REF
72.00 REF
BALCONY ACCESS ON SECOND FLOOR LEVEL
6" X 36" WIRETRAY REF 708378021
HANDRAIL
TOP OF TEST SUPPORT BLDG. ROOF
BOTTOM OF ROOF BEAMS
30" X 186" PENETRATION ENVELOPE REF 708374001
30" TALL X 48" LONG REMOVABLE HANDRAIL SECTION TYP 22 PLCS
WIRETRAY ELEVATIONS
HANDRAIL REF
276.00 REF
8.00 REF
253.50 REF
132.00 REF
205.25 REF
114.00 REF
6" X 24" DIAGNOSTICS WIRETRAY REF 708378021
6" X 24" VERTICAL WIRETRAY REF 708378021
ELEV. 940' 6"
NORTH WALL BALCONY
SECOND FLOOR ELEV.
BIOLOGICAL SHIELD
FILE: 1056 708378017RE
VIEW/IMAGE: 1/8
LAYERS: 34,35
PLOT SCALE: .025
PLOT DATE: 10/21/81
NOTES:
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY-MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
APPROVED TITLE I
EBT-P
TEST SUPPORT BALCONY
I&C RACK LAYOUT
76301
708378017
WBS 2.1.8

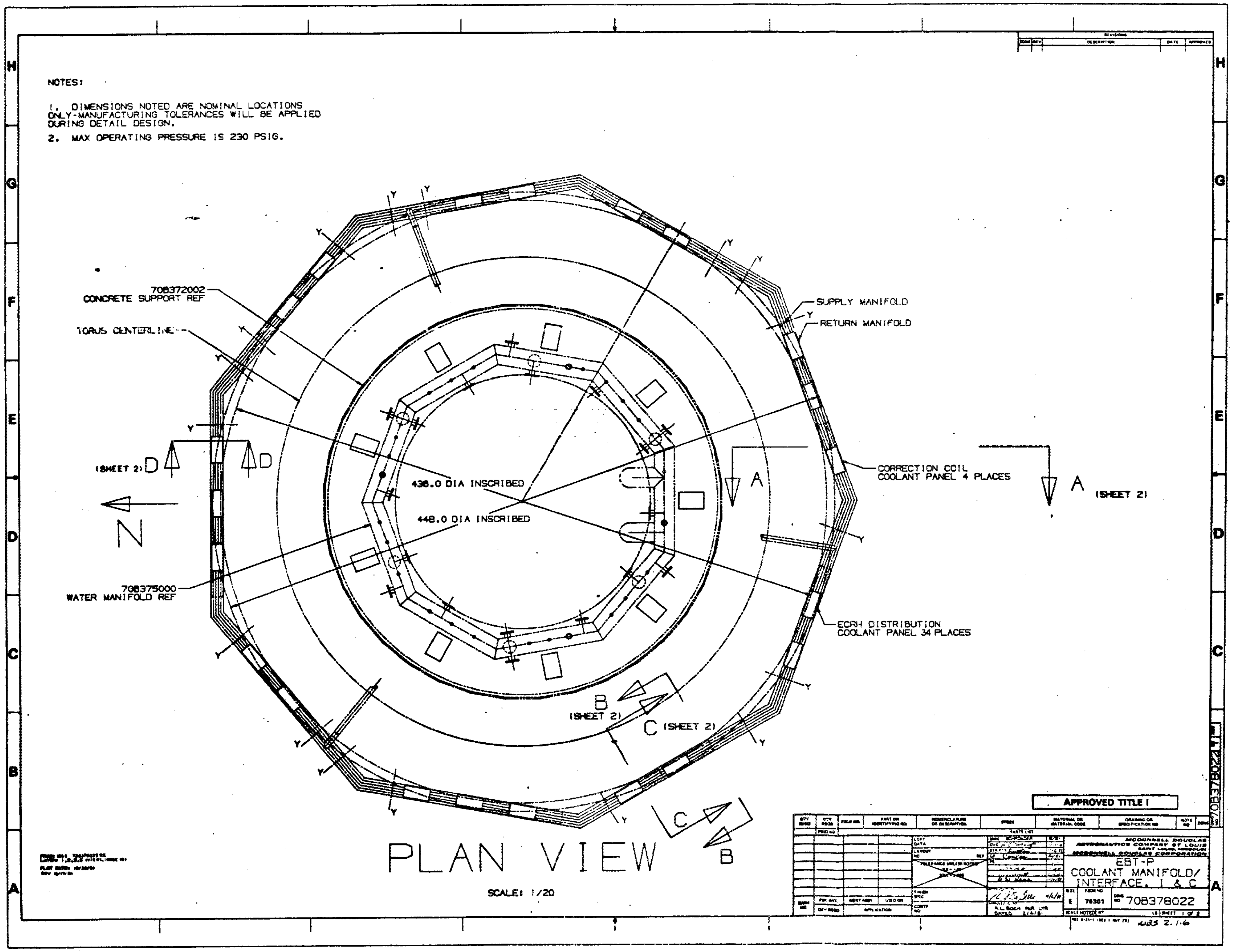

ADDED SHT. 4&5
REVISED SHT. 1
793.00
657.00 REF
642.00
517.88
411.00 REF
630.00 REF
315.00 REF
52.00
45.00
GYROTRON POWER SUPPLY WIRING REF 708371003
8 X 24 WIRETRAY TYP
903.00
852.00
528.00
428.00
300.00 REF
204.00
102.00
41.00 TYP
84.00 TYP
200.59 TYP 4 PLCS
284.00 TYP 4 PLCS
600.00 REF
279.00 TYP 4 PLCS
215.59 TYP 4 PLCS
428.00
137.00
4.00
12.00 R TYP
CONTROL ROOM WALL REF
800.00
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY. MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
NOTES:
APPROVED TITLE !
SCALE: 1/4 INCH = 1 FOOT
PLAN VIEW
LEVEL 1
FILE: 1056 708378021RE
VIEW/IMAGE: 1/3
LAYERS: 1,5,6,15,81
PLOT SCALE: .0208333
PLOT DATE: 10/21/81
EBT-P
WIRETRAY ROUTING
ENVELOPES
708378021
WBS 2.1.6


PLAN VIEW: LEVEL 2
SCALE: 1 INCH = 40 INCHES
6" X 24" WIRETRAY
6" X 12" WIRETRAY
6" X 36" WIRETRAY
CONTROL ROOM WALL REF
6" X 24" VERTICAL WIRETRAY
12" X 12" WIRETRAY
30" X 198" PENETRATION ENVELOPE REF 708374001
6" X 6" WIRETRAY TYP 2 PLCS
6" TALL X 12" WIDE WIRETRAY TYP 2 PLCS
10" TALL X 12" WIDE WIRETRAY
399.00 DIA INSCRIBED CENTERLINE
APPROVED TITLE I
FILE: 1056 708378021RE
VIEW/IMAGE: 1/4
LAYERS: 20,25,70,71
PLOT SCALE: .025
PLOT DATE: 10/21/81
EBT-P
WIRETRAY ROUTING ENVELOPES
708378021
WBS 2.1.6

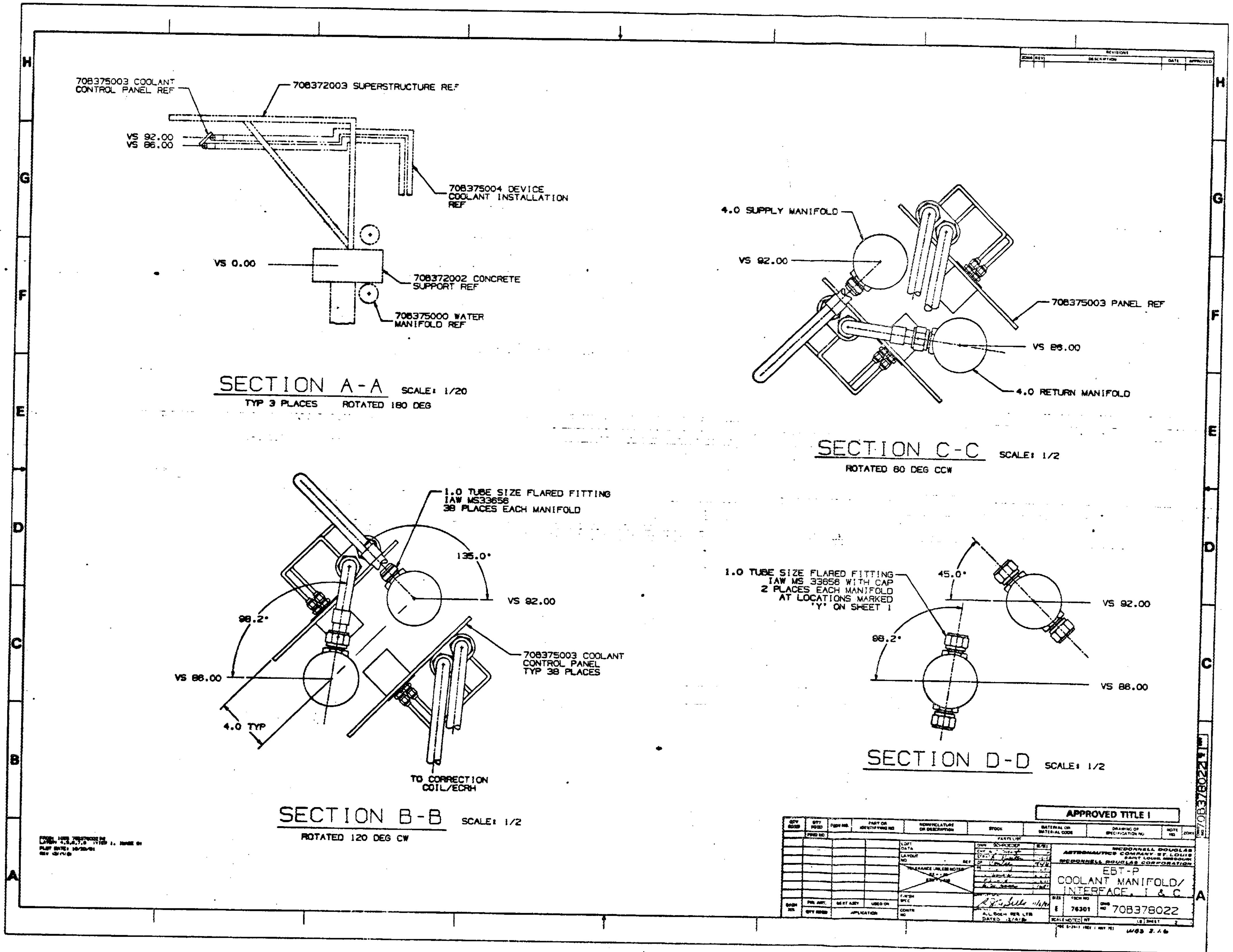

ADDED SHT. 4&5
REVISED SECT. A-A
BALCONY- NORTH WALL REF
PENETRATION ENVELOPE REF 708374001 2 PLACES
SUPERSTRUCTURE-TORUS REF
TORUS REF
ROOF-MECHANICAL BLDG REF
30.00 REF
12.00 REF
6.00 REF
10.00 REF
8.00 REF
6.00 REF
12.00 R TYP
6.00
98.00 REF
132.00 REF
183.25 REF
98.00 REF
205.25
30.00 REF
6.00 REF
161.00
146.50 REF
136.00 REF
114.00 REF
159.00 REF
161.00
146.50 REF
143.50 REF
114.00 REF
180.00 REF
GYROTRON POWER SUPPLY WIRING ENVELOPES REF 708371003
GYROTRON 8 PL REF
GYROTRON POWER SUPPLY WIRING ENVELOPES REF 708371003
SECTION A-A SHT. 2
APPROVED TITLE I
SCALE: 1 INCH = 40 INCHES
FILE: 1058 708378021RE
VIEW/IMAGE: 1/8
LAYERS: 10,50
PLOT SCALE: .025
PLOT DATE: 10/21/81
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
WIRETRAY ROUTING ENVELOPES
76301
708378021
WBS 2.1.6

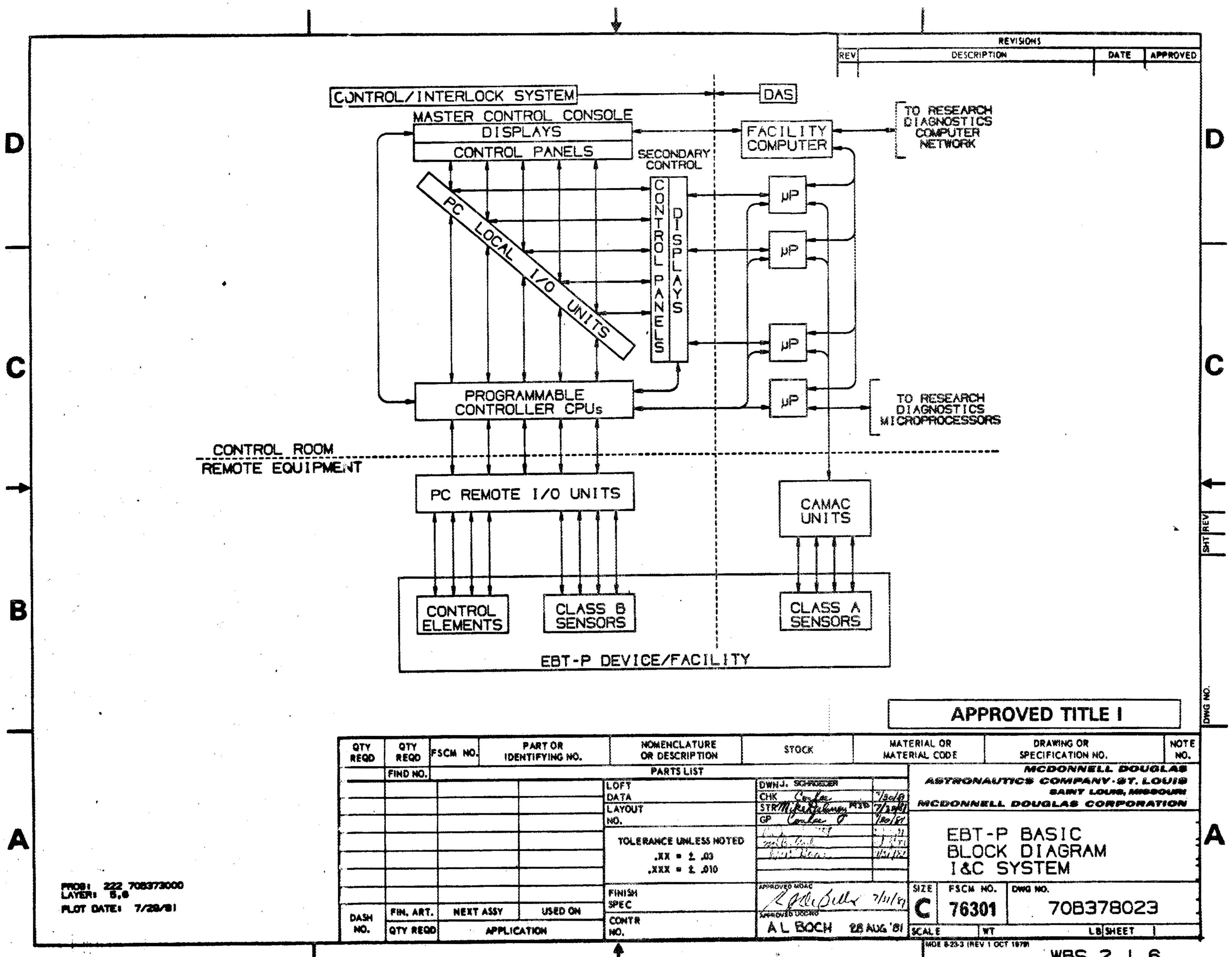

SHT. 4 WITH VIEW B-B ADDED
TORUS BLDG. ROOF
TEST SUPPORT BLDG. ROOF
8" X 24" VERTICAL WIRETRAY
30" X 196" PENETRATION ENVELOPE REF 708374001
SECOND FLOOR WIRETRAY
960.00
528.00 REF
456.00 REF
205.25
30.00 REF
FIRST FLOOR WIRETRAY
SECOND FLOOR
30" X 86" PENETRATION ENVELOPE REF 708374001
183.25 REF
30.00 REF
8" X 24" DIAGNOSTICS WIRETRAY
132.00 REF
114.00
22.00 REF
6.00
180.00 REF
161.00
146.50
140.50
114.00 REF
FIRST FLOOR
12.00 R TYP
159.00 REF
18.43
339.49
TORUS CENTERLINE
FIRST FLOOR WIRETRAY
GYROTRON POWER SUPPLY WIRING ENVELOPES REF 708371003
SECTION B-B SHT. 2
ROTATED 90 DEG. CCW
APPROVED TITLE I
FILE: 1056 708378021RE
VIEW/IMAGE: 1/8
LAYERS: 35,36
PLOT SCALE: .0208333
PLOT DATE: 10/21/81
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
WIRETRAY ROUTING
ENVELOPES
76301
708378021
A.L. BOCH OCT. 9, '81
WBS 2.1.6

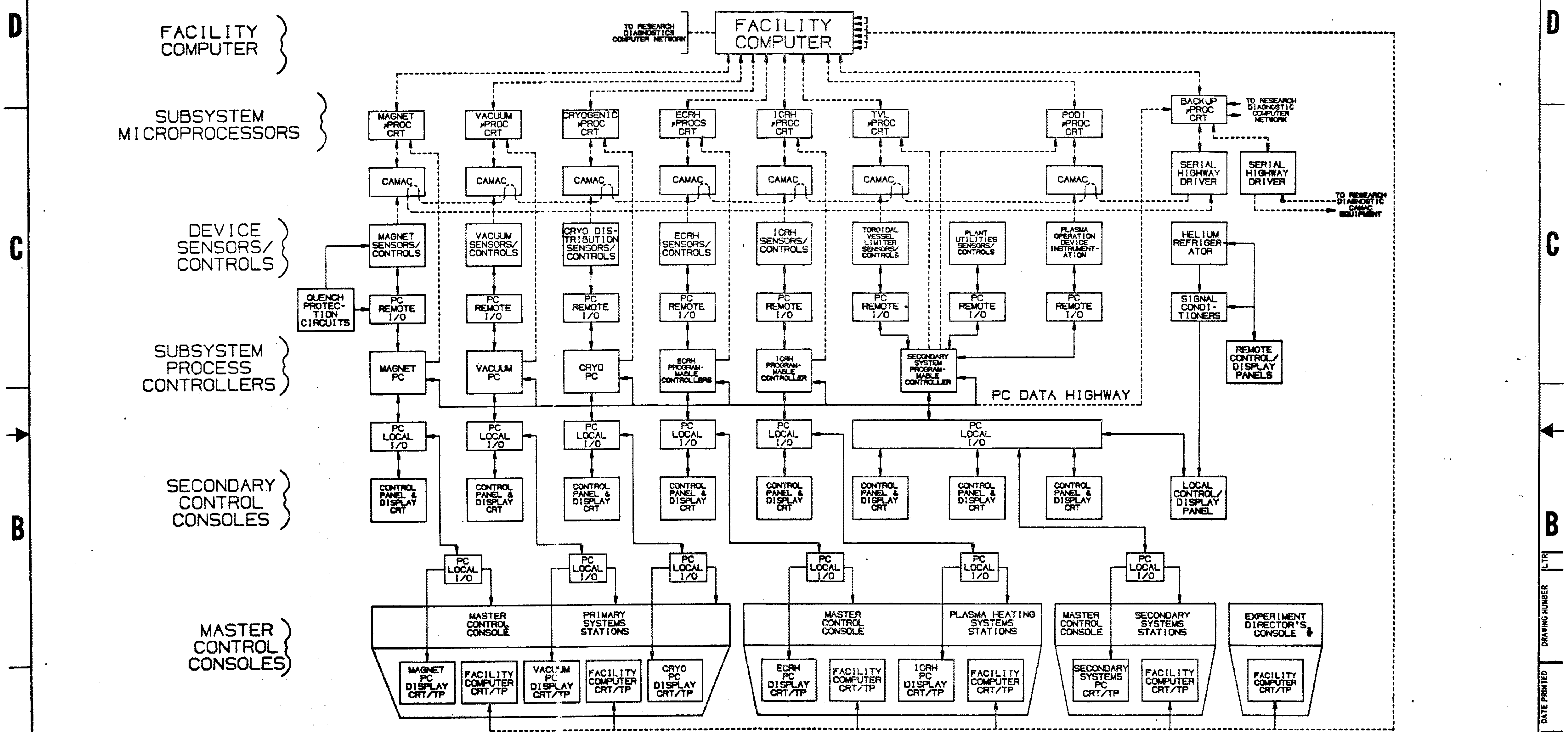

SHT. 5 ADDED WITH REVISED VIEW C-C
6" X 24" VERTICAL WIRETRAY REF
NORTH WALL BALCONY
6" X 24" VERTICAL WIRETRAY
6" X 24" WIRETRAY TO CONTROL ROOM REF 708378012
642.00
315.00 REF
411.00 REF
205.25 REF
132.00 REF
114.00 REF
98.00
456.00 REF
6" X 24" WIRETRAY REF
SECOND FLOOR
MECH. BLDG. ROOF
180.00 REF
161.00 REF
146.50 REF
140.50 REF
21.00 REF
28.93
40.03
180.00 REF
146.50
12.00 R TYP
258.49
18.43
657.00 REF
GYROTRON POWER SUPPLY WIRING ENVELOPES REF 708371003
FIRST FLOOR
SECTION C-C SHT. 2
ROTATED 180 DEG. CW
FILE: 1056 708378021RE
VIEW/IMAGE: 1/7
LAYERS: 51,52
PLOT SCALE: .025
PLOT DATE: 10/21/81
APPROVED TITLE I
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
WIRETRAY ROUTING ENVELOPES
76301
708378021
A.L. BOCH OCT. 5, '81
WBS 2.1.6


NOTES:
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY-MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
2. MAX OPERATING PRESSURE IS 230 PSIG.
708372002
CONCRETE SUPPORT REF
TORUS CENTERLINE
(SHEET 2) D
D
N
708375000
WATER MANIFOLD REF
438.0 DIA INSCRIBED
448.0 DIA INSCRIBED
SUPPLY MANIFOLD
RETURN MANIFOLD
CORRECTION COIL
COOLANT PANEL 4 PLACES
A
A (SHEET 2)
ECRH DISTRIBUTION
COOLANT PANEL 34 PLACES
B
(SHEET 2)
C (SHEET 2)
C
B
PLAN VIEW
SCALE: 1/20
APPROVED TITLE I
PARTS LIST
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P
COOLANT MANIFOLD/
INTERFACE, I & C
SIZE E
76301
DWG NO 708378022
SHEET 1 OF 2
WBS 2.1.6

E-37/E-38


708375003 COOLANT CONTROL PANEL REF
708372003 SUPERSTRUCTURE REF
VS 92.00
VS 86.00
708375004 DEVICE COOLANT INSTALLATION REF
VS 0.00
708372002 CONCRETE SUPPORT REF
708375000 WATER MANIFOLD REF
SECTION A-A SCALE: 1/20
TYP 3 PLACES ROTATED 180 DEG
4.0 SUPPLY MANIFOLD
VS 92.00
708375003 PANEL REF
VS 86.00
4.0 RETURN MANIFOLD
SECTION C-C SCALE: 1/2
ROTATED 60 DEG CCW
1.0 TUBE SIZE FLARED FITTING IAW MS33656 38 PLACES EACH MANIFOLD
135.0°
VS 92.00
98.2°
708375003 COOLANT CONTROL PANEL TYP 38 PLACES
VS 86.00
4.0 TYP
TO CORRECTION COIL/ECRH
SECTION B-B SCALE: 1/2
ROTATED 120 DEG CW
1.0 TUBE SIZE FLARED FITTING IAW MS 33656 WITH CAP 2 PLACES EACH MANIFOLD AT LOCATIONS MARKED 'Y' ON SHEET 1
45.0°
VS 92.00
98.2°
VS 86.00
SECTION D-D SCALE: 1/2
APPROVED TITLE I
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
EBT-P
COOLANT MANIFOLD/
INTERFACE, I & C
76301
708378022


REVISIONS
REV
DESCRIPTION
DATE
APPROVED
CONTROL/INTERLOCK SYSTEM
DAS
MASTER CONTROL CONSOLE
DISPLAYS
CONTROL PANELS
SECONDARY CONTROL
FACILITY COMPUTER
TO RESEARCH DIAGNOSTICS COMPUTER NETWORK
PC LOCAL I/O UNITS
CONTROL PANELS
DISPLAYS
μP
μP
μP
μP
PROGRAMMABLE CONTROLLER CPUs
TO RESEARCH DIAGNOSTICS MICROPROCESSORS
CONTROL ROOM
REMOTE EQUIPMENT
PC REMOTE I/O UNITS
CAMAC UNITS
CONTROL ELEMENTS
CLASS B SENSORS
CLASS A SENSORS
EBT-P DEVICE/FACILITY
APPROVED TITLE I
D
C
B
A
PROB: 222 70B373000
LAYER: 5,6
PLOT DATE: 7/28/81
QTY REQD
QTY REQD
FSCM NO.
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
STOCK
MATERIAL OR MATERIAL CODE
DRAWING OR SPECIFICATION NO.
NOTE NO.
FIND NO.
PARTS LIST
LOFT DATA
LAYOUT NO.
TOLERANCE UNLESS NOTED
.XX = ± .03
.XXX = ± .010
FINISH SPEC
CONTR NO.
DASH NO.
FIN. ART.
NEXT ASSY
USED ON
QTY REQD
APPLICATION
DWN J. SCHROEDER
CHK
STR
GP
APPROVED MDAC
APPROVED USDOE
A L BOCH 28 AUG '81
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P BASIC
BLOCK DIAGRAM
I&C SYSTEM
SIZE C
FSCM NO. 76301
DWG NO. 70B378023
SCALE
WT
LB SHEET
WBS 2.1.6



SOLID LINE = CONTROL/INTERLOCK CHANNEL
DASHED LINE = DATA ACQUISITION/DATA DISPLAY CHANNEL

PROB: 222 708373000
LAYERS: 7,8
PLOT DATE: 7/29/81

QTY REQD	QTY REQD	FSCM NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	STOCK	MATERIAL OR MATERIAL CODE	DRAWING OR SPECIFICATION NO.	NOTE NO.	ZONE
	FIND NO.	PARTS LIST							

LOFT DATA / LAYOUT NO.
TOLERANCE UNLESS NOTED .XX = ± .03 .XXX = ± .010
FINISH SPEC
CONTR NO.
DASH NO. | FIN. ART. | NEXT ASSY | USED ON | QTY REQD | APPLICATION

DWN J. SCHROEDER
CHK
STR
GP
APPROVED MDAC
APPROVED UCC-ND A L BOCH 28 AUG. '81

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION

EBT-P DATA FLOW LOGIC DIAGRAM I&C SYSTEM

SIZE D | FSCM NO. 76301 | 70B378024
SCALE | WT | LB | SHEET 1

WBS 2.1.6

E-43/E-44

APPROVED TITLE I