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FUSION ELMO BUMPY TORUS ENERGY

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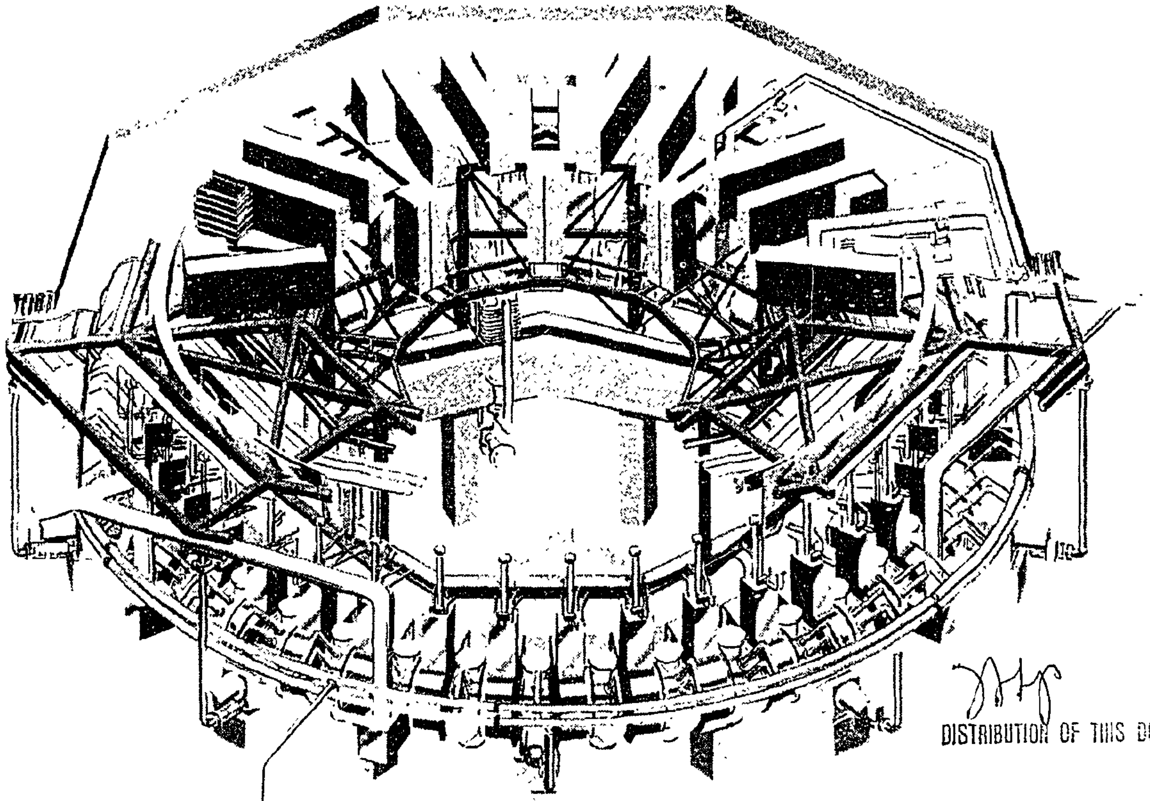
Elmo Bumpy Torus Proof Of Principle

PHASE II — TITLE 1 REPORT

Volume I DEVICE SUMMARY



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PRELIMINARY DESIGN REPORT

EBT-P DEVICE SUMMARY

VOLUME I

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ACRONYMS, ABBREVIATIONS AND SYMBOLS

ARE	Aspect Ratio Enhancement
B	Magnetic Field Strength
BLDG	Building
CAMAC	Computer Automated Measurement and Control
CDR	Critical Design Review
CPU	Central Processing Unit
CRT	Cathode Ray Tube
cw	Continuous Wave
CRYO	Cryogenic
Cy	Calendar year
DAS	Data Acquisition System
DC	Direct Current
DOE	Department of Energy
EBT	Elmo Bumpy Torus
EBT-I	Elmo Bumpy Torus-One
EBT-P	Elmo Bumpy Torus-Proof of Principle
EBT-S	Elmo Bumpy Torus-Scale
ECRH	Electron Cyclotron Resonance Heating
eV	Electron Volt
Fy	Fiscal year
G	Giga, i.e., 10^9
GAI	Gilbert Associates Incorporated
G/C	Gilbert/Commonwealth
GDC	General Dynamics Convair
GFE	Government Furnished Equipment
GHe	Gaseous Helium
GN_2	Gaseous Nitrogen
GPM	Gallons Per Minute
He	Helium
HVAC	Heating Venting and Airconditioning
I&C	Instrumentation and Control

ACRONYMS, ABBREVIATIONS AND SYMBOLS (Continued)

ICRH	Ion Cyclotron Resonance Heating
IDR	Interim Design Review
I/O	Input/Output
k	Kilo, i.e., 10^3
ℓ	Liter
LHe	Liquid Helium
m	Milli, i.e., 10^{-3}
M	Mega, i.e., 10^6
MC	Mirror Coil
MCC	Master Control Console
MDAC	McDonnell Douglas Astronautics Company
MDC	McDonnell Douglas Corporation
MLI	Multilayer Insulation
n	Density
ORNL	Oak Ridge National Laboratory
PACE	Plant and Capital Equipment
PC	Programmable Controller
PDP	Programmed Data Processor
PDR	Preliminary Design Review
RF	Radio Frequency
SCC	Secondary Control Console
SCFM	Standard Cubic Feet Per Minute
T	Tesla
T_e	Electron Temperature
T_i	Ion Temperature
torr	Pressure of 1 mm mercury
Y-12	ORNL Fusion Facility Location at Oak Ridge

Greek

β_c	Core beta
τ_{Ee}	Electron Energy confinement time

1.0 SUMMARY

The Elmo Bumpy Torus (EBT) concept is one of the leading approaches to the development of energy using magnetic fusion. The EBT concept was originally developed in the early 1970's at Oak Ridge National Laboratory (ORNL) where concept feasibility was demonstrated in the EBT-Initial (EBT-I) experiments and later on an upgraded version of this device known as EBT-Scale (EBT-S). The favorable results from the EBT-I/S experiments complemented by positive theoretical physics predictions led to the decision in 1978 by the Department of Energy to proceed with the Elmo Bumpy Torus – Proof-of-Principle (EBT-P) experiment. McDonnell Douglas Astronautics Company (MDAC) won the competitive bid to design and build the EBT-P device at the Oak Ridge Valley Industrial Park. The project began in October 1980, with completion scheduled for May 1985.

This document presents a summary of the EBT-P Preliminary Design (Title I) effort. The work was performed, under the direction of ORNL, for the Department of Energy by MDAC-St. Louis. Major subcontractors assisting MDAC included General Dynamics for the magnet system, Gilbert Associates for the device utilities and facility architecture and engineering, and Lockheed - Oak Ridge for engineering support services. The Title I period of performance was from 1 October 1980 to 1 March 1982.

An isometric view of the EBT-P device that evolved from the Title I effort is shown in Figure 1-1. EBT-P is a 4.5 m major radius toroidal device, consisting of 36 sectors. Each sector consists of a mirror cavity, vacuum liner and a superconducting mirror coil. A steady-state hydrogen plasma is confined by the magnetic field generated by the 36 mirror coils each having a 17 cm throat radius. Each mirror coil consists of a liquid-helium-cooled NbTi winding enclosed in a stainless steel dewar. Stabilization and heating of the plasma are provided by the injection of microwave power at 28 GHz and 60 GHz. Four 60-GHz and two 28-GHz gyrotrons, 200 kW (cw) output power each, provide the microwave heating for start-up. After initial operation, the device power will be increased with the addition of one megawatt of 20-90 MHz Ion Cyclotron Resonance Heating (ICRH) and 400 kW of 60 GHz power to achieve proof-of-principle plasma parameters levels within 3 years. Primary pumping of the toroidal vessel is accomplished through the use of five 3500-liter/sec turbomolecular pumps which are shielded from scattered microwave power by attenuation shields. The entire device is surrounded by an eight foot thick bi-level concrete

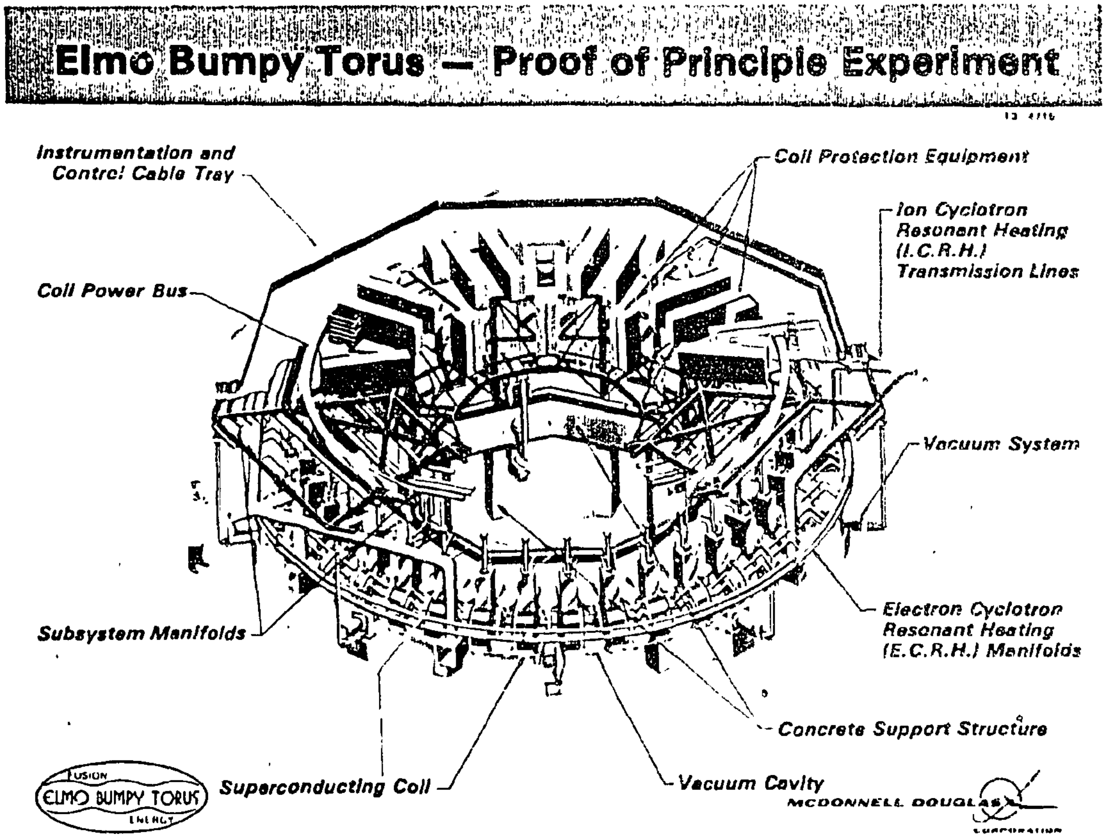

Elmo Bumpy Torus — Proof of Principle Experiment
Instrumentation and Control Cable Tray
Coil Protection Equipment
Ion Cyclotron Resonant Heating (I.C.R.H.) Transmission Lines
Coil Power Bus
Vacuum System
Electron Cyclotron Resonant Heating (E.C.R.H.) Manifolds
Subsystem Manifolds
Concrete Support Structure
Superconducting Coil
Vacuum Cavity
ELMO BUMPY TORUS
MCDONNELL DOUGLAS

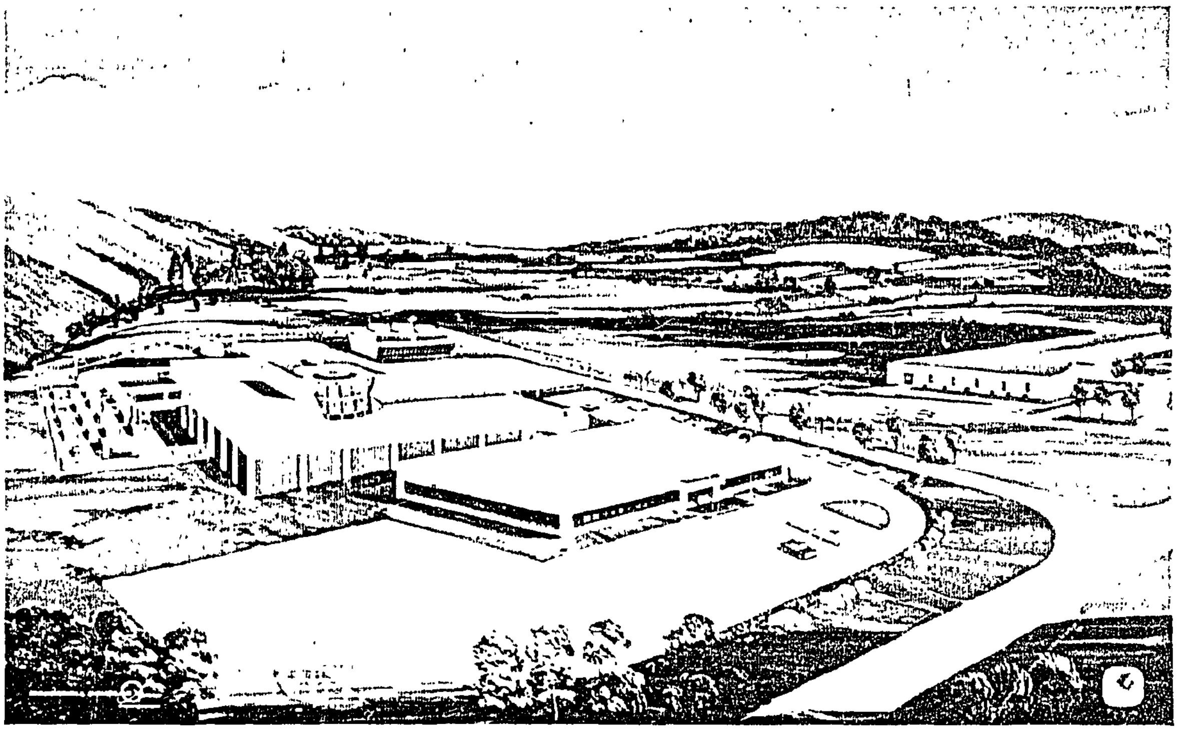
FIGURE 1–1

enclosure designed to limit radiation outside the enclosure to 0.25 mrem/hr in uncontrolled areas. A cyrogenic system is provided to store, supply, and distribute liquid nitrogen and liquid helium required for device operation.

The eight major systems of the device are the toroidal vessel, magnets, microwave, vacuum pumping, instrumentation and control, cryogenics, device utilities, and support structures. Preliminary Design Reviews (PDR's) were held for each of the eight device systems, and individual system design reports were prepared by MDAC and approved by ORNL. Volumes II through IX of this report describe these systems in detail. Only two systems, the toroidal vessel and the vacuum pumping system, underwent significant changes from the original baseline design during Title I. The toroidal vessel was changed from an elastomer seal/aluminum vessel design to a metal seal/stainless steel vessel design, and the vacuum pumping system was changed from a cryosorption pump system to a turbomolecular pump system. Both of these concept changes primarily resulted from the effect on seals of the harsh x-ray radiation environment.

The EBT-P facility, Figure 1-2, will be built with McDonnell Douglas funds on an eleven acre site at the Oak Ridge Valley Industrial Park, Oak Ridge, Tennessee. The property, which is owned by McDonnell Douglas Corporation, is 1.5 miles from the ORNL fusion research facilities within the Y-12 Plant and is accessible via existing roads. The major structures in the EBT-P site are the Administration Building, the Test Support Building, the Mechanical Equipment Building, the Power Supply Pad, and the Cooling Tower.

Major activities performed during the Title I period included an expanded definition of the design criteria, design analyses and trade studies, design drawings and accommodation of inputs from the complementary concurrent development program. The preliminary design effort also included the preparation of the following plans: Management, Configuration Control, Quality Assurance, Safety Analysis, Manufacturing and Procurement. The preliminary design task is now complete, and work has begun on the detailed design (Title II) of the device.



ELMO BUMPY TORUS FUSION FACILITY

FIGURE 1-2

2.0 INTRODUCTION

Recent Department of Energy (DOE) policy on the development of fusion energy places increased emphasis on the testing of alternate concepts to permit comparisons with tokamaks and mirrors in the mid-1980's. The EBT concept was selected in December 1978 from among nine competing concepts by a DOE-convened panel of senior scientists and engineers. The EBT concept was the only one deemed programmatically and technically ready for acceleration to the proof-of-principle phase. Positive physics results both from theory and the EBT-I experiment at ORNL and the potential reactor advantages provided the basis for the selection of the EBT concept. Since 1978, the Elmo Bumpy Torus-Scale (EBT-S) experiment, a modification of EBT-I, at ORNL has provided further confirmation of the EBT scaling laws and greatly increased confidence in the feasibility of achieving a power reactor based on this concept.

The mission need for EBT-P was established in September 1978, by DOE/ER-0018 "The Department of Energy Policy for Fusion Energy." This policy statement expresses the DOE plans for fusion energy including the investigation of promising fusion confinement concepts to determine their viability by conducting appropriate physics experiments, first at the proof-of-principle level and then in a major scaling experiment. The statement also specifically calls for a proof-of-principle test of one or more concepts which are alternatives to the mainline tokamak and mirror approaches.

Currently in the magentic fusion program EBT-P is the only proof-of-principle experiment underway. There are also two major scaling experiments under construction: one based upon a closed magnetic geometry, the tokamak, and the other based upon an open magnetic geometry, the tandem mirror.

EBT-P represents a significant step forward with respect to scaling and is the device which will give definitive resolutions to several physics issues related to the concept. EBT-P is expected to have most of the important dimensionless plasma parameters near the values required for a reactor. EBT-P can also be a key step in assessing the overall reactor potential of fusion energy since it combines some of the best features of mirrors and tokamaks with its own unique advantages; such as continuous operation and ease of accessibility because of its large aspect ratio.

2.1 PURPOSE AND OBJECTIVES

The goal of the EBT-P project is the successful design, procurement, fabrication, and operation of an EBT-type device designed to advance the EBT magnetic confinement fusion concept to the proof-of-principle level. The general objectives of the EBT program and specifically the EBT-P project are to:

- Extend plasma parameters into the reactor range and determine the validity of previously developed scaling laws for the parameter regime characteristic of EBT-P plasmas.
- Determine if core plasmas of intermediate values of beta (plasma pressure/magnetic pressure) can be confined in a stable fashion.
- Provide significant advances in the following technology areas which would also be of benefit to the fusion program in general:
  - High current density superconducting magnets of intermediate size.
  - High power, high frequency gyrotrons and their accompanying microwave transmission systems.

The EBT-P objectives in terms of quantitative physics parameters are presented in Table 2-1. The quantitative physics objectives for EBT-P are as follows:

- Attain reasonably pure hydrogen plasma conditions at around 1 kilo-electron volt ion temperature and approximately $10^{13}/cm^3$ plasma density, and provide stable confinement with the product of density and energy confinement time near 10^{12} $cm^{-3}s$, under steady state conditions.

TABLE 2–1 EBT-P PHYSICS PARAMETERS

13–4979A

PARAMETER (1)	EBT-P BASELINE (2)	
	START-UP	PROOF-OF-PRINCIPLE
N	36	36
R(m)	4.5	4.5
B_{RES}(T)	2.1	2.1
n (cm^{-3})	1.0×10^{13}	1.5×10^{13}
T_e(keV)	2.0	5.0
T_i(keV)	0.4	2.5
CORE β (%)	1.5	5.0
τ_E (ms)	30	60
$n\tau_E$ (cm^{-3} s)	3×10^{11}	10^{12}
P_{ECRH} (MW)	0.8 @ 60 GHz 0.4 @ 28 GHz	1.2 @ 60 GHz 0.4 @ 28 GHz
P_{ICRH} (MW)	0	1.0

(1) ALL DENSITIES AND TEMPERATURES ARE NOMINAL VALUES WITH A NOMINAL 30% UNCERTAINTY.

(2) THESE BASELINE PLASMA PARAMETERS ARE AT LEVEL CONSISTENT WITH ADDRESSING ONLY THE PROOF-OF-PRINCIPLE PHYSICS ISSUES.

13–4987B

N — NUMBER OF MIRROR COILS

R — TORUS MAJOR RADIUS

B_{RES} — MAGNETIC FIELD STRENGTH AT RESONANCE

n — PARTICLE DENSITY

T_e — ELECTRON TEMPERATURE

T_i — ION TEMPERATURE

CORE β — RATIO OF CORE PLASMA PRESSURE AT THE MIDPLANE IN THE CENTER OF TORUS TO THE MAGNETIC PRESSURE AT THE RINGS

τ_E — ELECTRON ENERGY CONFINEMENT TIME

$n\tau_E$ — DENSITY-CONFINEMENT TIME PRODUCT

P_{ECRH} — ELECTRON CYCLOTRON RESONANCE HEATING POWER

P_{ICRH} — ION CYCLOTRON RESONANCE HEATING POWER

- Provide microwave and auxiliary ion heating systems capable of attaining core plasma betas in the 5 percent range.

- Provide superconducting magnets capable of producing magnetic fields of at least 2.2 telsa on axis at the cavity mid-plane.

- Provide a microwave heating system capable of creating the relativistic electron rings needed for plasma stability and having temperatures in the range of 1.0 MeV.

- Provide the capability for future upgrades to study methods of particle control, effects of modifications in the magnetic geometry and various microwave injection approaches.

- Provide the requisite diagnostics to determine the behavior of the plasma during operation.

None of the above objectives can be realized with the existing experiment, EBT-S, primarily due to its limited size and magnetic field and the restrictions these physical limitations place on achievable plasma parameters. It is specifically due to these limitations and the encouraging data from EBT-S that the decision was made to construct EBT-P. The EBT-P device will be a factor of three larger than EBT-S in major radius and over a factor of two larger in resonant magnetic field.

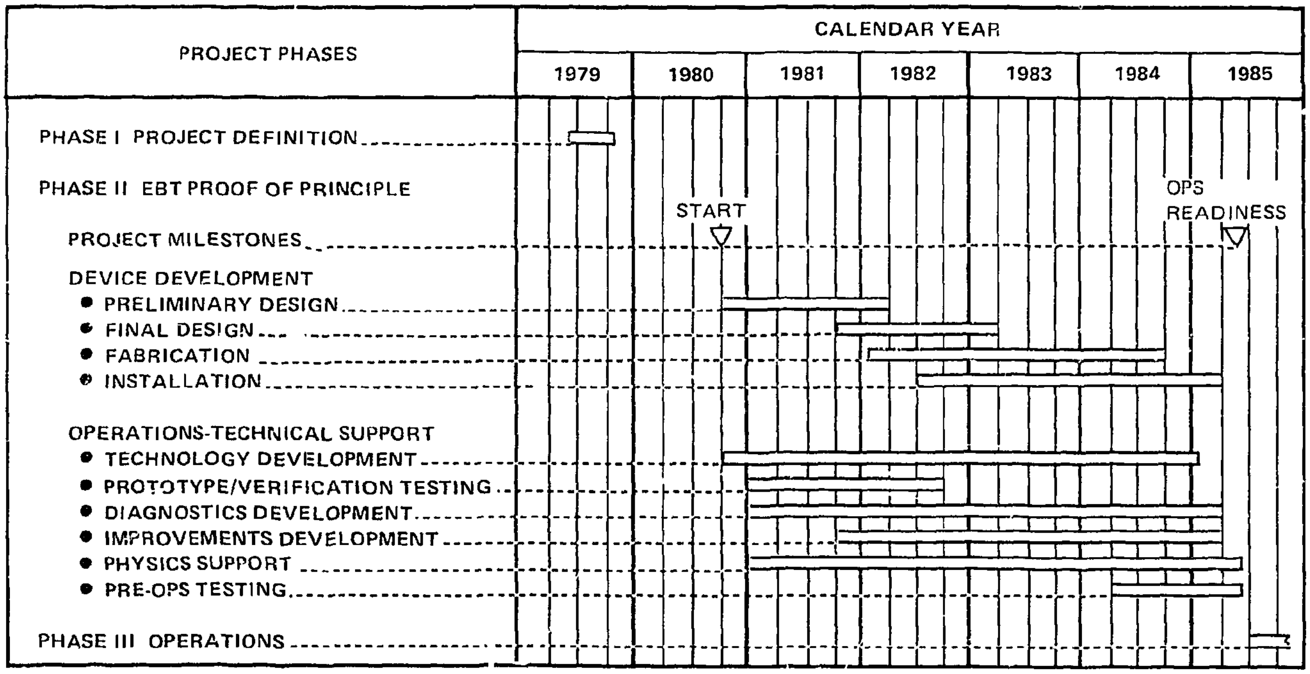
2.2 PROJECT BACKGROUND

The EBT-P project is being conducted in three phases:

I - Project definition (completed);
II - Design, fabrication, and installation (in progress); and
III - Operations.

An overview schedule of these phases is given in Figure 2-1.

EBT-P PROJECT OVERVIEW SCHEDULE



13–4958B

FIGURE 2–1

2.2.1 Phase I - Phase I project definition studies were completed in October 1979. Four industrial teams were selected from among several organizatioins to conduct project definition studies. These teams were Ebasco Services, Inc.; Grumman Aerospace Corporation; McDonnell Douglas Astronautics Company; and Westinghouse Electric Corporation. Each team was awarded a subcontract to perform a four-month project definition study including a proposed reference design. Concurrently, ORNL conducted a similar study. Following completion of the project definition studies, extensive discussions were held among the subcontractors, ORNL, and DOE to identify agreed-on physics and technology constraints and to establish goals for the project consistent with schedule and budget requirements.

Using the information derived from the project definition studies and from the subsequent discussions, ORNL prepared a proposed reference design for EBT-P. Following extensive review by DOE, including review by an EBT-P panel which convened in early 1980 to evaluate the proposed reference design and reassess the EBT program, approval was obtained to continue the project into Phase II.

2.2.2 Phase II - In April 1980 ORNL released the Phase II requests for proposals (RFP) to the four candidate industrial participants. The RFP specified the design criteria and also requested the use of the approved reference design as a guideline in preparing the proposals. Each industrial participant was requested to submit a proposal for the government-owned ORNL site (Building 9201-2) and was allowed to submit proposals for one or more alternate sites. The proposals were received by ORNL in May 1980 and evaluated according to criteria outlined in the RFP. ORNL selected the best proposal for the ORNL site and the best proposal for an alternate site and forwarded these recommendations to DOE headquarters in August 1980. DOE made the site selection, choosing the site it considered to be the most advantageous for the EBT-P program and for the fusion program. In September 1980 McDonnell Douglas Astronautics Company, St. Louis, Missouri, was selected as the EBT-P Phase II Contractor for design and construction of EBT-P in the Oak Ridge Valley Industrial Park. In October 1980 McDonnell Douglas was awarded a letter subcontract to begin Title I preliminary engineering design, and Phase II of the EBT-P project was officially begun.

In late 1980 the initial project baseline definition was completed based on a total estimated cost of $86 million with April 30, 1985 as the target completion date for Phase II.

2.2.3 Phase III - EBT-P Phase III experimental operations are scheduled to start 1 May 1985. During Phase II, a Scientific Program Plan will be prepared that describes the ule of experiments that will be conducted in Phase III. EBT-P is being designed for n-year operational life.

The primary objective of the experimental program is to resolve the outstanding physics issues of EBT confinement. The first year of operation will be carried out with 1.2 MW ECRH power only and will concentrate on studying the scaling of electron heated plasmas, in particular hot electron rings, from EBT-S to EBT-P. In effect, the aim of the first year experiments is to verify that the EBT concept has scaled to EBT-P conditions.

At the end of the first year of operation, 0.4 MW of ECRH power and 1 MW of ICRH power will be added to the device. This added heating power is required to achieve proof-of-principle levels to determine ion energy transport, ring power balance and stability of the core plasma at finite beta ($\approx 5\%$). This series of experiments is expected to take about two years.

Plans for further experiments and upgrades of the device will be based on the results of the proof-of-principle experiments. It is expected that further experiments will include operation at the full design magnetic field with ECRH heating at 90 GHz.

3.0 TITLE I DESIGN OVERVIEW

This section presents a brief summary of the EBT-P design as developed during the Title I preliminary design phase. A brief discussion of the major design criteria and a description of the device is included. The detail information on the design as well as the rationale and analysis supporting the baseline system are presented in the Title I system reports (References 1 through 8).

3.1 DESIGN CRITERIA

Design of the EBT-P device is based on the overall device criteria listed below. The specific criteria for each EBT-P system were established during Title I based on the better definition provided by the Title I design effort. A reference "EBT-P Design Criteria" document was prepared during Title I (Reference 9). The overall device criteria are as follows:

Overall Device Criteria

1. EBT-P shall be a steady-state device, capable of 16-hours continuous operation in a 24-hour period with a hydrogen plasma.
2. The superconducting mirror coils shall initially provide a maximum field on axis at the coil throat of 3.2 Tesla (T) with a mirror ratio of 2.2 at 60 GHz. Mirror coil design shall also be capable of providing 4.8 T for operation at 90 GHz.
3. The major radius of the device shall be 4.5 meters with a minimum throat diameter (diameter of vacuum surface in the coil throat) of 34 cm.
4. The mirror coil/x-ray shield/toroidal vessel integrated design shall clear the 16.0 cm flux line.
5. An ECRH system shall be initially provided to supply 1200 kW (cw) of microwave power at 60 GHz and 400 kW (cw) at 28 GHz measured at the output of the tube.
6. An ICRH system transmitter and power supply of 1 MW (measured at the output of the transmitter) shall be provided at a fixed center frequency within the range of 20-90 MHz.
7. An ECRH-compatible vacuum system shall be provided for initial torus evacuation, impurity removal from surface outgassing during operation, and hydrogen pumping to maintain pressure control. Base pressure shall not exceed 2 x 10^{-7} torr.

8. The cumulative error field Δ B/B, with all coils energized shall not exceed 1 x 10^{-4} averaged around the torus along the minor axis. Global field error correction coils shall be capable of creating an applied Δ B/B, of 1 x 10^{-3} on the minor axis at any angle in a vertical plane.
9. Design of the facility shall incorporate features which ensure that radiation levels do not exceed 2.5 mrem/hr at the shield wall outer surface in controlled areas and 0.25 mrem/hr in non-controlled areas.

3.2 OVERALL DEVICE FEATURES

An overview of the general arrangement of EBT-P is illustrated in Figure 1-1. The EBT-P device is a toroidal magnetic fusion device with a 4.5 meter radius and 36 sectors. Additional key design parameters are listed in Table 3-1. Each sector is comprised of a mirror cavity, coil vacuum liner and a superconducting mirror coil. The toroidal vessel is comprised of alternating mirror cavity and coil vacuum liner sectors. Four actively cooled, replaceable limiters are positioned in each mirror cavity to intercept scattered electrons and Bremsstrahlung and thus prevent excessive heating and erosion of the toroidal vessel walls.

Table 3-1. Critical Baseline Design Parameters

Toroidal Vessel	
Number of Sectors	36
Major Diameter	9.0 m
Clear Bore Diameter	34 cm
Magnets	
Number of Magnets	36
Peak Field On Coil	5.1 T
Cumulative Error Field, Δ B/B	$<1 \times 10^{-4}$
Correction Coil Capability, Δ B/B	1×10^{-3}
Plasma Heating (Proof-of-Principle)	
28 GHz ECRH	0.4 MW
60 GHz ECRH	1.2 MW
20-90 MHz ICRH	1.0 MW
Torus Vacuum	
Pumping Speed ℓ/Sec (Hydrogen)	10,000 ℓ/sec
Base Pressure	2×10^{-7} torr
Operating Pressure	1×10^{-4} To 1×10^{-6} torr

The steady-state plasma is confined by the magnetic field generated by the liquid helium-cooled NbTi superconducting coils, each contained in a separate vacuum dewar. A shield is provided at the throat and sides of each coil to protect it from x-ray radiation. Power is supplied to the series connected mirror coils from a high current d.c. power supply through helium-vapor-cooled leads.

Stabilization and heating of the plasma are achieved by the injection of 0.4 MW of microwave power at 28 GHz and 1.2 MW of microwave power at 60 GHz into the toroidal vessel. Microwave power is transmitted from the gyrotrons to the toroidal vessel via an overmoded, segmented manifold system having symmetrical connections to each mirror cavity.

Primary pumping of the toroidal vacuum vessel is accomplished by the use of five turbomolecular pumps. A roughing system is utilized for initial pumpdown of the vacuum vessel, coil dewars, and to provide foreline pumping for the turbomolecular pumps. Primary pumping of the coil vacuum dewars is accomplished with four turbomolecular pumps that are manifolded to serve all 36 mirror coil dewars. The torus pumping system will be shielded from microwave power by a water cooled, perforated copper plate in each pumping port.

The entire torus and magnet structure is cantilevered from a structural concrete "bucking" ring which is designed to restrain the magnetic and dead-weight loading of the torus. A superstructure is provided above the device to serve as a platform for mounting mirror coil electrical components and as a mount for cryogenic and vacuum manifolds, waveguides, and other ancillary equipment.

Liquid helium and nitrogen are supplied to the device for cooling the superconducting mirror coils and gyrotron magnets. The closed-loop liquid helium system delivers saturated liquid helium from the refrigeration/liquefaction equipment to the device use points via a vacuum jacketed, superinsulated distribution system. The open-loop liquid nitrogen system supplies liquid nitrogen from a storage dewar to the device use point at which the spent nitrogen is vented to the atmosphere.

The semi-automatic Instrumentation and Control (I & C) system provides for the sequential and orderly startup and operation of the device and furnishes the proper data to verify device operation. The I & C system includes data acquisition, device system instrumentation, and safety instrumentation.

The EBT-P device will be housed in a bi-level concrete enclosure which provides adequate x-ray shielding to attenuate the radiation levels to safe limits. Personnel access into the enclosure is through appropriately mazed entrances on two sides of the enclosure. The upper level of the enclosure houses the device with its support structure and overhead superstructure for ancillary equipment. The lower level contains mainly the microwave generating and support equipment.

3.3 MAJOR SYSTEMS DESCRIPTION

The EBT-P device is comprised of the following systems:

- Toroidal Vessel
- Magnet System
- Microwave System
- Vacuum Pumping System
- Instrumentation and Control
- Cryogenic System
- Device Utilities
- Support Structure

A brief description of each system is presented in subsequent paragraphs.

Toroidal Vessel - The major components of the toroidal vessel assembly are the mirror cavities, coil vacuum liners, seals, and limiters. The key design features of the toroidal vessel are illustrated in Figures 3-1 and 3-2. Each sector consists of a mirror cavity and a vacuum liner. The vacuum liner extends through the coil bore and is nonintegral with the mirror coil dewar. The liner has sufficient clearance to accommodate independent magnet alignment, fabrication tolerances, and liner thermal distortion without generating loads on the coil dewar wall. Thermal expansion of the torus is accommodated by radially restrain-

EBT-P PLASMA CAVITY AND VACUUM LINER

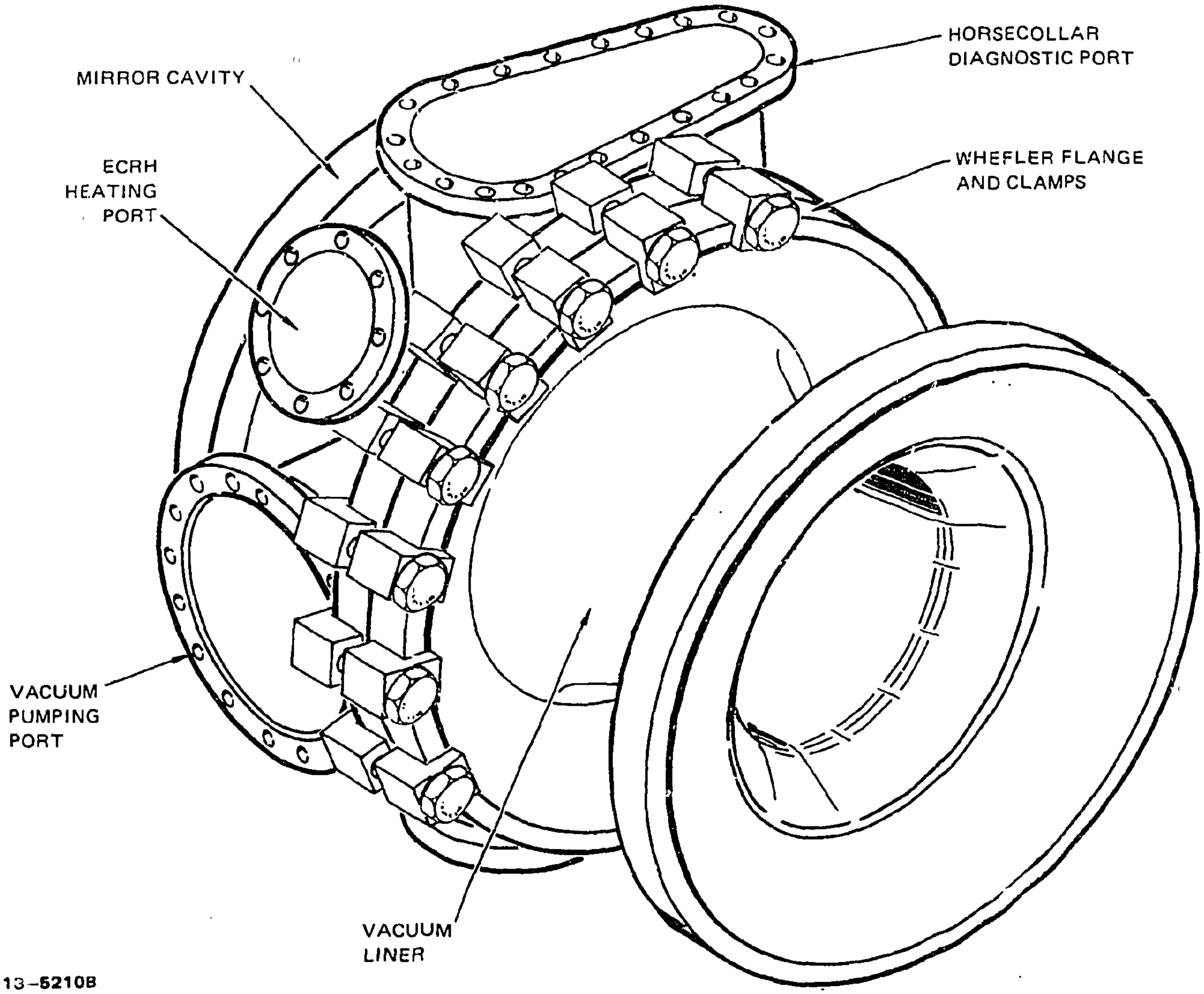


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FIGURE 3–1

TOROIDAL VESSEL ASSEMBLY

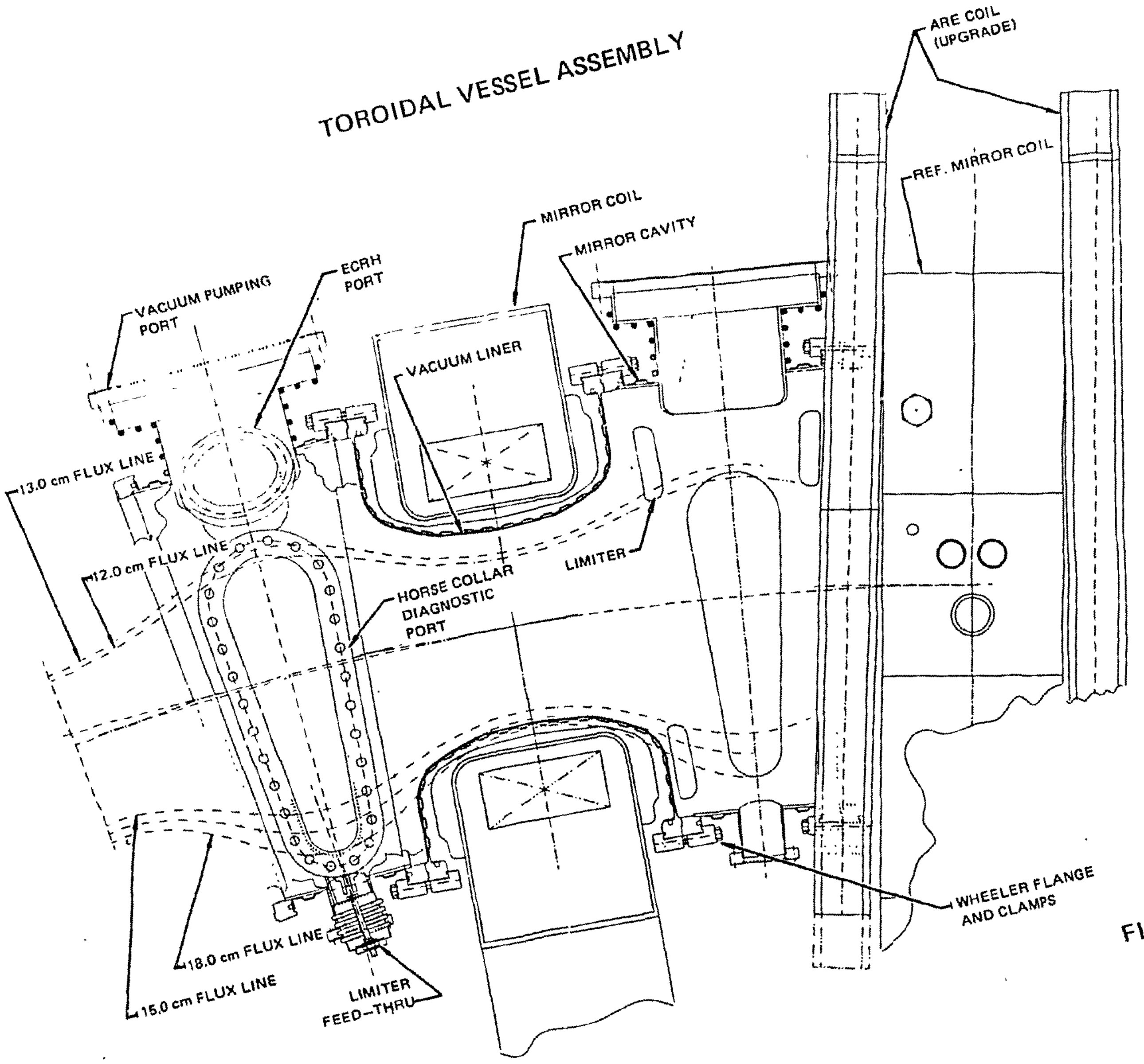

FIGURE 3–2

13–4953A

ing the torus to the structural bucking ring, via a system of support struts, and allowing the torus to "collapse on itself" by deflecting the thin sidewalls of the vacuum liner.

The toroidal vessel provides a number of ports for diagnostic view of the plasma, vacuum pumping ports, feed through ports for the ECRH waveguides, ion gage ports and limiter feed-throughs for cooling and supporting the limiters. The mirror cavity port arrangement is shown in Figure 3-2. Two large "horsecollar" ports are provided on the vertical centerline of each mirror cavity to allow viewing across the plasma diameter for diagnostic purposes. The horsecollar ports provide flexibility for accommodating any plasma diagnostic currently anticipated.

Four actively-cooled limiters are positioned in each mirror cavity to intercept scattered electrons and Bremsstrahlung and prevent the vessel walls from excessive heating and erosion. The limiters are fabricated from aluminum with a copper liner and are designed for replacement through the horsecollar ports without the necessity of disassembly of the toroidal vessel. The limiters on the inboard side of the plasma are adjustable to provide uniform heat loading on all sectors. The vacuum liner is contoured to match the limiting flux line geometry created by the limiter.

The choice of the proper vacuum seal and the vessel wall material was a key issue that was resolved through a major trade study during Title I. The seals must maintain a vacuum of 2×10^{-7} torr or less while exposed to an operating environment comprised of x-rays, microwaves, elevated temperatures, and thousands of thermal cycles over the ten-year life span of the device. The vacuum vessel has 540 primary seals of different size and shape. Metal seals were chosen to improve maintainability because of the inability of elastometric seals to withstand the intense x-ray environment (10^9 rads) for extended periods. In particular, Wheeler flanges were chosen for the large cavity seals and Conflat and Helicoflex seals for the ports.

Stainless steel was chosen as the vacuum vessel material because practically all previous experience with metal seal systems has been with stainless steel vessels. The particular vacuum vessel design chosen is a corrugated structure in which the corrugations act as the coolant passages. Structures of this type have been proven as successful structural cooling concepts and are commercially available from specialty companies. Extensive thermal/mechanical analysis of this design verified that adequate cooling of the vessel can be achieved by minimizing the spacing between corrugations. An additional advantage of the corrugated stainless steel design is the thinner cooling cross section, relative to an aluminum skin and tube concept. This results in an increase in the vacuum liner throat diameter and, therefore, an increase in the passing particle fraction.

Magnet System - The EBT-P magnet system consists of the mirror coil and vacuum dewar assemblies, x-ray shields, and the power supply and protection system. The design variables for the EBT-P mirror coil are closely related to the required physics parameters of the device. The input parameters of plasma radius, number of sectors, coil width, annulus field, coil winding to flux line distance, passing particle fraction, and coil length-to-width ratio determine the mirror coil parameters. The critical mirror coil parameters are tabulated in Table 3-2. Figures 3-3 and 3-4 depict the key features of the magnet assembly.

The coil winding cross section is rectangular, 21.1 cm wide and 10 cm thick. The coils are cooled to 4.2 K by a liquid helium pool-boiling bath. The coils are capable of upgrade operation at field levels compatible with 90 GHz ECRH bulk heating frequency, with a maximum field of 7.4 Tesla on the coil.

Table 3-2. Mirror Coil Design Parameters

Parameter	Initial (60 GHz)	Up-Grade (90 GHz)
Mean Coil Radius	29.0 cm	29.0 cm
Mirror Ratio	2.2:1	2.2:1
Torus Major Radius	4.5 m	4.5 m
Midplane Field On Axis	1.5 T	2.2 T
Throat Field On Axis	3.2 T	4.8 T
Peak Field On Coil	4.9 T	7.4 T
Coil Current Density	6,667 A/cm^2	10,000 A/cm^2

MAGNET ASSEMBLY FEATURES

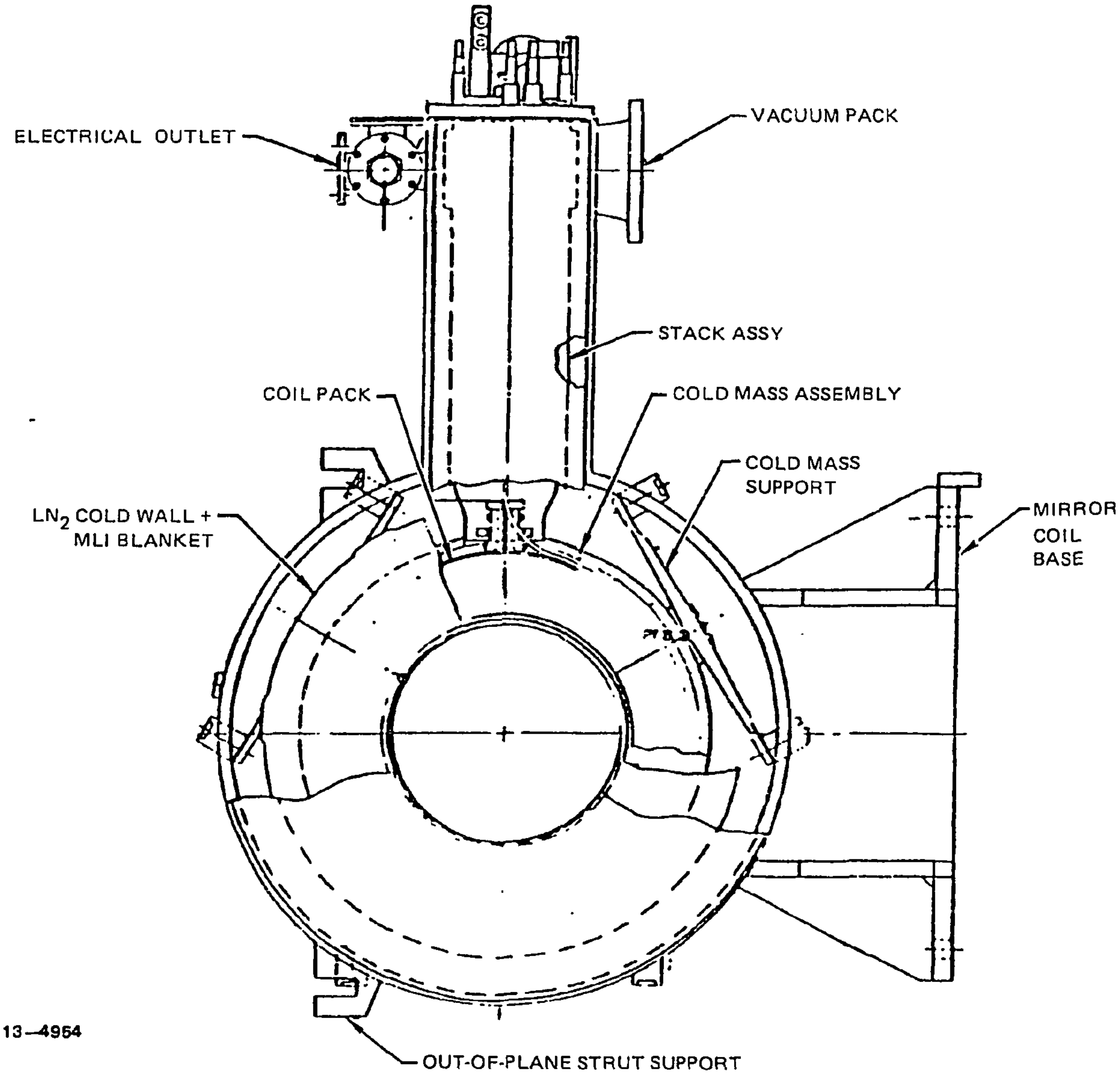

FIGURE 3–3

MAGNET EXPLODED VIEW

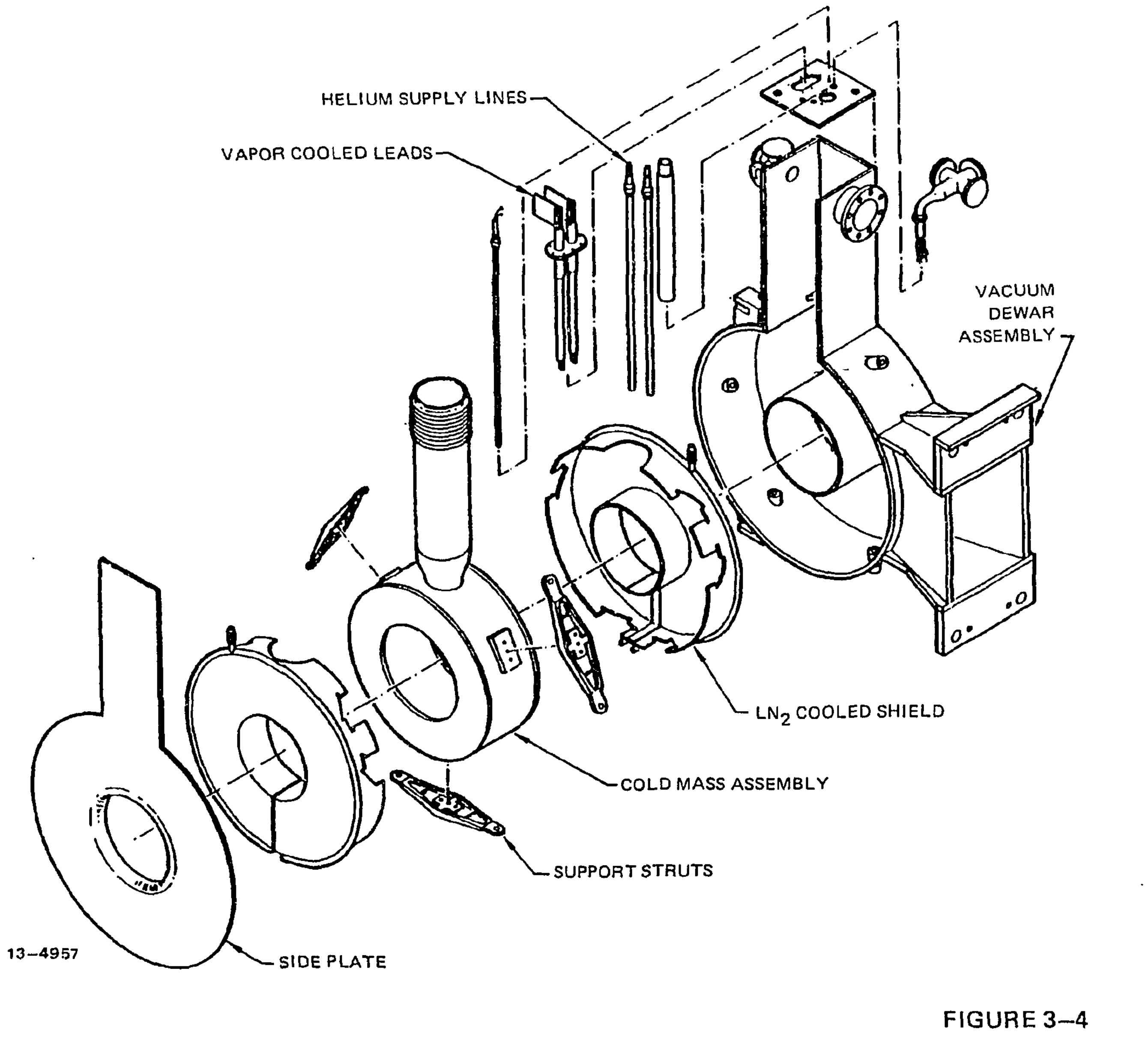

FIGURE 3–4

A summary description of the mirror coil design is shown in Table 3-3. Each mirror coil consists of a single grade, ventilated superconducting coil pack in a pool-boiling liquid helium-cooled configuration. The conductor used in the coil windings is NbTi/Cu rectangular monolith with twisted superconducting filaments. Turn-to-turn and layer-to-layer insulation consists of a 50% coverage of spiral-wrapped nomex tape. The uninsulated area of the conductor serves as flow channels for the liquid helium coolant. The G-10CR/polyimide ground insulation concept provides a helium plenum along the sidewalls of the conductor pack and separate plenum against the coil bobbin. The winding concept is a layer winding with a half-pancake on one side to minimize the lead effects on the magnet's stray fields.

Table 3-3. Mirror Coil Design Summary

• Coil Mass Assembly	• Monolithic NbTi Superconductor • Helium Ventilated Coil Pack • Layer Wound With Pancake Entry
• LN_2	• Copper Sheet With Trace Cooling Tubes • MLI On Both Sides
• Vacuum Dewar	• Titanium Truss Supports • Dewar Alignment Is External
• Support Structure	• Adjustable After Installation

Each mirror coil is supported within a separate stainless steel vacuum dewar by a thermally resistive cold mass support structure which consists of three titanium alloy tangential trusses. The dewar and cold mass supports are designed to minimize heat leak into the liquid helium environment, minimize thermal radiation from the dewar wall to the mirror coil, and withstand gravity and magnetic loads during normal operation and fault conditions. The vacuum dewar provides a thermally insulating vacuum for the 4.2 K mirror coil. A superinsulated liquid nitrogen (LN_2) traced copper shield, located between the dewar wall and the cold mass assembly, serves to reduce the radiative head load to the coil. The LN_2 shield is also thermally attached to the titanium support trusses to reduce the conductive heat leak through the supports.

A lead x-ray shield is located at the bore and on the sides of the vacuum dewar to limit the amount of x-ray energy deposited in each superconducting coil to less than 10 watts. This shield design, along with a thin stainless steel toroidal vessel, contoured along the 16.5 cm flux line provides a passing particle fraction of more than 35%.

The Mirror Coil Power Supply/Distribution Subsystem consists of a high current, DC power supply, current distribution system and a hardwired quench protection system. A single power supply, controlled by a digital data link with the I & C subsystem, powers all 36 magnets. High current connection between components are made with copper busbar or multiple cables arranged to minimize the error fields at the torus minor axis. A computer simulation analysis of the power distribution system has been performed for both steady-state operation as well as transient effects during startup and shutdown to verify the design.

The magnet protection subsystem incorporates emergency dump resistors to discharge the mirror coils. Each coil has an individual resistor. The quench detection subsystem contains three basic montoring units in each magnet: a normal zone voltage detector, a vapor-cooled lead monitor, and a liquid helium level sensor. These units detect an abnormality in the operational status of the superconducting coil and initiate an emergency discharge with no operator or computer intervention.

The Magnet Development Program has demonstrated the successful performance of two development coils, D-1 and D-2, at fields compatible with 90 GHz device operation. These coils validated the basic technical approach to the mirror coils. The prototype magnet, where possible and when economically efficient, has been fabricated at the same time components were being produced for the two developmental dewars. In addition, where tooling was common and could be used for the production magnets, such items were fabricated to promote learning experience and lower cost for the production program. Conductor for the prototype is now being procured from two separate sources, AIRCO and IGC.

During Title I, joint tradeoff studies accomplished by the three organizations (MDAC/ORNL/GDC) addressed the design of the helium and LN_2 refrigeration systems, instrumentation and control, x-ray shielding, magnetic alignment, and quench protection-power supply systems.

Specific accomplishments include:

- Fabrication release of development dewars which contain and support the ORNL cold mass assemblies.
- Design and development of cold mass supports which meet thermal and stress criteria and x-ray environment.
- Helium stack design which meets refrigeration system, thermal, and quench pressure criteria.
- Dewar design which meets passing particle fraction criteria.

Microwave System - The electron cyclotron resonant heating (ECRH) system serves to both stabilize and heat the plasma. The ECRH system is composed of four subsystems: the gyrotrons, gyrotron mount and support equipment, microwave distribution, and gyrotron power supplies. The general features of the microwave system are shown in Figure 3-5 and summarized in Table 3-4. The basic design is an extension of the proven EBT-S manifold distribution system design.

The ECRH system includes six 200kW gyrotrons at 60 GHz for heating the bulk plasma and two 200kW gyrotrons at 28 GHz for heating the annulus plasma. Each tube is rigidly mounted on an oil-filled tank that provides both electrical isolation and oil cooling for the high voltage cathode. The tubes and their mounts are located in the lower level of the enclosure. The 28 GHz gyrotrons use a conventional water cooled focus magnet. The 60 GHz gyrotrons employ a superconducting focus magnet that is cooled with liquid helium supplied by the cryogenic system.

Each gyrotron is powered by a separate power supply which powers the beam, the gun anode and the heater. Each power supply is independently variable, regulated, and has bus crowbar capability for fault conditions. Table 3-5 lists the 60 GHz gyrotron power supply performance requirements. In addition to this power supply, ion pump, focus magnet, and cathode magnet power supplies are provided for each gyrotron.

MICROWAVE DISTRIBUTION SYSTEM

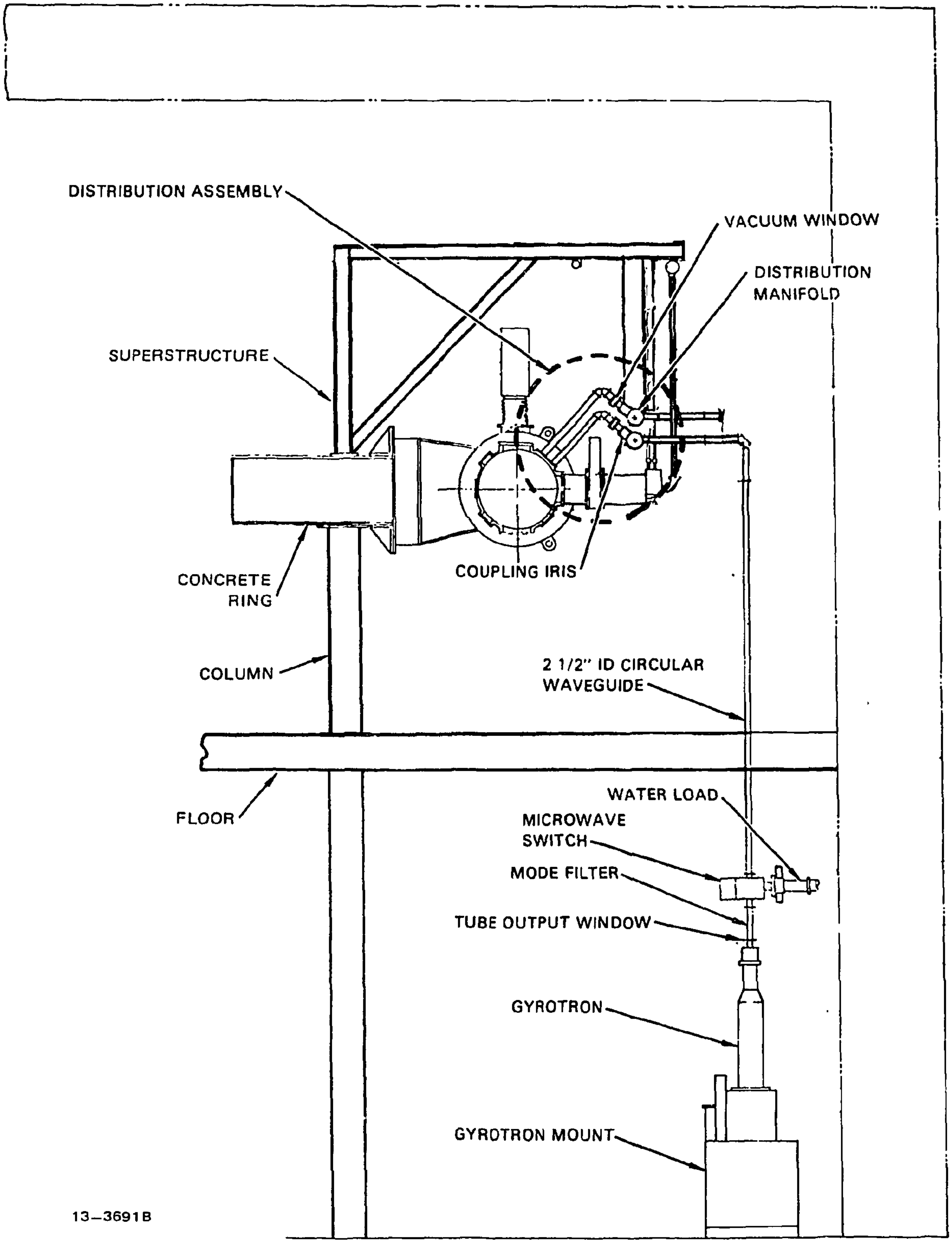

FIGURE 3–5

Table 3-4. Microwave System Baseline Design Features

A. GYROTRONS
- 200 kW cw
- 60 GHz (6)
- 28 GHz (2)

B. GYROTRON SUPPORT
- Socket
- Socket Mount
- Gyrotron Magnets

C. DISTRIBUTION SYSTEM
- Remotely Controlled Microwave Switch and Water Load
- Segmented Manifold with Manual Length Adjustment
- 2, 3, 4, or 6 Gyrotron Inputs at 60 GHz
- 1 or 2 Gyrotron Inputs at 28 GHz
- Irises For Controlling Power to Cavities
- Right Angle Bend to Cavity
- Window Between Bend and Iris
- Arc Detectors and Calorimeters

D. POWER SUPPLIES
- Weather Proofed
- No Series Regulators Proposed - Requirement Depends on Tube Development

Table 3-5. 60 GHz Gyrotron Power Supply Performance

Beam Power Supply
- Input: 13.8 kV 1200 kVA, 3ϕ, 60 Hz
- Output: −90 kV dc, 10A, 900 kW

Electron Gun Power Supply
- Input: 480 V, 3ϕ, 60 Hz
- Output: 40 kV dc, 100 mA, 4 kW

Heater Power Supply
- Input: 120 V, 1ϕ, 60 Hz
- Output: Variable 0 To 120 V ac 5[illegible]A MAX

The ECRH distribution systems (28 GHz and 60 GHz) use overmoded circular waveguide components to distribute the microwave power to multimode toroidal manifolds which, in turn, couple energy to each mirror cavity through waveguide connecting links. This system is very similar to that used on EBT-S. The properties of the overmoded circular waveguide components are largely understood, however, the control of the power splitting from the toroidal manifold requires substantial development. When developed this distribution method will provide evenly distributed unpolarized power to the mirror cavities. The manifolds and waveguide links are positioned to feed the torus in the upper, outer quadrant of each cavity. This placement minimizes diagnostic interference and facilitates upgrades to a polarized core heating system utilizing waves launched into the outer edge of the magnet throat. The manifolds are segmented by conducting plates to isolate gyrotron outputs. Power is uniformly distributed from the manifold to the mirror cavities by coupling irises.

The final ECRH system design will evolve from the gyrotron and microwave distribution, research and development programs at ORNL. The system design and R & D effort will be closely coordinated to complement each other.

To meet the proof-of-principle objectives, Ion Cyclotron Resonant Heating (ICRH) of the bulk plasma will be required in addition to the 60 GHz ECRH. Two 20 MHz to 90 MHz, 500 kW ICRH power amplifiers will be procured during the current EBT-P Phase II program, and facility interfaces will be designed to accommodate the complete ICRH system. However, design, procurement, and installation of the ICRH RF transmission system, tuning network, and antennas will not be completed until after the first year of EBT-P operation.

Vacuum Pumping System - The vacuum pumping systems consist of five subsystems; (1) Torus roughing, (2) Primary torus pumping, (3) Mirror coil dewar pumping, (4) Gyrotron magnet dewar pumping, and (5) Gas flow and control. General features of these subsystems are depicted in Table 3-6 and discussed in subsequent paragraphs.

Table 3-6. Vacuum Pumping Subsystems

Torus Roughing

- One Two-Stage Mechanical Pump and Blower System for torus roughing.
- 2 Two-Stage Mechanical Pumps and Blowers for foreline pumping, with provisions for addition of two more systems.

Primary Torus Pumping

- Five TMP 3500 Turbomolecular Pumps with provisions for future addition of five more identical turbopumps.

Mirror Coil Dewar Pumping

- One Mechanical Pump and Blower System for dewar roughing
- Four Turbomolecular Pumps on a high vacuum manifold
- 2 Two-Stage mechanical pumps and blowers for foreline pumping

Gyrotron Magnet Dewar Pumping

- One Mobile Turbomolecular Pump System

Gas Flow and Control

- Torus Ion Gauge
- Piezoelectric Valve/Pressure Feedback and Control Loop
- Mass Flowmeter

The torus roughing pumps and primary high vacuum pumps are shown in Figure 3-6. A roots blower backed by a two-stage rotary vane mechanical pump evacuate the torus to the 10^{-3} torr region. Five 3500 liter/sec turbomolecular pumps then evacuate the torus to its ultimate pressure of 2×10^{-7} torr. During plasma operation the turbopumps remove impurities from the vacuum surfaces and maintain a stable plasma at an edge pressure between 1×10^{-6} and 1×10^{-4} torr.

TORUS VACUUM PUMPING SYSTEM

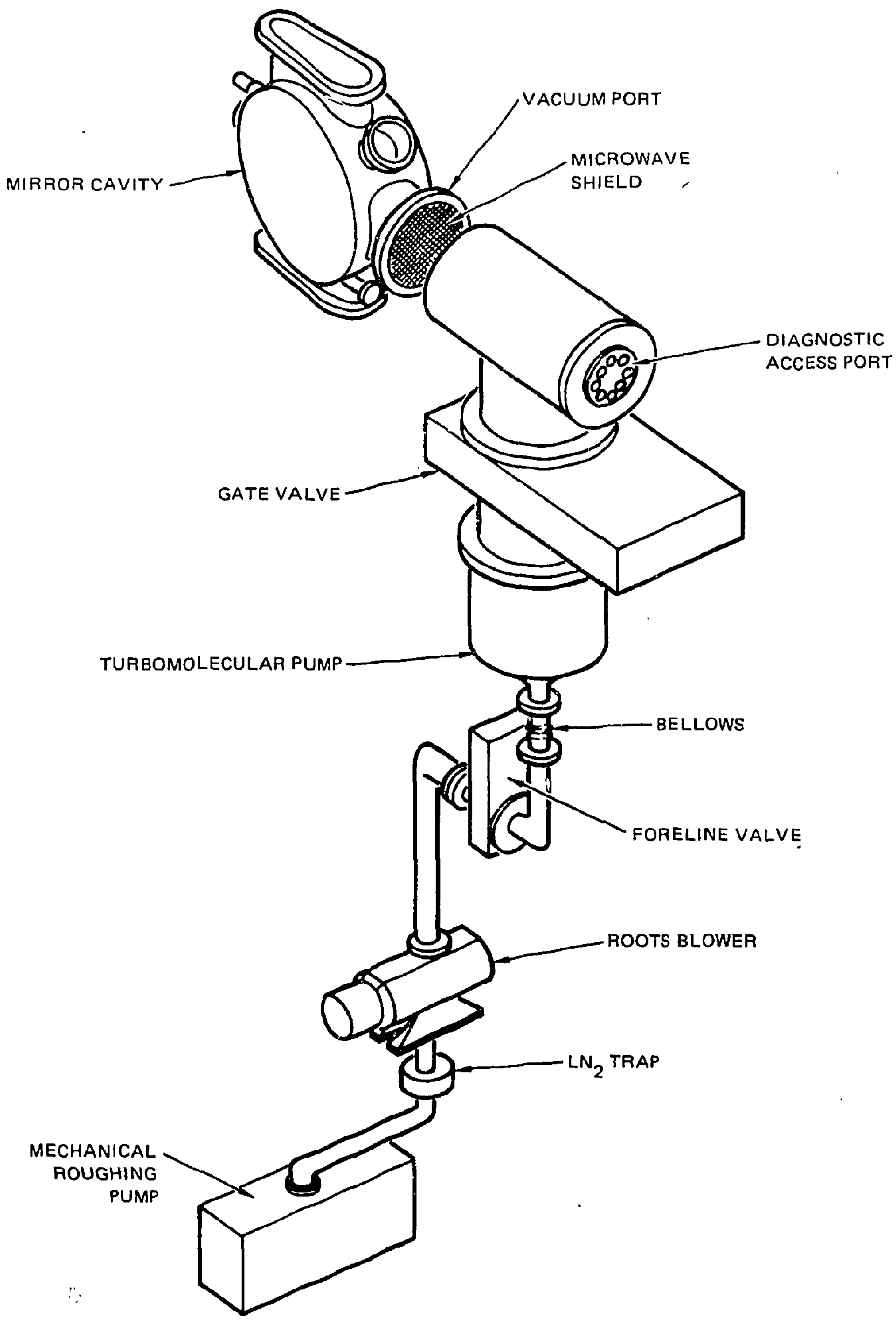

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FIGURE 3–6

The gaseous helium cryopumps, the former baseline, were determined to be unsuitable for use on EBT-P because of their low tolerance for x-rays and their incompatibility with the microwave and radiation environment. A trade study was performed to evaluate various high-vacuum pump systems. The two primary candidates were liquid helium cryopumps and turbomolecular pumps. Turbomolecular pumps were selected because of their proven experience, lower development risk, high pumping speeds and capability to perform in the EBT-P x-ray, microwave, and magnetic field environments.

To enable the vacuum components to survive the EBT-P x-ray environment, special radiation resistant turbomolecular pumps will be used. All roots blower and mechanical pumps will be located outside the device enclosure in a benign environment. Microwave protection is afforded by 50 dB attenuation shields and microwave absorbing ducts.

A diagram of the mirror coil dewar pumping system is shown in Figure 3-7. Roots blower backed by mechanical pumps are also used for roughing and foreline pumping. Four 2200 liter/sec turbomolecular pumps on a high-vacuum manifold serve the 36 mirror coil dewars. This pumping system evacuates the dewar to 10^{-5} torr prior to cooldown and pumps on a continuous basis to maintain vacuum in the dewar.

The gyrotron magnet dewars do not require dedicated, continuous vacuum pumping. Vacuum pumping of these dewars is a maintenance task utilizing a mechanical roughing pump and a mobile turbomolecular pump.

The gas flow monitoring and control subsystem supplies hydrogen gas and up to two minority species gases to the plasma and provides pressure control. Hyrdrogen control is achieved with a piezoelectric valve in a pressure feedback and control loop with a torus ion gauge. The hydrogen flow is measured with a mass flowmeter, and the minority species flows are ratiometrically controlled (compared to hydrogen).

Instrumentation and Control (I & C) System - This system consists of the integral subsystems and primary/secondary interfaces listed in Table 3-7. Figure 3-8 shows the basic interconnections among the principal I & C components. Control/interlock functions are handled by several programmable controllers (PC's). The PC's connect control panels

MIRROR COIL VACUUM PUMP SYSTEM

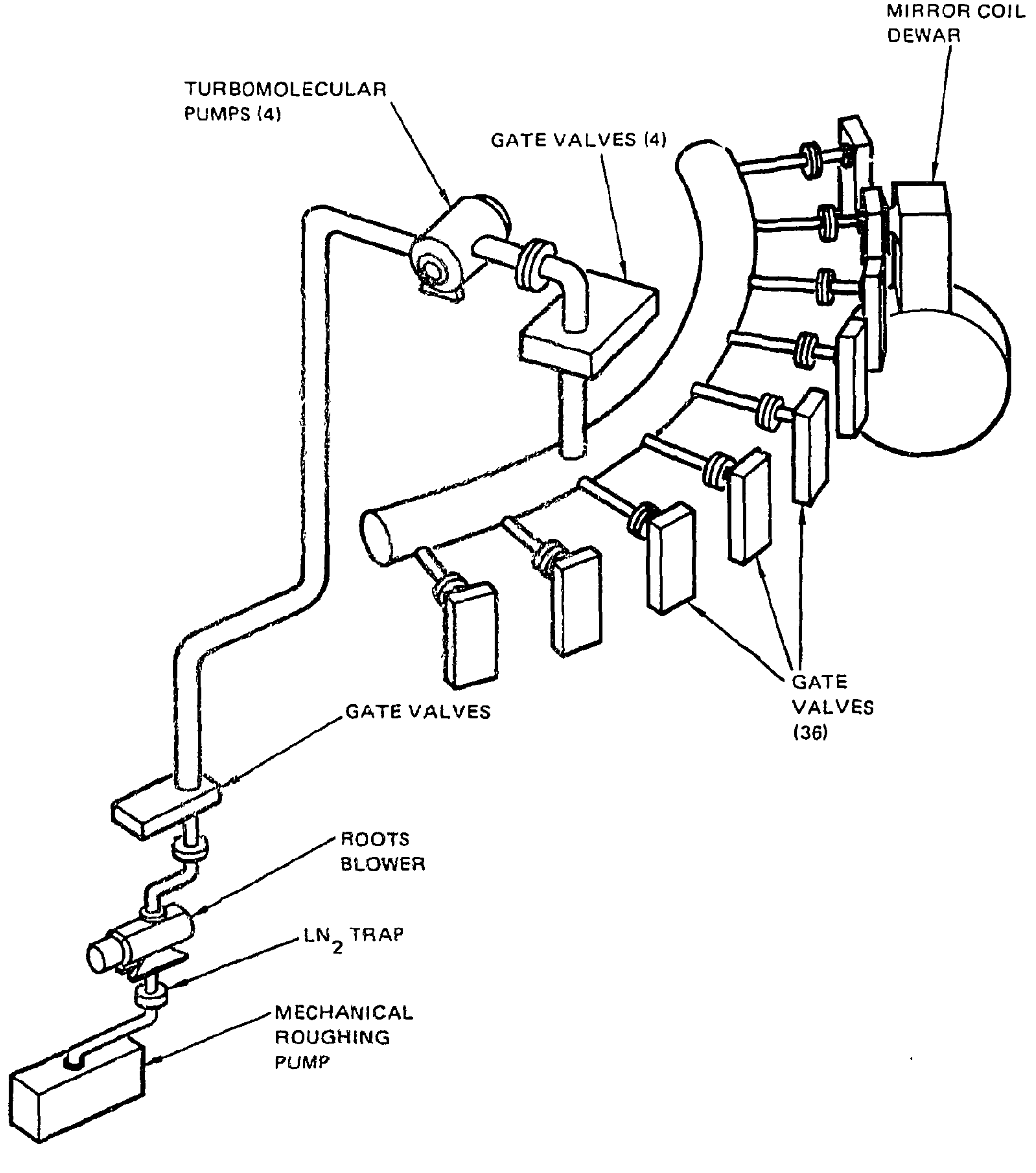

FIGURE 3–7

I&C SYSTEM BASIC BLOCK DIAGRAM

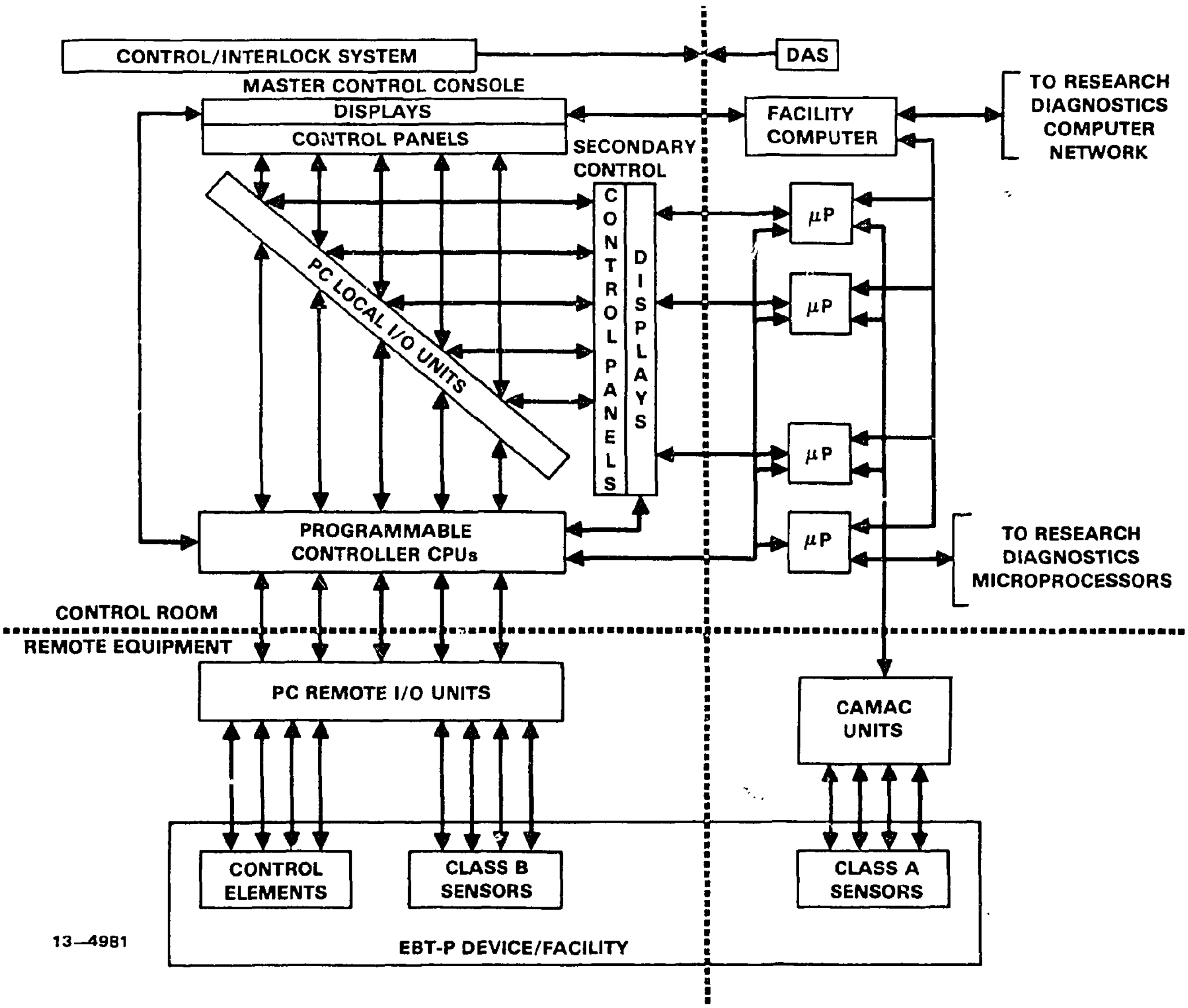

FIGURE 3–8

Table 3-7. EBT-P I&C System Components

- Integral Subsystems
  - Facility Computer
  - Microprocessor/Data Acquisition Systems (DAS)
  - Programmable Controller/Interlock System
  - Master Control Console (MCC)
  - Secondary Control Console (SCC)
  - Experiment Direction Console
  - Master Timer Subsystem
  - Key Interlock Subsystem
- Primary Interfaces
  - Magnet I & C Interfaces
  - 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 I & C Interface
- Secondary Interfaces
  - Grounding System Interface
  - Research Diagnostics Computer Network Interface
  - Research Diagnostics Microprocessor Interface
  - Personnel Safety Interface

to control elements (e.g.; valves, relays, power supplies, etc.) associated with the EBT-P device. Control panels are located in two areas of the Control Room (see Figure 3-9) in the Master Control Console (MCC) and in the Secondary Control Console (SCC) areas. Normal device operation is centered at the MCC stations while the SCC stations provide back-up control in case of a MCC station malfunction. The MCC stations contain color CRT terminals with touch panel overlays, both of which communicate with the PC's. Operators

CONTROL ROOM FLOOR PLAN

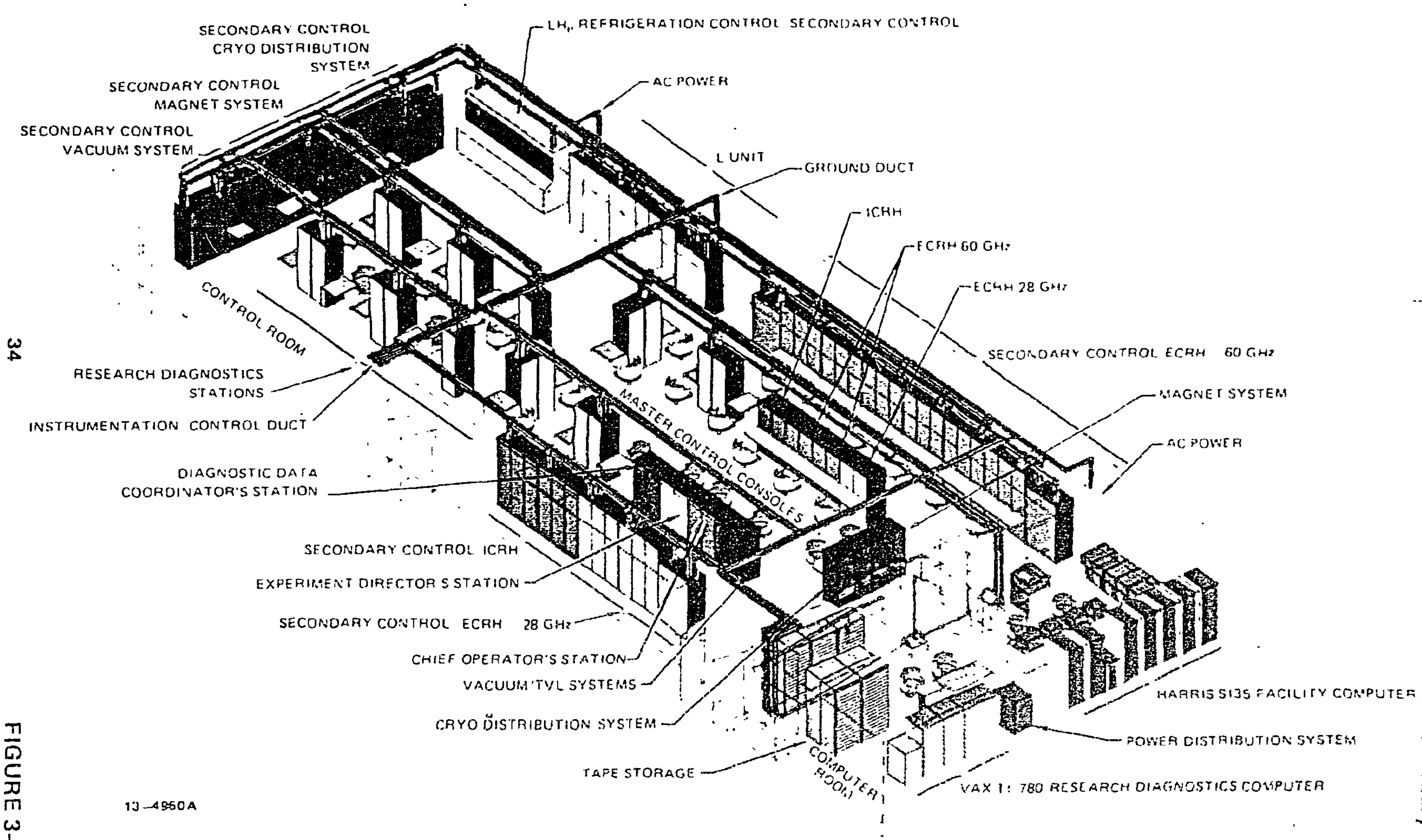

FIGURE 3-9

use "touch software control buttons" displayed on the CRT screens to control EBT-P device operation and to call up various graphical data displays which show the instantaneous state of the EBT-P device. The choice of CRT displays and touch panels resulted from a trade study which considered various alternatives ranging from an all-hardwired option (switches, potentiometers, digital and analog panel meters) to the selected option using CRT's, touch panels and software. Cost and risk assessment favor the selected MCC option. Present design of the SCC stations allows a more manual, less-software-intensive form of control to be implemented as a backup for the MCC. The present baseline incorporates hardwired switches in the SCC stations.

The Data Acquisition System (DAS) is the second major I & C subsystem and principally functions to collect and store EBT-P device operation data from numerous sensors which are not actively involved in control/interlock functions. A CAMAC subsystem interfaces the Class A sensors to PDP 11/23 microprocessors dedicated to the various I & C primary and secondary interfaces. These microprocessors function as data buffers for the large facility computer (a Harris S135) in which data archiving tasks operate. The Facility Computer also extracts selected data from the PC's to complete the device operation data base. This data base, partially or totally, is available to the Research Diagnostics Computer Network for use by plasma experimentalists as they analyze plasma diagnostics data. The Harris S135 Computer is being supplied to the EBT-P project from MDAC capital equipment on a no-charge, lease-free basis. It will be used for software development at MDAC-St. Louis prior to delivery to Oak Ridge.

There is a clear, intentional separation of control/interlock functions and data acquisition activities in the I & C design. Design criteria requiring long duration, reliable device operation are met by using high reliability industrial PC hardware optimized for control/interlock functions. Less critical DAS functions are handled by the microprocessor/facility computer hardware. PC software also incorporates features which provide redundancy to handle a failure of one of the PC's. Similarly, alternative communication links are provided between the CAMAC subsystem and the Facility Computer to handle a failure of one of the microprocessors.

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 multi-tasking 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-TIME 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)

The I & C system design has three levels of interlocking to ensure personnel and device safety. A hard-wired Kirk key interlock subsystem provides the first interlock level and requires that a walk-around be performed prior to device operation to clear personnel from restricted areas and retrieve keys needed to unlock various hardwired circuits. The interlock programming inherent in the design of the PC software forms the second level of interlocking. Finally, several hardwired interlock circuits are provided to handle faults which occur on fast time scales (<1 msec). These include the quench detection circuits associated with the superconducting magnet system and the crowbar trigger circuits associated with the gyrotron and with the ICRH RF power supplies.

Additional personnel safety functions are provided by the gamma/neutron radiation area monitor system and by the microwave/RF radiation area monitor system. These systems provide audio alarms if pre-set thresholds are exceeded in continuously-occupied areas (e.g.; >0.25 mrem/hr for gamma/neutron radiation and >10 mW/cm^2 for RF radiation).

Cryogenic System - The cryogenic system is composed of the liquid helium and liquid nitrogen subsystems. The primary function of the EBT-P cryogenic system is to deliver liquid helium (LHe) and liquid nitrogen (LN_2) to the device use points and to liquefy helium to compensate for device losses. Liquid use points include the 60 GHz gyrotron magnets, mirror coils, and diagnostics. A trimetric view of the cryogenic system is shown in Figure 3-10. Major components of the cryogenic system are located in or adjacent to the mechanical equipment building with the exception of the liquid helium dewar which is located on the device enclosure roof.

The LHe system is a closed loop system consisting of two compressors, a refrigerator/liquefier, a 17,000 liter LHe storage dewar, three warm gaseous helium (GHe) storage tanks, and a helium distribution system. The compressors supply helium gas for storage operation. Each compressor has the capacity to supply helium to maintain the system in the standby mode while the other is being maintained. High pressure gas is filtered

CRYOGENIC SYSTEM

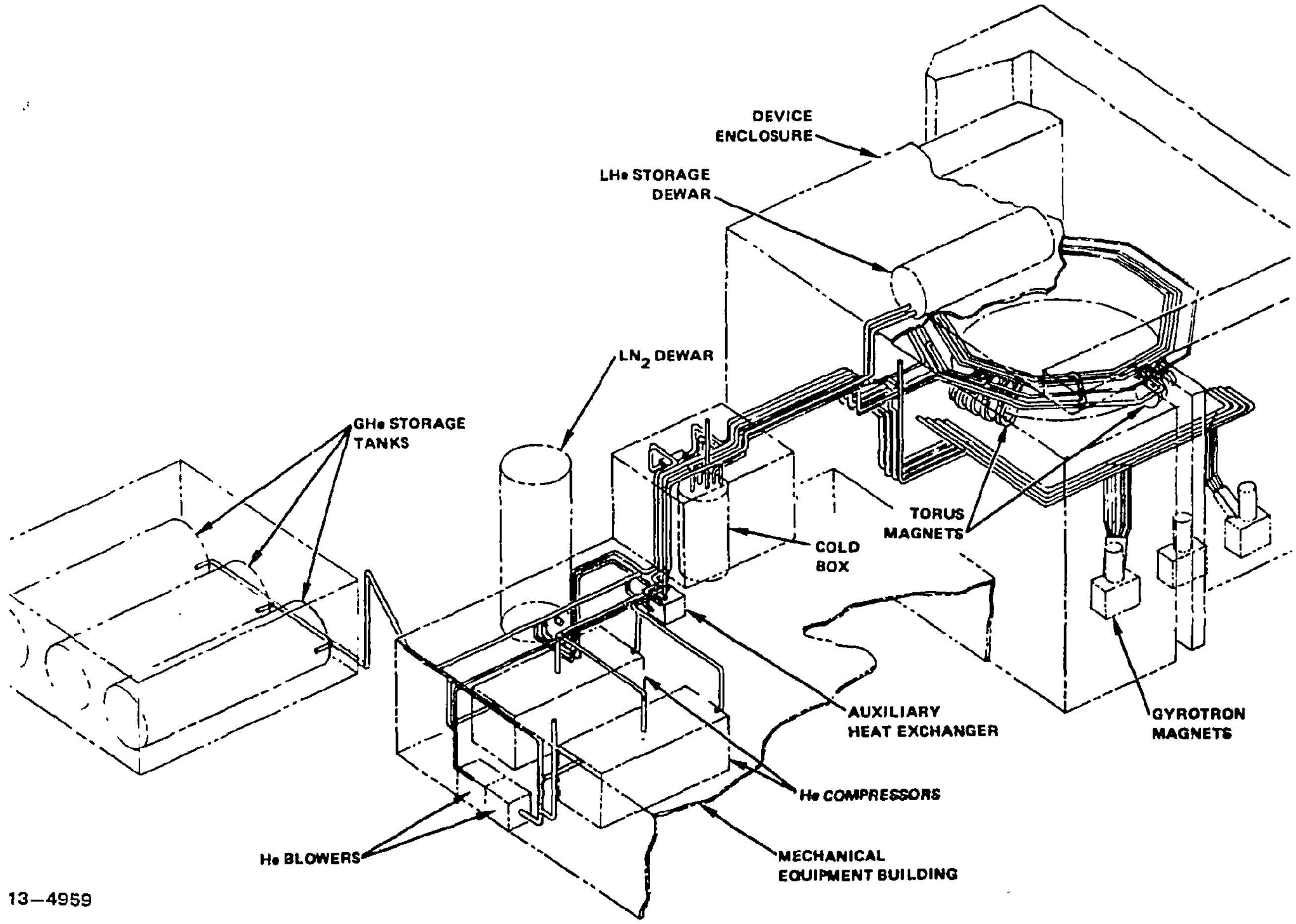

FIGURE 3–10

and delivered to the LHe storage dewar from the cold box. An integral Joule Thompson valve liquefies the gas at the dewar inlet. Cold GHe that is not liquefied in the expansion is returned to the cold box to refrigerate the incoming high pressure helium stream from the compressors. Warm GHe from the device use points is returned to the compressor inlet. Since the output capacity of the two compressors exceeds the flow requirements for mirror coil cooldown, separate piping is used between the cold box and LHe dewar, thus allowing some liquid production during the cooldown mode.

Liquid helium is delivered to the use points via the helium distribution system by head pressure resulting from the elevated location of the dewar. The helium distribution system delivers 4.2 K LHe to the device use points, returns 4.2 K vapor to the cold box, and ambient temperature gas to the compressor system. All liquid and cold gas lines are vacuum jacketed and superinsulated. Within the device enclosure, the LHe flow is split to service both the lower (gyrotrons) and upper (mirror coils) levels of the test center. Individual drops at each level interface with the use points. The cryogenic distribution system is protected by a burst disc and relief valves. Liquid helium for the mirror coils is supplied on demand and is controlled by a liquid level sensor in the mirror coil stack. Liquid helium for the gyrotron magnets is supplied by batch filling dewars prior to the beginning of operation.

The EBT-P LHe system is designed to produce 280 liters per hour of liquid helium at 4.2 K for mirror coil electrical lead cooling and 2000 Watts at 4.2 K to accommodate conduction, radiation, and x-ray heating losses of the coils and distribution system. The refrigerator/liquefier is designed for operation as a liquefier, as a refrigerator, or as a refrigerator/liquefier to permit adjustment of the cycle mass flow to match the variable load and temperature requirements of the EBT-P System.

The LN_2 system is an open-loop system which provides LN_2 to the refrigerator/liquefier for gaseous helium precooling, and to the mirror coils, gyrotron magnets, diagnostics and liquid helium storage dewar for cooling themal shields and structural supports. The system consists of LN_2 storage dewar, cryogenic distribution, and vent systems. The LN_2 storage dewar is periodically replenished by mobile LN_2 tank trucks. Liquid nitrogen at approximately 80 K is supplied to the mirror coil and gyrotron magnet insulated shields on demand by a quasiflooded system. Liquid nitrogen is supplied to batch fill diagnostic devices prior to device operation. Spent nitrogen gas from the device use points is collected and vented outside the device facility. The liquid nitrogen distribution system is configured to supply continuous liquid flow to both levels of the device enclosure and is of vacuum-jacketed, superinsulated construction. The system is sized to support steady-state operation of the device for up to 16 continuous hours in a 24-hour period.

Device Utilities - The device utilities include the following subsystems: demineralized water cooling, electrical distribution, instrument air, and the device enclosure.

The demineralized water cooling system consists of a 50,000 gallon water storage tank, a 15,000 gallon water neutralizing tank, two 10,000 GPM main circulating pumps, purification systems, filters, heat exchangers, sampling panel and associated piping and valves. Water quality is maintained by a clean-up demineralizer. Demineralized cooling water is supplied to the following use points: vacuum liners, mirror cavities, limiters, microwave shields, gyrotron tubes, microwave waveguides, RF power amplifiers, turbomolecular pumps, and the gaseous helium compressors. Distribution of the cooling water is by means of stainless steel supply and return headers within the torus area equipment and to the microwave area equipment. Provisions for the following upgrades will be provided in the distribution system: ARE coils, additional plasma heating (5 MW, max), RF tuning stubs, RF antennae and 15 gyrotrons.

Temperature, pressure, flowmeter, and flowswitch instrumentation is provided to monitor flow and temperature parameters to enable proper system control and operation and detection of system anomalies. The total operation of the system is under microprocessor control.

The electrical distribution subsystem is composed of:

- 2.4 kV power distributed to the helium compressors and water pumps
- 480/240 V distributed to the gyrotron magnet power supplies, ICRH power amplifiers, vacuum pumps, helium refrigerator/liquefier, demineralized water/cooling tower water purification systems liquefier, diagnostics, air compressor/dryer, and device enclosure HVAC.

- 120 V distributed to miscellaneous users
- 120 V uninterruptable power supply

Power from the uninterruptable power supply busses will be distributed to specific critical controls and monitors to provide a safe and orderly shutdown of critical systems in the event of a complete power outage and to preserve accumulated data within computer memories.

The cooling tower system consists of a mechanical draft, three cell tower (20 MW capacity), two cooling tower water pumps, cooling tower water chemical treatment equipment, automatic water strainer, fire protection, and associated piping and valves.

The instrument air subsystem provides compressed air to drive pneumatic valves and air-driven shop tools. This air will be generated by a 420 SCFM and 100 psig compressor and then routed by piping/tubing to the various use points.

The bi-level device enclosure is constructed of standard aggregate, reinforced concrete and serves to provide adequate x-ray shielding to reduce the maximum external area exposure levels to .25 mrem/hr adjacent to the shielding walls. The enclosure wall thickness is 8 feet and the ceiling thickness is 5 feet. Labyrinths are provided at both levels for equipment and personnel access. Lighting, wall penetrations (diagnostic windows), fire protection, a bridge crane, and power distribution are provided within the enclosure (see Figure 3-13, Device Enclosure).

Support Structure - The support structure provides structural support for the mirror coils, protection system equipment, toroidal vessel and much of the device ancillary equipment. As illustrated in Figure 3-11, the support structure is comprised of a primary support and a superstructure. The mirror coils and toroidal vessel are cantilevered from the primary support structure which consists of a stainless steel reinforced concrete "bucking ring". The bucking ring is supported by nine concrete columns that extend from the floor of the device enclosure to a distance of seven feet above the floor of the second level. An outer aluminum ring is attached to the outer periphery of the concrete ring and provides a mount for the mirror coils and attachment points for the toroidal vessel support. The toroidal vessel support consists of three support struts at each mirror cavity which con-

SUPPORT STRUCTURE

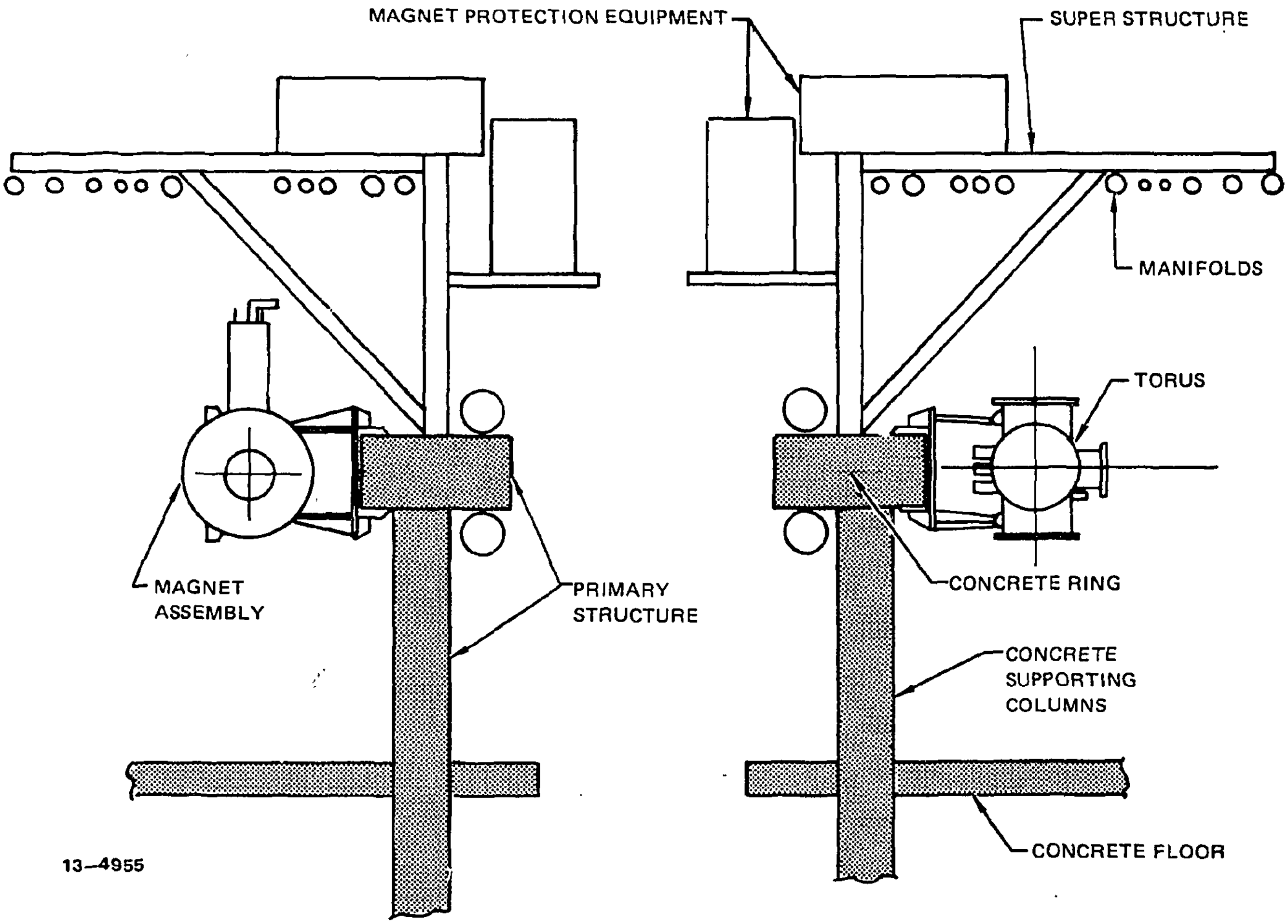

FIGURE 3–11

strains and thus prevents imposing loads into the mirror coil dewar which would affect magnet alignment. The "bucking ring" mount concept was chosen because of the inherent accessibility to the device offered by this concept. The reinforced concrete ring was chosen over an all-metal structure because of lower cost, improved structural stiffness, and better access to the inside of the device.

The superstructure is a welded aluminum truss which is mounted above the concrete ring and provides support for the magnet protection equipment, cryogenic and vacuum manifolds, and instrumentation and control cable trays. The superstructure, being located above the toroidal vessel, allows for most of the ancillary equipment to be suspended above the torus and thus provides greater experimental and diagnostic access to the device.

3.4 FACILITY OVERVIEW

The EBT-P Facility will be built on an eleven acre site at the Oak Ridge Valley Industrial Park, Oak Ridge, Tennessee. The property, which is owned by McDonnell Douglas Corporation, is approximately 1-1/2 miles from the ORNL Y-12 area via existing roads.

The EBT-P Facility shown in Figure 3-12 consists of the Administration Building, the Test Support Building, the Mechanical Equipment Building, and the Power Supply Pad.

The Administration Building will have offices jointly occupied by ORNL and MDAC personnel, a conference room, a canteen, library, lobby, computer room, and restroom facilities. Parking areas will surround three sides of the Administration Building.

The Administration Building will be interconnected with the two-story Test Support Building by an enclosed walkway. The Test Support Building will surround three sides of the biologically shielded EBT-P device enclosure, as shown in Figure 3-13. The grade level will have accommodations for a machine shop, diagnostic labs, instrumentation/electronics shop, a battery-powered uninterruptable power supply, a bonded parts and equipment storage area, and restrooms. The second level, interconnected by an elevator and three stairways, will contain the control and data acquisition room, a computer room, a dark room, electronics shop, diagnostic lab, technician work areas, restrooms, and floor space for

EBT-P PLOT PLAN

1. ADMINISTRATION BUILDING – 12,500 FT^2
2. TEST SUPPORT BUILDING – 29,600 FT^2
3. DEVICE ENCLOSURE – 5,250 FT^2
4. MECHANICAL EQUIPMENT BUILDING – 6,720 FT^2
5. POWER SUPPLY PAD – 27,500 FT^2

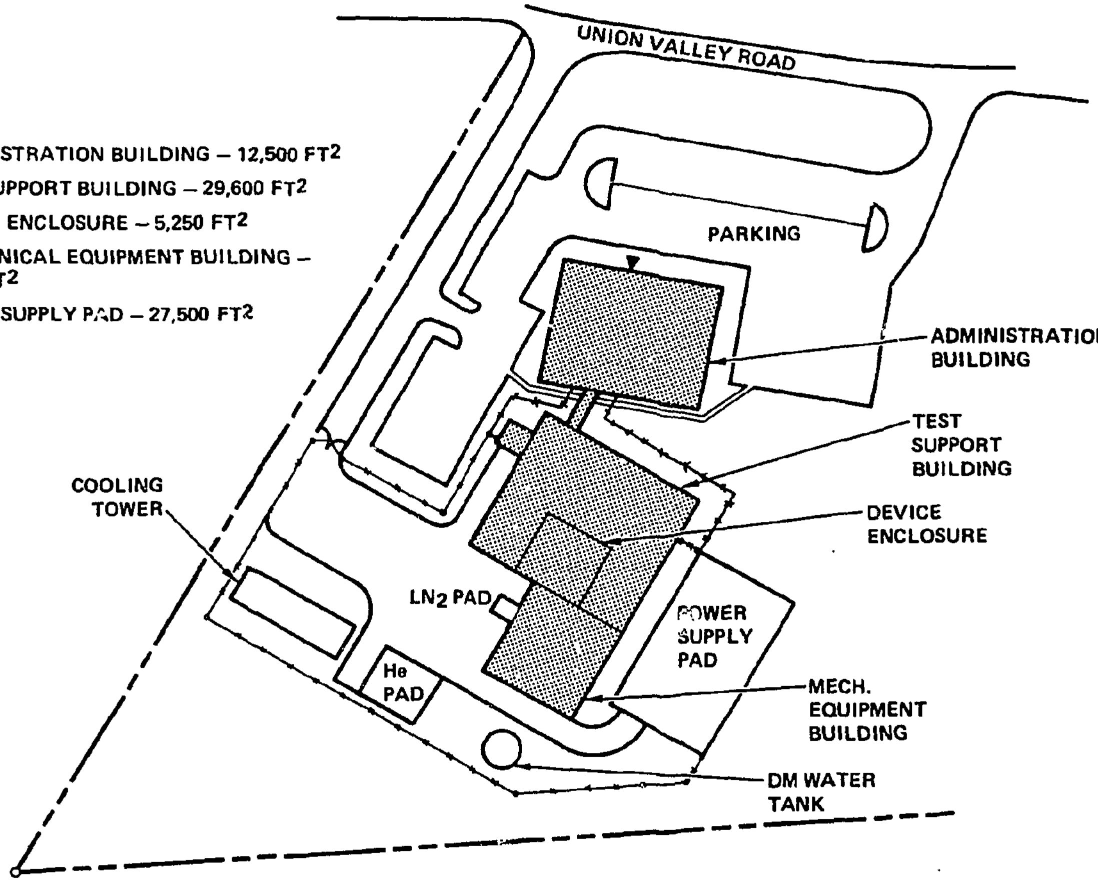

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FIGURE 3–12

DEVICE ENCLOSURE

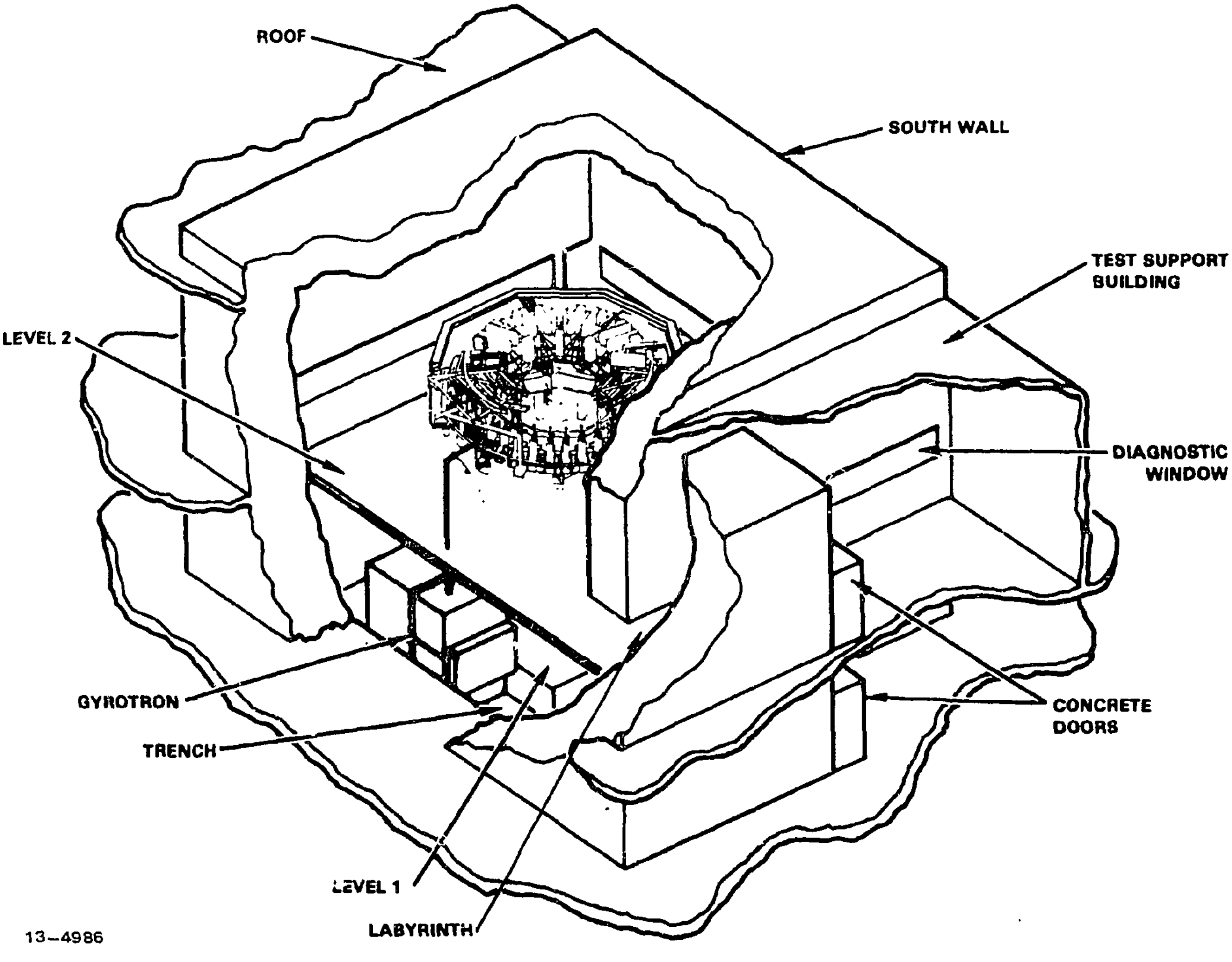


FIGURE 3-13

the superconducting magnets power supply, the global field error correction coils power supply, ICRH final power amplifiers, and for plasma diagnostic devices.

A Mechanical Equipment Building adjoins the Test Support Building. The building will provide floor space for major mechanical systems such as the cryogenic refrigerator/liquefier system, the demineralized water control and processing system, and the instrument air system.

Outside the Test Support and Mechanical Equipment Buildings are located the LN_2 storage dewar pad, a cooling tower basin, a demineralized water storage tank pad, a gaseous helium storage tank pad, a cooling tower water treatment building, waste water neutralizer tank pad, and a power supply pad. Incoming power controls and step-down power amplifiers are placed on the power supply pad.

All buildings are protected by fire detection and automatic water sprinkler systems. Outdoors, fire protection is provided by detectors, spray nozzle hose reels, and fire hydrants. The operating area is enclosed by a security fence system. All external doors are provided with industrial type locks and intrusion alarms. All fire or intrusion alarms are annunciated in the Administrative Building lobby and within the Test Support Building. External lights provide illumination of all outdoor areas. Lightning protection and buildings grounding are provided per applicable codes.

4.0 SCHEDULES

The EBT Master Schedules for Phase II (PACE) are shown in Figures 4-1 and 4-2. Each major system/task is identified by its Work Breakdown Structure (WBS) Number.

Figure 4-1 provides an overview of the major tasks against the program period of performance. Start and completion date for each major activity is noted.

Figure 4-2 provides a more detailed picture for each major system. Significant milestones (e.g.; PDR, CDR, Title II Go-Ahead, etc.) are identified for each system.

The System Critical Path runs through the design, fabrication and installation of the Magnets followed by the Microwave and Cryogenic Systems.

PACE
EBT-P DEVICE OVERVIEW SCHEDULE

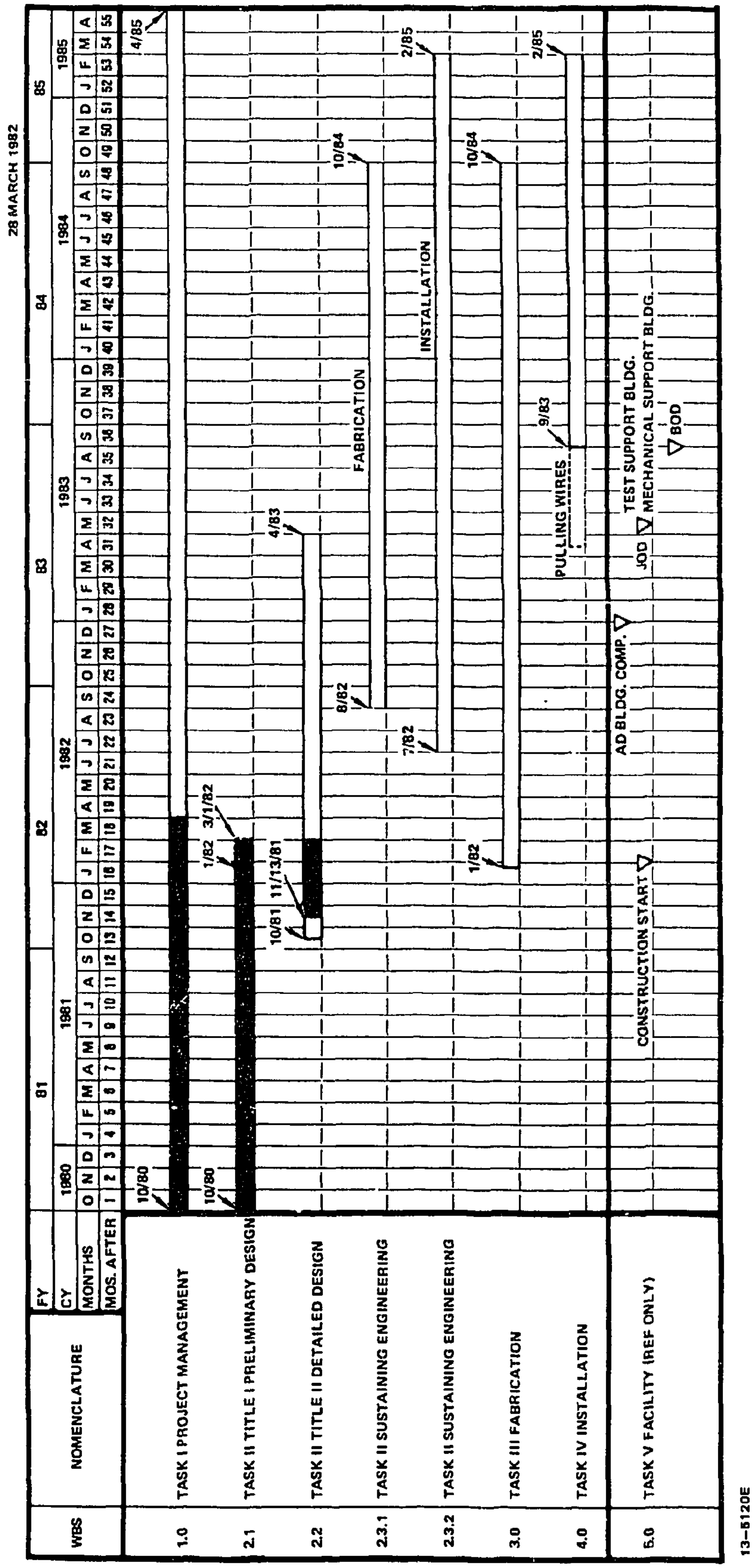
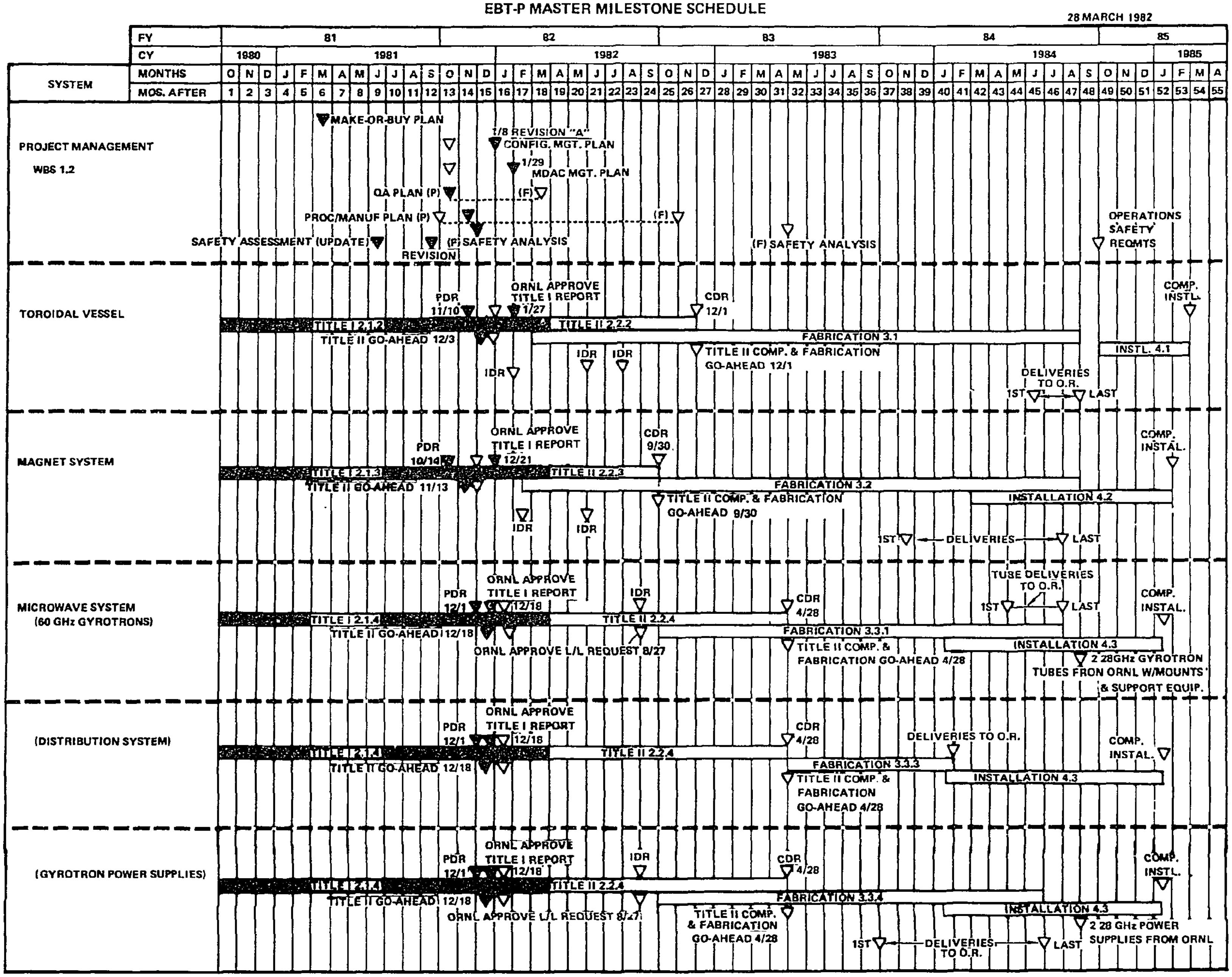


FIGURE 4–1

PACE
EBT-P MASTER MILESTONE SCHEDULE



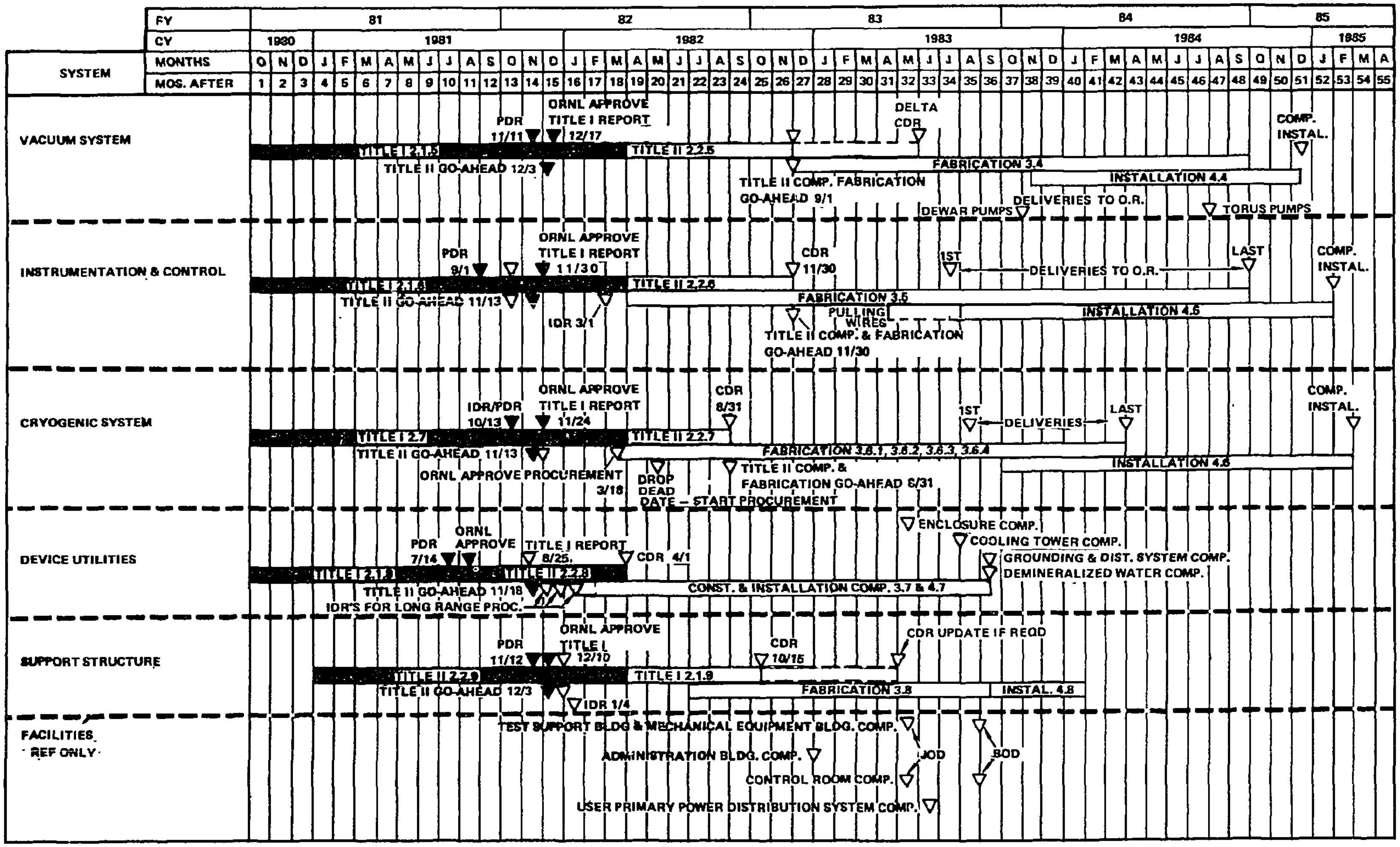
NOTE: ORNL APPROVE ALL LONG LEAD REQUESTS AT THE IDR

13-5121E

FIGURE 4-2

PACE
EBT-P MASTER MILESTONE SCHEDULE (Continued)

28 MARCH 1982



NOTE: ORNL APPROVE ALL LONG LEAD REQUESTS AT THE IDR

13–5122E

FIGURE 4–2 (Cont.)

5.0 REFERENCES

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