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FUSION ELMO BUMPY TORUS ENERGY

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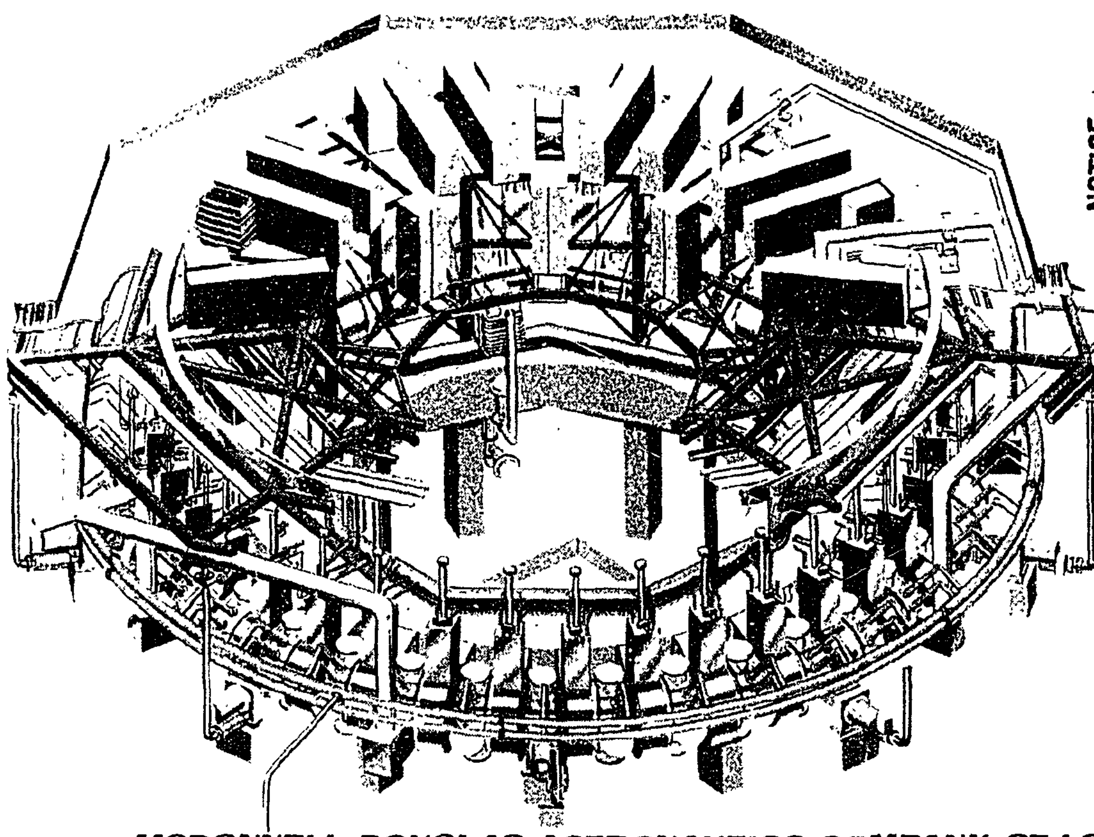
Elmo Bumpy Torus Proof Of Principle,

PHASE II — TITLE 1 REPORT.

Volume IX. SUPPORT STRUCTURE



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PRELIMINARY DESIGN REPORT

SUPPORT STRUCTURE

VOLUME IX

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Reference Index

TABLE OF CONTENTS

LIST OF PAGES

ii - viii
1 - 47
A-1 - A-34
B-1 - B-34

LIST OF FIGURES

LIST OF TABLES

LIST OF DRAWINGS

PAGE

ACRONYMS, ABBREVIATIONS AND INITIALISMS

ARE	Aspect Ratio Enhancement
ASME	American Society of Mechanical Engineers
CRT	Cathode Ray Tube
EBT-P	Elmo Bumpy Torus-Proof of Principle
ECRH	Electron Cyclotron Resonance Heating
I&C	Instrumentation and Control
ICRH	Ion Cyclotron Resonance Heating
MDAC	McDonnell Douglas Astronautics Company
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PDC	Proposed Design Change
TF	Toroidal Field
UCC-ND	Union Carbide Corporation - Nuclear Division

1.0 INTRODUCTION AND SUMMARY

The EBT-P support structure provides structural support for the 36 mirror coil magnets, magnet protection system, the toroidal vessel, and much of the device ancillary equipment (reference Figure 1-1).

The structure is comprised of a primary support and a superstructure. The primary support is a reinforced concrete ring located directly inboard of the torus and is supported by nine columns. The toroidal vessel and the mirror coil magnets are cantilevered from the ring with the centerline of the torus located eight feet above the floor. The superstructure is an aluminum truss structure that rests on the concrete ring. The superstructure provides support for the device ancillary equipment.

The primary support structure reference design at the beginning of Title I consisted of an all stainless steel structure which resembled a wagon wheel having an outer ring and radial beams connecting to a center hub. This structure was expensive to fabricate because of the large amounts of stainless steel and much welding, plus the structure limited access to the inboard side of the torus.

Early in Title I a concept was conceived which would eliminate the costly stainless steel "wagon wheel" design and replace it with the current reinforced concrete ring design. By going to the current design the structural stiffness was increased, the fabrication and installation costs were reduced and better access to the inboard side of the device was provided. A Proposed Design Change (PDC) was written and approved by ORNL. (PDC No. 1, 24 April 1981).

Figure 1-2 summarizes the design features of the support structure.

FIGURE 1-1. ELMO BUMPY TORUS - PROOF OF PRINCIPLE EXPERIMENT

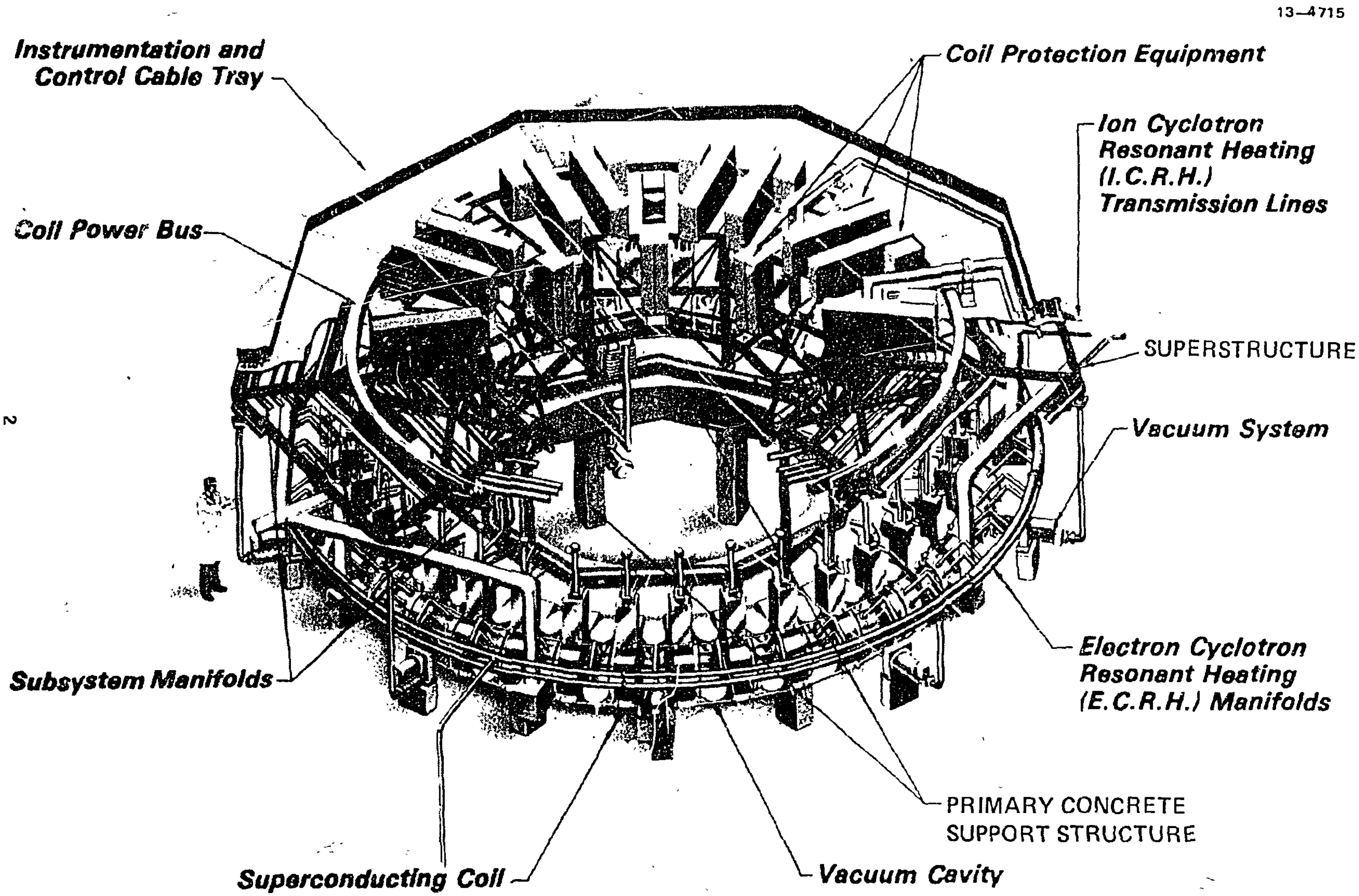


FIGURE 1-2. SUPPORT STRUCTURE DESIGN FEATURES SUMMARY

- STRUCTURE IS NON-MAGNETIC
  - PRIMARY - ALUMINUM, CONCRETE, STAINLESS STEEL
  - SUPERSTRUCTURE - ALUMINUM
- ALLOWS INBOARD ACCESS TO DEVICE AND ANCILLARY EQUIPMENT
- ALLOWS DIAGNOSTIC ACCESS TO ALL FOUR SIDES OF TORUS
- PROVIDES RIGID MOUNTING BASE FOR MIRROR COIL MAGNETS
- ALLOWS UPGRADE ACCOMMODATION OF ARE COILS

2.0 PURPOSE AND SCOPE

The purpose of this Title I report is to summarize the results of the preliminary design and technical analyses performed on the support structure system for the EBT-P device. The scope of the Title I effort is to 1) establish the basic concept and general arrangement of the support structure, 2) define system interfaces, and 3) perform necessary load and structural analyses to establish load paths and approximate structural sizes.

3.0 DESIGN CRITERIA

The structural design criteria for the Elmo Bumpy Torus-Proof of Principle (EBT-P) experimental device is documented in Report No. EBT-P013 and is included in its entirety in the appendix of this report. The following sections describe the structural design criteria philosophy that will be used during detail design of the support structure.

The basic intent is to guide the design of the EBT-P support structure using structural criteria normally approved for building construction since no specific structural design criteria exists for a device of this type. This approach will provide a reasonable continuity between the design of the device and the design of the facility. This approach has been used on similar fusion energy devices. Where it is deemed that building criteria are inadequate, a more conservative path will be followed. The EBT-P device will be designed as a nonnuclear structure as it is a plasma physics experimental apparatus that does not present the potential hazards normally associated with currently operating pressurized water reactors. Federal, state, and local regulations will be complied with where applicable to establish strength requirements. Where regulations are not available or where regulations are not appropriate due to the special nature of the EBT-P device, sound engineering judgement will be used.

3.1 DEFINITIONS

Design Conditions - The combinations of loads and temperatures, based on the structural design criteria, which uniquely establish the structural design requirements.

Detrimental Deformations - Structural deformations, deflections, or displacements shall not (1) cause unacceptable contact, misalignment, or divergence between adjacent components; (2) cause a component to exceed the dynamic space envelope established for that component; (3) reduce the strength or rated life of the structure below specified levels; (4) jeopardize the proper functioning of equipment; (5) endanger personnel; (6) degrade the functional characteristics of the experiment below specified levels.

Ultimate Factor of Safety - Ratio of ultimate load to limit load used to account for uncertainties and variations from item to item in material properties, fabrication quality and details, and internal and external load distributions.

Limit Load - The maximum load, or combination of loads, which the structure is expected to experience in a specific condition.

Load Factor - Load factor in a given direction is the summation of all of the externally applied forces in that direction divided by the weight.

Margin of Safety - A measure of the residual load carrying capability of a structure above ultimate or yield loads.

Predicted Temperature - Predicted temperature is the worst case temperature any portion of the structure is expected to experience in a specific condition. Predicted temperature is analogous to limit load.

Safety Factor - Ratio of load carrying capability of a structure to design load conditions at predicted temperature.

Stress Ratio - The ratio of minimum stress to maximum stress in a load cycle.

Structural Requirements - The values of specific parameters, such as loads and temperatures, associated with the conditions derived from the structural design criteria, and used to define the structural configuration.

Structural Design Criteria - The standards or rules by which judgements are formed relative to the design conditions and resulting structural requirements.

Ultimate Load - The product of the ultimate factor of safety times limit load.

Yield Factor of Safety - Ratio of yeild load to limit load used to account for uncertainties and variations from item to item in material properties, fabriction quality and details, and internal and external load distributions.

Yield Load - The product of the yield factor of safety times limit load.

3.2 CODES AND SPECIFICATIONS

Figure 3-1 outlines the codes and specifications that will be used as a guide for structural evaluation of the device support structure. The latest editions prior to the start of Title II detailed design will be followed.

3.3 DESIGN LOAD DESCRIPTIONS

The loads that will be used in the EBT-P design analysis are described in the following sections. These loads represent all the significant forces acting on the device.

Dead Loads - Dead loads are the loads produced by the weight of the equipment including structure, piping, instrumentation, insulation, ancillary equipment and cooling fluids. Table 3-1 lists the design mass properties of the device equipment.

Normal Operating Magnetic Loads - Normal operating magnetic loads are those due to the operation of the magnets for the normal operating conditions (reference Report No. EBT-P013).

Magnetic Fault Loads - Magnetic fault loads are those due to the operation of the magnets for the magnetic fault conditions (reference Report No. EBT-P013).

Seismic Loads - Seismic loads are those loads due to the response of the structure to an earthquake.

For preliminary design, estimated incremental acceleration values, as determined using the Uniform Building Code specified methods, shall be used as follows. The support structure shall be designed to withstand separate equivalent static incremental accelerations of 0.15g in any horizontal direction and 0.10g in the vertical direction. For design of attached equipment, the equivalent static incremental acceleration shall be 1.0g in any direction.

FIGURE 3-1. CODES AND SPECIFICATIONS

Tennessee State, Anderson County, and City of Oak Ridge

- Building and Safety Codes

Southern Building Code Congress

- Southern Standard Building Code (SBC)

American National Standards Institute

- American National Standard Building Code Requirements for Minimum Design Loads in Buildings and Other Structures A58.1

International Conference of Building Officials

- Uniform Building Code (Only Those Sections Pertaining To Earthquake Seismic Loads, Seismic Zone Number 2)

American Institute of Steel Construction (AISC)

- "Manual of Steel Construction," AISC, Eighth Edition, 1980

American Iron and Steel Institute (AISI)

- "Cold-Formed Steel Design Manual," AISI, latest edition.
- "Specification for the Design of Cold-Formed Stainless Steel Structural Members," 1980 Edition.

The Aluminum Association

- "Aluminum Construction Manual Series" Latest Edition.

American Welding Society (AWS)

- Welding of Bridges, Buildings, and Structures with Tubular Members, AWS D1.1, Latest Edition.

Research Council on Structural Connections

- "Specifications for Structural Joints Using ASTM A325 or A490 Bolts," April 26, 1978.

FIGURE 3-1. CODES AND SPECIFICATIONS (Continued)

American Concrete Institute

- Building Code Requirements for Reinforced Concrete ACI 318-77.

National Concrete Masonry Association

- TR758, Specifications for Design and Construction of Loadbearing Concrete Masonry.

For detailed design, a dynamic response analysis shall be performed to verify the adequacy of the preliminary design acceleration levels. If higher levels are determined, they shall be used. The dynamic analysis shall consider the EBT-P facility to be located in a zone 2 seismic risk area, as defined by the Uniform Building Code. The analysis shall use the zone 2 design ground response spectra, a defined by NRC Regulatory Guide 1.60 (Document 1.4.2).

3.4 DESIGN CONDITIONS

The EBT-P device shall be designed for normal operation (including the effects of seismic events), magnetic fault conditions, and non-operating conditions. In general, coexistant loads shall be added directly. An exception to this rule occurs for thermal loads. When thermal loads act to relieve other loads, thermal and other loads shall be considered as separate conditions.

Normal Operating Conditions - Normal operation of the EBT-P device includes operation of any or all of its associated systems and subsystems including planned upgrade equipment. Normal operation shall encompass all combinations of TF and ARE coil currents within the allowable envelope defined in the Device Structural Design Criteria (reference Appendix A). The effects of seismic events shall be considered during normal operation.

TABLE 3-1. EBT-P MASS PROPERTIES

	LBS.
SUPPORT STRUCTURE WEIGHTS:	
REINFORCED CONCRETE SUPPORT RING	101736
REINFORCED CONCRETE COLUMNS	50967
ALUMINUM SUPERSTRUCTURE	4212
ALUMINUM STRUCTURAL RING	5836
GROUT	7076
EQUIPMENT WEIGHTS ACTING ON CONCRETE STRUCTURE:	
MAGNETS AND SHIELDING	162000
VACUUM LINERS	2772
MIRROR CAVITIES	9900
FLANGES	9175
VACUUM VESSEL COOLANT	600
WATER COOLING PANELS	15120
INSTRUMENTATION	39348
COOLANT SUPPLY MANIFOLD	7977
COOLANT RETURN MANIFOLD	7977
ARE COILS	36000
FIELD CORRECTION COILS	5760
OUT-OF-PLANE STRUTS	2052
TOROIDAL VESSEL SUPPORTS	468
EQUIPMENT WEIGHTS ACTING ON ALUMINUM SUPERSTRUCTURE:	
BYPASS DIODES	1800
DUMP RESISTORS	3600
CIRCUIT BREAKERS	13500
SUPPORT STRUCTURE FOR MOUNT/BUS	1125
INSULATION/ISOLATION	1125
POWER BUS BARS AND CABLING	2700
CRYOGENIC MANIFOLDS	7740
ECRH WAVEGUIDES	9900
WIRE TRAY AND CABLES	9135
INSTRUMENTATION AND CONTROL PANELS	4500
VACUUM PUMPS FOR MIRROR COILS	400
MIRROR COIL VACUUM MANIFOLD SYSTEM	8760
COOLANT SUPPLY/RETURN MANIFOLDS	3672
ALUMINUM GRATING AND MISCELLANEOUS EQUIPMENT	3305

Normal operating loads shall be the result of the combination of the following loads.

- Dead Lo
- Normal ... ing Magnetic Loads (including ARE coils)
- Pressure Loads (coolant pressure and vacuum pressure)
- Thermal Loads
- Seismic Loads
- Preloads

Magnetic Fault Conditions - The TF coil protection system is designed such that if conditions if one of the TF coils indicate that it may quench (stop acting as a superconductor) an emergency discharge is initiated. The ARE coil system is immediately deactivated and the TF coils are electrically paired and connected to dump resistors. The TF coil system should then become safely deenergized. Magnetic fault conditions occur if the ARE coil system fails to deactivate or if one or more TF coil pairs remain operative.

The EBT-P device support structure shall be designed for the worst case of operating and nonoperating TF coils, including up to eighteen adjacent coils on (half-torus on). However, the TF coils shall be designed for the more probable and slightly lower out-of-plane load for two adjacent coils.

The effects of seismic events shall not be considered during fault conditions because of the low probability that an earthquake would occur during a magnetic fault condition and the low probability that an earthquake would trigger a magnetic fault.

Fault loads shall be the result of the combination of the following loads:

- Dead Loads
- Magnetic Fault Loads
- Pressure Loads (coolant pressure and vacuum pressure)
- Thermal Loads
- Preloads

Non-Operating Conditions - Structural requirements due to non-operating conditions are generally much less severe than the operating loads and are only of importance to localized structure provided for handling and maintenance. Where reasonable, a 150 pound ultimate handling load shall be used for brackets, supports, etc. lacking defined design loads.

3.5 DYNAMIC CONSIDERATIONS

The start-up and shut-down processes for the TF coil system and the start-up process for the ARE coil system shall be considered, from a structural design viewpoint, as quasi-static phenomena. However, the shut-down process for the ARE coil system occurs with sufficient rapidity to be dynamically significant. Therefore, the effects of an ARE coil system shut-down shall be addressed as a dynamic condition.

Equipment mounting shall be designed to minimize the effects of vibration to the maximum extent practicable. Where this is not possible, the effects of vibration shall be considered in equipment design.

3.6 GENERAL CRITERIA

Environments - The effects of x-rays and other structurally deleterious environments will be included in the analysis. Generally little effect is expected on the structural materials.

Operating Criteria - The primary operating criteria of the device support structure are to support the cryogenic magnets (mirror coils), plasma chamber (toroidal vessel), magnet protection system and miscellaneous piping. The magnets must be held to a very tight tolerance over the 10 year life of the facility without requiring realignment of the mirror coils.

3.7 SPECIFIC CRITERIA

Structural adequacy of EBT-P device support structure is assured by satisying the intent of various codes and standards commonly used to design building structures and associated equipment.

The Device Structural Design Criteria, Appendix A, specifies various loads and corresponding strength requirements for the EBT-P device. The purpose of that document is to supply the structural analyst with a collected set of criteria for various structural materials and types of structures. It is intended that application of these criteria during detailed structural design will result in structures that satisfy contractual requirements, insurance underwriters requirements, and building and safety code requirements of the EBT-P sites local governmental jurisdictions, State of Tennessee, Anderson County, and city of Oak Ridge.

The General Design Criteria for UCC-ND Projects (Y/EF-538/R4 Issue No. 4) was reviewed for guidance in establishing structural design criteria. Y/EF-538/R4 is directed towards the design of buildings and facilities and their equipment and is not specifically germaine to the structural design of the device primary support structure. Although it is not a contractual required document for the device primary support structure the adopted structural design criteria appears to be largely in agreement with it.

Minimum design loads for EBT-P device structures considers the loads recommended by American National Standard A58.1. (Building Code Requirements for Minimum Design Loads for Buildings and Other Structures), the Southern Standard Building Code, seismic forces in accordance with the Uniform Building Code (UBC), and the special characteristics and loads of the EBT-P device. With the exception of the concrete structure which uses ultimate strength, the load factors and load combinations (limit loads) are intended to apply to all structural materials used in building construction to obtain one common and consistent set of loads throughout the structure. These load combinations result in loads which are at least as high as those required by various commonly used codes. The use of one set of limit design loads, independent of material, will minimize confusion, particularly sense some materials (e.g. A286, titanium, and copper) may not be covered by commonly used codes.

The design loads for EBT-P are dead loads, normal operating magnetic loads or magnetic fault loads, pressure loads, thermal loads, seismic loads, preloading, handling loads, shipping loads, and possibly vibratory loads. Although electromagnetic loads are live loads, they are always to be taken at the full actual value even though the codes sometimes allow reductions to live loads. Design loading conditions are selected combinations of these basic loads. The significance of and applicability of these basic loads depend on which component is being considered. Pressure and thermal loads can be applied to the device primary support structure through the toroidal vessel (plasma chamber) attachments. The device primary support structure holds the toroidal vessel in position and restrains the movement of the toroidal vessel due vacuum pressure loading and thermal growth. Many of the loads such as dead loads require iterations. Two iterations on dead loads have been completed.

The load combinations to be used reflect the low probability of the concurrent occurrence of a maximum intensity earthquake and loading due to faulty operation of the magnet protection system. This approach is consistent with the philosophy of building codes to not require design to low probability load combinations such as maximum wind loading and maximum seismic loading. The existence of concurrent dead, live and normal operation magnetic loads along with applicable factors of safeties or derating of strength capabilities and excess strength above the minimum required, provides confidence that many, if not all, low probability load combinations could still be handled without failure.

However, because normal operating magnetic loads are considered as live loads for the EBT-P device primary support structure, an exception to ACI-318 Section 9.3 load combinations for concrete structures is necessary. If a seismic event were to occur, there is a significant probability of full normal operation magnetic loads existing, along with dead loads. Because of the criticalness of magnet alignment the overload factor will not be allowed to minimize permanent deflections.
Thus, the factors of safety applied to dead and live loads will not be reduced by the multiplication factor .75 for the loading combinations including seismic loads.

Seismic loads are those loads due to the response of the structure to an earthquake. Seismic loads for Title I design were based on the Uniform Building Code (UBC) seismic criteria for seismic risk zone 2. Those seismic loads will be used as a minimum. The support structure will be designed to withstand separate equivalent static incremental accelerations of 0.15g in any horizontal direction and 0.10g in the vertical direction. For design of equipment attachment, the equivalent static incremental acceleration will be at least 1.0g in any direction. During Title II detailed design seismic response analyses will be performed to verify the adequacy of the Title I preliminary design acceleration levels because the device support structure does not resemble a building. If the seismic response analyses predicts higher seismic loads, then these higher loads would be used subsequently. Current judments are that the seismic loads will increase. The dynamic analysis will consider the EBT-P facility to be located in a zone 2 seismic risk area, as defined by the Uniform Building Code. The analysis will use the zone 2 design ground response spectra as defined by NRC Regulatory Guide 1.60 (Document 1.4.2), as shown in the Device Structural Design Criteria. Attachment loads of equipment and piping will also be determined as well as the need for deflection limiters and damping devices.

Other vibratory loads will tend to be local. Steps will be taken to isolate sources of vibration. Where the vibrations can't be isolated, they will be considered. The number of of cycles applied will be consistent with the expected number of operating hours for that vibration source for the 10 year operation of the EBT-P device.

Fatigue will be considered, but it is not expected to alter the design any due to the low stress levels resulting from meeting static strength requirements.

Any device primary support structure steel will satisfy the strength requirements of the "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings," as published by the American Institute of Steel Construction (AISC). The elastic design or working stress method will be used. The "Commentary on AISC Specification," will be used to interpret the codes intent and application. Strength criteria for stainless steel will be used that satisfies the intent of the AISC Specification.

The "Steel Construction Manual" published by the American Institute of Steel Construction (AISC) outlines the application of the AISC Specification and will be used as a guide for design of steel structures.

The "Specification for the Design of Cold Formed Steel Structural Members" and the "Specification for the Design of Cold Formed Stainless Steel Structural Members," published by the American Iron and Steel Institute (AISI), will be used, in conjunction with the "Steel Construction Manual," as a guide for design of lightweight steel structures.

The "Specification for Aluminum Structures," Aluminum Construction Manual Series, Section 1 and its "Commentary," published by the Aluminum Association, will be used as a guide to design aluminum structures such as the superstructure and the structural ring that supports the magnets. The superstructure supports the magnet protection system and many pipes, lines and wires. The "Specification for Aluminum Structures" is largely based on the "Specification for the Design, Fabrication and Erection of Structural Steel for "Buildings" and is intended to be consistent with the steel design philosophies while recognizing the different characteristics of aluminum.

Bolted mechanical joint design will use as a guide the "Specification for Structural Joints Using ASTM A325 or A490 Bolts," approved by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation and the Commentary on the specification published by the American Institute of Steel Construction. Criteria for other fasteners such as nonmagnetic fasteners used on the EBT-P device will be based on satisfying the intent of the specification for structural joints using ASTM A325 and A490 bolts. The joints will be sized to prevent adverse effect on magnet alignment during normal operating conditions or magnetic fault conditions.

Welded connections of the device primary support structure will be evaluated using the "Structural Welding Code," AWS D1.1, of the American Welding Society (AWS) as a guide in determining strength requirements.

Reinforced concrete parts of the device primary support structure will use as a guide the "Building Code Requirements for Reinforced Concrete" (ACI-318) and the "Commentary on ACI 318" for determining the minimum strength requirements, except that more realistic (and more conservative) load combinations will be used with seismic loading. Nonmagnetic stainless steel reinforcing rods will be used. Adjustments will be made for their strengths relative to standard rerods. The rerods will be welded for structural continuity in some areas and for electrical continuity many other places. Other stainless steel rods may be welded to the reinforcing rods to allow threading for mechanical attachment. The reductions in strength and cross section due to welding will be included in the strength calculations where applicable.

The grout between the aluminum bucking ring and the concrete support structure will be evaluated using the "Specification for Design and Construction of Loadbearing Concrete Masonry," by the National Concrete Masonry Assocation as a guide to strength requirements. Tension capability will not be counted on from the grout. Redundant loads paths will be provided across the grout. The redundant load paths are vertical and radial rods connecting the aluminum structural ring to the concrete ring portion of the primary support structure.

3.8 SUPPORT STRUCTURE STRENGTH CRITERIA SUMMARY

- All support structure of reinforced concrete shall meet the strength requirements of the Building Code Requirements for Reinforced Concrete (ACI-318) except that the load combination equations of Section 9.3 for a seismic event will not be reduced by the 0.75 multiplication factor. For conditions without seismic loading, the basic equation, $U = 1.4D + 1.7L$ shall apply. Capacity reduction factors shall be used as specified in the above document. These factors account for deficiencies in material strengths, workmanship, and dimensions.
- All support structure of structural steel shall satisfy the strength requirements of the Specification for the Design, Fabrication and Erection of Structural Steel for Buildings as published by the American Institute of Steel Construction.
- All support structure of cold-formed steel shall satisfy the strength requirements of the Design of Cold-Formed Steel Structural Members of the American Iron and Steel Institute.
- All support structure of stainless steel shall satisfy the strength requirements of the Specification for the Design of Cold-Formed Stainless Steel Structural Members as published by the American Iron and Steel Institute.
- All support structure welding shall meet the strength requirements of the Structural Welding Code AWS D1.1 of the American Welding Society.

- All steel or stainless steel high strength bolts shall meet the strength requirements of the Specification for Structural Joints Using ASTM A325 or ASTM A490 Bolts as published by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation.
- All support structure of aluminum shall satisfy the strength requirements of the Specification for Aluminum Structures, Aluminum Construction Manual, Section 1 of the Aluminum Association.

3.9 MISCELLANEOUS STRUCTURES STRENGTH CRITERIA

The strength requirements of all structural components not addressed by a specific code or specification discussed above or in the Device Structural Design Criteria will be based on a factor of safety of 2.0 for ultimate strength and no detrimental deformations at limit load.

4.0 DESIGN DESCRIPTION

The support structure is comprised of a primary support and a superstructure. The function of the support structure is to provide support for the device and much of the related ancillary equipment. The mirror coil magnets and the toroidal vessel are both cantilevered from the primary support which consists of a reinforced concrete ring supported by nine columns. The superstructure is a nine sided truss structure which is mounted above the concrete ring and provides support for the magnet protection system, cryogenic and vacuum manifolds, ECRH distribution manifolds, and instrumentation and control wire trays. The block diagram shown on Figure 4-1 shows the various subsystems which are supported by and/or interface with the support structure. Every subsystem interfaces in some way with the support structure.

4.1 PRIMARY SUPPORT

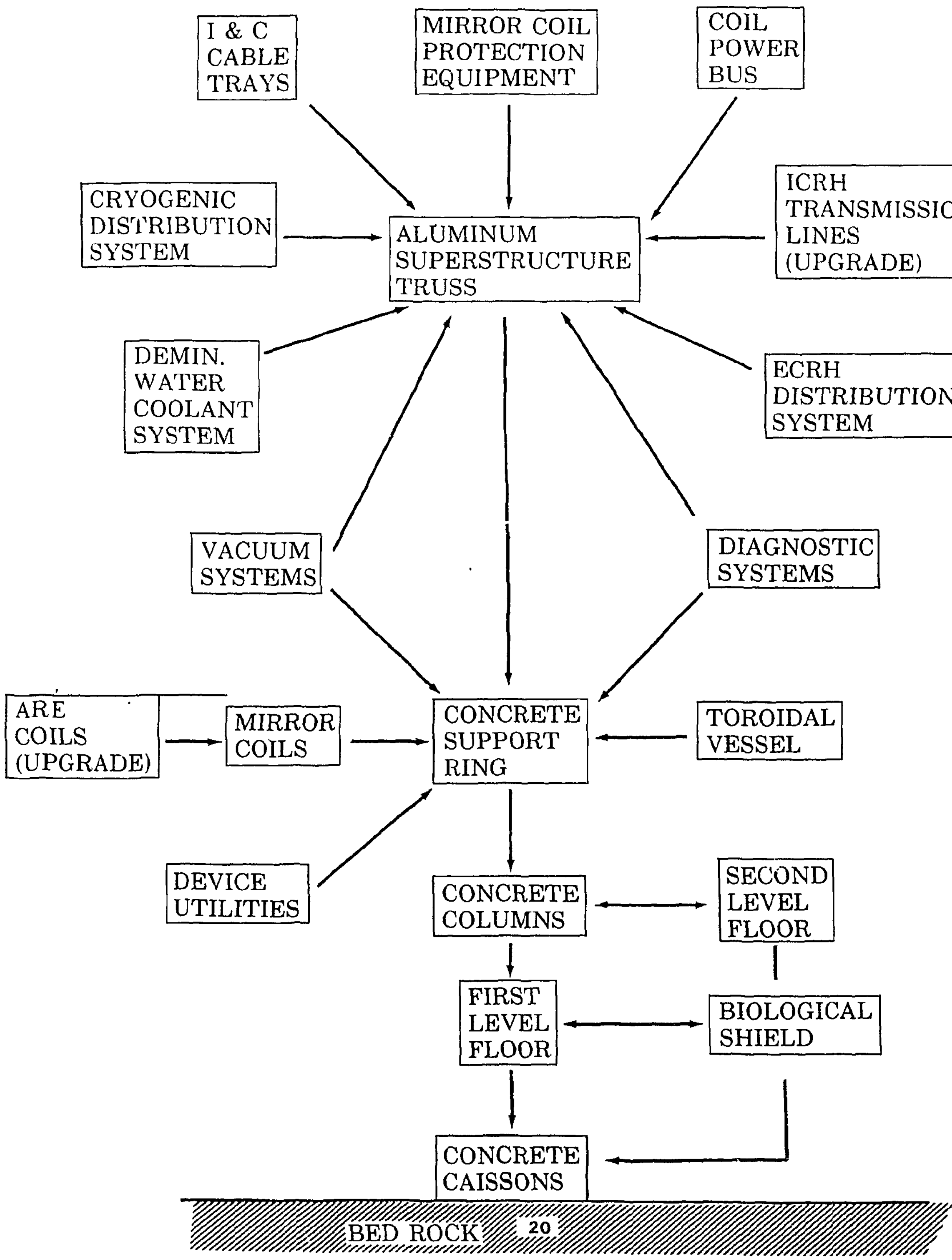
The primary support structure is shown in Figure 4-2 (DWG 70B372002). It consists of non-magnetic reinforced concrete ring supported by nine reinforced concrete columns. The concrete ring has a cross-section of 24 inches (61 cm) by 48 inches (122 cm) deep and is positioned such that the torus centerline is held eight feet above the second level floor of the device enclosure building. An outer aluminum ring (DWG 70B372008) is attached to the outer periphery of the concrete ring. The aluminum ring provides mounts for the mirror coil magnets in addition to providing attachment points for the toroidal vessel support.

The outer ring is fabricated in 9 segments which are installed and aligned on the concrete ring prior to grouting in place. Provisions on the outer ring, such as jack screws and threaded tie bolts are used for adjustment of the ring during alignment. Preliminary alignment procedure were written during Title I and can be found in the Title I report of magnetic system, Vol. III. More detailed procedures will be written during Title II.

4.2 SUPERSTRUCTURE

The superstructure is a welded aluminum truss structure which provides mounting platforms for the magnet protection equipment. The upper platform supports the nine magnet

FIGURE 4-1. SUBSYSTEM INTERFACES WITH SUPPORT STRUCTURE



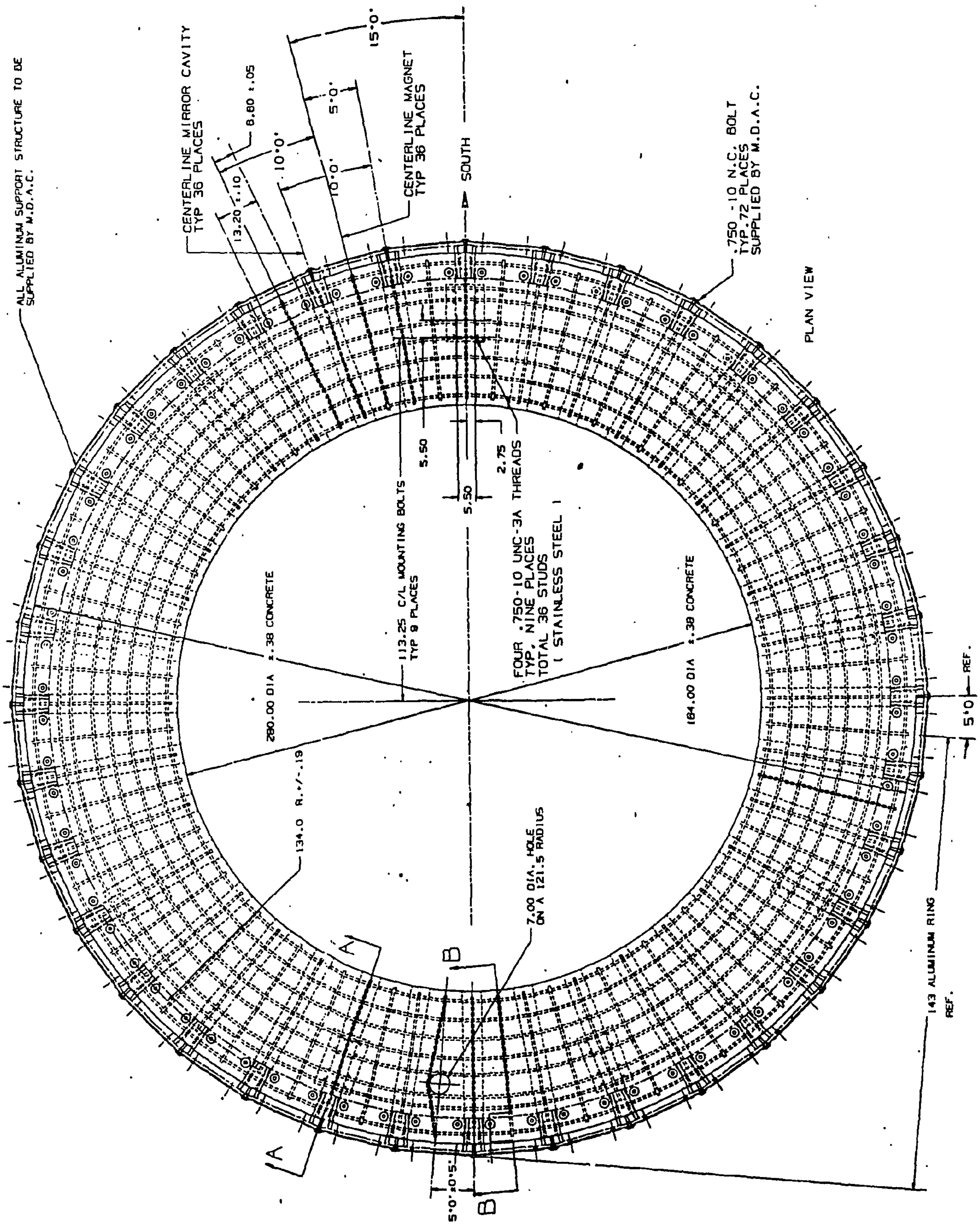
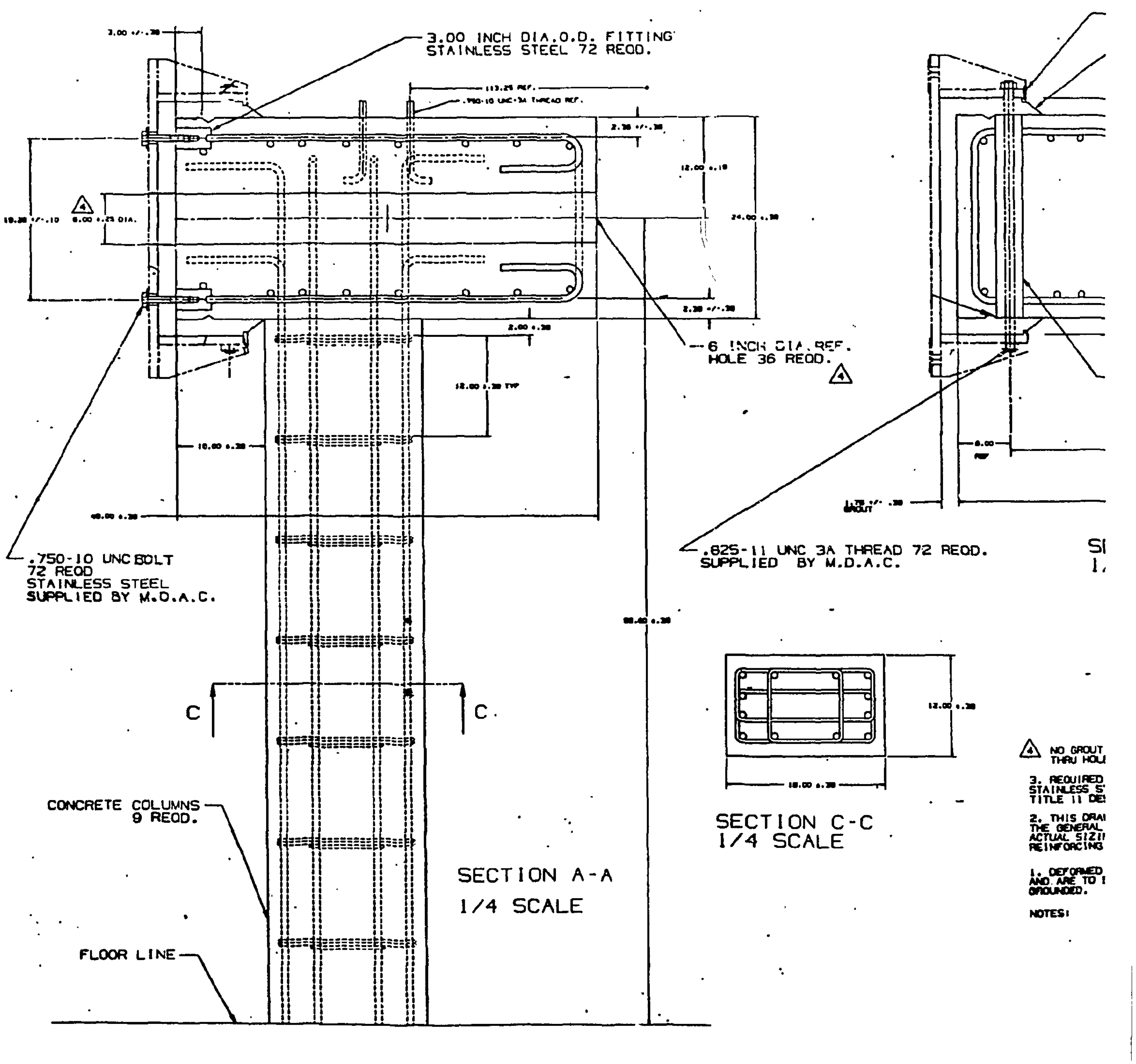
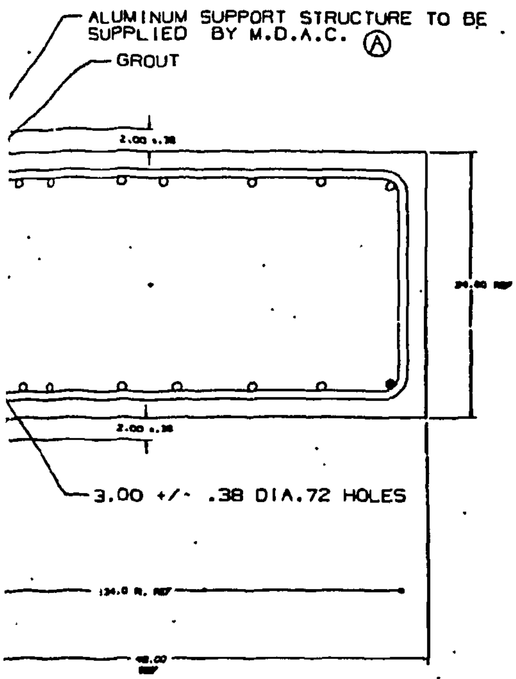


FIGURE 4-2a. PRIMARY SUPPORT STRUCTURE PLAN VIEW

FIGURE 4-2b. PRIMARY SUPPORT STRUCTURE SECTION VIEWS





SECTION B-B
1/4 SCALE

NO GROUT IS TO BE PLACED THE SIX INCH DIA. THRU HOLE AREA 36 HOLES.

. REQUIRED MATERIAL STRENGTH OF THE CONCRETE AND NON-MAGNETIC 'AINLESS STEEL REINFORCING ROD WILL BE DETERMINED DURNING ITLE II DESIGN.

. THIS DRAWING IS AN ENVELOPE DRAWING TO SHOW E GENERAL LAYOUT AND INTERFACES OF THE SUPPORT STRUCTURE. TUAL SIZING AND PLACEMENT OF THE NON-MAGNETIC STAINLESS STEEL INFORCING RODS WILL BE PERFORMED DURING TITLE II DESIGN.

DEFORMED REINFORCING BARS ARE NON-MAGNETIC STAINLESS STEEL D ARE TO BE WELDED TO FORM ONE CONTINUOUS CIRCUIT, AND WILL BE OUNDED.

ITES:

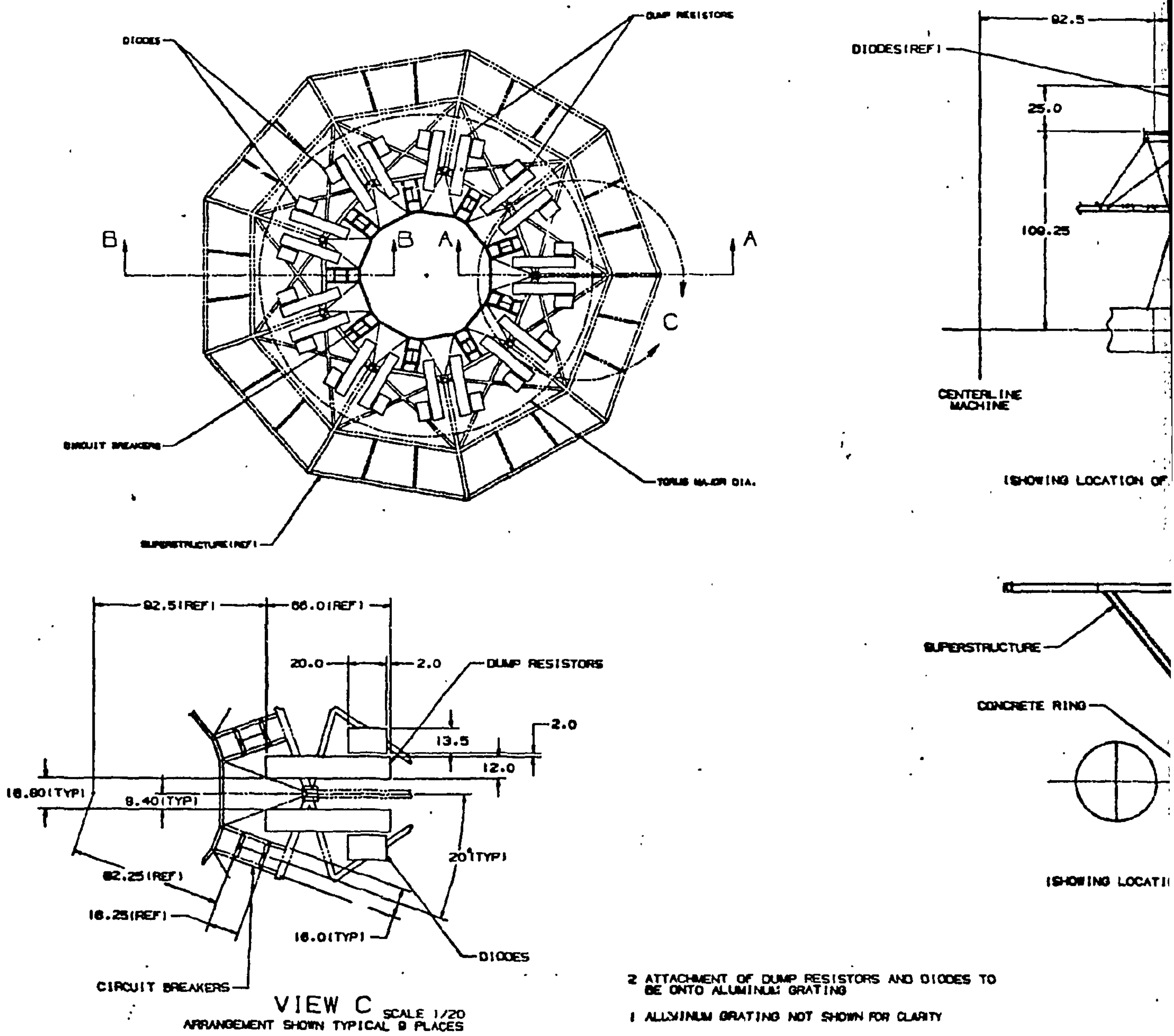
dump resistors, diodes, and connecting bus. (Figure 4-3, DWG 70B376000) The lower platform supports nine circuit breakers. An I&C cable tray rests on the upper platform which allow cables to drop to equipment around the torus. The cryogenic manifolds hang below the upper platform and various lines are dropped down to the magnet dewar stacks. The superstructure, being located above the toroidal vessel, allows for most ancillary equipment to be suspended above the torus and thus provides greater experimental and diagnostic access to the device.

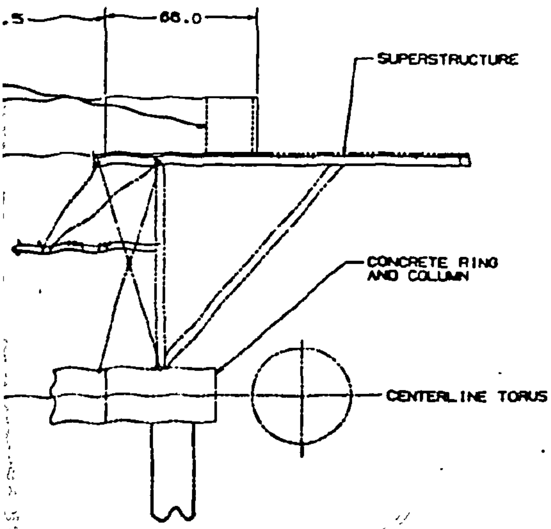
The upper platform has a "nonagon" shaped plan view, incorporating primary members which are loaded in axial, bending, and torsion, and secondary members loaded mainly in bending. (Figure 4-4)

Nine "gallows" frames form the vertical plan structure and are located over the nine concrete columns of the support structure. Vertical forces are transmitted as axial loads in these frames and transferred to the support structure through 4-3/4" dia. studs at nine places. The "gallows" frames are attached by the studs which pick up a baseplate on the frames. Horizontal forces, due to seismic loadings, are transferred to the concrete ring via pre-loaded diagonal tension members which run from the top of each frame vertical member to the base of the adjacent frame vertical member. From a weight and structural efficiency standpoint the members of the superstructure are mainly square or rectangular aluminum tubes, the exception being the diagonal tension members; these are round aluminum bars. The inner lower platform support the magnet protection equipment circuit breakers and control panels for the toroidal vessel and limiter coolant system. Provision will also be made for mounting four turbomolecular pumps used on the vacuum system to evacuate magnet dewars. Comprised of aluminum angle and zee sections the platform is supported by struts extended from the inner rails of the platform to the top of the vertical member of the frames. The outboard side of the platform is supported by a horizontal member in the plane of the platform running between adjacent vertical truss members. These members are braced by tying them into the diagonal tension member.

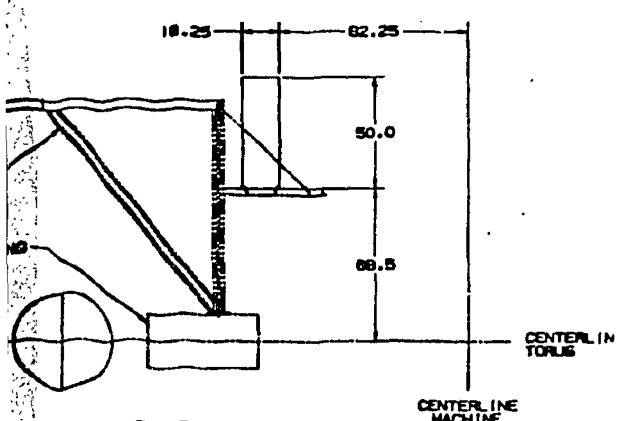
A commercial structural grating is bolted to the upper platform, and provides support for the magnet protection system components, support brackets for the system manifolds, magnet power bussing, and the I and C wire trays. Access holes are provided through the grating for any drops to the torus, e.g. power feed to the coils.

FIGURE 4-3. MAGNET PROTECTION SUPPORT ARRANGEMENT



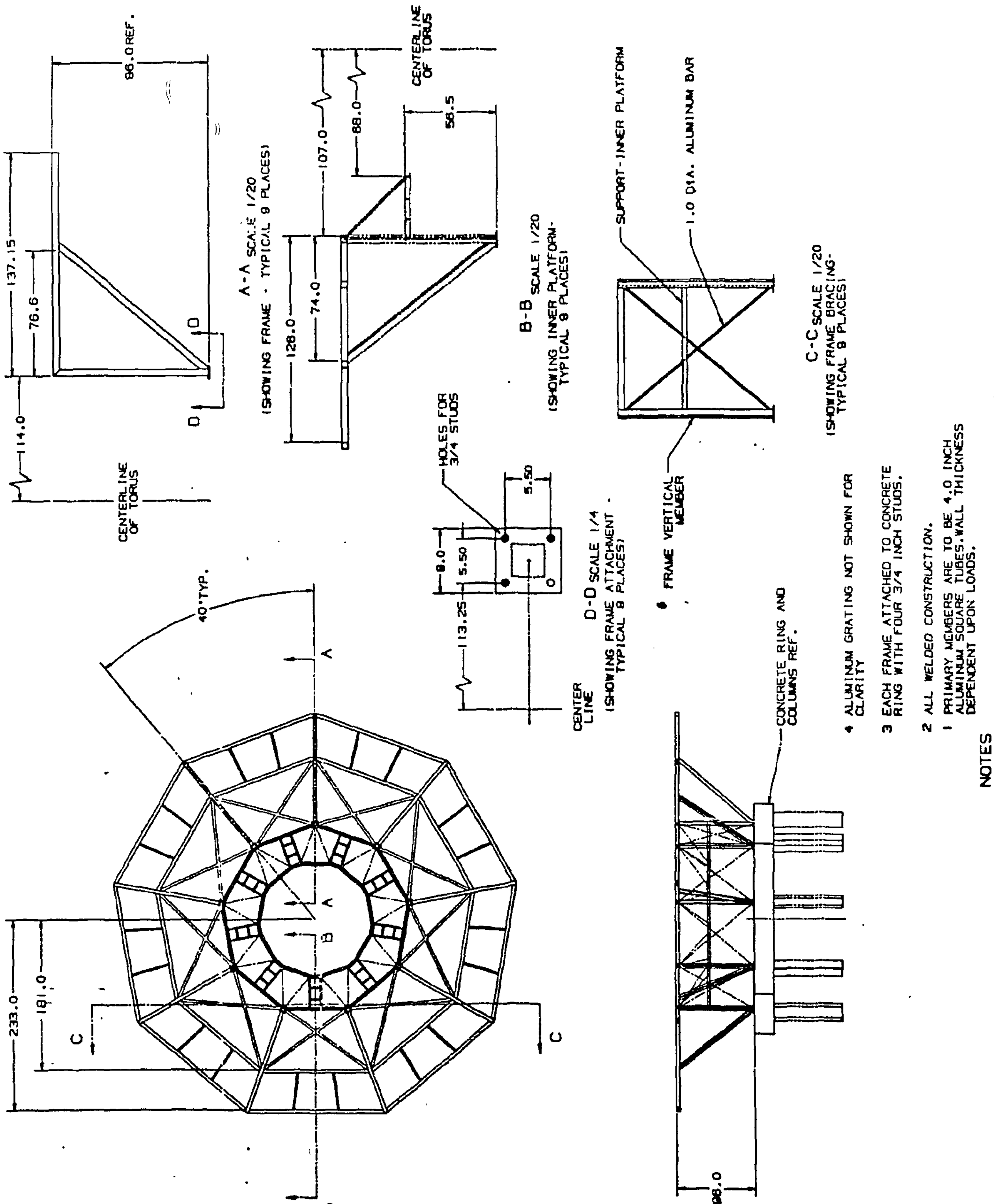


A-A SCALE 1/20
LOCATION OF DUMP RESISTORS AND DIODES)



B-B SCALE 1/20
ING LOCATION OF CIRCUIT BREAKERS)

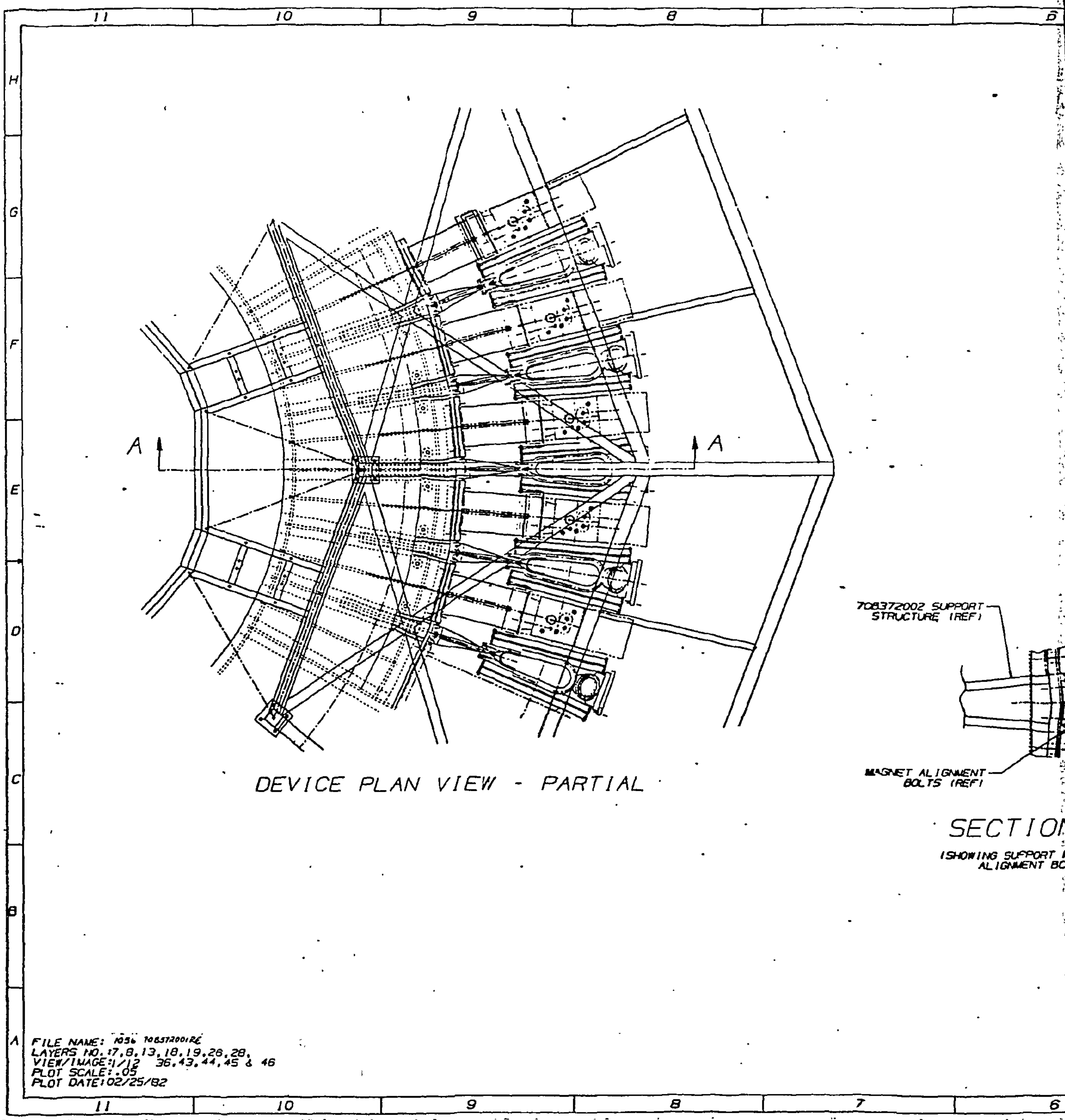
FIGURE 4-4. SUPERSTRUCTURE



4.3 TOROIDAL VESSEL SUPPORT

The toroidal vessel support consists of two support members at each mirror cavity. (Figure 4-5, DWG 70B372001) The toroidal vessel support arrangement constrains the vessel from radial growth during operation and thus prevents loads from going into the magnet dewar which might affect the magnet alignment. Thermal circumferential growth of the vessel is allowed by flexing of the vacuum liner side walls.

Each of the 36 toroidal vessel segments is supported from the aluminum outer ring of the Primary Support structure by two members located at the upper and lower edge of the ring and in a vertical plane. The lower member is a cantilever beam designed to carry radial, vertical, and lateral loads. The upper member is a pin ended strut capable of only axial loads in the radial direction. Radial and vertical adjustment of the toroidal vessel segments is accomplished by eccentric bushings in the lower beam and corresponding length adjustments of the upper strut.


11
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A
DEVICE PLAN VIEW - PARTIAL
708372002 SUPPORT STRUCTURE (REF)
MAGNET ALIGNMENT BOLTS (REF)
SECTION
(SHOWING SUPPORT
ALIGNMENT BO
FILE NAME:
LAYERS NO.:7,8,13,18,19,26,28,
VIEW/IMAGE:1/12 36,43,44,45 & 46
PLOT SCALE:.05
PLOT DATE:02/25/82
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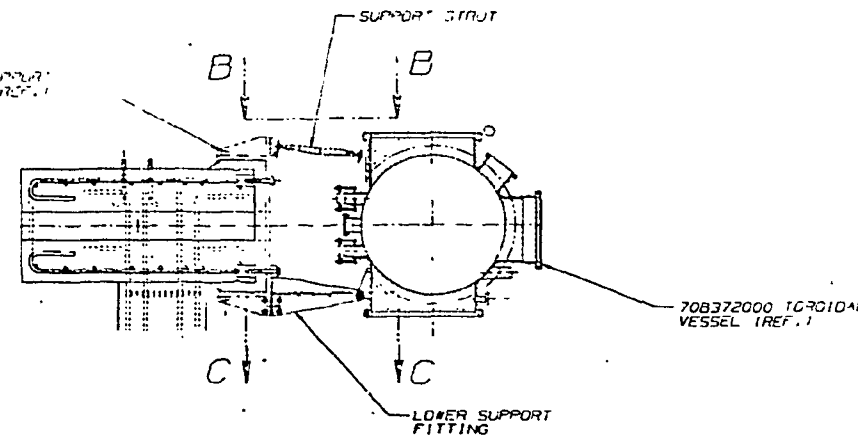
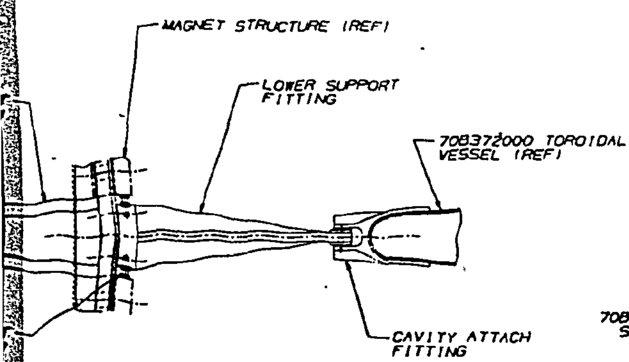


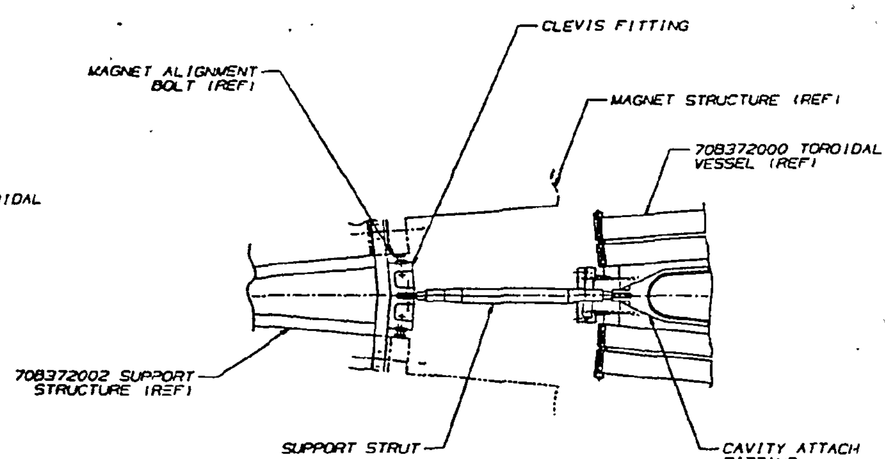
SECTION A-A

(SHOWING TOROIDAL VESSEL SUPPORT SYSTEM)
TYPICAL 36 PLACES



CTION C-C SCALE 1/4

NG SUPPORT FITTING INCORPORATING
LIGNMENT BOLTS FOR MAGNET)



SECTION B-B SCALE 1/4

(SHOWING RADIAL PLANE ORIENTATION OF SUPPORT STRUT)

NOTES:

1. TOROIDAL VESSEL VACUUM CAVITY SEGMENT IS ALIGNED WITH THE VACUUM LINERS BY MEANS OF ECCENTRIC BUSHINGS AND SHIMS ON THE LOWER SUPPORT FITTING AND BY ADJUSTING THE LENGTH OF THE SUPPORT STRUT

APPROVED TITLE I

EBT-P, TOROIDAL VESSEL SUPPORT

E 76301 70B372001

#58.S 2.1.9

5.0 SUPPORTING ANALYSES

The support structure for the EBT-P device is shown in Figure 4-4. To determine the internal load distributions a NASTRAN finite element model was constructed on the device support structure. This model includes the concrete ring, columns (down to ground level), and the aluminum superstructure. Dead weight loads, electromagnetic loads and seismic loads were applied to determine internal load distributions.

The NASTRAN finite element model is shown in Figure 5-1. Beam elements were used to represent the concrete ring, columns, and superstructure. The base (first floor level) of each of the nine columns were constrained against movement and rotation. At the second floor level the columns were constrained from lateral movement only. To transfer the loads from the center of the mirror coils and toroidal vessel to the concrete ring, very stiff beam elements were used. During Title II detail design the model will be updated and refined to include the actual stiffnesses. The out-of-plane struts connecting the mirror coils will also be modeled. The lateral stiffness of the mirror coils room temperature dewars, toroidal vessel struts, and other structural members will also be modeled. Also during Title II a structural stability analysis of the toroidal array will be performed to ensure that mirror coil alignment is maintained.

Material properties for a 4000 psi strength concrete were used. A 5000 psi strength concrete will likely by used during Title II. For the reinforcing rods, 316 austenitic stainless steel material properties were used. Aluminum alloy 5456 material properties were used for the metal bucking ring and superstructure. For the concrete ring elements an equivalent stiffness was used. This equilavent stiffness included the 2 ft x 4 ft concrete cross section, the stainless steel reinforcing rods bars and the 1.0 inch thick aluminum ring.

5.1 PRIMARY SUPPORT STRUCTURE ANALYSES

The dead weight loads acting on the concrete support structure are summarized in Figure 5-2. The dead weight loads acting at the center of the mirror coil result from the weight of the mirror coil, ARE coils, out-of-plane struts, and field correction coil. Dead weight loads acting at the toroidal vessel centerline include the weight of the vacuum liner, mirror cavity, flanges, coolant, and instrumentation. A dead weight load of 139 lbs/in. of circumference acting on the concrete support structure includes the weight of the concrete ring,

FIGURE 5-1. NASTRAN FINITE ELEMENT MODEL OF THE DEVICE SUPPORT STRUCTURE

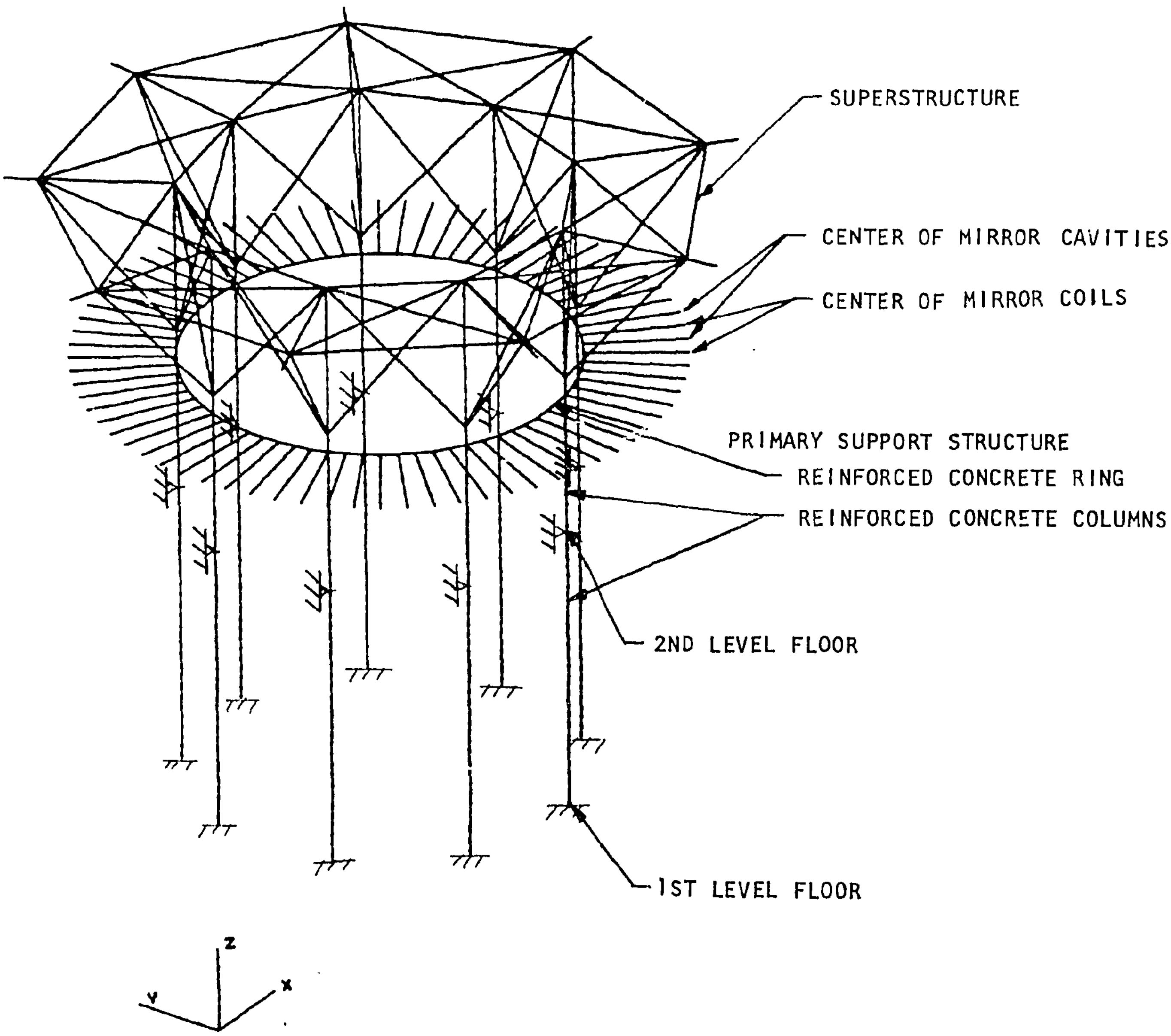


FIGURE 5-2. LOADS APPLIED TO DEVICE FINITE ELEMENT MODEL

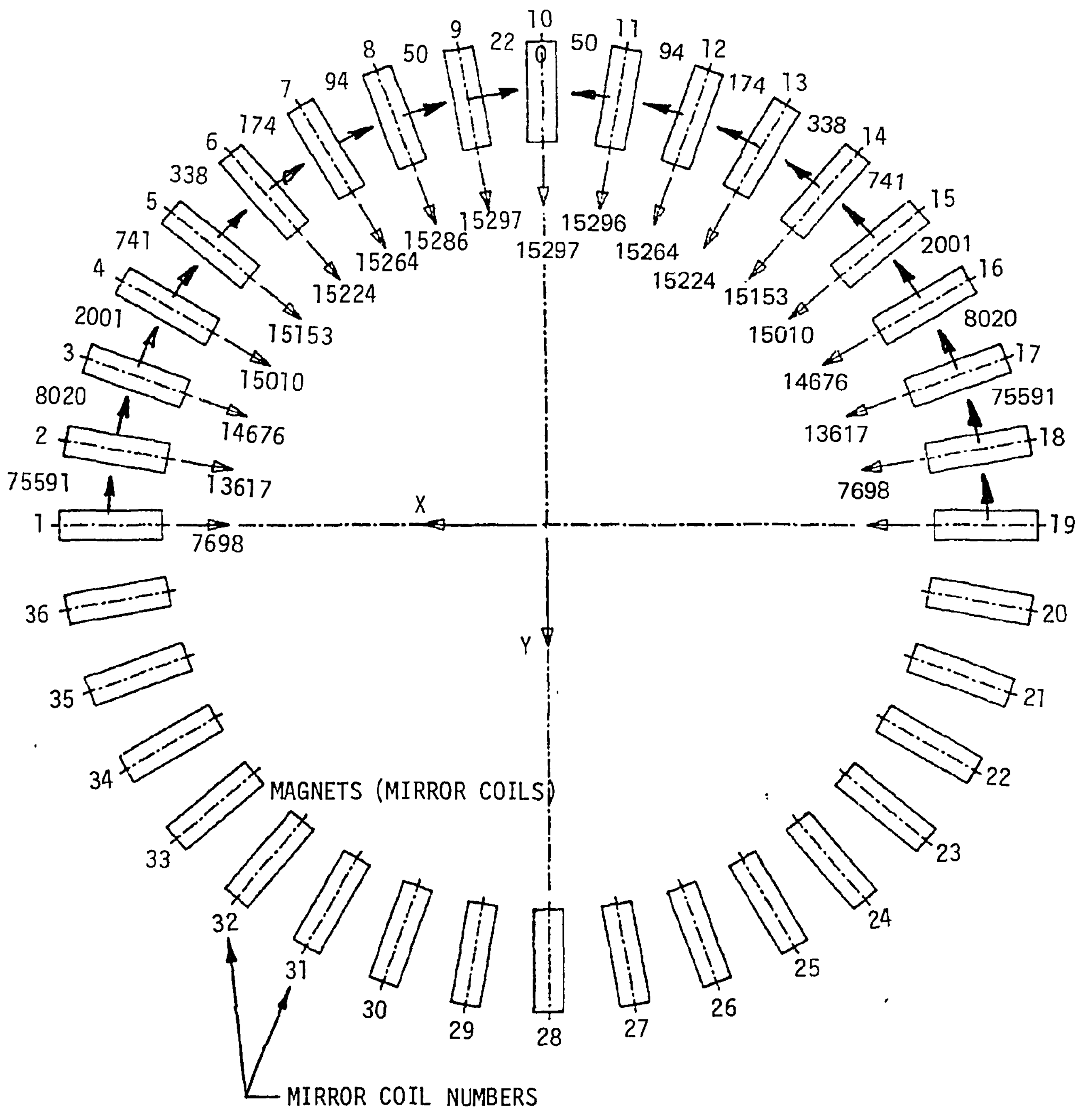
A) DEAD LOAD (WEIGHT)	
MIRROR COIL CENTERLINE	5717 LB/COIL
TOROIDAL VESSEL	863 LB/SECTOR
CONCRETE SUPPORT RING + EQUIPMENT	242 LB/IN OF CIRCUMFERENCE
SUPERSTRUCTURE + EQUIPMENT	75474 LB
B) LIVE LOAD	
MAGNET CENTERING FORCE	17900 LB/COIL
MAGNET OUT-OF-PLANE FORCE	75591 LB TOROIDAL (FAULT COND.)
C) SEISMIC LOAD	
HORIZONTAL	0.15g
VERTICAL	0.10g

grout, aluminum ring, coolant manifolds, and coolant. The dead weight acting on the superstructure includes the magnet protection equipment, cryo manifolds, ECRH distribution, vacuum system, wire tray, instrumentation, and coolant manifolds.

Live loads acting on the structure are electromagnetic forces. A centering force of 17,900 lb/coil results from normal operation. A load acting in the toroidal direction (out-of-plane) at the center of the mirror coil results when some of the mirror coils remain on during shut down of the device. A peak out-of-plane force of 75,591 lb occurs when half of the mirror coils remain on. The distribution of these magnet loads are shown in Figure 5-3.

Mechanical attachment of the mirror coils and the toroidal vessel to the concrete ring is made through the aluminum bucking ring that forms a rim around the outboard perimeter of the concrete ring. Stresses in the ring must be kept below the yield strength in order to maintain mirror coil alignment. The loads from the toroidal vessel are small relative to the loads from the mirror coils. During normal operation the loads from the mirror coils are a combination of dead weight, magnetic centering load, and preload of out-of-plane struts. The dead weight load includes the mirror coil, ARE coils, field correction coils, and the out-of-plane struts. The out-of-plane struts will be preloaded in tension to prevent free play in the magnet support attachment during normal operations. Seismic loads add to the normal operating loads for seismic conditions. The highest loading on the bucking ring occurs during a magnetic fault condition. Seismic loading in the toroidal direction are expected to be much smaller. The stresses in the aluminum bucking ring could exceed the

FIGURE 5-3. MAGNETIC FAULT LOADS
(HALF OF MIRROR COILS ON)



yield strength during a magnetic fault condition if the out-of-plane struts were not effective in balancing loads between mirror coils. The struts are expected to be effective in supporting the outboard end of the mirror coils. The update of the structural model during Title II will include the out-of-plane struts and the flexibility of the mirror coil attachment. Gussets have been added to the bucking ring adjacent to the mounting bolts to lower the local bending stresses.

Seismic loads were also included in the analysis of the concrete support structure. These seismic loads were calculated based on the Uniform Building Code method for a seismic risk zone 2. The equivalent static incremental acceleration of 0.15 g in any horizontal and 0.10 g in the vertical direciton were applied noncurrently. A dynamic response analysis for seismic motion has been initiated to improve seismic loading estimate for use in Title II.

The dead loads, live loads, and seismic loads were applied to the NASTRAN finite element model according to the load combinations given in the Concrete Building Code (ACI-318). These load combinations are shown in Figure 5-4. However, further study indicated that because normal operating magnetic loads are considered as live loads, an exception to ACI-318 is necessary. If a seismic event were to occur, there is a significant probability of full normal operation magnetic loads existing, along with full dead loads and magnet alignment is critical. Therefore, the factors of safety applied to dead and live loads will not be reduced by the multiplication factor 0.75 (overload factor). This change will be incorporated into the load combination conditions during detail design (Title II). The seismic loads and the electromagnetic fault loads were not applied simultaneously.

FIGURE 5-4. LOAD COMBINATIONS APPLIED TO STRUCTURE. BASED ON ACI 318

1) 1.4 DL + 1.7 LL
2) 1.05 DL + 1.275 LL + 1.4025 EH
3) 1.05 DL + 1.275 LL + 1.4025 EV
4) .9 DL + 1.43 EH
5) .9 DL + 1.43 EV
6) MAGNET FAULT CONDITION

DL - DEAD LOAD
LL - LIVE LOAD
EH - HORIZONTAL EARTHQUAKE LOAD
EV - VERTICAL EARTHQUAKE LOAD

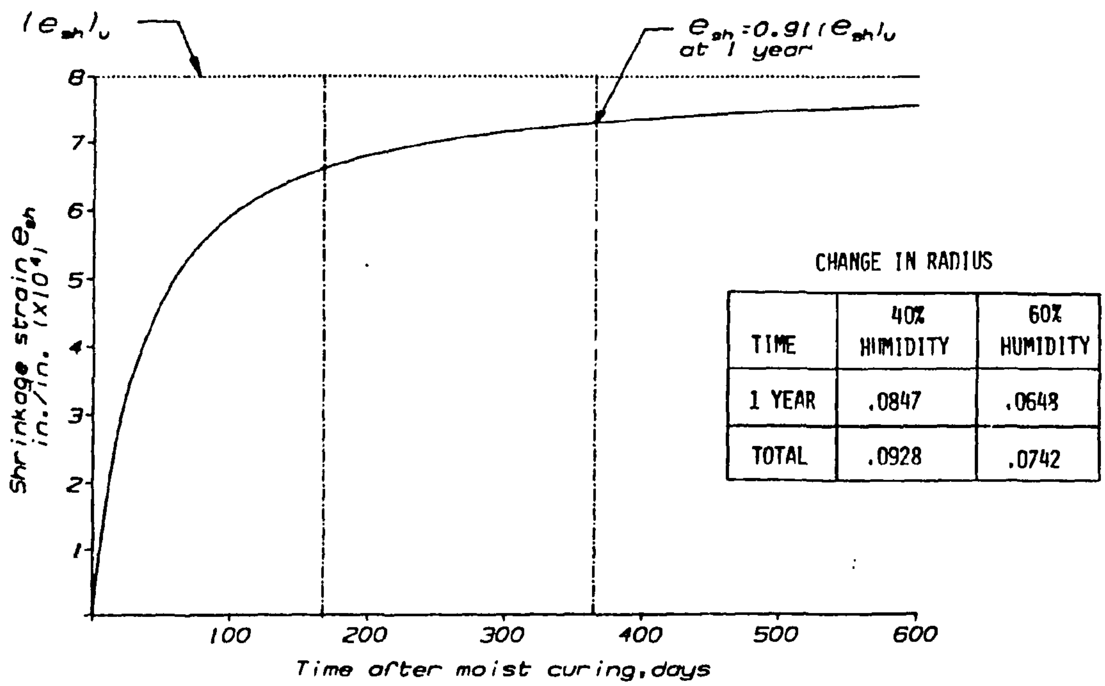
Maximum loads in the reinforced concrete ring and reinforced concrete columns result from addition of the dead weight and live load combination (1.4DL + 1.7LL) with the magnetic fault conditon loads. Peak loads acting on the structure occur at the interseciton of the concrete ring and vertical columns. The peak loads on the vertical columns are a 210 ft kips bending moment and a 80 kips axial load. To carry these loads in the 12 inch by 18 inch rectangular columns 12 - #6 rods (0.75 inch diameter) were used. The reinforcing rods were positioned as shown in Figure 4-2b. To hold the vertical rods in position and provide lateral support so that individual rods cannot buckle #3 (.375 inch diameter) lateral ties were used. The location of these lateral ties are shown in Figure 4-2b. Reinforcing rods will be used to connect the second level floor to the columns. The number and sizes of these rerods will be determined during Title II when floor loading is finalized.

The maximum loads acting on the concrete ring were a 300 ft. kips bending moment acting about the long axis (four foot edge) and a 200 ft. kips bending moment acting about the short axis (two foot edge). The peak axial load in the ring was 153 kips. To carry these loads 16 - #6 rods were located as shown in Figure 4.2b. Lateral ties (#6 rods) were located as shown in Figure 4.2a.

During detail design (Title II), loads obtained from the refined model will be used to update the sizing and placement of the nonmagnetic stainless steel reinforcing rods. Required material strength of the concrete and nonmagnetic stainless steel reinforcing rods will also be defined. For preliminary design (Title I) a compressive strength of 4000 psi was used for the concrete and a tensile yield strength of 50,000 psi was used for the nonmagnetic stainless steel reinforcing rods.

Shrinkage of the concrete was considered to determine total movement of the structure. The dimensional stability of the concrete support ring after 1 year is shown in the cure time/contraction curve of Figure 5-5. Approximately 91% of the total shrinkage due to drying will occur within the first year. For the concrete bucking ring the shrinkage will be symmetric. The columns will also be getting shorter. At a 40% relative humidity, the estimated total change in radius of the concrete support ring is 0.0928 inch. After one year of curing, the concrete will shrink an additional 0.0084 inches. If the ambient relative humidity is 60% the additional change in radius after one year of curing will be 0.0067 inch. These estimates do not include the stainless steel reinforcing rods which can reduce the

FIGURE 5-5. CONCRETE CURE TIME/CONTRACTION CURVE



CHANGE IN RADIUS

TIME	40% HUMIDITY	60% HUMIDITY
1 YEAR	.0847	.0648
TOTAL	.0928	.0742

Standard shrinkage strain variation with time after moist curing (for 4 in. or less slump, 40% ambient relative humidity and minimum thickness of member 6 in. or less, after 7 days moist cured). Reference 1

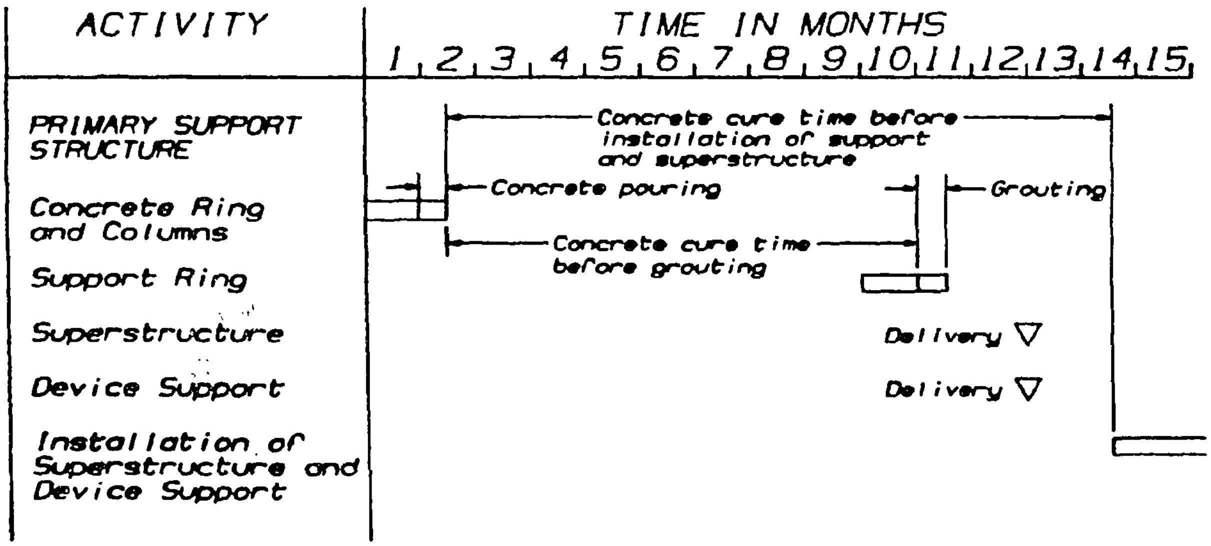
amount of shrinkage by 50%. Other factors that affect the amount of shrinkage are: amount of water per unit volume of concrete, amount of aggregate, size of aggregate, and type of aggregate. At the time alignment is done, updated estimates of the remaining shrinkage will be made. Because of the symmetry, the residual shrinkage will not alter the accuracy of magnetic field closure.

Fabrication and installation schedule for the support structure is shown in Figure 5-6 to reflect the 1 year concrete cure time before installation of the device and superstructure.

5.2 SUPERSTRUCTURE ANALYSES

A preliminary structural analysis of the magnet protection subsystem support structure was performed using a finite element model to determine the internal load distribution.

FIGURE 5-6. FABRICATION AND INSTALLATION SCHEDULE



The loading applied to the model represented the dead weight of the magnet protection subsystem components with a load factor applied to account for seismic accelerations. A conventional strength analysis of the individual beams was performed using the internal loads thus determined.

The computer program used to construct and run the finite element model is called 3DFSAP, a 3-dimensional frame structural analysis program. The code was written by TRW and is maintained by McDonnell Douglas Automation Co. as an interactive analysis program. This interactive code was used because it allows rapid screening of truss concepts. Bar elements in 3DFSAP are linear elastic and are capable of carrying axial loads, shear loads and bending moments. Forces must be applied at nodes.

A CRT graphics generated representation of the support structure model is shown in Figure 5-7. The model has 27 nodes and 81 bar elements. The support structure frame simulates a space truss with redundant pinned-end numbers, i.e. the members are loaded axially utilizing primarily the stiffest load path. The members were modeled and are planned to be built with 4 inch square tubing to provide multi-directional moment-carrying capability for mounting of discrete mass items and for load path redundancy (through bending of truss members). The 9 nodes which represent the interfaces with the massive concrete support structure were constrained from all rotations and translations. The superstructure is attached to the concrete support ring at nine pads by 4-3/4 in. bolts set in the concrete at each pad location.

A list of all the major mass items which are supported by the superstructure is given in Table 5-1. In addition, the weight of the superstructure and the aluminum grating were included. Since the 3DFSAP code requires the loads to be input as point loads at the nodes, the loading from component and support structure distributed masses were resolved into point loads and concentrated moments and applied to the model. A load factor of 4.5 g's acting simultaneously in two horizontal transverse and one vertical direction was applied to the masses. These load factors were overly conservative, early estimates, based on Nuclear Energy (NE) Standards appropriate for individual component attachment analysis. They provide considerable latitude for accomodating any increase in component weights or additional components during the Title II detailed design phase. The primary consideration for the Title I analysis was to ensure that the structure provide adequate, efficient, and redundant load paths.

FIGURE 5-7. 3-D SAP FINITE ELEMENT MODEL OF THE SUPERSTRUCTURE

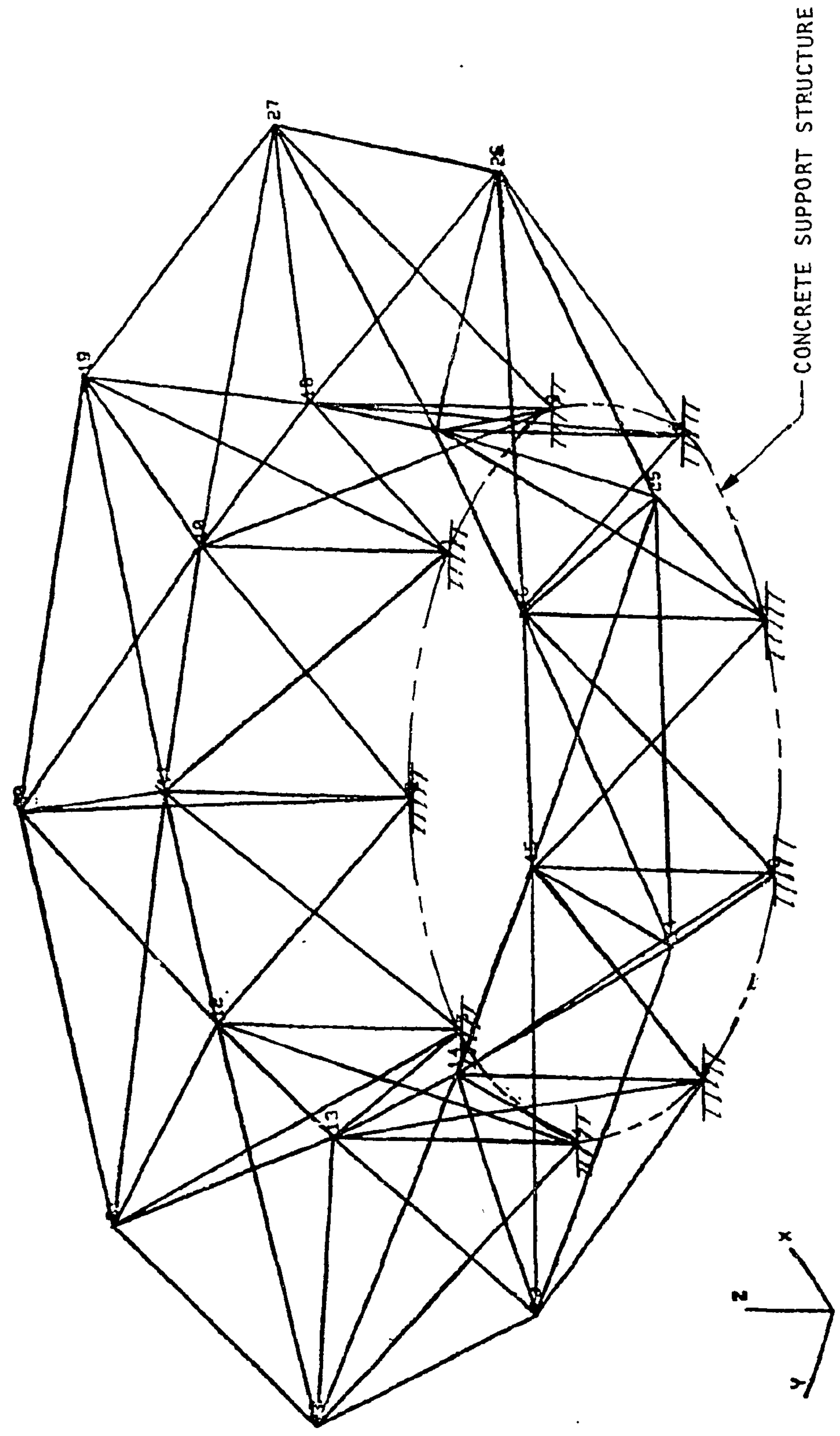


TABLE 5-1.

EQUIPMENT WEIGHTS ACTING ON ALUMINUM SUPERSTRUCTURE:	LBS.
BYPASS DIODE	1800
DUMP RESISTORS	3600
CIRCUIT BREAKERS	13500
SUPPORT STRUCTURE FOR MOUNT/BUS	1125
INSULATION/ISOLATION	1125
POWER BUSS AND CABLING	2700
CRYOGENIC MANIFOLDS	7740
ECRH WAVEGUIDES	9900
WIRE TRAY AND CABLES	9135
INSTRUMENTATION AND CONTROL PANELS	4500
VACUUM PUMPS FOR MIRROR COILS	400
MIRROR COIL VACUUM MANIFOLD SYSTEM	8760
COOLANT SUPPLY/RETURN MANIFOLDS	3672
ALUMINUM GRATING AND MISCELLANEOUS EQUIPMENT	3305

The results of the 3DFSAP code are member loads and node deflections. The maximum member forces and moments were selected and analyses were done for the critical loading on each member. These analyses included simple beam stress calculations as well as beam column stability checks. A summary of Margins of Safety is shown in Table 5-2. The element numbers referenced in column 1 of the table are shown in Figure 5-8. The margins are based on a tube wall thickness of .125 in. and material of 5456-H111 aluminum. This material was selected for its weldability and good post weld strength. The maximum deflection anywhere in the frame is 0.35 in. at the nodes on the outer periphery of the frame for the large seismic load factors used for this structure during Title I.

An aluminum grating will be mounted atop the superstructure to provide support for the magnet protection subsystem components and to provide convenient attach points for the various cryogenic manifold hangers. The grating beams the loads to the box members that frame the top platform. The diagonal box members in the top platform help support the grating. The grating selected in the preliminary design phase consisted of rectangular cross bars held together with swaged bars. Initial rough sizing held deflections to 0.5 in. and stress to 12 ksi maximum under maximum seismic loading. The Title II detailed analysis

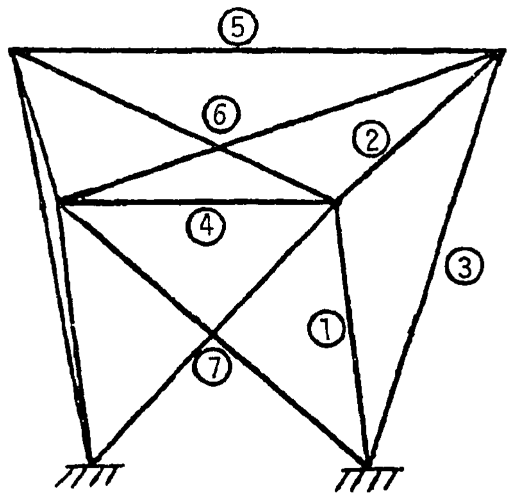
TABLE 5-2. MARGIN OF SAFETY SUMMARY

ELEMENTS	AXIAL LOAD-P (LB.)	BENDING MOMENT M (IN-LB)	CRITICAL FAILURE MODE	MARGIN OF SAFETY M.S. ⚠1
1	−9946	7976	BEAM-COLUMN BUCKLING	+.61
2	2654	37915	TENSION + BENDING STRESS	+.55
3	−5413	25914	BEAM-COLUMN BUCKLING	+.73
4	−5458	4066	BEAM-COLUMN BUCKLING	+.03
5	−2488	17479	BEAM-COLUMN BUCKLING	+.21
6	−4726	9215	BEAM-COLUMN BUCKLING	+.26
7	13360	—	DIRECT TENSION STRESS	+.17

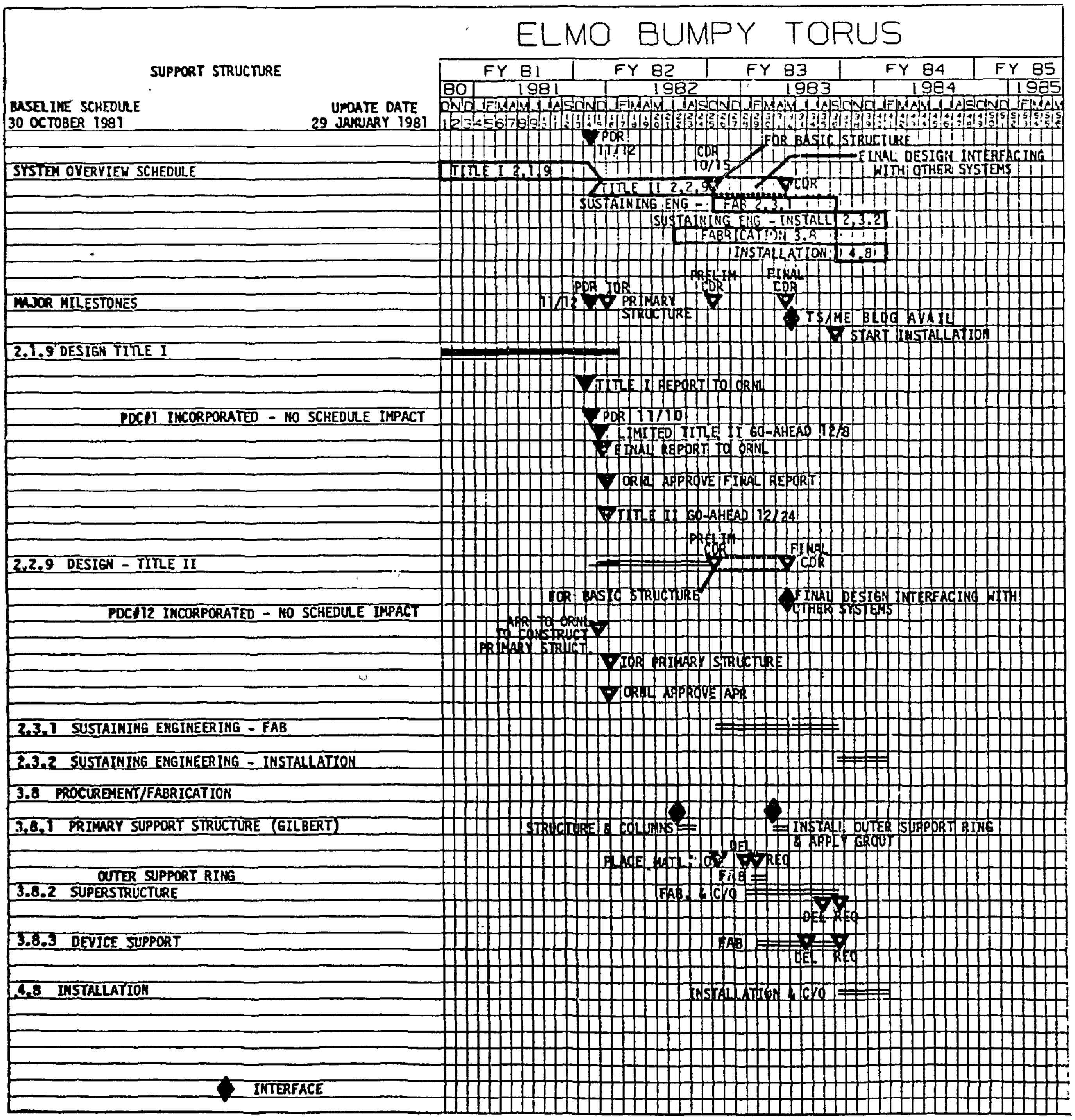
⚠1 A MEASURE OF THE RESIDUAL LOAD CARRYING CAPABILITY OF A STRUCTURE ABOVE THE APPLIED LOADS.

of the superstructure should allow some reduction in grating weight because of anticipated reduction in seismic load factors. The model of the superstructure will also be updated during Title II. Consideration of dead weight deflections at the outer perimeter of the superstructure will likely necessitate an increase in the tubing wall thickness.

FIGURE 5-8. ELEMENT NUMBERS FOR TABLE 5-2



6.0 SCHEDULES



7.0 REFERENCES

1. Dan E. Branson and M.L. Christiason. "Time-Dependent Concrete Properties Related to Design—Strength and Elastic Properties, Creep, and Shrinkage," *Designing for Effects of Creep, Shrinkage, Temperature in Concrete Structures* (SP-27). Detroit: American Concrete Institute, 1971 (pp. 257-277).

APPENDIX A

DEVICE STRUCTURAL DESIGN CRITERIA, EBT-P013

ELMO BUMPY TORUS - PROOF OF PRINCIPLE

DEVICE STRUCTURAL DESIGN CRITERIA

FEBRUARY 1982

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Table of Contents

1.0 Introduction

This document establishes the structural design criteria for the Elmo Bumpy Torus - Proof of Principle (EBT-P) experimental device. This device is intended to further the development of the technology needed to utilize the EBT concept for a full scale commercial fusion reactor. The criteria specified herein define the minimum levels of design requirements that will assure, with a high degree of certainty, the structural integrity of the device in a cost-effective manner.

1.1 Scope

The criteria specified herein are applicable to the EBT-P device and its associated equipment exclusive of the facility, the points of interface being at the bases of the device support columns and at the device utility connections.

1.2 Design Philosophy

The basic intent of this document is to guide the design of the EBT-P device using structural criteria normally approved for building construction as no specific structural design criteria exist for a device of this type. This approach will provide a reasonable continuity between the design of the device and the design of the facility. This approach has been used on similar fusion energy devices. Where it is deemed that building criteria are inadequate, such as in the magnet and vacuum system designs and in the application of seismic loads, a more conservative path will be followed. The EBT-P device will be designed as a non-nuclear structure as it is a plasma physics experimental apparatus that does not present the potential hazards normally associated with currently operating pressurized water reactors. Federal, state, and local regulations will be complied with where applicable to establish strength requirements. Where regulations are not available or where regulations are not appropriate due to the special nature of the EBT-P device, sound engineering judgement will be used.

1.3 Definitions

Design Conditions - The combinations of loads and temperatures, based on the structural design criteria, which uniquely establish the structural design requirements.

Detrimental Deformations - Structural deformations, deflections, or displacements shall not (1) cause unacceptable contact, misalignment, or divergence between adjacent components; (2) cause a component to exceed the dynamic space envelope established for that component; (3) reduce the strength or rated life of the structure below specified levels; (4) jeopardize the proper functioning of equipment; (5) endanger personnel; (6) degrade the functional characteristics of the experiment below specified levels.

Factor of Safety - Ratio of ultimate load to limit load used to account for uncertainties and variations from item to item in material properties, fabrication quality and details, and internal and external load distributions.

Limit Load - The maximum load, or combination of loads, which the structure is expected to experience in a specific condition.

Load Factor - Load factor in a given direction is the summation of all of the externally applied forces in that direction divided by the weight.

Margin of Safety - A measure of the residual load carrying capability of a structure above ultimate or yield loads.

Predicted Temperature - Predicted temperature is the worst case temperature any portion of the structure is expected to experience in a specific condition. Predicted temperature is analogous to limit load.

Stress Ratio - The ratio of minimum stress to maximum stress in a load cycle.

Structural Requirements - The values of specific parameters, such as loads and temperatures, associated with the conditions derived from the structural design criteria, and used to define the structural configuration.

Structural Design Criteria - The standards or rules by which judgements are formed relative to the design conditions and resulting structural requirements.

Ultimate Load - The product of the ultimate factor of safety times limit load.

Yield Load - The product of the yield factor of safety times limit load.

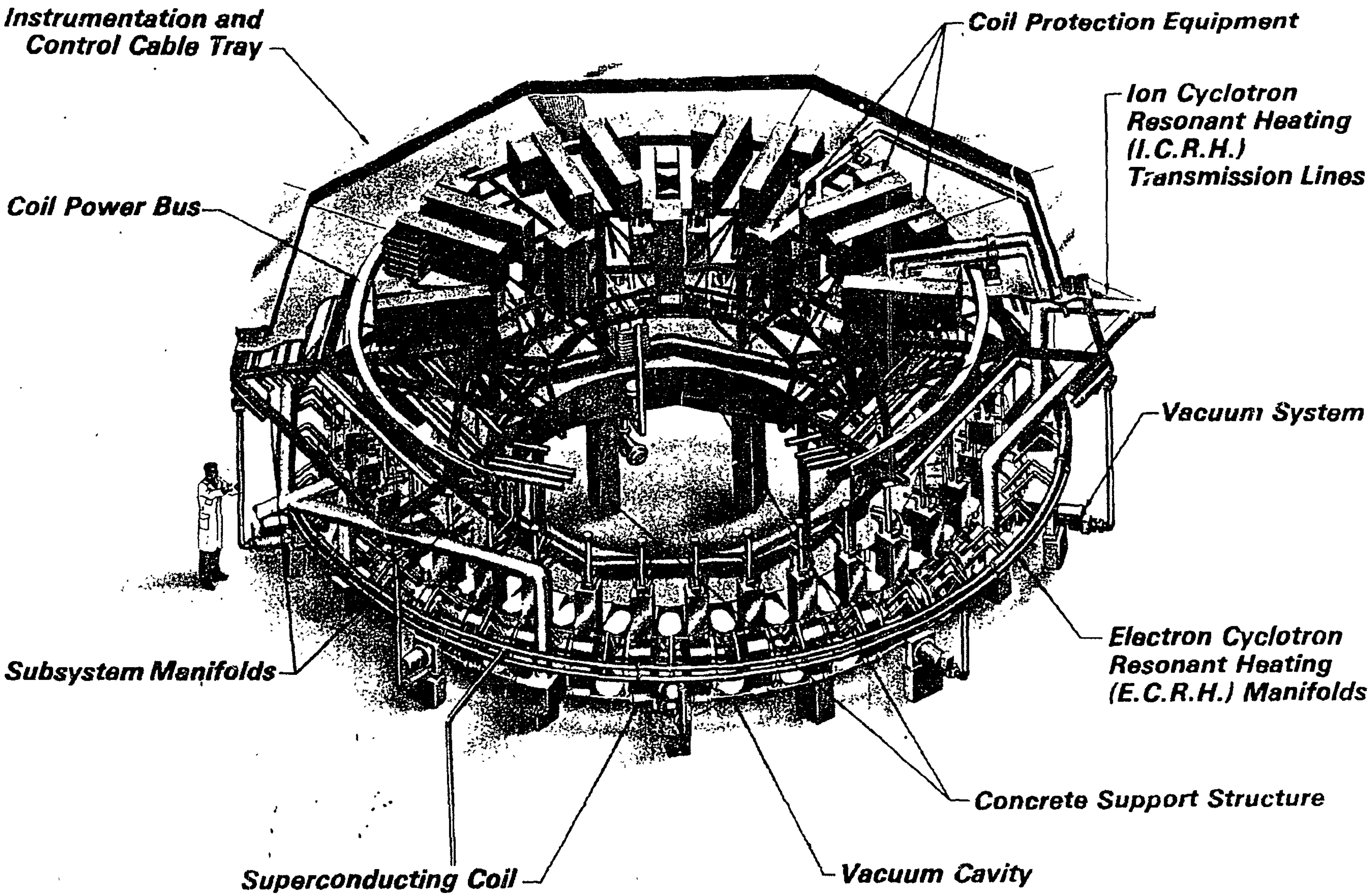
2.0 Device General Description

Figure 1 shows the EBT-P device. The heart of the device is the torus which consists of a toroidal vacuum vessel, 36 toroidal field (TF) magnet coils (also referred to as mirror coils) and 72 aspect ratio enhancement (ARE) magnet coils (which are to be added during a later device upgrade). It is within this vessel that a hydrogen plasma is confined by the magnetic field and heated by microwave energy to high temperatures. The major systems of the device are described in the following sections.

2.1 Toroidal Vessel System

The toroidal vessel is composed of 36 mirror cavity sectors alternating with 36 vacuum liner sectors. See Figures 2 and 3. The mirror cavity sectors contain actively cooled limiters which protect the vacuum liner walls from excessive heating and erosion from high energy plasma particles. Access and diagnostic ports are provided in each mirror cavity sector. The vacuum liner is located

FIGURE 1
EBT-P DEVICE



NOTE: ARE coils are not shown.

FIGURE 2
EBT-P TOROIDAL VESSEL COMPONENTS

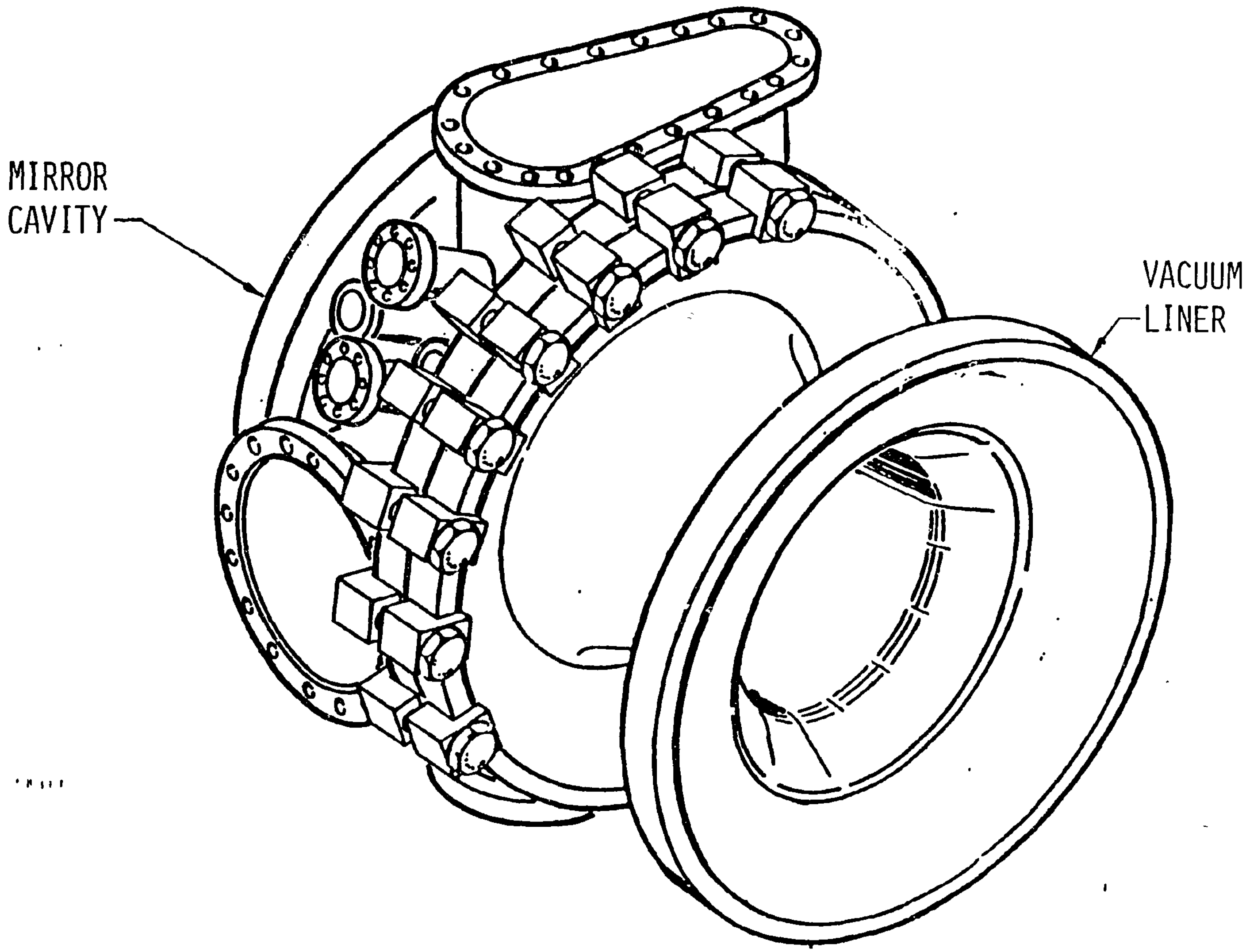
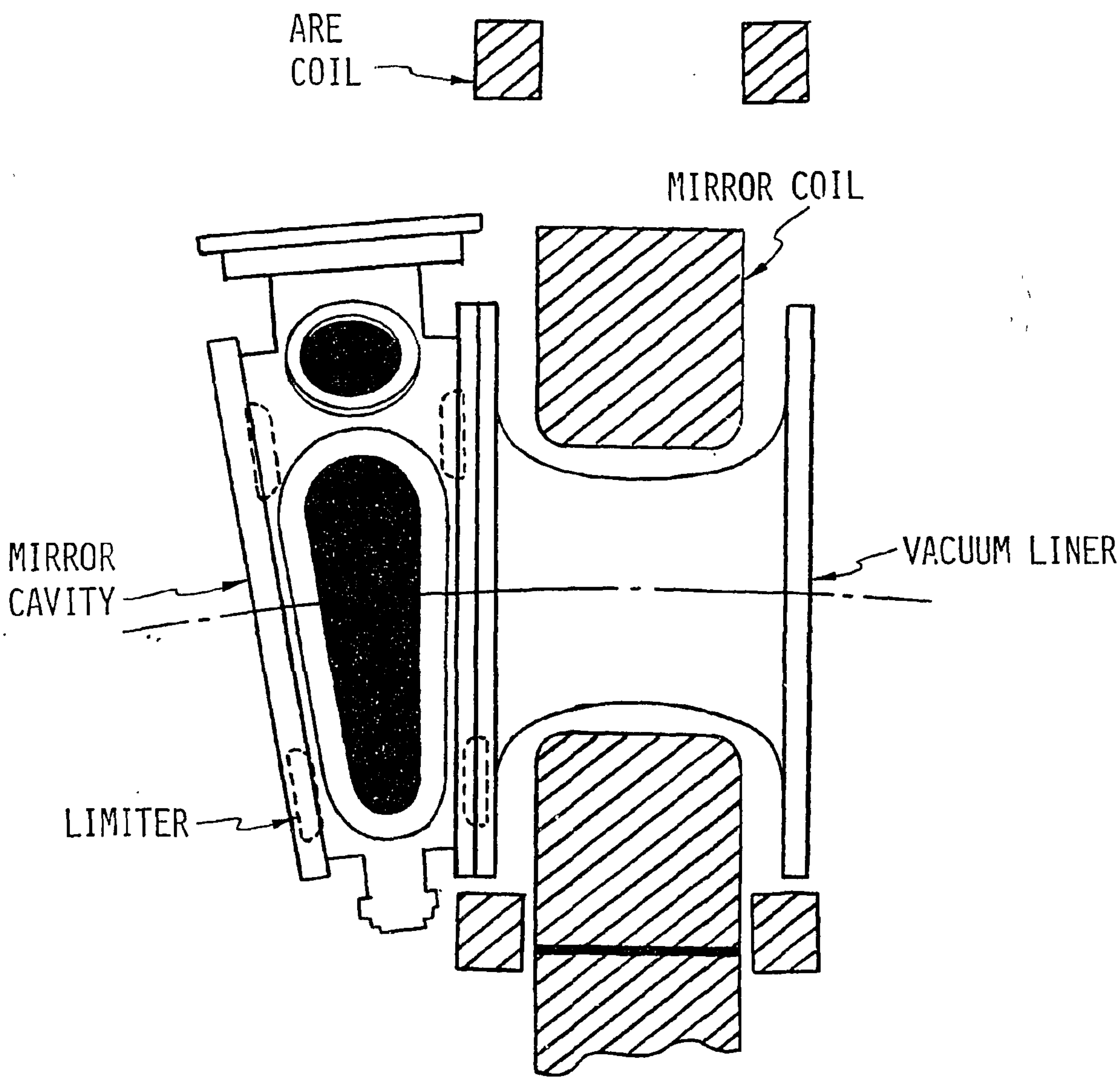


FIGURE 3
EBT-P TOROIDAL VESSEL AND
MAGNET COIL CONFIGURATION



in the bore of each TF coil with a radial clearance that results in the toroidal vacuum vessel being nonintegral with the TF coil assembly. The sidewall of each vacuum liner acts as a flex joint to accommodate thermal expansion and facilitate alignment of the torus. The toroidal vessel forms the first wall and is actively cooled.

2.2 Magnet System

The magnet system consists of the 36 superconducting TF coils and 72 ARE coils which are to be added during a later device upgrade. The geometry of the coils is shown in Figure 3. Each TF coil consists of a liquid helium cooled winding enclosed in a stainless steel case. The TF coils are mounted inside the room temperature vacuum dewar via tangential support struts that carry the magnetic loads from the coils, to the dewar outer ring, and then to the device support structure. Power is supplied to the TF coils from a high current dc power supply through helium vapor cooled leads connected in series.

The ARE coils are conventional magnet coils used to improve the plasma shape. They are connected in series to a power supply that is controlled separately from the TF coil supply. Current in the ARE coils may flow in either direction with respect to the TF coil current.

2.3 Microwave System

The microwave system consists of power supplies, electrical distribution systems, gyrotrons, microwave distribution tubing called waveguides, and miscellaneous distribution components. The microwave system is also known as the ECRH (electron cyclotron resonance heating) system.

The microwave system converts primary facility power to satisfy the specific power requirements of the microwave sources (gyrotrons). The microwave energy from the microwave sources is then distributed to the toroidal vessel to stabilize and heat the plasma to high temperatures.

2.4 Vacuum Pumping System

The vacuum pumping system provides independent vacuum pumping for the EBT-P toroidal vessel and for the TF coil vacuum dewars. The system includes roughing pumps to pump the toroidal vessel from atmosphere to 1×10^{-3} torr and high vacuum pumps to decrease the pressure to 1×10^{-7} torr. Provision is also made for accumulated gas removal and microwave shielding.

2.5 Instrumentation System

The instrumentation system is the basic control system of the EBT-P device. The system includes the data acquisition system, sensor and control elements, and device control and interlock elements.

2.6 Cryogenic System

The cryogenic system stores, supplies, distributes and controls helium and nitrogen required for device operation. Liquid and gaseous helium is supplied to the device in a closed loop. Nitrogen liquid and gas are supplied to the device in an open loop. A variety of piping and valves are used to supply these cryogenic coolants from storage tanks to mirror coils, gyrotrons, and cryopump panels.

2.7 Device Utilities

The device utilities consist of a demineralized water cooling system, electrical service, and instrument air systems. Instrument air is used as a pneumatic medium for device control.

2.8 Support Structure

The torus, TF coils and ARE coils are cantilevered from a nonmagnetic-steel-reinforced concrete ring which includes an aluminum outer rim used to facilitate mechanical attachment. The concrete ring is supported by reinforced concrete columns that extend up from the basement floor through the main floor. An aluminum truss superstructure is mounted atop the concrete ring and provides support for the magnet coil protection equipment, cable trays, and device piping.

2.9 Diagnostic System

The diagnostic system consists mainly of research diagnostics which are relatively complex instrument systems that are used to diagnose properties of the EBT-P plasma. The diagnostic system contains a wide array of mechanical and structural components.

3.0 Design Load Descriptions

The loads that will be used in the EBT-P design analysis are described in the following sections. These loads represent all the significant forces acting on the device.

3.1 Dead Loads

Dead loads are the loads produced by the weight of the equipment including structure, piping, instrumentation, insulation, and cooling fluids. Table 1 lists the design mass properties of the device equipment.

3.2 Normal Operating Magnetic Loads - Normal operating magnetic loads are those due to the operation of the magnets for the normal operating conditions of Section 4.1.

3.3 Magnetic Fault Loads

Magnetic fault loads are those due to the operation of the magnets for the magnetic fault conditions of Section 4.2.

3.4 Pressure Loads

Pressure loads are those loads due to the combination of internal and external operating pressures for the vacuum vessels, tanks, instrument air and coolant systems. External atmospheric pressure shall be 14.4 $\pm$ 0.5 psia. Internal pressure shall vary from 0 psi to the maximum operating pressure at operating temperature or pre-set relief pressure, whichever is greater. Over-pressure due to a nitrogen purge shall be considered. The structure shall be designed to withstand all other loads with or without pressure loads.

3.5 Thermal Loads

Thermal loads are loads due to temperature gradients through the structure and elongation or shrinkage due to temperature change. For the purpose of tolerance evaluation, as-built temperature shall be assumed to be 68°F except where it is known to be different as in brazing operations at elevated temperatures.

3.6 Seismic Loads

Seismic loads are those loads due to the response of the structure to an earthquake.

For preliminary design, estimated incremental acceleration values, as determined using the Uniform Building Code specified methods, shall be used as follows. The support structure shall be designed to withstand separate equivalent static incremental accelerations of 0.15g in any horizontal direction and 0.10g in the vertical direction. For design of attached equipment, the equivalent static incremental acceleration shall be 1.0g in any direction.

TABLE 1

EBT-P MASS PROPERTIES

	WEIGHT ∿ LBS.
SUPPORT STRUCTURE	
REINFORCED CONCRETE SUPPORT RING	101736
REINFORCED CONCRETE COLUMNS	50967
ALUMINUM SUPERSTRUCTURE	4212
ALUMINUM STRUCTURAL RING	5836
GROUT	7076
EQUIPMENT SUPPORTED BY CONCRETE STRUCTURE	
TF COILS AND SHIELDING	162000
VACUUM LINERS	2772
MIRROR CAVITIES	9900
FLANGES	9175
VACUUM VESSEL COOLANT	600
WATER COOLING PANELS	15120
INSTRUMENTATION/ DIAGNOSTICS	39348
COOLANT SUPPLY MANIFOLD	7977
COLLANT RETURN MANIFOLD	7977
ARE COILS	36000
FIELD CORRECTION COILS	5760
OUT-OF-PLANE STRUTS	2052
TOROIDAL VESSEL SUPPORTS	468
EQUIPMENT SUPPORTED BY ALUMINUM SUPERSTRUCTURE	
BYPASS DIODES	1800
DUMP RESISTORS	3600
CIRCUIT BREAKERS	13500
MOUNT/BUS SUPPORT STRUCTURE	1125
INSOLATION/ISOLATION	1125
POWER BUS BARS AND CABLES	2700
CRYOGENIC MANIFOLDS	7740
ECRH WAVEGUIDES	9900
WIRE TRAY AND CABLES	9135
INSTRUMENTATION AND CONTROL PANELS	4500
TF COIL VACUUM PUMPS	400
TF COIL VACUUM MANIFOLD SYSTEM	8760
COOLANT SUPPLY/RETURN MANIFOLDS	3672
ALUMINUM GRATING AND MISCELLANEOUS EQUIPMENT	3305

For detailed design, a dynamic response analysis shall be performed to verify the adequacy of the preliminary design acceleration levels. If higher levels are determined, they shall be used. The dynamic analysis shall consider the EBT-P facility to be located in a zone 2 seismic risk area, as defined by the Uniform Building Code. The analysis shall use a ground acceleration of .10G as defined by the National Bureau of Standards, NBS-SP-510. Two percent (2%) of critical damping shall be used. The resulting ground response spectra, as defined by NRC Regulatory Guide 1.6 (Document 1.4.2), are shown in Figures 4a and 4b. The response spectra shall be applied in two horizontal directions and one vertical direction simultaneously. The resulting loads shall be resolved by the square root of the sum of the squares.

3.7 Preloads

Preloads are the loads in the structure resulting from the as-assembled tightness of fasteners, including the out-of-plate struts.

4.0 Design Conditions

The EBT-P device shall be designed for normal operation (including the effects of seismic events), magnetic fault conditions, and non-operating conditions. In general, coexistant loads shall be added directly. An exception to this rule occurs for thermal loads. When thermal loads act to relieve other loads, thermal and other loads shall be considered as separate conditions.

4.1 Normal Operating Conditions

Normal operation of the EBT-P device includes operation of any or all of its associated systems and subsystems including planned upgrade equipment. Normal operation shall encompass all combinations of TF and ARE coil currents within the allowable envelope defined by the solid lines of Figure 5.

The design of the TF coils, however, shall be restricted to the reduced envelope shown as dashed lines on Figure 5. This reduction results from two considerations. First, the upper right hand cutoff is required in order not to exceed a steady-state centering force of 17900 pounds. This load is an early design estimate that has been specified in the design of the TF coil cold mass support struts. Second, the lower right hand cutoff results from a dynamic springback force of the same magnitude, produced when the ARE coils are instantaneously deactivated.

The effects of seismic events shall be considered during normal operation.

FIGURE 4a. HORIZONTAL SEISMIC DESIGN GROUND RESPONSE SPECTRA

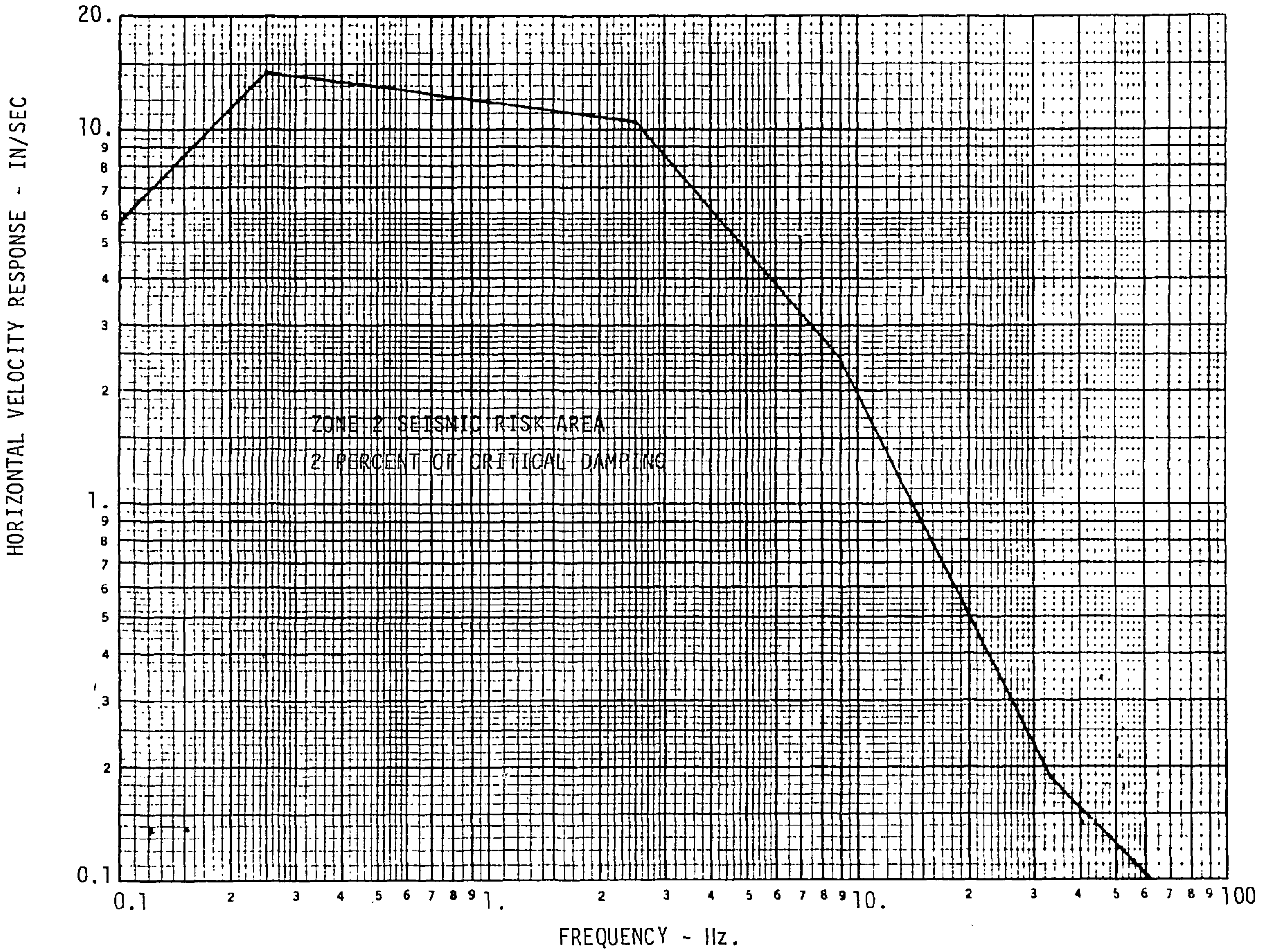


FIGURE 4b. VERTICAL SEISMIC DESIGN GROUND RESPONSE SPECTRA

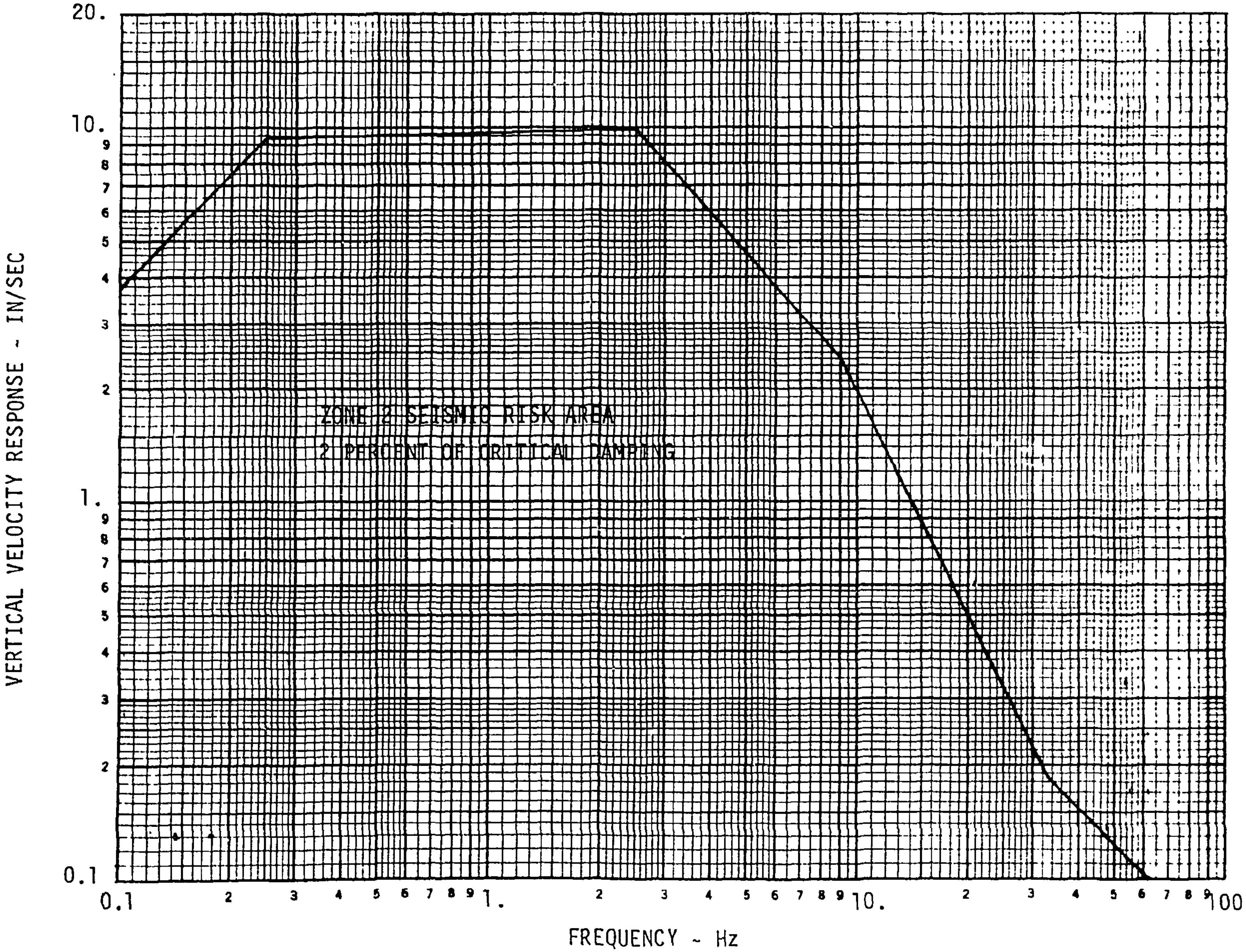
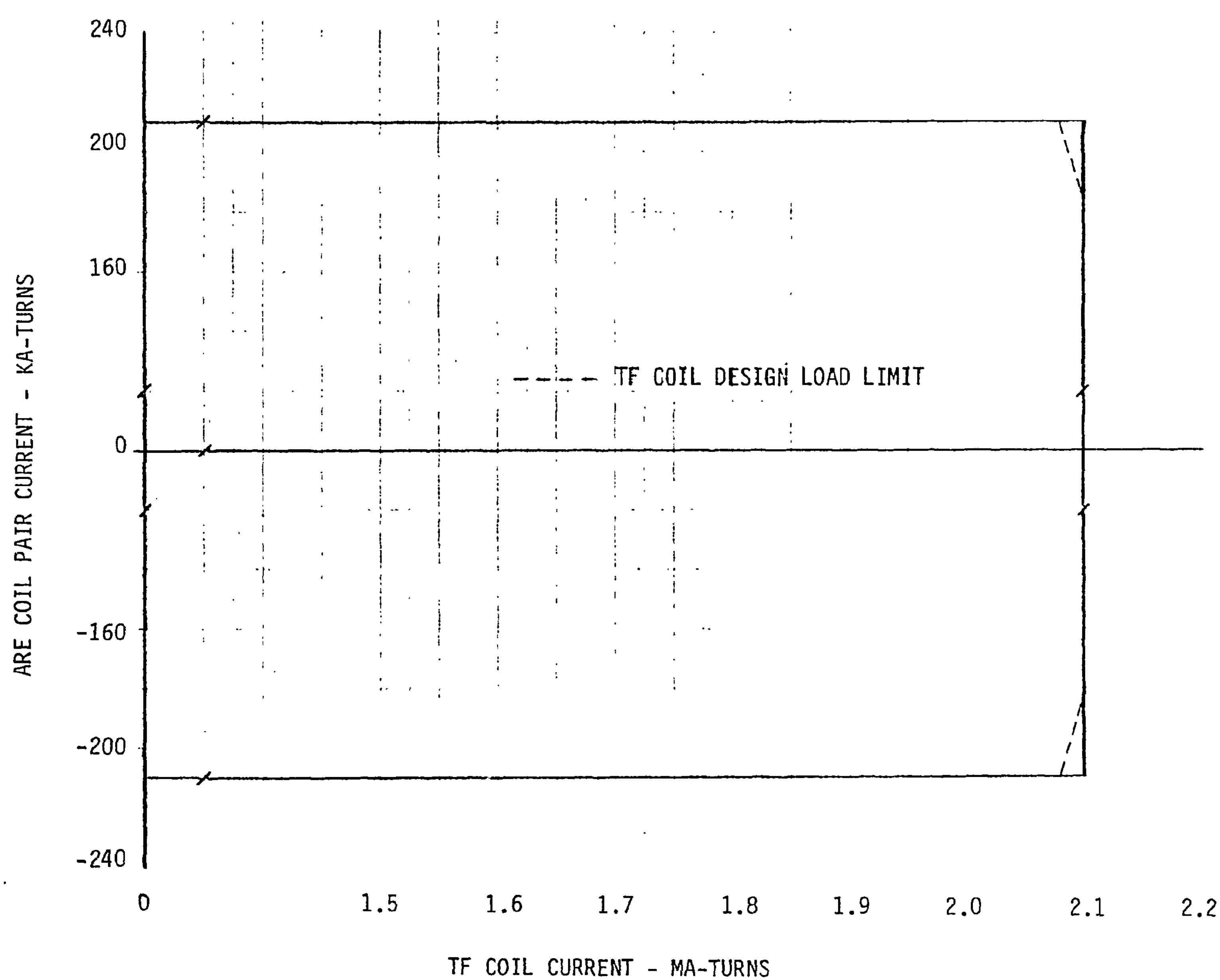


FIGURE 5
EBT-P MAGNET SYSTEM ALLOWABLE OPERATING ENVELOPE



Normal operating loads shall be the result of the combination of the following loads:

- o Dead Loads
- o Normal Operating Magnetic Loads
- o Pressure Loads
- o Thermal Loads
- o Seismic Loads
- o Preloads

4.2 Magnetic Fault Conditions

The TF coil protection system is designed such that if conditions in one of the TF coils indicate that it may quench (stop acting as a superconductor) an emergency discharge is initiated. The ARE coil system is immediately deactivated and the TF coils are electrically paired and connected to dump resistors. The TF coil system should then become safely deenergized. Magnetic fault conditions occur if one or more TF coil pairs remain operative.

The EBT-P device shall be designed for the worst case of operating and nonoperating TF coils, that is, nineteen adjacent coils on (half-torus on). However, the TF coils shall be designed for two adjacent coils on due to the TF coil design load limit.

The effects of seismic events shall not be considered during fault conditions because of the low probability that an earthquake would occur during a magnetic fault condition and the low probability that an earthquake would trigger a magnetic fault.

Fault loads shall be the result of the combination of the following loads:

- o Dead Loads
- o Magnetic Fault Loads
- o Pressure Loads
- o Thermal Loads
- o Preloads

4.3 Non-Operating Conditions

Structural requirements due to non-operating conditions are generally much less severe than the operating loads and are only of importance to localized structure provided for handling and maintenance. Table 2 presents the shipping and handling loads that are applicable to EBT-P device components. Where reasonable, a 150 pound ultimate handling load shall be used for brackets, supports, etc. lacking defined design loads.

4.4 Dynamic Considerations

The start-up and shut-down processes for the TF coil system and the start-up process for the ARE coil system shall be considered, from a structural design viewpoint, as quasi-static phenomena. However, the shut-down process for the ARE coil system occurs with sufficient rapidity to be dynamically significant. Therefore, the effects of an ARE coil system shut-down shall be addressed as a dynamic condition.

Equipment mounting shall be designed to minimize the effects of vibration to the maximum extent practicable. Where this is not possible, the effects of vibration shall be considered in equipment design.

Table 2 EQUIPMENT SHIPPING AND HANDLING LOAD FACTORS

DESIGN CONDITION	IN SHIPPING CONTAINER	OUT OF SHIPPING CONTAINER	LOAD FACTOR n_x	LOAD FACTOR n_y	LOAD FACTOR n_z	SIMULTANEOUS OR INDEPENDENT IN EACH AXIS	COMMENTS	NOTES
1. HANDLING DURING ASSEMBLY, TESTING, AND INSTALLATION	X	X	±2.5	±2.5	±2.5	SIMUL		1, 2
2. HOISTING	X	X	APPLY A LOAD FACTOR OF 2.0 ALONG THE EXISTING AXIS WITH A 20° CONE OF ACTION RELATIVE TO THE AXIS.					
3. TOWING (DOLLY)	X	X	±2.0	±2.0	±6.0	SIMUL		1, 3
4. HANDLING THE PACKAGED VEHICLE DURING SHIPPING	X		±2.0	±2.0	±4.0	SIMUL		1, 2
5. TRUCK TRANSPORT	X		±2.0	±2.0	±6.0	SIMUL		1, 3
6. RAIL TRANSPORT	X		±3.0	± .75	±3.0	SIMUL		1, 3
7. MARINE TRANSPORT	X		± .5	±2.5	±2.5	SIMUL		1, 3
8. AIR TRANSPORT	X		±1.5 −3.0	±1.5	±4.5 −2.0	INDEP	12.3 PSID BURST ON SHIPPING CONTAINER (AIRCRAFT PRESSURIZATION MALFUNCTION AT 40,000)	1, 3, 4
9. AIRCRAFT EMERGENCY LANDING	X		+1.5 −9.0	±1.5	+4.5 −2.0	INDEP		1, 3, 5

NOTES:

1. THE LOAD FACTORS ARE APPLICABLE TO THE EQUIP. AND CONTAINER, i.e., THE LOAD FACTORS RESULT FROM FORCES APPLIED TO THE EQUIP OR SHIPPING CONTAINER BY THE HANDLING EQUIPMENT OR TRANSPORTING VEHICLE.
2. THE LOAD FACTORS n_x AND n_y (LONGITUDINAL AND LATERAL) ARE PARALLEL TO THE EARTH'S SURFACE AND n_z IS PERPENDICULAR TO THE EARTH'S SURFACE (POSITIVE UPWARD). LOAD FACTORS APPLICABLE TO THE VEHICLE DEPEND UPON ITS PARTICULAR ORIENTATION.
3. THE LOAD FACTORS n_x, n_y, AND n_z ARE IN THE TRANSPORTING VEHICLE LONGITUDINAL, LATERAL, AND VERTICLE AXES RESPECTIVELY (n_x POSITIVE TOWARD, n_z POSITIVE UPWARD). LOAD FACTORS APPLICABLE TO THE TRANSPORTED EQUIPMENT DEPEND UPON ITS ORIENTATION WITHIN THE TRANSPORTATION VEHICLE
4. DIFFERENTIAL PRESSURE IS GIVEN, CONTAINER INTERNAL PRESSURE – 15 PSIA.
5. FOR THE EMERGENCY LANDING CONDITION, THE FACTOR OF SAFETY REQUIREMENTS DO NOT APPLY. THE ONLY REQUIREMENT IS CREW SAFETY.

4.5 Design Life Cycles

The EBT-P device shall be designed to meet the strength requirements specified herein with the specified factors of safety at the end of a 10-year design lifetime. The design lifetime shall be distributed according to the following criteria:

- 1000 $\frac{hrs}{yr}$ operating time (all power on, plasma formed)
- 7000 $\frac{hrs}{yr}$ standby time (vacuum and cryogenic temperature maintained)
- 700 $\frac{hrs}{yr}$ down time (entire system down)

The operating time shall be distributed during the design lifetime at the operating power levels specified in Table 3.

Design life analyses shall consider the following time-dependent criteria:

- 1000 thermal cycles per year at the operating power levels of Table 3. The toroidal vessel, however, shall be designed for 1000 thermal cycles per year at the maximum 7.0 MW operating power level in order to withstand possible hotspots. The heating power input to the toroidal vessel at this operating power level is 5 MW and the resulting toroidal vessel steady-state heat fluxes are as follows:

Vacuum Liner	Coil Throat Region	20.0 W/cm^2
	Side Wall Region	13.5 W/cm^2
Mirror Cavity	(including all surfaces created by ports)	5.0 W/cm^2

- 2000 gyrotron power cycles per year at the operating power levels of Table 3.
- 20 gyrotron cryogenic cycles per year.
- 200 TF coil power cycles per year.
- 20 TF coil cryogenic cycles per year.
- 2 TF coil fault conditions per year.
- 1 seismic event.
- A factor on cycles (scatter factor) of 10 relative to the average life fatigue curve for the applicable stress ratio and stress concentration. For pressure and vacuum vessels, the ASME Boiler and Pressure Vessel Code may be used as an alternate method. Then the fatigue life design curve is based on reducing the average life curve for a stress ratio of -1.0 by the greater of a scatter factor of 20 on cycles or a reduction factor of 2.0 on stress amplitude.

TABLE 3

DESIGN LIFETIME DISTRIBUTION OF
OPERATING TIME AT POWER LEVEL

	OPERATING TIME ∼ HRS (a)	
OPERATING POWER LEVEL (ECRH/ICRH POWER OUTPUT)	2.6 MW	7.0 MW
HEATING POWER INPUT TO THE VACUUM VESSEL (b)	2.0 MW	5.0 MW
OPERATING YEAR 1	1000	
2	1000	
3	1000	
4		1000
5		1000
6		1000
7		1000
8		1000
9		1000
10		1000
TOTAL OPERATING TIME ∼ HRS	3000	7000

NOTES:

(a) Based on an average operating time of:

$$1000 \ \frac{hrs}{yr} \approx 8 \ \frac{hrs}{day} * 5 \ \frac{days}{week} * 26 \ \frac{wks}{yr}$$

(b) Heating power input to the vacuum vessel is equal to the ECRH/ICRH power output minus power losses in the distribution system.

5.0 Strength Criteria

As the EBT-P device will be located in the state of Tennessee, the design of the device shall satisfy the strength requirements of the applicable documents sanctioned by that state. As of this writing, the State of Tennessee has endorsed the "Standard Building Code" (also known as the Southern Standard Building Code), 1976 edition, published by the Southern Building Code Congress International, Incorporated, of Birmingham, Alabama. As the 1979 edition has since been published along with the 1981 addenda, these latter revisions shall be used in anticipation of their future adoption by the state and the following documents are in accordance therewith. Furthermore, it is believed that the documents cited herein should also satisfy the strength requirements of the Uniform Building Code as well as all other model codes and insurance underwriters' requirements. Where the strength requirements of any document are deemed inappropriate because of the special nature of the EBT-P device, exceptions will be taken and noted and sound engineering judgement will be used.

The strength criteria of the EBT-P device will be addressed in the following sections according to (a) criteria that are applicable for particular systems (the toroidal vessel and magnet systems and the support structure) which have unique requirements and (b) equipment that is common to many systems.

All EBT-P structures and components shall be designed for no detrimental deformations at limit load for any design condition specified in Section 4.0 or proof loading conditions at design temperature. This does not preclude small, localized nondetrimental plastic deformations.

Effects of x-rays and other structurally deleterious environments shall be included in the analysis.

Specific exceptions to the following strength criteria will be considered on an individual basis, providing the structural capacity, safety, and functional requirements of the nonconforming item is deemed adequate by the MDAC EBT-P Project Management, Strength, Safety, and Design departments.

Unless specified otherwise in a MDAC approved procurement specification, the latest edition of the noted specifications and codes will be used.

5.1 Toroidal Vessel System Strength Criteria

- o The toroidal vessel system shall satisfy the strength requirements of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 2. Some of the pertinent data of this document are shown in Table 4.
- o The toroidal vessel shall be designed with the factors of safety for shell buckling as shown in Table 5.

5.2 Magnet System Strength Criteria

- o The magnet system shall meet the strength requirements of the ASME Boiler and Pressure Code, Section VIII, Divisions 1 and 2 with the exception that the maximum stress allowable limit for the bobbin shall, in all cases, be limited to two-thirds of material yield stress. Strength criteria extracted from this document are shown in Table TBD.
- o The magnet system cold mass supports shall be designed using the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF as a guide only.

5.3 Support Structure Strength Criteria

- o All support structure of reinforced concrete shall meet the strength requirements of the Building Code Requirements for Reinforced Concrete (ACI-318) except that the load combination equations of Section 9.3 shall be replaced by the following equations:

$$U = 1.4D + 1.7L + 1.87E$$

$$U = .9D + 1.7L + 1.87E$$

where:

U = required strength

D = dead load (including thermal loads)

L = live load (normal operating magnetic)

E = seismic load

TABLE 4

TOROIDAL VESSEL STRENGTH CRITERIA

Design Load Combinations o Normal Operating Conditions Defined in Section 4.1 o Fault Conditions Defined in Section 4.2.
Stress Intensity K Factors o Normal Operating Conditions K = 1.0 o Fault Conditions K = 1.2
Design Stress Intensity (S_M) shall not exceed: Vessel Walls o 1/3 of min. ult. tensile strength at room temp. o 1/3 of min. ult. tensile strength at temp. o 2/3 of min. tensile yield strength at room temp. o 2/3 of min. tensile yield strength at temp. Bolts o 1/3 of min. tensile yield strength at room temp. o 1/3 of min. tensile yield strength at temp.
Stress Allowable Limits o General primary membrane stress ∿ K S_M o Local primary membrane stress ∿ 1.5 K S_M o Primary membrane plus bending stress ∿ 1.5 K S_M o Primary plus secondary stress ∿ 3.0 S_M

Table 5 - Vacuum Vessel Structural Stability

The factor of safety for shell buckling will depend upon the method employed for buckling analysis as follows:		
(1)	Theoretical linear analysis including linear Eigenvalue solutions from finite element and finite difference computer codes	5.0
(2)	Theoretical analyses methods that take into account at least one nonlinearity.	3.0
(3)	Empirical analysis or theoretical analyses utilizing a correlation factor based on test results.	1.5

These equations shall be evaluated both with and without the live load and/or seismic load. (See Table 6 for the resulting significant load combinations). This departure from ACI-318 reflects the following considerations:

a. The live load will likely be present during a seismic event;
b. The live load will likely be at its full operating value;
c. The transient nature of the seismic load will be accounted for by dynamic analysis; and,
d. The live load does not have a gravity stabilizing effect.

The first three considerations result in the deleting of the .75 factor as used in equations 9-2 and 9-3 of ACI-318. The fourth consideration results in including the live load in equation 9-3.

Table 7 presents the capacity reduction factors that shall be used as specified in the above document. These factors account for deficiencies in material strengths, workmanship, and dimensions.

- All support structure of structural steel shall satisfy the strength requirements of the Specification for the Design, Fabrication and Erection of Structural Steel for Buildings as published by the American Institute of Steel Construction. Table 8 shows the allowable stresses to be used as specified in this document.
- All support structure of cold-formed steel shall satisfy the strength requirements of the Design of Cold-Formed Steel Structural Members of the American Iron and Steel Institute. Strength criteria extracted from this document are shown in Table TBD.
- All support structure of stainless steel shall satisfy the strength requirements of the Specification for the Design of Cold-Formed Stainless Steel Structural Members as published by the American Iron and Steel Institute. Strength criteria extracted from this document are shown in Table TBD.
- All support structure welding shall meet the strength requirements of the Structural Welding Code AWS D1.1 of the American Welding Society.
- All steel or stainless steel high strength bolts shall meet the strength requirements of the Specification for Structural Joints Using ASTM A325 or ASTM A490 Bolts as published by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation. Strength criteria extracted from this document are shown in Table TBD.
- All support structure of aluminum shall satisfy the strength requirements of the Specification for Aluminum Structures, Aluminum Construction Manual, Section 1 of the Aluminum Association. Table 9 shows the factors of safety to be used as specified in this document.

Table 6

Reinforced Concrete

Load Combination Equations

$U = 1.4D + 1.7L + 1.87E$ $U = 1.4D + 1.7L$ $U = 1.4D + 1.87E$ $U = 1.4D$ $U = .9D + 1.7L + 1.87E$ $U = .9D + 1.87E$
where: U = required strength D = dead load (including thermal load) L = live load (normal operating magnetic load) E = seismic load
The numerical factors above are factors of safety. They account for underestimation of design loads, loads due to unanticipated use, and effects of construction methods.

TABLE 7

REINFORCED CONCRETE
CAPACITY REDUCTION FACTORS

Bending with or without axial tension	0.90
Axial tension	0.90
Shear and torsion	0.85
Compression members, spirally reinforced	0.75
Compression members, tied	0.70
Bearing on Concrete	0.70
Bending in plain concrete	0.65

Capacity reduction factors account for deficiencies in material strengths, workmanship, and dimensions. The required strength, U, is increased by the capacity reduction factor, ϕ, such that the required strength is equal to U/ϕ.

TABLE 8 - STRUCTURAL STEEL ALLOWABLE STRESSES

	Yield Stress — F_y (ksi)			Yield Stress — F_y (ksi)					
	36.0	42.0	45.0	50.0	55.0	60.0	65.0	90.0	100.0
SECTION 1.5 ALLOWABLE STRESSES									
1.5.1.1 Tension									
Tension on the net section, except at pin holes: $F_t = 0.60F_y \leq 0.50F_{TS}$ where F_{TS} = minimum tensile strength	22.0	25.2	27.0	30.0	33.0	36.0	39.0	52.5*	57.5*
Tension on the net section at pin holes in eyebars, pin-connected plates or built-up members: $F_t = 0.45F_y$	16.2	19.0	20.3	22.5	24.8	27.0	29.3	40.5	45.0
1.5.1.2 Shear									
Shear on the gross section (see Table 3 for reduced values for girder webs): $F_v = 0.40F_y$	14.5	17.0	18.0	20.0	22.0	24.0	26.0	36.0	40.0
1.5.1.3 Compression									
1.5.1.3.1 Compression on the gross section of axially loaded compression members when Kl/r is less than C_c: Formula (1.5-1) $F_a = \dfrac{\left[1 - \dfrac{(Kl/r)^2}{2C_c^2}\right]F_y}{\dfrac{5}{3} + \dfrac{3(Kl/r)}{8C_c} - \dfrac{(Kl/r)^3}{8C_c^3}}$	Table 1-36	Table 1-42	Table 1-45	Table 1-50	Table 1-55	Table 1-60	Table 1-65	Table 1-90	Table 1-100
...3.2 ...ession on the gross section of ...loaded compression members .../r exceeds C_c: Form... (1.5-2) $F_a = \dfrac{12\pi^2 E}{23(Kl/r)^2}$	Table 1-36	Table 1-42	Table 1-45	Table 1-50	Table 1-55	Table 1-60	Table 1-65	Table 1-90	Table 1-100
...1.3.3 Compression on the gross section of axially loaded bracing and secondary members when l/r exceeds 120: Formula (1.5-3) $F_{as} = \dfrac{F_a \text{ [by Formula (1.5-1) or (1.5-2)]}}{1.6 - \dfrac{l}{200r}}$	Table 1-36	Table 1-42	Table 1-45	Table 1-50	Table 1-55	Table 1-60	Table 1-65	Table 1-90	Table 1-100

* Value equal to 0.50 times minimum tensile strength (= $0.50F_{TS}$)

TABLE 8 - (CONTINUED)

	Yield Stress — F_y (ksi)			Yield Stress — F_y (ksi)					
	36.0	42.0	45.0	50.0	55.0	60.0	65.0	90.0	100.0
1.5.1.3 Compression (cont'd)									
1.5.1.3.4 Compression on the gross area of plate girder stiffeners: $F_a = 0.60F_y$	22.0	25.2	27.0	30.0	33.0	36.0	39.0	54.0	60.0
1.5.1.3.5 Compression on the web of rolled shapes at the toe of fillet: $F_a = 0.75F_y$	27.0	31.5	33.8	37.5	41.3	45.0	48.8	67.5	75.0
1.5.1.4 Bending									
1.5.1.4.1 Tension and compression for compact, adequately braced members symmetrical about, and loaded in, the plane of their minor axis: $F_b = 0.66F_y$	24.0	28.0	29.7	33.0	36.3	39.6	42.9	—	—
when									
a. Flanges are continuously connected to web									
b. $b_f/2t_f \leq 52.2/\sqrt{F_y}$	8.7	8.1	7.8	7.4	7.0	6.7	6.5	—	—
c. $b/t_f \leq 190/\sqrt{F_y}$	31.7	29.3	28.3	26.9	25.6	24.5	23.6	—	—
d. Use Formula (1.5-4): $d/t \leq 412\left(1 - 2.33\frac{f_a}{F_y}\right)/\sqrt{F_y}$	$68.7 - 4.4f_a$	$63.6 - 3.5f_a$	$61.4 - 3.2f_a$	$58.3 - 2.7f_a$	$55.6 - 2.4f_a$	$53.2 - 2.1f_a$	$51.1 - 1.8f_a$	—	—
except that d/t need not be less than $257/\sqrt{F_y}$	42.8	39.7	38.3	36.3	34.7	33.2	31.9	—	—
e. $l \leq 76.0b_f/\sqrt{F_y}$	$12.7b_f$	$11.7b_f$	$11.3b_f$	$10.7b_f$	$10.2b_f$	$9.8b_f$	$9.4b_f$	—	—
and $l \leq \frac{20{,}000}{(d/A_f)F_y}$	$\frac{556}{d/A_f}$	$\frac{476}{d/A_f}$	$\frac{444}{d/A_f}$	$\frac{400}{d/A_f}$	$\frac{364}{d/A_f}$	$\frac{333}{d/A_f}$	$\frac{308}{d/A_f}$	—	—

TABLE 8 - (CONTINUED)

	Yield Stress — F_y (ksi)			Yield Stress — F_y (ksi)					
	36.0	42.0	45.0	50.0	55.0	60.0	65.0	90.0	100.0
1.5.1.4 *Bending (cont'd)*									
1.5.1.4.2 Tension and compression for members which meet the requirements of Sect. 1.5.1.4.1 except subparagraph b:									
when $\frac{\sout{52.2}\ 65}{\sqrt{F_y}} < \frac{b_f}{2t_f}$	~~8.7~~ 10.9	~~8.1~~ 10.0	~~7.8~~ 9.7	~~7.4~~ 9.2	~~7.0~~ 8.8	~~6.7~~ 8.4	~~6.5~~ 8.1	—	—
and $\frac{b_f}{2t_f} < \frac{95.0}{\sqrt{F_y}}$	15.8	14.7	14.2	13.4	12.8	12.3	11.8	—	—
use Formula (1.5-5): $F_b = \sout{F_y\left[0.733 - 0.0014\left(\frac{b_f}{2t_f}\right)\sqrt{F_y}\right]}$									
Values of F_b for $\frac{b_f}{2t_f}$ = 7.00	—	—	—	—	—	39.4	42.5	—	—
8.00	—	—	[illegible]9.6	32.7	35.7	38.8	41.8	—	—
9.00	23.7	27.3	[illegible]9.2	32.2	35.2	38.1	41.0	—	—
10.00	23.4	27.0	28.8	31.7	34.6	37.5	40.3	—	—
11.00	23.1	26.6	28.4	31.2	34.0	36.8	39.6	—	—
12.00	[illegible]	26.2	27.9	30.7	33.5	36.2	—	—	—
13.00	[illegible]	25.8	27.5	30.2	—	—	—	—	—
14.00	[illegible]	25.5	27.1	—	—	—	—	—	—
15.00	[illegible]	—	—	—	—	—	—	—	—
1.5.1.4.3 Tension and compression for ~~doubly-~~ symmetrical I and H shape ~~members~~ meeting the requirements of ~~Sect.~~ 1.5.1.4.1, except subparagraphs ~~c, d and~~ e, and bent about their ~~minor axis~~ (except members of A514 steel), ~~solid~~ round and square bars; ~~and solid rec-~~ tangular bars bent about ~~their weaker~~ axis: $F_b = 0.75F_y$	27.0	31.5	33.8	37.5	41.3	45.0	48.8	—	—
1.5.1.4.4 Tension and compression for ~~box-type~~ flexural members not included ~~in Sect.~~ 1.5.1.4.1, but which meet the ~~require-~~ ments of Sect. 1.9: $F_b = 0.60F_y$	22.0	25.2	27.0	30.0	33.0	36.0	39.0	54.0	60.0
when $l \leq 2500b/F_y$	69.4b	59.5b	55.6b	50.0b	45.5b	41.7b	38.5b	27.8b	25.0b

	Yield Stress — F_y (ksi)			Yield Stress — F_y (ksi)					
	36.0	42.0	45.0	50.0	55.0	60.0	65.0	90.0	100.0
1.5.1.4 Bending (cont'd)									
1.5.1.4.5 **Tension for flexural members not covered in Sect. 1.5.1.4.1, 1.5.1.4.2, 1.5.1.4.3 or 1.5.1.4.4:** $F_b = 0.60F_y$	22.0	25.2	27.0	30.0	33.0	36.0	39.0	54.0	60.0
1.5.1.4.6a **Compression for flexural members included under Sect. 1.5.1.4.5, having an axis of symmetry in, and loaded in, the plane of their web; compression for channels bent about their major axis: The larger value computed by Formula (1.5-6a) or (1.5-6b) and Formula (1.5-7), but not more than** $F_b = 0.60F_y$	22.0	25.2	27.0	30.0	33.0	36.0	39.0	54.0	60.0
when $l/r_T \leq \sqrt{\frac{102 \times 10^3 \times C_b}{F_y}}$ *	$53\sqrt{C_b}$	$49\sqrt{C_b}$	$48\sqrt{C_b}$	$45\sqrt{C_b}$	$43\sqrt{C_b}$	$41\sqrt{C_b}$	$40\sqrt{C_b}$	$34\sqrt{C_b}$	$32\sqrt{C_b}$
When this limit is exceeded, use Formula (1.5-6a): $F_b = \left[\frac{2}{3} - \frac{F_y(l/r_T)^2}{1{,}530 \times 10^3 \times C_b}\right]F_y$ *	$24.0 - \frac{(l/r_T)^2}{1181C_b}$	$28.0 - \frac{(l/r_T)^2}{867C_b}$	$30.0 - \frac{(l/r_T)^2}{756C_b}$	$33.3 - \frac{(l/r_T)^2}{612C_b}$	$36.7 - \frac{(l/r_T)^2}{506C_b}$	$40.0 - \frac{(l/r_T)^2}{425C_b}$	$43.3 - \frac{(l/r_T)^2}{362C_b}$	$60.0 - \frac{(l/r_T)^2}{189C_b}$	$66.7 - \frac{(l/r_T)^2}{153C_b}$
unless $l/r_T \geq \sqrt{\frac{510 \times 10^3 \times C_b}{F_y}}$ *	$119\sqrt{C_b}$	$110\sqrt{C_b}$	$106\sqrt{C_b}$	$101\sqrt{C_b}$	$96\sqrt{C_b}$	$92\sqrt{C_b}$	$89\sqrt{C_b}$	$75\sqrt{C_b}$	$71\sqrt{C_b}$
in which case, use Formula (1.5-6b): $F_b = \frac{170 \times 10^3 \times C_b}{(l/r_T)^2}$ *									
When the compression flange is solid and approximately rectangular in cross-section and its area is not less than that of the tension flange, use Formula (1.5-7): $F_b = \frac{12 \times 10^3 \times C_b}{ld/A_f}$ *									

***For values of C_b see Fig. A1, p. 5-104.**

TABLE 8 - (CONTINUED)

	Yield Stress — F_y (ksi)			Yield Stress — F_y (ksi)					
	36.0	42.0	45.0	50.0	55.0	60.0	65.0	90.0	100.0
1.5.1.4. Bending (cont'd)									
1.5.1.4.6b Compression for flexural members included under Sect. 1.5.1.4.5, which do not satisfy the requirements of Sect. 1.5.1.4.6a, and which if bent about their major axis are braced so that									
$l \leq (76.0b_f/\sqrt{F_y})$	$12.7b_f$	$11.7b_f$	$11.3b_f$	$10.7b_f$	$10.2b_f$	$9.8b_f$	$9.4b_f$	$8.0b_f$	$7.6b_f$
$F_b = 0.60F_y$	22.0	25.2	27.0	30.0	33.0	36.0	39.0	54.0	60.0
1.5.1.5 Bearing (on contact area)									
1.5.1.5.1 Bearing on milled surfaces, including bearing stiffeners and pins in reamed, drilled, or bored holes:									
$F_p = 0.90F_y$	33.0	38.0	40.5	45.0	49.5	54.0	58.5	81.0	90.0
1.5.1.5.2 Bearing on expansion rollers and rockers:									
$F_p = \left(\frac{F_y - 13}{20}\right) 0.66d$	0.76d	0.96d	1.08d	1.22d	1.39d	1.55d	1.72d	2.54d	2.87d
1.5.2 Rivets, Bolts, and Threaded Parts									
1.5.2.2 Bearing on projected area of bolts in bearing-type connections and on rivets:									
$F_p = 1.35F_y$	48.6	56.7	60.8	67.5	74.3	81.0	87.8	121.5	135.0

TABLE 9

FACTORS OF SAFETY FOR USE WITH ALUMINUM ALLOWABLE STRESS SPECIFICATIONS

Tension Members	
F.S. on tensile strength, n_u	**1.95**
F.S. on yield strength, n_y	**1.65**
Columns	
F.S. on buckling strength, n_u	1.95
F.S. on crippling strength of thin sections, n_u	1.95
F.S. on yield strength for short columns, n_y	1.65
Beams	
F.S. on tensile strength, n_u	1.95
F.S. on tensile yield strength, n_y	1.65
F.S. on compressive yield strength for short beams, n_y	1.65
F.S. on buckling strength, n_y	1.65
F.S. on crippling strength of thin sections, n_y	1.65
F.S. on shear buckling of webs, n_a	1.20
Connections	
F.S. on bearing strength	1.2 × 1.95 = 2.34
F.S. on bearing yield strength; n_y	1.65
F.S. on shear strength of rivets and bolts	1.2 × 1.95 = 2.34
F.S. on shear strength of fillet welds	1.2 × 1.95 = 2.34
F.S. on tensile strength of butt welds, n_u	1.95
F.S. on tensile yield strength of butt welds, n_y	**1.65**

5.4 Vacuum Equipment Strength Criteria

All vacuum equipment shall satisfy the strength requirements of the following documents:

- o ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1 and 2.
- o American Vacuum Society Tentative Standards. Applicable strength criteria extracted from these documents are shown in Table TBD.

5.5 Cryogenic Equipment Strength Criteria

All cryogenic equipment shall satisfy the strength requirements of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. Strength criteria extracted from this document are shown in Table TBD.

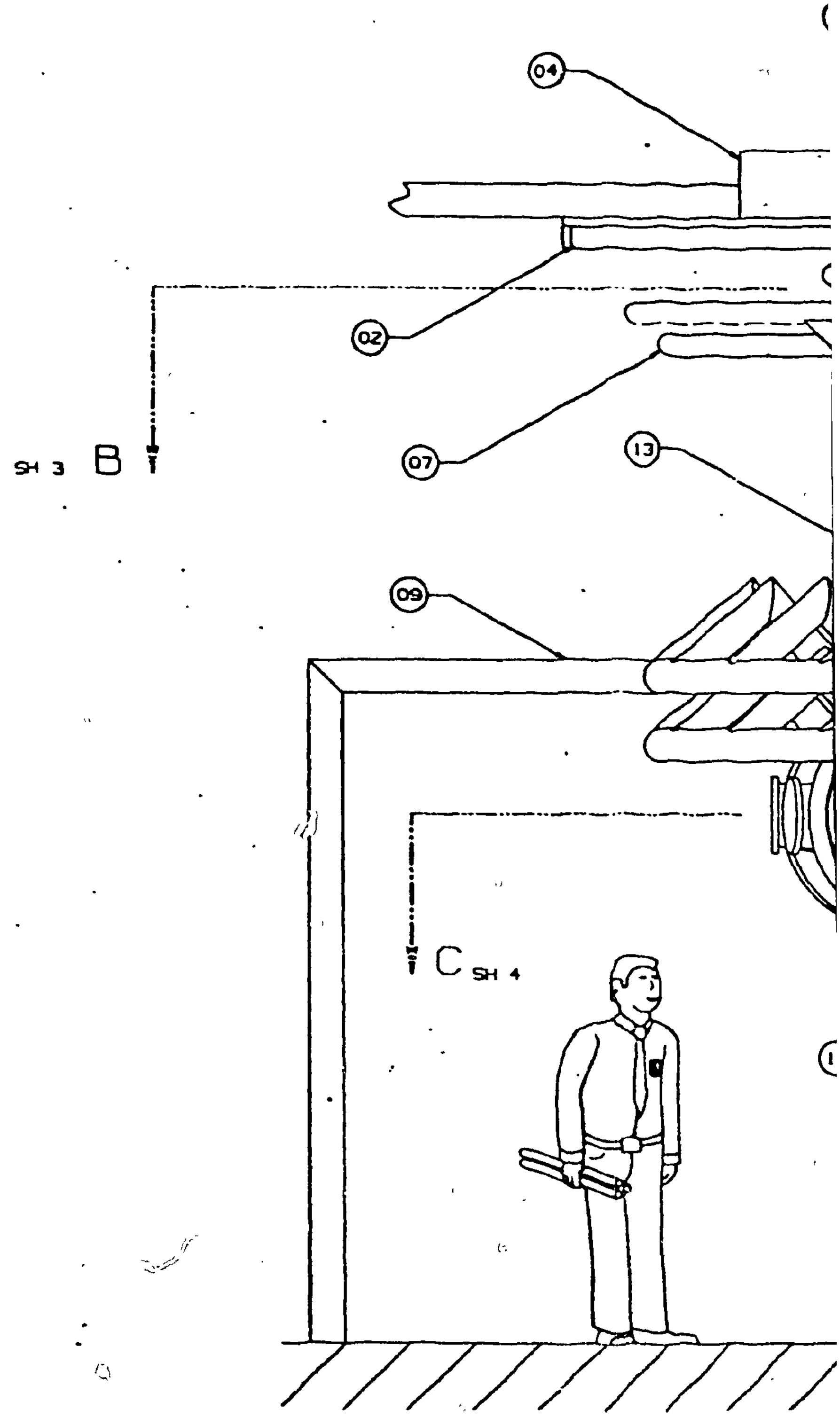
5.6 Piping Equipment Strength Criteria

All piping equipment shall meet the strength requirements of ANSI B31.1 Power Piping and ANSI B16.5 Steel Pipe Flanges, Flanged Valves, and Fittings as published by the American National Standards Institute or the strength requirements of the Tubular Exchanger Manufactures (TEMA) Standards as applicable. Pertinent strength criteria extracted from these documents are shown in Table TBD. Means of accommodating thermal expansions and contractions shall be employed where possible and cost efficient. Where they are not employed, thermal loading shall be considered.

5.7 Miscellaneous Equipment Strength Criteria - The strength requirements of all miscellaneous equipment not addressed in the preceeding sections shall be based on a factor of safety of 2.0 for ultimate strength.

APPENDIX B

SYSTEM DRAWINGS



2. SOME DETAILS OMITTED FOR CLARITY.
1. DRAWING DOES NOT REFLECT PDC 12, TURBO MOLECULAR PUMP VACUUM SYSTEM.

NOTES:

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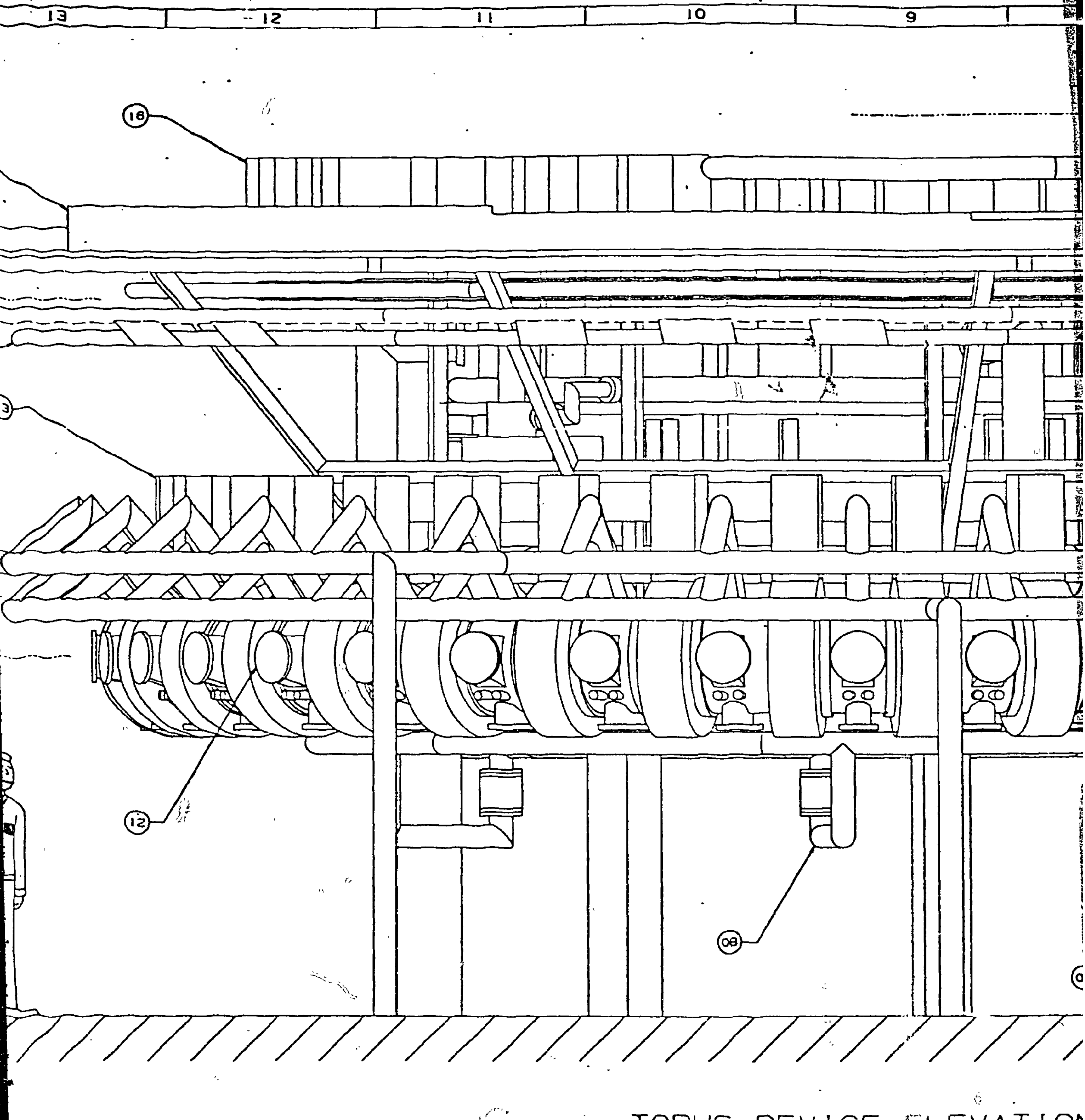
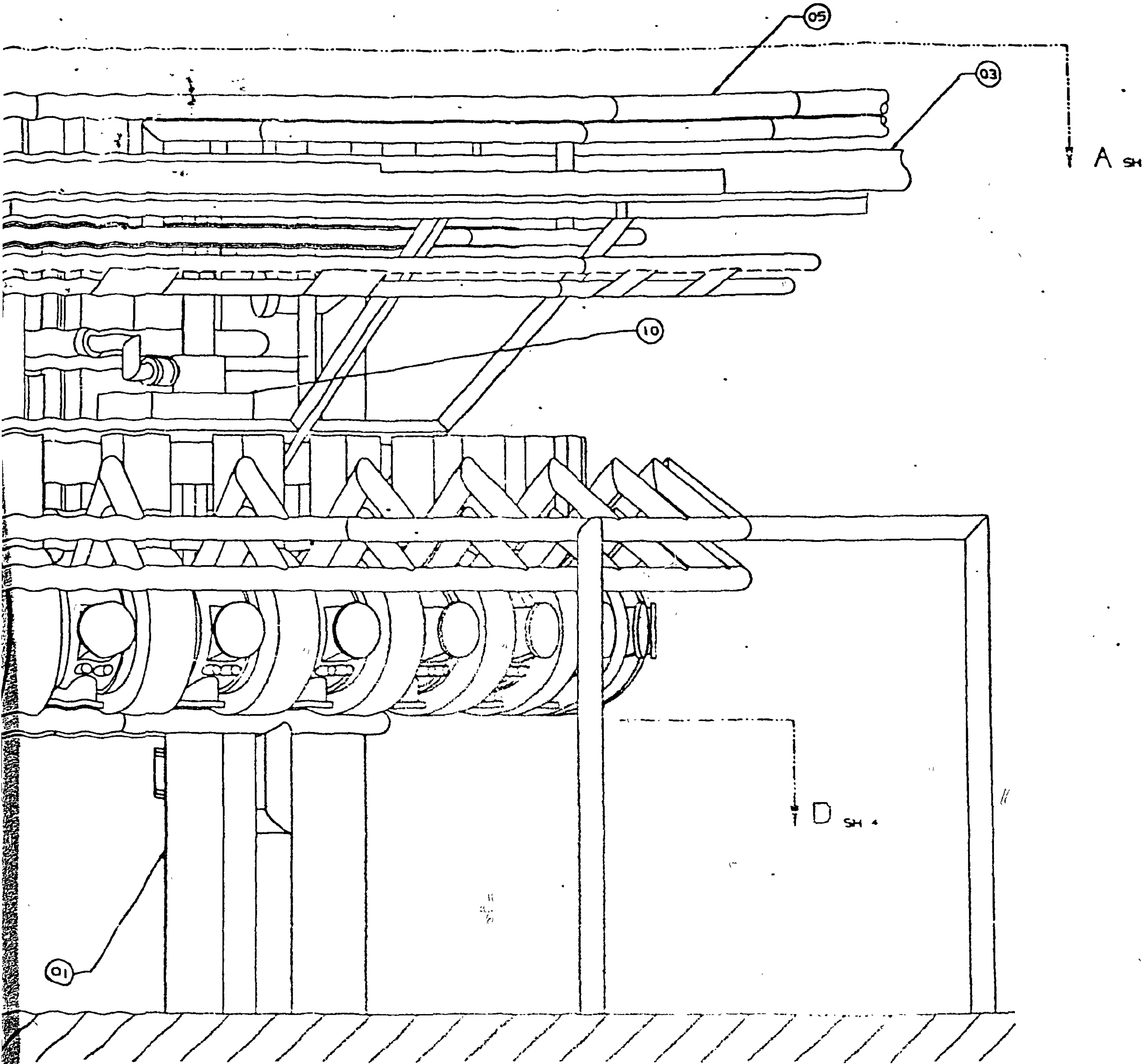


TORUS DEVICE ELEVATION
LOOKING EAST



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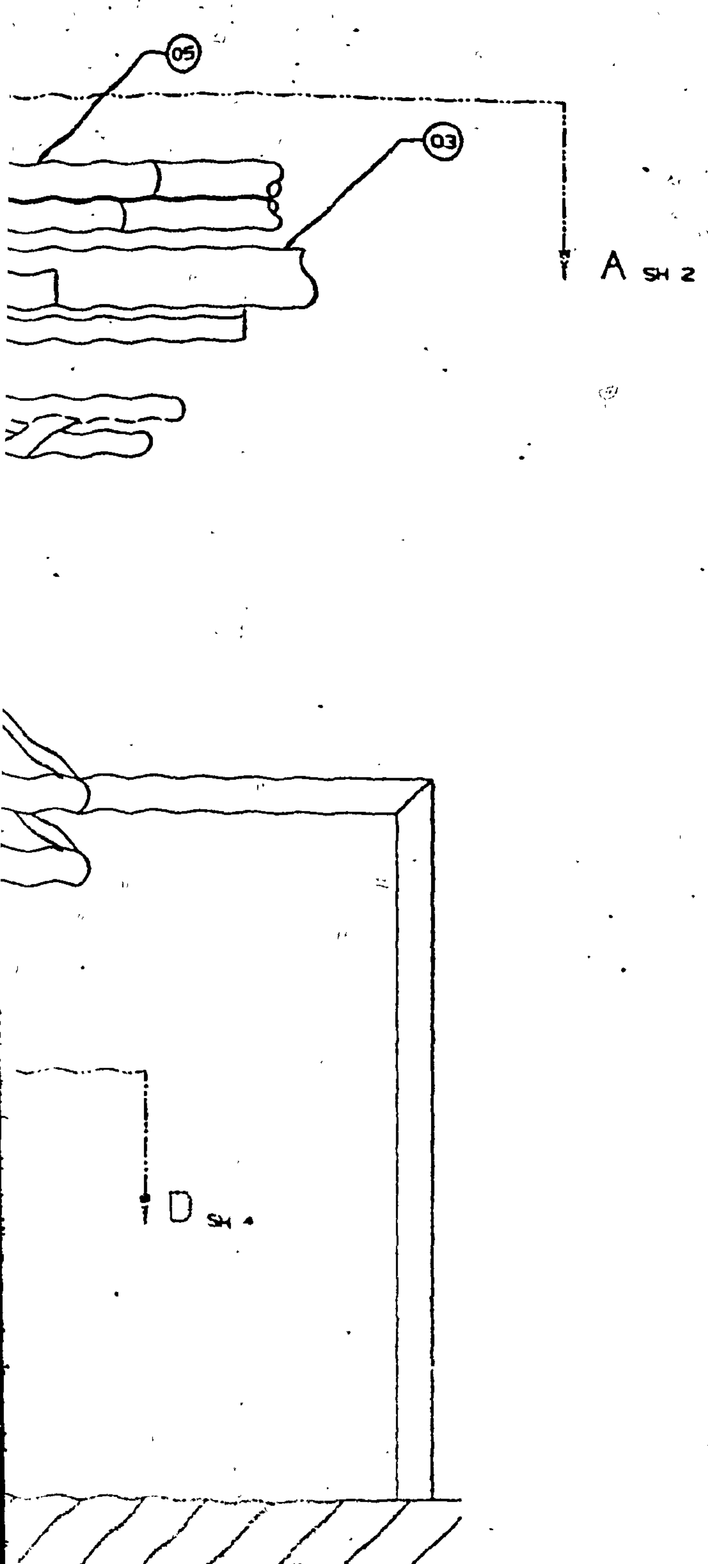
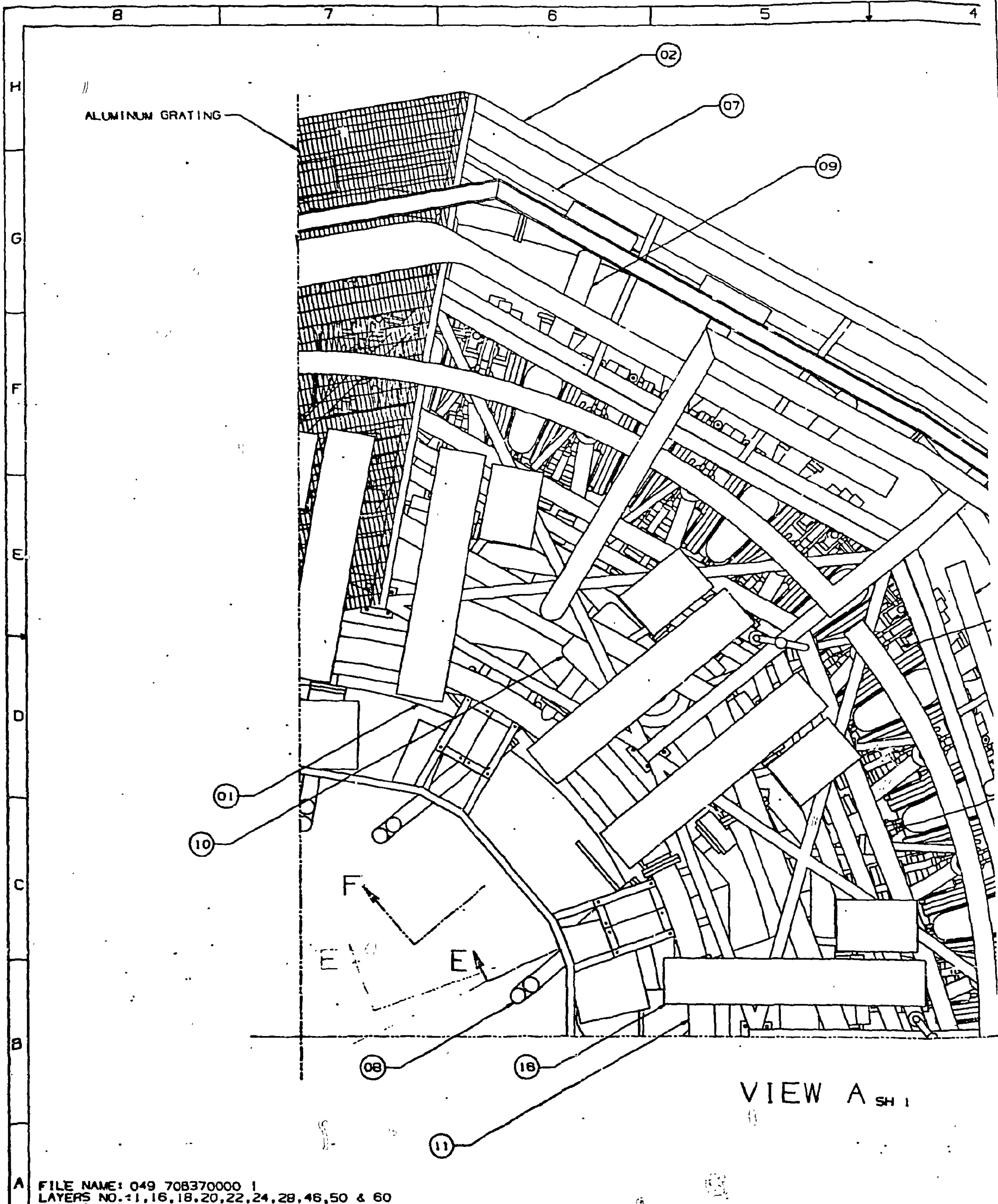


TABULATION		
C/O	DWG NO.	DWG TITLE
01	708372002	SUPPORT STRUCTURE PRIMARY
02	708372003	SUPERSTRUCTURE
03	708378005	MAGNET POWER LINE ROUTING ENVELOPE
04	708378021	WIRETRAY ROUTING ENVELOPES
05	708373008	MAGNET SUPPLY/RETURN MANIFOLDS, CRYO
06	708373010	MAGNET SUPPLY/RETURN ENVELOPES, CRYO
07	708378022	COOLANT MANIFOLD/INTERFACE, I & C
08	708375004	INSTALLATION-DEVICE COOLANT, TORUS
09	708371004	ENVELOPES MICROWAVE DISTRIBUTION SYSTEMS
10	708377001	CRYOPUMP INSTL. S C MAGNET
11	708377003	MANIFOLD ASSY-MAGNET ROUGHING-REGENERATION
12	708372004	VACUUM CAVITY PORT ARRANGEMENT
13	708376001	MAGNET ENVELOPE/INTERFACE
14	708372005	VACUUM LINER
15	708372001	TOROIDAL VESSEL SUPPORT
16	708378020	MAGNET PROTECTION SYSTEM INSTL./ENVELOPE
17	708377010	VACUUM PUMPING SYS-PRIMARY-TORUS
18	708372000	TOROIDAL VESSEL ASSEMBLY
19	708375001	DEVICE COOLANT PANELS

APPROVED TITLE I



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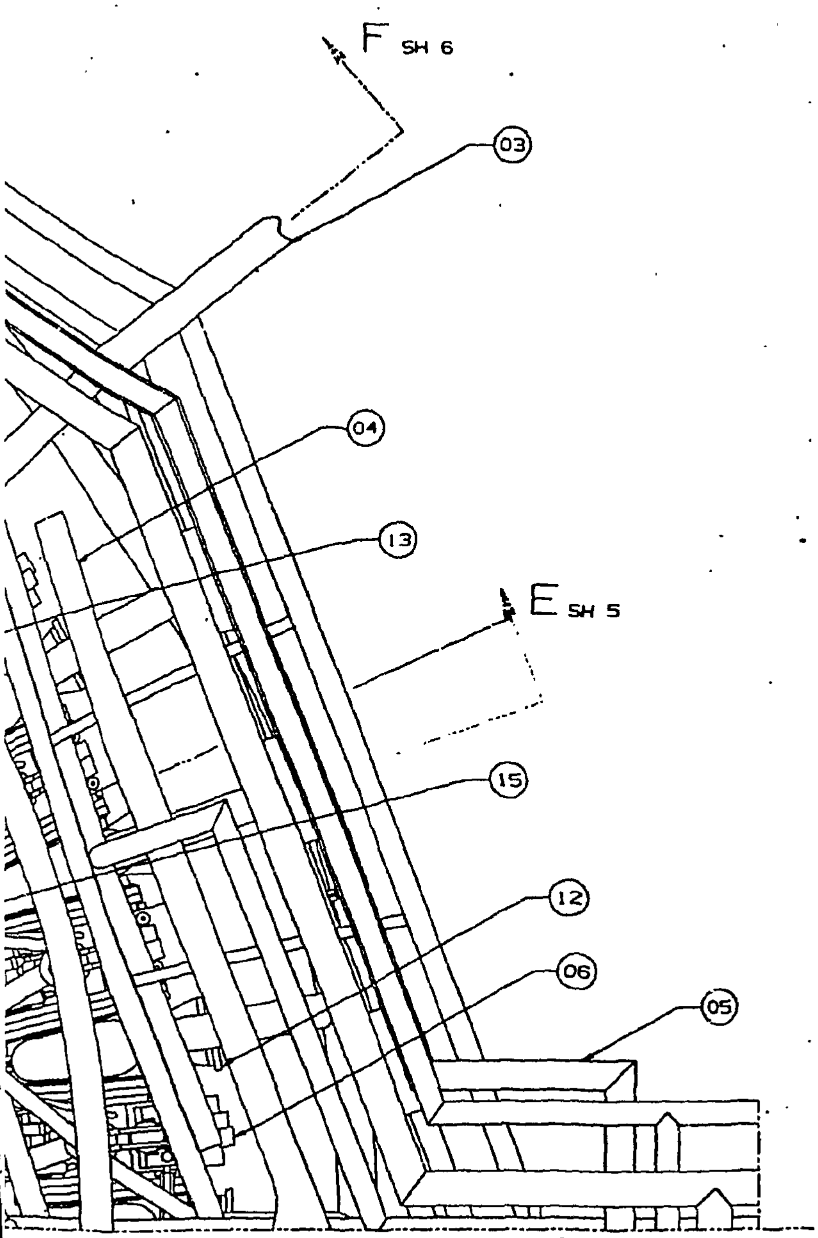
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS DIVISION



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McDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
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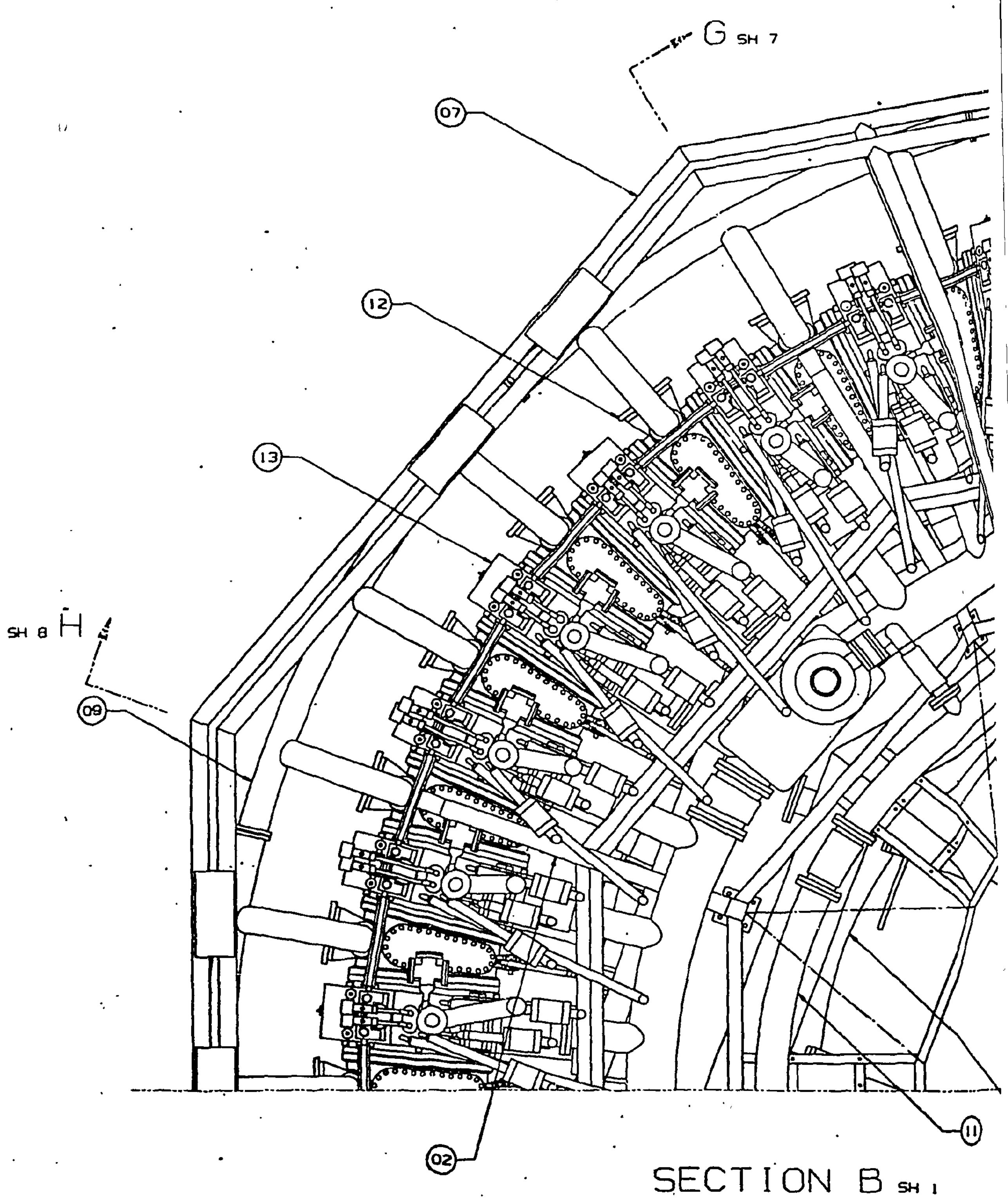
EBT-P
GENERAL
ARRANGEMENT

E 76301 DWG NO. 70B370000

WBS 2.1.g



SECTION B SH 1

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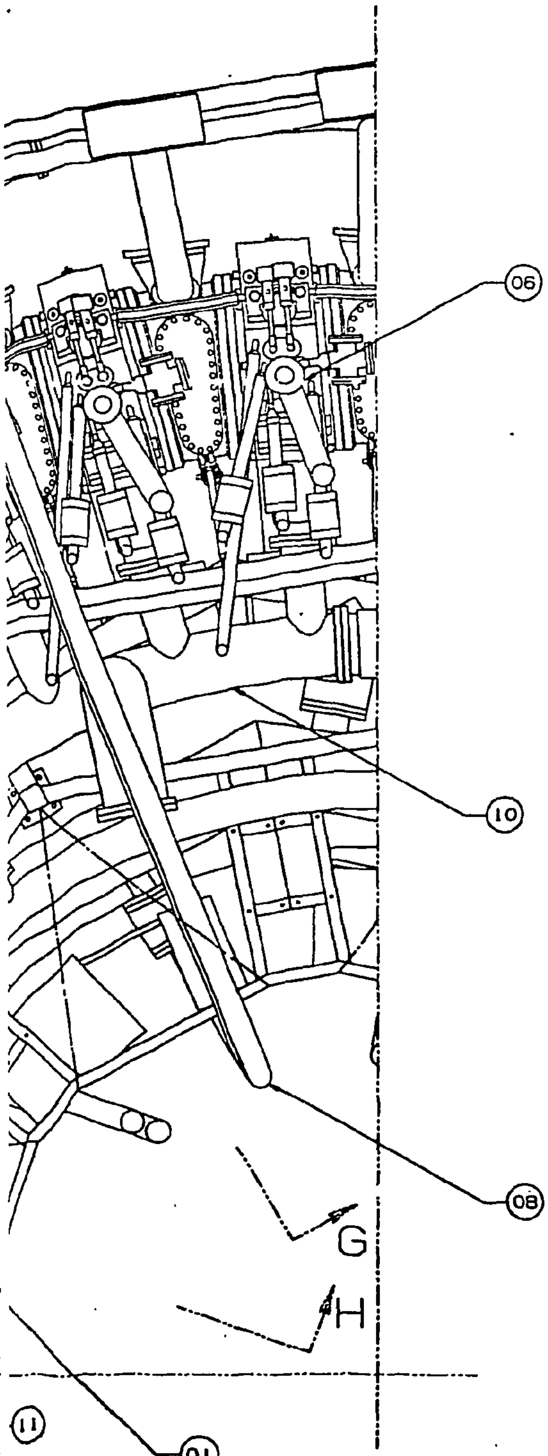

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DWN A. E. HARTMAN JR.

A L BOCH 6/8/82

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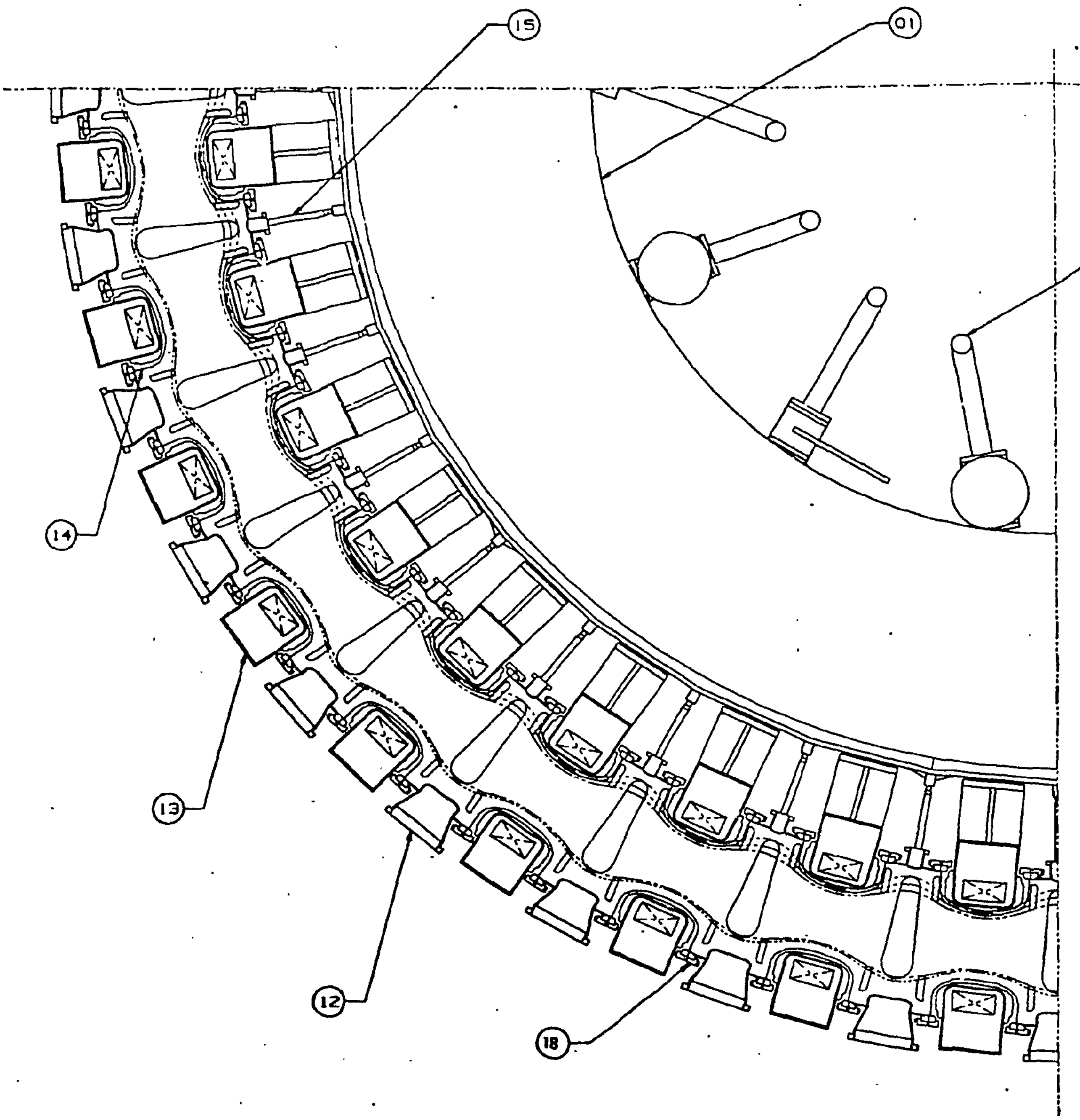
MCDONNELL DOUGLAS CORPORATION

EBT-P
GENERAL
ARRANGEMENT

E 76301 DWG NO. 70B370000

SCALE 1/10

W.B.S. 2.1.9



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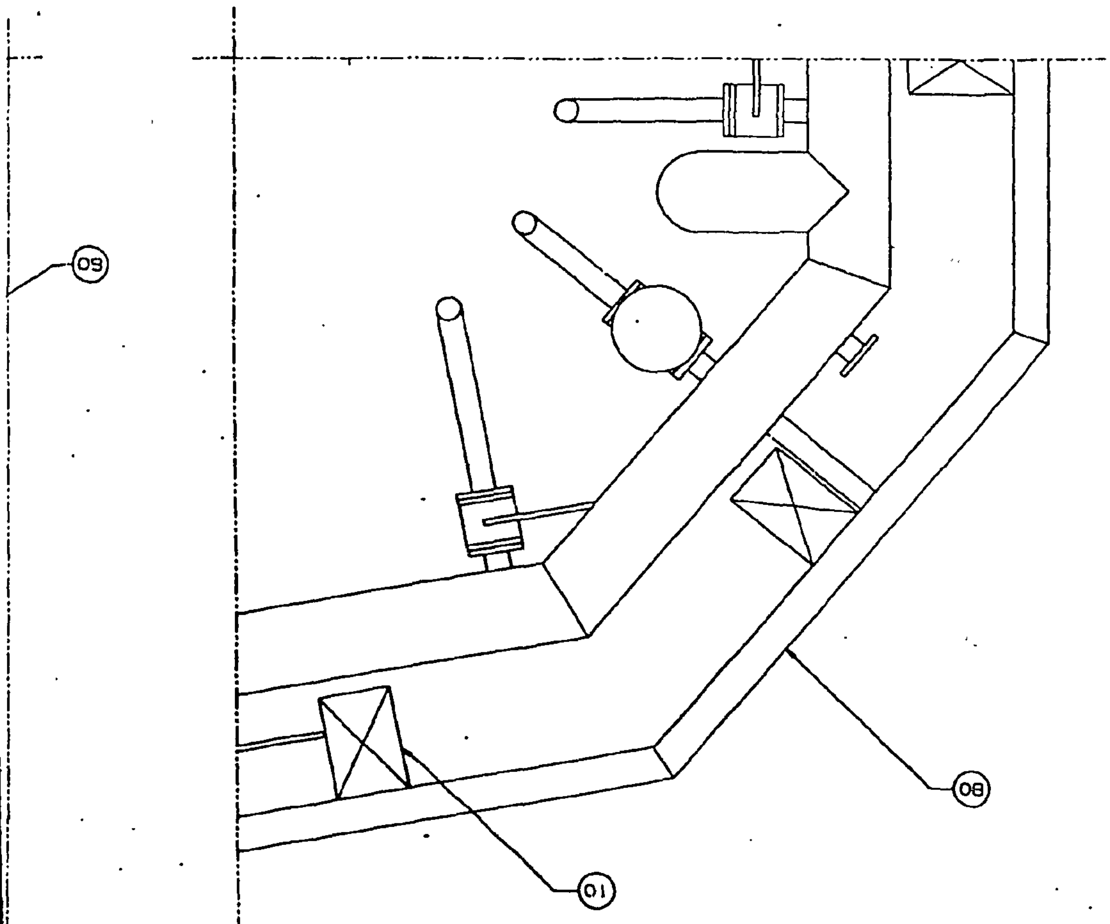

SECTION D SH 1

APPROVED TITLE I

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DRN A. E. HARTMAN JR.

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McDONNELL DOUGLAS CORPORATION

EBT-P
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E	76301	DWG NO. 70B370000

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APPLICATION

A L BOCH

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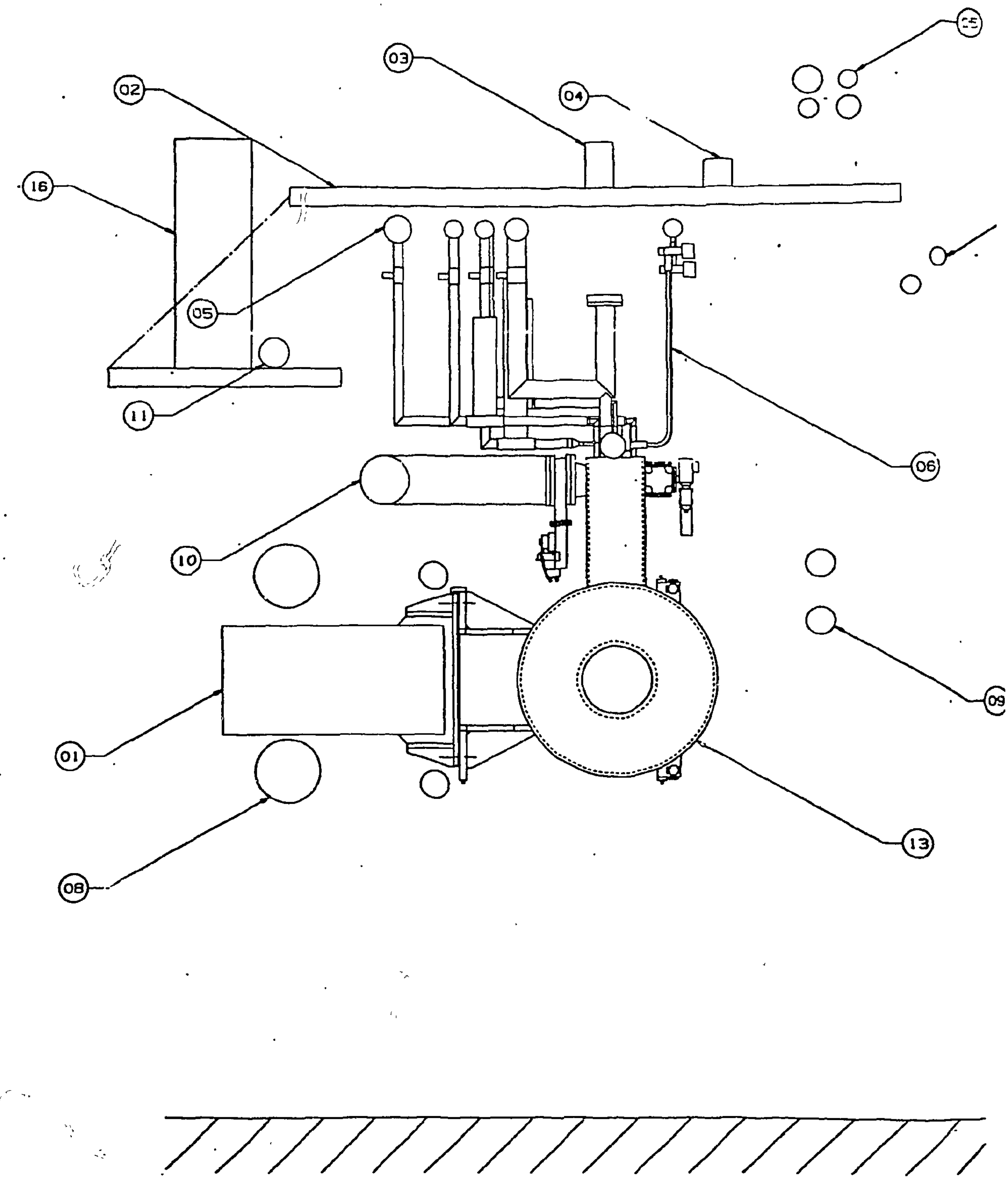
70B370000



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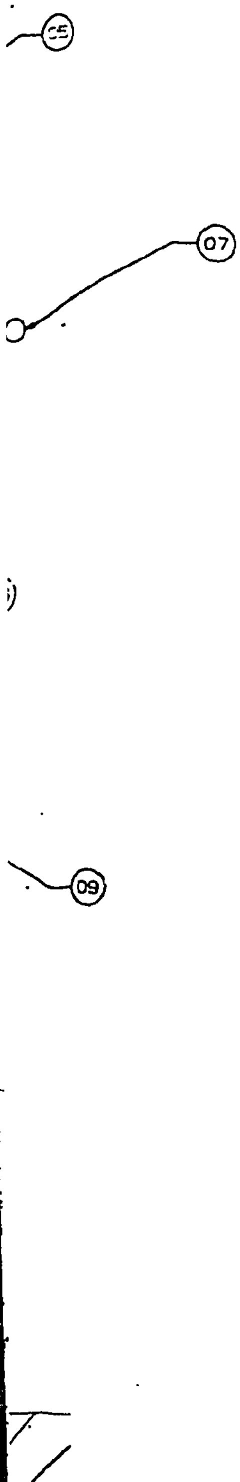

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DRN A. E. HARTMAN JR

APPROVED UFC NO A L BOCH 6/8/82

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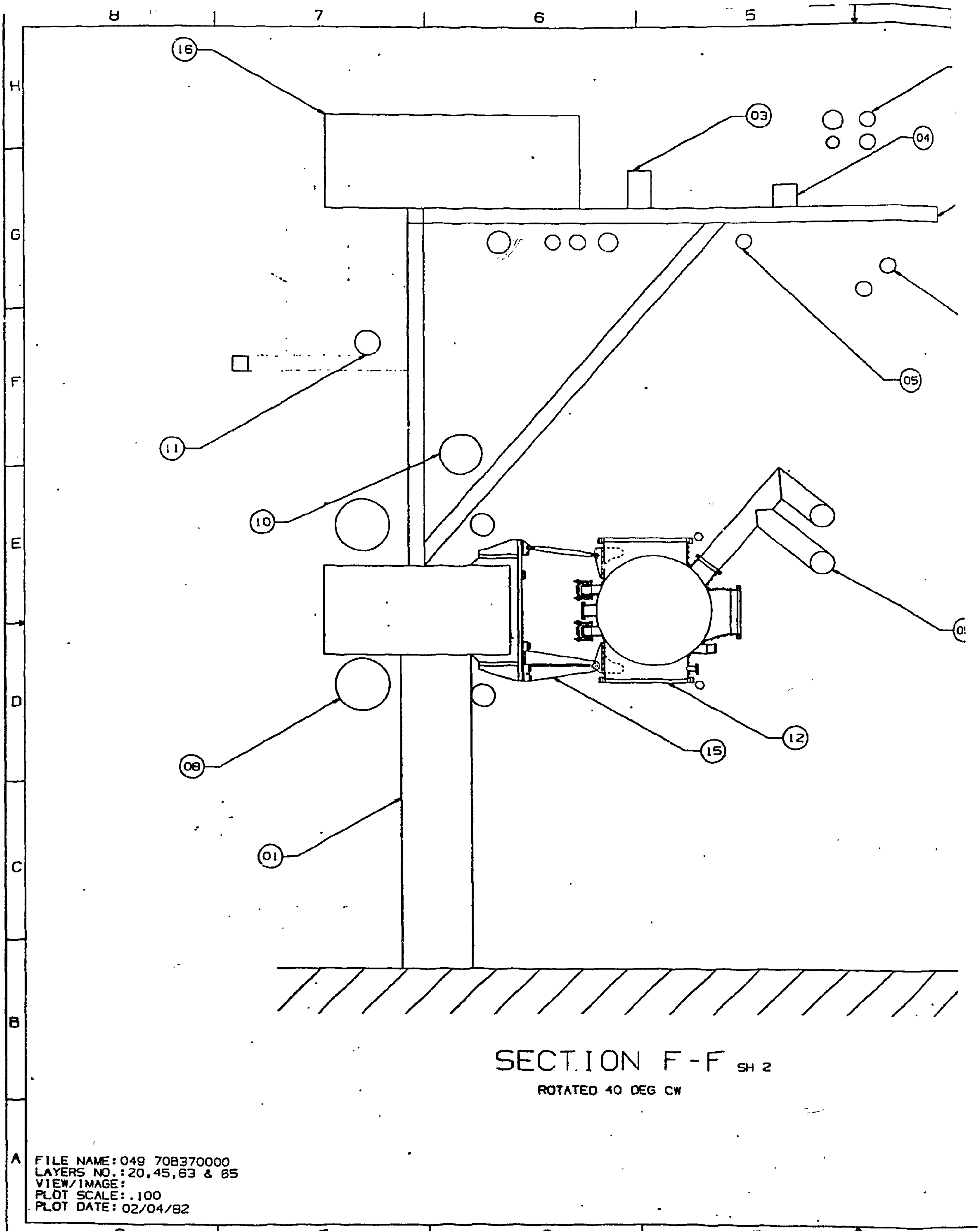

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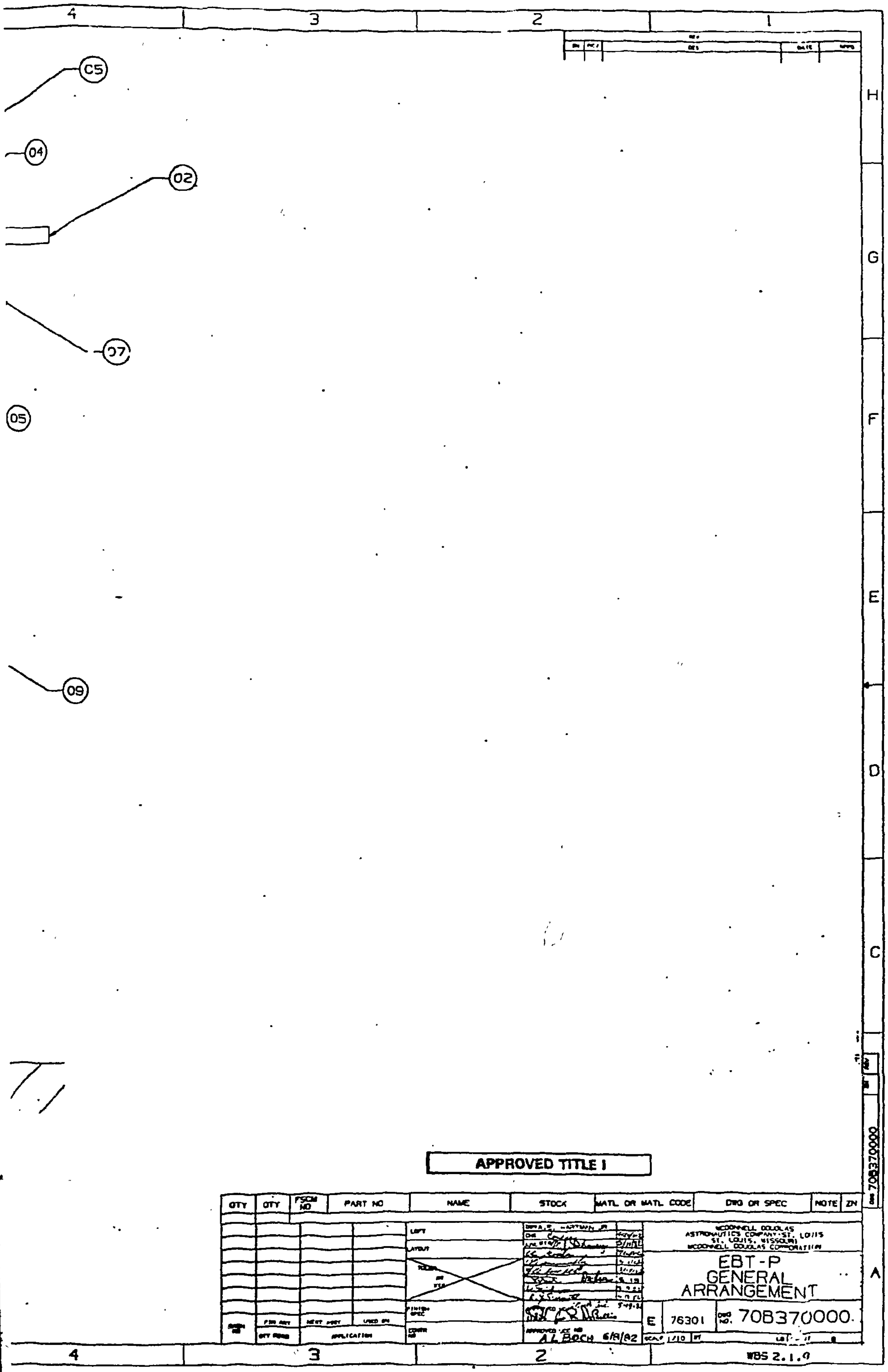
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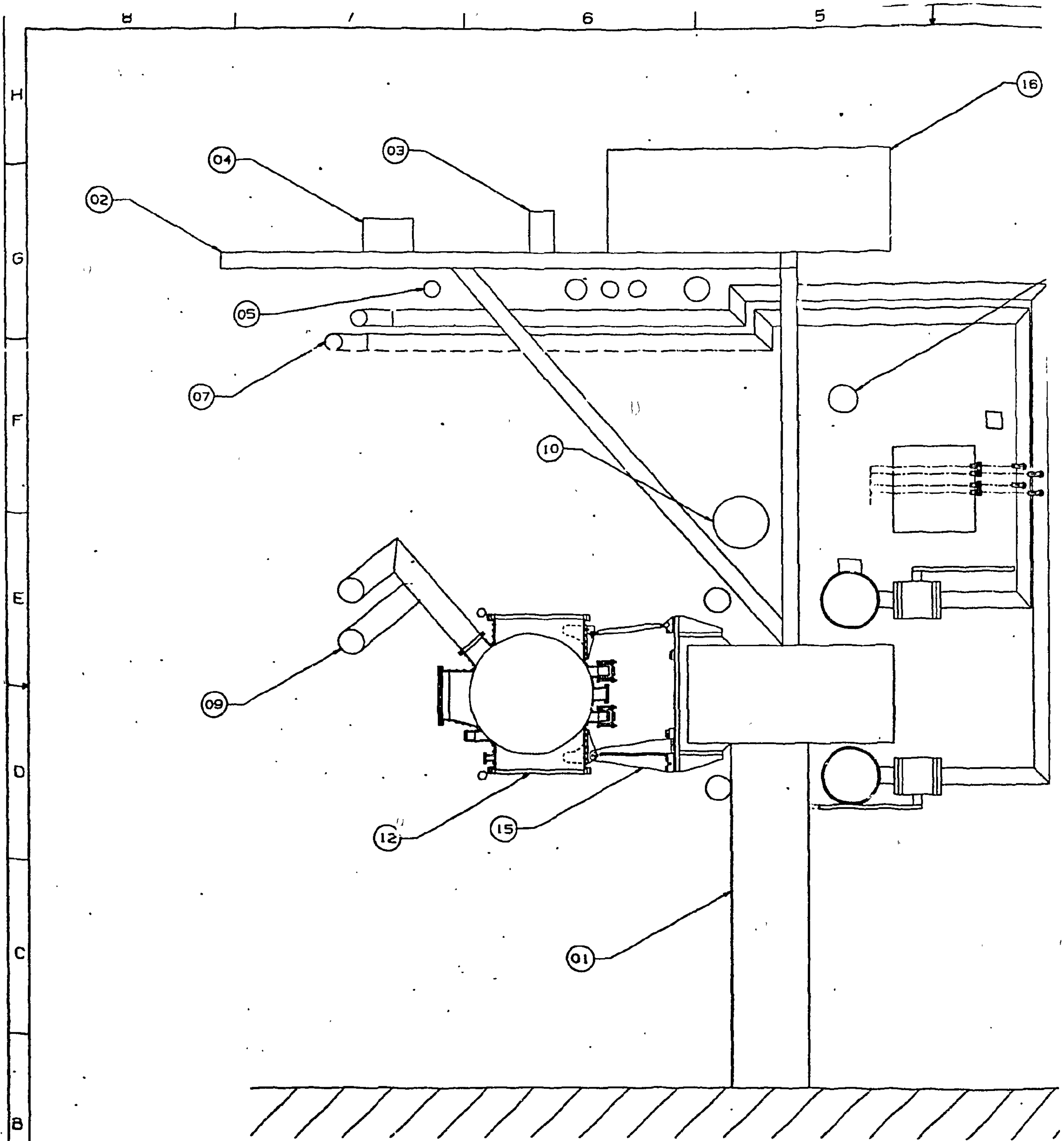

SECTION G-G SH 3

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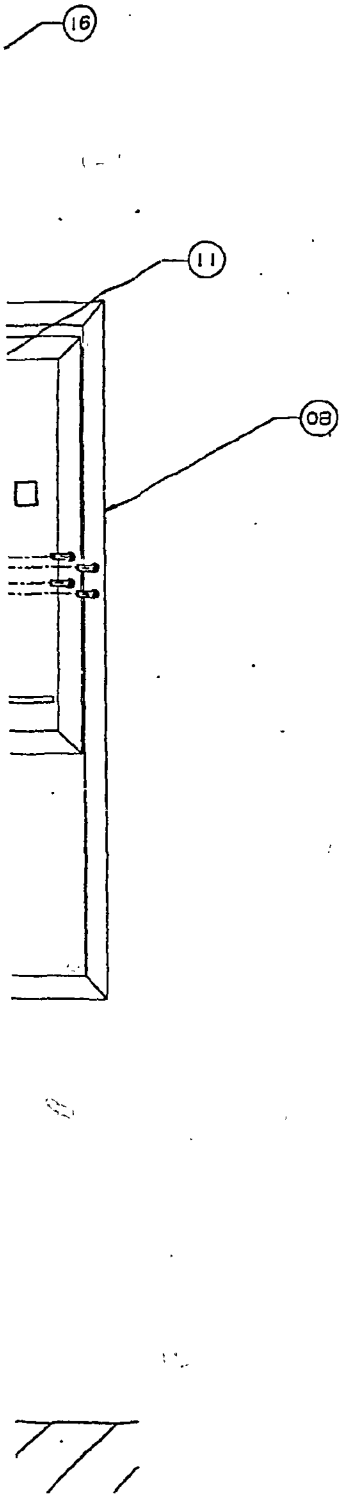

APPROVED TITLE I

QTY	QTY	FSCM NO	PART NO	NAME	STOCK	MATL OR MATL CODE	DWG OR SPEC	NOTE	ZN

DRN A.C. HARTMAN JR

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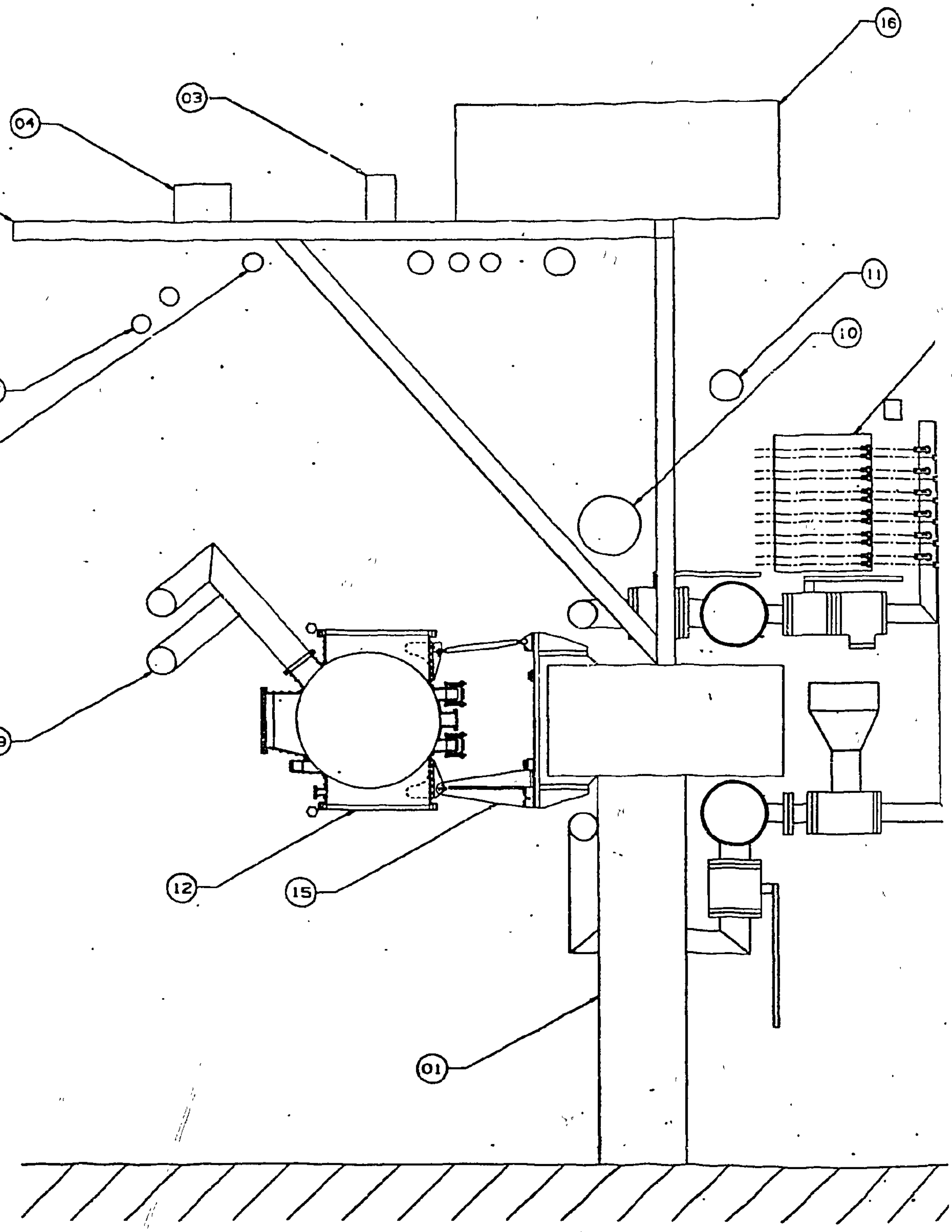
E	76301	DWG NO. 708370000

SCALE 1/10

WBS 2.1.9



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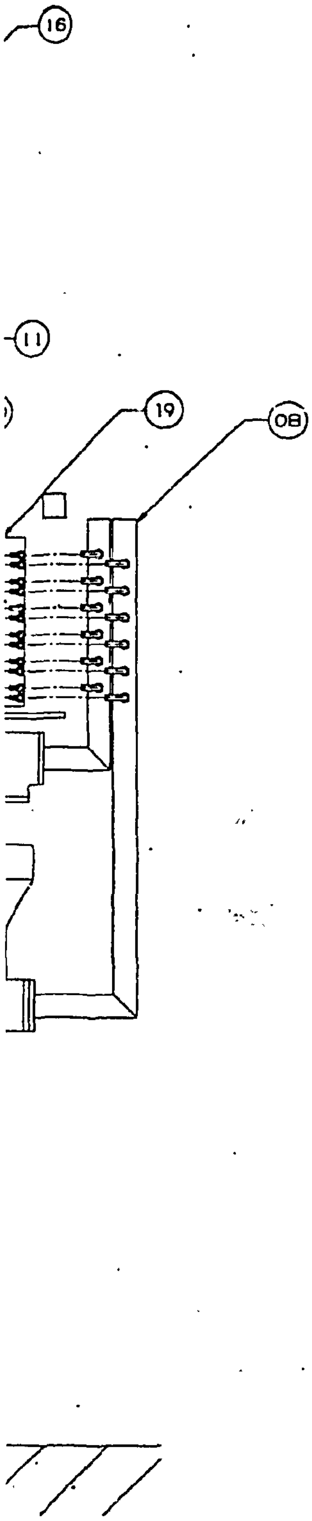

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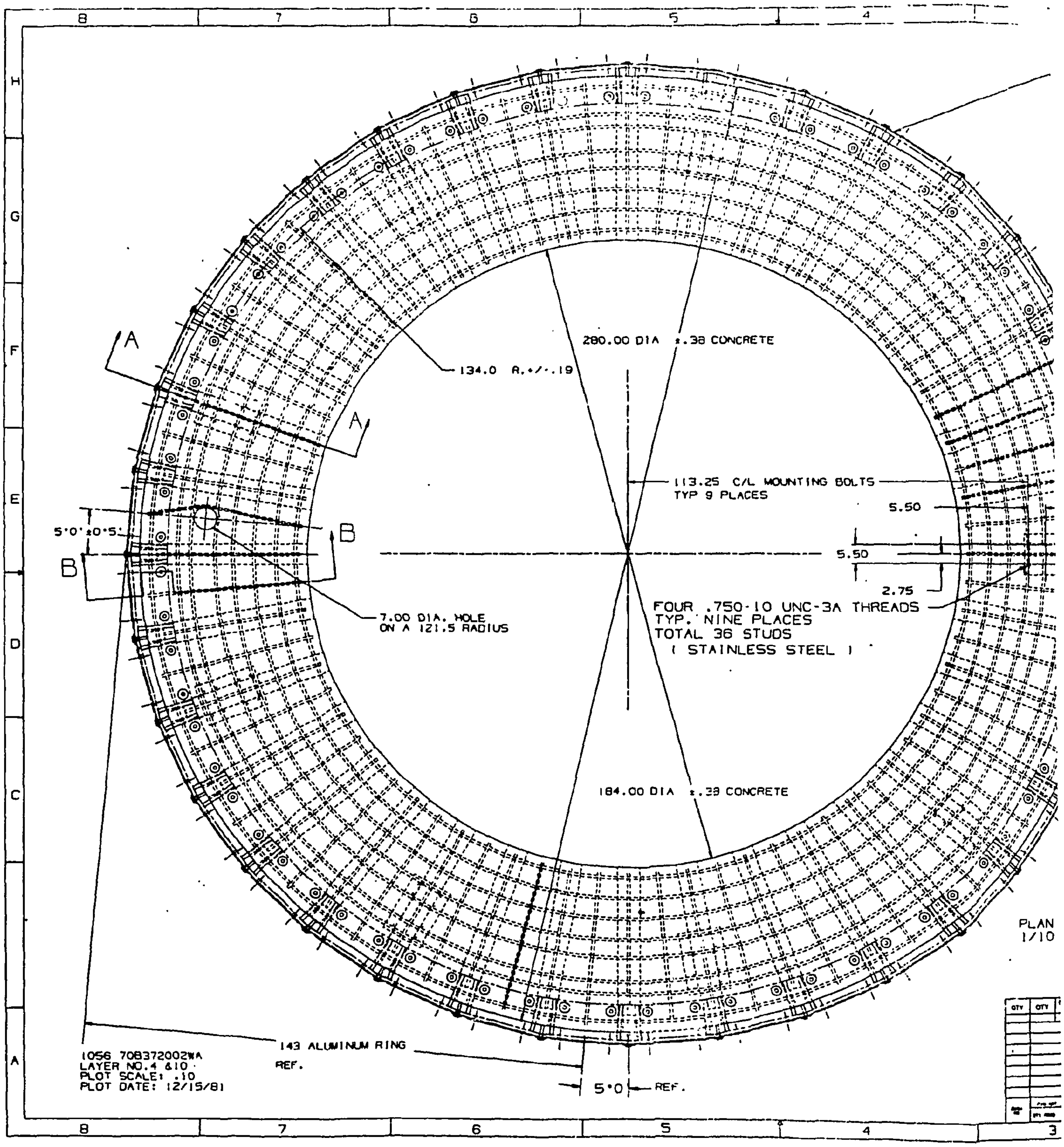
EBT-P GENERAL ARRANGEMENT

E 76301 DWG NO. 708370000

A. Bosh 6/8/62

SCALE 1/10

WBS 2.1.9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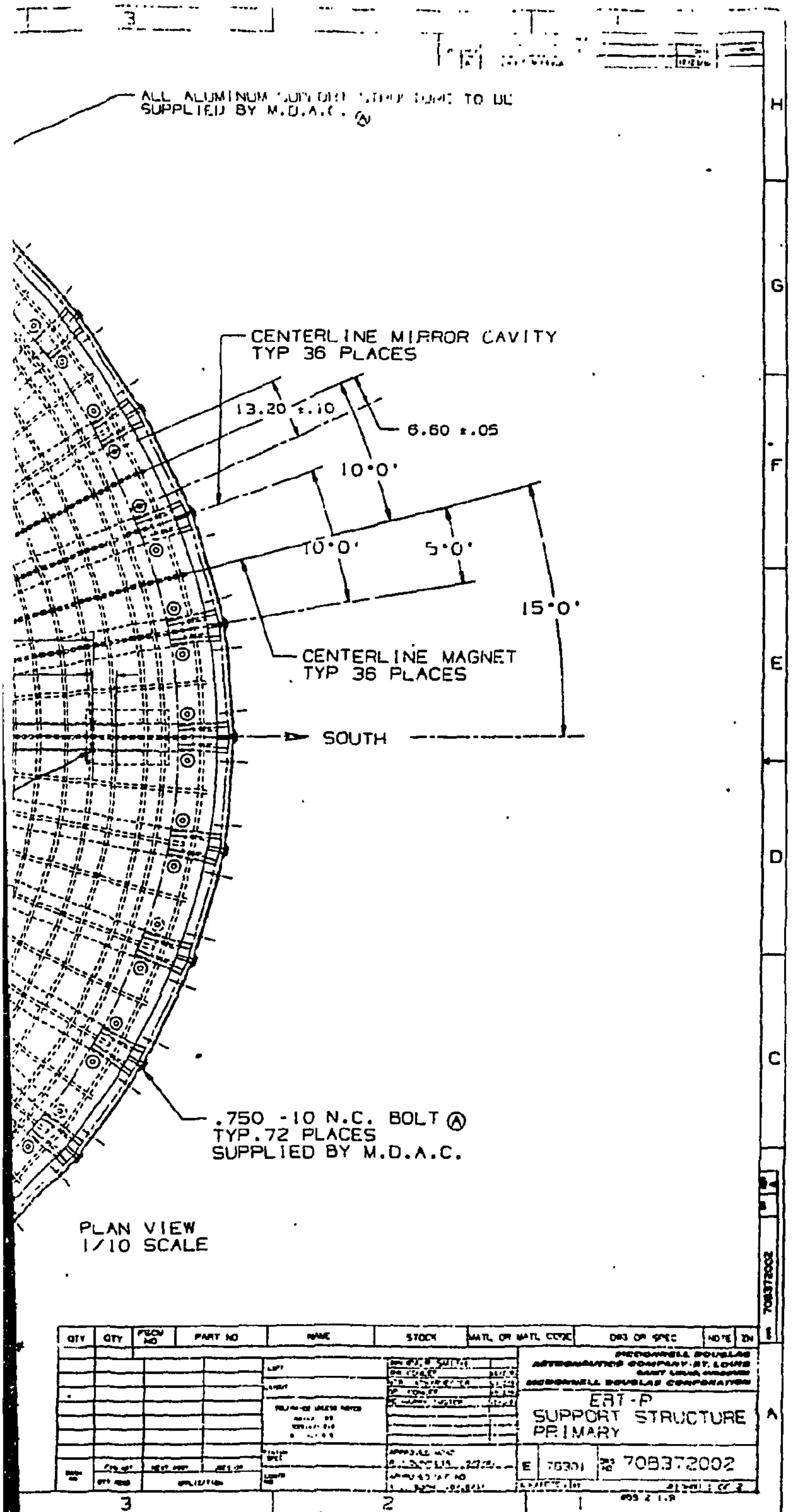
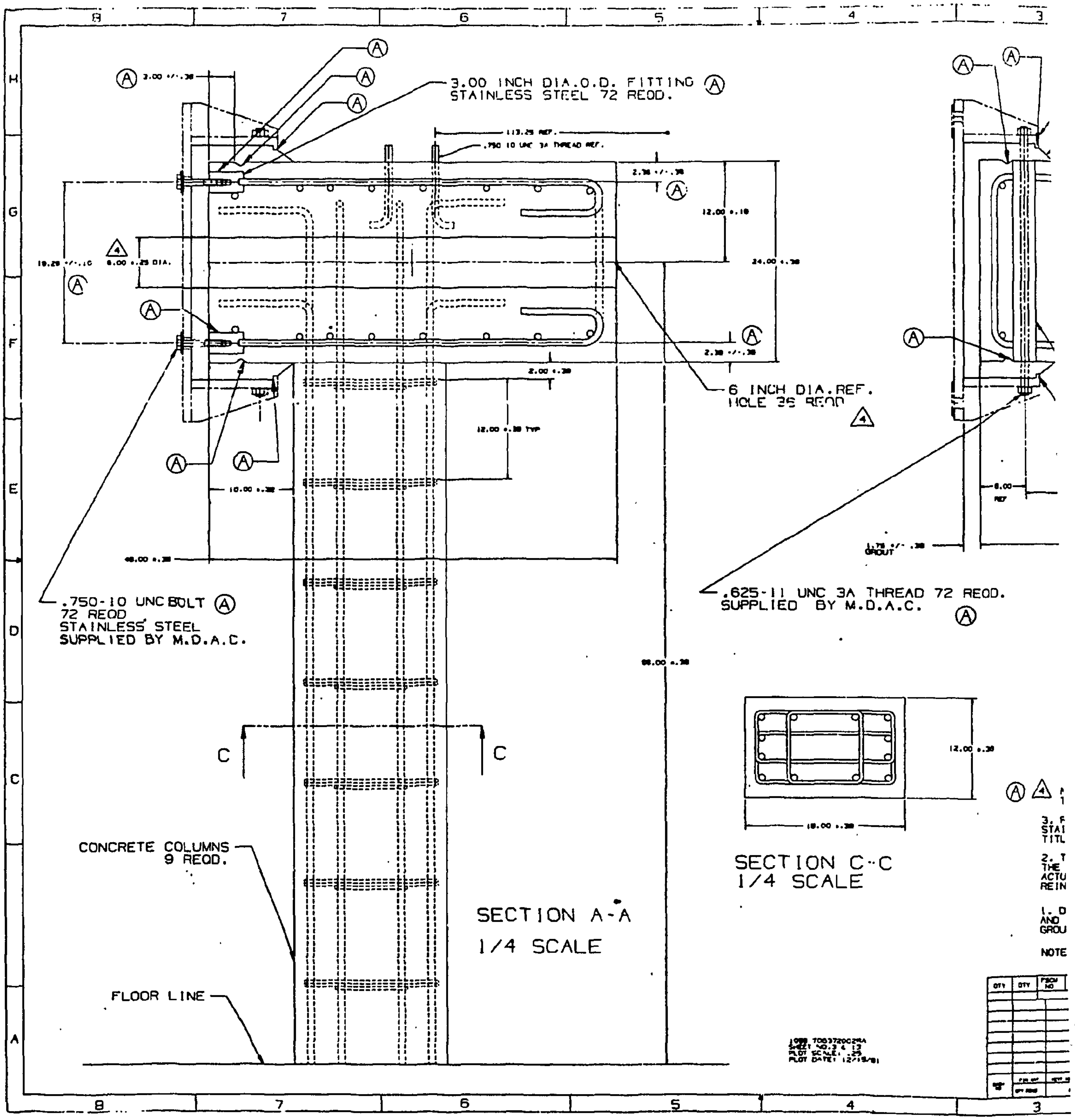
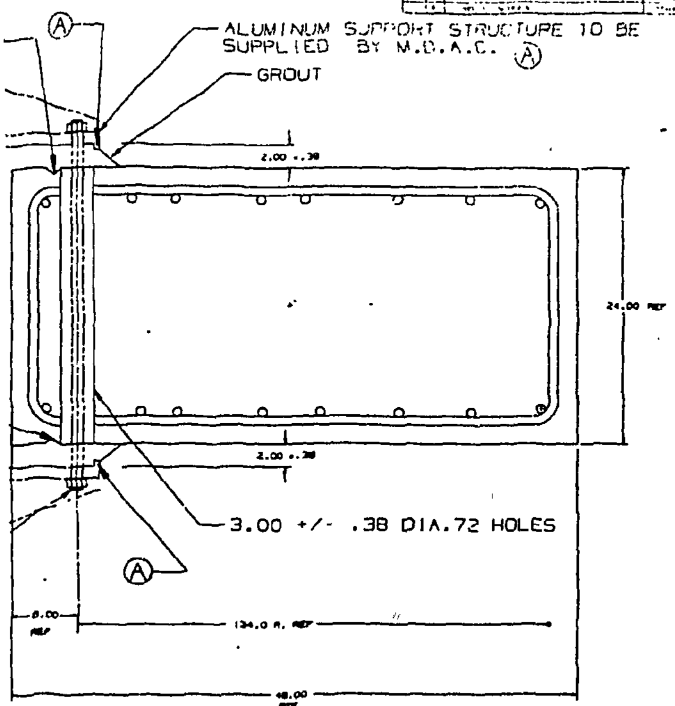
5.50
2.75
5'0"±0'5"
B
B
FOUR .750-10 UNC-3A THREADS
TYP. NINE PLACES
TOTAL 36 STUDS
(STAINLESS STEEL)
7.00 DIA. HOLE
ON A 121.5 RADIUS
184.00 DIA ±.38 CONCRETE
PLAN
1/10
143 ALUMINUM RING
REF.
5'0" REF.
1056 708372002WA
LAYER NO.4 &10
PLOT SCALE: .10
PLOT DATE: 12/15/81



ALL ALUMINUM SUPPORT STRUCTURE TO BE SUPPLIED BY M.D.A.C.
CENTERLINE MIRROR CAVITY
TYP 36 PLACES
13.20 ±.10
6.60 ±.05
10°0'
10°0'
5°0'
15°0'
CENTERLINE MAGNET
TYP 36 PLACES
SOUTH
.750 -10 N.C. BOLT
TYP.72 PLACES
SUPPLIED BY M.D.A.C.
PLAN VIEW
1/10 SCALE
QTY
QTY
PART NO
NAME
STOCK
MATL OR MATL CODE
DWG OR SPEC
NOTE
ZN
MCDONNELL DOUGLAS CORPORATION
ERT-P
SUPPORT STRUCTURE
PRIMARY
E
76301
708372002
H
G
F
E
D
C
A
3
2
1


3.00 INCH DIA.O.D. FITTING
STAINLESS STEEL 72 REQD.
6 INCH DIA.REF.
HOLE 36 REQD
.750-10 UNC BOLT
72 REQD
STAINLESS STEEL
SUPPLIED BY M.D.A.C.
.625-11 UNC 3A THREAD 72 REQD.
SUPPLIED BY M.D.A.C.
C
C
SECTION C-C
1/4 SCALE
CONCRETE COLUMNS
9 REQD.
SECTION A-A
1/4 SCALE
FLOOR LINE



OD.

SECTION B-B
1/4 SCALE

(A) 4 NO GROUT IS TO BE PLACED THE SIX INCH DIA. THRU HOLE AREA 36 HOLES.

3. REQUIRED MATERIAL STRENGTH OF THE CONCRETE AND NON-MAGNETIC STAINLESS STEEL REINFORCING ROD WILL BE DETERMINED DURNING TITLE II DESIGN.

2. THIS DRAWING IS AN ENVELOPE DRAWING TO SHOW THE GENERAL LAYOUT AND INTERFACES OF THE SUPPORT STRUCTURE. ACTUAL SIZING AND PLACEMENT OF THE NON-MAGNETIC STAINLESS STEEL REINFORCING RODS WILL BE PERFORMED DURING TITLE II DESIGN.

1. DEFORMED REINFORCING BARS ARE NON-MAGNETIC STAINLESS STEEL AND ARE TO BE WELDED TO FORM ONE CONTINUOUS CIRCUIT, AND WILL BE GROUNDED.

NOTES:

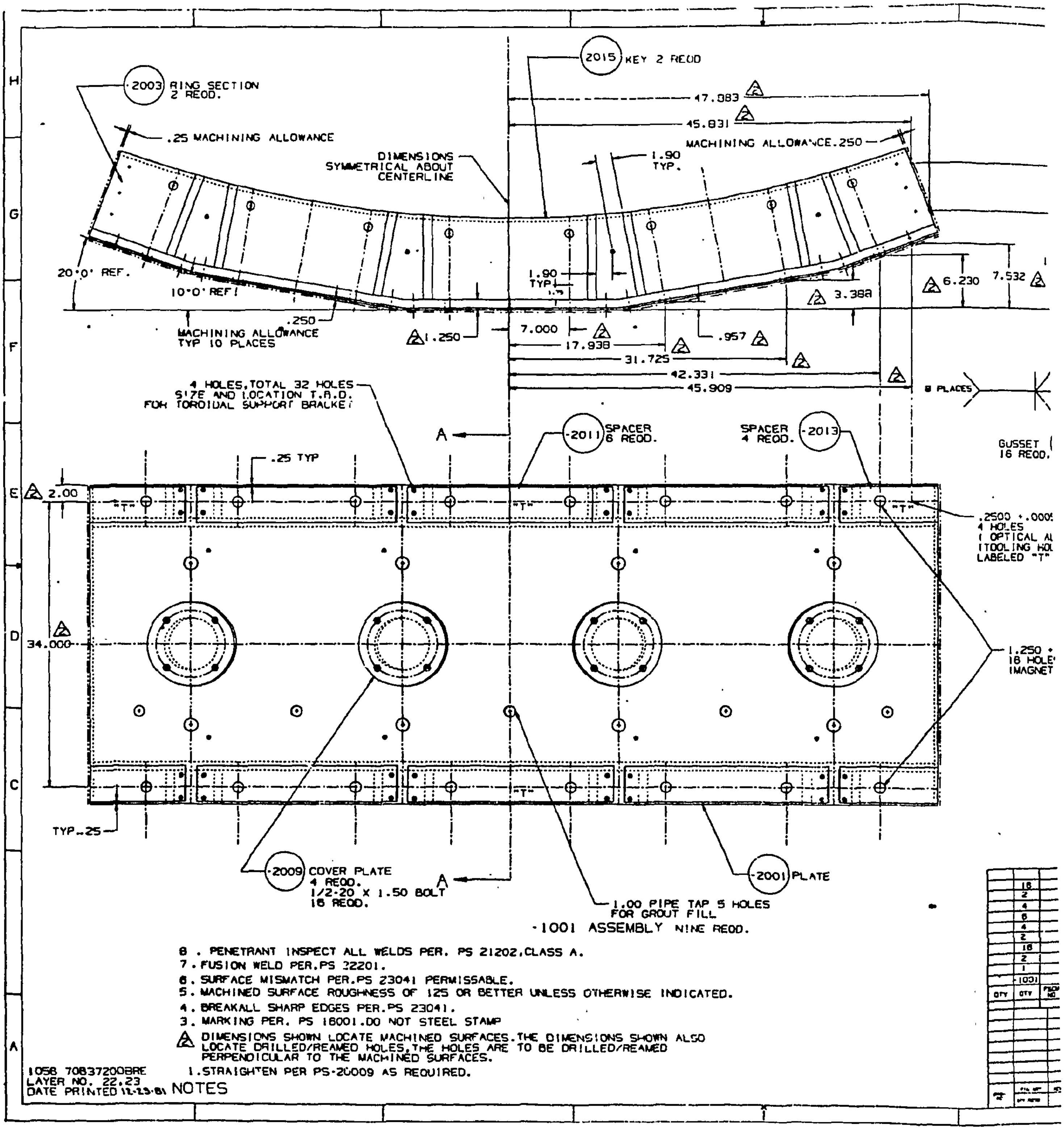
QTY	QTY	FSCM NO	PART NO	NAME	STOCK	MATL OR MATL CODE	DWG OR SPEC	NOTE	ZN

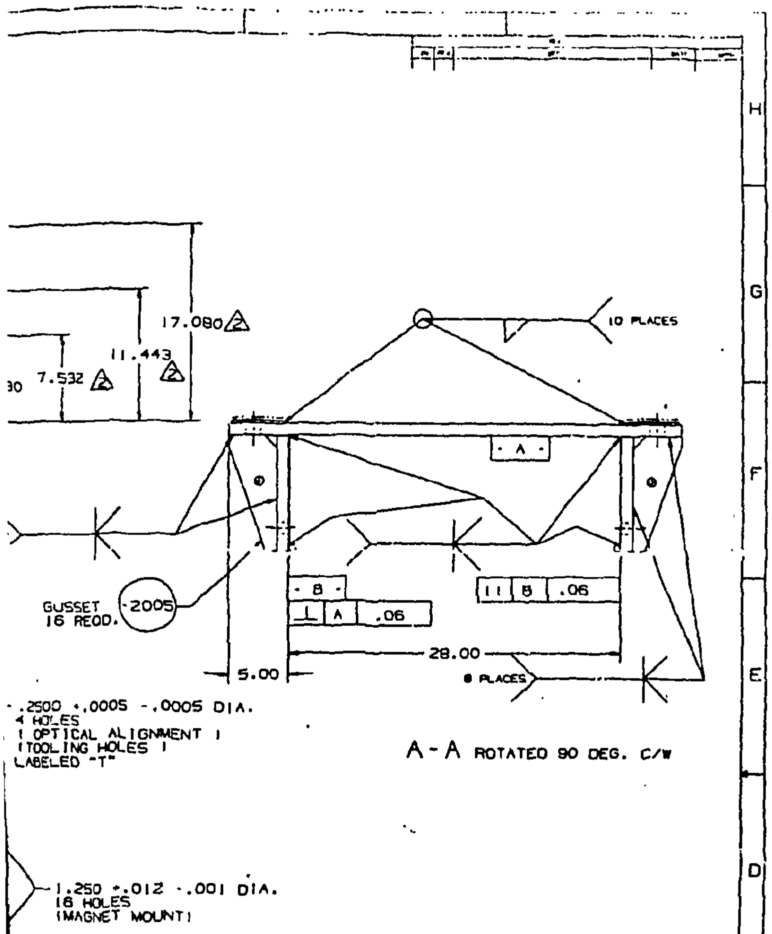
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
MCDONNELL DOUGLAS CORPORATION

EBT-P
SUPPORT STRUCTURE
PRIMARY

E 76301 DWG NO 70B372002

3 | 2 | 1 WBS 2.1.9


-2003 RING SECTION 2 REQD.
.25 MACHINING ALLOWANCE
DIMENSIONS SYMMETRICAL ABOUT CENTERLINE
-2015 KEY 2 REQD
47.083
45.831
MACHINING ALLOWANCE .250
1.90 TYP.
20°0' REF.
10°0' REF
.250
MACHINING ALLOWANCE TYP 10 PLACES
1.250
7.000
17.938
31.725
42.331
45.909
.957
3.388
6.230
7.532
4 HOLES, TOTAL 32 HOLES SIZE AND LOCATION T.B.D. FOR TOROIDAL SUPPORT BRACKET
-2011 SPACER 8 REQD.
SPACER 4 REQD. -2013
GUSSET 16 REQD.
.25 TYP
2.00
34.000
TYP .25
-2009 COVER PLATE 4 REQD. 1/2-20 X 1.50 BOLT 16 REQD.
1.00 PIPE TAP 5 HOLES FOR GROUT FILL
-2001 PLATE
-1001 ASSEMBLY NINE REQD.
8. PENETRANT INSPECT ALL WELDS PER. PS 21202, CLASS A.
7. FUSION WELD PER. PS 22201.
6. SURFACE MISMATCH PER. PS 23041 PERMISSABLE.
5. MACHINED SURFACE ROUGHNESS OF 125 OR BETTER UNLESS OTHERWISE INDICATED.
4. BREAKALL SHARP EDGES PER. PS 23041.
3. MARKING PER. PS 16001.00 NOT STEEL STAMP
2. DIMENSIONS SHOWN LOCATE MACHINED SURFACES. THE DIMENSIONS SHOWN ALSO LOCATE DRILLED/REAMED HOLES. THE HOLES ARE TO BE DRILLED/REAMED PERPENDICULAR TO THE MACHINED SURFACES.
1. STRAIGHTEN PER PS-20009 AS REQUIRED.
NOTES
1058 70837200BRE
LAYER NO. 22.23
DATE PRINTED 12-23-81



APPROVED TITLE I

QTY	QTY	FSCM NO	PART NO	NAME	STOCK	MATL OR MATL CODE	DWG OR SPEC	NOTE	ZN
	16			BOLT	1/2 -20 X 1.50	STEEL	REMOVE AFTER GROUTING		
	2		-2015	KEY	.5X.5X92.5	AL-AL 5456 H 321	00-A 250/9 COND H321		
	4		-2013	SPACER	.5X12.X4.25	AL-AL 5456 H 321	00-A 250/8 COND H321		
	6		-2011	SPACER	.5X23.8X4.25	AL-AL 5456 H 321	00-A 250/9 COND H321		
	4		-2009	COVER PLATE	.5 X10.50.	AL-AL 5450 H 321	00 A 250/9 COND H321		
	2		-2007	ANGLE	1.X14.X6.	AL-AL 5458 H 321	00-A 250/9 COND H321		
	16		-2005	GUSSET	1.X10.X4.	AL-AL 5458 H 321	00-A 250/9 COND H321		
	2		-2003	RING SECTION	1.X97.X19.	AL-AL 5456 H 321	00-A 250/9 COND H321		
	1		-2001	PLATE	1.Y38.X100.	AL-AL 5458 H 321	00-A 250/9 COND H371		
	-103)			ASSEMBLY					

708372008

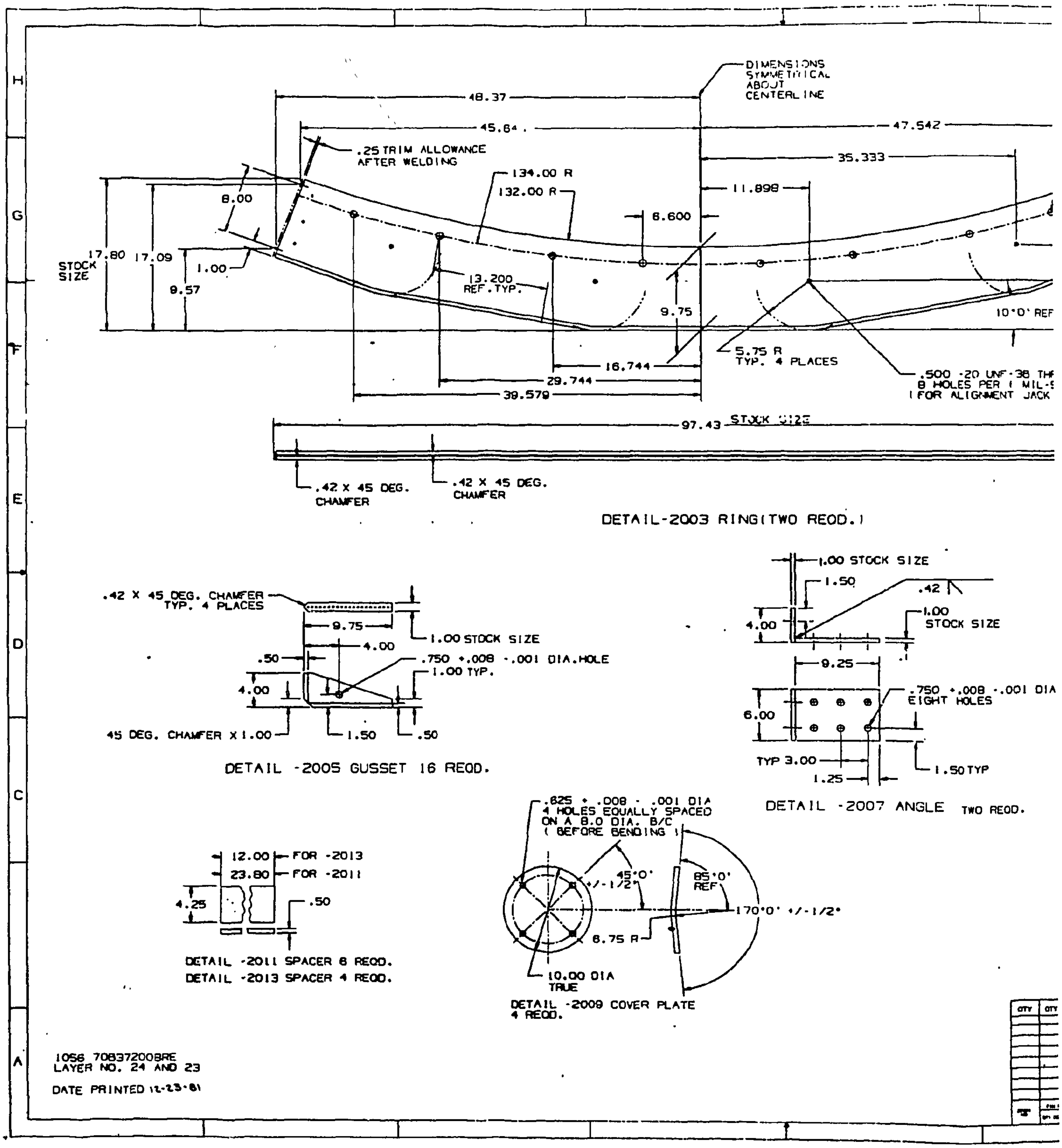
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
MCDONNELL DOUGLAS CORPORATION

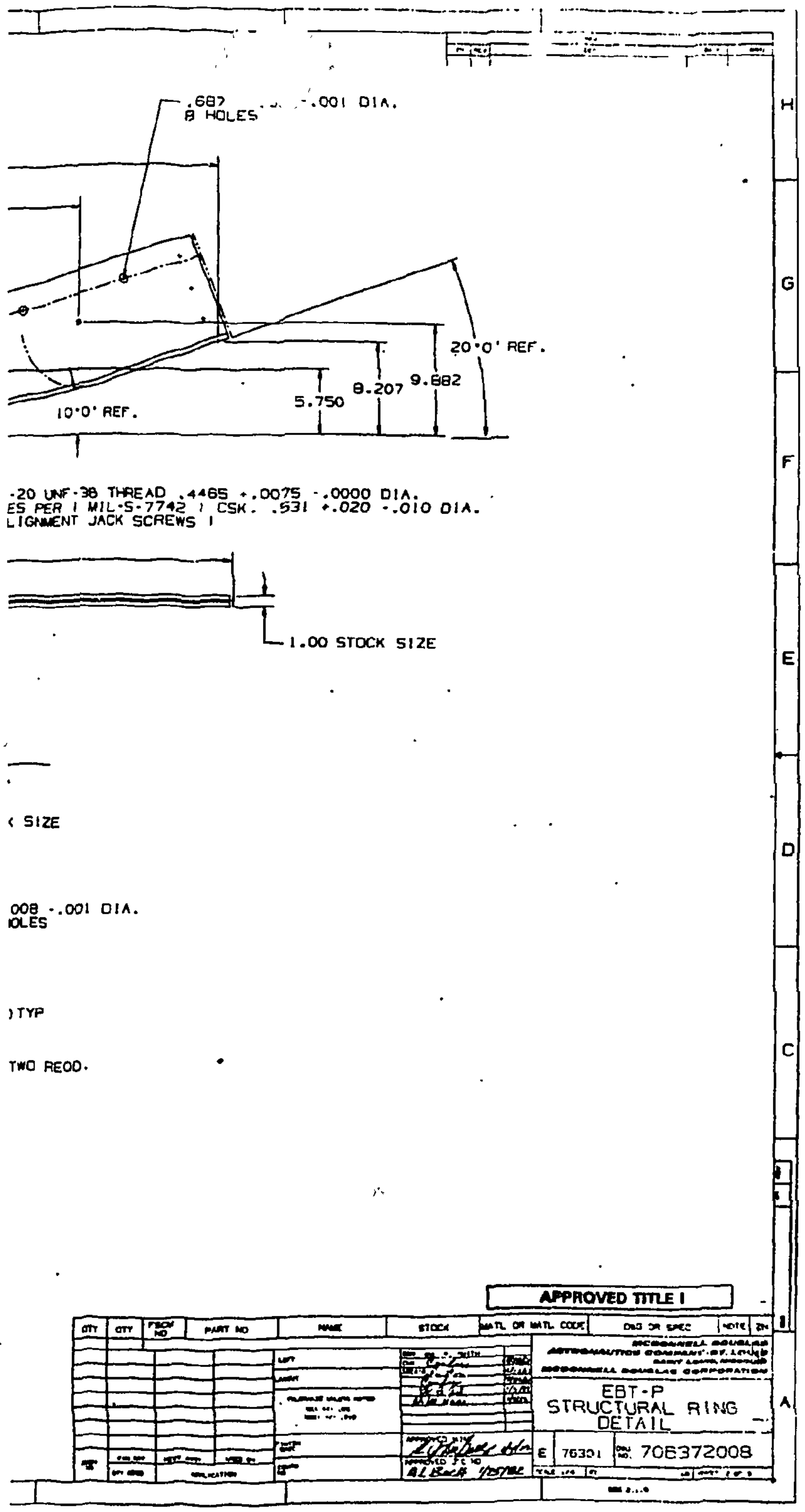
EBT-P
STRUCTURAL RING
DETAIL

A.L. Bock

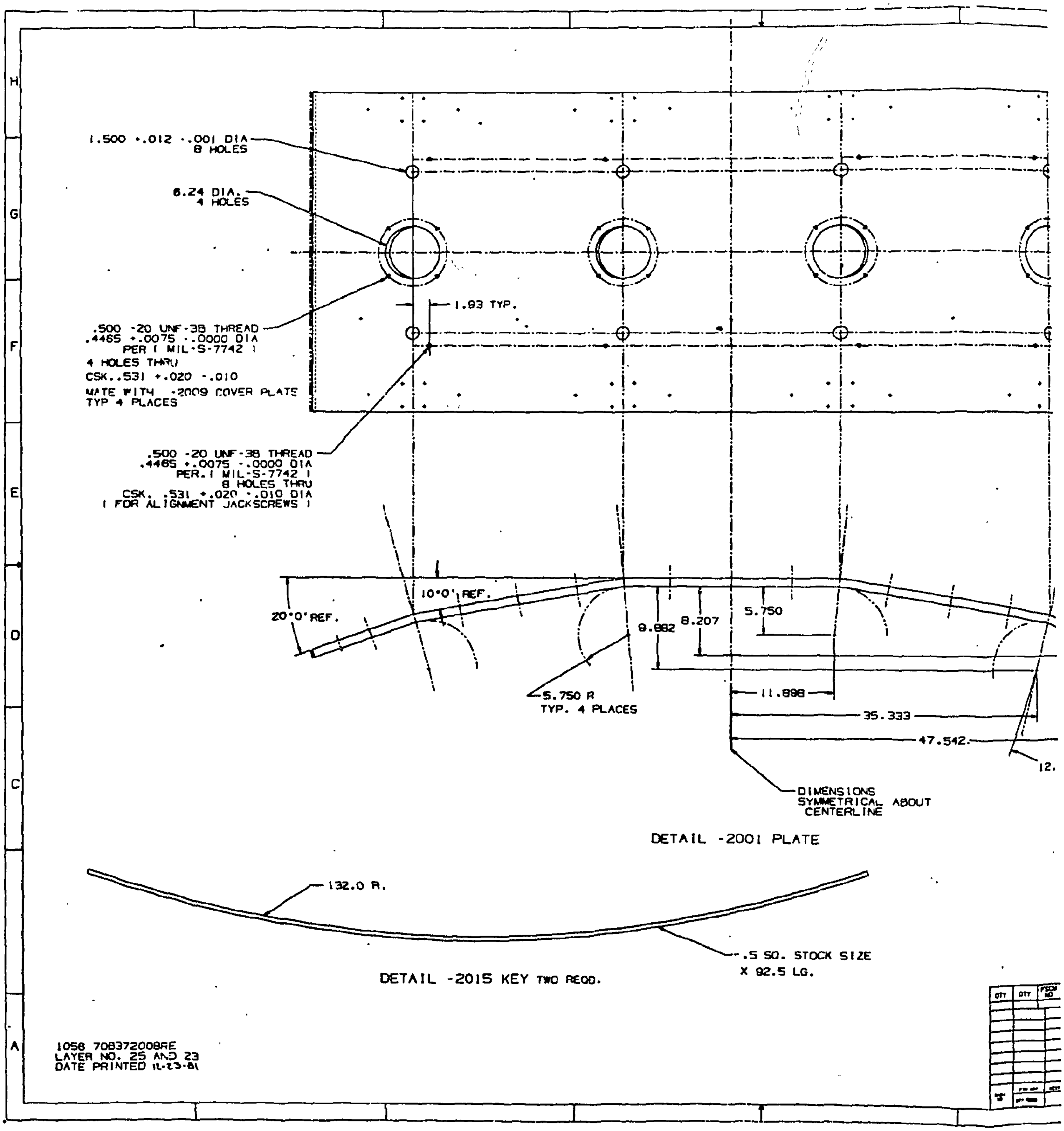
E	76301	DWG NO. 708372008

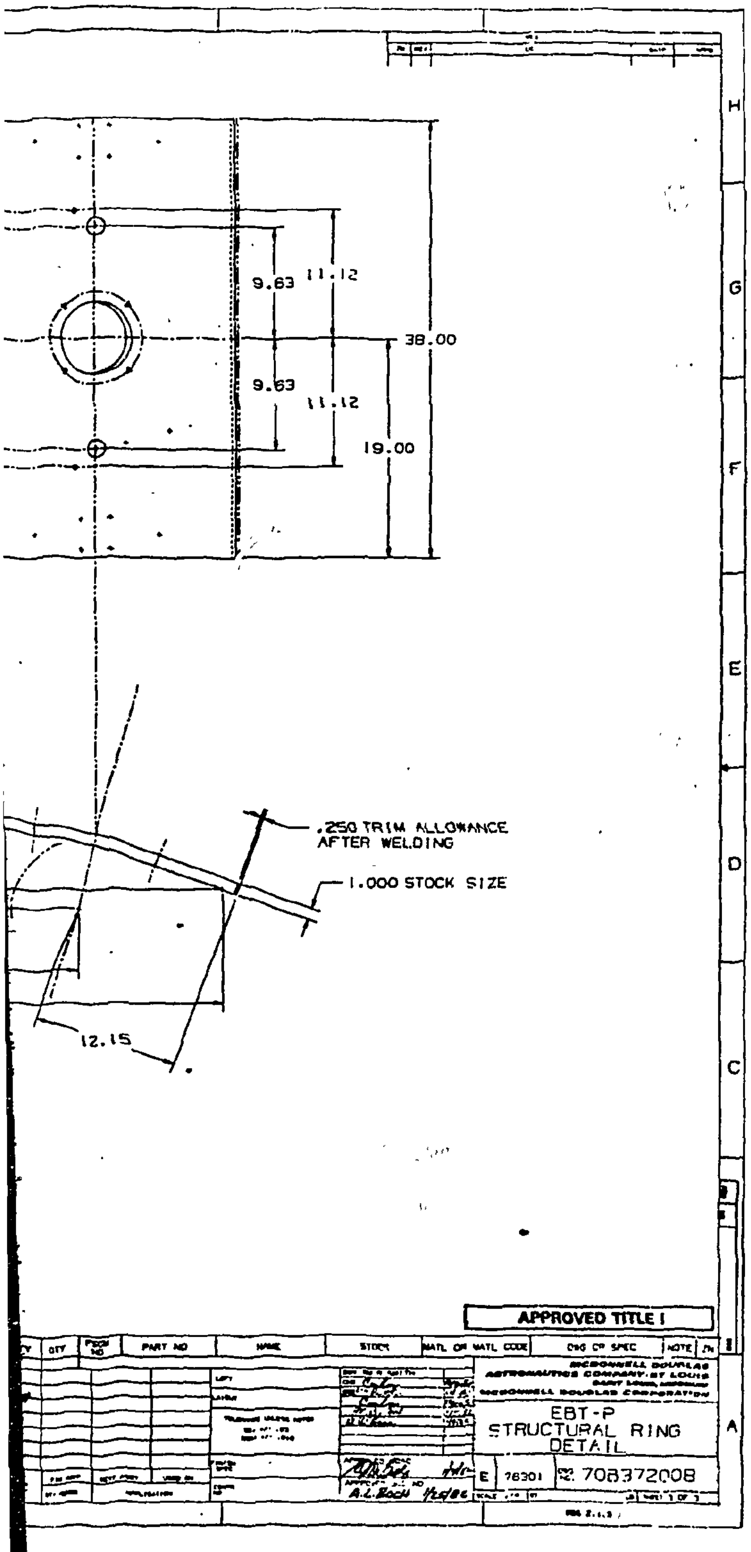
C/G 139.6 R


DIMENSIONS SYMMETRICAL ABOUT CENTERLINE
48.37
45.64
47.542
.25 TRIM ALLOWANCE AFTER WELDING
35.333
134.00 R
132.00 R
11.898
8.00
8.600
STOCK SIZE
17.80
17.09
1.00
9.57
13.200 REF. TYP.
9.75
10'0' REF
5.75 R TYP. 4 PLACES
16.744
29.744
39.579
.500 -20 UNF-3B THR 8 HOLES PER MIL-S FOR ALIGNMENT JACK
97.43 STOCK SIZE
.42 X 45 DEG. CHAMFER
.42 X 45 DEG. CHAMFER
DETAIL-2003 RING (TWO REQD.)
.42 X 45 DEG. CHAMFER TYP. 4 PLACES
9.75
1.00 STOCK SIZE
4.00
.50
.750 +.008 -.001 DIA.HOLE
1.00 TYP.
4.00
45 DEG. CHAMFER X 1.00
1.50
.50
DETAIL -2005 GUSSET 16 REQD.
1.00 STOCK SIZE
1.50
.42
4.00
1.00 STOCK SIZE
9.25
.750 +.008 -.001 DIA EIGHT HOLES
6.00
TYP 3.00
1.25
1.50 TYP
DETAIL -2007 ANGLE TWO REQD.
.625 + .008 - .001 DIA 4 HOLES EQUALLY SPACED ON A 8.0 DIA. B/C (BEFORE BENDING)
12.00 FOR -2013
23.80 FOR -2011
4.25
.50
45°0' +/-1/2°
85°0' REF
170°0' +/-1/2°
8.75 R
10.00 DIA TRUE
DETAIL -2011 SPACER 8 REQD.
DETAIL -2013 SPACER 4 REQD.
DETAIL -2009 COVER PLATE 4 REQD.
1056 70837200BRE
LAYER NO. 24 AND 23
DATE PRINTED 12-23-81
H
G
F
E
D
C
A
QTY
QTY

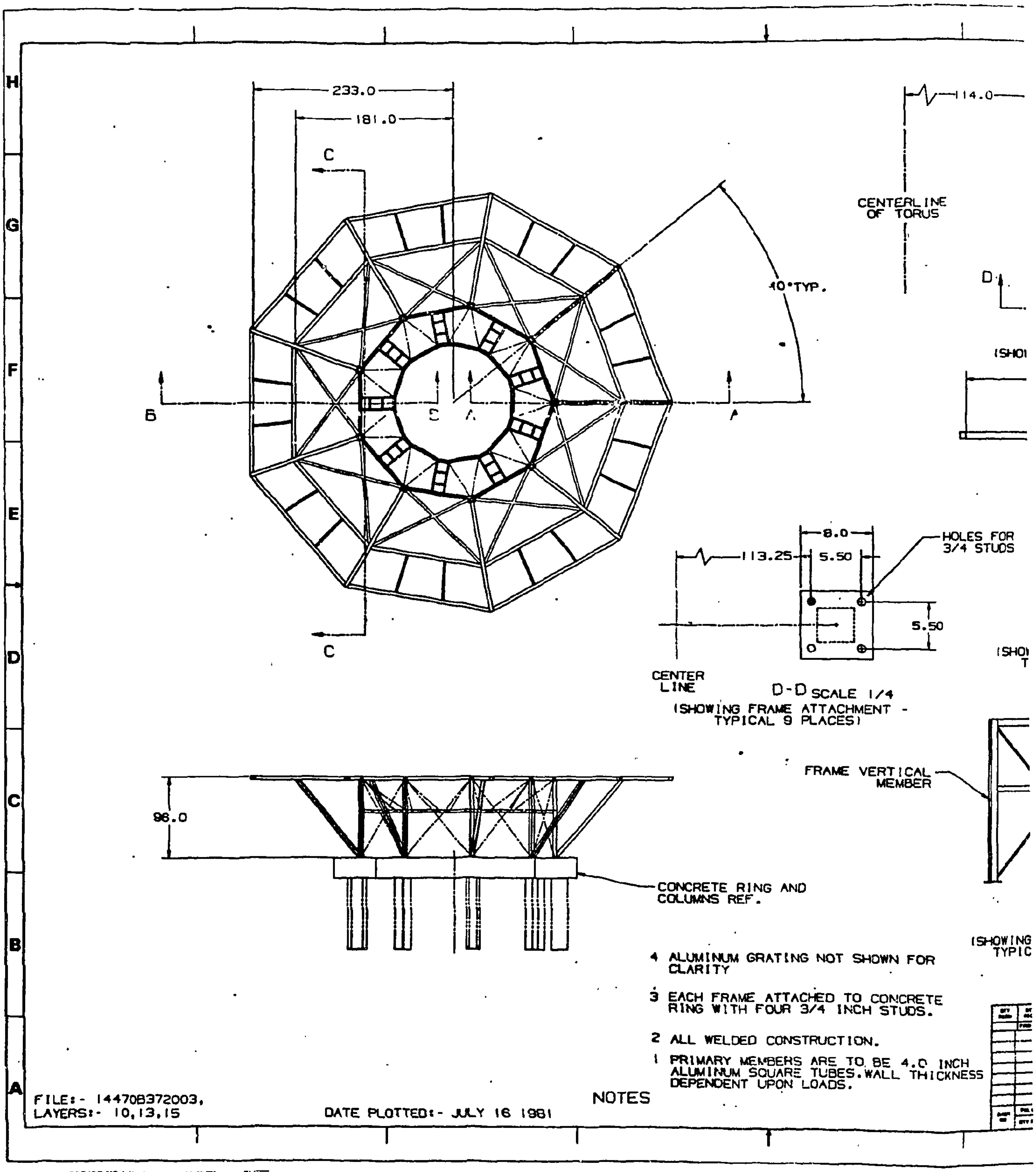


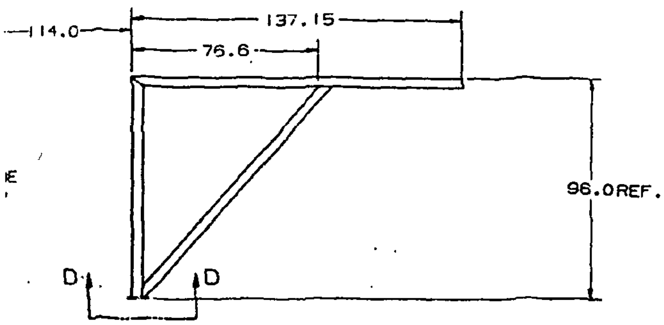
.687 -.001 DIA.
8 HOLES
20°0' REF.
10°0' REF.
5.750
8.207
9.882
-20 UNF-3B THREAD .4465 +.0075 -.0000 DIA.
ES PER (MIL-S-7742) CSK. .531 +.020 -.010 DIA.
LIGNMENT JACK SCREWS)
1.00 STOCK SIZE
(SIZE
008 -.001 DIA.
IOLES
) TYP
TWO REQD.
H
G
F
E
D
C
A
APPROVED TITLE I
QTY
PART NO
NAME
STOCK
MATL OR MATL CODE
DWG OR SPEC
NOTE
EBT-P
STRUCTURAL RING
DETAIL
E
76301
706372008


H
G
F
E
D
C
A
1.500 +.012 -.001 DIA
8 HOLES
6.24 DIA.
4 HOLES
1.93 TYP.
.500 -20 UNF-3B THREAD
.4465 +.0075 -.0000 DIA
PER (MIL-S-7742)
4 HOLES THRU
CSK..531 +.020 -.010
MATE WITH -2009 COVER PLATE
TYP 4 PLACES
.500 -20 UNF-3B THREAD
.4465 +.0075 -.0000 DIA
PER.(MIL-S-7742)
8 HOLES THRU
CSK. .531 +.020 -.010 DIA
(FOR ALIGNMENT JACKSCREWS)
10°0' REF.
20°0' REF.
9.882
8.207
5.750
5.750 R
TYP. 4 PLACES
11.898
35.333
47.542
12.
DIMENSIONS
SYMMETRICAL ABOUT
CENTERLINE
DETAIL -2001 PLATE
132.0 R.
.5 SQ. STOCK SIZE
X 92.5 LG.
DETAIL -2015 KEY TWO REQD.
1058 70B372008RE
LAYER NO. 25 AND 23
DATE PRINTED 11-23-81

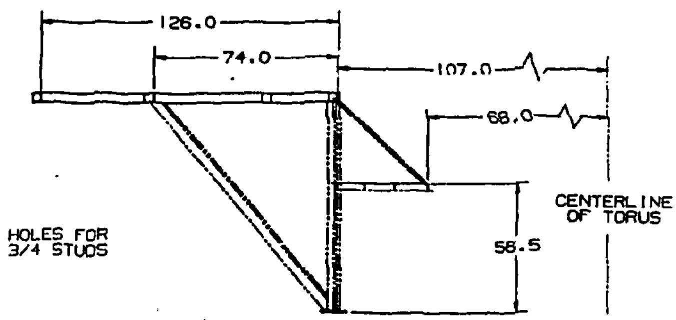


9.63
11.12
38.00
9.63
11.12
19.00
.250 TRIM ALLOWANCE AFTER WELDING
1.000 STOCK SIZE
12.15
APPROVED TITLE I
QTY
PART NO
NAME
STOCK
MATL OR MATL CODE
DWG OR SPEC
NOTE
McDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST LOUIS
McDONNELL DOUGLAS CORPORATION
EBT-P STRUCTURAL RING DETAIL
A.L. Boch
E
76301
70B372008
H
G
F
E
D
C
A

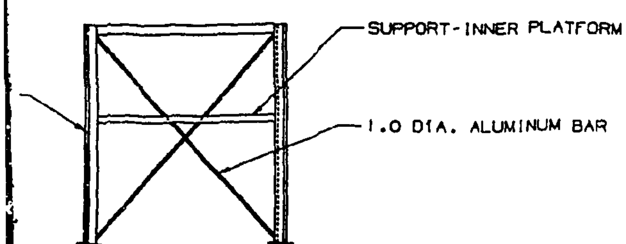

233.0
181.0
C
C
B
A
40°TYP.
CENTERLINE OF TORUS
114.0
D
8.0
113.25
5.50
5.50
HOLES FOR 3/4 STUDS
CENTER LINE
D-D SCALE 1/4
(SHOWING FRAME ATTACHMENT - TYPICAL 9 PLACES)
96.0
CONCRETE RING AND COLUMNS REF.
FRAME VERTICAL MEMBER
(SHOWING TYPIC
4 ALUMINUM GRATING NOT SHOWN FOR CLARITY
3 EACH FRAME ATTACHED TO CONCRETE RING WITH FOUR 3/4 INCH STUDS.
2 ALL WELDED CONSTRUCTION.
1 PRIMARY MEMBERS ARE TO BE 4.0 INCH ALUMINUM SQUARE TUBES. WALL THICKNESS DEPENDENT UPON LOADS.
NOTES
FILE:- 14470B372003,
LAYERS:- 10,13,15
DATE PLOTTED:- JULY 16 1981



A-A SCALE 1/20
(SHOWING FRAME - TYPICAL 9 PLACES)



B-B SCALE 1/20
(SHOWING INNER PLATFORM- TYPICAL 9 PLACES)



C-C SCALE 1/20
(SHOWING FRAME BRACING- TYPICAL 9 PLACES)

APPROVED TITLE I

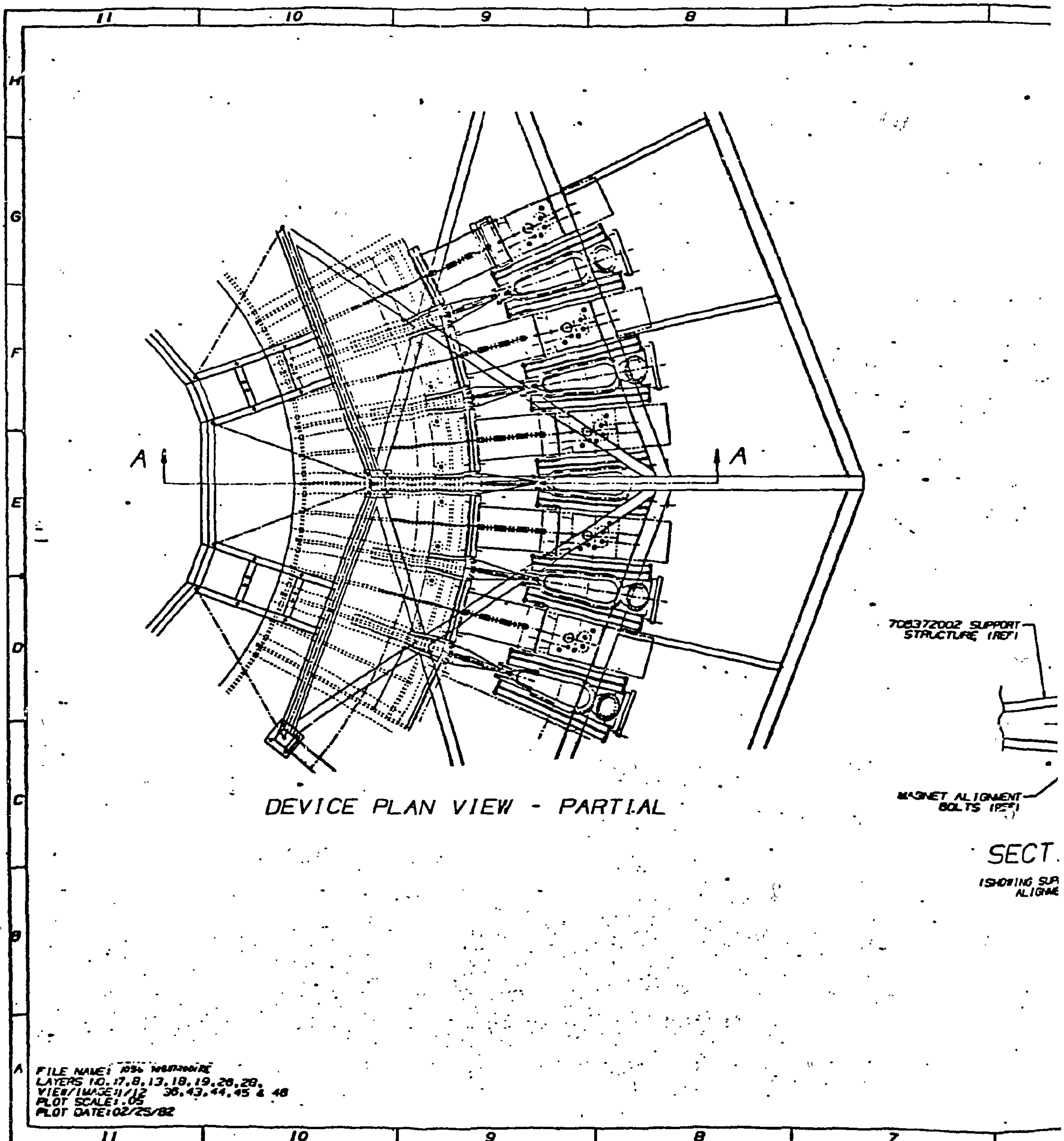
McDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
McDONNELL DOUGLAS CORPORATION

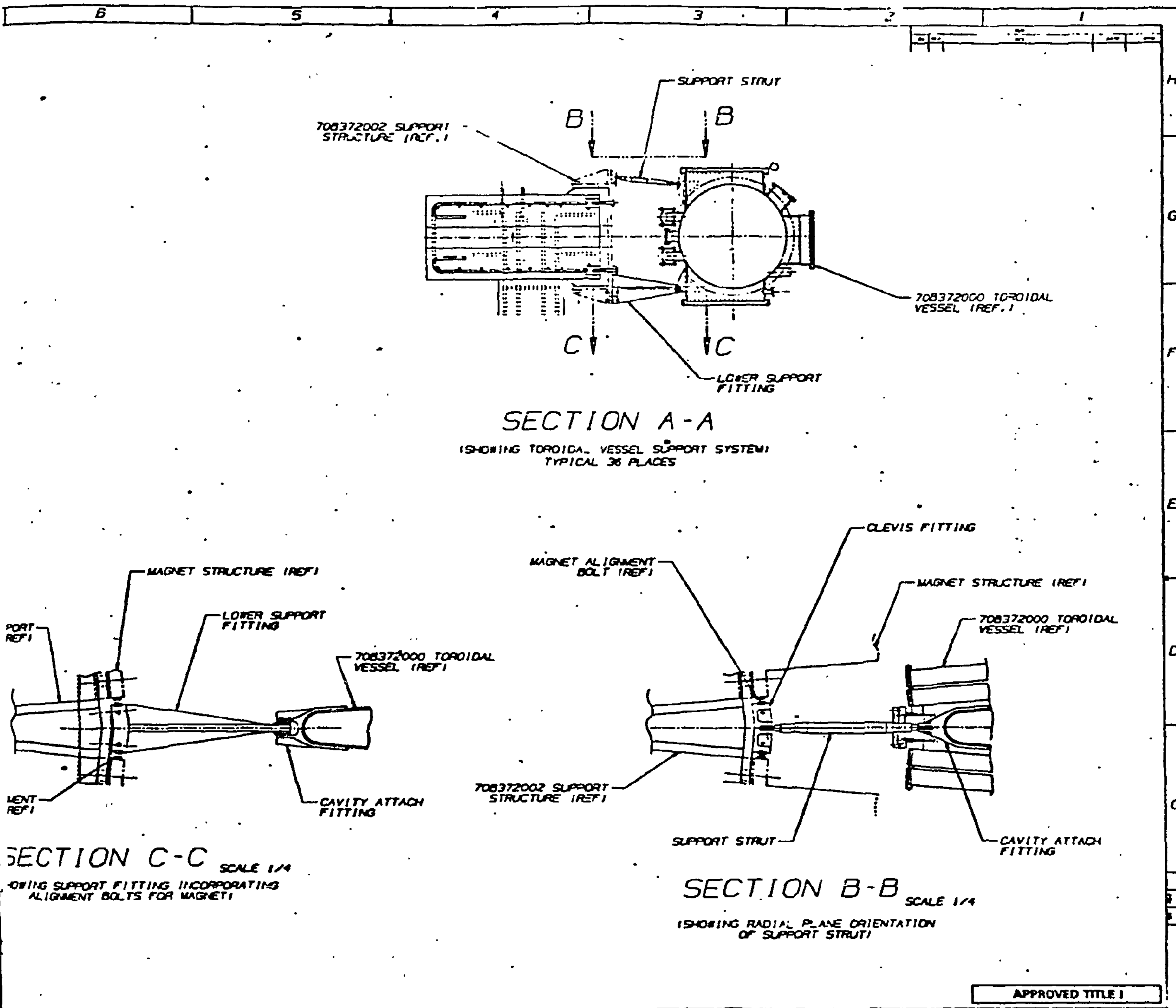
EBT-P SUPERSTRUCTURE

E 76301 708372003

A L BOCH 15 OCT 81

W B S 2.1.9


A
A
DEVICE PLAN VIEW - PARTIAL
708372002 SUPPORT
STRUCTURE (REF)
MAGNET ALIGNMENT
BOLTS (REF)
SECT.
(SHOWING SU
ALIGNM
FILE NAME:
LAYERS 1.0.:7,8,13,18,19,26,28,
VIEW/IMAGE:1/12 36,43,44,45 & 48
PLOT SCALE:.05
PLOT DATE:02/25/82



1. TOROIDAL VESSEL VACUUM CAVITY SEGMENT IS ALIGNED WITH THE VACUUM LINERS BY MEANS OF ECCENTRIC BUSHINGS AND SHIMS ON THE LOWER SUPPORT FITTING AND BY ADJUSTING THE LENGTH OF THE SUPPORT STRUT

NOTES:

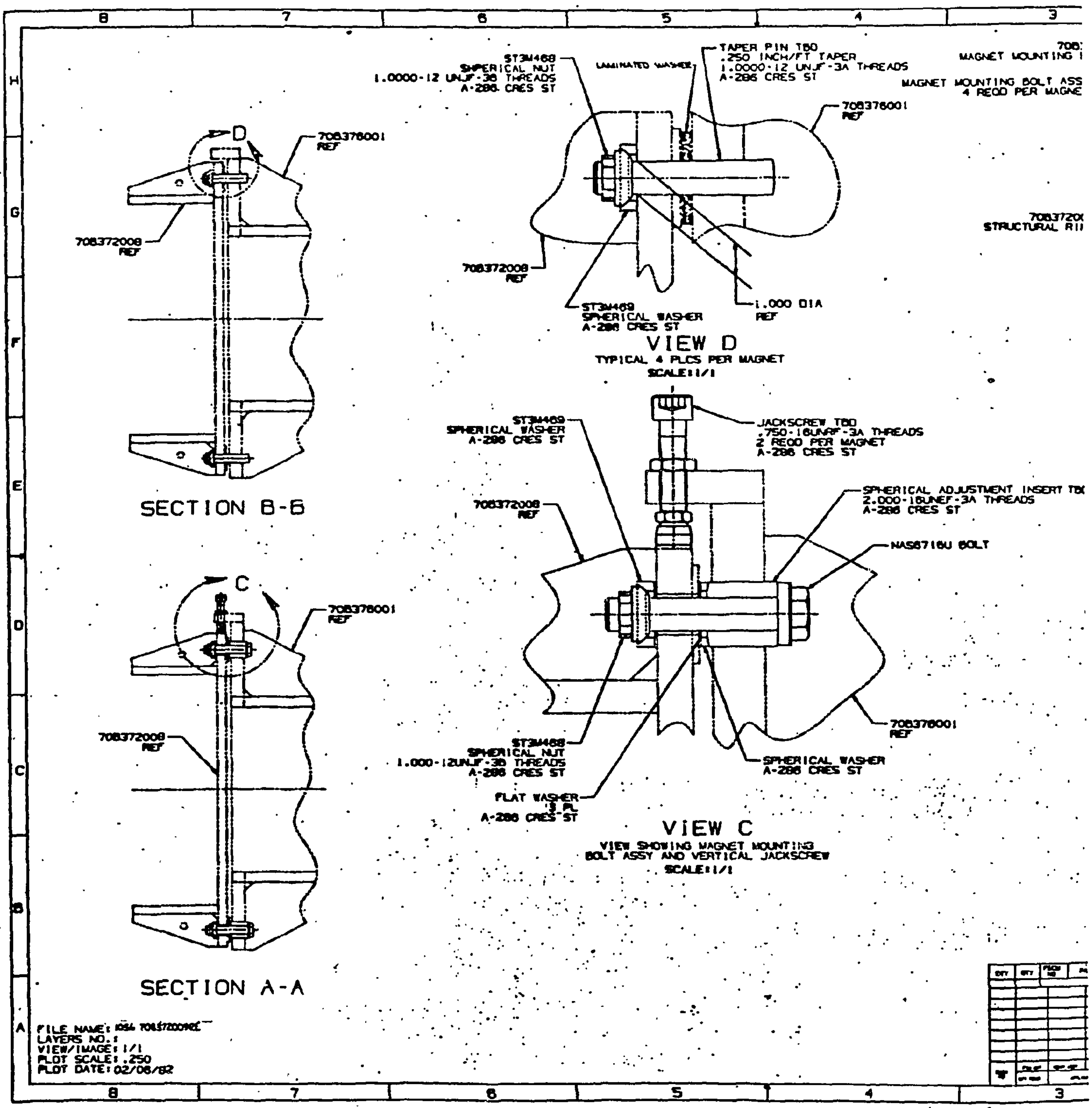
APPROVED TITLE I

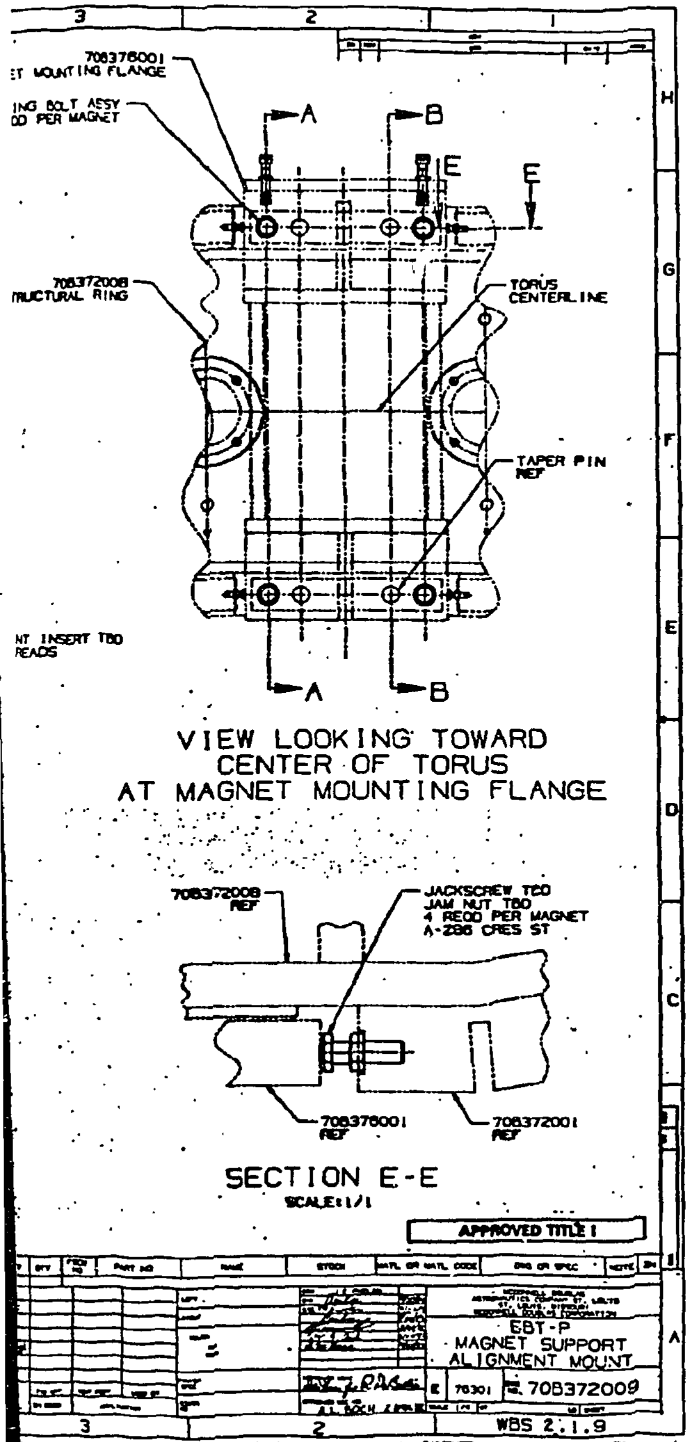
EBT-P, TOROIDAL VESSEL SUPPORT

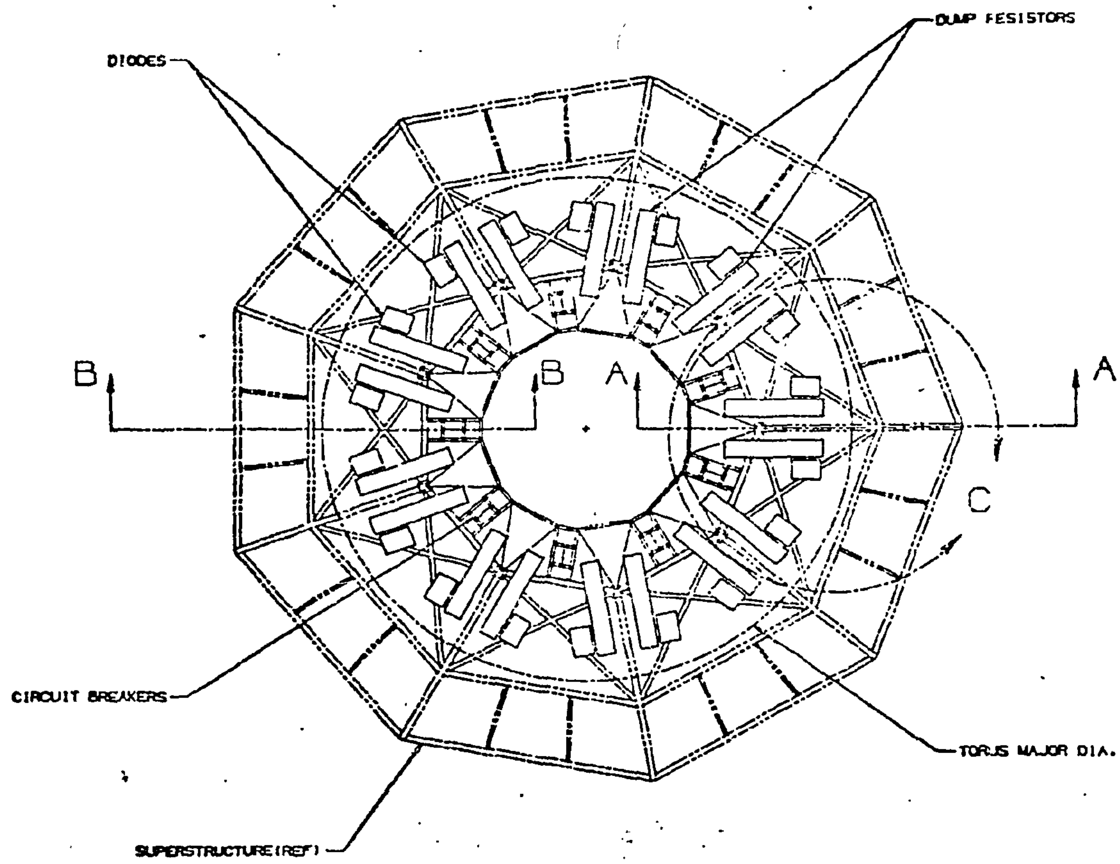
76301

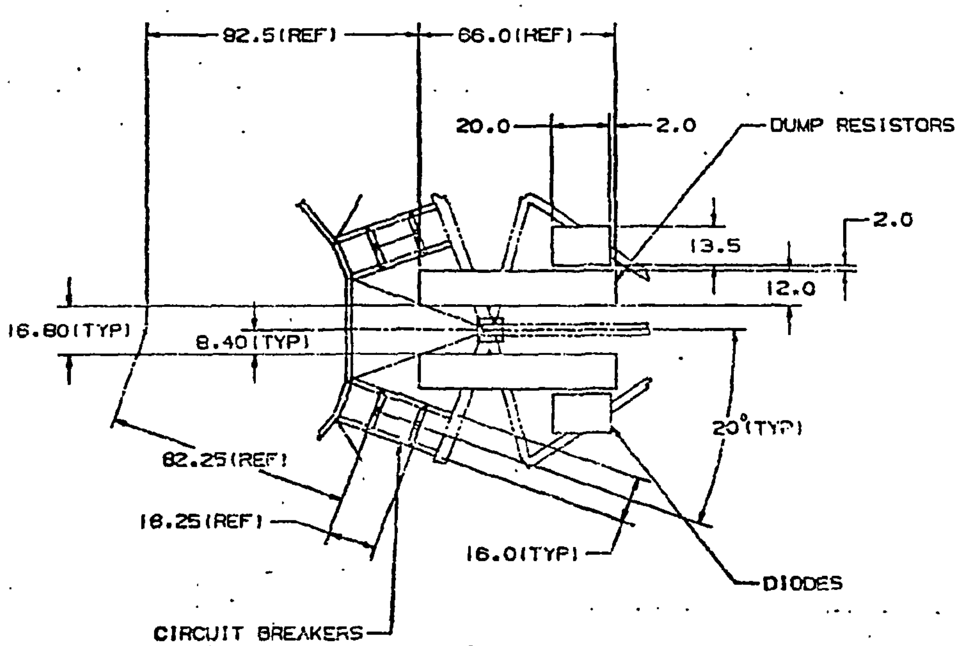
708372001

MSB.S 2.1.9


SECTION B-B
SECTION A-A
VIEW D
TYPICAL 4 PLCS PER MAGNET
SCALE:1/1
VIEW C
VIEW SHOWING MAGNET MOUNTING BOLT ASSY AND VERTICAL JACKSCREW
SCALE:1/1
ST3M468 SPHERICAL NUT 1.0000-12 UNJF-3B THREADS A-286 CRES ST
LAMINATED WASHER
TAPER PIN TBD .250 INCH/FT TAPER 1.0000-12 UNJF-3A THREADS A-286 CRES ST
MAGNET MOUNTING BOLT ASS 4 REQD PER MAGNE
708376001 REF
708372008 REF
ST3M469 SPHERICAL WASHER A-286 CRES ST
1.000 DIA REF
JACKSCREW TBD .750-16UNRF-3A THREADS 2 REQD PER MAGNET A-286 CRES ST
SPHERICAL ADJUSTMENT INSERT TB 2.000-16UNEF-3A THREADS A-286 CRES ST
NAS6716U BOLT
ST3M468 SPHERICAL NUT 1.000-12UNJF-3B THREADS A-286 CRES ST
FLAT WASHER 3 PL A-286 CRES ST
SPHERICAL WASHER A-286 CRES ST
FILE NAME:
LAYERS NO.:
VIEW/IMAGE: 1/1
PLOT SCALE: .250
PLOT DATE: 02/06/82


708376001
MOUNTING FLANGE
708372008
TORUS CENTERLINE
TAPER PIN REF
VIEW LOOKING TOWARD CENTER OF TORUS AT MAGNET MOUNTING FLANGE
708372008 REF
JACKSCREW TBD
JAM NUT TBD
4 REQD PER MAGNET
A-286 CRES ST
708376001 REF
708372001 REF
SECTION E-E
SCALE: 1/1
APPROVED TITLE I
EBT-P
MAGNET SUPPORT
ALIGNMENT MOUNT
708372009
WBS 2.1.9





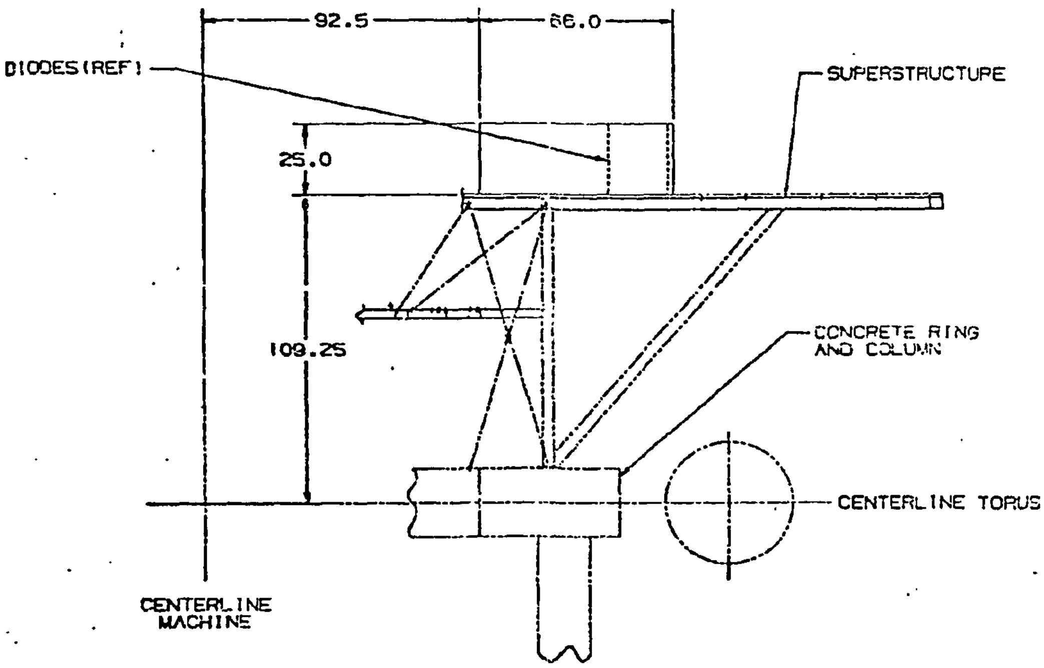
VIEW C SCALE 1/20
ARRANGEMENT SHOWN TYPICAL 9 PLACES

2 ATTACHMENT OF DUMP RESISTORS BE UNTO ALUMINUM GRATING

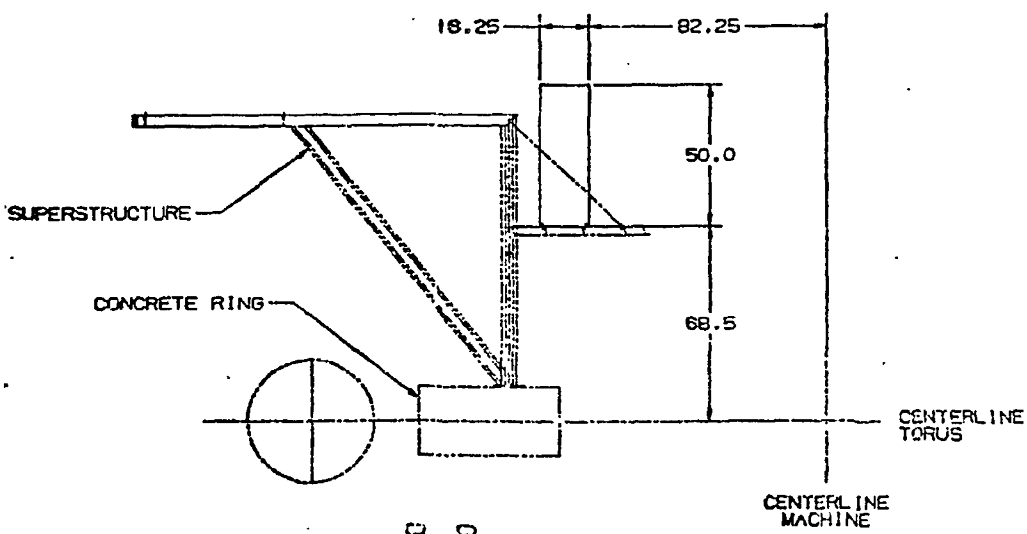
1 ALUMINUM GRATING NOT SHOWN R

NOTES

FILE:-144EBT-P SUPERST LAYERS:-18,49,50,51 DATE PLOTTED:- JULY 2 1981 PLOT SCALE:- .025



A - A SCALE 1/20
(SHOWING LOCATION OF DUMP RESISTORS AND DIODES)



B - B SCALE 1/20
(SHOWING LOCATION OF CIRCUIT BREAKERS)

.APPROVED TITLE I

ESISTORS AND DIODES TO
TING

SHOWN FOR CLARITY

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
MCDONNELL DOUGLAS CORPORATION

EBT-P, MAGNET PROTECTION SYSTEM INSTL./ENVELOPE

E 76301 7053376000

A.L. BOCH

W.B.S 2.1.3