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MASTER

QUALITY-ASSURANCE APPROACH FOR THE ELMO BUMPY TORUS PROOF-OF-PRINCIPLE EXPERIMENT

PRESENTED

AT THE

I.E.A.

FUSION ENERGY QUALITY-ASSURANCE WORKSHOP

PRINCETON PLASMA PHYSICS LABORATORY

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BY

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EBT-P QUALITY ASSURANCE PROJECT MANAGEMENT

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BACKGROUND

McDonnell Douglas Astronautics Co. - St. Louis (MDAC) has been involved in fusion energy research since 1974. In that time we have been awarded 39 separate contracts in this vital field. Elmo Bumpy Torus (EBT) has been one of our top priority fusion programs since 1977. We at MDAC recognize the importance of this technology both to the Company and the nation. Fusion energy is the key to our future energy needs and a reduction of our dependence on dwindling fossil fuel reserves. The promise of almost limitless, clean energy without the pollution or severe radioactive disposal problems associated with other forms of energy production presents an irresistible impetus for our efforts. We made our early commitment to EBT with the aforementioned criteria in mind. Also, EBT presented us with an opportunity for meaningful industrial participation and the potential of EBT as a commercial reactor due to its high aspect ratio and continuous operation. While the EBT Proof-of-Principle device will not attempt actual fusion, it represents the next level of development of the EBT concept towards establishment of the EBT as a fusion reactor.

EBT PROGRAM ORGANIZATION

Having made this decision for long-term participation in EBT we organized a specialized research and engineering team including a staff of five plasma physicists representing the principal areas of theory, experimentation, magnetics and heating. This team has been at work since February 1978.

Simultaneously with establishment of the physics staff we organized an engineering group whose members possess extensive experience in structures, cyrogenics, microwaves, superconducting magnets, vacuum, and instrumentation. This MDAC engineering team is supplemented by specialist subcontractors as needed. Roy DeBellis, who has the proper mix of analytical, management and hardware experience skills for ensuring a successful, creative program has been selected to lead this challenging project.

DEVICE GENERAL DESCRIPTION

The Elmo Bumpy Torus Proof-of-Principle device (EBT-P) is a toroidal device with a 4.5m major radius and 36 sectors. Each sector is composed of a mirror cavity, vacuum liner and superconducting mirror coil. The steady-state hydrogen plasma is contained by the magnetic field generated by the 36 mirror coils. Each coil consists of a liquid-helium cooled niobium titanium/copper winding enclosed in a stainless steel case. The coils are mounted inside the vacuum dewar via an orthogonal system of struts that carries the magnetic loads from the coils, to the dewar outer ring, and then to the device support structure. A tungsten/lead shield, located at the bore and sides of the coil vacuum dewar, external to it, protects the superconducting winding from x-ray radiation. Power is supplied to the mirror coils by a high current dc power supply through helium-vapor-cooled leads connected in series.

TOROIDAL VESSEL

The toroidal vessel itself is composed of 36 mirror cavity sectors alternating with 36 vacuum liner sectors. The vacuum liner is located in the bore of each mirror coil vacuum dewar with a radial clearance that results in the vacuum torus being nonintegral with the mirror coil assembly. The sidewall of each vacuum liner acts as a flex joint to accommodate thermal expandion and misalignment of the torus. Access ports are provided in each mirror cavity sector, which is located between each vacuum liner. The mirror cavity sectors contain actively cooled limiters which are designed to protect the toroidal vessel walls from excessive heating and erosion.

MICROWAVE POWER

Heating of the plasma electrons is provided by the injection of microwave power at 28GHz and 60GHx into the toroidal vessel. Microwave power is transmitted from gyrotron power sources to the toroidal vessel via an overhead, segmented manifold system having symmetrical connections to each mirror cavity. Initial experiment start-up will include four 60GHz and two 28GHz gyrotrons. After one year of operation it is planned to improve the device with two additional 60GHz gyrotrons and one megawatt of ion heating.

VACUUM SYSTEM

Primary vacuum pumping of the toroidal vessel is accomplished through the use of nine 3000-liter/sec cryosorption pumps, one located on every fourth mirror cavity. A roughing system, composed of a mechanical pump, two nitrogen cryosorption pumps, and a turbomolecular pump, is utlized for initial pumpdown of the vacuum vessel and coil dewars, and for regeneration of the primary cryosorption pumps. Primary pumping of the coil vacuum dewars is accomplished with a 1000-liter/sec cryosorption pump on each dewar. The torus cryosorption pumps will be shielded from scattered microwave power by a water-cooled, perforated copper plate in each pumping port.

SHIELDING

The device is surrounded by a 45-in. thick concrete biological radiation shield designed to limit radiation outside the enclosure to 0.25mR/hr. Entrance to the device will be through labyrinths designed to attenuate reflected radiation. The gyrotrons regulator, crowbar portion of the gyrotrons power supplies, and coil power supplies will be located just outside the shielded area. The gyrotron tubes with mounting base, are directly below the device inside a shielded area.

CRYOGENIC SYSTEM

The cryogenic cooling system manifolds for the magnets consist of liquid nitrogen and liquid helium supply and vent lines. These cryogenic manifolds run along the inside of the toroidal vessel and above the horizontal midplane of the torus to maximize access to the torus. The manifolds which supply the cryopumps for the toroidal vessel run along the outside of the vessel, are above the midplane of the torus and are supported by the superstructure above the toroidal vessel. All manifolds are fabricated from straight sections because it is more cost effective to manufacture in this configuration. This is especially true for the double wall cryogenic lines.

DEVICE UTILITIES

Water cooling manifolds are provided for the toroidal vessel and are located along the inside of the torus immediately above and below the torus horizontal midplane. The water cooling manifolds for the gyrotrons are located near the ceiling of the first level and the building outer structural wall.

The vacuum manifolds for the magnet dewars are located inside the inner radius of the torus and above the midplane. This manifold is connected through gate valves to each of the 36 magnet dewars. The vacuum regeneration manifold for the toroidal vessel cryopumps is outboard and above the midplane of the torus and supported by the support structure. Nine of the 36 mirror cavities are connected to this regeneration vacuum manifold through the cryopumps. Additional cryopumps may be added if necessary.

QUALITY ASSURANCE

The Quality effort for EBT-P was approached with great care. We recognized early in the planning of the Quality Program the challenges faced by this undertaking and the importance to future programs. A significant challenge is the design, development and implementation of effective quality requirements for the EBT-P that may, and probably will, effect future fusion energy programs. It is our aim to assure that these precedents represent carefully thought out approaches to Quality Assurance and that they will be applicable and appropriate to current and future fusion programs.

QA REQUIREMENT REVIEW

The aim of the EBT-P Quality Assurance Planning is to assure that the design parameters will be properly interpreted and transformed into high quality hardware. To this end we reviewed the program parameters, goals and requirements to determine the level of the Quality effort required to assure product quality. We then compared these requirements to our existing systems for assuring the quality of Military, NASA and commercial hardware. Due to the unique requirements of a fusion energy system, neither MIL-Q-9858A, MIL-I-45208A, nor the NHB 5300.4 series of quality documents was appropriate to EBT-P. Fission quality documents were reviewed, but due to the extreme difficulties of assuring the quality of fission reactors as opposed to a fusion device, these were not appropriate.

Based on this review, we tailored and molded those portions of Military, NASA and commercial specifications applicable to the EBT-P Project. The result of this effort has been tailored into the Quality Assurance Program Plan. This approach allows the flexibility needed to respond to changing program requirements, as often occurs with new technology.

QA ORGANIZATION

The Project Quality Assurance Manager is responsible for the cost effective development and implementation of the Quality Assurance effort. He reports to the MDAC Director of Quality Assurance in the functional line organization, and the EBT-P Project Manager for project priorities and direction. This approach assures his organizational freedom to identify and evaluate quality problems and to initiate, recommend or provide solutions.

The MDAC Project Quality Assurance Manager serves as an active interface with the Quality Organization at ORNL. He supports ORNL's design and drawing Quality Assurance Reviews and audits as required. The PQAM also interfaces with the Quality Organizations of our suppliers to ensure quality requirements are properly interpreted and implemented. He may call upon the functional departments within the Quality Assurance Subdivision for their assistance as required.

QUALITY ASSURANCE ASSESSMENT

An evaluation of the consequences of failure of selected equipment and/or facilities to perform satisfactorily in service has been performed. To take advantage of the knowledge and experience of all participating disciplines in anticipating quality problems, each organization in the program has contributed to this assessment function. This assessment gives consideration to safety, environment, costs, schedule delays, program goals, public reaction or other significant factors relevant to the total program.

The failure assessment has addressed those items whose failure to perform satisfactorily could result in significant and unacceptable consequences. An evaluation of state-of-the-art, experience, normal industrial practices and the organizations involved has been used to identify these high risk components or areas.

Where failure could result in unacceptable consequences, additional quality precautions will be implemented. These will include: Increased surveillance of in-house operations (i.e., special inspections and/or tests, specialized NDT requirements); source inspection; pre-shipment reviews, both in-house and at suppliers facilities; inputs to critical Design Reviews and failure analysis. While there are uncertainties inherent in pursuing new technology, we will stirve to minimize these through the application of these additional quality requirements. Our aim is to prevent problems by thorough advanced planning, attention to detail and the proper implementation of QA requirements.

If it is determined that the consequences of failure are not significant for a particular component or system, then we will use existing QA systems to the extent necessary to ensure the inherent quality designed into the EBT-P system. These quality procedures are documented in our Corporate Quality Assurance Regulations (CQARs) and Quality Assurance Standard Practices (QASPs).

DRAWING REVIEW

Drawings will be reviewed by Quality Program Management to assure that all quality requirements necessary to ensure a quality product are included. On site construction drawings (those directly associated with building construction) will not be reviewed by MDAC but by the Gilbert/Commonwealth on site Quality Assurance Manager. Quality Assurance will support the Preliminary and Final Design Reviews and other scheduled reviews for resolution of quality problems and to assure understanding and timely incorporation of the quality requirements. Approved and released engineering drawings will define the equipment and configuration.

Drawing changes are defined and implemented by Engineering Order and include change effectivity. In any case, Quality Assurance will determine product conformance to the Engineering Drawing requirements.

SUPPLIER QUALITY ASSURANCE

All suppliers will be selected on the basis of their established reputation, ability to perform, and, if necessary, the results of quality surveys. Suppliers of high risk procurement items will be required to meet the requirements of MDAC CQAR #10 Rev. A, which uses MIL-I-45208A as a guide. Control of these suppliers will be accomplished through inspection, engineering evaluation and functional testing.

Procurement Quality Assurance will provide source inspectors at suppliers when Quality Assurance Management determines that this is necessary. This determination will be based upon many factors, including: high risk of the supplied component as defined in the Quality Assurance Assessment; inaccessability of necessary inspection parameters after final assembly or closure; part cost and/or criticality; inadequate test or inspection equipment at the construction site; or lack of an adequate nonconformance control system at the supplier.

In addition, General Dynamics as the supplier of the magnets is required to submit a Quality Plan in conformance to the requirements of CQAR #10 Rev. A. Gilbert/Commonwealth, as facilities subcontractor, is also required to submit a Quality Plan documenting the quality system to be used during the construction phase. Other suppliers may also be required to submit Quality Plans, if part complexity or criticality dictates.

Suppliers of modified or MDAC designed items, not included in the foregoing, will be required to submit necessary objective evidence of quality conformance. This evidence may include: test data, inspection documentation, or Certificates Of Conformance.

Suppliers of non-critical "off-the-shelf" hardware and/or components will be required to supply Certificates Of Conformance as a minimum.

RECEIVING INSPECTION

The extent of receiving inspection will be predicated upon item complexity and criticality and the quality evidence required from the supplier.

Incoming materials have Receiving Inspection Operations Sheets (RIOSs) prepared which detail inspections to be performed and/or data required to accompany the item. These RIOSs, with test data or other evidence of quality conformance attached, are then forwarded to the MDAC Quality Assurance Record Center for retention for the time period specified by contract.

FABRICATION CONTROL

Quality Assurance reviews and accepts Manufacturing Work Instructions (MWIs) to verify needed process controls, inspection points, test equipment, fixtures, tooling, proper sequencing of operations, etc. MWIs are reviewed against Engineering Drawing requirements.

Detailed procedures assure that fabrication operations are accomplished under controlled conditions. Fabrication operations are performed as specified on the MWIs. The MWI identifies the special tools to be used and applicable drawings and process specifications. In-process inspections are performed on components and assemblies throughout all phases of fabrication and assembly. These inspections are accomplished to ensure early detection of fabrication discrepancies and to ensure that characteristics not available later in the process of fabrication receive adequate inspection. Reports of nonconformances to approved drawings or documentation are made to the assigned Quality Engineer who initiates the necessary corrective action.

FINAL INSPECTION AND TEST

Completed components and assemblies are subjected to final inspection and test as necessary to ensure compliance to the applicable specification, Acceptance Test Procedure (ATP) and/or Company requirements. Quality Assurance inspects each component for mechanical and electrical defects. If hardware is modified, repaired or replaced after final testing, necessary re-insepction and retest is then performed. Upon completion of these activities, including a review of applicable manufacturing records, the acceptable components are released for shipment.

NONCONFORMANCE CONTROL

All nonconformances detected are documented on the Nonconformance Record (NR) and reviewed by the designated Quality Engineer and the appropriate Project Engineering personnel. These personnel disposition the nonconformance in one of the following ways: rework to drawing configuration, scrap, acceptable "as is", or repair. These dispositions must be approved by the assigned Quality Engineer and Project Engineering personnel.

SHIPPING INSPECTION

MDAC Standard Procedures provide necessary work and inspection instructions for handling, storage, preservation, packaging and shipment in a manner to prevent damage, deterioration or degradation and assure delivery of quality products. Components are protected during fabrication, processing and storage to prevent handling damage. Critical, sensitive, hazardous and high value components are given special attention. Items to be shipped are inspected to verify identification and to ensure that preservation and packaging meet contractual requirements.

REMOTE SITE OPERATIONS

MDAC will provide for resident Quality Assurance personnel at the construction site in Oak Ridge. These personnel are responsible for surveillance during installation and testing. Quality Program Management will be the point of contact, at Oak Ridge, between Customer Quality Management and subcontractors Quality Organizations. Both MDAC and Gilbert/Commonwealth will conduct site surveillance to assure that systems, components, and structures meet the design criteria. Those items identified in the failure assessment program will be under special scrutiny to assure strict adherence to design and safety parameters. Although

MDAC has the overall quality responsibility for on-site operations, the experience of Gilbert/Commonwealth Quality Assurance in the construction of energy producing systems, will be used in the most cost effective manner consistent with maximum overall project quality.

Components, subsystems and systems will be subjected to inspection and test as necessary to ensure compliance to applicable specifications, Acceptance Test Proceudres and/or customer requirements. Quality Assurance will inspect each component, subsystem and system for selected mechanical and electrical defects. In addition, Quality Assurance will either perform, or verify performance of, and analyze, or verify analysis of, all required field and laboratory tests. If hardware is modified, repaired or replaced after final testing, necessary re-inspection and retest must be performed. Insofar as possible the component, subsystem or system will be released as acceptable upon completion of these activities.

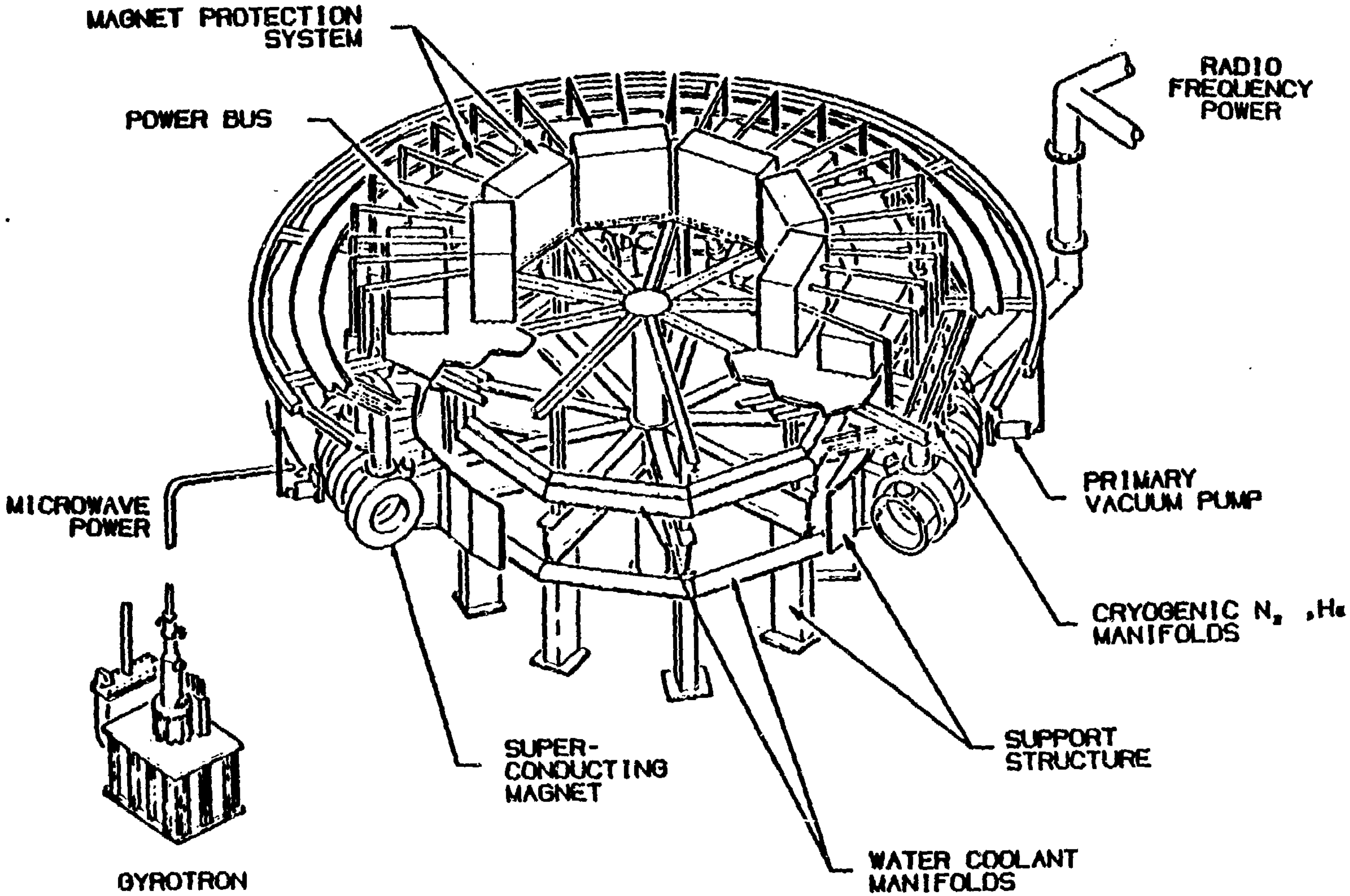
When nonconformances are detected during the course of site surveillance activities, MDAC or Gilbert/Commonwealth will initiate a Nonconformance Record for review by MDAC Quality Assurance and Project Engineering personnel. These nonconformances will be identified and dispositioned per MDAC Standard Practices with the advice and concurrence of Gilbert/Commonwealth personnel, if deemed appropriate.

MDAC Quality Assurance personnel will witness the pre-operational testing and review the test data.

CONCLUSIONS

We at MDAC feel that our approach to the Quality Assurance of the EBT device will result in a high quality product which meets the requirements of the program and will lead to the success of this experimental device. Moreover, the quality system developed will be applicable and appropriate to future fusion energy devices with which we will become involved.

EBT-P REFERENCE DESIGN



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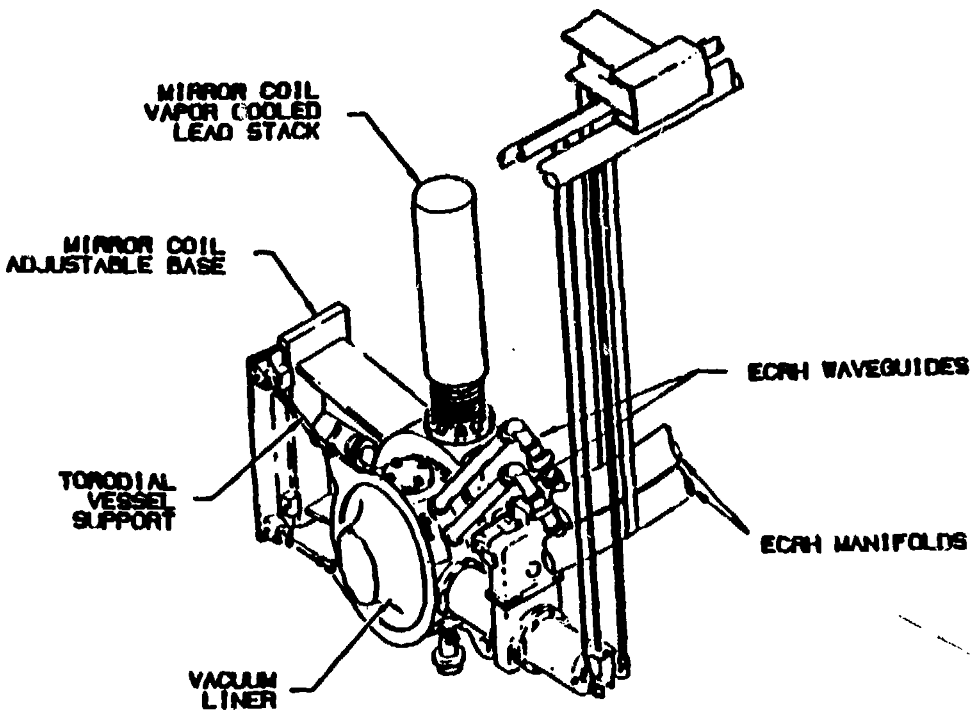
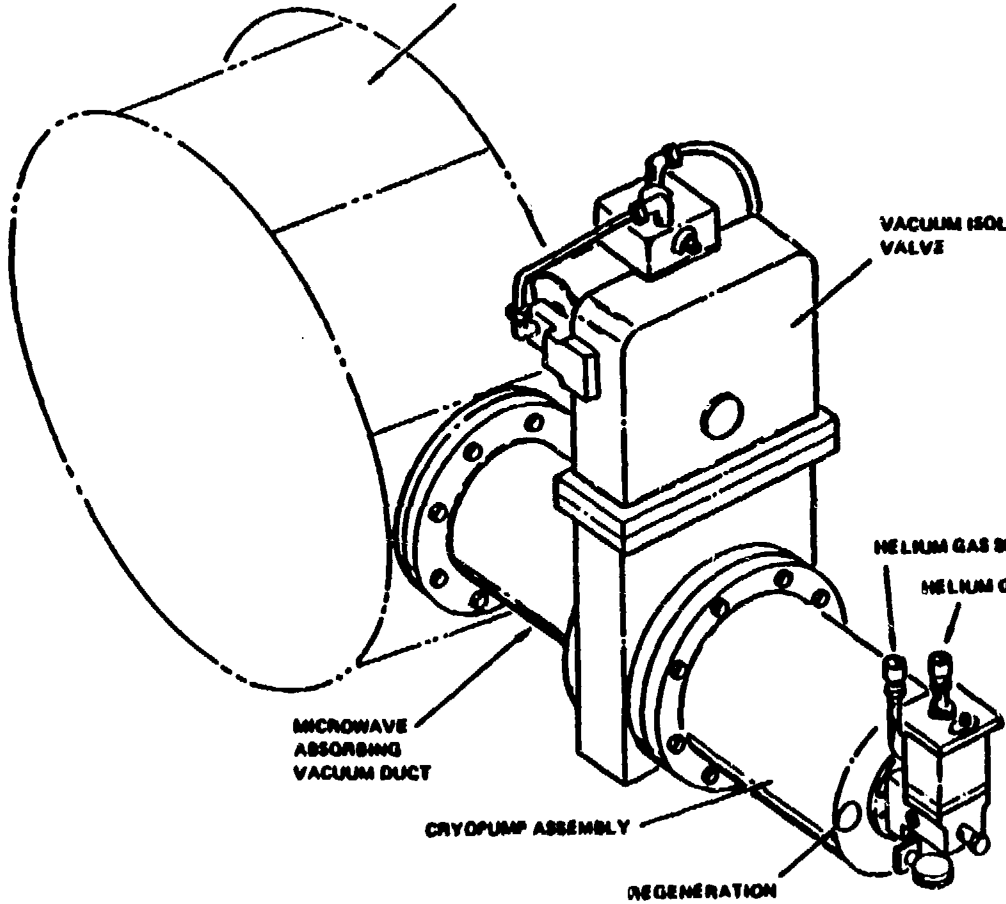
EBT-P TYPICAL TORUS SECTOR

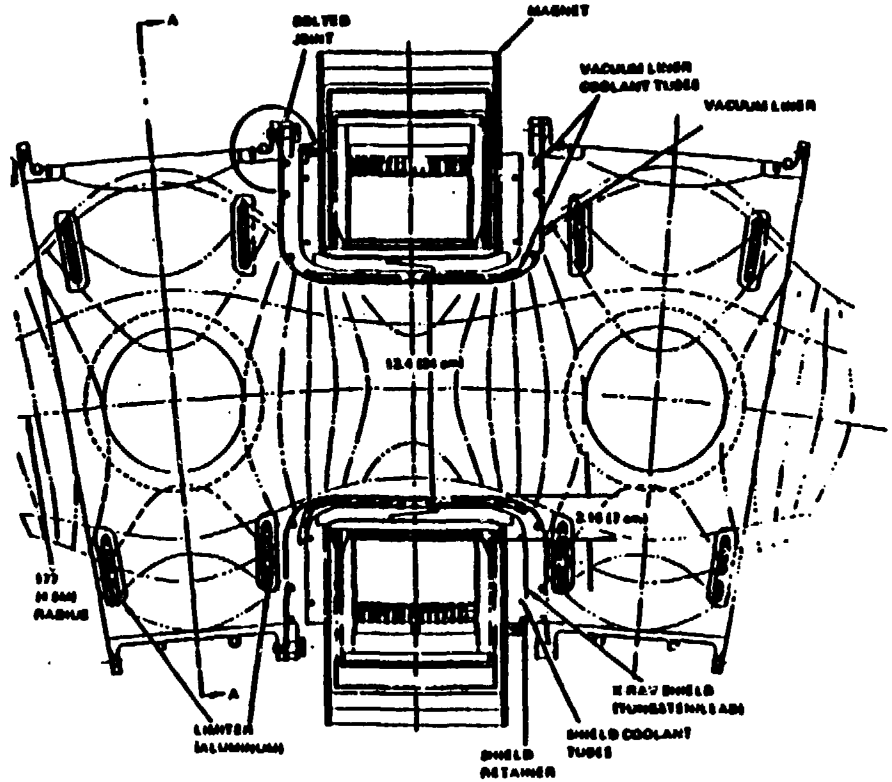


EBT-P CRYOPUMP

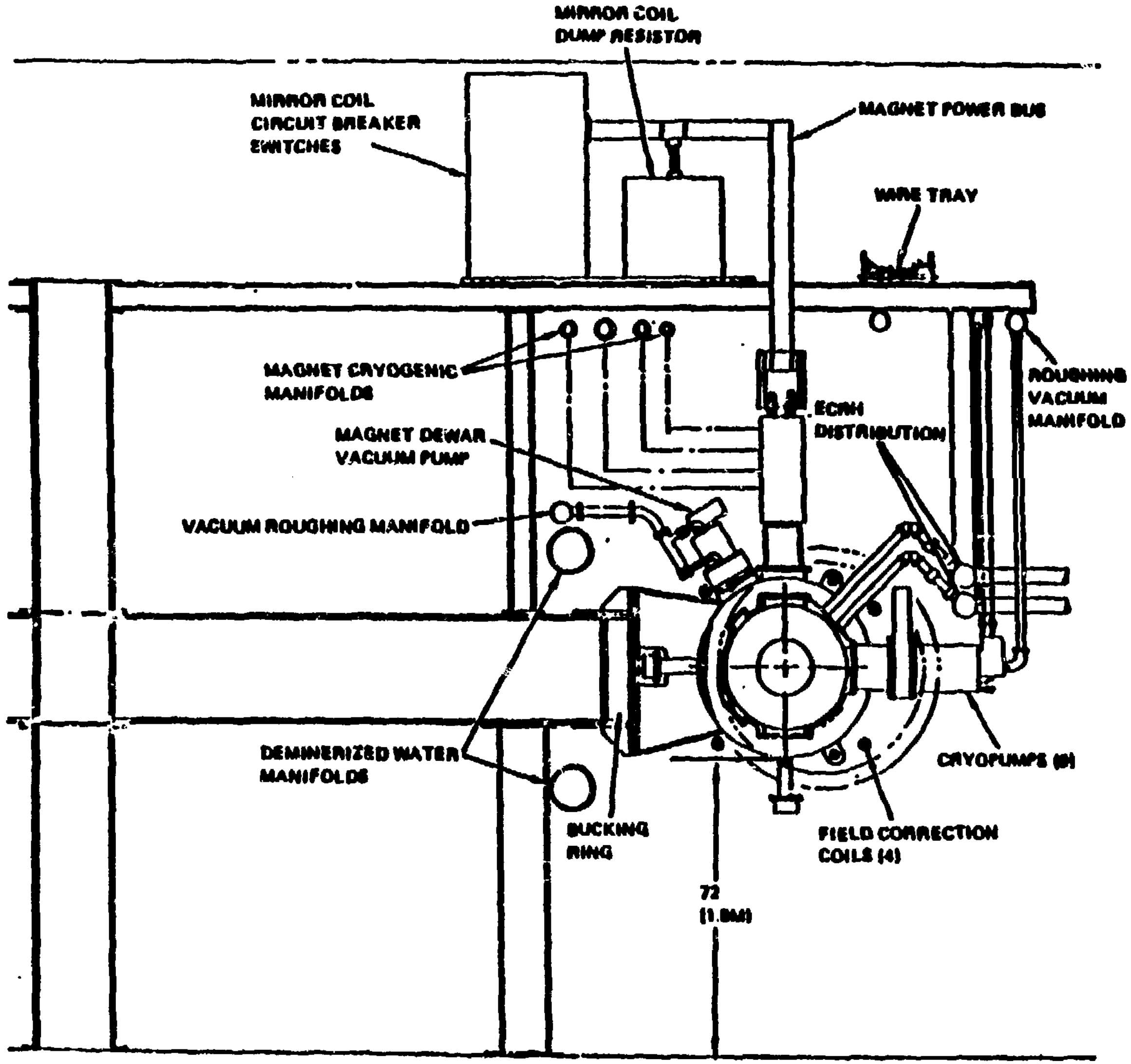


ELMO BUMPY TORUS

EBT-P SECTION VIEW
THRU TORUS MIDPLANE



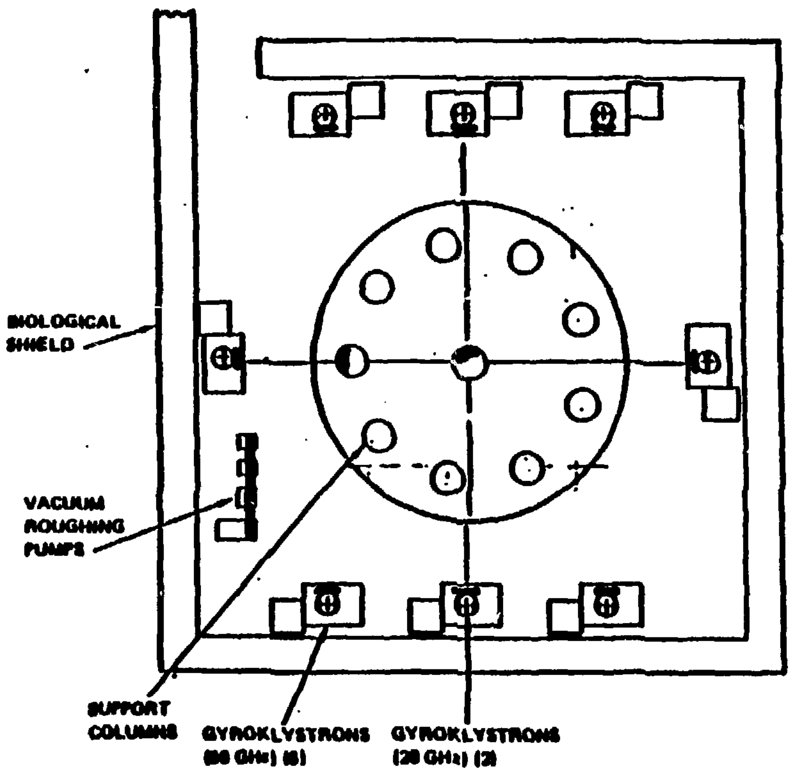
EBT-P VERTICAL SECTION



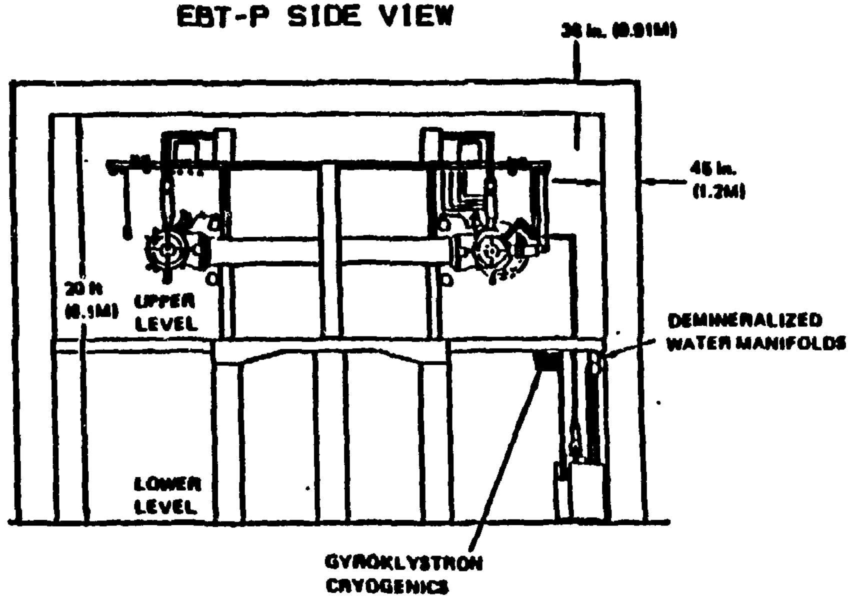
FUSION ELMO BUMPY TORUS ENERGY

EBT-P INSTALLATION VIEWS

EBT-P LOWER LEVEL-TOP VIEW



EBT-P SIDE VIEW



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