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# THE NATIONAL RF TEST FACILITY AS A MULTIPURPOSE DEVELOPMENT TOOL*

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Abstract: Additions and modifications to the National RF Test Facility design have been made that (1) focus its use for technology development for future large systems in the ion cyclotron range of frequencies (ICRF), (2) expand its applicability to technology development in the electron cyclotron range of frequencies (ECRF) at 60 GHz, (3) provide a facility for ELMO Bumpy Torus (EBT) 60-GHz ring physics studies, and (4) permit engineering studies of steady-state plasma systems, including superconducting magnet performance, vacuum vessel heat flux removal, and microwave protection. The facility will continue to function as a test bed for generic technology developments for ICRF and the lower hybrid range of frequencies (LHRF). The upgraded facility is also suitable for mirror halo physics experiments.

The base facility is a simple mirror comprising two EBT Proof-of-Principle (EBT-P) developmental superconducting magnet coils. A coil-to-coil spacing of 85 cm yields a mirror ratio of 2.7:1, so magnetic field strength ranges from 1.3 to 3.4 T. The vacuum vessel is a large, stainless steel cavity. Internal cooling panels will be added when high-power radio-frequency (rf) sources are available. Multiple ports, including one 47 cm by 162 cm, provide good access for diagnostics and testing. The expected background plasma characteristics, with 60-GHz generation, are $n \sim 0.4\text{-}2 \times 10^{13}$ cm$^{-3}$ and $T \sim$ 5-10 eV. Although the plasma can be ring stabilized, end losses yield an energy loss time of 2-8 µs.

Elements of the upgraded facility are (1) a closed-cycle liquid helium refrigerator system, (2) an x-ray-shielded enclosure for ring physics, and (3) a 60-GHz source and test fixture. These changes, mandated by one or more of the subprograms, will dramatically increase the capabilities of the facility.

## Introduction

The RF/Ring Physics Test Facility (RFTF) is designed to serve a dual purpose. Studies of both rf heating technology development and electron ring physics at 60 GHz will be supported. A single facility can meet the objectives of both programs at a significantly lower cost than if two separate experimental facilities were constructed. This facility is in the design and construction phase at the Oak Ridge National Laboratory (ORNL).

In support of rf technology development, the following major areas of antenna development can be addressed on RFTF:

1. thermal stress,
2. steady-state operations,
3. voltage breakdown,
4. high-power coupling,
5. feedthroughs,
6. high heat flux,
7. impurity control, and
8. configuration selection.

Study in these areas would support such devices as the Doublet III upgrade (DIII-D), the Tokamak Fusion Test Reactor (TFTR), the Tokamak Fusion Core Experiment (TFCX), and the Direct Current Tokamak (DCT).

Hot electron ring physics issues that will be investigated include:

1. ring temperature scaling in the synchrotron radiation regime and
2. whistler and hot-electron interchange instabilities.

The addition of the ring physics investigation capability has increased the scope of RFTF over that previously described [1].

## Facility Description

Two superconducting magnets from the EBT-P Magnet Development Program [2,3] like that shown in Fig. 1 will be used to produce a simple mirror field

Fig. 1. EBT-P magnet development program coil D-1.

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with a 2.7:1 mirror ratio. The magnet centerlines will be spaced 85 cm apart. The peak design field in the throat is 3.4 T on axis and 5.5 T at the conductor. Individual magnets have been successfully tested at up to 7.4 T [4,5]. The spacing selected is a compromise between the desire for a large axial width port and the mirror ratio that allows 60-GHz ring physics studies to be carried out. The magnetic geometry is shown in Fig. 2. The magnet mechanical loading at this spacing is 13,590 kg (30,000 lb) with 5.5 T at the conductor. This is well below the 33,070-kg (73,000-lb) design load for the EBT-P magnets. The forces will be accommodated by an external frame structure independent from the vacuum vessel. System components are described below.

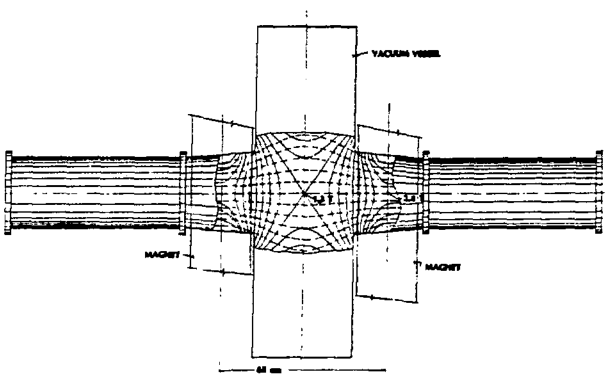


Fig. 2. Magnetic geometry. Dashed lines indicate field lines; solid curves indicate mod-B contours.

## Vacuum Vessel

A rectangular, nonmagnetic stainless steel vacuum vessel, shown in Fig. 3, was designed to obtain the largest port width possible with the 85-cm magnet spacing. The vessel has a 47- by 162-cm port on one side for the main antenna with many smaller diagnostic ports facing it on the other side. Extensions for vacuum pumping pass through the warm bore of the magnet.

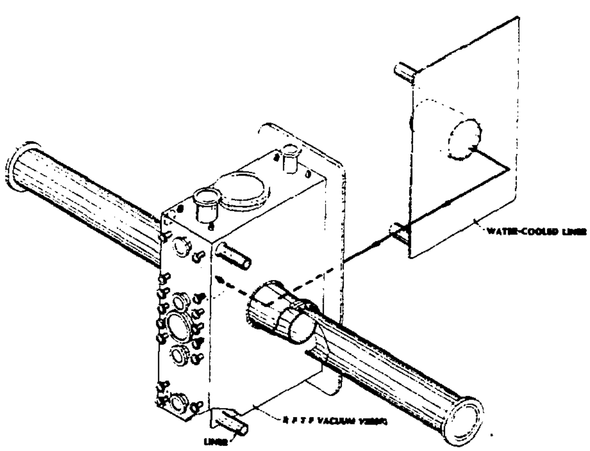


Fig. 3. Vacuum vessel with conceptual design of water-cooled liner.

A special design problem was the sealing of the large port in a manner compatible with high-power, 60-GHz microwave operation. Normal O-ring designs are not acceptable because of microwave heating. Metal O-rings and C-rings were judged susceptible to arcing problems on the basis of experience in the EBT-Scale (EBT-S) device. The seal picked was based on the EBT-S design [6]. As shown in Fig. 4, a 4- to 6-mil interference lip is designed to protect a Viton O-ring from the microwaves. Advantages of this design include low sealing forces and easy blankoff flange removal and installation.

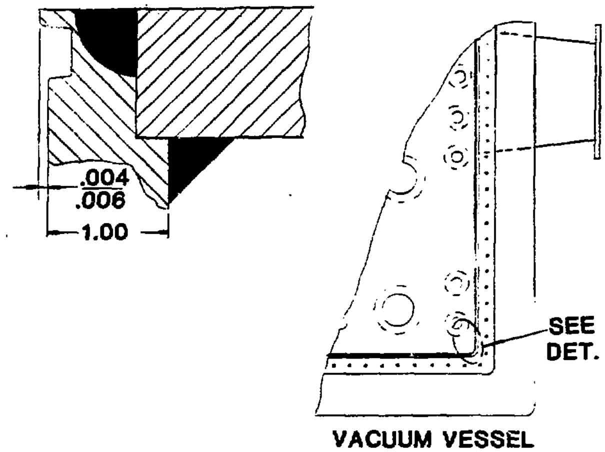


Fig. 4. Vacuum vessel large port: O-ring detail.

Heat distribution from rf pulses will be mapped using 24 thermocouples embedded in the walls and an infrared camera. Water-cooled copper liners will then be designed based on this mapping. A conceptual design for the liners is shown in Fig. 3. Four 10-cm (4-in.) ports have been provided in the vessel for water supply and return manifolds.

Operation of the superconducting magnets in RFTF should provide valuable experience in learning how to distinguish plasma-induced flux changes from induced voltages in the magnets that result from growing normal zones.

Figure 5 shows the vacuum vessel in place between the magnets with 35-cm-diam (14-in.-diam) pumping extensions connecting the vessel to two 25.4-cm (10-in.) turbomolecular vacuum pumps. The pumps are located where the magnetic field is below 100 G and are shielded for up to 110 G. The expected base vacuum for the system is approximately $5 \times 10^{-7}$ T. Microwave cutoff screens will be installed to protect the pumps from microwave power.

## Lead-Shielded Enclosure

The electron ring produced by electron cylotron resonance heating (ECRH) at 60 GHz is expected to have a temperature on the order of 2 MeV. When the scattered electrons strike the wall, they produce an x-ray spectrum, creating the need for a shielded enclosure. Scalings from EBT-S and EBT-P indicate that 15-cm-thick (6-in.-thick) lead walls and a 10-cm-thick (4-in.-thick) ceiling should provide adequate personnel shielding.

Figure 6 shows the proposed enclosure. Entrance to the experiment will be through a simple maze. Utilities are brought into the enclosure through a raised "penthouse" over the magnets. The roof panels are designed to be easily removed by crane for overhead access, especially near the large port.

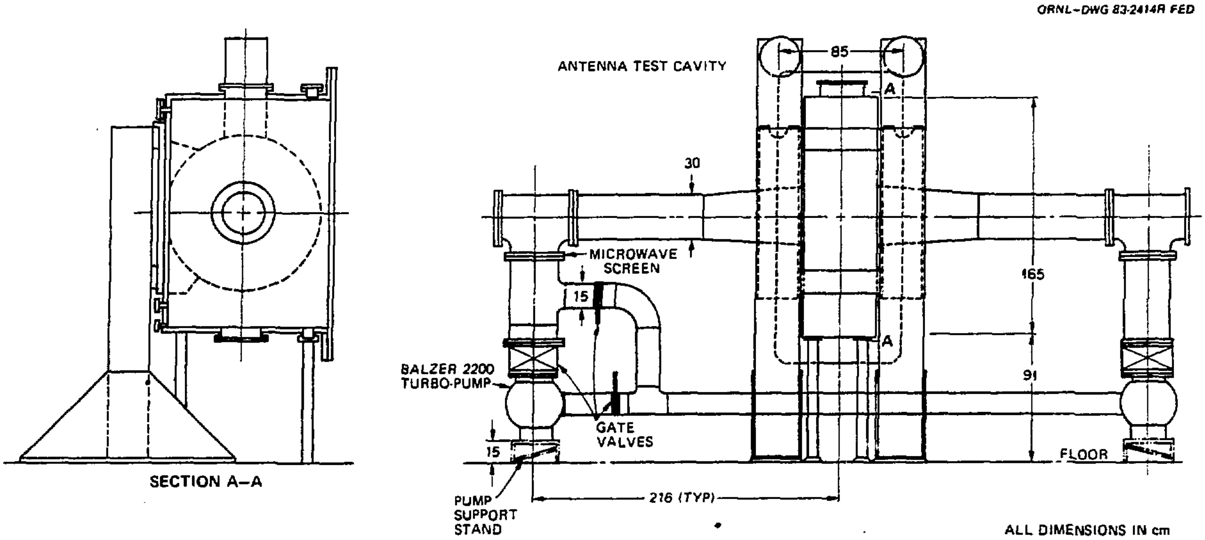


Fig. 5. Vacuum vessel and superconducting magnets with vacuum pumping system.

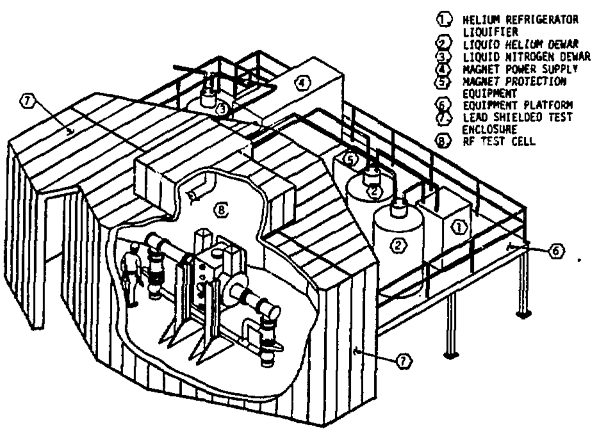


Fig. 6. Test facility with lead enclosure and raised equipment platform.

Next to the enclosure are a raised platform for electrical and cryogenic system components and a control area for instrument and control components and for various diagnostics.

Cryogenic System

It is currently proposed to use a closed-cycle liquid helium cryogenic system with refrigerator/liquefier (R/L) to service the two superconducting magnets. The required capacity is 60 W of refrigeration at 4.6 K and 16 L/h of liquefaction. This is the calculated demand of the two magnets and distribution system plus a 50% contingency. This approach was selected in place of "batch filling" because of the high estimated operating cost of the batch system for reasonable duty cycles for the facility. A process and instrumentation diagram of the helium system is shown in Fig. 7. Level control in the magnets will be by back pressure regulation. A buffer Dewar flask is used in the return line to isolate the R/L from pressure fluctuation. A separate liquid nitrogen system will be used to supply the refrigerator and the cold walls in the magnets. The refrigerator is to be located on the raised platform adjacent to the enclosure with its compressor underneath at floor level, as shown in Fig. 6.

Instrumentation and Control

Instrumentation and control (I&C) systems for RFTF operation will include monitoring and control of the vacuum system, monitoring of the vessel pressure, monitoring of the vessel temperature, and monitoring and quench protection of the magnet [7]. A process and logic controller (PLC) with graphic displays will be used to control the cryogenic system during steady-state operation, to monitor magnet and vacuum system operation, and to control system interlocks. Hardware and software experience with the proposed PLC unit was gained during the EBT-P design effort and is being transferred to the RFTF design.

60-GHz Gyrotron System

The 60-GHz system to be constructed will consist of a 60-GHz gyrotron and its supporting subsystems: a platform on which various components can be conveniently mounted and connected to the gyrotron output, a means of connecting the gyrotron output to a waveguide that will deliver energy to either RFTF or EBT-S, and generic instrumentation.

The principal subsystems will be (1) primary electrical power for the gyrotron and associated I&C; (2) water cooling for the gyrotron magnet, dummy load, electron beam collector, and miscellaneous components; and (3) I&C and interlocks for gyrotron operation in support of RFTF. A view of the system is shown in Fig. 8.

RF Sources and Plasma Sources

The rf sources available to support first-year RFTF operations cover a wide range of frequencies. The first is a 100-kW cw source, adjustable from 2 to 30 MHz, for ion cyclotron resonance heating (ICRH) studies. The second is a 50-kW, 73- to 87-MHz source for ICRH studies for DIII-D and TFTR. The third is a 50-kW cw system, adjustable from 175 to 215 MHz, that is available for support of fast-wave current drive

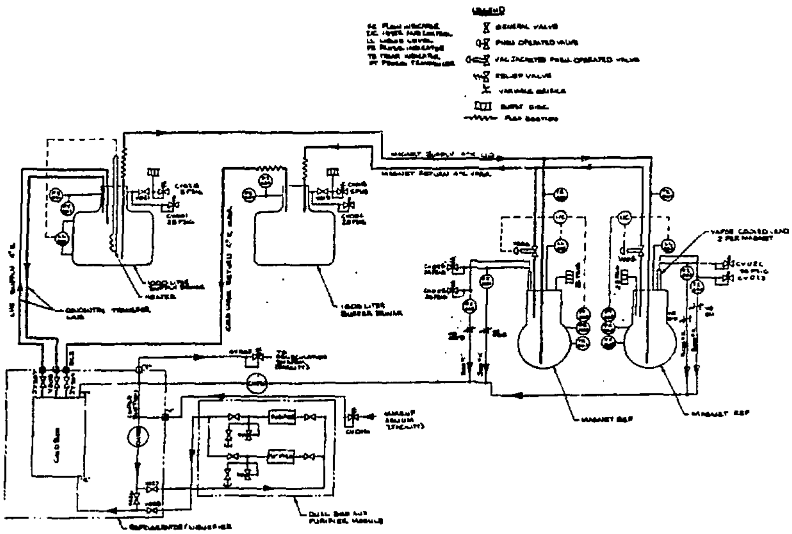

Fig. 7. Liquid helium process and instrumentation diagram.

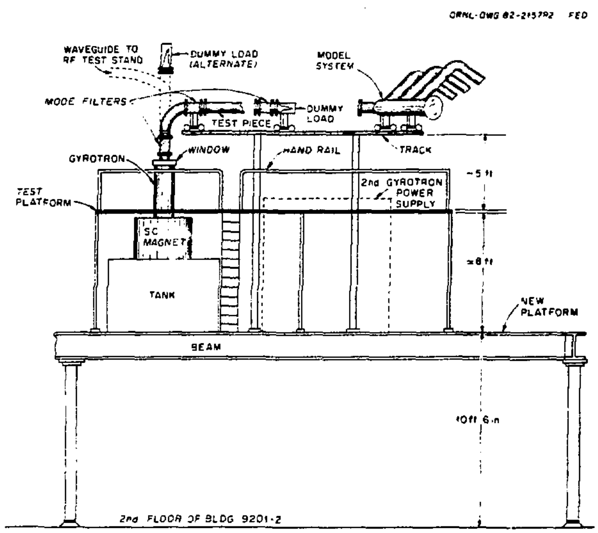


Fig. 8. Gyrotron test stand.

experiments or ICRH experiments for DCT. The fourth source is a 200-kW cw, 28-GHz gyrotron system that is available for ECRF studies as well as for generating a cw plasma load. In addition to these rf systems, an rf system from the Fusion Materials Irradiation Test (FMIT), which can deliver 1000 kW cw at 80 MHz (with a ±1-MHz tuning range), has been acquired by ORNL. Modifications of the FMIT power amplifier system are being investigated that will enable operation in the frequency range from 40 to 80 MHz. A 60-GHz, 200-kW cw gyrotron will operate in the second quarter of FY 1985 to generate higher-density plasmas and to provide the power for ECRF component development.

For experimental flexibility, it is desirable to have a plasma source that could operate continuously and quiescently over a wide range of density ($10^{10}$ to $10^{13}$ cm$^{-3}$) and temperature (T $\sim$ 1-10 eV), would be independent of magnetic field, and would require little or no gas throughput. Because no single source can satisfy all of these requirements, three different types of sources are being considered to generate a reasonable subset of desired plasma parameters. Initial steady-state plasmas with temperatures of $\sim$5 eV and densities of $>10^{12}$ cm$^{-3}$ will be formed by cyclotron resonance breakdown using the 28-GHz or 60-GHz gyrotrons mentioned above. The second source to be used is a washer gun source; although it is inherently short pulse ($\sim$3 ms), it is expected to produce $\sim$10-eV, $\sim 5 \times 10^{13}$-cm$^{-3}$ plasmas. The third plasma source envisioned for this facility is a cold cathode arc that can produce a localized, continuous, $\sim$10-eV, $\sim 10^{13}$-cm$^{-3}$ plasma. Several of these cold cathode arcs would be used to provide some density and profile control. The actual number that can be accommodated by the pumping system must be determined experimentally.

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