C ONF -830406 - -105

DESIGN FOR THE NATIONAL RF TEST FACILITY AT ORNL[a]

W. L. Gardner, D. J. Hoffman, W. R. Becraft,[b] C. W. Blue, S. K. Combs, W. K. Dagenhart,
H. H. Haselton, P. H. Hayes, J. A. Moeller,[c] L. W. Owen, N. S. Ponte,
P. M. Ryan, D. E. Schechter, C. R. Stewart, W. L. Stirling,
D. J. Taylor, and J. H. Whealton

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830
(615) 574-1121

CONF-830406--105

DE83 017180

DESIGN FOR THE NATIONAL RF TEST FACILITY AT ORNL[a]

W. L. Gardner, D. J. Hoffman, W. R. Becraft,[b] C. W. Blue, S. K. Combs, W. K. Dagenhart,
H. H. Haselton, P. H. Hayes, J. A. Moeller,[c] L. W. Owen, N. S. Ponte,
P. M. Ryan, D. E. Schechter, C. R. Stewart, W. L. Stirling,
D. J. Taylor, and J. H. Whealton

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830
(615) 574-1121

ABSTRACT

Conceptual and preliminary engineering design for the National RF Test Facility at Oak Ridge National Laboratory (ORNL) has been completed. The facility will comprise a single mirror configuration embodying two superconducting development coils from the ELMO Bumpy Torus Proof-of-Principle (EBT-P) program on either side of a cavity designed for full-scale antenna testing. The coils are capable of generating a 1.2-T field at the axial midpoint between the coils separated by 1.0 m. The vacuum vessel will be a stainless steel, water-cooled structure having an 85-cm-radius central cavity. The facility will have the use of a number of continuous wave (cw), radio-frequency (rf) sources at levels including 600 kW at 80 MHz and 100 kW at 28 GHz. Several plasma sources will provide a wide range of plasma environments, including densities as high as $\sim 5 \times 10^{13}$ cm^{-3} and temperatures on the order of $\sim$10 eV. Furthermore, a wide range of diagnostics will be available to the experimenter for accurate appraisal of rf testing.

INTRODUCTION

Radio-frequency (rf) heating experience[1-3] on major confinement devices has demonstrated the necessity of developing and testing certain components on facilities off line from the physics experiment. As larger, longer pulse experiments are proposed to be performed in reactorlike plasmas, it has become clear that careful attention must be paid to the technology development needs. A national rf program plan[4] identifies the desirability of an rf test facility dedicated to the development and assessment of rf systems and components.

The ORNL facility, as presently envisioned, will foster the development of reactor-relevant components and will provide sufficient volume to test full-scale components for such devices as PLT, TFTR, D-III, ATF, MFTF-B, and TMX-Upgrade. In addition to allowing more efficient use of confinement device operating time, the greater physical access and experimental availability made possible by a dedicated test facility will provide the opportunity not only for a more careful assessment and diagnosis of rf system components, but also for the testing and evaluation of theoretical models of launcher/plasma interaction.

The key features of the ORNL test facility are the presence of a plasma load and the availability of cw, high power rf sources over a wide range of frequencies. The cw, high power sources enable (1) testing of component power handling capabilities, thermal cycling, fatigue, and suitability of materials, (2) assessment of cooling requirements and fabrication techniques, and (3) treatment of generic systems problems. The plasma environment is necessary to duplicate the low radiation resistance and time-varying VSWRs encountered on confinement experiments. Furthermore, the presence of a plasma is necessary for evaluating the properties and performance of such components as Faraday shields, current feeds, couplers, insulators, windows, and waveguides.

FACILITY DESCRIPTION

The rf test facility as depicted conceptually in Fig. 1 will be a simple mirror configuration using the two superconducting development coils from the EBT-P program. Given the constraints that these coils place on the facility design, trade-offs were made to optimize vacuum vessel access, magnetic field

---

[a] Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

[b] General Electric Company.

[c] Grumman Aerospace Corporation.

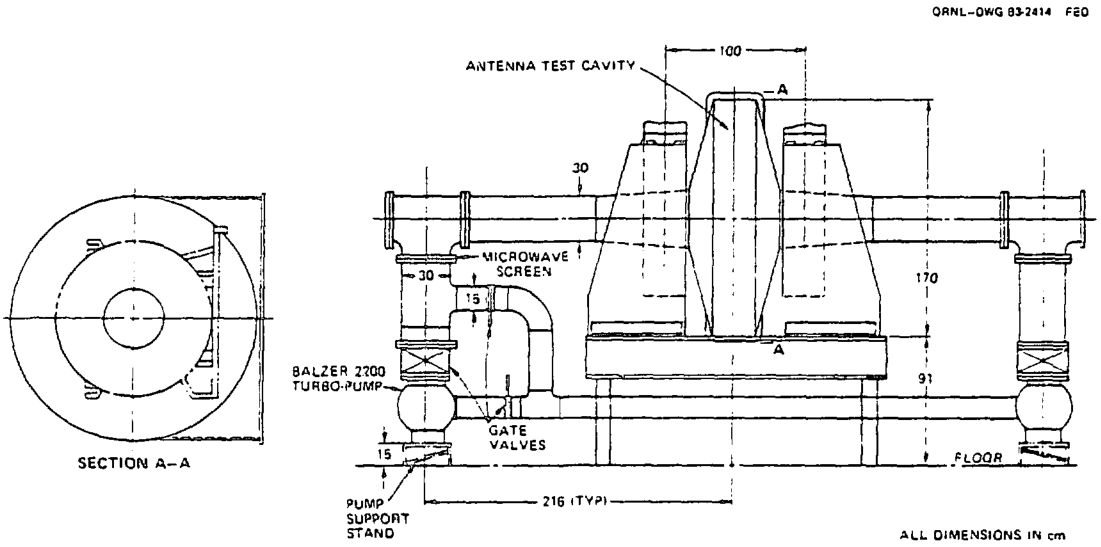

Fig. 1. Conceptual drawing of the ORNL rf test facility.

strength, cooling of critical surfaces, and vacuum pumping speed. Discussed below are the criteria for and descriptions of the major subsystems to be incorporated into this facility.

The Magnet System

An EBT-P development coil as depicted in Fig. 2 has an inner diameter of 43 cm, an outer diameter of 107 cm, and a thickness of 30 cm. Each coil weighs 1800 kg. A maximum field of 7.4 T can be achieved in each coil, and a maximum field of 4.4 T can be achieved on axis in the throat. At this writing the maximum field ratings have been achieved in the test of the first coil. As a compromise between maintaining the large access necessary to test full-scale launchers and also maintaining reasonably high field strengths, the coils have a 1.0-m throat-to-throat separation. This will allow a maximum field of 1.2 T at the axial midpoint between coils. Figure 3 shows the magnetic geometry under maximum field conditions for the chosen coil separation. Contours of mod-B are in increments of 0.6 T.

Preliminary tests to determine the cooling requirements for the coils indicate that approximately 250 L of liquid helium (LHe) is needed to cool each coil from liquid nitrogen (LN_2) temperatures and that each will have a boiloff rate of ~15 L/h. The LHe system has been conservatively sized for demands about 25% higher than this. As presently conceived, two pressure-fed 1000-L Dewar flasks will provide a continuous flow of LHe to the magnets at a rate matched to the total boiloff. The boiloff will be recovered via a compressor, stored, and

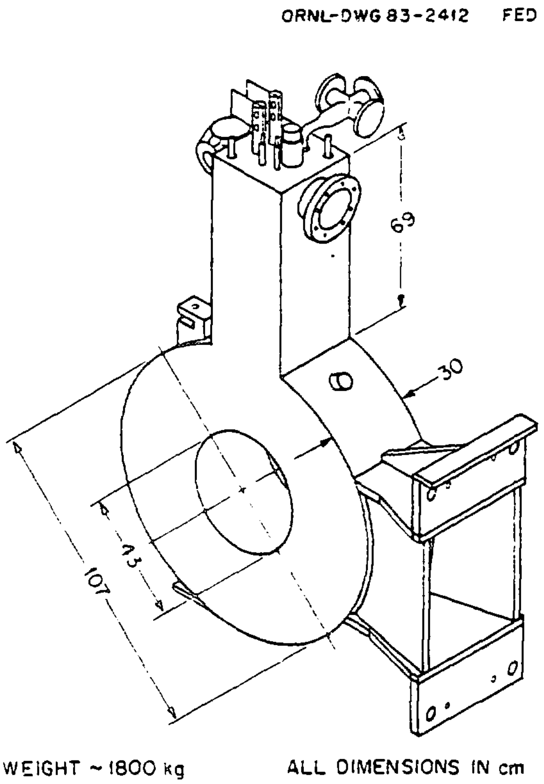

Fig. 2. Perspective of the test facility coil assembly.

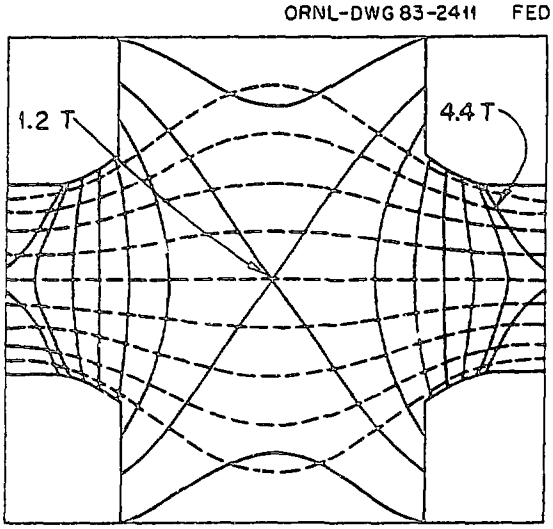

Fig. 3. The magnetic geometry of the test facility coils at maximum field strength. Throat-to-throat coil separation is 100 cm. Dashed curves indicate field lines; solid curves indicate mod-B contours.

subsequently reliquefied. Demand for LN$_2$ will be adequately supplied by a 15,000-L tanker through vacuum-jacketed transfer lines to a 500-L intermediate storage Dewar flask and thence to the coils as required. The LN$_2$ system is open ended and vented to the atmosphere.

Electrically the coils will require approximately 1800 A to reach full field. A 12-V, 3000-A dc supply having <1% ripple will be available for this purpose. Fully tested quench protection circuitry will be provided with the coils.

The magnet support structure for the facility is designed to accommodate 1.5 times the expected full field attractive force of 14,500 kG.

Vacuum Vessel and Associated Subsystems

The vacuum vessel design was primarily influenced by the desire to maximize access, yet maintain reasonably high field strengths. Additional design considerations include the physical constraints of the coils, power handling under full rf power loads, and protection of the vacuum system turbopumps from high magnetic fields.

As indicated in Fig. 4, the maximum cross section of the central cell is a disc 170 cm in diameter. The antenna access port is 170 by 46 cm and is adequate for installing and testing the full-scale prototype antennas planned for current machine upgrades. In addition, enough access is available to permit 25 additional diagnostic ports of various sizes.

The magnetic field configuration is an important consideration in designing and cooling the central cavity and in placing and shielding the turbopumps. Figure 3 showed the magnetic geometry at full field, but normal operation will be at approximately 75% of full field to allow the 28-GHz, mod-B resonance surface to extend across the central region of the central cell. As discussed later, initial plasmas for this facility will be produced by a 28-GHz gyrotron. Representative mod-B resonance contours are shown in Fig. 4, as are associated field lines representing plasma loss paths to the walls. Cooling is concentrated where these resonant field lines intersect the vacuum vessel walls as shown. The initial operating phase of this facility will have the capability of delivering no more than 1 MW of cw power to the plasma acting as an antenna load. Based upon this input power, cooling has been sized to handle the expected $\sim$15-W/cm^2 power density on the walls in the region of maximum plasma loss. Other sections have cooling cilities of 4 to 7.5 W/cm^2. Each cooling circuit will be monitored calorimetrically to determine overall power flow patterns and magnitudes. In addition, approximately 80 thermocouples will be installed along the vessel to permit detailed mapping of the heat load during operation.

The vacuum system calls for two 3000-L/s Balzer turbopumps backed by a single Roots blower-mechanical pump combination. Vacuum diagnostics and controls are based on standard ion and thermocouple gages, with logic interlocks controlling electropneumatic valves for system protection.

The turbopumps provide pumping of the central cavity through long throats and microwave screens, as shown in Fig. 4. These long throats and microwave screens were designed to facilitate adequate magnetic and microwave shielding, respectively, for the pumps without severely limiting gas conductance from the central cell. In fact, the vacuum system was sized to handle expected plasma source gas loads and maintain a central cell pressure of $\leq 10^{-4}$ torr.

RF Sources, Plasma Sources, and Diagnostics

The rf sources available at the test facility to support first-year operations cover three frequency ranges. There is a 100-kW cw source adjustable from 2 to 30 MHz for ion cyclotron resonance heating (ICRH) studies. A

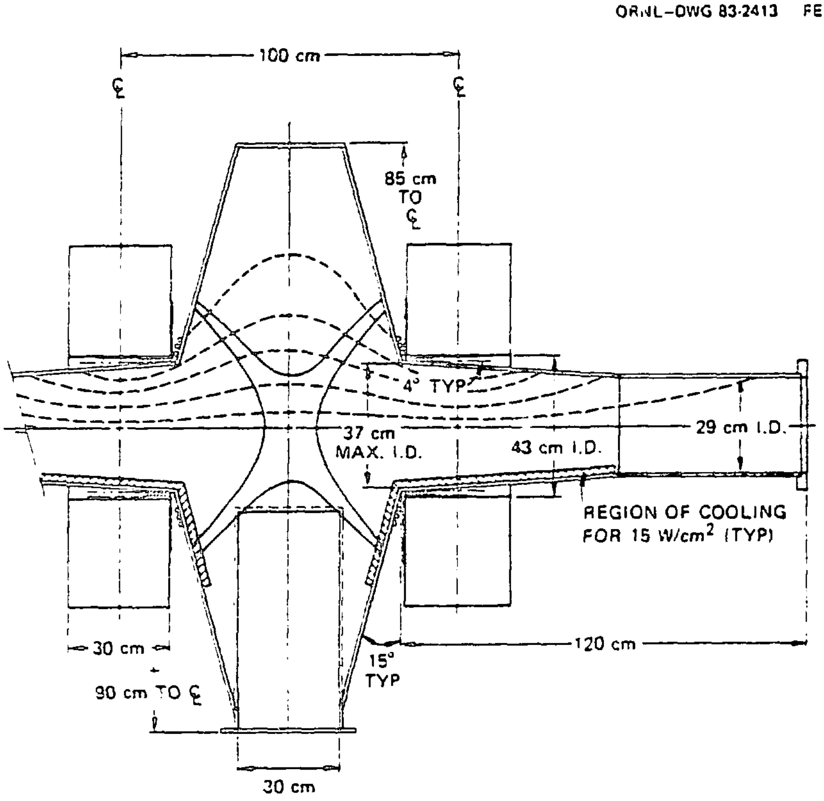

Fig. 4. Test facility schematic indicating mod-B surfaces near the 28-GHz resonance as well as representative field lines along which plasma is lost. Also shown is the area where cooling will be most concentrated.

50-kW cw system adjustable from 175 to 215 MHz is available for support of fast-wave current-drive experiments. The third source is a 100-kW cw, 28-GHz gyrotron system that is available for electron cyclotron resonance heating (ECRH) studies as well as generating a cw plasma load. In addition to these presently available rf systems, ORNL is acquiring a Fusion Materials Irradiation Test (FMIT) rf system capable of 600-kW cw operation at 80 MHz (±1-MHz tuning range). Modifications are being investigated that will enable operation over the frequency ranges of 15 to 30 MHz (lumped element) and 30 to 60 MHz (cavity) in addition to its design frequency.

For experimental flexibility, it would be desirable to have a plasma source that could be tuned over a wide range of density (10^{10} to 10^{14} cm^{-3}) and temperature ($T_e \sim$ 1-10 eV, $T_i \sim$ 1-10 eV) and would be quiescent, operate continuously, require little or no gas throughput, and operate independently of the magnetic field strength. Because a single such source would be impractical, three different types of sources will be used over the near term to generate a reasonable subset of desired plasma parameters. Because it is easily implemented, initial continuous plasmas with temperatures of ~10 eV and densities of the order of 10^{12} cm^{-3} will be formed by cyclotron resonance breakdown using the gyrotron system mentioned above. A washer gun plasma source, though inherently short pulse (~3 ms), is expected to produce ~10-eV, ~5 × 10^{13}-cm^{-3} plasmas. The third plasma source being envisioned for this facility is a cold cathode arc that is being designed to produce a localized, continuous, ~10-eV, ~10^{13}-cm^{-3} plasma. The number of these cold cathode arcs that can be accommodated by the pumping system will be determined experimentally.

To obtain an accurate appraisal of rf testing, a complete diagnostics package is being prepared for the facility. Thus far, power loading on the vessel walls and rf components will be measured by calorimetry consisting of ΔT transducers and flowmeters on the water cooling circuits. Relative power flux measurements will be mapped by thermocouples and an infrared camera. Current distributions on antennas will be measured with rf current probes and distributed voltage sensors. Electromagnetic field quantities will be sampled by movable probes such as square-law diodes and magnetic loops. Plasma densities will be measured by Langmuir probes and a microwave interferometer, and electron temperatures will be gaged by optical spectrometry as well as the Langmuir probes. Data acquisition will be handled by a PDP-11/34 computer system on a shared basis with the present neutral beam High Power Test Facility. It is expected that additional diagnostics will be added as experimental and testing programs evolve.

REFERENCES

1. Equipe TFR, pp. 75-84 in *Plasma Physics and Controlled Nuclear Fusion Research. Proceedings of the 8th International Conference, Brussels, 1980*, Vol. 2, International Atomic Energy Agency, Vienna, 1981.

2. P. L. COLESTOCK et al., paper A3 in *Proceedings of the 4th Topical Conference on Radio Frequency Heating in Plasmas*, University of Texas, Austin, 1981.

3. JFT-2 Group, p 259 in *Heating in Toroidal Plasmas. Proceedings of the 3rd Joint Varenna-Grenoble International Symposium*, Commission of the European Communities, Brussels, 1982.

4. *The National RF Technology Research and Development Program Plan*, CONF-820758, to be published at Oak Ridge National Laboratory.