Distribution Category:
Magnetic Fusion Energy
(UC-20)

ANL/FPP/TM-209

ANL/FPP/TM--209

DE87 008076

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

DISCLAIMER

SIZE LIMITATIONS FOR MICROWAVE CAVITY TO SIMULATE HEATING OF BLANKET MATERIAL IN FUSION REACTOR

by

David Wolf*

January 1987

*Work supported by the U. S. Department of Energy/Office of Fusion Energy
under Contract No. #W-31-109-ENG-38.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

TABLE OF CONTENTS

<u>Page</u>	
ABSTRACT.....	1
I. Introduction.....	2
II. Background and Microwave Heating.....	2
III. Field Configuration and Boundary Conditions.....	3
IV. Height and Width Limits.....	7
V. Modal Analysis.....	9
VI. Acknowledgments.....	17
References.....	17

LIST OF FIGURES

<u>Number</u>		<u>Page</u>
1.	Geometry of Blanket Material Sample in Cavity.....	4
2.	Comparison Between Exponential and Sine-Squared Functions....	8
3.	Sample Section and Matching Section.....	10
4.	Plot of Electric Field at $Z = 0$ Interface, $a = 0.17$	15
5.	Plot of Electric Field at $Z = 0$ Interface with $a = 0.19$	16

LIST OF TABLES

<u>Number</u>		<u>Page</u>
1.	k_{1n} and k_{2n} for $a = .361$ m.....	11
2.	Coefficients of Modes for $a = .361$ m.....	14

**SIZE LIMITATIONS FOR MICROWAVE CAVITY TO SIMULATE
HEATING OF BLANKET MATERIAL IN FUSION REACTOR**

by

David Wolf

ABSTRACT

The power profile in the blanket material of a nuclear fusion reactor can be simulated by using microwaves at 200 MHz. Using these microwaves, ceramic breeder materials can be thermally tested to determine their acceptability as blanket materials without entering a nuclear fusion environment. A resonating cavity design is employed which can achieve uniform cross sectional heating in the plane transverse to the neutron flux. As the sample size increases in height and width, higher order modes, above the dominant mode, are propagated and destroy the approximation to the heating produced in a fusion reactor. The limits at which these modes develop are determined in the paper.

I. INTRODUCTION

In a nuclear fusion reactor, the blanket section is subjected to a neutron flux produced by the fusion of deuterium and tritium atoms in the plasma. By selecting a proper material, in this case a lithium compound (γ -LiAlO₂), these neutrons react with the blanket material and breed more tritium fuel by the reaction¹

The blanket also converts the kinetic energy of the escaping neutrons into heat, which is then transferred to a coolant and eventually to a generator to produce electricity.

The heating of the blanket material in the fusion reactor is related to the power loss in the material. In the reactor, the power profile (volumetric power loss) is²

$$P(z) = P_0 e^{-qz} \quad [1]$$

where

$$P_0 = 2.4 \times 10^7 \text{ W/m}^3$$

$$q = 8.8 \text{ m}^{-1}$$

$$z = \text{blanket depth.}$$

As can be seen from the above equation, the power loss is independent of both x and y and is thus uniform across these cross sections.

II. BACKGROUND AND MICROWAVE HEATING

For lossy materials, the dielectric constant is composed of real and imaginary parts. It is the imaginary part that enters into the volumetric power loss in the equation³

$$P(z) = \frac{1}{2} \omega \epsilon_{im} \epsilon_0 E(z)^2 \quad [2]$$

where

ω = angular frequency = $200 \text{ MHz} \times 2\pi$

ϵ_{im} = imaginary part of the dielectric constant = $(\epsilon_r + j\epsilon_{im})\epsilon_0$

$E(z)$ = the electric field at the point.

For the material chosen, $\gamma\text{-LiAlO}_2$, $\epsilon_r = 2.87$ and $\epsilon_{im} = .01$. In deriving the field configurations, ϵ_{im} may be neglected since it is much smaller than ϵ_r .

In the cavity design, the blanket material sample in Fig. 1 is bordered on two sides by another dielectric, on the bottom, top, and front by copper walls, and the back face is matched to a loading cavity. Although copper is not a perfect conductor, it is sufficient to approximate it as such, since the power loss in the copper walls is much less than that in the blanket section.

III. FIELD CONFIGURATION AND BOUNDARY CONDITIONS

To find the electric field, Maxwell's equations and the scalar Helmholtz equation are used.⁴ The magnetic field is then given by

$$\vec{\nabla} \times \vec{E} = j\omega\mu\vec{H}$$

assuming an $e^{j\omega t}$ time dependence.

Boundary conditions imposed by the conducting walls force the tangential electric field to be zero at the walls. In the blanket section we desire a TE mode.⁵ This will result in an electric field that only has a y component and is zero only at the side walls. Solving Maxwell's equations under these constraints leads to a general solution for the field in the blanket section

$$E_y = E_0 \cos(k_x x) \cos(k_y y) \sin(k_z (l-z))$$

where l is the z coordinate of the front wall and k_x , k_y , and k_z have yet to be determined. As apparent, this equation is not independent of x and y and will thus not accurately approximate the power profile we desire. In order to eliminate the y dependence, we must set $k_y = 0$. Since $k_y = m\pi/d$ ($m=0,1,2,\dots$), this requires that we allow only TE_{n0} modes to propagate. To achieve this, we must restrict the height of the cavity, thus the value of d, such that the $m = 1$ mode is not propagated. To begin with, a value of 0.10 m is used.

Fig. 1 Geometry of Blanket Material Sample in Cavity

We cannot eliminate the x dependence in a similar manner, for if $k_x = 0$ and E_y must equal zero at the side walls, then there could not be a field in the cavity. To circumvent this problem, the second material is placed between the lithium sample and the side walls (see Fig. 1). The electric field then becomes

$$\begin{aligned} E_y &= C_2 \cos(k_2 x) \sin(k_z(l-z)) & |x| < a \\ &= C_1 \sin(k_1(x-b)) \sin(k_z(l-z)) & a < |x| < b \end{aligned} \quad [3]$$

and the uniform heating of the sample is obtained by setting $k_2 = 0$.

The fields must be continuous across the boundaries $x = -a$ and $x = a$. Continuity of $\vec{E}$ fields leads to

$$C_2 \cos(k_2 a) \sin(k_z(l-z)) = C_1 \sin(k_1(a-b)) \sin(k_z(l-z)) \quad [4]$$

Continuity of $\vec{H}$ fields is related to the derivatives of the $\vec{E}$ fields. We need only examine $\partial \vec{E} / \partial x$ since the other derivatives are satisfied when Eq. [4] is. Continuity of $\partial \vec{E} / \partial x$ yields

$$-C_2 k_2 \sin(k_2 a) \sin(k_z(l-z)) = C_1 k_1 \cos(k_1(a-b)) \sin(k_z(l-z)) \quad [5]$$

Combining Eqs. [4] and [5]

$$-k_2 \tan(k_2 a) = k_1 \cot(k_1(a-b)) \quad [6]$$

The scalar Helmholtz equation, $\nabla^2 \vec{E} + \omega^2 \epsilon \mu \vec{E} = 0$, must also be satisfied. Applying this to Eq. [3] yields

$$-k_2^2 - k_z^2 + \omega^2 \epsilon_2 \epsilon_0 \mu = 0 \quad [7]$$

$$-k_1^2 - k_z^2 + \omega^2 \epsilon_1 \epsilon_0 \mu = 0 \quad [8]$$

where

$$\epsilon_2 = 2.87, \text{ relative dielectric constant for } \gamma\text{-LiAlO}_2$$

$\epsilon_1 = 8.5$, relative dielectric constant for alumina, Al_2O_3

$\mu = 4\pi \times 10^{-7}$ Henry/m, permeability of free space.

Equations [6], [7], and [8] give us three equations in three unknowns that must be solved numerically. However, as mentioned earlier, we desire $k_2 = 0$. If this is so, then Eq. [6] reduces to

$$k_1 (a-b) = (n + \frac{1}{2})\pi \quad (n = \dots, -1, 0, 1, \dots) \quad [9]$$

and eliminating k_2 from Eqs. [7] and [8]

$$k_1^2 - k_2^2 = \omega^2(\epsilon_1 - \epsilon_2)\epsilon_0\mu \quad [10]$$

or

$$k_1 = \sqrt{\omega^2(\epsilon_1 - \epsilon_2)\epsilon_0\mu} = 9.94 \text{ m}^{-1} \quad [11]$$

Using this value for k_1 in Eq. [9] and solving for the smallest value for $(a-b)$,

$$(b-a) = \frac{\pi}{2k_1} = 0.15797 \text{ m}$$

Therefore, as long as the width of the alumina on the sides of the lithium sample is fixed at .15797 m, then $k_2 = 0$ is an acceptable solution to the equations and we have achieved the uniformity of the power loss across the sample.

Although we have successfully simulated the uniform heating of the sample, the electric field now varies sinusoidally with z . Therefore, from Eq. [2], the power profile is now proportional to $\sin^2(k_z(l-z))$ instead of the actual power profile in Eq. [1]. In order to match the sine-squared function to the exponential function of Eq. [1], we look for the point, z_0 , where the functions and their first derivatives match. Setting the functions equal,¹

$$A \sin^2(k_z(l-z_0)) = B e^{-qz_0} \quad [12]$$

where A and B are arbitrary amplitudes. Setting the derivatives equal,

$$-2Ak_z \sin(k_z(l-z_0)) \cos(k_z(l-z_0)) = -Bq e^{-qz_0} \quad [13]$$

Substituting Eq. [12] into Eq. [13] and solving for $(l-z_0)$,

$$(l-z_0) = \frac{1}{k_z} \tan^{-1} \left(\frac{2k_z}{q} \right) \quad [14]$$

We can solve for k_z from Eq. [8] with $k_2 = 0$, giving

$$k_z = \sqrt{\omega^2 \epsilon_2 \epsilon_0 \mu} = 7.099 \text{ m}^{-1} \quad .$$

Evaluating Eq. [14] now given

$$(l-z_0) = .143 \text{ m.}$$

Therefore, the blanket section is to be built with a depth of .173 m (.143 for the optimal point plus another .03 for region of interest) with $l = .173$, $z_0 = .03$ m. The magnitude of B is chosen so that at $z = 0$, the power loss is 24 W/cc. A is then found from Eq. [12] with $z_0 = .03$, giving $A = 25.53$ W/cc. These two functions are graphed in Fig. 2. Over the first six centimeters of the blanket section, the graphs are within 7% of each other.

IV. HEIGHT AND WIDTH LIMITS

Operating at 200 MHz and with a sample section of .1 m across, only the first mode, the one with $k_2 = 0$, is allowed to propagate. However, as the width of the sample section increases, higher modes for which k_2 does not equal zero are also propagated and thus disrupt the uniformity in the x and y directions. By solving the equations for the next values of k_1 , k_2 , and a , we are able to determine the maximum width of the cavity. If we keep the dimension of $(b-a)$ at .15797, the dominant mode in the alumina is the first one. As we allow a to increase, different values of k_1 and k_2 are found using Eq. [6]. By setting $k_z = 0$, we can find the cutoff frequencies for the first two modes. As the width of the cavity increases, the cutoff frequencies of the modes decrease, until at $a = .362$ m, the cutoff frequency of the second

Fig. 2 Comparison between Exponential and Sine-Squared Functions

mode is less than 200 MHz. Therefore, in order to ensure that the second mode does not propagate and interfere with the first, the width of the blanket section must be kept below .722 m.

To determine the maximum height of the cavity, we again look for the largest dimension in the y direction before the second mode is propagated. As we saw earlier, the general solution to Maxwell's equations involves a $\cos(k_y y)$ term, where $k_y = m\pi/d$ ($m = 0, 1, 2, \dots$). Up to this point, we have been only considering the $m = 0$ mode. Now we must solve slightly different equations. Eqs. [7] and [8] become

$$-k_2^2 - k_y^2 - k_z^2 + \omega^2 \epsilon_2 \epsilon_0 \mu = 0 \quad [15]$$

and

$$-k_1^2 - k_y^2 - k_z^2 + \omega^2 \epsilon_1 \epsilon_0 \mu = 0 \quad [16]$$

respectively. Once again we must find the set of k_1 , k_2 , and d that satisfy these two equations along with Eq. [6]. Doing this, we find that the smallest value for d is .442 m. When d is greater than this, the $m = 1$ mode is propagated along with the $m = 0$ mode, and the uniformity of the cavity heating is destroyed.

V. MODAL ANALYSIS

The design of Fig. 1 must be linked to a matching section to complete the cavity. One type is shown in Fig. 3. At the interface between the matching section and the blanket section, higher order modes are generated to satisfy the continuity conditions discussed earlier. These modes may be tolerated if their magnitudes are sufficiently small and if they do not interfere greatly with the uniform heating of the sample. In the matching section, the dominant term of the electric field is

$$E_y = A_0 \cos(r_0 x) \sin(r_{z0}(z_1 + z))$$

where z_1 is the coordinate of the back wall. With the discontinuity of media, the higher modes generated cause the electric fields on both sides of the interface to become infinite sums. In the matching section, the field is

Fig. 3 Sample Section and Matching Section

$$E_y = \sum_{m=0}^{\infty} A_m \cos(r_m x) \sin(r_{zm} (z_1 + z)) \quad [17]$$

where

$$r_m = (m + \frac{1}{2})\pi/b \quad (m = 0, 1, 2, \dots)$$

In the blanket section, for which $z > 0$, the field becomes

$$E_y = \sum_{n=0}^{\infty} C_{2n} \cos(k_{2n} x) \sin(k_{zn} (l - z)) \quad |x| < a \quad [18]$$

$$= \sum_{n=0}^{\infty} C_{1n} \sin(k_{1n} (x-b)) \sin(k_{zn} (l-z)) \quad a < |x| < b$$

k_{1n} and k_{2n} must be found numerically from Eqs. [6], [7], and [8], with the first five solutions given in Table 1.

TABLE 1.
 k_{1n} and k_{2n} for $a = .361$ m

n	k_{1n} (in m^{-1})	k_{2n} (in m^{-1})
0	9.9435	0.0000
1	12.2335	7.1104
2	17.1987	14.0328
3	22.8498	20.5730
4	28.5603	26.7735

Using Eq. [7], r_{zm} and k_{zn} can be found and are

$$r_{zm} = \sqrt{\omega^2 \epsilon_m \epsilon_0 \mu - r_m^2}$$

$$k_{zn} = \sqrt{\omega^2 \epsilon_i \epsilon_o \mu - k_{ln}^2}$$

where ϵ_m = the relative dielectric constant of the matching section, here chosen to be that of alumina, 8.5. Note that if either r_{zm} or k_{zn} is imaginary, then $B \sin(jx) = jB \sinh(x)$, which is a valid expression for the field. The value of z_1 can now be determined. z_1 is chosen so that at $z = 0$, the first modes and their derivatives match. This requires that

$$A_0 \sin(r_{z0} z_1) = C_{20} \sin(k_{z0} \ell)$$

and

$$A_0 r_{z0} \cos(r_{z0} z_1) = -C_{20} \cos(k_{z0} \ell) \quad .$$

Combining these and solving for z_1 ,

$$z_1 = \frac{1}{r_{z0}} \tan^{-1} \left(\frac{-r_{z0}}{k_{z0}} \tan(k_{z0} \ell) \right) \quad [19]$$

For $a = .361$, Eq. [19] gives $z_1 = .1505$ m.

As before, $\vec{E}$ and $\nabla \vec{E}$ must be continuous across the boundary, $z = 0$. Setting the fields equal yields

$$\sum_{m=0}^{\infty} A_m \cos(r_m x) \sin(r_{zm} z_1) = \sum_{n=0}^{\infty} C_{2n} \cos(k_{2n} x) \sin(k_{zn} \ell) \quad |x| < a \quad [20]$$

$$= \sum_{n=0}^{\infty} C_{1n} \sin(k_{1n} (x-b)) \sin(k_{zn} \ell) \quad a < |x| < b \quad .$$

Using the orthogonality of $\cos(r_m x)$, we multiply both sides by $\cos(r_m x)$ and integrate from $-b$ to b giving

$$\begin{aligned}
A_m \sin(r_m z_1) = & \sum_{n=0}^{\infty} \frac{1}{b} \sin(k_{zn} \ell) \left[2 \int_0^a C_{2n} \cos(k_{2n} x) \cos(r_m x) dx \right. \\
& \left. + 2 \int_a^b C_{1n} \sin(k_{1n} (x-b)) \cos(r_m x) dx \right] \quad . \quad [21]
\end{aligned}$$

Using Eqs. [4] and [5] to find C_{1n} in terms of C_{2n} , and performing the above integration leads to

$$\begin{aligned}
A_m \sin(r_m z_1) = & \sum_{n=0}^{\infty} \frac{2C_{2n} \sin(k_{zn} \ell)}{b} \left(\frac{1}{k_{1n}^2 - r_m^2} - \frac{1}{k_{2n}^2 - r_m^2} \right) \quad [22] \\
& \times (r_m \sin(r_m a) \cos(k_{2n} a) - k_{2n} \sin(k_{2n} a) \cos(r_m a)) \quad .
\end{aligned}$$

$\vec{V_E}$ must also be continuous across the boundary. Taking the z derivative of Eqs. [17] and [18] and equating them gives

$$\begin{aligned}
\sum_{m=0}^{\infty} A_m r_m \cos(r_m x) \cos(r_m z_1) = & \sum_{n=0}^{\infty} -C_{2n} k_{zn} \cos(k_{2n} x) \cos(k_{zn} \ell) \quad |x| < a \\
& [23] \\
= & \sum_{n=0}^{\infty} -C_{1n} k_{zn} \sin(k_{1n} (x-b)) \cos(k_{zn} \ell) \quad a < |x| < b \quad .
\end{aligned}$$

Multiplying by $\cos(r_m x)$ and integrating as before, Eq. [23] becomes

$$\begin{aligned}
A_m r_m \cos(r_m z_1) = & \sum_{n=0}^{\infty} \frac{-C_{2n} k_{zn} \cos(k_{zn} \ell)}{b} \left(\frac{1}{k_{1n}^2 - r_m^2} - \frac{1}{k_{2n}^2 - r_m^2} \right) \quad [24] \\
& \times (r_m \sin(r_m a) \cos(k_{2n} a) - k_{2n} \sin(k_{2n} a) \cos(r_m a))
\end{aligned}$$

Setting $A_0 = 1$, we can solve the infinite set of equations in [22] and [24] using a matrix of the truncated set of equations and thus determine the coefficients of the first several modes.⁶ These are given in Table 2.

TABLE 2.
Coefficients of Modes for $a = .361$ m.

n	C_{2n}	A_n
0	0.8588	1.000
1	2.6918	-0.5546
2	0.0521	-0.0310
3	-0.0604	-

As can be seen from the table, the dominant mode in the cavity is not the first one, for which $k_2 = 0$, rather it is the second mode. Therefore, the power loss will not be uniform across the blanket material. As the value of a decreases, the coefficient of the first mode increases, and that of the second mode decreases, since the region of desired flatness decreases and the field becomes closer to the dominant cosine wave in the matching section.

By performing the above modal analysis for varying values of a , we find that for $a = .17$, the variation of E across the lithium sample is less than 10%. If a increases to .19, the variation becomes approximately 20%. From Eq. [2] we can find the magnitude of the electric field needed at the interface,

$$E(0) = \left(\frac{2P_0}{\omega \epsilon_{im} \epsilon_0} \right)^{1/2} = 0.656 \text{ MV/m}.$$

Taking this value for A_0 , we can plot the approximate electric field at $z = 0$. This is shown in Fig. 4 for $a = .17$ and in Fig. 5 for $a = .19$.

In order to keep the heating of the lithium sample to within 10% of being uniform, the largest blanket section that can be used for this type of section experiment is 17 cm x 44.2 cm x 17.3 cm. This blanket section is bordered on the sides by a section of alumina that is 15.797 cm wide, and is attached to a matching section of more alumina that is 15.96 cm deep. The exponential decay

Fig. 4 Plot of Electric Field at $Z = 0$ Interface, $a = 0.17$

Fig. 5 Plot of Electric Field at $Z = 0$ Interface with $a = 0.19$

in the z direction has been approximated by a sine-squared, with the first six centimeters being a close match.

VI. ACKNOWLEDGMENTS

I would like to thank Dr. Robert Kustom for providing the topic for this project, offering his guidance, and answering my innumerable questions. I would also like to thank Doug Couwenhoven, my colleague, for assisting me with this project.

VII. REFERENCES

1. Fendley, Paul, "Waveguide and Cavity Designs to Reproduce a Fusion Reactor Blanket Material Power Profile," Argonne Summer Research Participant, 1984.
2. Kustom, R. L., et al., "Design of the Waveguide for Microwave Heating of Solid Lithium Ceramic Blankets," ANL/FPP/TM-198, Argonne National Laboratory, 1985.
3. Harrington, Roger, Time-Harmonic Electromagnetic Fields, (McGraw-Hill, New York, 1961).
4. Lorrain, Paul and Carson, Dale, Electromagnetic Fields and Waves, (W. H. Freeman & Co., New York, 1970).
5. Kraus, John, Electro-Magnetics, (McGraw-Hill, New York, 1952).
6. Mittra, R. and Lee, S. W., Analytical Techniques in the Theory of Guided Waves, (Macmillan, New York, 1971).

DISTRIBUTION LIST FOR ANL/FPP/TM-209**Internal:**

C. Baker	D. Gruen	C. Reed
M. Billone	A. Hassanein	D. Smith
J. Brooks	T. Hua	H. Stevens
Y. Cha	C. Johnson	D. Sze
O. Chopra	A. Krauss	L. Turner
R. Clemmer	Y. Liu	T. Yule
D. Ehst	B. Loomis	FPP Files (15)
K. Evans	S. Majumdar	ANL Contract File
P. Finn	R. Mattas	ANL Libraries
Y. Gohar	B. Picologlou	ANL Patent Dept.
L. Greenwood	K. Porges	TIS Files (5)

External:

DOE-TIC, for distribution per UC-20 (103)
 Manager, Chicago Operations Office
 S. Berk, Office of Fusion Energy
 M. Cohen, Office of Fusion Energy
 R. Dowling, Office of Fusion Energy
 G. Haas, Office of Fusion Energy
 G. R. Nardella, Office of Fusion Energy
 A. Opdenaker, Office of Fusion Energy
 T. Reuther, Office of Fusion Energy
 P. Stone, Office of Fusion Energy
 S. Abdel-Khalik, University of Wisconsin
 M. Abdou, University of California, Los Angeles
 J. Anderson, Los Alamos National Laboratory
 S. Baron, Brookhaven National Laboratory
 W. Bauer, Sandia Laboratories
 L. Bromberg, Massachusetts Institute of Technology
 D. Cohn, Massachusetts Institute of Technology
 R. Conn, University of California, Los Angeles
 J. Crocker, EG&G Idaho, Inc.
 J. Davis, McDonnell Douglas Astronautics Company
 S. Dean, Fusion Power Associates
 T. Drolet, Ontario Hydro, CANADA
 C. Flanagan, Fusion Engineering Design Center/Oak Ridge National Laboratory
 H. Forsen, Bechtel National, Inc.
 H. Furth, Princeton Plasma Physics Laboratory
 J. Garner, TRW, Inc.
 N. Ghoneim, University of California, Los Angeles
 P. Gierszewski, Canadian Fusion Fuels Technology Project
 J. Gordon, TRW, Inc.
 R. A. Gross, Columbia University
 R. Hancox, Culham Laboratory
 C. Henning, Lawrence Livermore National Laboratory
 N. Hoffman, Energy Technology Engineering Center
 G. Hollenberg, Hanford Engineering Development Laboratory
 M. Kazimi, Massachusetts Institute of Technology

A. Klein, University of Oregon
 R. Krakowski, Los Alamos National Laboratory
 G. Kulcinski, University of Wisconsin, Madison
 R. Little, Princeton University
 G. Logan, Lawrence Livermore National Laboratory
 P. Lykoudis, Purdue University
 J. Maniscalco, TRW, Inc.
 G. Miley, University of Illinois-Urbana
 R. Moir, Lawrence Livermore National Laboratory
 D. Montgomery, Massachusetts Institute of Technology
 D. Moyer, Grumman Aerospace Corporation
 S. Piet, EG&G Idaho, Inc.
 P. Reardon, Brookhaven National Laboratory
 F. Ribe, University of Washington
 M. Rogers, Monsanto Research Corporation
 D. Rowe, Rowe and Associates
 P. Rutherford, Princeton University
 J. Schmidt, Princeton Plasma Physics Laboratory
 K. Schultz, GA Technologies Inc.
 J. Scott, Oak Ridge National Laboratory
 T. Shannon, Fusion Engineering Design Center/Oak Ridge National Laboratory
 W. Stacey, Jr., Georgia Institute of Technology
 D. Steiner, Rensselaer Polytechnic Institute
 K. Symon, Synchrotron Radiation Center
 K. Thomassen, Lawrence Livermore National Laboratory
 A. Tobin, Grumman Aerospace Corporation
 T. Tomabechi, Japan Atomic Energy Research Institute, JAPAN
 W. Verbeeck, CEC, BELGIUM
 Prof. Vetter, Kernforschungszentrum Karlsruhe und Verwaltung, GERMANY
 G. L. Woodruff, University of Washington
 Bibliothek, Max-Planck-Institute fur Plasmaphysik, WEST GERMANY
 C.E.A. Library, Fontenay-aux-Roses, FRANCE
 Librarian, Culham Laboratory, ENGLAND
 Library Laboratorio Gas Ionizati, ITALY
 Thermonuclear Library, Japan Atomic Energy Research Institute, JAPAN