MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0147574 0

ORNL/TM-10199

ornl

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Measurement of the Hydrogen Recombination Coefficient in the TEXT Tokamak as a Function of Outgassing and Power Radiated During Tokamak Discharges

R. A. Langley
W. L. Rowan
R. V. Bravenec
K. Nelin

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this report, send in name with report and the library will arrange a loan.

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A02 Microfiche A01

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.

ORNL/TM-10199
Dist. Category UC-20 f,g

Fusion Energy Division

MEASUREMENT OF THE HYDROGEN RECOMBINATION COEFFICIENT IN THE TEXT TOKAMAK AS A FUNCTION OF OUTGASSING AND POWER RADIATED DURING TOKAMAK DISCHARGES

R. A. Langley

W. L. Rowan
R. V. Bravenec
K. Nelin
Fusion Research Center, University of Texas, Austin

Date Published — October 1986

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0147574 0

ABSTRACT

The global recombination rate coefficient k_r for hydrogen has been measured in the TEXT tokamak vacuum vessel for various surface conditions. An attempt was made to correlate the measured values of k_r with residual gas analyzer (RGA) data taken before each measurement of k_r and with the power radiated during tokamak discharges produced after each measurement of k_r. The results show that k_r increases during a series of tokamak discharges, k_r is relatively insensitive to power radiated during tokamak discharges, and k_r increases with the RGA measurements of mass 28 and 40 but not with those of mass 18. In addition, it was found that the mass 18 (H_2O) signal decreased as glow discharge experiments with hydrogen were performed.

1. INTRODUCTION

The hydrogen isotopes deuterium and tritium are used as fuel for magnetically confined fusion reactors. In the interaction of hydrogen with the reactor wall and in-vessel components (e.g., limiters), important areas of concern are fueling, recycling, and hydrogen inventory in the solid materials. The hydrogen inventory in the walls builds up mainly through hydrogen's surface recombination rate at the wall, its diffusion in the solid bulk of the wall, and its solubility in the bulk wall material. The effective parameter is $\sigma k_r/D$, where σ is the surface roughness factor, k_r is the surface recombination rate, and D is the bulk diffusion coefficient.

Laboratory measurements have been made of σk_r and D. The results for σk_r for stainless steel are found to vary by up to four orders of magnitude at any given temperature[1] depending on, with decreasing uncertainty, surface condition, specific type of material, and technique of measurement used. Reported values of k_r are in actuality measurements of σk_r. Experimental measurements of σ have yielded values greater than the geometrical area by up to a factor of 20 depending on surface conditioning (e.g., mechanical polishing and electropolishing). The results for D in stainless steel have been measured but have an uncertainty of perhaps a factor of 2 (ref. 2).

The largest uncertainties observed in σk_r are in all probability associated with surface conditions—that is, oxide layer thickness,[3,4] oxygen surface coverage,[5] and any deposited surface impurity layers.

The purpose of this experimental work was to study the effects of surface condition, as determined by outgassing measurements and power radiated during tokamak plasma discharges, on the measured values of σk_r for various vacuum conditions experienced in the Texas Tokamak (TEXT) vacuum vessel. The remainder of this paper describes the tokamak and the experimental method, presents the experimental results, and discusses the implications of the results.

2. THE TEXT TOKAMAK

The TEXT tokamak is a moderate-size device with a major radius of 100 cm, a minor plasma radius of 27 cm, a centerline field of 3 T, a nominal plasma current of 300 kA, a pulse length of 500 ms, and a firing period of 2 min. The vacuum vessel is type 304 stainless steel with 14 straight bellows sections and no insulating breaks. The vacuum vessel is of all-welded construction and uses metal seals for all ports.

The vessel is circular in cross section with a volume of 2.5×10^6 cm^3 and a surface area of 3.7×10^5 cm^2. The vessel is pumped by two turbomolecular pumps with isolation valves. A residual gas analyzer (RGA) is provided for monitoring vacuum cleanliness. The nominal cleaning technique is Taylor-type discharge cleaning provided by a 400-Hz generator. At present only ohmic heating is used.

The facility has a wide range of plasma diagnostics. Of particular interest to this experiment is the bolometer system used to measure the power radiated during plasma discharges. This system is described in ref. 6.

3. EXPERIMENTAL METHOD

The experimental method used in this experiment to determine σk_r is similar to that used to measure σk_r in the Impurity Study Experiment (ISX-B) tokamak.[1] The object is to measure the time evolution of the H_2 number density in the vacuum vessel during a glow discharge and correlate it with $\sigma k_r/D$. This is accomplished by measuring the time evolution of the pressure. The experimental method is to pump the vacuum chamber to its ultimate pressure, usually $\sim 10^{-6}$ torr; make an RGA scan to determine the composition of the background gases; then close off all pumping ports so that there is no pumping. The wall outgassing rate is then determined by measuring the pressure rise as a function of time; typical outgassing rates range from 5×10^{-12} to 1×10^{-12} torr/cm^2·s. Following this measurement H_2 gas is admitted to a pressure of about 30 mtorr, and a glow discharge is struck by applying a dc voltage between the torus wall and a stainless steel electrode inserted into the central volume of the torus. The gas is ionized to only a few percent, and the discharge current is sustained by ions accelerated across the dark space hitting the wall, with the concomitant emission of secondary electrons that are in turn accelerated from the wall across the dark space and into the glow region.

Usually the glow discharge was started with approximately 30 mtorr of H_2 in the vessel. At this pressure and down to about 15 mtorr the glow became somewhat unsteady, and usually the glow discharge was purposely terminated above this pressure. At an applied voltage of 440 V the current was steady and constant down to pressure below 15 mtorr.

In those cases where the glow discharge was not uniform and steady, the experiment was terminated and restarted at a later time. When a nonuniformity was visually observed it generally occurred at one of the large diagnostic port openings.

The relationship between $\sigma k_r/D$ and the time evolution of the H_2 number density during the glow discharge is given by

$$\sigma k_r/D \propto \left(T_w \frac{A}{V} \frac{1}{K}\right)^2 \phi_0 \quad , \tag{1}$$

where K is the measured slope of the vessel pressure vs the square root of time from the beginning of the glow discharge, T_w is the wall temperature, A and V are the vacuum vessel area and volume, and ϕ_0 is the incident ionic hydrogen flux. The analytical derivation of Eq. (1) is given in ref. 7. The incident flux is determined directly from

$$\phi_0 = \frac{I}{eA} \frac{f}{1+\gamma} \quad , \tag{2}$$

where I is the discharge current, A is the vessel area, f is the average number of hydrogen nuclei per incident charge, and γ is the secondary electron coefficient.[8] Values of γ for H_2^+ and H^+ on H_2 gas–covered stainless steel are difficult to predict, but indications are that γ may be fairly low (i.e., less than 0.05) because of the low electron density in the absorbed hydrogen layer.[9] Previous measurements of the ion energy distributions for hydrogen glow discharges have shown that H_2^+ is the dominant ion at ≈85% while H^+ was found at a level of ≈15%; therefore an appropriate value for f is 1.75 (ref. 1). Using these two values yields

$$\phi_0 = 1.66 \frac{I}{eA} \quad . \tag{3}$$

For all measurements in this series, the discharge current was held constant at 0.87 A so that Eq. (1) becomes

$$\sigma k_r/D = 4.85 \times 10^{-15} \frac{1}{K^2} \text{ cm}^2 \quad ,$$

where the units of K are (mtorr/min$^{1/2}$).

Each measurement of $\sigma k_r/D$ was preceded by RGA measurements of masses 2, 14, 15, 16, 17, 18, 28, 40, and 44 and followed by a series of standardized tokamak discharges to determine a value for the radiated power.

4. RESULTS AND CONCLUSIONS

Data were taken during three separate time periods. The first period started November 11, 1985, and lasted four days; the second period started April 6, 1986, and lasted three days; and the third period started April 21, 1986, and lasted three

days. During the first period no radiated power measurements were made due to operational problems with the bolometer system. The second period was terminated on April 9, 1986, because of a serious leak in the vessel wall caused by interaction of the tokamak plasma with a weld joint. The initial indication of this leak occurred on April 8, 1986, with significant increases in the RGA signals of masses 16, 28, and 40, indicating that the leak initially occurred sometime on April 7. It should be noted that while the signals from masses 6 16, 28, and 40 increased, the mass 18 signal decreased. The third operating period was terminated due to the schedule of other experiments.

The first measurements of σk_r were made during a day of tokamak discharges (1) before discharges were begun, (2) during the noon break, and (3) after completion of discharges. The experimentally determined values of $\sigma k_r/D$ increased during the day from 1.2×10^{-15} to 2.3×10^{-15} cm^2. Similar data taken on succeeding days confirmed the result. Previous work has shown that $\sigma k_r/D$ increased with vacuum vessel cleanliness over long time periods (i.e., a period of days).[1] The present result indicates that tokamak discharges clean the vacuum vessel during a day's operation and can therefore lead to varying recycle conditions throughout a day.

Analysis of RGA data taken just before and after the vacuum leak leads to the conclusion that the vacuum vessel was initially in a relatively clean state and that oxygen entering through the leak was pumped, probably chemisorbed, by the walls, while nitrogen and argon were not pumped to any large extent by the walls.

As only a very limited amount of data on the radiated power, P_R, was obtained, no definitive conclusions can be drawn about a correlation between radiated power and σk_r. However, it appears that large changes in σk_r are not reflected as large changes in P_R.

Finally, it appears that operation with hydrogen glow discharges removes oxygen from the vacuum vessel wall via the interaction of hydrogen with oxygen to form water, which is subsequently pumped.[10]

REFERENCES

1. R. A. Langley and H. C. Howe, "Determination of the Global Recombination Rate Coefficient for the ISX-B Tokamak," *J. Nucl. Mater.* **121,** 237 (1984).

2. M. B. Lewis and K. Farrell, *Appl. Phys. Lett.* **36,** 819 (1980).

3. J. H. Austin and T. S. Elleman, *J. Nucl. Mater.* **43,** 119 (1972).

4. J. H. Austin, T. S. Elleman, and K. Verghese, *J. Nucl. Mater.* **48,** 307 (1973).

5. W. R. Wampler, *Appl. Phys. Lett.* **48,** 405 (1986).

6. J. Schivell, G. Reda, J. Lownance, and H. Hsuan, *Rev. Sci. Instrum.* **10,** 1527 (1982).

7. H. C. Howe and R. A. Langley, "Measurement of the Recombination Rate Coefficient of a Tokamak Vacuum Vessel Wall," *J. Vac. Sci. Technol.* **A1**(3), 1435 (1983).

8. Equation (2) was obtained from ref. 1, Eq. (2). In ref. 1 f was incorrectly defined; the correct definition is given in this text.

9. P. F. Little, p. 574 in *Electron-Emission: Gas Discharge,* ed. S. Flugge, vol. 21 of *Encyclopedia of Physics,* Springer-Verlag, Berlin, 1956.

10. This effect has also been observed on TFTR (F. Dylla, Princeton Plasma Physics Laboratory, Princeton, N.J., private communication, 1986).

ORNL/TM-10199
Dist. Category UC-20 f,g

INTERNAL DISTRIBUTION

1. L. A. Berry
2. R. E. Clausing
3. J. L. Dunlap
4. A. C. England
5. C. C. Klepper
6–10. R. A. Langley
11. P. K. Mioduszewski
12. J. A. Rome
13. M. J. Saltmarsh
14. J. Sheffield
15. J. E. Simpkins
16. T. Uckan
17. R. A. Zuhr
18–19. Laboratory Records Department
20. Laboratory Records, ORNL-RC
21. Document Reference Section
22. Central Research Library
23. Fusion Energy Division Library
24–25. Fusion Energy Division Publications Office
26. ORNL Patent Office

EXTERNAL DISTRIBUTION

27. Office of the Assistant Manager for Energy Research and Development, U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, TN 37831
28. J. D. Callen, Department of Nuclear Engineering, University of Wisconsin, Madison, WI 53706-1687
29. J. F. Clarke, Office of Fusion Energy, Office of Energy Research, ER-50 Germantown, U.S. Department of Energy, Washington, DC 20545
30. R. W. Conn, Department of Chemical, Nuclear, and Thermal Engineering, University of California, Los Angeles, CA 90024
31. S. O. Dean, Fusion Power Associates, 2 Professional Drive, Suite 248, Gaithersburg, MD 20879
32. H. K. Forsen, Bechtel Group, Inc., Research Engineering, P. O. Box 3965, San Francisco, CA 94105
33. J. R. Gilleland, GA Technologies, Inc., Fusion and Advanced Technology, P.O. Box 81608, San Diego, CA 92138
34. R. W. Gould, Department of Applied Physics, California Institute of Technology, Pasadena, CA 91125
35. R. A. Gross, Plasma Research Laboratory, Columbia University, New York, NY 10027
36. D. M. Meade, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08544

37. M. Roberts, International Programs, Office of Fusion Energy, Office of Energy Research, ER-52 Germantown, U.S. Department of Energy, Washington, DC 20545
38. W. M. Stacey, School of Nuclear Engineering and Health Physics, Georgia Institute of Technology, Atlanta, GA 30332
39. D. Steiner, Nuclear Engineering Department, NES Building, Tibbetts Avenue, Rensselaer Polytechnic Institute, Troy, NY 12181
40. R. Varma, Physical Research Laboratory, Navrangpura, Ahmedabad 380009, India
41. Bibliothek, Max-Planck Institut fur Plasmaphysik, D-8046 Garching, Federal Republic of Germany
42. Bibliothek, Institut fur Plasmaphysik, KFA, Postfach 1913, D-5170 Julich, Federal Republic of Germany
43. Bibliotheque, Centre des Recherches en Physique des Plasmas, 21 Avenue des Bains, 1007 Lausanne, Switzerland
44. F. Prevot, CEN/Cadarache, Departement de Recherches sur la Fusion Controlee, 13108 Saint-Paul-lez-Durance Cedex, France
45. Documentation S.I.G.N., Departement de la Physique du Plasma et de la Fusion Controlee, Centre d'Etudes Nucleaires, B.P. 85, Centre du Tri, 38041 Grenoble Cedex, France
46. Library, Culham Laboratory, UKAEA, Abingdon, Oxfordshire, OX14 3DB, England
47. Library, FOM-Instituut voor Plasma-Fysica, Rijnhuizen, Edisonbaan 14, 3439 MN Nieuwegein, The Netherlands
48. Library, Institute of Plasma Physics, Nagoya University, Nagoya 464, Japan
49. Library, International Centre for Theoretical Physics, Trieste, Italy
50. Library, Laboratorio Gas Ionizatti, CP 56, I-00044 Frascati, Rome, Italy
51. Library, Plasma Physics Laboratory, Kyoto University, Gokasho, Uji, Kyoto, Japan
52. Plasma Research Laboratory, Australian National University, P.O. Box 4, Canberra, A.C.T. 2000, Australia
53. Thermonuclear Library, Japan Atomic Energy Research Institute, Tokai Establishment, Tokai-mura, Naka-gun, Ibaraki-ken, Japan
54. R. A. Blanken, Experimental Plasma Research Branch, Division of Applied Plasma Physics, Office of Fusion Energy, Office of Energy Research, ER-542 Germantown, U.S. Department of Energy, Washington, DC 20545
55. K. Bol, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08544
56. R. A. E. Bolton, IREQ Hydro-Quebec Research Institute, 1862 Montee Ste.-Julie, Varennes, P.Q. JOL 2P0, Canada

57. D. H. Crandall, Experimental Plasma Research Branch, Division of Applied Plasma Physics, Office of Fusion Energy, Office of Energy Research, ER-542 Germantown, U.S. Department of Energy, Washington, DC 20545
58. R. L. Freeman, GA Technologies, Inc., P.O. Box 81608, San Diego, CA 92138
59. K. W. Gentle, RLM 11.222, Institute for Fusion Studies, University of Texas, Austin, TX 78712
60. R. J. Goldston, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08544
61. J. C. Hosea, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08544
62. S. W. Luke, Division of Confinement Systems, Office of Fusion Energy, Office of Energy Research, ER-55 Germantown, U.S. Department of Energy, Washington, DC 20545
63. E. Oktay, Division of Confinement Systems, Office of Fusion Energy, Office of Energy Research, ER-55 Germantown, U.S. Department of Energy, Washington, DC 20545
64. D. Overskei, GA Technologies, Inc., P.O. Box 81608, San Diego, CA 92138
65. R. R. Parker, Plasma Fusion Center, NW 16-288, Massachusetts Institute of Technology, Cambridge, MA 02139
66. W. L. Sadowski, Fusion Theory and Computer Services Branch, Division of Applied Plasma Physics, Office of Fusion Energy, Office of Energy Research, ER-541 Germantown, U.S. Department of Energy, Washington, DC 20545
67. J. W. Willis, Division of Confinement Systems, Office of Fusion Energy, Office of Energy Research, ER-55 Germantown, U.S. Department of Energy, Washington, DC 20545
68. A. P. Navarro, Division de Fusion, Junta de Energia Nuclear, Avenida Complutense 22, Madrid (3), Spain
69. Laboratory for Plasma and Fusion Studies, Department of Nuclear Engineering, Seoul National University, Shinrim-dong, Gwanak-ku, Seoul 151, Korea
70. H. F. Dylla, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08544
71. P. H. LaMarche, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08544

72–76. W. L. Rowan, Institute for Fusion Studies, University of Texas, Austin, TX 78712

77. R. V. Bravenec, Institute for Fusion Studies, University of Texas, Austin, TX 78712
78. K. Nelin, Institute for Fusion Studies, University of Texas, Austin, TX 78712

79. A. J. Wootton, Institute for Fusion Studies, University of Texas, Austin, TX 78712

80–271. Given distribution according to TIC-4500, Magnetic Fusion Energy (Distribution Category UC-20 f,g: Experimental Plasma Physics, Theoretical Plasma Physics)