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**Atomic Data for Controlled
Fusion Research, Revisions
and Additions to Sections D.1
Sputtering, D.5 Ion Reflection
from Surfaces, and D.6 Trapping**

MASTER

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**Atomic Data for Controlled Fusion Research,
Revisions and Additions to Sections D.1 Sputtering,
D.5 Ion Reflection from Surfaces, and D.6 Trapping**

E. W. Thomas
Georgia Institute of Technology

S. W. Hawthorne, F. W. Meyer, and B. J. Farmer
Controlled Fusion Atomic Data Center,
Physics Division, Oak Ridge National Laboratory

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Abstract

Data on sputtering, ion reflection from surfaces, and trapping have been collected, evaluated, and compiled into tables and complementary graphs for presentation as a revision and addition to Sections D.1, D.5, and D.6 of *Atomic Data for Controlled Fusion Research* (ORNL-5206, -5207), issued in 1977 as a compilation of atomic and molecular cross sections of interest to controlled thermonuclear research. Section D.1 presents, in self-contained data sets, sputtering coefficients as functions of various incident and target materials, temperatures, angles of incidence, and incident energies. Other relevant sputtering data are also compiled. Section D.5 includes data on particle and energy reflection coefficients as functions of impacting and target materials and angles of emergence or incidence. The energy distributions of neutrals plus ions are also covered in Section D.5. Contained in Section D.6 are data on trapping coefficients, trapped fluence, reemission rates, and replacement cross sections and efficiencies. Data sets are composed of tabular data, computer-generated graphs, estimates of the accuracy or confidence level of the data, bibliographical references, and explanatory notes. Bibliographical sources include reports, conference proceedings, and open literature publications from 1960 to the present. The explanatory notes present such information as experimental procedures and the preparation, composition, and form of materials used. A revised table of contents is provided.

Introduction

This publication presents revisions and additions to selected sections of the "Surface Collisions" portion of *Atomic Data for Controlled Fusion Research, Vol. II* (ORNL-5207), issued in 1977 in looseleaf notebook form to accommodate these planned revisions. The present report is designed to replace the original Sections D.1, D.5, and D.6. An updated Table of Contents is also provided, to be substituted for pages ix to xv of the parent compilation. Although the tables and graphs presented herein are entirely self-contained, it is suggested that they be inserted appropriately into the original binder. To disassemble this report, simply remove the screw posts.

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**Table of Contents for Sections C.6 - F
of ORNL-5207, Representing Revisions and Additions to
Sections D.1, D.5, and D.6**

The following Table of Contents appeared as pages ix - xv in ORNL-5207 (the second volume of *Atomic Data for Controlled Fusion Research*). The contents pages of Sections D.1, D.5, and D.6 have been updated to reflect the revisions and additions presented in this report. Aside from the correction of minor errors, the contents listings for Sections C.6, C.7, D.2 - D.4, and E.1 - F are identical to those given in ORNL-5207. They are reproduced here to facilitate the appropriate placement of the new table of contents for D.1, D.5, and D.6 into the original publication.

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Tables and Graphs for Section D.1
Sputtering

D.1.2

Sputtering of Be and BeO by H^+ , D^+ , and He^+

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	$H^+ + Be$	$D^+ + Be$	$He^+ + Be$	$D^+ + BeO$
1.0 E-01			4.0 E-02	
2.0 E-01			9.3 E-02	
3.0 E-01			1.4 E-01	3.3 E-02
5.0 E-01			2.2 E-01	4.4 E-02
7.0 E-01			2.9 E-01	4.9 E-02
1.0 E 00			3.5 E-01	5.2 E-02
2.0 E 00	1.4 E-02		3.1 E-01	4.2 E-02
3.0 E 00	1.5 E-02	3.0 E-02	2.2 E-01	3.0 E-02
4.0 E 00	1.6 E-02	1.9 E-02	1.5 E-01	
5.0 E 00		1.0 E-02	1.2 E-01	
7.0 E 00			7.6 E-02	
9.0 E 00			6.7 E-02	

References: $H^+ + Be$: C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964). $D^+ + Be$: G. K. Wehner, Report No. 3031 to USAEC (1966). $He^+ + Be$: H. Fetz and H. Oechsner, in 6th Int. Conf. on Ionization Phenomena in Gases (Paris, 1963), Vol. II, p. 39; D. Rosenberg and G. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, Report No. 3031 to USAEC (1966). $D^+ + BeO$: J. A. Borders et al., J. Nucl. Mater. 76 & 77, 168 (1978); G. K. Wehner, Report No. 3031 to USAEC (1966).Accuracy: See note (1) below.Notes: (1) The data for He^+ impact represent liberal interpolations between fragmentary data sets; they should be used with caution. Interpolation is from 6.0 E-01 to 5.0 E 00 keV.

(2) Borders et al. contend that in practical experiments the surface of bulk beryllium is always BeO: Thus they would conclude that all measurements to date are in fact on BeO.

(3) Most of the data for D^+ were taken with D_2^+ and D_3^+ ions; they are plotted here as though they were for D^+ of the same velocity.

D.1.3

SPUTTERING OF BE AND BEO
BY H^+ , D^+ , AND He^+

D.1.4

Sputtering of C (Graphite) by H^+ , D^+ , and He^+

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	He^+
1.0 E-01	7.8 E-03	1.7 E-02	
2.0 E-01	9.3 E-03	2.3 E-02	
3.0 E-01	9.3 E-03	2.4 E-02	7.6 E-02
5.0 E-01	8.4 E-03	2.3 E-02	8.5 E-02
7.0 E-01	7.7 E-03	2.0 E-02	8.7 E-02
1.0 E 00	6.9 E-03	1.8 E-02	8.8 E-02
2.0 E 00	5.0 E-03	1.2 E-02	9.0 E-02
3.0 E 00	3.8 E-03	9.3 E-03	8.7 E-02
5.0 E 00	3.0 E-03		7.8 E-02
7.0 E 00			6.8 E-02

Reference:

J. Bohdansky, H. L. Bay, and W. Ottenberger, J. Nucl. Mater. 76 & 77, 163 (1978).

Accuracy: Unspecified; also see note 1 below.

Notes: (1) The sputtering coefficient of carbon varies greatly from one form to another and between materials produced by different manufacturers. Values may differ by a factor of two from those shown above. [See R. Behrisch et al., J. Nucl. Mater. 60, 321 (1976); also J. A. Borders et al., J. Nucl. Mater. 76 & 77, 168 (1978).]

(2) Sputtering of carbon films differs somewhat from the data shown here; see J. N. Smith, C. H. Meyer, and J. K. Layton, J. Nucl. Mater. 67, 234 (1977).

(3) Some of these data were taken with H_2^+ and D_2^+ projectiles; they are plotted here as though they were for H^+ and D^+ of the same velocity.

D.1.5

SPUTTERING OF C (GRAPHITE)
BY H^+ , D^+ , AND He^+

D.1.6

Sputtering of C (Graphite) by H^+ and He^+ as a Function
of Temperature (normal incidence)

Temperature (°C)	Sputtering Coefficients, S (atoms/ion)				
	H^+ (0.67 keV)	H^+ (1.0 keV)	H^+ (2.0 keV)	H^+ (3.0 keV)	He^+ (6.0 keV)
2.0 E 01					9.1 E-02
2.0 E 02		2.0 E-03	4.0 E-03	2.0 E-03	
3.0 E 02		2.5 E-03	6.0 E-03	3.0 E-03	
4.0 E 02	1.3 E-02	8.0 E-03	7.0 E-03	5.0 E-03	
4.5 E 02	2.7 E-02	1.6 E-02	9.0 E-03	8.0 E-03	
5.0 E 02	4.3 E-02	3.0 E-02	1.3 E-02	1.2 E-02	
5.5 E 02	6.8 E-02	5.1 E-02	2.0 E-02	1.9 E-02	
6.0 E 02	8.0 E-02	7.0 E-02	3.2 E-02	3.0 E-02	9.9 E-02
6.5 E 02	8.1 E-02	7.8 E-02	6.0 E-02	3.0 E-02	
7.0 E 02	6.7 E-02	5.5 E-02	5.0 E-02	2.0 E-02	
7.5 E 02		4.0 E-02	3.5 E-02	1.2 E-02	

Reference:

J. Roth et al., J. Nucl. Mater. 63, 222 (1976).

Accuracy: $\pm 20\%$

Notes: (1) The sample material is pyrolytic graphite from Union Carbide with the surface cut parallel to the c-axis. It is well known that sputtering coefficients of carbon vary greatly depending on manufacturer, form of material, and orientation of the surface; variations of at least a factor of two are to be expected - see reference cited.

(2) Many other measurements of sputtering are available, generally for incident energies of 1 eV or less. For a complete listing see B. M. U. Scherzer et al., in Proc. Int. Symposium on Plasma Wall Interaction, Julich, 1976 (Pergamon Press, Oxford, 1977), p. 353.

(3) The data were taken using H_2^+ and H_3^+ projectiles; they are shown here as though they were for protons of the same velocity with S given as atoms ejected per nucleon incident.

D.1.7

SPUTTERING OF C (GRAPHITE)
BY H^+ AND He^+

D.1.8

Sputtering of Carbon by H^+ at Elevated Temperature

(normal incidence, 650°C)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)
1.0 E-02	7.6 E-02
2.0 E-02	8.8 E-02
3.0 E-02	9.9 E-02
5.0 E-02	1.08 E-01
1.0 E-01	1.14 E-01
2.0 E-01	1.14 E-01
3.0 E-01	1.10 E-01
5.0 E-01	1.00 E-01
1.0 E 00	7.7 E-02
2.0 E 00	5.4 E-02
3.0 E 00	4.4 E-02
5.0 E 00	3.1 E-02
1.0 E 01	1.9 E-02
2.0 E 01	1.2 E-02
3.0 E 01	8.0 E-03

Reference:

J. Roth et al., J. Nucl. Mater. 63, 222 (1976).

Accuracy: Unknown

Notes: (1) These data are based on experiment only for energies above 0.8 keV; at lower energies the data represent a theoretical estimate that has never been tested.

(2) The target material is pyrolytic graphite from Union Carbide with the surface cut parallel to the c-axis. It is well known that sputtering coefficients of carbon vary greatly with manufacturer, form of material, and orientation of the surface; variations of at least a factor of two are to be expected - see reference cited.

(3) The data were taken using H_2^+ and H_3^+ projectiles; they are plotted as though they were protons of the same velocity with S given as atoms ejected per nucleon incident.

D.1.9

SPUTTERING OF CARBON BY H^+
(NORMAL INCIDENCE, $650^{\circ}C$)

Sputtering of Ti by H^+ , D^+ , T^+ , and He^+

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	H^+	D^+	T^+	He^+
1.0 E-01			1.2 E-03	1.0 E-02
2.0 E-01	5.5 E-04	2.0 E-03	7.7 E-03	3.5 E-02
3.0 E-01	1.7 E-03	4.5 E-03	1.3 E-02	5.2 E-02
5.0 E-01	3.3 E-03	7.8 E-03	2.0 E-02	7.3 E-02
1.0 E 00	4.8 E-03	1.0 E-02	2.5 E-02	8.5 E-02
2.0 E 00	4.2 E-03	1.0 E-02	2.3 E-02	7.7 E-02
3.0 E 00	3.3 E-03	8.9 E-03	2.0 E-02	6.3 E-02
5.0 E 00	2.3 E-03	6.3 E-03	1.5 E-02	4.5 E-02
1.0 E 01	1.4 E-03	3.4 E-03	9.5 E-03	2.8 E-02

References:

B. M. U. Scherzer, R. Behrisch, and J. Roth, in Proc. Int. Symposium on Plasma Wall Interaction, Julich, 1976 (Pergamon Press, Oxford, 1977), p. 353; J. Bohdanský, J. Roth, and M. K. Sinha, in Proc. 9th Symposium on Fusion Technology, Garmisch (Pergamon Press, Oxford, 1976), p. 541; D. Rosenberg and G. K. Wehner, J. Appl. Phys. **33**, 1842 (1962).

Accuracy: H^+ , D^+ , T^+ see below; He^+ : $\pm 5\%$

Threshold Energies: Estimated to be 61 eV for H^+ , 31 eV for D^+ , 22 eV for T^+ , and 17 eV for He^+ .

Note: (1) The data reproduced here for H^+ , D^+ , and T^+ are largely an "estimate" by Scherzer et al., based in part on the fragmentary data of the other references cited. The limited experimental data differ from the values given here by up to a factor of two. These data should be used with caution.

D.1.11

SPUTTERING OF TI BY H^+ ,
 D^+ , T^+ , AND HE^+

D.1.12

Sputtering of Stainless Steel (Types 304 & 316)

and Fe by H^+ , D^+ , T^+ , and He^+

(Note: the sputtering coefficients for these three targets are essentially the same.)

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	H^+	D^+	T^+	He^+
1.0 E-01		3.3 E-03	1.1 E-02	
2.0 E-01	2.6 E-03	1.1 E-02	2.6 E-02	6.0 E-02
3.0 E-01	4.0 E-03	1.7 E-02	3.6 E-02	7.8 E-02
5.0 E-01	6.4 E-03	2.4 E-02	4.4 E-02	1.0 E-01
1.0 E 00	1.0 E-02	2.9 E-02	5.2 E-02	1.3 E-01
2.0 E 00	1.1 E-02	2.7 E-02		1.4 E-01
3.0 E 00	9.5 E-03	2.3 E-02		1.3 E-01
5.0 E 00	6.5 E-03	1.6 E-02		1.1 E-01
1.0 E 01	4.0 E-03	1.0 E-02		1.0 E-01

References:

J. Bohdanský, H. L. Bay, and J. Roth, Proc. 7th Int. Vacuum Congress and 3rd Int. Conf. on Solid Surfaces (Pergamon Press, Oxford, 1977), p. 1509;
 J. A. Borders, R. A. Langley, and K. L. Wilson, J. Nucl. Mater. **76 & 77**, 168 (1978); R. Behrisch et al., J. Nucl. Mater. **60**, 321 (1976);
 H. Von Seefeld et al., J. Nucl. Mater. **63**, 215 (1976).

Accuracy: $\pm 20\%$ or better, but see note below.

Threshold Energies: Estimated to be 65 eV for H^+ , 53 eV for D^+ , and 18 eV for He^+ .

Notes: (1) Some data were taken with H_2^+ and D_2^+ ; they are shown here as though they were for H^+ and D^+ of the same velocity.

(2) Measurements at the lower energies differ greatly between authors. At 200 eV for H^+ , published values range from 4×10^{-4} to 3.5×10^{-3} ; the data used here are by Bohdanský et al., and are probably the most accurate.

(3) The data for T are an estimate based on an empirical scaling law.

D.1.13

SPUTTERING OF SS AND FE BY H^+ ,
 D^+ , T^+ , AND HE^+

D.1.14

Sputtering of Stainless Steel (Type 316)
 by H^+ and He^+ as a Function of Temperature
 (normal incidence)

Temperature (°C)	Sputtering Coefficients, S (atoms/ion)			
	H^+ (0.66 keV)	H^+ (1 keV)	H^+ (6 keV)	He^+ (4 keV)
1.0 E 02	7.8 E-03	1.0 E-02	5.2 E-03	1.2 E-01
2.0 E 02	1.0 E-02		6.9 E-03	1.3 E-01
3.0 E 02	1.2 E-02		8.7 E-03	1.5 E-01
4.0 E 02	1.4 E-02		9.4 E-03	1.5 E-01
5.0 E 02	1.5 E-02		9.8 E-03	1.5 E-01
6.0 E 02	9.4 E-03	1.5 E-02	1.0 E-02	

Reference:

J. Roth, J. Bohdanský, and W. O. Hofer, in Proc. Int. Symposium on Plasma Wall Interaction, Julich, 1976 (Pergamon Press, Oxford, 1977), p. 309.
 (See note 1 below).

Accuracy: Unknown

Notes: (1) The data from the reference cited have been renormalized to the sputtering coefficients shown in Table D.1.12.

(2) Some data were taken using H_2^+ and are shown here as though they were for H^+ of the same velocity.

D.1.15

SPUTTERING OF SS (TYPE 316)
BY H^+ AND HE^+

D.1.16

Surface Composition Change Due to Sputtering
of Stainless Steel (Type 316) by Hydrogen Ions at 3-keV Energy
(normal incidence)

Dose (ions/cm ²)	Temperature (°C)	% Atomic Concentration Surface			
		<u>Fe</u>	<u>C</u>	<u>O</u>	<u>Other</u>
0.0 E 00	30	13	62	17	8
1.0 E 17	30	20	45	27	8
2.0 E 17	30	19	38	32	11
3.0 E 17	30	19	38	33	10
4.0 E 17	30	19	35	35	11
5.0 E 17	30	20	30	38	12
6.0 E 17	30	23	20	39	18
7.0 E 17	30	30	10	41	19
8.0 E 17	30	38	7	33	22
9.0 E 17	30	47	5	21	27
1.0 E 18	30	52	5	18	25

Reference:

R. Bastasz and G. J. Thomas, J. Nucl. Mater. 76 & 77, 183 (1978).

Notes: (1) These data should be taken only as showing a general behavior, not necessarily as representing behavior expected for other samples because:

(a) This particular target clearly carried carbonaceous and oxide layers, which are certainly a function of target preparation.

(b) The ion beam used was not mass analyzed and contained unknown fractions of H⁺, H₂⁺, and H₃⁺; H⁺ was expected to predominate.

D.1.17

SPUTTERING OF SS (TYPE 316)
BY 3-KEV H^+

D.1.18

Sputtering of Co by H^+ , D^+ , and He^+

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	He^+
1.0 E-01			1.0 E-02
2.0 E-01			4.1 E-02
3.0 E-01			7.5 E-02
5.0 E-01	3.3 E-03	2.1 E-02	1.5 E-01
1.0 E 00	6.6 E-03	2.5 E-02	
2.0 E 00	1.0 E-02	2.9 E-02	
3.0 E 00	1.1 E-02	3.0 E-02	
5.0 E 00	9.5 E-03	2.8 E-02	
7.0 E 00	7.8 E-03	2.3 E-02	

References:

C. R. Finfgeld, Report No. ORO-3557-15 to USAEC (1967); D. Rosenberg and G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

Accuracy: See note 1 below.

Notes: (1) The data for H^+ and D^+ should be treated with caution. The data points scatter by a factor of two about the line shown here, and other measurements from the reference used differ by a factor of two from more recent and more reliable experiments.

(2) Some data were taken using H_2^+ and D_2^+ ; they are plotted here as though the projectiles were for H^+ and D^+ of the same velocity.

D.1.19

SPUTTERING OF CO BY H^+ ,
 D^+ , AND He^+

D.1.20

Sputtering of Ni by H^+ , D^+ , T^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	H^+	D^+	T^+	${}^4He^+$
8.0 E-02	4.1 E-04	4.4 E-03	1.3 E-02	
1.0 E-01	8.8 E-04	6.3 E-03	1.7 E-02	5.3 E-02
2.0 E-01	4.1 E-03	1.8 E-02	3.8 E-02	9.3 E-02
3.0 E-01	7.0 E-03	2.7 E-02	5.2 E-02	1.2 E-01
5.0 E-01	1.1 E-02	3.7 E-02	6.7 E-02	1.5 E-01
1.0 E 00	1.4 E-02	4.2 E-02	8.5 E-02	1.8 E-01
2.0 E 00	1.4 E-02	4.0 E-02		2.0 E-01
3.0 E 00	1.3 E-02	3.5 E-02		2.0 E-01
5.0 E 00	1.2 E-02	2.8 E-02		1.9 E-01
8.0 E 00	8.5 E-03	2.3 E-02		1.7 E-01

Reference:

J. Bohdanský, H. L. Bay, and J. Roth, in Proc. 7th Int. Vacuum Congress and 3rd Int. Conf. on Solid Surfaces (Pergamon Press, Oxford, 1977), p. 1509.

Accuracy: $\pm 10\%$

Notes: (1) The data for T^+ are estimates based on an empirical scaling law.

(2) Some data were taken with H_2^+ and D_2^+ ; they are shown here as though they were for H^+ and D^+ of the same velocity.

D.1.21

SPUTTERING OF NI BY H^+ , D^+ ,
 T^+ , AND $^4He^+$

D.1.22

Sputtering of Ni-Based Alloy (Microfer and Inconel)

by H^+ , D^+ , T^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	H^+	D^+	T^+	${}^4He^+$
7.0 E-02		1.8 E-03	9.0 E-03	
1.0 E-01	5.2 E-04	5.3 E-03	1.7 E-02	
2.0 E-01	3.1 E-03	1.5 E-02	3.8 E-02	8.8 E-02
3.0 E-01	6.0 E-03	2.2 E-02	4.8 E-02	1.2 E-01
5.0 E-01	9.5 E-03	3.0 E-02	6.0 E-02	1.5 E-01
1.0 E 00	1.3 E-02	3.7 E-02	7.0 E-02	1.8 E-01
2.0 E 00	1.5 E-02	3.6 E-02		2.0 E-01
3.0 E 00	1.3 E-02	3.3 E-02		2.0 E-01
5.0 E 00	1.0 E-02	2.7 E-02		1.7 E-01
8.0 E 00	6.0 E-03	2.2 E-02		1.3 E-01

Reference:

J. Bohdansky, H. L. Bay, and J. Roth, in Proc. 7th Int. Vacuum Congress and 3rd Int. Conf. on Solid Surfaces (Pergamon Press, Oxford, 1977), p. 1509.

Accuracy: $\pm 10\%$

Notes: (1) The data for T^+ are estimates based on an empirical scaling law.

(2) Some data were taken with H_2^+ and D_2^+ ; they are shown here as though they were for H^+ and D^+ of the same velocity.

SPUTTERING OF NI ALLOY BY H^+ , D^+ ,
 D^+ , T^+ , AND $^4He^+$

D.1.24

Sputtering of Cu by H^+ , D^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	${}^4He^+$
1.0 E-01			4.5 E-02
2.0 E-01			1.1 E-01
3.0 E-01			1.6 E-01
5.0 E-01			2.4 E-01
1.0 E 00	4.1 E-02		3.4 E-01
2.0 E 00	3.8 E-02	9.2 E-02	3.6 E-01
3.0 E 00	3.5 E-02	9.0 E-02	3.4 E-01
5.0 E 00	2.7 E-02	8.0 E-02	3.0 E-01
1.0 E 01	1.6 E-02	6.2 E-02	2.3 E-01
2.0 E 01	9.0 E-03	4.0 E-02	1.8 E-01
3.0 E 01	6.2 E-03	3.0 E-02	1.5 E-01
5.0 E 01	3.7 E-03	1.9 E-02	
1.0 E 02	1.8 E-03	8.0 E-03	
2.0 E 02		3.1 E-03	
3.0 E 02		1.9 E-03	
5.0 E 02		1.1 E-03	
1.0 E 03		4.6 E-04	

References:

H^+ Impact: C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964); R. Weissman and R. Behrisch, Radiat. Eff. 19, 69 (1973).

D^+ Impact: G. K. Wehner, Report No. 3031 to USAEC (1966); M. Kaminsky, Adv. Mass Spectrom. 3, 69 (1966); O. C. Yonts et al., J. Appl. Phys. 31, 447 (1960).

He^+ Impact: C. E. KenKnight (see under H^+ above); O. C. Yonts (see under D^+ above).

Accuracy: Unknown

Notes: (1) The data shown here involve very liberal interpolations between fragmentary experimental results; they should therefore be used with caution. Interpolations are from 5.0 E 00 to 4.0 E 01 keV for H^+ ; 3.0 E 01 to 3.0 E 02 keV for D^+ ; and 5.0 E-01 to 1.0 E 01 keV for He^+ .

(2) Some data were taken with H_2^+ and D_2^+ ; they are plotted here as though they were for H^+ and D^+ of the same velocity.

(3) Data above 100 keV for D^+ are for the 100 crystal face of Cu; the remaining data are for polycrystalline Cu.

SPUTTERING OF CU BY H^+ ,
 D^+ , AND $^4He^+$

D.1.26

Sputtering of Nb by H^+ , D^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	${}^4He^+$
1.0 E-01			3.0 E-04
2.0 E-01		2.0 E-04	6.0 E-03
3.0 E-01		6.4 E-04	1.2 E-02
5.0 E-01	2.5 E-04	1.8 E-03	2.5 E-02
1.0 E 00	1.1 E-03	4.3 E-03	5.0 E-02
2.0 E 00	2.6 E-03	6.8 E-03	7.2 E-02
3.0 E 00	2.9 E-03	7.0 E-03	7.8 E-02
5.0 E 00	2.9 E-03	7.0 E-03	8.0 E-02
1.0 E 01	2.2 E-03	5.5 E-03	7.8 E-02
2.0 E 01	1.3 E-03	3.4 E-03	6.7 E-02
3.0 E 01	9.5 E-04	2.4 E-03	5.7 E-02
5.0 E 01	6.0 E-04	1.5 E-03	4.2 E-02
1.0 E 02	3.0 E-04	7.5 E-04	2.8 E-02

References:

B. M. U. Scherzer, R. Behrisch, and J. Roth, in Proc. Int. Symposium on Plasma Wall Interaction, Julich, 1976 (Pergamon Press, Oxford, 1977), p. 353; W. Eckstein, B. M. U. Scherzer, and H. Verbeek, Radiat. Eff. **18**, 135 (1973); A. J. Summers, N. J. Freeman, and N. R. Daly, J. Appl. Phys. **42**, 4774 (1971); D. Rosenberg and G. K. Wehner, J. Appl. Phys. **33**, 1842 (1962).

Accuracy: H^+ , D^+ see below; He^+ : $\pm 5\%$.

Threshold Energies: Estimated to be 180 eV for H^+ , 90 eV for D^+ , 61 eV for T^+ , and 46 eV for He^+ .

Note: (1) The data reproduced here for H^+ and D^+ are an "estimate" by Scherzer et al., based in part on the experimental data of the other cited references. The experimental data are fragmentary and contradictory: The values given here differ from certain experimental measurements by a factor of two; they should be used with caution.

D.1.27

SPUTTERING OF NB BY H^+ ,
 O^+ , AND $^4He^+$

D.1.28

Variation of Sputtering Coefficient with Angle of

Incidence (with Respect to Surface Normal)

for D^+ and ${}^4He^+$ on Nb

(room temperature)

Incidence Angle (degrees)	Sputtering Coefficients, S (atoms/ion)	
	D^+ (12.2 keV)	${}^4He^+$ (36.5 keV)
0.0 E 00	4.8 E-03	5.0 E-02
1.0 E 01	5.2 E-03	5.3 E-02
2.0 E 01	5.7 E-03	5.4 E-02
3.0 E 01	6.8 E-03	5.8 E-02
4.0 E 01	8.1 E-03	6.6 E-02
5.0 E 01	1.1 E-02	8.1 E-02
6.0 E 01	1.2 E-02	9.6 E-02

Reference:

A. J. Summers, N. J. Freeman, and N. R. Daly, J. Appl. Phys. 42, 4774 (1971). (See note 1 below).

Accuracy: Nominally $\pm 20\%$

Notes: (1) The data from the reference cited have been renormalized to the sputtering coefficients for normal incidence shown in Table D.1.26.

(2) Some of the data were taken with D_2^+ and are shown here as though they were for D^+ of the same velocity.

SPUTTERING VS. ANGLE OF INCIDENCE
FOR D^+ AND $^4He^+$ ON NB

D.1.30

Sputtering of Mo by H^+ , D^+ , T^+ , $^3He^+$, and $^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	H^+	D^+	T^+	$^3He^+$	$^4He^+$
1.5 E-01		3.0 E-04	1.4 E-03		1.1 E-02
3.0 E-01	1.0 E-04	1.8 E-03	5.5 E-03	1.3 E-02	2.4 E-02
5.0 E-01	4.3 E-04	3.5 E-03	8.5 E-03	1.8 E-02	3.6 E-02
1.0 E 00	1.1 E-03	6.2 E-03	1.2 E-02	2.7 E-02	4.8 E-02
2.0 E 00	2.0 E-03	7.8 E-03	1.4 E-02	3.1 E-02	5.2 E-02
4.0 E 00	2.1 E-03	7.7 E-03	1.3 E-02	3.0 E-02	4.9 E-02
8.0 E 00	1.7 E-03	4.8 E-03	1.1 E-02	2.5 E-02	4.2 E-02
9.0 E 00					4.1 E-02

Reference:H. J. Bay, J. Roth, and J. Bohdanský, J. Appl. Phys. 48, 4722 (1977).Accuracy: $\pm 20\%$ or better.Threshold Energies: Estimated to be 245 eV for H^+ , 120 eV for D^+ , and 55 eV for T^+ , $^3He^+$, and $^4He^+$.Notes: (1) The data for T are estimates based on an empirical scaling law.(2) Some data were taken with H_2^+ and D_2^+ ; they are shown here as though they were for H^+ and D^+ of the same velocity.

D.1.31

SPUTTERING OF MO BY H^+ , D^+ , T^+
 ${}^3\text{He}^+$, AND ${}^4\text{He}^+$

D.1.32

Sputtering of Ag by H^+ , D^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	${}^4He^+$
1.0 E 00	3.0 E-02	9.0 E-02	
2.0 E 00	3.1 E-02	9.0 E-02	3.6 E-01
3.0 E 00	3.2 E-02	9.2 E-02	4.6 E-01
5.0 E 00	3.2 E-02	9.2 E-02	4.7 E-01
7.0 E 00	3.1 E-02	9.0 E-02	4.4 E-01
1.0 E 01	3.1 E-02	7.5 E-02	4.0 E-01
1.2 E 01	3.1 E-02	6.5 E-02	3.8 E-01

Reference:F. Gronlund and W. J. Moore, J. Chem. Phys. 32, 1540 (1960).Accuracy: Unspecified

Note: (1) The data at 1 keV were taken with 2-keV H_2^+ and D_2^+ ; they are shown as though they were for H^+ and D^+ of the same velocity.

D.1.33

SPUTTERING OF AG BY H^+ ,
 D^+ , AND $^4He^+$

D.1.34

Sputtering of Ta by H^+ , D^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	${}^4He^+$
2.0 E-01			2.0 E-03
3.0 E-01			3.0 E-03
5.0 E-01		1.3 E-03	8.0 E-03
1.0 E 00		1.6 E-03	
2.0 E 00	6.3 E-04	1.9 E-03	
3.0 E 00	8.0 E-04	2.2 E-03	
5.0 E 00	1.0 E-03	2.8 E-03	
7.0 E 00	1.2 E-03	3.4 E-03	
1.0 E 01		4.1 E-03	
2.0 E 01		5.2 E-03	
3.0 E 01		5.4 E-03	

References:

M. I. Guseva, Radio Eng. and Electronic Physics No. 7, 1563 (1962);
 C. R. Finfgeld, Report No. ORO-3557-15 to USAEC (1967); D. Rosenberg and
 G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

Accuracy: See note 1 below.

Notes: (1) The data for H^+ and D^+ should be treated with caution. The experimental techniques employed were insensitive, and for other cases yield data which differ by a factor of two or more from measurements by other groups.

(2) Some data were taken using H_2^+ and D_2^+ ; they are plotted here as though the projectiles were H^+ and D^+ of the same velocity.

SPUTTERING OF TA BY H^+ ,
 D^+ , AND $^4He^+$

D.1.36

Sputtering of W by H^+ , D^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	${}^4He^+$
2.0 E-01			1.0 E-03
3.0 E-01			3.7 E-03
5.0 E-01		2.7 E-04	8.7 E-03
1.0 E 00	1.6 E-04	8.7 E-04	2.0 E-02
2.0 E 00	3.2 E-04	1.3 E-03	3.2 E-02
3.0 E 00	3.6 E-04	1.4 E-03	3.7 E-02
5.0 E 00	3.4 E-04	1.3 E-03	3.9 E-02
1.0 E 01	2.4 E-04	9.8 E-04	3.2 E-02

References:

B. M. U. Scherzer, R. Behrisch, and J. Roth, in Proc. Int. Symposium on Plasma Wall Interaction, Julich, 1976 (Pergamon Press, Oxford, 1977), p. 353; D. Rosenberg and G. K. Wehner, J. Appl. Phys. **33**, 1842 (1962); C. R. Finfgeld, ERDA Report ORO-3557-15 (1975).

Accuracy: H^+ , D^+ see below; He^+ : $\pm 5\%$.

Threshold Energies: Estimated to be 420 eV for H^+ , 310 eV for D^+ , and 110 eV for He^+ .

Note: (1) The data reproduced here for H^+ and D^+ are largely an "estimate" by Scherzer et al., based in part on fragmentary data from the other references cited. The limited experimental data differ from the values given here by up to a factor of two. These data should be used with caution.

D.1.37

SPUTTERING OF W BY H^+ ,
 D^+ , AND $^4HE^+$

D.1.38

Sputtering of Au by H^+ , D^+ , T^+ , $^3He^+$, and $^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	H^+	D^+	T^+	$^3He^+$	$^4He^+$
1.5 E-01		6.0 E-04	3.5 E-03	-	3.0 E-02
2.0 E-01		2.0 E-03	8.5 E-03	1.8 E-02	4.0 E-02
3.0 E-01		6.4 E-03	1.6 E-02	3.0 E-02	6.0 E-02
5.0 E-01	1.5 E-03	1.4 E-02	2.8 E-02	5.0 E-02	9.5 E-02
1.0 E 00	5.5 E-03	2.6 E-02	5.0 E-02	8.0 E-02	1.5 E-01
2.0 E 00	1.2 E-02	3.8 E-02	7.2 E-02	1.1 E-01	1.8 E-01
3.0 E 00	1.6 E-02	4.2 E-02	8.0 E-02	1.3 E-01	1.9 E-01
5.0 E 00	1.6 E-02	4.3 E-02	7.8 E-02	1.4 E-01	1.8 E-01
7.0 E 00	1.4 E-02	4.0 E-02	7.0 E-02	1.3 E-01	1.7 E-01

Reference:

H. L. Bay, J. Roth, and J. Bohdansky, J. Appl. Phys. 48, 4722 (1977).

Accuracy: $\pm 20\%$ or better.

Threshold Energies: Estimated to be 230 eV for H^+ , 135 eV for D^+ , and 55 eV for T^+ , $^3He^+$, and $^4He^+$.

Notes: (1) The data for T^+ are estimates based on an empirical scaling law.

(2) Some data were taken with H_2^+ and D_2^+ ; they are shown here as though they were for H^+ and D^+ of the same velocity.

SPUTTERING OF AU BY H^+ , D^+ , T^+
 ${}^3\text{He}^+$, AND ${}^4\text{He}^+$

D.1.40

Energy Distribution of Gold Atoms Sputtered

from Au by H^+ Impact

(normal incidence, room temperature)

Energy of Sputtered Particles (eV)	Flux of Sputtered Particles (arbitrary units)	
	H^+ (15-keV Impact)	H^+ (30-keV Impact)
5.0 E-01	8.0	6.5
1.0 E 00	13.0	9.5
2.0 E 00	14.0	10.0
3.0 E 00	13.0	9.0
5.0 E 00	10.0	6.5
1.0 E 01	5.0	3.4
2.0 E 01	2.0	1.3
3.0 E 01	1.0	0.6
5.0 E 01	0.4	0.25

Reference:

P. Hucks et al., J. Nucl. Mater. 76 & 77, 136 (1978).

Accuracy: $\pm 5\%$

Note: (1) The fluxes are in arbitrary units; the numbers for 15-keV and 30-keV impact have no relative significance.

D.1.41

ENERGY DISTRIBUTION OF AU SPUTTERED
FROM AU BY H^+ IMPACT

D.1.42

Sputtering of U by H^+ and He^+

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)	
	H^+	He^+
1.33 E 01	4.0 E-04	
2.0 E 01	4.2 E-04	
3.0 E 01	5.0 E-04	
5.0 E 01	4.9 E-04	1.4 E-02
7.0 E 01	3.3 E-04	1.3 E-02
1.0 E 02	2.4 E-04	1.0 E-02
1.2 E 02	2.3 E-04	

Reference:

R. Gregg and T. A. Tombrello, Radiat. Eff. 35, 243 (1978).

Accuracy: Unknown

Notes: (1) Considerable (factors of two) variation in yield was observed depending on bombardment dose and preliminary cleaning procedures. It is not clear that these data are for a clean surface of U.

(2) Some of the data were taken using H_2^+ and H_3^+ ; they are plotted here as though they were for H^+ of the same velocity.

D.1.43

SPUTTERING OF U
BY H^+ AND HE^+

Sputtering of H_2O from Thick Layers of Iceby Impact of H^+ , D^+ , He^+ , C^+ , and O^+

(normal incidence)

Energy (keV)	Sputtering Coefficients, S (molecules/ion)				
	H^+	D^+	He^+	$^{12}C^+$	$^{16}O^+$
5.0 E 00		1.1 E 02			
1.0 E 01		2.0 E 02			
2.0 E 01		3.2 E 02			
3.0 E 01		4.0 E 02			
3.5 E 01		4.3 E 02			
5.0 E 02	4.0 E-01				
1.5 E 03	2.0 E-01		1.0 E 01	5.2 E 02	6.4 E 02

References: D^+ Impact: G. M. McCracken, Vacuum 24, 463 (1975). H^+ , He^+ , C^+ , O^+ Impact: W. L. Brown et al., Phys. Rev. Lett. 40, 1027 (1978).

Notes: (1) These data are for the rate of erosion of thick condensed films held at low temperatures (77 K for the work with D^+ , 15 to 100 K for the other study). They do not represent the removal of thin adsorbed layers, a process which exhibits coefficients many orders of magnitude smaller. For this work the film thicknesses exceed the projectile range.

(2) It is not clear that the mechanism involved here represents a conventional sputtering process. The data are, however, functionally analogous to sputtering and are therefore included here.

SPUTTERING OF H_2O BY H^+ , D^+
 He^+ , C^+ , AND O^+

D.1.46

Sputtering of B_4C by H^+ , D^+ , and ${}^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	${}^4He^+$
1.0 E-01	8.8 E-03	2.9 E-02	
2.0 E-01	1.5 E-02	3.6 E-02	1.0 E-01
3.0 E-01	1.6 E-02	3.5 E-02	1.2 E-01
5.0 E-01	1.6 E-02	3.2 E-02	1.3 E-01
7.0 E-01	1.5 E-02	2.9 E-02	1.4 E-01
1.0 E 00	1.3 E-02	2.5 E-02	1.3 E-01
2.0 E 00	8.3 E-03	1.9 E-02	1.1 E-01
3.0 E 00	5.4 E-03	1.4 E-02	8.7 E-02
4.0 E 00	4.1 E-03	1.3 E-02	6.8 E-02

Reference:

J. Bohdanský, H. L. Bay, and W. Ottenberger, J. Nucl. Mater. 76 & 77, 163 (1978).

Accuracy: Unspecified

Note: (1) Some of these data were taken with H_2^+ , H_3^+ , D_2^+ , and D_3^+ projectiles; they are presented as though they were for H^+ and D^+ of the same velocity.

SPUTTERING OF B_4C BY
 H^+ , D^+ , AND $^4He^+$

Sputtering of SiC by H^+ , D^+ , and $^4He^+$

(The data are for normal incidence and room temperature. For elevated temperatures see note 1.)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	$^4He^+$
1.0 E-01		1.2 E-02	
2.0 E-01	5.0 E-03	2.2 E-02	8.5 E-02
3.0 E-01	8.8 E-03	2.6 E-02	1.0 E-01
5.0 E-01	1.3 E-02	3.0 E-02	1.3 E-01
7.0 E-01	1.4 E-02	3.1 E-02	1.4 E-01
1.0 E-00	1.3 E-02	3.0 E-02	1.5 E-01
2.0 E-00	9.8 E-03	2.6 E-02	1.5 E-01
3.0 E 00	6.8 E-03	2.2 E-02	1.2 E-01
5.0 E 00	4.0 E-03	1.6 E-02	8.8 E-02
7.0 E 00		1.1 E-02	6.3 E-02
8.0 E 00		1.0 E-02	

Reference:

J. Bohdanský, H. L. Bay, and W. Ottenberger, J. Nucl. Mater. 76 & 77, 163 (1978).

Accuracy: Unspecified

Notes: (1) J. Roth et al. [J. Nucl. Mater. 63, 222 (1976)] have measured the temperature dependence as follows for 0.33-keV H^+ .

room temperature	1.5×10^{-2}
535 °C	2.1×10^{-2}
610 °C	1.9×10^{-2}

Note that the room temperature value disagrees with the (more recent and more accurate) value given above.

(2) Some of these data were taken with H_2^+ , H_3^+ , D_2^+ , and D_3^+ projectiles; they are presented as though they were for H^+ and D^+ of the same velocity.

SPUTTERING OF SIC BY H^+ ,
 D^+ , AND $^4He^+$

D.1.50

Sputtering of TiC by H^+ , D^+ , and $^4He^+$

(normal incidence, room temperature)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	H^+	D^+	$^4He^+$
2.0 E-01		5.6 E-03	2.8 E-02
3.0 E-01	1.8 E-03	9.4 E-03	3.8 E-02
5.0 E-01	4.0 E-03	1.4 E-02	5.3 E-02
7.0 E-01	5.3 E-03	1.6 E-02	6.1 E-02
1.0 E 00	6.5 E-03	1.8 E-02	7.2 E-02
2.0 E 00	7.8 E-03	2.0 E-02	8.0 E-02
3.0 E 00	7.8 E-03	1.9 E-02	7.8 E-02
5.0 E 00	7.0 E-03	1.7 E-02	6.8 E-02
7.0 E 00		1.5 E-02	6.1 E-02
8.0 E 00		1.4 E-02	5.9 E-02

Reference:

J. Bohdanský, H. L. Bay, and W. Ottenberger, J. Nucl. Mater. 76 & 77, 163 (1978).

Accuracy: Unspecified

Note: (1) Some of these data were taken with H_2^+ , H_3^+ , D_2^+ , and D_3^+ projectiles; they are presented as though they were for H^+ and D^+ of the same velocity.

SPUTTERING OF TIC BY
H⁺, D⁺, AND ⁴HE⁺

Sputtering of Various Materials by H^+

(These data are an estimate only; see note 1 below.)

Data are for normal incidence and room temperature.)

Target Material		Sputtering Coefficients, S (atoms/ion)	
<u>Z</u>	<u>Metal</u>	<u>H^+ (2.33 keV)</u>	<u>H^+ (3.5 keV)</u>
4	Be	1.5 E-02	1.6 E-02
13	Al	1.4 E-02	1.3 E-02
22	Ti	7.7 E-03	5.5 E-03
23	V	8.8 E-03	9.1 E-03
26	Fe	1.0 E-02	1.2 E-02
27	Co	1.7 E-02	1.8 E-02
28	Ni	1.9 E-02	1.9 E-02
29	Cu	3.0 E-02	3.1 E-02
40	Zr	5.1 E-03	3.8 E-03
42	Mo	5.5 E-03	5.5 E-03
46	Pd	1.3 E-02	1.2 E-02
47	Ag	2.9 E-02	2.6 E-02
73	Ta	7.0 E-04	1.5 E-03
74	W	6.4 E-04	8.0 E-04
75	Re	2.2 E-03	2.9 E-03
77	Ir	4.0 E-03	7.0 E-03
78	Pt	5.6 E-03	6.1 E-03
79	Au	1.2 E-02	1.7 E-02

Reference:C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964).Accuracy: Quoted as $\pm 3\%$ by the authors, but see below.

Notes: (1) This set of data is presented to show the general trend of sputtering coefficients across the periodic table. For some elements there are more accurate data which are to be preferred; where available, these are shown elsewhere in this section. Absolute magnitudes of these data differ by a factor of two from more recent and more reliable measurements on certain elements.

(2) The data are in fact taken with H_2^+ and H_3^+ at energies of approximately 7 keV (actually between 6.9 and 7.5 keV). We have assumed (as did the original authors) that the data for H_2^+ when divided by two were an estimate for 3.5-keV H^+ and the data for H_3^+ when divided by three were an estimate for 2.33-keV H^+ .

SPUTTERING OF VARIOUS MATERIALS
BY H^+

D.1.54

Sputtering of Various Materials by He^+

(These data are an estimate only; see note 1 below.)

Data are for normal incidence and room temperature.)

Target Material		Sputtering Coefficients, S (atoms/ion)			
Z	Metal	He^+ (0.1 keV)	He^+ (0.2 keV)	He^+ (0.3 keV)	He^+ (0.6 keV)
4	Be	4.0 E-02	9.5 E-02	1.5 E-01	3.4 E-01
6	C	8.0 E-03	2.0 E-02	3.5 E-02	8.5 E-02
13	Al		5.0 E-03	8.0 E-03	2.1 E-02
14	Si	1.5 E-02	4.5 E-02	7.5 E-02	1.5 E-01
22	Ti	1.0 E-02	3.8 E-02	5.0 E-02	8.0 E-02
23	V	3.0 E-03	2.0 E-02	3.8 E-02	9.0 E-02
25	Cr	3.0 E-02	7.0 E-02	1.1 E-01	2.0 E-01
26	Fe	3.0 E-02	6.5 E-02	9.0 E-02	1.7 E-01
27	Co	1.0 E-02	4.2 E-02	7.5 E-02	1.5 E-01
28	Ni	2.8 E-02	6.0 E-02	9.5 E-02	1.8 E-01
29	Cu	4.5 E-02	1.1 E-01	1.6 E-01	2.7 E-01
32	Ge	1.0 E-02	3.0 E-02	5.0 E-02	8.0 E-02
40	Zr		4.0 E-03	1.3 E-02	2.5 E-02
41	Nb		5.0 E-03	1.0 E-02	3.0 E-02
42	Mo	1.0 E-03	5.0 E-03	1.5 E-02	4.0 E-02
45	Rh	4.0 E-03	1.5 E-02	3.0 E-02	6.5 E-02
46	Pd	2.0 E-02	5.7 E-02	8.2 E-02	1.6 E-01
47	Ag	3.0 E-02	8.2 E-02	1.2 E-01	2.3 E-01
72	Hf			2.0 E-03	1.0 E-02
73	Ta		2.0 E-03	3.0 E-03	1.2 E-02
74	W		1.0 E-03	4.0 E-03	8.0 E-03
76	Os	5.0 E-04	2.0 E-03	4.0 E-03	2.2 E-02
77	Ir		1.0 E-03	3.0 E-03	1.0 E-02
78	Pt		4.0 E-03	1.0 E-02	3.5 E-02
79	Au		2.0 E-02	3.5 E-02	8.0 E-02
90	Th		5.0 E-04		2.0 E-03
92	U		2.0 E-03	4.0 E-03	1.3 E-02

Reference:D. Rosenberg and G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).Accuracy: See note 1 below.

Note: (1) These data are presented to show the general trend of sputtering coefficients across the periodic table. They were obtained using ions from a plasma and are in fact the sputtering coefficient divided by $1 + \gamma$ where γ is the secondary electron emission coefficient of the target; γ may be of the order 0.3 so that actual sputtering coefficients should be about 30% higher than shown here. For some targets more reliable direct measurements are available and are reproduced elsewhere in this section; where available, these other data should be used.

D.1.55

SPUTTERING OF VARIOUS MATERIALS BY He^+

Self-Sputtering Coefficients for

Al, Ni, Cu, Co, and Nb

(normal incidence, room temperature)

Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)				
	<u>Al</u>	<u>Ni</u>	<u>Cu</u>	<u>Co</u>	<u>Nb</u>
2.0 E-02	1.6 E-02				
3.0 E-02	2.5 E-02				
5.0 E-02	5.0 E-02		1.5 E-01		
7.0 E-02	9.2 E-02	6.3 E-02	2.7 E-01		
1.0 E-01	1.7 E-01	1.8 E-01	4.7 E-01	1.4 E-01	
2.0 E-01	4.7 E-01	4.6 E-01	1.1 E 00	2.4 E-01	
3.0 E-01	7.0 E-01	7.2 E-01	1.7 E 00	3.2 E-01	
5.0 E-01	1.0 E 00	1.2 E 00	2.4 E 00	5.0 E-01	
1.0 E 00	1.3 E 00	1.8 E 00	3.5 E 00	9.3 E-01	
2.0 E 00	1.2 E 00	2.5 E 00	4.4 E 00		
3.0 E 00	1.1 E 00	3.0 E 00	5.0 E 00		
5.0 E 00	9.4 E-01		5.8 E 00		
1.0 E 01	7.0 E-01		6.9 E 00		2.5 E 00
2.0 E 01	5.5 E-01		7.8 E 00		2.4 E 00
3.0 E 01	4.8 E-01		8.1 E 00		3.0 E 00
5.0 E 01	3.8 E-01		8.2 E 00		3.5 E 00
8.0 E 01					4.0 E 00

References:

Al⁺ + Al: W. H. Hayward and A. R. Wolter, J. Appl. Phys. 40, 2911 (1969);
O. Almen and G. Bruce, Nucl. Instrum. Meth. 11, 279 (1961).

Ni⁺ + Ni: E. Hecht1, H. L. Bay, and J. Bohdanský, Appl. Phys. (Germany) 16, 147 (1978).

Cu⁺ + Cu: W. H. Hayward and A. R. Wolter, J. Appl. Phys. 40, 2911 (1969);
O. Almen and G. Bruce, Nucl. Instrum. Meth. 11, 279 (1961).

Nb⁺ + Nb: A. J. Summers, N. J. Freeman, and N. R. Daly, J. Appl. Phys. 42,
4774 (1971).

Co⁺ + Co: A. Fontell and E. Arminen, Can. J. Phys. 47, 2405 (1969).

Accuracy: Unknown

Note: (1) The data for Al involve a liberal interpolation from 5.0 E-01
to 4.0 E 01 keV energy.

SELF-SPUTTERING COEFFICIENTS FOR
AL, NI, CU, CO, AND NB

D.1.58

Self-Sputtering Coefficients for

Ag, Au, Cr, and Zn

(normal incidence, room temperature)

Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)			
	<u>Ag</u>	<u>Au</u>	<u>Cr</u>	<u>Zn</u>
3.0 E-02	1.1 E-01	3.3 E-02	2.4 E-02	1.7 E-01
5.0 E-02	4.0 E-01	1.2 E-01	5.0 E-02	4.4 E-01
7.0 E-02	5.6 E-01	2.9 E-01	1.0 E-01	5.5 E-01
1.0 E-01	8.2 E-01	6.0 E-01	2.0 E-01	6.4 E-01
2.0 E-01	1.5 E 00	1.4 E 00	4.6 E-01	7.2 E-01
3.0 E-01	2.2 E 00	2.0 E 00	7.0 E-01	
5.0 E-01	3.2 E 00	2.8 E 00	1.1 E 00	
1.0 E 00	5.0 E 00	4.5 E 00		
2.0 E 00	7.3 E 00	6.8 E 00		
3.0 E 00	9.0 E 00	8.7 E 00		
5.0 E 00	1.1 E 01	1.2 E 01		
1.0 E 01	1.4 E 01	1.8 E 01		
2.0 E 01	2.1 E 01	2.7 E 01		
3.0 E 01	2.6 E 01	3.4 E 01		
5.0 E 01	3.5 E 01	4.3 E 01		
1.0 E 02	3.8 E 01			
2.0 E 02	3.6 E 01			
3.0 E 02	3.4 E 01			
5.0 E 02	3.3 E 01			

References:

- Ag⁺ + Ag: H. Andersen and H. L. Bay, Radiat. Eff. 19, 139 (1973);
W. H. Hayward and A. R. Wolter, J. Appl. Phys. 40, 2911 (1969).
Au⁺ + Au: W. H. Hayward and A. R. Wolter, J. Appl. Phys. 40, 2911 (1969);
E. P. Eernisse, Appl. Phys. Lett. 29, 14 (1976).
Cr⁺ + Cr: W. H. Hayward (see above).
Zn⁺ + Zn: A. Fontell and E. Arminen, Can. J. Phys. 47, 2405 (1969).

Accuracy: Unknown

Note: (1) The data for Au involve a liberal interpolation from 4.0 E-01 to 4.0 E 01 keV energy.

SELF-SPUTTERING COEFFICIENTS FOR
AG, AU, CR, AND ZN

D.1.60

Coefficients for Self-Sputtering of Various

Materials at 45-keV Energy

(normal incidence, room temperature)

Projectile	Target	Z	Sputtering Coefficients, S (atoms/ion at 45 keV)
C ⁺	C	6	4.4 E-01
Mg ⁺	Mg	12	5.6 E-01
Al ⁺	Al	13	5.0 E-01
Si ⁺	Si	14	6.0 E-02
Ca ⁺	Ca	20	6.9 E-01
Sc ⁺	Sc	21	3.7 E-01
Ti ⁺	Ti	22	2.5 E-01
V ⁺	V	23	7.5 E-01
Cr ⁺	Cr	24	1.0 E 00
Fe ⁺	Fe	26	2.8 E 00
Co ⁺	Co	27	3.5 E 00
Ni ⁺	Ni	28	3.8 E 00
Cu ⁺	Cu	29	8.1 E 00
Zn ⁺	Zn	30	2.2 E 01
Zr ⁺	Zr	40	1.3 E 00
Nb ⁺	Nb	41	1.3 E 00
Mo ⁺	Mo	42	2.2 E 00
Pd ⁺	Pd	46	8.1 E 00
Ag ⁺	Ag	47	2.7 E 01
Cd ⁺	Cd	48	8.4 E 01
In ⁺	In	49	1.4 E 01
Sn ⁺	Sn	50	9.5 E 00
Ta ⁺	Ta	73	3.2 E 00
W ⁺	W	74	4.9 E 00
Pt ⁺	Pt	78	1.4 E 01
Au ⁺	Au	79	5.2 E 01
Pb ⁺	Pb	82	5.3 E 01

Reference:O. Almen and G. Bruce, Nucl. Instrum. Meth. 11, 279 (1961).Accuracy: Unknown

Note: (1) This set of data is presented to show the general trend of self-sputtering coefficients across the periodic table. For some cases there are more accurate data which are to be preferred; where available, they are shown in the preceding two sets of tables and graphs.

COEFFICIENTS FOR SELF-SPUTTERING
OF VARIOUS MATERIALS AT 45 KEV

Cross Sections for Sputtering Adsorbed H and O from

W and Mo by H^+ and He^+ Impact

(room temperature, for angle of incidence see note 3)

Explanation: When an adsorbed layer of density N_0 (adsorbed molecules or atoms cm^{-2}) is bombarded by a projectile beam of density J_0 (ions $cm^{-2} sec^{-1}$), the adsorbate density N_t at time t is given by $N_t = N_0 \exp - J_0 \sigma t$. The cross section for adsorbate sputtering is σ .

Energy (keV)	Projectile Adsorbate Substrate	Sputtering Cross Section (cm^2)		
		$^3He^+$ H W(100)	$^4He^+$ O Mo(poly)	H^+ O Mo(poly)
8.0 E-01		5.0 E-16		
1.0 E 00		6.0 E-16		
1.5 E 00		1.1 E-15	1.6 E-17	
1.8 E 00		1.2 E-15		
6.7 E 00				3.5 E-18
1.0 E 01				3.4 E-18
2.0 E 01				1.6 E-18

References:

E. Taglauer and W. Heiland, J. Nucl. Mater. 76 & 77, 328 (1978); K. Akaishi et al., J. Nucl. Mater. 76 & 77, 378 (1978); E. O. Rausch et al., J. Appl. Phys. 48, 4347 (1977).

Accuracy: Unknown. The published data scatter by up to $\pm 50\%$ about the line reproduced here.

Notes: (1) The symbol (100) after the substrate symbol indicates that the target was the (100) face of a single crystal.

(2) The symbol (poly) after the substrate symbol indicates that the target was polycrystalline.

(3) The incidence angles were as follows:

Substrate W(100) - 60° measured from the surface normal.

$^4He^+$ on substrate Mo(poly) - normal to the surface.

H^+ on substrate Mo(poly) - 60° to the surface normal.

(4) The data for H^+ removal of O from Mo are deduced from sputtering coefficients.

D.1.63

SPUTTERING CROSS SECTIONS FOR H^+
AND HE^+ ON W AND MO

Cross Sections for Sputtering Adsorbed O, CO,

and S from a Ni Surface by He⁺ Impact

(room temperature; for angle of incidence, see note 3)

Explanation: When an adsorbed layer of density N_0 (adsorbate molecules or atoms cm^{-2}) is bombarded by a projectile beam of density J_0 (ions $\text{cm}^{-2} \text{sec}^{-1}$), the adsorbate density N_t at time t is given by $N_t = N_0 \exp - J_0 \sigma t$. The cross section for adsorbate sputtering is σ .

Energy (keV)	Projectile Adsorbate Substrate	Sputtering Cross Section (cm^2)			
		³ He ⁺ O Ni(110)	⁴ He ⁺ CO Ni(110)	⁴ He ⁺ S Ni(110)	⁴ He ⁺ CO Ni(poly)
4.0 E-01			4.0 E-15		
5.0 E-01		7.0 E-17	5.4 E-15		
7.5 E-01		6.4 E-17	9.4 E-15		
1.0 E 00		5.7 E-17	1.3 E-14		
1.2 E 00		5.1 E-17	1.4 E-14		
1.5 E 00		4.1 E-17			
2.0 E 00					2.6 E-15

References:

E. Taglauer, G. Marin, and W. Heiland, in Proc. Int. Symposium on Plasma Wall Interaction, Julich, 1976 (Pergamon Press, Oxford, 1977) p. 301;
 E. Taglauer, U. Beitatz, G. Marin, and W. Heiland, J. Nucl. Mater. 63, 193 (1976); R. J. MacDonald, W. Heiland, and E. Taglauer, Appl. Phys. Lett. 33, 576 (1978).

Accuracy: Unknown. The published data scatter by up to $\pm 50\%$ about the line reproduced here.

Notes: (1) The symbol (110) after substrate symbol indicates that the target surface was the (110) plane of a single crystal.

(2) The symbol (poly) after substrate symbol indicates that the target was polycrystalline.

(3) The incidence angle for the three studies with Ni(110) was 60° measured from the surface normal; for the study with Ni(poly) the corresponding angle was 45° .

D.1.65

SPUTTERING CROSS SECTIONS FOR
HE⁺ ON NI

Neutron Sputtering of V, Co, Nb, and Au

(Materials are polycrystalline.

Temperatures are room temperature.)

Material	Neutron Energy (MeV)	Upper Bound to Sputtering Coefficients (atoms/neutron)	Principal Reference
V	14.8	$< 5 \times 10^{-5}$	5
Co	16 (avg)	$< 2 \times 10^{-5}$	1
Nb	14.8	$< 10^{-4}$ "certain"	2, 3
		$< 5 \times 10^{-5}$ "most likely"	2, 3
Au	14.8	$< 4 \times 10^{-5}$	1, 4

References:

- (1) L. H. Jenkins et al., J. Nucl. Mater. 63, 438 (1976).
- (2) R. Behrisch et al., J. Appl. Phys. 48, 3914 (1977).
- (3) O. K. Harling et al., J. Appl. Phys. 48, 4315 (1977).
- (4) O. K. Harling et al., J. Nucl. Mater. 63, 422 (1976).
- (5) M. Kaminsky and S. K. Das, J. Nucl. Mater. 66, 333 (1977).

Accuracy: Unknown

Notes: (1) In most neutron sputtering measurements the quoted results are an upper bound set by the limits of detectability. Numerous earlier measurements exist (not quoted here but largely cited in references 2, 3, and 4) giving larger upper bounds reflecting poorer detection sensitivity.

(2) All quoted measurements involve removal of less than one monolayer of a surface covered with an unknown amount of oxide; consequently, the data may not be representative of bulk metal.

(3) Early reports of "chunk" ejection appear to be related to the method of target preparation and are not reported by most workers; see reference 2.

(4) For a theoretical estimate see R. Behrisch, Nucl. Instrum. Meth. 132, 293 (1976).

Tables and Graphs for Section D.5

Ion Reflection from Surfaces

Introductory Notes

- (1) Definitions of particle reflection coefficient R_N and energy reflection coefficient R_E are as follows: A projectile beam of energy E_0 falls on a target, and a fraction $r(E_0, E) dE$ is scattered back with energies in the interval $E \rightarrow E+dE$ (integrated over all emergent angles).

$$R_N = \int_0^{E_0} r(E_0, E) dE$$

represents the ratio of the total backscattered flux to the incident flux; this is termed the particle reflection coefficient.

$$R_E = \frac{1}{E_0} \int_0^{E_0} E r(E_0, E) dE$$

represents the fraction of the incident energy that is carried away by the outgoing particles; this is termed the energy reflection coefficient and is generally measured directly. [See, for example, H. H. Andersen et al., J. Appl. Phys. 47, 13 (1976).]

- (2) It has generally been found that particle or energy reflection coefficients (R_N and R_E) are the same for most projectile-target combinations when plotted as a function of "reduced energy" ϵ , where

$$\epsilon = \frac{32.5 A_2 E}{(Z_1^{2/3} + Z_2^{2/3})^{1/2} (A_1 + A_2) Z_1 Z_2}$$

Here Z_1 and Z_2 are the atomic numbers of the projectile and target; A_1 and A_2 are the masses of the projectile and target; and E is the projectile energy (in keV). [See, for example, J. Schou et al., J. Nucl. Mater. 76 & 77, 359 (1978).] This equation may be used to reliably estimate R_N or R_E for D and T using available data for H or He.

D.5.3

- (3) The scattered particles at some recoil energy E include a flux I^+ of H^+ , a flux I^- of H^- , and a flux I^0 of H^0 . The "fraction of particles charged" is the ratio $\frac{I^+ + I^-}{I^+ + I^- + I^0}$.

The positive fraction is $\frac{I^+}{I^+ + I^- + I^0}$,

the negative fraction is $\frac{I^-}{I^+ + I^- + I^0}$,

and the neutral fraction is $\frac{I^0}{I^+ + I^- + I^0}$.

In all cases the fractions are determined at a specified recoil energy E . The fraction is dependent only on the recoil energy and is not a function of the original incoming projectile energy.

D.5.4

Particle Reflection Coefficient (R_N) for H^+ and D^+ on C

and Energy Reflection Coefficient (R_E) for H^+ on Al

(normal incidence, room temperature)

Energy (keV)	Particle and Energy Reflection Coefficients, R_N and R_E		
	R_N (H^+ on C)	R_N (D^+ on C)	R_E (H^+ on Al)
1.5 E 00	9.2 E-02		
2.0 E 00	6.5 E-02	6.5 E-02	
3.0 E 00	3.7 E-02	3.7 E-02	
5.0 E 00	1.6 E-02	1.6 E-02	
7.0 E 00	8.4 E-03	8.4 E-03	
1.0 E 01	4.2 E-03		4.5 E-03
1.5 E 01			3.1 E-03
2.0 E 01			2.0 E-03
2.5 E 01			1.1 E-03

References:

C target: W. Eckstein and H. Verbeek, J. Nucl. Mater. 76 & 77, 365 (1978).

Al target: G. Sidenius and T. Lenskjær, Nucl. Instrum. Meth. 132, 673 (1976).

Accuracy: Unknown

Notes: (1) For definitions of R_N and R_E see note 1 at the beginning of this section.

(2) To estimate R_N and R_E for D^+ or T^+ see note 2 at the beginning of this section.

D.5.5

R_N AND R_E FOR
 H^+ AND D^+ ON C AND AL

D.5.6

Particle Reflection Coefficient (R_N) for H^+ , D^+ , and He^+ on Ti, TiH_2 , and TiD_2

(normal incidence, room temperature)

Energy (keV)	Particle Reflection Coefficient, R_N				
	H^+ on Ti	D^+ on Ti	He^+ on Ti	H^+ on TiH_2	D^+ on TiD_2
6.0 E-01		1.8 E-01			
1.0 E 00		1.8 E-01			
2.0 E 00		1.5 E-01			
2.5 E 00	1.2 E-01	1.4 E-01	1.6 E-01	1.0 E-01	1.1 E-01
3.0 E 00		1.2 E-01			
5.0 E 00	7.0 E-02	8.4 E-02	1.2 E-01	5.8 E-02	6.9 E-02
7.0 E 00		6.6 E-02	1.0 E-01		
1.0 E 01		5.2 E-02			

Reference:W. Eckstein and H. Verbeek, J. Nucl. Mater. 76 & 77, 365 (1978).Accuracy: UnknownNotes: (1) For definition of R_N see note 1 at the beginning of this section.(2) To estimate R_N for T^+ see note 2 at the beginning of this section.

D.5.7

R_N FOR H^+ , He^+
AND He^+ ON Ti , TiH_2 AND TiO_2

D.5.8

Particle and Energy Reflection Coefficients (R_N and R_E)for H^+ on Stainless Steel and Ni

(normal incidence, room temperature)

Energy (keV)	Particle and Energy Reflection Coefficients, R_N and R_E			
	R_N (H^+ +SS)	R_E (H^+ +SS)	R_N (H^+ +Ni)	R_N (D^+ +Ni)
1.5 E 00			1.6 E-01	
2.5 E 00	1.8 E-01		1.3 E-01	1.7 E-01
3.0 E 00	1.7 E-01		1.2 E-01	1.6 E-01
5.0 E 00	1.2 E-01		8.8 E-02	1.2 E-01
7.0 E 00	9.6 E-02		6.8 E-02	1.0 E-01
1.0 E 01	7.0 E-02	1.6 E-02	5.1 E-02	8.0 E-02
1.5 E 01	5.0 E-02	1.0 E-02	3.5 E-02	6.0 E-02
2.0 E 01		7.0 E-03		
3.0 E 01		4.0 E-03		

References: R_N , H^+ + SS: W. Eckstein et al., J. Nucl. Mater. 63, 199 (1976). R_E , H^+ + SS: G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976). R_N , H^+ & D^+ + Ni: W. Eckstein and H. Verbeek, J. Nucl. Mater. 76 & 77, 365 (1978).Accuracy: Unknown. Scatter in the data is sometimes as high as $\pm 15\%$.Notes: (1) For definition of R_N and R_E see note 1 at the beginning of this section.(2) In principle it is possible to estimate R_N and R_E for D^+ and T^+ from data for H^+ using the rule given in note 2 at the beginning of this section. However, it is noted that the data for H^+ and D^+ impact on Ni, shown above, do not in fact follow this generally accepted rule; the reason is unknown.

D.5.9

R_N AND R_E FOR H^+ ON STAINLESS STEEL AND NI

D.5.10

Particle and Energy Reflection Coefficients (R_N and R_E)for H^+ and He^+ Impact on Cu

(normal incidence, room temperature)

Energy (keV)	Particle and Energy Reflection Coefficients, R_N and R_E		
	R_N H^+	R_E H^+	R_E He^+
5.0 E 00	1.5 E-01	3.5 E-02	8.5 E-02
7.0 E 00	1.2 E-01	2.8 E-02	6.0 E-02
1.0 E 01	8.8 E-02	2.1 E-02	3.8 E-02
2.0 E 01	5.0 E-02	1.0 E-02	
3.0 E 01		6.0 E-03	

References:

R_N for H^+ : G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976).

R_E for H^+ : H. H. Andersen et al., J. Appl. Phys. 47, 13 (1976).

R_E for He^+ : J. Schou et al., J. Nucl. Mater. 76 & 77, 359 (1978).

Accuracy: $\pm 10\%$

Notes: (1) For definitions of R_N and R_E see note 1 at the beginning of this section.

(2) To estimate R_N and R_E for D^+ or T^+ see note 2 at the beginning of this section.

D.5.11

R_N AND R_E FOR H^+
AND HE^+ IMPACT ON CU

Particle and Energy Reflection Coefficients (R_N and R_E)for H^+ on Nb

(normal incidence, room temperature)

Energy (keV)	Particle and Energy Reflection Coefficients, R_N and R_E		
	R_N (H^+ +Nb)	R_E (H^+ +Nb)	R_N (D^+ +Nb)
1.3 E 00		8.4 E-02	
1.5 E 00		8.2 E-02	
2.0 E 00		7.7 E-02	
3.0 E 00		6.5 E-02	
5.0 E 00	1.0 E-01	4.5 E-02	2.3 E-01
7.0 E 00	9.0 E-02	3.4 E-02	
1.0 E 01	7.7 E-02	2.3 E-02	1.7 E-01
2.0 E 01	5.0 E-02	1.0 E-02	
2.5 E 01	4.0 E-02	8.0 E-03	
3.0 E 01		6.2 E-03	
4.0 E 01		4.2 E-03	

References:

R_N , H^+ + Nb: G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976); W. Eckstein et al., J. Nucl. Mater. 63, 199 (1976).

R_E , H^+ + Nb: G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976); H. Sorensen, in Proc. Int. Symposium on Plasma Wall Interaction Julich, 1976 (Pergamon Press, Oxford, 1977), p. 437.

R_N , D^+ + Nb: W. Eckstein et al. (see above).

Accuracy: Unknown. In some cases data points scatter by 30% from the lines shown here.

Notes: (1) For definitions of R_N and R_E see note 1 at the beginning of this section.

(2) In principle it is possible to estimate R_N and R_E for D^+ and T^+ from data for H^+ using the rule given in note 2 at the beginning of this section. However, it is noted that the data for H^+ and D^+ impact on Nb shown here do not in fact follow this generally accepted rule; the reason is unknown.

D.5.13

R_N AND R_E
FOR H^+ ON NB

D.5.14

Particle Reflection Coefficient (R_R) as a
Function of Emergence Angle, for 15.4-keV H^+ on Nb
(normal incidence, room temperature)

Scattering Angle (degrees)	Particle Reflection Coefficient, R_R - Relative Values (incident energy, 15.4 keV)
0.0 E 00	0.0 E 00
1.0 E 01	5.2 E 00
2.0 E 01	8.7 E 00
3.0 E 01	1.2 E 01
4.0 E 01	1.3 E 01
5.0 E 01	1.3 E 01
6.0 E 01	1.2 E 01
7.0 E 01	8.3 E 00
8.0 E 01	4.0 E 00
9.0 E 01	0.0 E 00

Reference:

H. Verbeek, J. Appl. Phys. 46, 2981 (1975).

Accuracy: Unknown

Notes: (1) The data are relative only.

(2) The data are scattering coefficients integrated over azimuthal angle.

(3) These data fit very well the equation $A \cos\beta \sin\beta$ where A is a constant and β is scattering angle.

(4) Only the data at or above 30° angle are measured; the data below 30° are an extrapolation.

(5) The scattering angle β is measured from the surface normal.

D.5.15

R_N VS. EMERGENCE ANGLE
FOR 15.4-KEV H^+ ON NB

Particle and Energy Reflection Coefficients

(R_N and R_E) for H⁺, D⁺, and He⁺ on Mo

(normal incidence, room temperature)

Energy (keV)	Particle and Energy Reflection Coefficients, R _N and R _E			
	R _N H ⁺ +Mo	R _E H ⁺ +Mo	R _N D ⁺ +Mo	R _N He ⁺ +Mo
2.5 E 00			1.5 E-01	
3.0 E 00			1.4 E-01	
5.0 E 00	1.1 E-01		1.2 E-01	1.1 E-01
7.0 E 00	9.0 E-02		1.0 E-01	1.0 E-01
1.0 E 01	6.9 E-02	2.1 E-02	8.0 E-02	8.8 E-02
1.5 E 01	4.9 E-02	1.3 E-02	5.8 E-02	7.1 E-02
2.0 E 01		9.5 E-03		5.9 E-02
3.0 E 01		6.2 E-03		

References:R_N: W. Eckstein et al., J. Nucl. Mater. 76 & 77, 365 (1978).R_E: G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976).Accuracy: UnknownNotes: (1) For definition of R_N and R_E see note 1 at the beginning of this section.

(2) In principle it is possible to estimate R_N and R_E for D⁺ and T⁺ impact from the data given here using the rule given in note 2 at the beginning of this section. However, it is noted that the data for H⁺ and D⁺ impact given above do not agree exactly with this rule; the reason is unknown.

R_N AND R_E FOR H^+ ,
 D^+ , AND HE^+ ON MO

D.5.18

Particle and Energy Reflection Coefficients (R_N and R_E)for H^+ and He^+ Impact on Ag

(normal incidence, room temperature)

Energy (keV)	Particle and Energy Reflection Coefficients, R_N and R_E		
	R_E H^+	R_N $^3He^+$	R_E $^4He^+$
1.0 E 00	1.3 E-01		
2.0 E 00	1.0 E-01		
3.0 E 00	8.2 E-02		
4.0 E 00	6.9 E-02		1.3 E-01
5.0 E 00	6.0 E-02		1.2 E-01
7.0 E 00	4.8 E-02		9.5 E-02
1.0 E 01	3.7 E-02		7.0 E-02
1.5 E 01	2.6 E-02	2.2 E-01	4.7 E-02
2.0 E 01	1.9 E-02	2.0 E-01	2.8 E-02
3.0 E 01	1.1 E-02	1.0 E-01	2.3 E-02
5.0 E 01			1.4 E-02
7.0 E 01			9.3 E-03

References:

R_E for H^+ : H. Sorensen, in Proc. Int. Symposium on Plasma Wall Interaction Julich, 1976 (Pergamon Press, Oxford, 1977) p. 437; G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976).

R_N for He^+ : J. Bottinger and N. Rud, KFA Julich, West Germany (unpublished).

R_E for He^+ : J. Schou et al., J. Nucl. Mater. 76 & 77, 359 (1978); D. Hildebrandt and R. Manns, Phys. Status Solidi A 38, K155 (1976); H. H. Andersen et al., J. Appl. Phys. 47, 13 (1976).

Accuracy: $\pm 10\%$

Notes: (1) For definitions of R_N and R_E see note 1 at beginning of this section.

(2) To estimate R_N and R_E for D^+ or T^+ see note 2 at the beginning of this section.

D.5.19

R_N AND R_E FOR H^+
AND HE^+ ON AG

D.5.20

Energy Reflection Coefficient (R_E) for H^+ and He^+ on Ta and Pb

(normal incidence, room temperature)

Energy (keV)	Energy Reflection Coefficient, R_E			
	H^+ +Ta	He^+ +Ta	H^+ +Pb	He^+ +Pb
1.0 E 01	3.3 E-02			
1.5 E 01	2.6 E-02			
2.0 E 01	2.0 E-02			
3.0 E 01	1.2 E-02	2.6 E-02	2.3 E-02	3.5 E-02
5.0 E 01		2.1 E-02	1.2 E-02	2.4 E-02
6.0 E 01		2.0 E-02	9.0 E-03	1.9 E-02
8.0 E 01		1.6 E-02		

References:

R_E , H^+ + Ta: G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976).

R_E , He^+ + Ta and all data for Pb: H. H. Andersen et al., J. Appl. Phys. 47, 13 (1976).

Accuracy: Unknown. Individual data points scatter by up to 20% from the lines shown here.

Notes: (1) For a definition of R_E see note 1 at the beginning of this section.

(2) In principle it is possible to estimate R_E for D^+ and T^+ using the data given here by means of the rule given in note 2 at the beginning of this section.

D.5.21

R_E FOR H^+
AND HE^+ ON TA AND PB

D.5.22

Particle Reflection Coefficient (R_N) for H^+ , D^+ , and He^+ Incident on W

(normal incidence, room temperature)

Energy (keV)	Particle Reflection Coefficient, R_N		
	$H^+ + W$	$D^+ + W$	$He^+ + W$
1.5 E 00	1.8 E-01	2.8 E-01	
3.0 E 00	1.7 E-01	2.2 E-01	
5.0 E 00	1.7 E-01	2.1 E-01	1.8 E-01
7.0 E 00	1.7 E-01	1.9 E-01	1.7 E-01
1.0 E 01	1.5 E-01	1.7 E-01	1.6 E-01
1.5 E 01	1.2 E-01	1.3 E-01	1.4 E-01
2.0 E 01			1.3 E-01

Reference:W. Eckstein and H. Verbeek, J. Nucl. Mater. 76 & 77, 365 (1978).Accuracy: UnknownNotes: (1) For a definition of R_N see note 1 at the beginning of this section.(2) In principle R_N for T^+ impact may be estimated using the rule given in note 2 at the beginning of this section.

D.5.23

R_N FOR H^+ , D^+
AND He^+ ON W

D.5.24

Particle and Energy Reflection Coefficients (R_N and R_E) for H^+ and He^+ Impact on Au

(normal incidence, room temperature)

Energy (keV)	Particle Reflection Coefficient, R_N , and Energy Reflection Coefficient, R_E			
	R_N H^+	R_E H^+	R_N $^3He^+$	R_E $^4He^+$
1.0 E 00		1.8 E-01		
2.0 E 00		1.7 E-01		
3.0 E 00		1.5 E-01		1.5 E-01
5.0 E 00	3.2 E-01	1.1 E-01		1.4 E-01
7.0 E 00	2.8 E-01	8.7 E-02		1.2 E-01
1.0 E 01	2.5 E-01	6.7 E-02		9.4 E-02
1.5 E 01	2.0 E-01	4.9 E-02	3.0 E-01	6.0 E-02
2.0 E 01	1.7 E-01	3.7 E-02	2.5 E-01	
3.0 E 01	1.3 E-01	2.5 E-02	1.9 E-01	
5.0 E 01	9.0 E-02	1.5 E-02		

References:

R_N for H^+ : G. Sidenius and T. Lenskjaer, Nucl. Instrum. Meth. 132, 673 (1976).

R_E for H^+ : H. H. Andersen et al., J. Appl. Phys. 47, 13 (1976).

R_N for $^3He^+$: J. Bottinger and N. Rud, KFA Julich, West Germany (unpublished).

R_E for $^4He^+$: J. Schou et al., J. Nucl. Mater. 76 & 77, 35 (1978).

Accuracy: $\pm 10\%$

Notes: (1) For definitions of R_N and R_E see note 1 at beginning of this section.

(2) To estimate R_N and R_E for D^+ or T^+ see note 2 at beginning of this section.

L.5.25

R_N AND R_E FOR H^+
AND He^+ ON AU

D.5.26

Energy Reflection Coefficient (R_E) as a Function
of Incidence Angle for H^+ on Au
(room temperature)

Energy (keV)	Energy Reflection Coefficient, R_E , as a Function of Incidence Angle θ (measured from the surface normal)				
	$\theta=0^\circ$	22.5°	45°	60°	75°
1.5 E 00	1.5 E-01		2.2 E-01	2.6 E-01	2.7 E-01
2.0 E 00	1.4 E-01	1.6 E-01	2.1 E-01	2.4 E-01	2.6 E-01
3.0 E 00	1.1 E-01	1.4 E-01	1.9 E-01	2.2 E-01	2.5 E-01
5.0 E 00	9.0 E-02	1.2 E-01	1.6 E-01	1.9 E-01	2.4 E-01
7.0 E 00	7.4 E-02	1.0 E-01	1.4 E-01	1.7 E-01	2.4 E-01
1.0 E 01	6.0 E-02		1.2 E-01	1.4 E-01	2.3 E-01

References:

H. Sorensen, Appl. Phys. Lett. 29, 148 (1976).

Accuracy: Data points scatter by up to 40% from the line shown here.

Notes: (1) For definition of R_E see note 1 at beginning of section.

(2) To estimate R_E for D^+ or T^+ see note 2 at beginning of section.

(3) The data for $\theta=0^\circ$ differ somewhat from the values shown in the preceding table and graph (R_E for H^+). The reason for this is not discussed by the authors of the reference cited. In any case the discrepancy is approximately equal to the combined uncertainties of the two determinations.

D.5.27

R_E VS. INCIDENCE ANGLE
FOR H^+ ON AU

D.5.28

Energy Reflection Coefficient (R_E) for

He^+ Impact on Various Targets

(normal incidence, room temperature)

Z	Element	Energy Reflection Coefficient, R_E	
		$\text{He}^+(12 \text{ keV})$	$\text{He}^+(14.5 \text{ keV})$
6	C	7.2 E-03	5.5 E-03
11	Na	8.2 E-03	6.2 E-03
12	Mg	8.0 E-03	6.2 E-03
13	Al	8.4 E-03	6.6 E-03
21	Sc	1.4 E-02	1.1 E-02
22	Ti	2.1 E-02	1.8 E-02
23	V	2.0 E-02	1.7 E-02
24	Cr	2.3 E-02	1.9 E-02
25	Mn	2.3 E-02	1.9 E-02
26	Fe	3.0 E-02	2.5 E-02
27	Co	3.4 E-02	2.9 E-02
28	Ni	4.1 E-02	3.5 E-02
29	Cu	4.2 E-02	3.5 E-02
30	Zn	3.3 E-02	2.9 E-02
31	Ga	3.5 E-02	3.0 E-02
33	As	3.6 E-02	3.3 E-02
40	Zr	2.6 E-02	2.2 E-02
41	Nb	2.9 E-02	2.3 E-02
42	Mo	3.9 E-02	3.1 E-02
46	Pd	5.0 E-02	4.3 E-02
47	Ag	5.8 E-02	5.0 E-02
48	Cd	5.5 E-02	4.5 E-02
49	In	4.5 E-02	4.0 E-02
50	Sn	4.4 E-02	3.9 E-02
51	Sb	4.5 E-02	4.0 E-02
52	Te	4.4 E-02	3.8 E-02
73	Ta	5.3 E-02	4.5 E-02
74	W	6.0 E-02	5.1 E-02
78	Pt	5.9 E-02	5.0 E-02
79	Au	7.5 E-02	6.5 E-02
81	Tl	8.0 E-02	7.0 E-02

Reference:

D. Hildebrandt and R. Manns, Phys. Status Solidi A 38, K155 (1976).

Accuracy: Unknown

Note: (1) For definition of R_E see note 1 at the beginning of this section.

D.5.29

R_E FOR HE^+ IMPACT
ON VARIOUS TARGETS

D.5.30

Energy Distribution of Neutrals Plus Ions for

Scattering of H^+ from Be, Nb, and Ta

Primary Ion Energy: 9.25 keV
Angle of Incidence α : 0° (i.e., normal incidence)
Angle of Emergence β : 45° (measured from surface normal)

Energy of
Emerging
Particle
(keV)

Particle Flux per Energy Interval
(arbitrary units)

	<u>Be</u>	<u>Nb</u>	<u>Ta</u>
2.5 E-01	1.7 E-02	4.2 E 0	1.3 E 0
5.0 E-01	2.5 E-02	8.0 E 0	2.3 E 0
1.0 E 00	2.2 E-2	6.8 E 0	4.2 E 0
2.0 E 00	9.2 E-3	3.6 E 0	3.7 E 0
3.0 E 00	4.0 E-3	1.6 E 0	2.7 E 0
4.0 E 00	2.8 E-3	1.1 E 0	1.9 E 0
5.0 E 00	2.0 E-3	1.0 E 0	1.5 E 0
6.0 E 00	1.2 E-3	7.0 E-1	1.2 E 0
7.0 E 00	5.0 E-4	5.0 E-1	9.0 E-1
8.0 E 00	5.0 E-4	4.0 E-1	7.0 E-1
9.0 E 00	0.0 E 0	0.0 E 0	5.0 E-1

Reference:

H^+ + Be, Nb, Ta: P. Meischner et al., J. Nucl. Mater. 53, 276 (1974).

Accuracy: Random error $< \pm 10\%$.

Note: (1) The particle flux is in arbitrary units, but the data sets for the different materials have a relative validity.

SCATTERED PARTICLE ENERGY DISTRIBUTION FOR H ON BE, NB, AND TA

Energy Distribution of Neutrals Plus Ions for

Scattering of D^+ from C, Ti, Mo, and W

Primary Ion Energy: 5 keV
 Angle of Incidence α : 0° (i.e., normal incidence)
 Angle of Emergence β : 45° (measured from surface normal)

Energy of Emerging Particle (keV)	Particle Flux per Energy Interval (arbitrary units)			
	<u>C</u>	<u>Ti</u>	<u>Mo</u>	<u>W</u>
2.5 E-01	6.3 E 00			1.9 E 01
5.0 E-01	8.1 E 00	1.2 E 01	1.4 E 01	1.9 E 01
1.0 E 00	4.5 E 00	1.3 E 01	1.4 E 01	2.0 E 01
1.5 E 00	2.7 E 00	1.1 E 01	1.2 E 01	1.9 E 01
2.0 E 00	1.6 E 00	9.5 E 00	1.1 E 01	1.9 E 01
2.5 E 00	1.0 E 00	7.4 E 00	1.0 E 01	1.9 E 01
2.7 E 00	8.0 E-01	6.4 E 00	8.7 E 00	1.8 E 01
3.0 E 00	0.0 E 00	5.8 E 00	8.0 E 00	1.6 E 01
4.0 E 00		2.5 E 00	4.1 E 00	1.0 E 01
4.3 E 00		2.3 E 00	3.5 E 00	8.5 E 00
4.5 E 00		0.0 E 00	2.6 E 00	7.0 E 00
4.7 E 00			1.0 E 00	5.0 E 00
5.0 E 00			0.0 E 00	0.0 E 00

Reference:W. Eckstein et al., J. Nucl. Mater. 76 & 77, 365 (1978).Accuracy: No better than $\pm 20\%$.

Note: (1) The particle flux is in arbitrary units, but the data sets for the different materials have a relative validity.

SCATTERED PARTICLE ENERGY DISTRIBUTION FOR D⁺ ON C, TI, MO, AND W

D.5.34

Energy Distribution of Neutrals Plus Ions for

Scattering of H^+ from Stainless Steel

Primary Ion Energy: 2.5, 5.0, 7.5, and 15 keV
 Angle of Incidence α : 0° (i.e., normal incidence)
 Angle of Emergence β : 45° (measured from surface normal)

Energy of Emerging Particle (keV)	Particle Flux per Energy Interval (arbitrary units)			
	H^+ (2.5 keV)	H^+ (5.0 keV)	H^+ (7.5 keV)	H^+ (15 keV)
2.5 E-01	2.4 E 01			
5.0 E-01	3.1 E 01	3.2 E 00	1.1 E 00	
1.0 E 00	3.8 E 01	4.6 E 00	1.6 E 00	3.3 E-01
1.5 E 00	3.5 E 01	4.7 E 00	1.8 E 00	4.3 E-01
2.0 E 00	2.4 E 01	4.1 E 00	1.7 E 00	4.7 E-01
2.5 E 00	1.0 E 01	3.5 E 00	1.6 E 00	4.9 E-01
3.0 E 00		2.9 E 00	1.4 E 00	4.9 E-01
4.0 E 00		1.7 E 00	1.0 E 00	4.6 E-01
5.0 E 00		8.7 E-01	7.6 E-01	4.1 E-01
6.0 E 00			5.0 E-01	3.5 E-01
7.0 E 00			3.4 E-01	2.9 E-01
7.5 E 00			2.8 E-01	2.6 E-01
8.0 E 00				2.3 E-01
9.0 E 00				1.9 E-01
1.0 E 01				1.6 E-01
1.2 E 01				1.2 E-01
1.4 E 01				9.0 E-02
1.5 E 01				8.0 E-02

Reference:

W. Eckstein et al., J. Nucl. Mater. 63, 199 (1976).

Accuracy: Unknown

Note: (1) The particle flux is in arbitrary units, but the data sets for the different projectile energies have a relative validity.

SCATTERED PARTICLE ENERGY DISTRIBUTION
FOR H^+ ON STAINLESS STEEL

D.5.36

Energy Distribution of Neutrals Plus Ions for

Scattering of H^+ , D^+ , and He^+ from Mo

Primary Ion Energy: 10 keV
Angle of Incidence α : 0° (i.e., normal incidence)
Angle of Emergence β : 45° (measured from surface normal)

Energy of Emerging Particle (keV)	Particle Flux per Energy Interval (arbitrary Units)		
	H^+	D^+	He^+
1.0 E 00	9.8 E 00	1.1 E 01	1.2 E 01
2.0 E 00	9.2 E 00	1.1 E 01	1.25 E 01
3.0 E 00	7.6 E 00	9.3 E 00	1.2 E 01
4.0 E 00	6.3 E 00	7.4 E 00	1.0 E 01
5.0 E 00	4.6 E 00	6.0 E 00	8.5 E 00
6.0 E 00	3.5 E 00	4.6 E 00	6.7 E 00
7.0 E 00	2.7 E 00	3.3 E 00	5.3 E 00
8.0 E 00	1.8 E 00	2.3 E 00	3.6 E 00
8.7 E 00	1.3 E 00	1.6 E 00	3.0 E 00
9.0 E 00	1.2 E 00	1.5 E 00	0.0 E 00
9.5 E 00	8.0 E-01	0.0 E 00	
1.0 E 01	0.0 E 00		

Reference:

W. Eckstein et al., J. Nucl Mater. 76 & 77, 365 (1978).

Accuracy: No better than $\pm 20\%$.

Note: (1) The particle flux is in arbitrary units, but the data sets for the different projectiles have a relative validity.

SCATTERED PARTICLE ENERGY DISTRIBUTION:
 H^+ , D^+ , AND HE^+ ON MO

D.5.38

Energy Distribution of Neutrals Plus Ions for

Scattering of H^+ from Ta

Primary Ion Energy: 12, 15, and 18 keV
Angle of Incidence α : 0° (i.e., normal incidence)
Angle of Emergence β : 45° (measured from surface normal)

Energy of Emerging Particle (keV)	Particle Flux per Energy Interval (arbitrary units)		
	H^+ (12 keV)	H^+ (15 keV)	H^+ (18 keV)
5.0 E-01	6.7 E 00	4.0 E 00	1.5 E 00
1.0 E 00	8.5 E 00	6.1 E 00	2.7 E 00
2.0 E 00	6.4 E 00	4.3 E 00	3.0 E 00
3.0 E 00	4.2 E 00	3.1 E 00	2.1 E 00
4.0 E 00	3.3 E 00	2.5 E 00	1.6 E 00
5.0 E 00	2.7 E 00	1.9 E 00	1.4 E 00
6.0 E 00	2.3 E 00	1.6 E 00	1.3 E 00
8.0 E 00	1.6 E 00	1.2 E 00	1.0 E 00
1.0 E 01	1.0 E 00	9.0 E-01	7.0 E-01
1.2 E 01	6.0 E-01	6.0 E-01	6.0 E-01
1.3 E 01	0.0 E 00	5.0 E-01	5.0 E-01
1.5 E 01		4.0 E-01	4.0 E-01
1.6 E 01		0.0 E 00	3.0 E-01
1.8 E 01			2.5 E-01
1.9 E 01			0.0 E 00

Reference:

P. Meischner et al., J. Nucl. Mater. 53, 276 (1974).

Accuracy: Random error $\pm 10\%$.

Note: (1) The particle flux is in arbitrary units, but the data sets for the different energies have a relative validity.

SCATTERED PARTICLE ENERGY DISTRIBUTION
FOR H^+ ON TA

Energy Distribution of Neutrals Plus Ions for

Scattering of H^+ from Au

Primary Ion Energy: 1.0, 1.5, 1.67, and 2.5 keV
 Angle of Incidence α : 0° (i.e., normal incidence)
 Angle of Emergence β : 45° (measured from surface normal)

Energy of Emerging Particle (keV)	Particle Flux per Energy Interval (arbitrary units)			
	H^+ (1 keV)	H^+ (1.5 keV)	H^+ (1.67 keV)	H^+ (2.5 keV)
2.5 E-01	9.0 E 00	2.0 E 00	1.6 E 00	6.0 E-01
5.0 E-01	9.2 E 00	2.7 E 00	1.9 E 00	7.0 E-01
7.5 E-01	9.1 E 00	3.2 E 00	2.1 E 00	6.0 E-01
1.0 E 00	5.0 E 00	3.3 E 00	2.1 E 00	6.0 E-01
1.25 E 00	0.0 E 00	3.1 E 00	2.2 E 00	6.0 E-01
1.5 E 00		1.0 E-01	1.9 E 00	5.0 E-01
1.75 E 00		0.0 E 00	0.0 E 00	4.6 E-01
2.0 E 00				4.0 E-01
2.25 E 00				3.0 E-01
2.5 E 00				0.0 E 00

Reference:

W. Eckstein and F. E. P. Matschke, Phys. Rev. B 14, 3231 (1976).

Accuracy: Unknown

Notes: (1) The particle flux is in arbitrary units, but the data sets for different projectile energies have a relative validity.

(2) The data were acquired using H_2^+ and H_3^+ projectiles but are shown here as though they were H^+ of equivalent flux and energy (per nucleon).

SCATTERED PARTICLE ENERGY DISTRIBUTION
FOR H^+ ON AU

D.5.42

Energy Distribution of Neutrals Plus Ions for

Scattering of D^+ from Au

Primary Ion Energy: 1.7, 2.0, 2.5, and 3.0 keV
 Angle of Incidence α : 0° (i.e., normal incidence)
 Angle of Emergence β : 45° (measured from surface normal)

Energy of Emerging Particle (keV)	Particle Flux per Energy Interval (arbitrary units)			
	D^+ (1.7 keV)	D^+ (2.0 keV)	D^+ (2.5 keV)	D^+ (3.0 keV)
2.5 E-01	2.4 E 00	1.8 E 00	1.0 E 00	6.5 E-01
5.0 E-01	2.6 E 00	2.0 E 00	1.2 E 00	7.5 E-01
7.5 E-01	3.2 E 00	2.3 E 00	1.3 E 00	8.0 E-01
1.0 E 00	3.8 E 00	2.6 E 00	1.5 E 00	8.7 E-01
1.25 E 00	3.8 E 00	2.7 E 00	1.6 E 00	8.7 E-01
1.5 E 00	3.1 E 00	2.6 E 00	1.5 E 00	8.2 E-01
1.75 E 00	0.0 E 00	2.2 E 00	1.3 E 00	7.8 E-01
2.0 E 00		3.0 E-01	1.2 E 00	7.2 E-01
2.25 E 00		0.0 E 00	9.0 E-01	6.2 E-01
2.5 E 00			3.0 E-01	5.2 E-01
2.75 E 00			0.0 E 00	4.0 E-01
3.0 E 00				1.0 E-01
3.1 E 00				0.0 E 00

Reference:

W. Eckstein and F. E. P. Matschke, Phys. Rev. B 14, 3231 (1976).

Accuracy: Unknown

Notes: (1) The particle flux is in arbitrary units, but the data sets for the different projectile energies have a relative validity.

(2) The data were acquired using D_2^+ and D_3^+ projectiles but are shown here as though they were D^+ of equivalent flux and energy (per nucleon).

D.5.43

SCATTERED PARTICLE ENERGY DISTRIBUTION FOR D^+ ON AU

D.5.44

Fraction of Reflected Particles Charged

as a Function of Recoil Energy: H^+

on Be, V, Cu, Nb, Mo, and Ta

Recoil Energy (keV)	Fraction of Reflected Particles Charged (%)	
	<u>Be</u>	<u>V, Cu, Nb, Mo, Ta</u>
5.0 E 00		1.0 E 01
1.0 E 01		2.0 E 01
2.0 E 01	3.2 E 01	3.4 E 01
3.0 E 01	4.5 E 01	4.7 E 01
4.0 E 01	5.6 E 01	5.6 E 01
5.0 E 01	6.6 E 01	6.3 E 01
6.0 E 01	7.3 E 01	6.8 E 01
7.0 E 01	7.7 E 01	7.2 E 01
8.0 E 01	8.3 E 01	7.5 E 01
9.0 E 01	8.5 E 01	7.8 E 01
1.0 E 02	8.7 E 01	8.1 E 01
1.2 E 02	9.0 E 01	8.4 E 01
1.5 E 02	9.3 E 01	8.7 E 01

Reference:

R. Behrisch et al., in Atomic Collisions in Solids, ed. by S. Datz et al. (Plenum Publ. Corp., New York, 1975), p. 315.

Accuracy: $\pm 10\%$

Notes: (1) For a definition of "charged fraction" see note 3 at the beginning of this section.

(2) Within experimental error the fraction is the same for V, Cu, Nb, Mo, and Ta. The data for Be differ from the rest, perhaps due to the fact that the surface has an oxide layer.

(3) Differences of the order of $\pm 5\%$ occur depending on the method of surface preparation; these data are for well annealed, mechanically polished specimens.

(4) Incidence angle varied from 0 to 15° , and emergent angle varied from 30° to 80° (both measured with respect to surface normal). Within these ranges the data vary by only $\pm 5\%$, which is less than the experimental accuracy.

D.5.45

FRACTION OF REFLECTION PARTICLES

CHARGED VS. RECOIL ENERGY: H^+

D.5.46

Charge State Fractions of Recoils

When H^+ Is Incident on Stainless Steel

Recoil
Energy
(keV)

Fraction of Recoils in Various
Charge States (%)

	H^+	H^-	H^0
2.5 E-01	5.0 E-01	5.0 E-01	9.9 E 01
5.0 E-01	2.5 E 00	2.5 E 00	9.5 E 01
1.0 E 00	5.0 E 00	5.0 E 00	9.0 E 01
1.5 E 00	5.7 E 00	5.7 E 00	8.9 E 01
2.0 E 00	6.7 E 00	5.4 E 00	8.8 E 01
4.0 E 00	8.0 E 00	4.5 E 00	8.7 E 01
6.0 E 00	1.1 E 01	3.2 E 00	8.6 E 01
8.0 E 00	1.2 E 01	2.5 E 00	8.6 E 01
1.0 E 01	1.5 E 01	2.0 E 00	8.3 E 01

Reference:

W. Eckstein et al., J. Nucl. Mater. 63, 199 (1974).

Accuracy: Unknown. Data points scatter by $\pm 2\%$ about the lines shown here.

Notes: (1) The meaning of "charge state fractions" is defined in note 3 at the beginning of this section.

(2) The projectiles were incident normal to the surface, and the recoils were detected at 45° to the surface normal.

D.5.47

CHARGE STATE FRACTIONS OF RECOILS
FOR H^+ ON STAINLESS STEEL

Tables and Graphs for Section D.6

Trapping

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D.6.2

Introductory Notes

(1) Historically, data on trapping and reemission have been presented in various forms. In this compendium we have generally retained the method of presentation employed in the original publication. The forms of display, their definitions, and relationship are as follows.

(a) Reemission refers to the emission of gas from the target while the target is being bombarded by the projectile ions; the reemission rate is generally measured by the rise in partial pressure of the projectile species as monitored in the vessel which contains the target. If the flux of ions (or atoms) incident on the surface is F_i and the flux of atoms emerging is F_e , then the rate of reemission, expressed as a percentage, is given by:

$$\text{reemission rate } R (\%) = \frac{F_e}{F_i} \times 100$$

The general form of reemission rate as a function of dose is shown in Fig. 1; reemission rate is plotted as a function of

Fig. 1. General form of reemission rate as a function of dose.

D.6.3

cumulative areal dose (ions or atoms/cm²), otherwise known as Fluence. At low dose the reemission is equal to the back-scattered fraction; all ions not backscattered are retained or trapped. As dose increases the reemission rate increases to a saturated value, which is normally 100%; at this value an atom is ejected for every ion or atom incident.

- (b) Trapping refers to the fraction of the incident flux which is retained in the target; this is generally determined by a direct measure of the retained projectile density. The measured quantity is the areal density of retained projectiles, or Trapped Fluence (atoms/cm²), plotted as a function of the incident projectile dose or fluence; a facsimile of such a presentation is shown in Fig. 2. For low dose the trapped density increases

Fig. 2. Retained projectile as a function of dose.

linearly with fluence; however, the trapped density is less than incident fluence by an amount equal to the fraction backscattered. The dashed line shows the behavior expected if all incident

D.6.4

particles not reflected are retained. At high dose the trapped density saturates, corresponding to the 100% reemission in Fig. 1; at this point, for each new ion incident one atom in the target is ejected.

One can relate the presentations of Figs. 1 and 2 as follows: The projectile atoms retained (Fig. 2) is equal to

$$\left(1 - \frac{R}{100}\right) \times \text{Fluence},$$

where R is the reemission rate (in %) from Fig. 1.

- (c) Saturation Density is the areal density of the retained atoms at saturation (i.e., at 100% reemission); in Fig. 1 it is the number of atoms represented by the area between the reemission curve and the 100% reemission line. An alternative terminology is Fluence Trapped at 100% Reemission.
- (d) Trapping Coefficient is the probability that an incident ion will be retained. Its maximum value of unity represents the condition where each incident ion is retained. The trapping coefficient will vary with fluence (or dose), eventually dropping to zero when the target saturates and each new ion incident causes one atom to be ejected. Trapping coefficient is equal to

$$1 - \frac{R}{100}$$

where R is the reemission rate (in %) discussed in note 1a above.

- (e) It should be noted that the reemission behavior is closely related to Temperature. The behavior shown in Figs. 1 and 2 is appropriate to temperatures where the implanted species has negligible diffusion. At temperatures where diffusion is significant the rising portion of Fig. 1 commences at essentially zero dose; this means also that the retained density of atoms displayed in Fig. 2 always falls below the 100% trapping line.

D.6.5

- (2) Replacement Cross Sections refer to the replacement of implanted species (e.g., D) by the arrival of a subsequent atom (such as H). In general, the cross section is evaluated as follows; the target is implanted with one species (e.g., D) to a saturation density (or trapped fluence at saturation) of n_{sat} atoms/cm². Subsequently the second species (e.g., H⁺) is directed onto the target with a flux density J_0 (atoms/cm²s), and the trapped fluence decreases with time t as

$$n = n_{\text{sat}} \exp - (J_0 \sigma t).$$

Consequently, the rate of removal of the first species (D in our example) is given by

$$\frac{dn}{dt} = n_{\text{sat}} J_0 \sigma \exp - (J_0 \sigma t).$$

σ is called the replacement cross section (or sometimes the gas sputtering cross section).

- (3) Replacement Efficiency is related to replacement cross section defined in note 2 above. It is the number of primary implanted atoms (in our example, D) removed for every secondary particle (in our example, H) incident, dn_D/dn_H for our example. It is often plotted as a function of the ratio of the fluence of incoming secondary particles (H in our example) to the saturation density of the primary implant (D in our example), that is to say, as a function of n_H/n_{sat} .

D.6.6

Trapped Fluence as a Function of Incident

Fluence for 50-, 150-, and 300-eV D^+ on C

(normal incidence, room temperature,
polycrystalline material)

Fluence Incident (D^+ ions/cm ²)	Fluence Trapped (D atoms/cm ²)		
	50 eV	150 eV	300 eV
2.0 E 15	1.2 E 15	1.4 E 15	2.0 E 15
3.0 E 15	1.7 E 15	2.0 E 15	3.0 E 15
5.0 E 15	2.6 E 15	3.3 E 15	5.0 E 15
1.0 E 16	4.4 E 15	6.2 E 15	1.0 E 16
2.0 E 16	6.6 E 15	1.2 E 16	2.0 E 16
3.0 E 16	8.0 E 15	1.6 E 16	2.6 E 16
5.0 E 16	9.8 E 15	2.0 E 16	3.5 E 16
1.0 E 17	1.2 E 16	2.6 E 16	4.7 E 16
2.0 E 17	1.3 E 16	2.9 E 16	5.5 E 16
3.0 E 17	1.4 E 16	3.0 E 16	5.8 E 16
5.0 E 17	1.4 E 16	3.0 E 16	6.0 E 16
1.0 E 18	1.4 E 16	3.0 E 16	6.1 E 16

Reference:

G. Staudermaier et al., J. Nucl. Mater. (to be published).

Accuracy: Unspecified

Note: (1) For a definition of trapping see note 1b at the beginning of this section.

TRAPPED FLUENCE VS. INCIDENT FLUENCE
FOR 50-, 150-, AND 300-EV D⁺ ON C

D.6.8

Trapped Fluence as a Function of Incident

Fluence for 500-eV, 700-eV, and 1-keV D^+ on C

(normal incidence, room temperature,
polycrystalline material)

Fluence Incident (D^+ ions/cm ²)	Fluence Trapped (D atoms/cm ²)		
	500 eV	700 eV	1 keV
2.0 E 15	2.0 E 15	2.0 E 15	2.0 E 15
3.0 E 15	3.0 E 15	3.0 E 15	3.0 E 15
5.0 E 15	5.0 E 15	5.0 E 15	5.0 E 15
1.0 E 16	1.0 E 16	1.0 E 16	1.0 E 16
2.0 E 16	2.0 E 16	2.0 E 16	2.0 E 16
3.0 E 16	3.0 E 16	3.0 E 16	3.0 E 16
5.0 E 16	5.0 E 16	5.0 E 16	5.0 E 16
1.0 E 17	7.8 E 16	8.7 E 16	9.3 E 16
2.0 E 17	8.8 E 16	1.1 E 17	1.2 E 17
3.0 E 17	9.0 E 16	1.2 E 17	1.3 E 17
5.0 E 17	9.0 E 16	1.2 E 17	1.3 E 17
1.0 E 18	9.0 E 16	1.2 E 17	1.3 E 17

Reference:

G. Staudenmaier et al., J. Nucl. Mater. (to be published).

Accuracy: Unspecified

Note: (1) For a definition of trapping see note 1b at the beginning of this section.

TRAPPED FLUENCE VS. INCIDENT FLUENCE
FOR 500-EV, 700-EV, AND 1-KEV D⁺ ON C

D.6.10

Fluence Trapped at Saturation

for D^+ on C

(normal incidence, room temperature,
polycrystalline material)

Energy (keV)	Fluence Trapped at Saturation (D atoms/cm ²)
<hr/>	
5.0 E-02	1.3 E 16
7.0 E-02	1.7 E 16
1.0 E-01	2.3 E 16
2.0 E-01	4.1 E 16
3.0 E-01	5.9 E 16
5.0 E-01	9.7 E 16
7.0 E-01	1.3 E 17
1.0 E 00	1.7 E 17
2.0 E 00	3.2 E 17
3.0 E 00	4.6 E 17
5.0 E 00	7.5 E 17
7.0 E 00	1.0 E 18
1.0 E 01	1.4 E 18

Reference:

G. Staudenmaier et al., J. Nucl. Mater. (to be published).

Accuracy: ±10%

Notes: (1) For a definition of trapped fluence and its relationship to reemission, see note 1 at the beginning of this section.

(2) The carbon used here is a flexible polycrystalline graphite strip known by the commercial name of "Papyex" (Le Carbone, France).

D.6.11

FLUENCE TRAPPED AT SATURATION

FOR D⁺ ON C

D.6.12

Reemission of Deuterium at Various

Temperatures for 20-keV D^+ on C(normal incidence, various temperatures,
polycrystalline material)

Fluence Incident (D^+ ions/cm ²)	Reemission Rate (%)			
	<u>293 K</u>	<u>773 K</u>	<u>973 K</u>	<u>1273 K</u>
0.0 E 00	0.0 E 00	0.0 E 00	0.0 E 00	0.0 E 00
2.0 E 16	0.0 E 00	0.0 E 00	0.0 E 00	6.0 E 00
4.0 E 16	0.0 E 00	0.0 E 00	0.0 E 00	1.1 E 01
6.0 E 16	0.0 E 00	0.0 E 00	2.0 E 00	1.4 E 01
8.0 E 16	0.0 E 00	0.0 E 00	7.0 E 00	2.6 E 01
1.0 E 17	0.0 E 00	0.0 E 00	1.0 E 01	3.5 E 01
2.0 E 17	0.0 E 00	0.0 E 00	5.0 E 01	4.6 E 01
4.0 E 17	0.0 E 00	4.0 E 00	7.7 E 01	5.3 E 01
6.0 E 17	0.0 E 00	1.1 E 01	8.4 E 01	5.5 E 01
8.0 E 17	0.0 E 00	2.4 E 01	8.7 E 01	5.6 E 01
1.0 E 18	3.0 E 00	3.5 E 01	9.0 E 01	5.6 E 01
1.2 E 18	1.0 E 01	4.4 E 01	9.1 E 01	
1.4 E 18	2.0 E 01	5.0 E 01		
1.6 E 18	2.7 E 01	5.5 E 01		
1.8 E 18	3.4 E 01	5.8 E 01		
2.0 E 18	3.7 E 01	6.1 E 01		

Reference:S. K. Erents, Inst. Phys. Conf. Ser. 28, 318 (1976).Accuracy: UnknownNotes: (1) For a definition of reemission and how it relates to trapping, see note 1 at the beginning of this section.

(2) The type of carbon used was not specified.

(3) The above data represent the reemission of deuterium in the form of D_2 and HD. In addition, there is some reemission of CD_4 at higher temperatures; this is believed to be less than 5% of the total deuterium emission.

D.6.13

REEMISSION OF DEUTERIUM
FOR 20-KEV D⁺ ON C

Cross Section for Replacement of Implanted

D by H Bombardment: Carbon Target

(normal incidence, room temperature,
polycrystalline target)

Energy (keV)	Replacement Cross Section (cm ²)
5.0 E-01	9.0 E-18
1.0 E 00	1.6 E-17
2.0 E 00	3.1 E-17
3.0 E 00	1.6 E-17
5.0 E 00	7.0 E-18
7.0 E 00	3.9 E-18
1.0 E 01	2.2 E-18
1.5 E 01	1.2 E-18
2.0 E 01	8.0 E-19
3.0 E 01	6.0 E-19

Reference:C. M. Braganza et al., J. Nucl. Mater. 75, 220 (1978).Accuracy: UnknownNotes: (1) For a definition of replacement cross section see note 2 at the beginning of this section.

(2) Implanted D and the incident H are at the same energy.

(3) The carbon used here is a flexible polycrystalline graphite strip known by the commercial name of "Papyex" (Le Carbone, France).

D.6.15

CROSS SECTION FOR REPLACEMENT OF D
BY H BOMBARDMENT: CARBON TARGET

D.6.16

Trapped Fluence at 50, 150, and 300 eV
as a Function of Incident Fluence for D⁺ on Si
(normal incidence, room temperature,
single crystal)

Fluence Incident (D ⁺ ions/cm ²)	Fluence Trapped (D atoms/cm ²)		
	<u>50 eV</u>	<u>150 eV</u>	<u>300 eV</u>
1.0 E 15			1.0 E 15
2.0 E 15			2.0 E 15
3.0 E 15	1.0 E 15	1.6 E 15	3.0 E 15
5.0 E 15	1.5 E 15	2.8 E 15	5.0 E 15
1.0 E 16	2.5 E 15	5.5 E 15	9.0 E 15
2.0 E 16	4.1 E 15	9.2 E 15	1.5 E 16
3.0 E 16	5.3 E 15	1.2 E 16	1.8 E 16
5.0 E 16	6.7 E 15	1.5 E 16	2.3 E 16
1.0 E 17	8.5 E 15	1.8 E 16	2.8 E 16
2.0 E 17	9.2 E 15	1.8 E 16	3.1 E 16
3.0 E 17	9.3 E 15	1.8 E 16	3.1 E 16
5.0 E 17			3.1 E 16
1.0 E 18			3.1 E 16

Reference:

G. Staudenmaier et al., J. Nucl. Mater. (to be published).

Accuracy: Unknown

Note: (1) For a definition of trapping see note 1b at the beginning of this section.

TRAPPED FLUENCE AT 50, 150, AND 300 EV
VS. INCIDENT FLUENCE FOR D⁺ ON SI

D.5.18

Trapped Fluence at 500 eV, 700 eV, and 1 keV
as a Function of Incident Fluence for D⁺ on Si
(normal incidence, room temperature,
single crystal)

Fluence Incident (D ⁺ ions/cm ²)	Fluence Trapped (D atoms/cm ²)		
	500 eV	700 eV	1 keV
1.0 E 15	1.0 E 15	1.0 E 15	1.0 E 15
2.0 E 15	2.0 E 15	2.0 E 15	2.0 E 15
3.0 E 15	3.0 E 15	3.0 E 15	3.0 E 15
5.0 E 15	5.0 E 15	5.0 E 15	5.0 E 15
1.0 E 16	1.0 E 16	1.0 E 16	1.0 E 16
2.0 E 16	2.0 E 16	2.0 E 16	2.0 E 16
3.0 E 16	2.8 E 16	3.0 E 16	3.0 E 16
5.0 E 16	4.0 E 16	4.5 E 16	5.0 E 16
1.0 E 17	4.9 E 16	5.8 E 16	7.2 E 16
2.0 E 17	5.1 E 16	6.7 E 16	8.0 E 16
3.0 E 17	5.3 E 16	7.0 E 16	8.3 E 16
5.0 E 17	5.4 E 16	7.0 E 16	8.5 E 16
1.0 E 18	5.4 E 16	7.0 E 16	8.5 E 16

Reference:

G. Staudenmaier et al., J. Nucl. Mater. (to be published).

Accuracy: Unknown

Note: (1) For a definition of trapping see note 1b at the beginning of this section.

TRAPPED FLUENCE AT 0.5, 0.7, AND 1.0 KEV
VS. INCIDENT FLUENCE FOR D⁺ ON SI

D.6.20

Fluence of Deuterium Trapped at Saturation

for D^+ on Si

(normal incidence, room temperature,
polycrystalline target)

Energy (keV)	Fluence Trapped at Saturation (D atoms/cm ²)
5.0 E-02	8.0 E 15
7.0 E-02	1.1 E 16
1.0 E-01	1.4 E 16
2.0 E-01	2.5 E 16
3.0 E-01	3.5 E 16
5.0 E-01	5.4 E 16
7.0 E-01	7.0 E 16
1.0 E 00	9.2 E 16

Reference:

G. Staudermaier et al., J. Nucl. Mater. (to be published).

Accuracy: ±10%

Note: (1) For a definition of trapped fluence and its relationship to reemission, see note 1 at the beginning of this section.

FLUENCE OF DEUTERIUM TRAPPED AT
SATURATION FOR D^+ ON SI

D.6.22

Reemission of Deuterium at Various Temperatures

for 20-keV D^+ on SiC(normal incidence, various temperatures,
20-keV energy, polycrystalline target)

Fluence Incident (D^+ ions/cm ²)	Reemission Rate (%)			
	293 K	773 K	973 K	1273 K
0.0 E 00	0.0 E 00	0.0 E 00	0.0 E 00	1.6 E 01
2.0 E 16	2.0 E 00	3.0 E 00	6.0 E 00	2.0 E 01
4.0 E 16	2.0 E 00	4.0 E 00	7.0 E 00	2.3 E 01
6.0 E 16	3.0 E 00	4.0 E 00	8.0 E 00	2.5 E 01
8.0 E 16	3.0 E 00	5.0 E 00	9.0 E 00	2.9 E 01
1.0 E 17	3.0 E 00	5.0 E 00	1.0 E 01	3.6 E 01
2.0 E 17	3.0 E 00	6.0 E 00	1.6 E 01	6.8 E 01
4.0 E 17	4.0 E 00	1.1 E 01	4.1 E 01	8.6 E 01
6.0 E 17	6.0 E 00	2.0 E 01	5.7 E 01	9.3 E 01
8.0 E 17	8.0 E 00	3.1 E 01	6.5 E 01	9.5 E 01
1.0 E 18	1.1 E 01	3.9 E 01	7.3 E 01	9.6 E 01
1.2 E 18	1.6 E 01	4.6 E 01	7.7 E 01	9.7 E 01
1.4 E 18	2.3 E 01	5.3 E 01	8.2 E 01	9.7 E 01
1.6 E 18	3.0 E 01	5.8 E 01	8.5 E 01	9.7 E 01
1.8 E 18	3.7 E 01	6.2 E 01	8.9 E 01	9.7 E 01
2.0 E 18	4.3 E 01	6.5 E 01	9.0 E 01	9.7 E 01

Reference:S. K. Erents, Inst. Phys. Conf. Ser. 28, 318 (1976).Accuracy: UnknownNote: (1) For a definition of reemission and how it relates to trapping, see note 1 at the beginning of this section.

REEMISSION OF DEUTERIUM
FOR 20-KEV D⁺ ON SIC

Trapping Coefficient as a Function of

Dose for 18-keV D^+ Impact on Ti(normal incidence, various temperatures,
18-keV energy, polycrystalline target)

Fluence Incident (D^+ ions/cm ²)	Trapping Coefficient			
	<u>477 K</u>	<u>531 K</u>	<u>699 K</u>	<u>728 K</u>
8.0 E 16			8.7 E-01	8.3 E-01
1.0 E 17			8.6 E-01	7.8 E-01
2.0 E 17			6.8 E-01	4.7 E-01
3.0 E 17	9.4 E-01	9.2 E-01	5.0 E-01	3.4 E-01
5.0 E 17	9.3 E-01	8.9 E-01	3.9 E-01	2.3 E-01
7.0 E 17	9.2 E-01	8.6 E-01	3.5 E-01	2.0 E-01
1.0 E 18	9.0 E-01	8.3 E-01	3.1 E-01	1.7 E-01
2.0 E 18	8.8 E-01	7.7 E-01	2.6 E-01	1.4 E-01
3.0 E 18	8.6 E-01	7.3 E-01	2.4 E-01	1.3 E-01
5.0 E 18	8.3 E-01	6.8 E-01	2.2 E-01	1.2 E-01

Reference:E. S. Hotston and G. H. McCracken, J. Nucl. Mater. 68, 277 (1977).Accuracy: UnknownNotes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) At low dose the coefficient should tend asymptotically to 0.97 because 3% of the beam is backscattered.

TRAPPING COEFFICIENT VS. DOSE
FOR 18-KEV D⁺ IMPACT ON TI

Trapping Coefficient as a Function of Temperature
 at a Fixed Fluence (or Dose) for 18-keV D⁺ Incident on Ti
 (normal incidence; various temperatures; fixed fluence,
 or dose, of 5×10^{18} ions cm⁻²; energy of 18 keV;
 polycrystalline target)

Temperature (K)	Trapping Coefficient
<hr/>	
1.0 E 02	1.3 E-01
2.0 E 02	8.0 E-01
3.0 E 02	9.6 E-01
4.0 E 02	9.6 E-01
5.0 E 02	8.8 E-01
6.0 E 02	4.4 E-01
7.0 E 02	1.7 E-01
8.0 E 02	5.0 E-02
9.0 E 02	3.0 E-02

Reference:

G. M. McCracken et al., Proc. 4th Int. Vacuum Congress, Inst. Phys. Conf. Ser. 5, 142 (1968).

Accuracy: Unknown. The random scatter of the data points about the line given here is approximately $\pm 10\%$.

Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) The data are for a fixed incident fluence (or dose) of 5×10^{18} D⁺ ions cm⁻². For information on how trapping coefficient varies with incident fluence, see adjacent figures.

D.6.27

TRAPPING COEFFICIENT VS. TEMPERATURE
FOR 18-KEV D^+ INCIDENT ON TI

Trapping Coefficient as a Function of Energy

at a Fixed Dose for H^+ Incident on Ti(normal incidence, temperature in the
region 403 to 503 K)

Energy (keV)	Trapping Coefficient
<hr/>	
3.0 E-01	1.7 E-01
5.0 E-01	4.5 E-01
1.0 E 00	7.8 E-01
2.0 E 00	8.2 E-01
3.0 E 00	9.0 E-01
4.0 E 00	9.4 E-01
5.0 E 00	9.7 E-01
6.0 E 00	9.5 E-01

Reference:J. Bohdanský et al., J. Nucl. Mater. 63, 115 (1976).Accuracy: See below.Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) Below 1 keV the data are believed to represent not Ti, but rather titanium oxide, which exists as a film on the sample. Thus, below 1 keV the accuracy of the data (insofar as they refer to Ti) are suspect.

(3) Fluence or dose used in the bombardment was between 3×10^{19} and 5×10^{20} ions cm^{-2} .

TRAPPING COEFFICIENT VS. ENERGY
FOR H^+ INCIDENT ON TI

Fluence Trapped at Saturation
for D^+ on Stainless Steel
(normal incidence, 90 K or 150 K temperature)

Energy (keV)	Fluence Trapped at Saturation (D atoms/cm ²)
1.25 E-01	2.4 E 16
2.0 E-01	3.6 E 16
3.0 E-01	5.3 E 16
5.0 E-01	8.8 E 16
7.0 E-01	1.2 E 17
1.0 E 00	1.7 E 17
2.0 E 00	3.4 E 17
3.0 E 00	5.0 E 17
5.0 E 00	8.1 E 17
7.0 E 00	1.0 E 18
1.0 E 01	1.3 E 18
1.5 E 01	1.6 E 18

References:

E. W. Thomas, Georgia Institute of Technology (to be published);
R. S. Blewer et al., J. Nucl. Mater. 76 & 77, 305 (1978).

Accuracy: $\pm 10\%$

Notes: (1) For a definition of trapped fluence and its relationship to reemission, see note 1 at the beginning of this section.

(2) Data up to 1 keV are by Thomas and are for a temperature of 90 K. Data at 1 keV and above are by Blewer et al., at a temperature of 150 K. The two data sets are in agreement at 1 keV.

(3) The work by Thomas uses type 304 stainless steel; the work by Blewer uses type 321.

FLUENCE TRAPPED AT SATURATION
FOR D⁺ ON STAINLESS STEEL

Reemission of Deuterium Due to D^+ Impact on
Stainless Steel (Type 304) at Low Temperature
(normal incidence, 90 K temperature)

Fluence Incident (D^+ ions/cm ²)	Reemission Rate (%)			
	$D^+(125 \text{ eV})$	$D^+(250 \text{ eV})$	$D^+(500 \text{ eV})$	$D^+(750 \text{ eV})$
0.0 E 00	5.0 E 01	4.0 E 01	4.0 E 01	3.5 E 01
2.0 E 16	5.0 E 01	4.0 E 01	4.0 E 01	3.5 E 01
4.0 E 16	5.5 E 01	4.6 E 01	4.0 E 01	3.5 E 01
5.0 E 16	8.5 E 01	5.2 E 01	4.0 E 01	3.5 E 01
6.0 E 16	9.5 E 01	5.9 E 01	4.0 E 01	3.5 E 01
8.0 E 16	1.0 E 02	7.2 E 01	4.0 E 01	3.5 E 01
1.0 E 17	1.0 E 02	8.5 E 01	4.0 E 01	3.5 E 01
1.2 E 17		9.7 E 01	5.1 E 01	3.5 E 01
1.4 E 17		1.0 E 02	7.6 E 01	3.5 E 01
1.6 E 17		1.0 E 02	9.6 E 01	3.8 E 01
1.8 E 17			9.9 E 01	5.2 E 01
2.0 E 17			1.0 E 02	6.3 E 01
2.5 E 17			1.0 E 02	8.8 E 01
3.0 E 17				9.8 E 01
3.5 E 17				1.0 E 02
4.0 E 17				1.0 E 02

Reference:

E. W. Thomas, Georgia Institute of Technology, (to be published).

Accuracy: $\pm 10\%$

Notes: (1) For a definition of reemission rate and how it relates to trapping, see note 1 at the beginning of this section.

(2) Further data for higher D^+ energies are to be found in the following table.

REMISSION OF DEUTERIUM DUE TO D⁺ IMPACT
ON STAINLESS STEEL

D.6.34

Reemission of Deuterium Due to D^+ Impact
on Stainless Steel (Types 304 and 321) at
Low Temperature
(normal incidence, 90 to 120 K temperature)

Fluence Incident (D^+ ions/cm ²)	Reemission Rate (%)			
	D^+ (1 keV)	D^+ (4 keV)	D^+ (7 keV)	D^+ (14 keV)
0.0 E 00	3.0 E 01	1.6 E 01	1.3 E 01	4.0 E 00
1.0 E 17	3.0 E 01	1.6 E 01	1.3 E 01	4.0 E 00
2.0 E 17	4.4 E 01	1.6 E 01	1.3 E 01	4.0 E 00
3.0 E 17	7.3 E 01	1.6 E 01	1.3 E 01	4.0 E 00
4.0 E 17	8.4 E 01	1.8 E 01	1.4 E 01	4.0 E 00
6.0 E 17	9.8 E 01	2.3 E 01	1.6 E 01	5.0 E 00
8.0 E 17	1.0 E 02	4.3 E 01	1.8 E 01	6.0 E 00
1.0 E 18	1.0 E 02	6.8 E 01	3.2 E 01	7.0 E 00
1.2 E 18		9.0 E 01	5.4 E 01	1.6 E 01
1.5 E 18		1.0 E 02	8.8 E 01	3.0 E 01
2.0 E 18		1.0 E 02	9.7 E 01	5.0 E 01
2.5 E 18			1.0 E 02	7.0 E 01
3.0 E 18			1.0 E 02	9.0 E 01
3.5 E 18				9.7 E 01
4.0 E 18				1.0 E 02

References:

R. S. Blewer et al., J. Nucl. Mater. 76 & 77, 305 (1978) (data for 4, 7, and 14 keV at 120 K temperature); E. W. Thomas, Georgia Institute of Technology (to be published), (data for 1 keV at 90 K temperature).

Accuracy: $\pm 10\%$

Notes: (1) For a definition of reemission rate and how it relates to trapping, see note 1 at the beginning of this section.

(2) Further data for lower D^+ energies are to be found in the preceding table.

(3) Type 304 stainless steel was used for the 1-keV data, type 321 for the remainder.

REEMISSION OF DEUTERIUM DUE TO D^+ IMPACT
ON STAINLESS STEEL

D.6.36

Reemission of Deuterium Due to D^+ Impact on Stainless

Steel at Room Temperature and Above

(normal incidence; data are for room temperature, but 500 K data are identical)

Fluence Incident (D^+ ions/cm ²)	Reemission rate (%)		
	D^+ (500 eV)	D^+ (750 eV)	D^+ (1000 eV)
0.0 E 00	4.0 E 01	3.5 E 01	3.0 E 01
1.0 E 16	7.8 E 01	5.5 E 01	4.2 E 01
2.0 E 16	9.2 E 01	7.2 E 01	5.3 E 01
4.0 E 16	1.0 E 02	8.7 E 01	6.7 E 01
6.0 E 16	1.0 E 02	9.4 E 01	7.5 E 01
8.0 E 16		9.8 E 01	8.1 E 01
1.0 E 17		1.0 E 02	8.5 E 01
1.2 E 17		1.0 E 02	8.9 E 01
1.4 E 17		1.0 E 02	9.1 E 01
1.6 E 17			9.3 E 01
1.8 E 17			9.4 E 01
2.0 E 17			9.6 E 01
2.2 E 17			9.7 E 01
2.4 E 17			9.8 E 01

Reference:

E. W. Thomas, Georgia Institute of Technology (to be published).

Accuracy: $\pm 10\%$

Notes: (1) For a definition of reemission rate and how it relates to trapping, see note 1 at the beginning of this section.

(2) Type 304 stainless steel was used.

REEMISSION OF DEUTERIUM DUE TO D^+ IMPACT
ON STAINLESS STEEL

D.6.38

Cross Section for Replacement of Implanted D

by H Bombardment: Stainless Steel Target

(normal incidence, room temperature)

Energy (keV)	Replacement Cross Section (cm ²)
3.0 E 00	2.5 E-17
5.0 E 00	6.2 E-17
7.0 E 00	6.0 E-17
1.0 E 01	5.0 E-17
1.5 E 01	4.0 E-17
2.0 E 01	3.2 E-17
3.0 E 01	2.5 E-17

Reference:

C. M. Braganza et al., J. Nucl. Mater. 76 & 77, 298 (1978).

Accuracy: Unknown

Notes: (1) For a definition of replacement cross section see note 2 at the beginning of this section.

(2) Implanted D and the incident H are at the same energy.

(3) Type 304 stainless steel was used.

CROSS SECTION FOR REPLACEMENT OF
D BY H BOMBARDMENT: SS TARGET

Replacement Efficiency of D in Stainless Steel

by Subsequent H Impact

(normal incidence, temperature 150 K)

The data are for 1-, 4-, 7-, and 14-keV D replaced,
 respectively, by 1-, 4-, 7-, and 14-keV H;
 the result is independent of energy.

Fluence Relative to Saturation (n_H/n_{sat})	Replacement Efficiency Deuterium Released per Incident Proton dn_D/dn_H
<hr/>	
0.0 E 00	1.0 E 00
5.0 E-01	5.4 E-01
1.0 E 00	2.8 E-01
1.5 E 00	1.6 E-01
2.0 E 00	1.1 E-01
2.5 E 00	1.0 E-01
3.0 E 00	8.0 E-02
3.5 E 00	6.0 E-02

Reference:R. S. Blewer et al., J. Nucl. Mater. 76 & 77, 305 (1978).Accuracy: $\pm 10\%$

Notes: (1) For explanation of this parameter see note 3 at the beginning of this section.

(2) Type 321 stainless steel was used.

D.6.41

REPLACEMENT EFFICIENCY OF D
IN SS BY H IMPACT

Reemission of Deuterium Due to D^+ Impact on Ni
at Various Temperatures

(normal incidence, various temperatures,
18-keV energy)

Fluence Incident (D^+ ions/cm ²)	Reemission Rate (%)		
	<u>208 K</u>	<u>273 K</u>	<u>323 K</u>
0.0 E 00	0.0 E 00	0.0 E 00	0.0 E 00
1.0 E 16	3.0 E 00	5.0 E 00	4.9 E 01
2.0 E 16	6.0 E 00	9.0 E 00	6.3 E 01
3.0 E 16	7.0 E 00	1.2 E 01	6.8 E 01
4.0 E 16	8.0 E 00	1.5 E 01	7.1 E 01
5.0 E 16	8.0 E 00	1.8 E 01	7.3 E 01
7.0 E 16	8.0 E 00	2.4 E 01	7.4 E 01
1.0 E 17	8.0 E 00	3.3 E 01	7.4 E 01
1.5 E 17	9.0 E 00	4.3 E 01	
2.0 E 17	1.8 E 01	4.8 E 01	
2.5 E 17		5.3 E 01	

Reference:

K. Erents and G. M. McCracken, Br. J. Appl. Phys. (J. Phys. D) Ser. 2, 2, 1397 (1969).

Accuracy: Unknown

Notes: (1) For a definition of reemission and how it relates to trapping, see note 1 at the beginning of this section.

(2) A measurement at lower temperature (77 K) is given by K. Erents and G. M. McCracken, Radiat. Eff., 3, 123 (1970).

D.6.43

REEMISSION OF DEUTERIUM
DUE TO D^+ IMPACT ON NI

D.6.44

Trapping Coefficient as a Function of Temperature

at a Fixed Fluence (or Dose) for 18-keV D^+ Incident on Zr

(normal incidence; various temperatures; fixed fluence, or dose, of 5×10^{18} ions cm^{-2} ; energy of 18 keV: polycrystalline target)

Temperature (K)	Trapping Coefficient
<hr/>	
2.0 E 02	5.5 E-01
3.0 E 02	9.6 E-01
4.0 E 02	9.6 E-01
5.0 E 02	9.4 E-01
6.0 E 02	8.7 E-01
7.0 E 02	6.6 E-01
8.0 E 02	4.3 E-01
9.0 E 02	3.6 E-01
1.0 E 03	3.5 E-01

Reference:

G. M. McCracken, et al., Proc. 4th Int. Vacuum Congress, Inst. Phys. Conf. Ser. 5, 149 (1968).

Accuracy: Unknown. The random scatter of the data points about the line shown here is approximately $\pm 10\%$.

Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) The data are for a fixed incident fluence (or dose) of 5×10^{18} D^+ ions cm^{-2} . For information on how trapping coefficient varies with incident fluence, see adjacent figures.

TRAPPING COEFFICIENT VS. TEMPERATURE
FOR 18-KEV D^+ INCIDENT ON ZR

Trapping Coefficient as a Function of Dose for

18-keV D^+ Incident on Zr(normal incidence, various temperatures,
polycrystalline target)

Fluence Incident (D^+ ions/cm ²)	Trapping Coefficient			
	<u>477 K</u>	<u>598 K</u>	<u>699 K</u>	<u>988 K</u>
1.0 E 17				9.3 E-01
2.0 E 17				9.0 E-01
3.0 E 17	9.7 E-01		9.0 E-01	8.5 E-01
5.0 E 17	9.7 E-01		8.5 E-01	7.5 E-01
7.0 E 17	9.7 E-01		8.0 E-01	6.6 E-01
1.0 E 18	9.7 E-01		7.5 E-01	5.5 E-01
2.0 E 18	9.7 E-01	9.1 E-01	6.1 E-01	3.6 E-01
3.0 E 18	9.7 E-01	8.8 E-01	5.3 E-01	2.8 E-01
5.0 E 18	9.7 E-01	8.4 E-01		2.1 E-01
7.0 E 18	9.7 E-01	8.1 E-01		
1.0 E 19	9.7 E-01	7.7 E-01		

Reference:E. S. Hotston and G. M. McCracken, J. Nucl. Mater. 68, 277 (1977).Accuracy: UnknownNotes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) The cited reference includes additional data at intermediate temperatures.

D.6.47

TRAPPING COEFFICIENT VS. DOSE FOR
18-KEV D⁺ INCIDENT ON IR

Trapping Coefficient as a Function of
Energy at a Fixed Dose for H^+ Incident on Zr
(normal incidence, temperature in the region
403 to 503 K, polycrystalline target)

Energy (keV)	Trapping Coefficient
<hr/>	
3.0 E-01	2.0 E-01
5.0 E-01	2.8 E-01
1.0 E 00	5.0 E-01
2.0 E 00	6.9 E-01
3.0 E 00	7.7 E-01
4.0 E 00	8.0 E-01
5.0 E 00	8.2 E-01
6.0 E 00	8.3 E-01

Reference:

J. Bohdanský et al., J. Nucl. Mater. 63, 115 (1969).

Accuracy: See below.

Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) Below 2 keV the data are believed to represent not Zr, but rather zirconium oxide, which exists as a film on the sample. Thus, below 2 keV the data (insofar as they refer to Zr) are suspect.

(3) Fluence, or dose, used in the bombardment was between 3×10^{19} and 5×10^{20} ions cm^{-2} .

D.6.49

TRAPPING COEFFICIENT VS. ENERGY
FOR H^+ INCIDENT ON ZR

Trapping Coefficient as a Function of Dose for

18-keV D^+ Incident on Nb(normal incidence, various temperatures,
polycrystalline target)

Fluence Incident (D^+ ions/ cm^2)	Trapping Coefficient			
	<u>77 K</u>	<u>328 K</u>	<u>453 K</u>	<u>563 K</u>
1.0 E 16	9.9 E-01		9.6 E-01	
2.0 E 16	9.9 E-01		9.6 E-01	9.5 E-01
3.0 E 16	9.9 E-01		9.6 E-01	9.3 E-01
5.0 E 16	9.9 E-01	9.8 E-01	9.6 E-01	8.9 E-01
7.0 E 16	9.9 E-01	9.8 E-01	9.6 E-01	8.0 E-01
1.0 E 17	9.9 E-01	9.8 E-01	9.5 E-01	7.0 E-01
2.0 E 17	9.9 E-01	9.8 E-01	9.4 E-01	5.1 E-01
3.0 E 17	9.9 E-01	9.8 E-01	9.4 E-01	4.0 E-01
5.0 E 17	9.9 E-01	9.7 E-01	9.3 E-01	2.7 E-01
7.0 E 17	9.7 E-01	9.6 E-01	9.2 E-01	2.5 E-01
1.0 E 18	9.3 E-01	9.5 E-01	9.1 E-01	2.4 E-01
2.0 E 18	3.3 E-01	9.5 E-01	8.9 E-01	2.4 E-01
3.0 E 18	2.0 E-01	9.5 E-01	8.8 E-01	2.4 E-01
5.0 E 18	1.4 E-01	9.5 E-01	8.7 E-01	2.4 E-01

References:

G. M. McCracken et al., Proc. 4th Int. Vacuum Congress, Inst. Phys. Conf. Ser. 5, 149 (1968).

Accuracy: Unknown

Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) The cited reference includes additional data at intermediate temperatures.

(3) Trapping in niobium is strongly influenced by preexisting defects and damage; see J. Bottinger et al., J. Appl. Phys. 48, 920 (1977).

D.6.51

TRAPPING COEFFICIENT VS. DOSE
FOR 18-KEV D^+ INCIDENT ON NE

Trapping Coefficient as a Function of Temperature
 at a Fixed Fluence (or Dose) for 18-keV D^+ Incident on Nb
 (normal incidence; various temperatures; fixed fluence,
 or dose, of 5×10^{18} ions cm^{-2} ; polycrystalline target)

Temperature (K)	Trapping Coefficient
<hr/>	
1.0 E 02	1.3 E-01
2.0 E 02	8.0 E-01
3.0 E 02	9.6 E-01
4.0 E 02	9.3 E-01
5.0 E 02	7.4 E-01
6.0 E 02	2.3 E-01
7.0 E 02	1.4 E-01
8.0 E 02	6.0 E-02
9.0 E 02	3.0 E-02

Reference:

G. M. McCracken et al., Proc. 4th Int. Vacuum Congress, Inst. Phys. Conf. Ser. 5, 149 (1968).

Accuracy: Unknown. The random scatter of the data points about the line shown here is approximately $\pm 10\%$.

Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) The data are for a fixed incident fluence (or dose) of 5×10^{18} D^+ ions cm^{-2} . For information on how trapping coefficient varies with incident fluence, see adjacent figures.

(3) Trapping in niobium is strongly influenced by preexisting defects and damage; see J. Bottinger et al., J. Appl. Phys. 48, 920 (1977).

D.6.53

TRAPPING COEFFICIENT VS. TEMPERATURE
FOR 18-KEV D^+ INCIDENT ON NB

1.1.1.1
Trapped Fluence as a Function of Incident Fluence
for D^+ on Mo with Various Predamage Conditions

(normal incidence; room temperature; 8-keV
 D^+ energy; predamage by 11-keV He^+ to
the fluences shown; single crystal target).

Fluence Incident (D^+ ions/cm ²)	Fluence Trapped (D atoms/cm ²)			
	No Predamage	Predamage: $6 \times 10^{14} He/cm^2$	Predamage: $3 \times 10^{15} He/cm^2$	Predamage: $10^{16} He/cm^2$
0.0 E 00	0.0 E 00	0.0 E 00	0.0 E 00	0.0 E 00
1.0 E 16	2.5 E 15	7.0 E 15	7.0 E 15	7.0 E 15
2.0 E 16	5.5 E 15	1.1 E 16	1.3 E 16	1.3 E 16
3.0 E 16	8.0 E 15	1.3 E 16	2.0 E 16	2.0 E 16
4.0 E 16	1.0 E 16	1.5 E 16	2.3 E 16	2.7 E 16
5.0 E 16	1.1 E 16	1.7 E 16	2.5 E 16	3.0 E 16
6.0 E 16	1.2 E 16	1.8 E 16	2.7 E 16	3.2 E 16
7.0 E 16	1.3 E 16	2.0 E 16	2.8 E 16	3.3 E 16
8.0 E 16	1.4 E 16	2.2 E 16	3.0 E 16	3.5 E 16
9.0 E 16	1.5 E 16	2.3 E 16	3.2 E 16	3.7 E 16
1.0 E 17	1.6 E 16	2.5 E 16	3.4 E 16	3.9 E 16

Reference:

J. Bottinger et al., J. Appl. Phys. 48, 920 (1977).

Accuracy: Unknown

Notes: (1) For a definition of trapping see note 1b at the beginning of this section.

(2) "Predamage" is created by a preliminary bombardment with 11-keV He^+ to the dose indicated; no quantitative measure of the damage was made.

(3) The cited reference includes additional data for predamage with other projectiles (Ne^+ , Bi^+).

(4) The data are for an aligned single crystal of Mo. Limited studies on polycrystalline Mo show similar behavior [see S. T. Picraux et al., J. Nucl. Mater. 63, 110 (1976)].

(5) Additional data are to be found in work by G. M. McCracken and S. K. Erents, in Applications of Ion Beams to Metals, ed. by S. T. Picraux et al. (Plenum Publ. Corp., New York, 1974), p. 585.

TABLE

Trapping Coefficient as a Function of Dose for

18-keV D^+ Incident on Kr

(normal incidence, various temperatures,
polycrystalline target)

Fluence Incident (D^+ ions/cm ²)	Trapping Coefficient			
	77 K	280 K	458 K	1003 K
2.0 E 16	9.7 E-01	9.5 E-01	9.2 E-01	
3.0 E 16	9.7 E-01	9.5 E-01	9.2 E-01	8.5 E-01
5.0 E 16	9.7 E-01	9.4 E-01	9.2 E-01	8.5 E-01
7.0 E 16	9.7 E-01	9.4 E-01	9.2 E-01	8.5 E-01
1.0 E 17	9.7 E-01	9.3 E-01	9.2 E-01	8.5 E-01
2.0 E 17	9.7 E-01	9.2 E-01	9.2 E-01	8.3 E-01
3.0 E 17	9.7 E-01	9.0 E-01	9.2 E-01	8.2 E-01
5.0 E 17	9.7 E-01	8.6 E-01	9.0 E-01	8.1 E-01
7.0 E 17	9.6 E-01	8.3 E-01	9.0 E-01	8.0 E-01
1.0 E 18	9.2 E-01	8.4 E-01	9.0 E-01	7.9 E-01
2.0 E 18	1.8 E-01	1.8 E-01	9.0 E-01	7.7 E-01
3.0 E 18	1.4 E-01	1.7 E-01	9.0 E-01	7.6 E-01
5.0 E 18	1.0 E-01	1.5 E-01	9.0 E-01	7.3 E-01
7.0 E 18				7.1 E-01

Reference:

C. M. McCracken et al., Proc. 4th Int. Vacuum Congress, Inst. Phys. Conf. Ser. 2, 149 (1968).

Accuracy: Unknown

Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) The cited reference includes additional data at intermediate temperatures.

1.6.57

Trapping Coefficient as a Function of Temperature

at a Fixed Fluence (or Dose) for

18-keV D^+ Incident on Br

(normal incidence; various temperatures;
fixed fluence, or dose, of 5×10^{18} ions cm^{-2} ;
polycrystalline target)

Temperature (K)	Trapping Coefficient
1.0 E 02	1.0 E-01
2.0 E 02	1.0 E-01
3.0 E 02	2.3 E-01
4.0 E 02	7.6 E-01
5.0 E 02	9.2 E-01
6.0 E 02	9.3 E-01
7.0 E 02	9.2 E-01
8.0 E 02	8.9 E-01
9.0 E 02	8.3 E-01
1.0 E 03	7.3 E-01

Reference:

G. M. McCracken et al., Proc. 4th Int. Vacuum Congress, Inst. Phys. Conf. Ser. 2, 149 (1968).

Accuracy: Unknown. The random scatter of the data points about the line shown here is approximately $\pm 10\%$.

Notes: (1) For a definition of trapping coefficient see note 1d at the beginning of this section.

(2) The data are for a fixed incident fluence (or dose) of 5×10^{18} D^+ ions cm^{-2} .

100.0

THE EFFECT OF TEMPERATURE ON THE THERMAL STABILITY OF POLYMERIZATION OF VINYL MONOMERS