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Report

RESULTS OF MONTE-CARLO STUDIES ON BACKSCATTERING AND SPUTTERING FROM "POCKET" AND "FINNED" STRUCTURES

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ABSTRACT

A Monte-Carlo computer program which has been developed for studying backscattering and sputtering processes involving high energy particles in complex vacuum structures has been used to show that useful reductions in backscattering and sputtering can be achieved by pocketing or finning the wall surfaces of plasma containment vessels.

*The work described in this report was carried out under contract to JET who have kindly given permission for the more general release of the results obtained.

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1. OBJECTIVES

1.1 The aim of the work described was to find how much backscattering and sputtering from a surface bombarded by energetic particles having a cosine incidence distribution could be reduced by making the surface a "pocket" or "finned" structure.

2. OUTCOME

2.1 Calculations show that reductions by factors between 2.3 and 2.6, relative to a "plane surface," can be achieved in the flux of sputtered material by using a "cylindrical pocket" structure. For the same structure the reduction in the flux of backscattered particles is by factors between 3.1 and 4.1. No significant reduction in the flux of sputtered material is achieved above a length to diameter ratio of about 2/1, although a slightly greater reduction in the flux of backscattered particles is likely for deeper pockets.

2.2 Honeycombing a wall with "cylindrical pockets" leaves approximately 10% of the surface area as a "plane surface." It is expected that the performance achieved by a "cylindrical pocket" would also be achieved by a "hexagonal pocket" which would give very little "plane surface" area. A hexagonal honeycomb structure should be easier to fabricate.

2.3 Useful reductions in the flux of backscattered and sputtered material can be achieved by using "rectangular fin" and "triangular fin" structures. The asymptotic ratio of depth to width for both of these structures is about 2/1. The "rectangular fin" structure gives reductions in the sputtering yield by factors between 2.0 and 2.8, and reductions in the flux of backscattered particles by factors between 2.3 and 2.9. For the "triangular fin" the flux of sputtered material is reduced by factors between 1.3 and 2.5 and backscattered particles by factors between 2.1 and 2.7.

2.4 The reduction in the backscattering coefficient is greatest at incidence energy 10keV and least at 1keV. The reduction in the sputtering coefficient is least at 5keV, greater reduction being achieved at 1keV and 10keV.

3. COMPUTER CALCULATIONS

3.1 These studies were performed using the Monte Carlo computer program, developed under joint JET and Culham sponsorship, for studying backscattering and sputtering in practical vacuum structures[(1)]. The program has been tested[(1)] to ensure that the modelling of the backscattering and sputtering processes gives results which are comparable to available experimental information.

3.2 Calculations were performed using a "plane surface," a "cylindrical pocket," a "rectangular fin" and a "triangular fin" structure. Length to diameter or depth to width ratios 1/1 and 2/1 were examined. The material of the surface and of the structures was chosen to be molybdenum. Each structure was bombarded uniformly over its entrance aperture with protons at incidence energies of 1keV, 5keV and 10keV, within a cosine distribution of incidence angles. The backscattering and sputtering coefficients obtained from the "plane surface" calculations were used as a basis of comparison for determining the reduction in the flux of backscattered particles and sputtered material from the "pocket" and "finned" structures.

3.3 Diagrams of the three types of "pocket" and "finned" structures studied are shown in Figure 1.

3.4 A table showing the calculated backscattering and sputtering coefficients[†] is given in Figure 2. Graphs of the backscattering and sputtering coefficients as functions of length to diameter or depth to width ratios are shown in Figures 4 to 9 inclusive.

3.5 A table giving the reduction in backscattering and sputtering for the asymptotic ratio of each structure, relative to a "plane surface," is shown in Figure 3.

3.6 The energy distributions of backscattered particles from the "plane surface" and from a 2/1 length to diameter ratio "cylindrical pocket" structure are plotted as a function of the relative emergence energy E/Eo and are shown in Figures 10 to 15 inclusive. The distributions obtained for the "rectangular fin" and "triangular fin" structures were similar to these.

3.7 The energy distributions of back-scattered particles from the "plane surface" and the "cylindrical pocket" structure show a "spike" just below the incidence energy. The "spike" is most significant at an incidence energy of 1keV, and least significant at 10keV. The "rectangular fin" and "triangular fin" structures produced similar distributions. It has not, as yet, been possible to ascertain the validity of the "spike" due to the lack of experimental results available for back-scattering at low incidence energies.

3.8 Polar diagrams of the angular distributions of particles backscattered with energy greater than 10eV, and of sputtered material, have been plotted for the "plane surface" and for a 2/1 length to diameter ratio "cylindrical pocket" structure. These are shown in Figures 16 to 21 inclusive.

The angular distributions obtained for the "rectangular" fin and "triangular" fin structures are similar to those shown. For sputtered material, especially, the statistics are too poor to obtain clear pictures of the angular distributions. Longer and more costly Monte Carlo calculations would be required to obtain more accurate pictures of the angular distributions.

3.9 To check if the 2/1 length to diameter or depth to width ratio was sufficiently close to the asymptote for protons incident at 10keV, a further calculation was performed using a "triangular fin" molybdenum structure with a depth to width ratio of 3/1. The protons were introduced as previously with incidence energy of 10keV. The results obtained showed no significant reduction in the flux of sputtered material. It seems likely that this would also be the case for "cylindrical pocket" and "rectangular fin" structures of ratios greater than 2/1. This assumption is based on the similarity in the trend of results of the various structures at both 1keV and 5keV incidence energies.

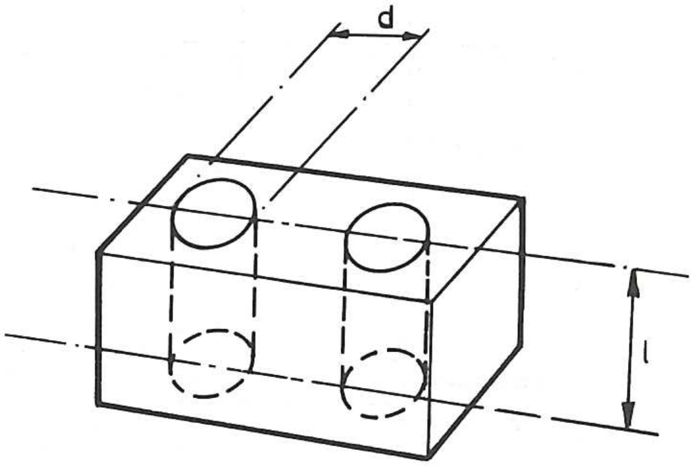
3.10 Using a wall formed with close packed "cylindrical pockets" approximately 10% of the surface area would be a "plane surface," and the effective backscattering and sputtering coefficients would be slightly larger than were obtained in the above calculations. Using "cylindrical pockets" with length to diameter ratios of 2/1 the effective backscattering coefficients would be 0.2189, 0.1405 and 0.1001 for incidence energies of 1keV, 5keV and 10keV respectively. For the same incidence energies, the effective sputtering coefficients would be 0.0026, 0.0032 and 0.0023.

3.11 It is expected that the performance achieved by a "cylindrical pocket" would also be achieved by a hexagonal section pocket. As a surface honeycomb structure this would have very little "plane surface" front area and so should provide the reduction in backscattering and sputtering calculated for individual "cylindrical pockets." A hexagonal honeycomb structure should also be easier to fabricate.

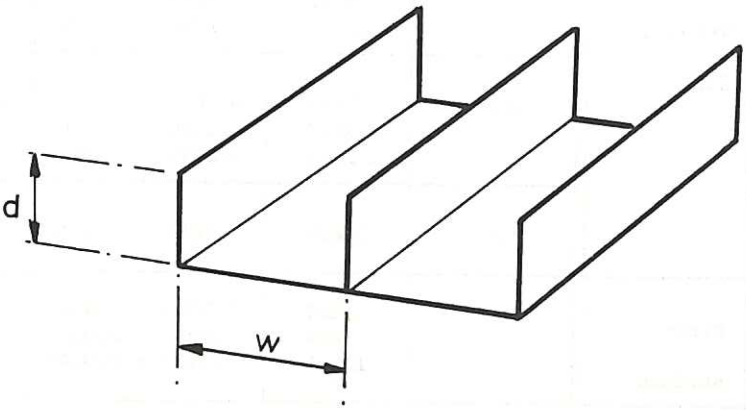
REFERENCES

1. Brown K P. A Monte Carlo computer program for analysis of backscattering and sputtering in practical vacuum systems. Culham Report CLM-R181, January 1978.
2. Bay H L, Roth J. and Bohdansky J. Light ion sputtering yields for molybdenum and gold at low energies. J. Appl. Phys. 48, p.4722-4728, November 1977.

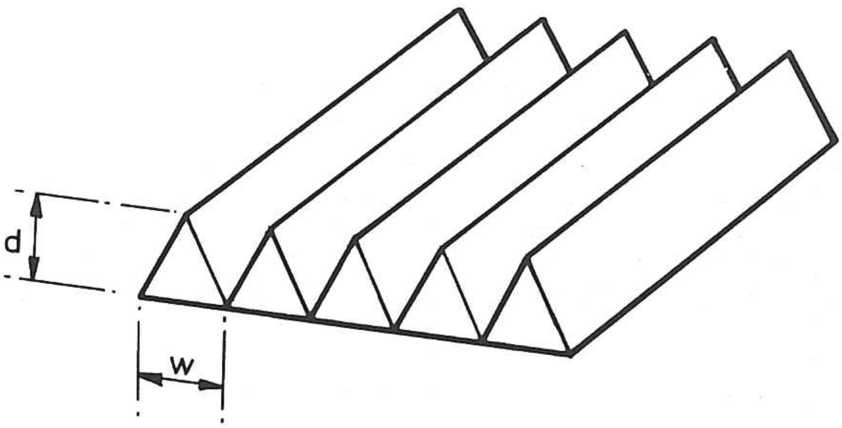
†Recent studies by Bay et al[2] for H^+ incident on Mo indicate sputtering co-efficients possibly a factor of 3 lower than obtained by the parameters used in running the program[1] for the present studies. Although this will affect the values of effective sputtering coefficients of plane surfaces, no significant change is expected in the relative advantages of the different methods of pocketing.



(a) Cylindrical Pockets



(b) Rectangular Fins



(c) Triangular Fins

Fig.1 The JET structures studied using Monte-Carlo.

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Type of structure	l/d or d/w ratio of pocket	Incident energy	Effective backscattering coefficient	Effective sputtering coefficient
Cylindrical pockets	1:1	1keV	0.2088 ± 0.0034	0.0011 ± 0.0003
		5keV	0.1303 ± 0.0036	0.0024 ± 0.0005
		10keV	0.0862 ± 0.0028	0.0029 ± 0.0005
	2:1	1keV	0.1799 ± 0.0030	0.0022 ± 0.0004
		5keV	0.1111 ± 0.0032	0.0028 ± 0.0005
		10keV	0.0761 ± 0.0027	0.0020 ± 0.0004
Rectangular fins	1:1	1keV	0.3236 ± 0.0054	0.0033 ± 0.0006
		5keV	0.2058 ± 0.0043	0.0044 ± 0.0007
		10keV	0.1500 ± 0.0036	0.0037 ± 0.0006
	2:1	1keV	0.2376 ± 0.0050	0.0026 ± 0.0006
		5keV	0.1583 ± 0.0040	0.0033 ± 0.0006
		10keV	0.1063 ± 0.0032	0.0016 ± 0.0004
Triangular fins	1:1	1keV	0.3462 ± 0.0054	0.0027 ± 0.0006
		5keV	0.2283 ± 0.0044	0.0049 ± 0.0007
		10keV	0.1494 ± 0.0036	0.0033 ± 0.0006
	2:1	1keV	0.2693 ± 0.0052	0.0023 ± 0.0005
		5keV	0.1790 ± 0.0042	0.0050 ± 0.0008
		10keV	0.1171 ± 0.0033	0.0020 ± 0.0005
	3:1	10keV	0.1085 ± 0.0032	0.0020 ± 0.0004
Plane surface		1keV	0.5698 ± 0.0060	0.0059 ± 0.0008
		5keV	0.4055 ± 0.0054	0.0066 ± 0.0008
		10keV	0.3163 ± 0.0049	0.0046 ± 0.0007

Fig.2 Table of effective backscattering and sputtering coefficients obtained from the JET calculations.

	CYLINDRICAL POCKET		RECTANGULAR FIN		TRIANGULAR FIN	
Incidence energy of protons	Reduction factor for backscattering	Reduction factor for sputtering	Reduction factor for backscattering	Reduction factor for sputtering	Reduction factor for backscattering	Reduction factor for sputtering
1 keV	3.16	2.68	2.39	2.26	2.11	2.56
5 keV	3.64	2.35	2.56	2.00	2.26	1.32
10 keV	4.15	2.30	2.97	2.87	2.70	2.30

Fig.3 Reduction factors, relative to a 'plane surface', for 'pocket' and 'finned' structures with ℓ/d and d/w ratios of 2/1.

BACKSCATTERING COEFFICIENTS OBTAINED FROM 'POCKET' AND 'FINNED' STRUCTURES.

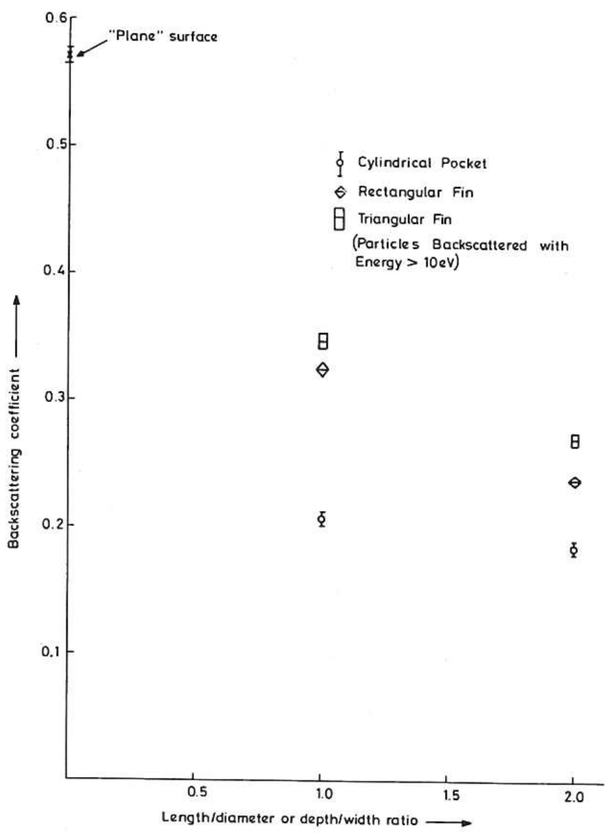

Fig.4 H^+ incident on Mo at 1 keV.

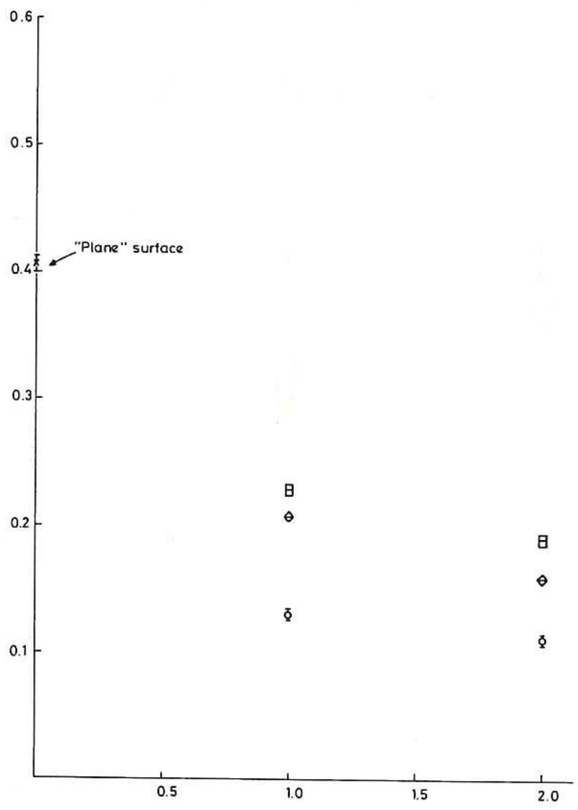

Fig.5 H^+ incident on Mo at 5keV.

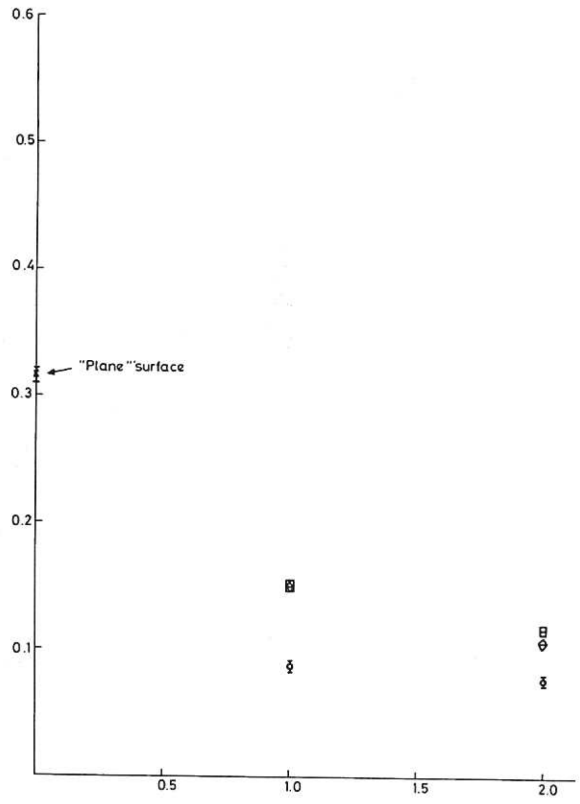

Fig.6 H^+ incident on Mo at 10keV.

SPUTTERING COEFFICIENTS OBTAINED FROM 'POCKET' AND 'FINNED' STRUCTURES.

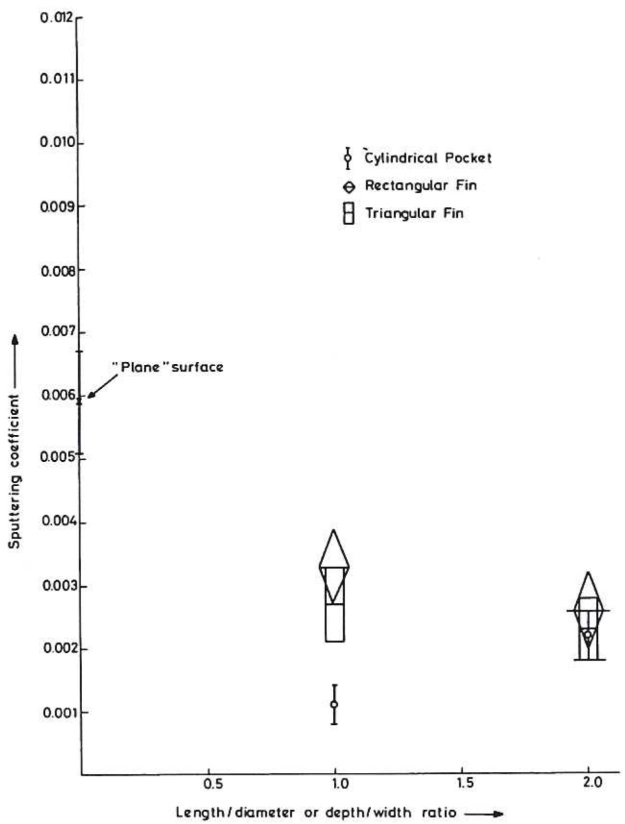

Fig.7 H^+ incident on Mo at 1keV.

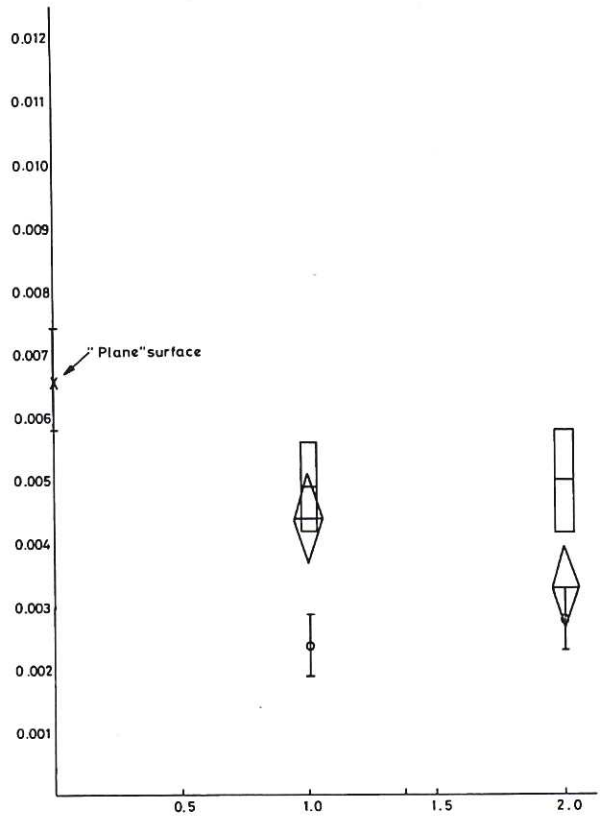

Fig.8 H^+ incident on Mo at 5keV.

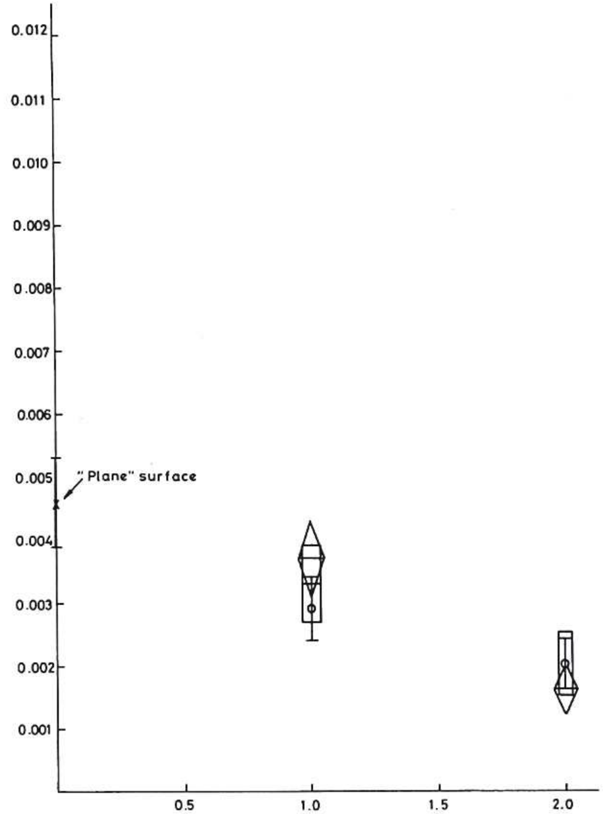

Fig.9 H^+ incident on Mo at 10keV.

ENERGY DISTRIBUTION OF BACKSCATTERED PRIMARY PARTICLES FROM A 'PLANE SURFACE' MOLYBDENUM STRUCTURE.

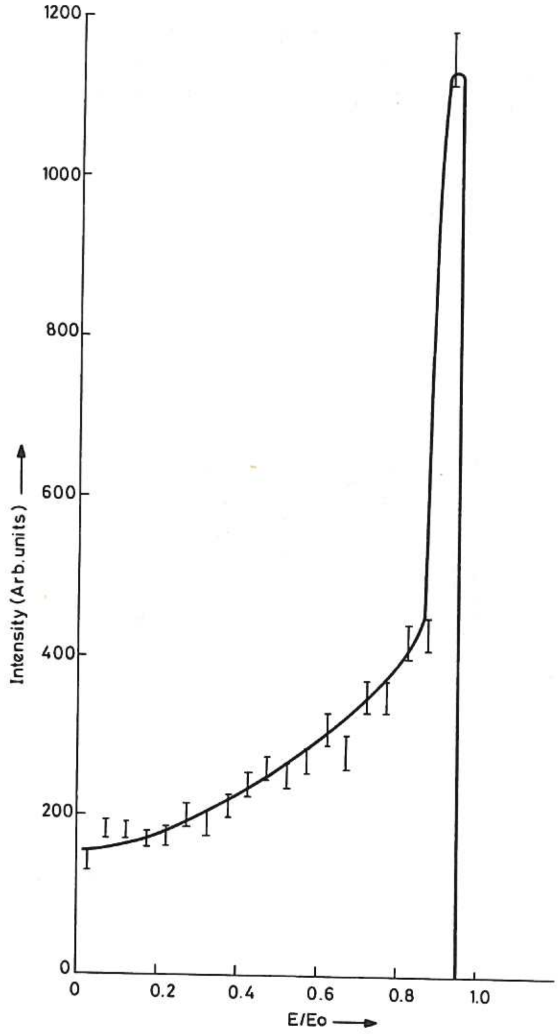

Fig.10 H^+ incident on Mo at 1keV within a cosine distribution of incidence angles over the surface.

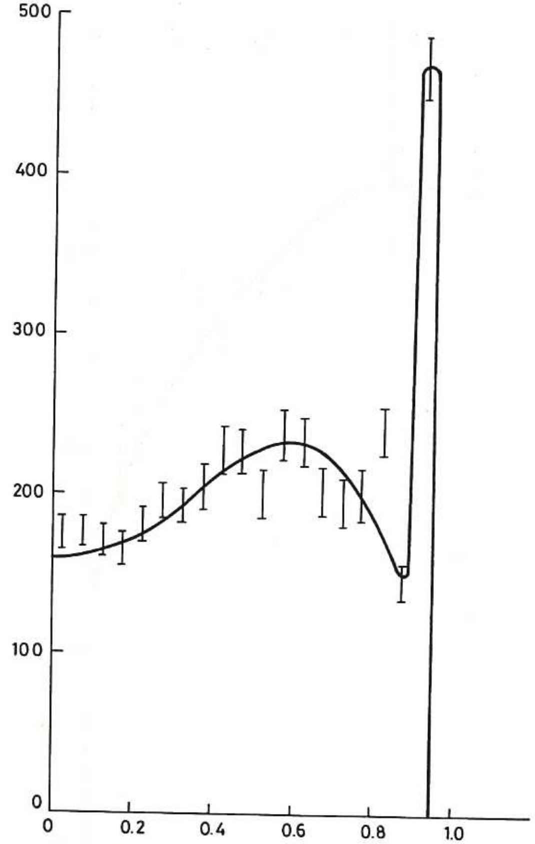

Fig.11 H^+ incident on Mo at 5keV within a cosine distribution of incidence angles over the surface.

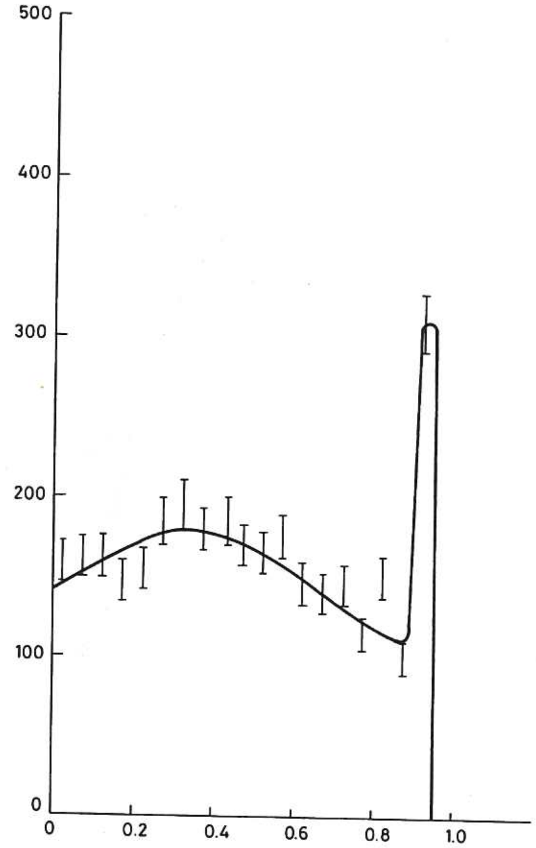

Fig.12 H^+ incident on Mo at 10keV within a cosine distribution of incidence angles over the surface.

ENERGY DISTRIBUTION OF BACKSCATTERED PRIMARY PARTICLES
FROM A 'CYLINDRICAL POCKET' MOLYBDENUM STRUCTURE ($\ell/d = 2/1$)

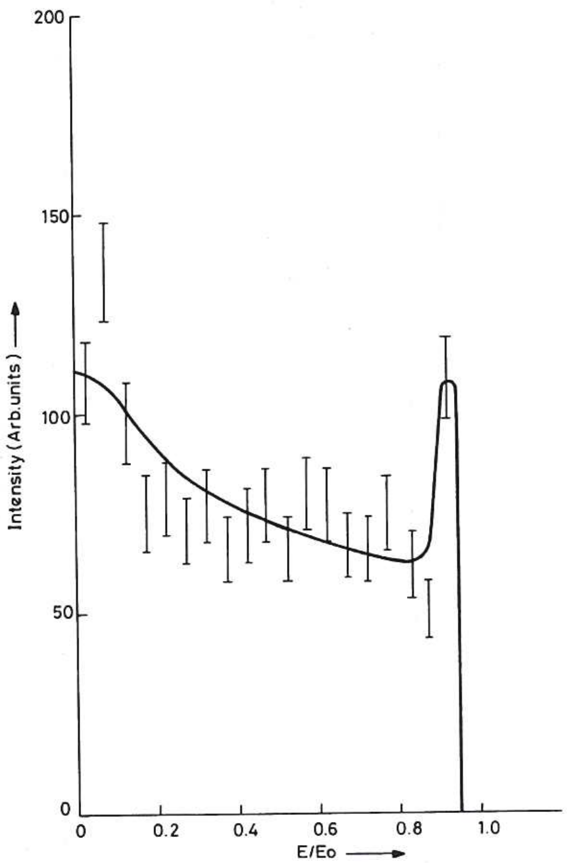

Fig.13 H^+ incident on Mo at 1keV within a cosine distribution of incidence angles over the entrance aperture of the "pocket".

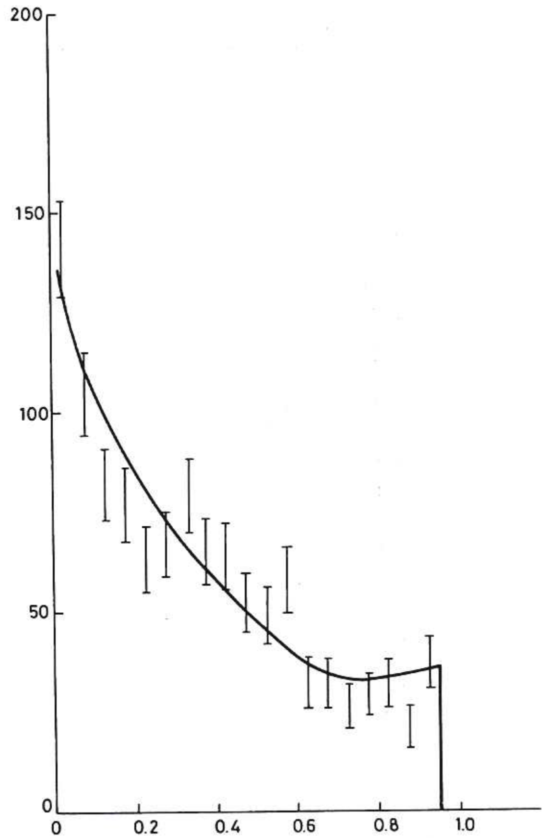

Fig.14 H^+ incident on Mo at 5keV within a cosine distribution of incidence angles over the entrance aperture of the "pocket".

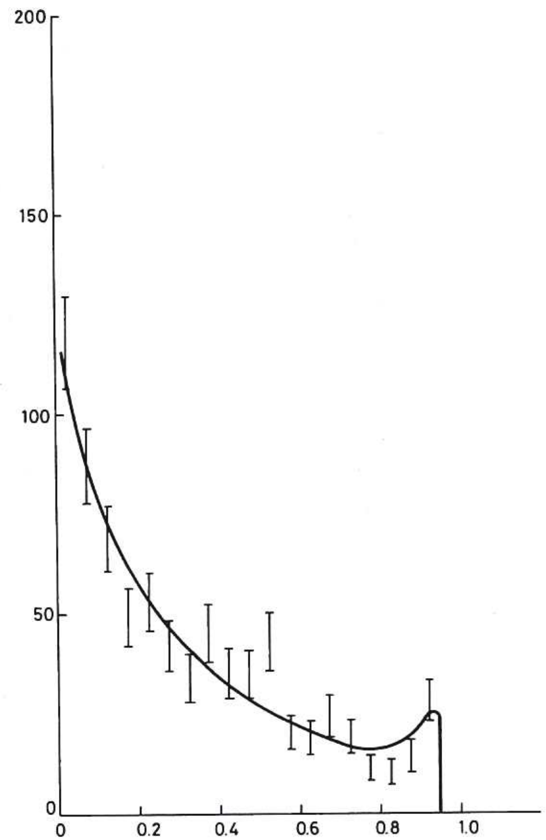

Fig.15 H^+ incident on Mo at 10keV within a cosine distribution of incidence angles over the entrance aperture of the "pocket".

ANGULAR DISTRIBUTIONS OF BACKSCATTERED AND SPUTTERED PARTICLES FROM A 'PLANE SURFACE' MOLYBDENUM STRUCTURE.

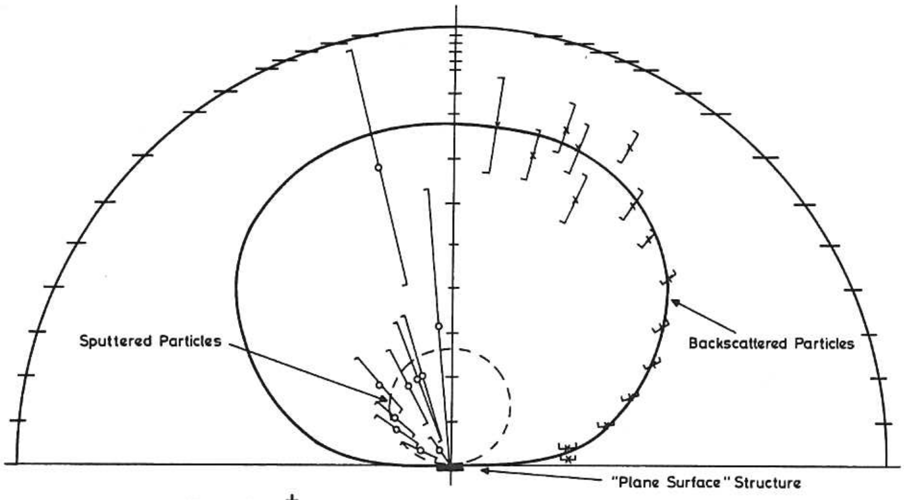

Fig.16 H^+ incident on Mo at 1keV within a cosine distribution of incidence angles over the surface.

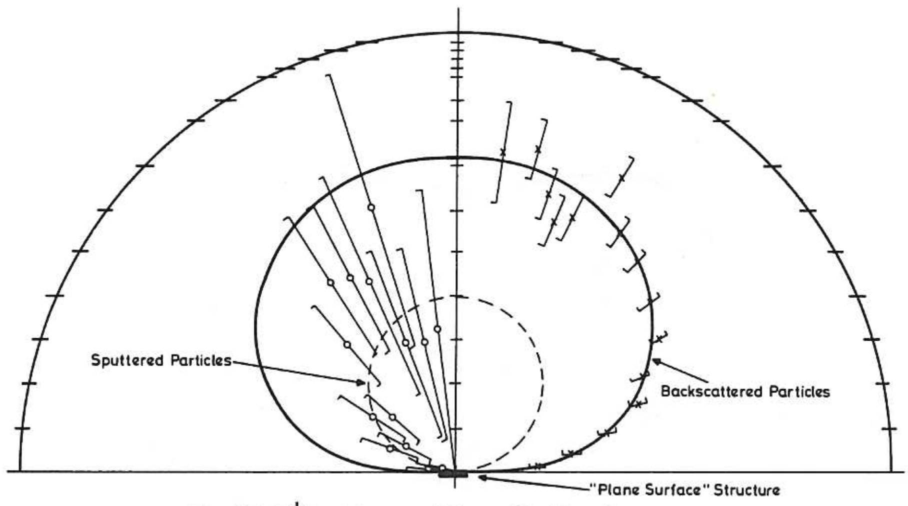

Fig.17 H^+ incident on Mo at 5keV within a cosine distribution of incidence angles over the surface.

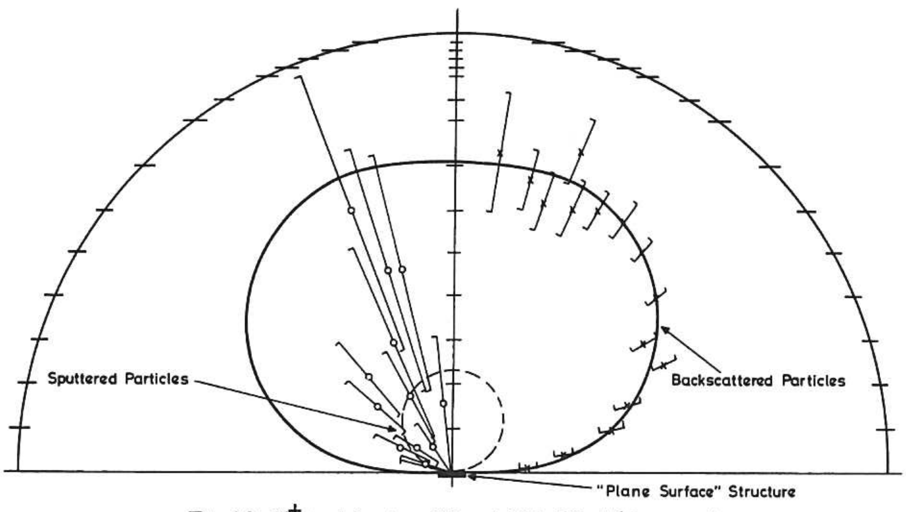

Fig.18 H^+ incident on Mo at 10keV within a cosine distribution of incidence angles over the surface.

ANGULAR DISTRIBUTIONS OF BACKSCATTERED AND SPUTTERED PARTICLES FROM A 'CYLINDRICAL POCKET' MOLYBDENUM STRUCTURE (ℓ/d = 2/1)

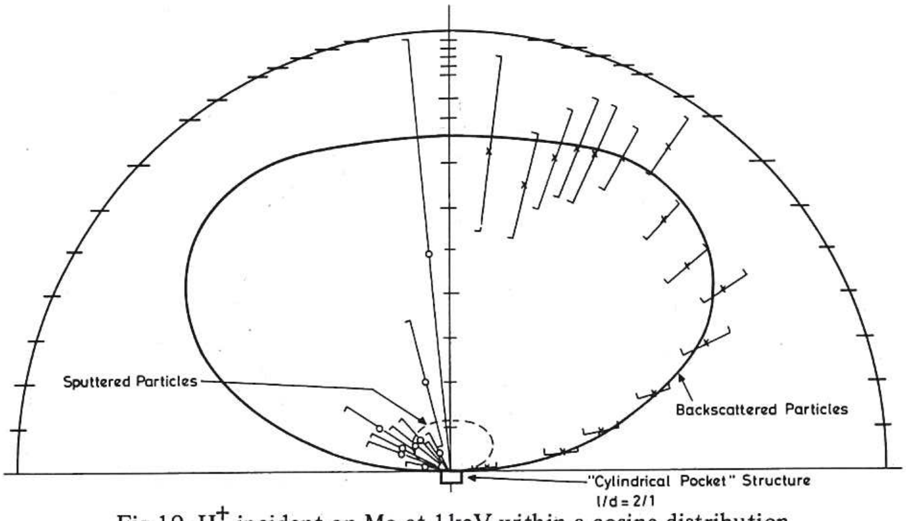

Fig.19 H^+ incident on Mo at 1 keV within a cosine distribution of incidence angles over the entrance aperture of the "pocket".

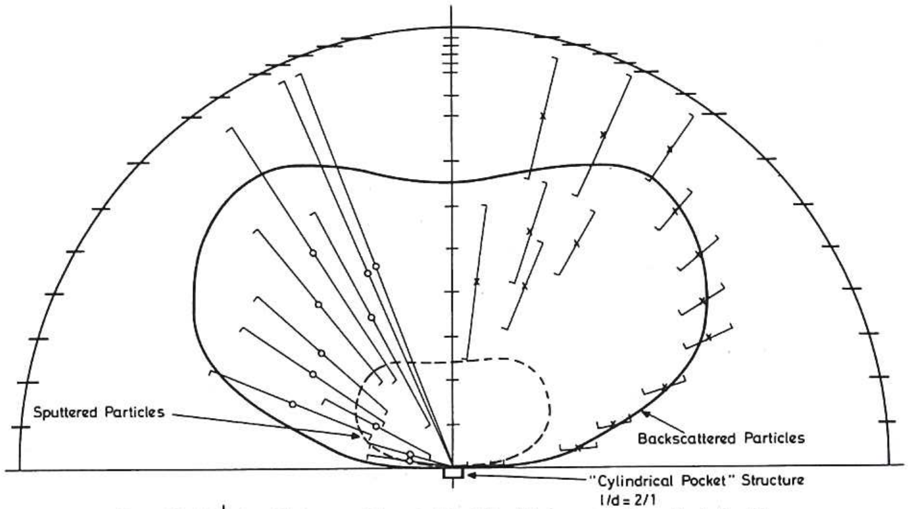

Fig.20 H^+ incident on Mo at 5 keV within a cosine distribution of incidence angles over the entrance aperture of the "pocket".

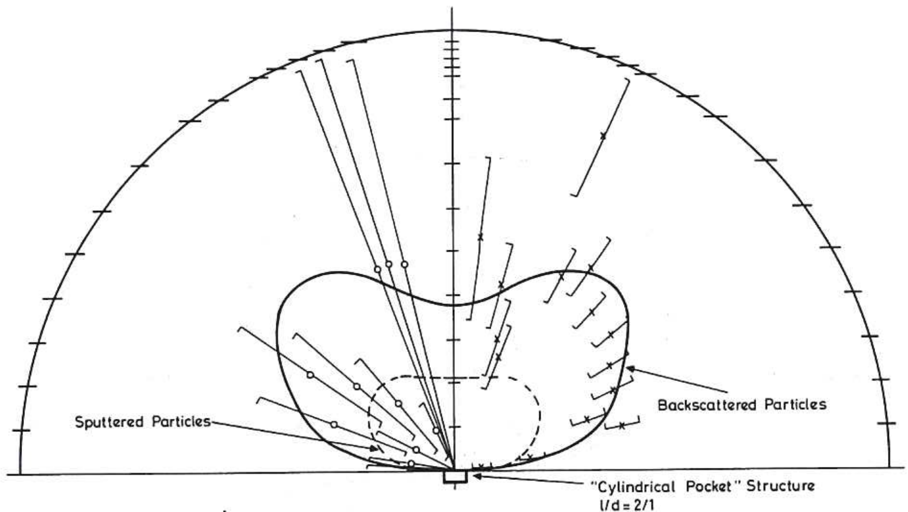

Fig.21 H^+ incident on Mo at 10 keV within a cosine distribution of incidence angles over the entrance aperture of the "pocket".

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