Assessment of Contamination from Ion Beam Impingement

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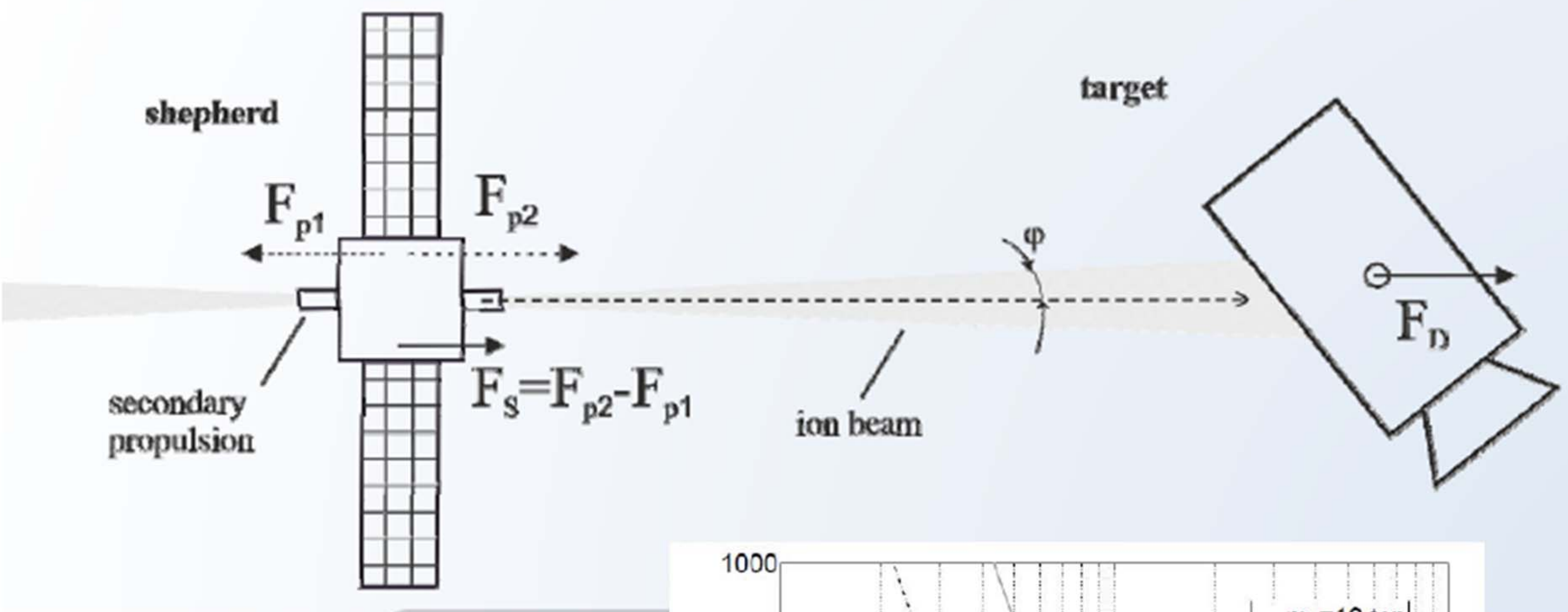
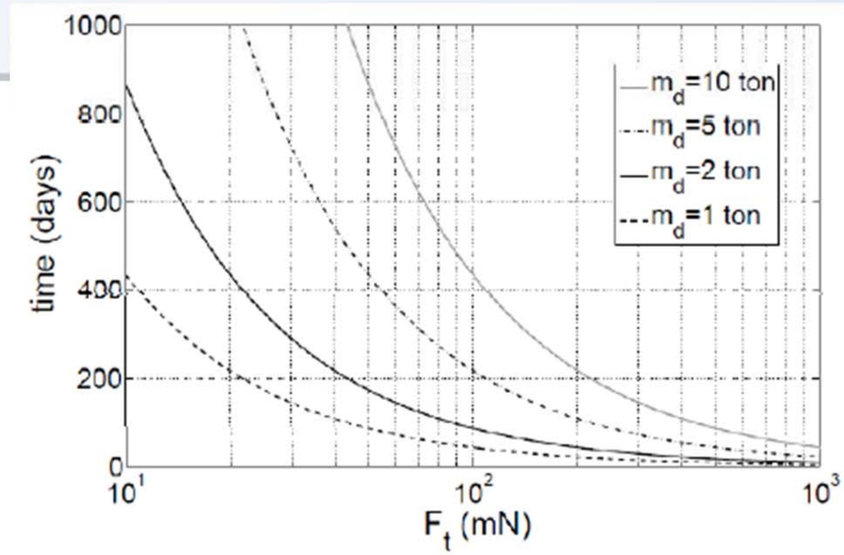
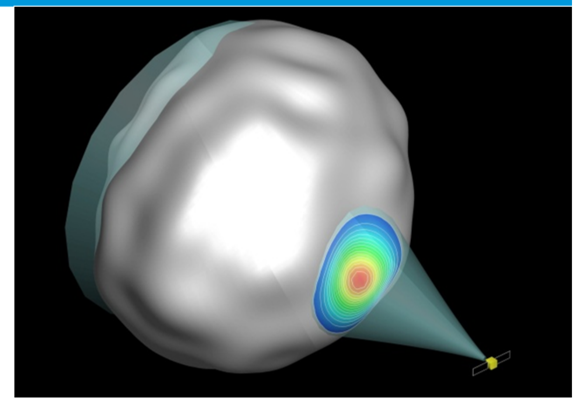
Ion beams Shepherd





Introduction - Ion beams Shepherd

- Electric propulsion is becoming common in space missions
- This works by emitting ions at high velocities
- Typically Xenon is propellant
- Ion energy is typically 1keV



Space Dynamics Group - Universidad Politécnica de Madrid

Thruster type	Xe Hall	Xe ion
Power range, W	300–6000	200–4000
I_{sp}, s (typical)	1600	2800
η (typical)	50%	65%
Plume divergence	30–40 deg	<20 deg
Thrust (mN)	~100	~100

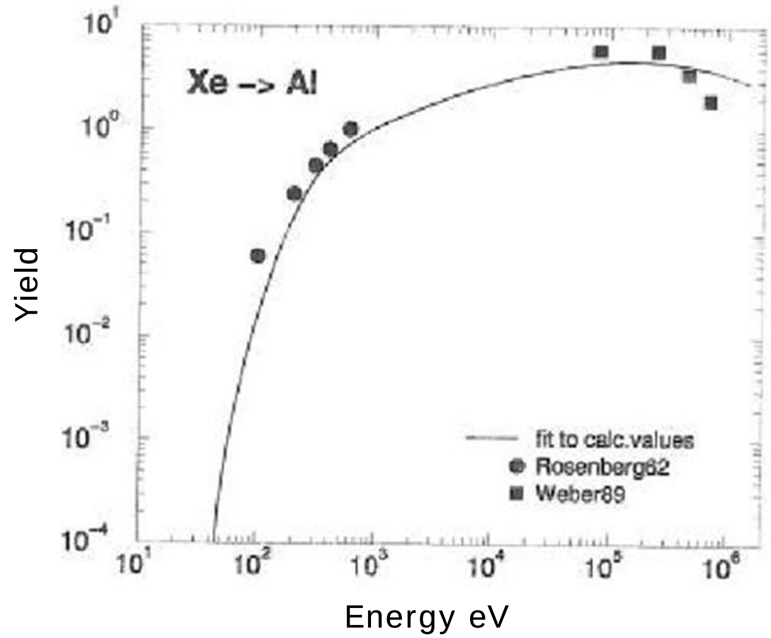
- Those characteristics lead to a potentially high backward flux of contaminants on the primary spacecraft - due to sputtering of the surface of the secondary object (i.e. asteroid, debris or spacecraft)

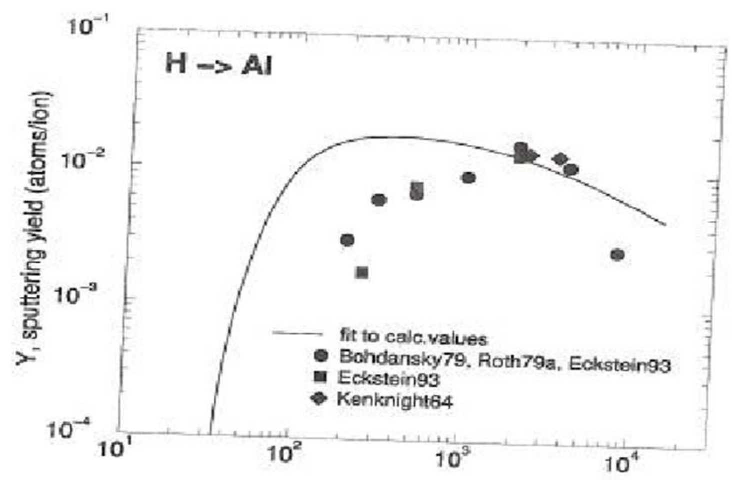
Sputtering by momentum transfer

- This is the ejection of surface atoms
- Momentum transfer from an impacting ion is the main mechanism
- Where surface atoms receive energy greater than binding energy, they are ejected
- The number of ejected atoms per ion is the sputtering yield

For many (metallic) materials/oxides, the yield for 1keV Xe+ ions is around 1.

A porous material will experience lower yield because of trapping of sputtered atoms.

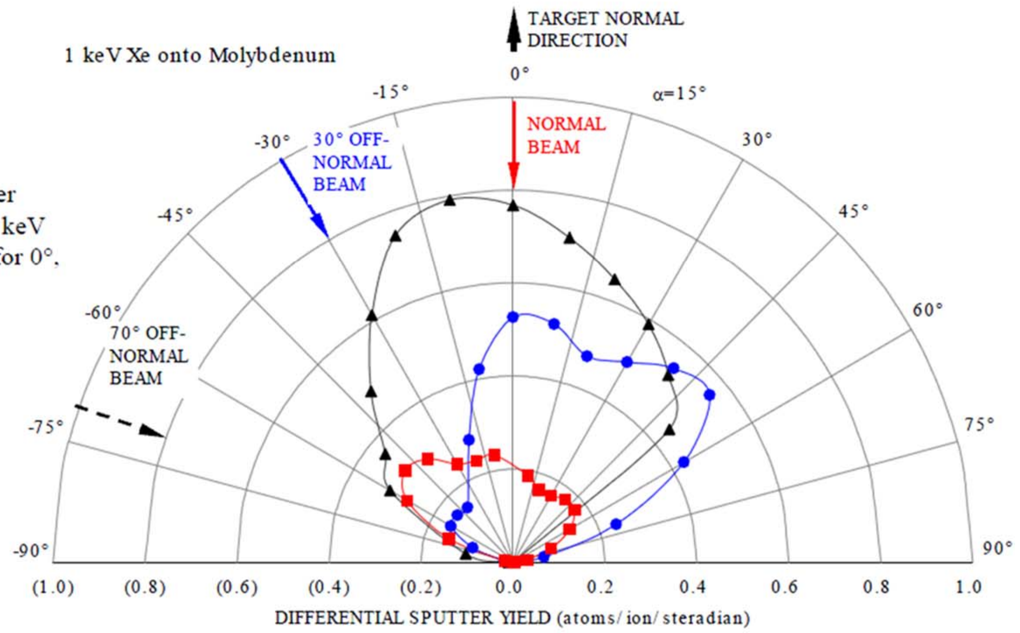




Sputtering by momentum transfer

Sputtering of compounds : various effects (partial yields, surface concentration, presence of volatiles, surface porosity, species reactivity, etc …)

Fig. 6a Differential sputter yield measurements for 1 keV Xe ions on a Mo target (for 0°, 30°, and 70° incidence)



Consequences:

- Erosion of the secondary object's surface
- Return flux of sputtered atoms to the primary spacecraft

Simple scaling rules

$$I = \frac{\text{Thrust}.e}{I_{sp} g_0 m_i}$$

$$E = \frac{m_i \left(I_{sp}.g_0\right)^2}{2.e}$$

$$\text{emission rate} = I / e$$

$$\text{sputter rate} = \eta.\text{emission rate}.Y$$

$$\text{sputter return flux density} = \frac{\text{sputter rate}}{2\pi R^2}$$

$$\text{erosion rate} = \frac{\text{sputter rate}.m_a}{\text{density.area}}$$

$$\text{deposition rate} = \frac{S.\text{sputter return flux density}.m_a}{\text{density}}$$

Assumptions :

- Yield independent on impact angle
- Yield constant with fluence
- Sputtered flux isotropic

Results

Case1 – Debris/spacecraft

Beam thrust	30mN
Beam propellant	Xe
Specific impulse	4000 s
Distance to target	10 m
Target material	Al
Target area	3 m^2
Erosion rate	0.6mm/year
Return flux	5.6×10^{15} /m^2/s

If all return flux adheres (S=1):

Deposition rate:
6nm/day or 2μ/year
(optical surfaces will become opaque in a few days)

Case 2 - Asteroid

Beam thrust	200mN
Beam propellant	Xe
Specific impulse	4000 s
Distance to target	30 m
Target material	Olivine
Target area	30 m^2
Erosion rate (porous)	0.032 mm/year
Erosion rate (non-porous)	0.53 mm/year
Return flux (porous)	2.5×10^{14} /m^2/s
Return flux (non-porous)	4.1×10^{15} /m^2/s

Deposition rate:
0.5nm/day or 0.2μ/year (porous)
8nm/day or 3μ/year(non-porous)

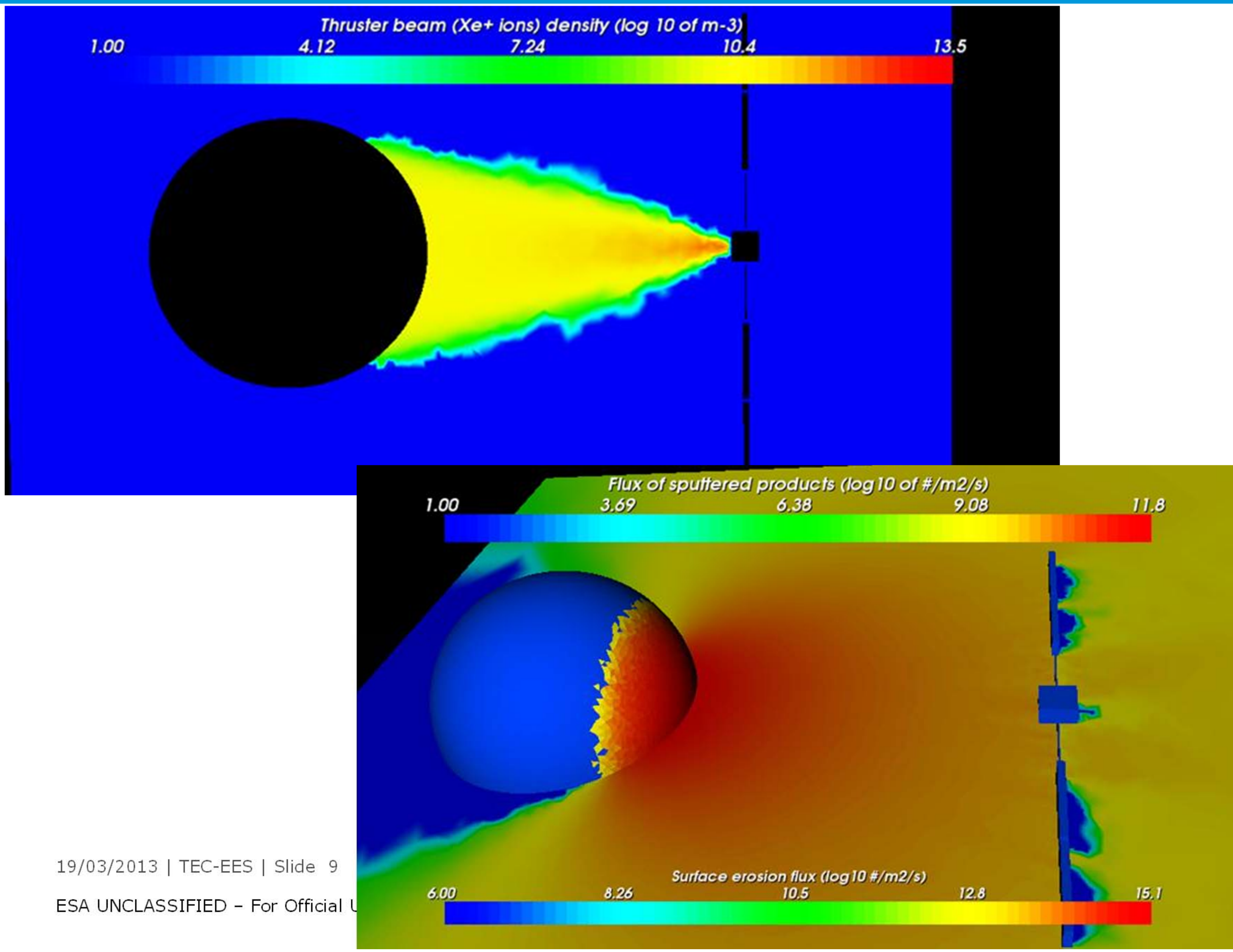
Element	Non-porous surfaces (x 10^{18} atoms/s)	Porous surfaces (x 10^{18} atoms/s)
Iron	3.41	0.20
Magnesium	5.93	0.36
Silicon	4.28	0.25
Oxygen	9.76	0.59
Total	23.4	1.40

SPIS simulation

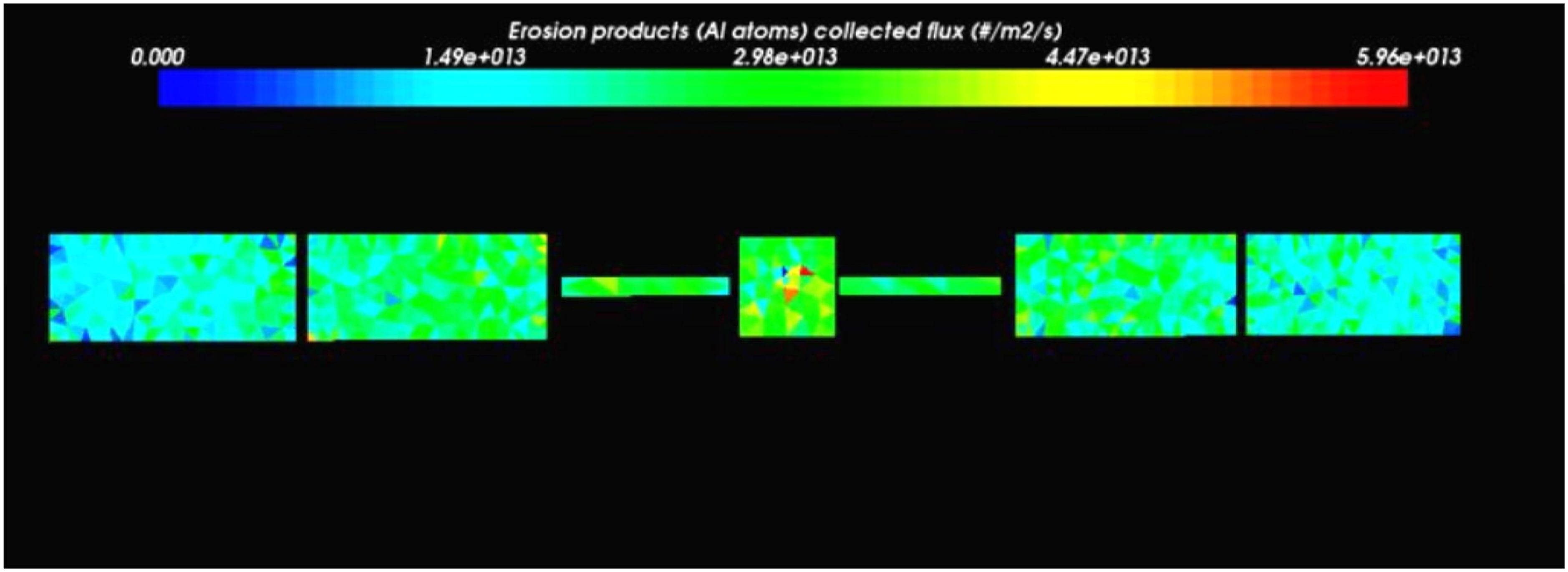
- SPIS framework allows to deal with the issue of backward contamination at the S/C scale
- Interaction of beam with surface not described at microscopic level. Physical Sputtering is modelled in a simple way but provides energy and angle dependant yield for a given target atomic number and density, and sublimation energy.
- Assumptions in SPIS model :

- simplified primary S/C geometry with solar panels and thruster
- spherical target (4m radius), target – s/c distance 10m
- Thruster characteristics (Isp) – target composition (Al) similar to case 1
- Thruster beam is Xe, 100% neutrals, 15° divergence
- sputtered flux reaching the primary s/c is 100% "absorbed"
- static solution (steady state, fixed target s/c attitude)

SPIS simulation



SPIS Simulation



- Surface distribution of “deposited” species on s/c surfaces : not uniform
- Deposition rate in good agreement with analytical estimate for case 1
- Adsorption of species not modelled

Adsoprtion of sputter products

TABLE IV. Calculated reflectance and transmittance of Al films evaporated under optimum conditions onto transparent substrates of $n=1.5$ for various wavelengths as a function of film thickness. (Calculated values agree with directly measured ones for film thicknesses >100 A; back surface antireflected.)

Film thickness (A)	220 R%	220 T%	300 R%	300 T%	400 R%	400 T%	546 R%	546 T%	650 R%	650 T%
40	14	82	19	74	25	65	33	51	38	42
80	33	60	43	47	52	36	60	24	63	18
120	52	40	62	27	70	19	74	12	75	9
160	67	25	74	16	79	11	81	7	82	5
200	76.3	15.2	81.5	9.1	84.9	5.9	85.6	3.5	85.4	2.6
240	82.4	9.1	86.0	5.1	88.1	3.3	88.1	2.0	87.5	1.4
280	86.2	5.4	88.4	3.1	90.0	1.9	89.5	1.1	88.8	0.8
320	88.5	3.2	90.0	1.8	91.1	1.1	90.4	0.5	89.6	0.4
360	89.8	1.9	90.9	1.0	91.7	0.6	90.9	0.4	90.0	0.3
400	90.6	1.1	91.4	0.5	92.1	0.4	91.2	0.2	90.3	0.2
500	91.5	0.3	92.0	0.1	92.5	<0.1	91.5	<0.1	90.6	<0.1

Sticking coefficient :

$$S=\frac{1}{2}\left(1-\tanh\left(\frac{T-T_C}{2\Delta T_C}\right)\right)=\frac{1}{1+e^{\frac{T-T_c}{\Delta T_c}}}$$

- ~20nm Al layer results in large decrease in transmittivity
- Risk of optical and power degradation and

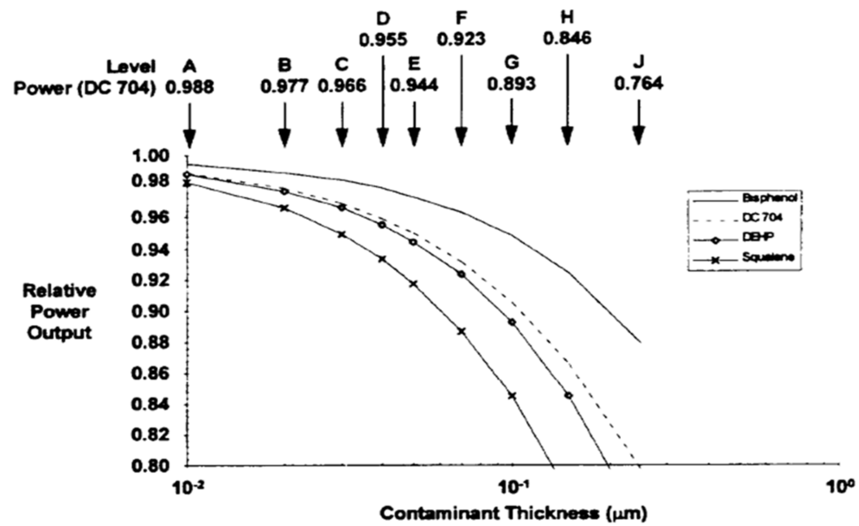


Figure 2-21. Solar array power as a function of MIL STD 1246C cleanliness levels.

Preliminary Conclusions and Guidelines to define mitigation strategies

- Surface Contamination by return flux appears to be potentially significant →problem when e.g. solar cells are coated

- If confirmed Mitigation Techniques have to be defined, e.g. :
- Low Atomic number propellant
- Low beam energy
- increased s/c to object distance
- active cleaning ...

- Laboratory tests need to be carried out in order to assess contamination levels in simulated environments using relevant materials and thrusters

- Development of low dispersion ion beams is also required in order to increase the s/c to object separation