NASA Astrophysics Research and Analysis (APRA)

Precision Optical Coatings for Large Space Telescope Mirrors

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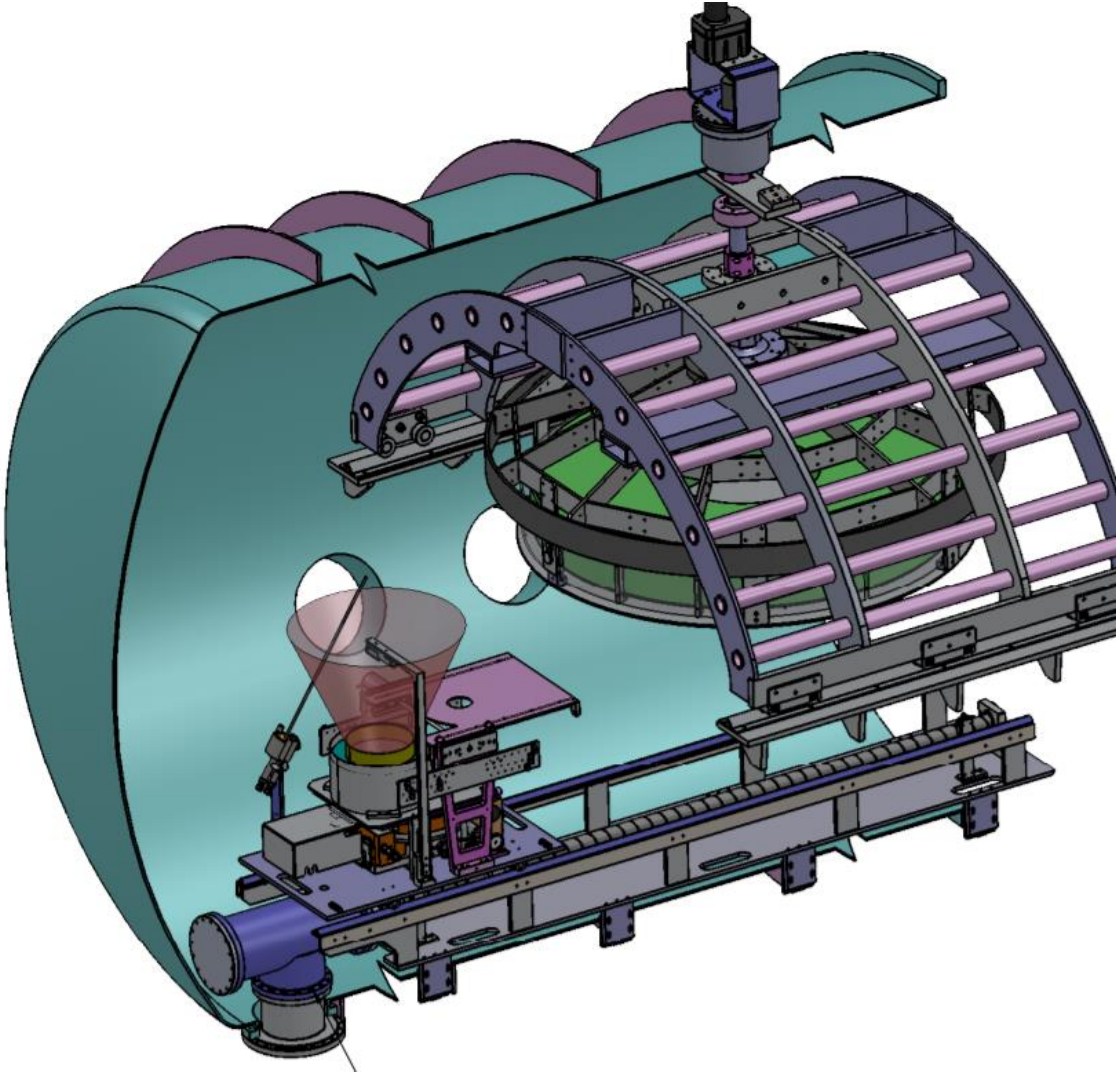
R&D Objectives:

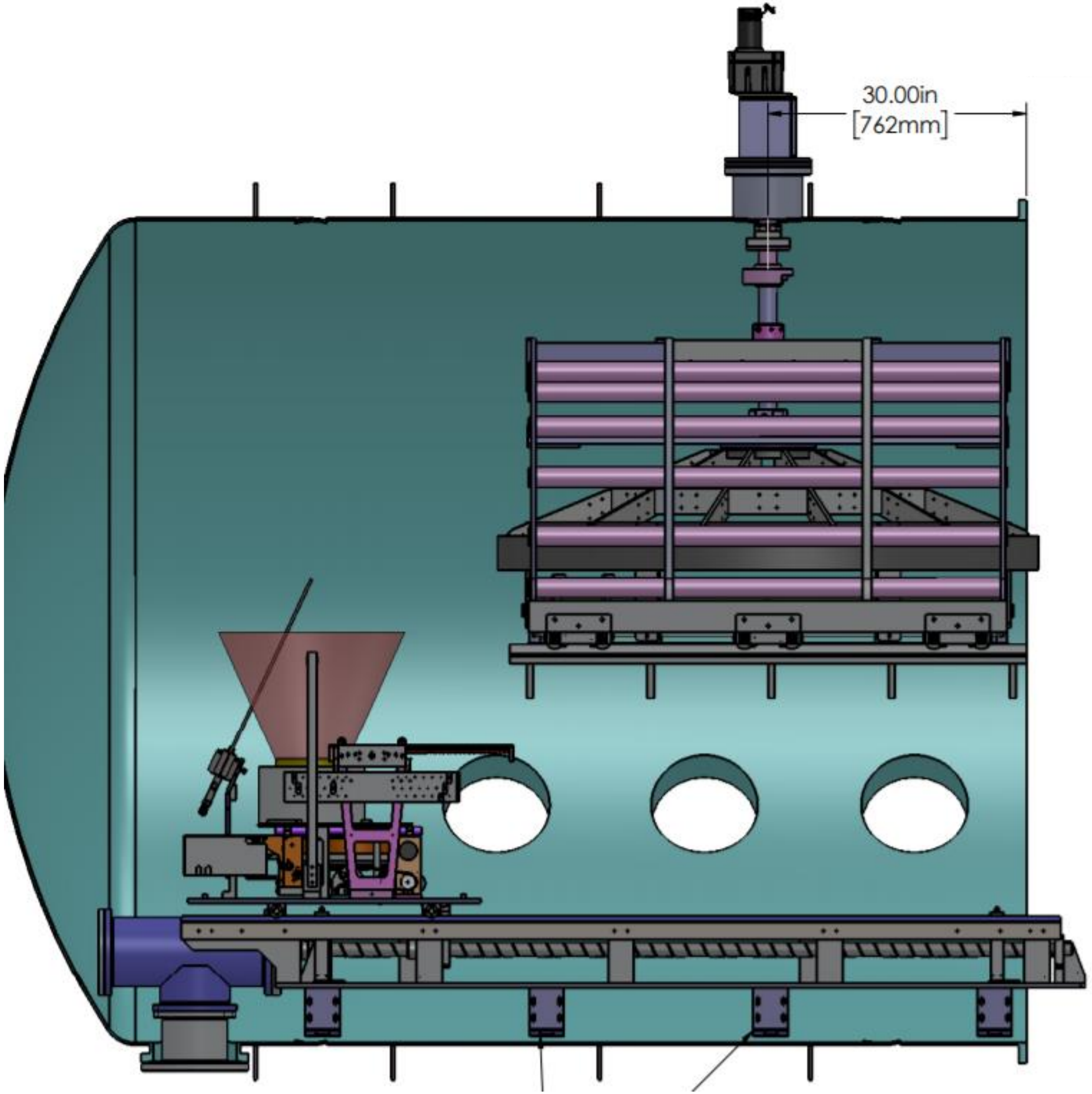
- Develop and demonstrate a broadband coating technology, which is scaleable to any size mirror (2-m diameter to 8-m diameter, limited only by the size of the vacuum chamber)

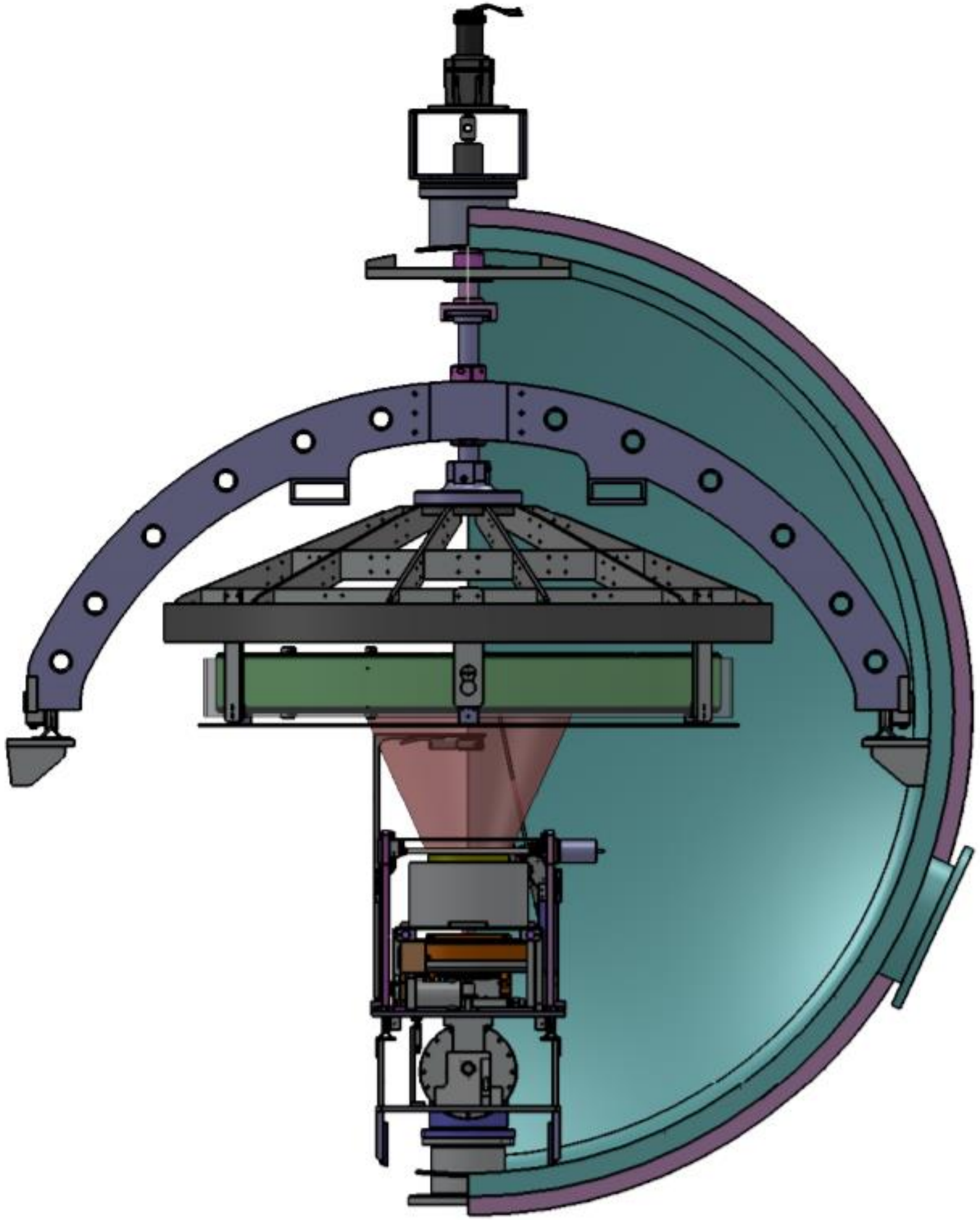
- Achieve as close to TRL-6 as possible within 3-years by making coatings and testing them in relevant environments such as simulated space radiation, ground-storage humidity, etc.

ZeCoat innovations for large FUV mirror coating:

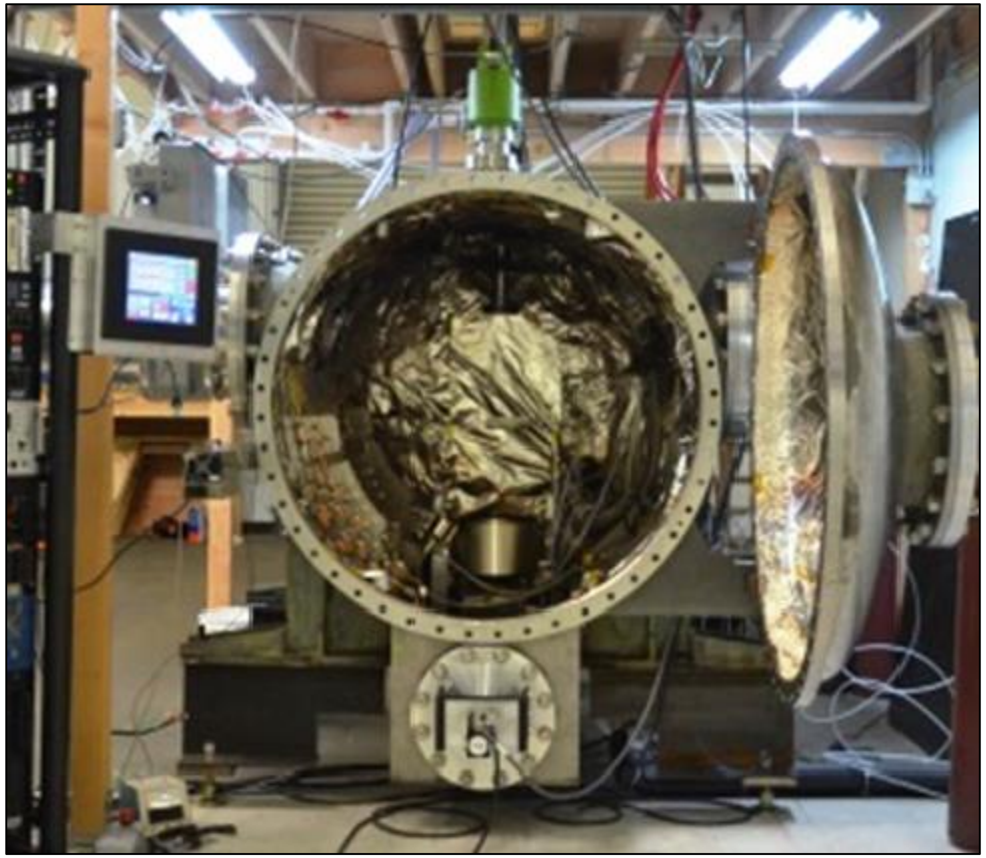
- Motion-controlled evaporation process for applying precision dielectric coatings, adhesion layers, etc.
- Battery-powered hexagonal filament array for making the aluminum reflector

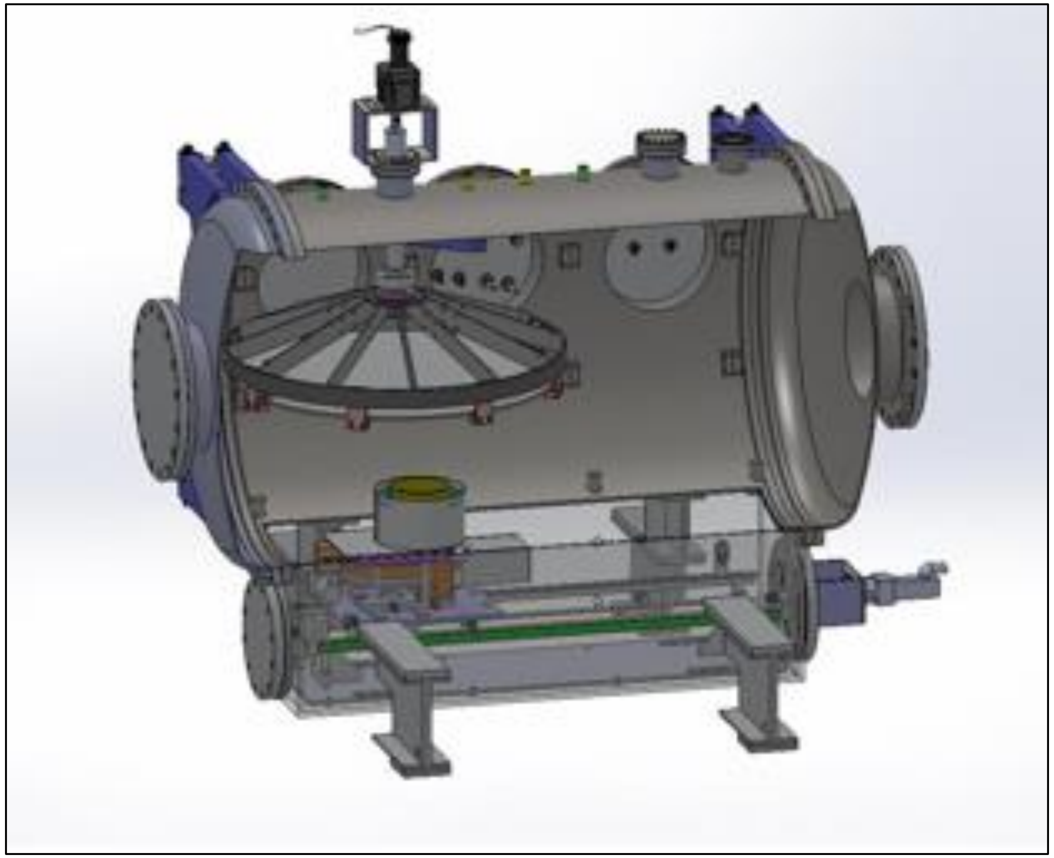



30.00in
[762mm]




ZeCoat's moving source technology to applies a very thin layer, quickly over a 1.1-m diameter area (process scalable to any size mirror)





NiCr layer thickness

Average thickness (nm)

		(nm)						
	Layers	1	2	3	5	6	8	8
	3	1.51	3.01	4.25	6.90	8.18	10.38	10.67
Radial	16	1.80	3.17	4.83	7.43	8.85	11.41	11.56
Position (cm)	33	1.49	2.80	4.38	6.70	8.17	10.38	10.51
	49	1.52	2.74	4.22	6.50	7.88	10.16	10.16

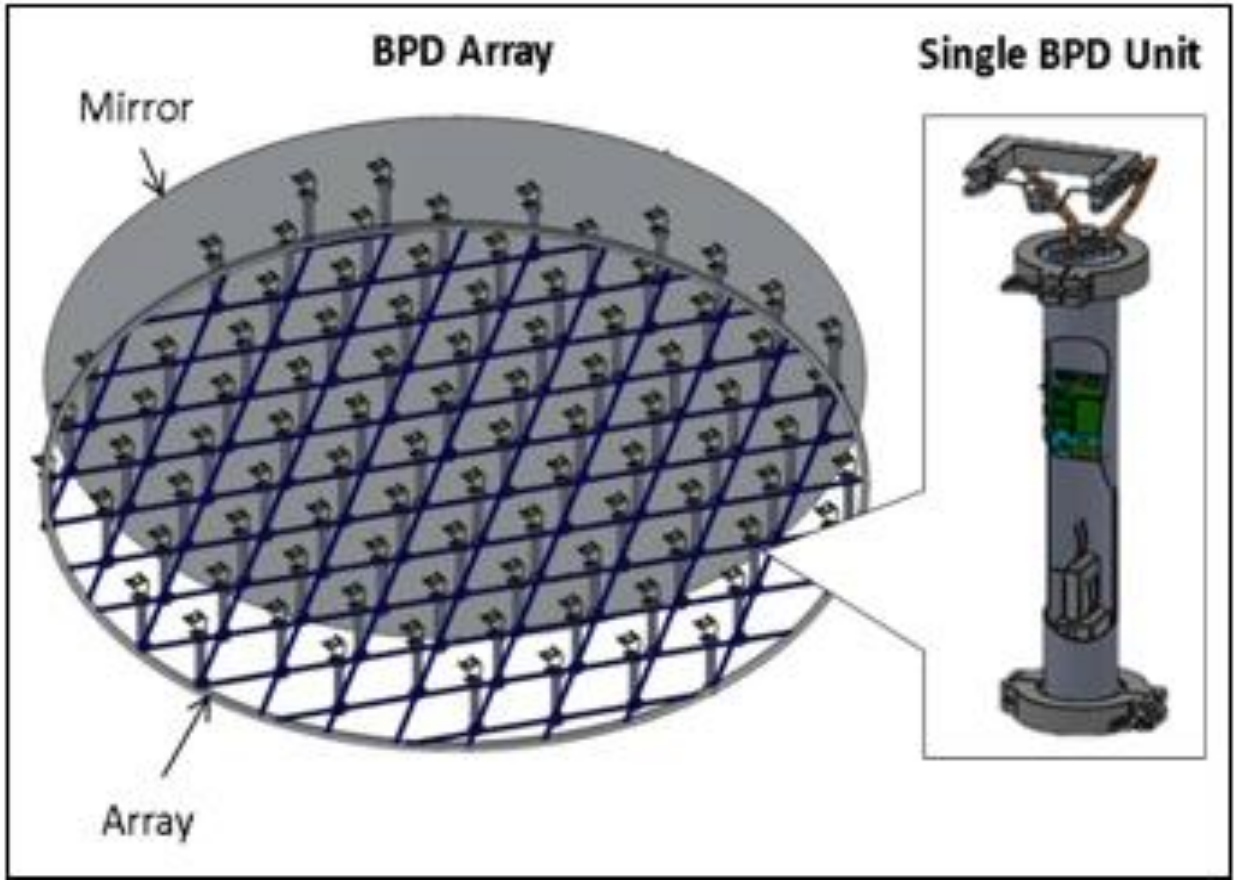
Average thickness per layer (nm)

		(nm)							
	Layers	1	2	3	5	6	8	8	Avg
	3	1.51	1.51	1.42	1.38	1.36	1.30	1.33	1.40
Radial	16	1.80	1.59	1.61	1.49	1.48	1.43	1.45	1.55
Position (cm)	33	1.49	1.40	1.46	1.34	1.36	1.30	1.30	1.38
	49	1.52	1.37	1.41	1.30	1.31	1.27	1.27	1.35
	Avg	1.58	1.46	1.47	1.38	1.38	1.32	1.34	1.42

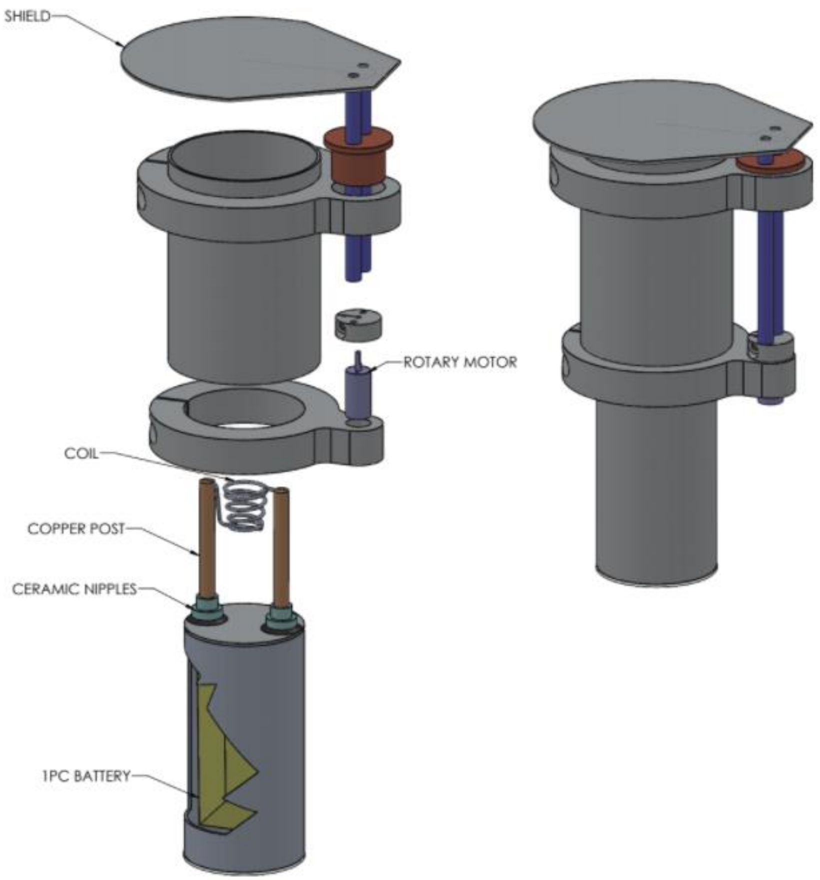
ZeCoat's Battery-powered Deposition (BPD)

Why use batteries to make aluminum?

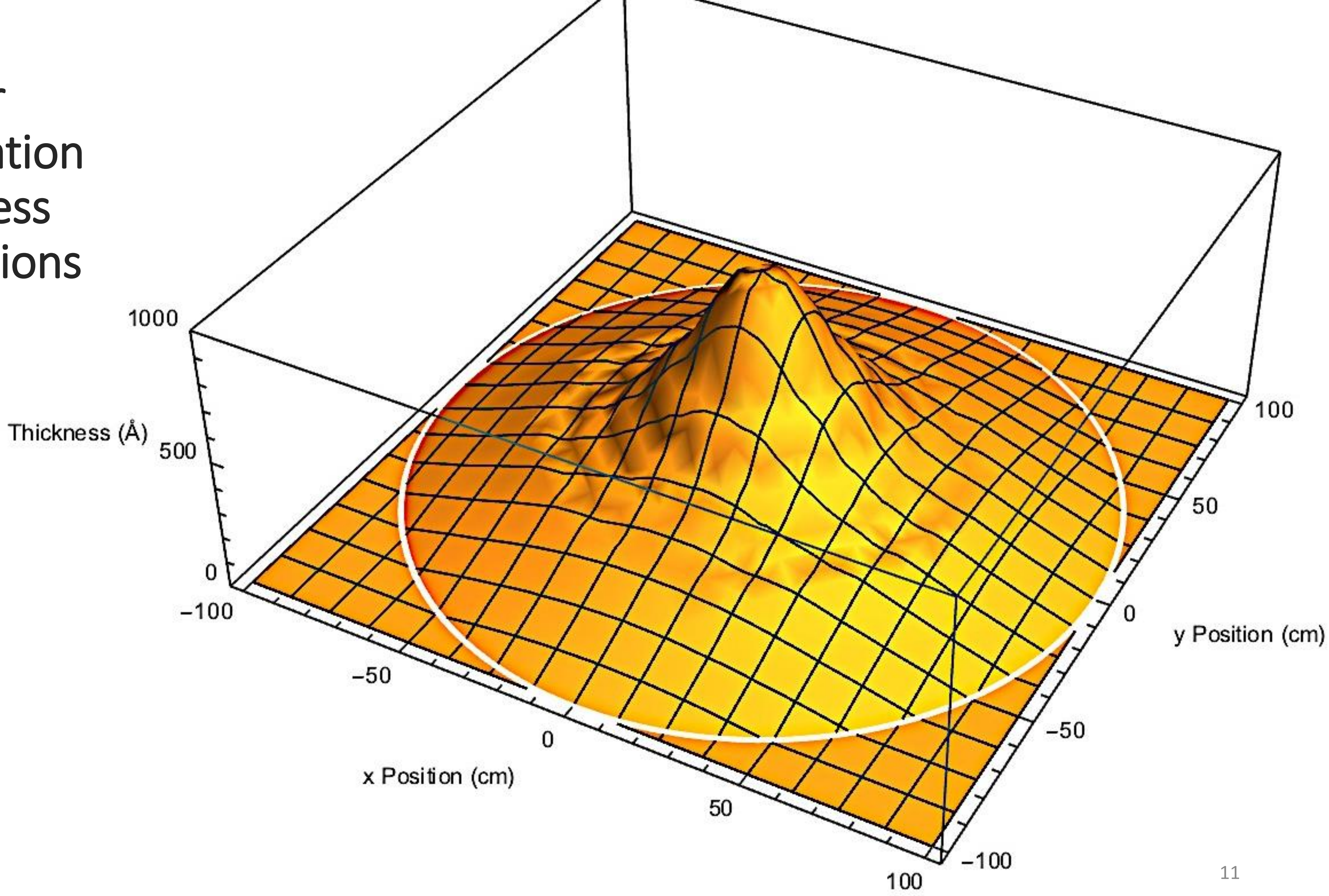
- High evaporation rates possible (1,000+ Å/sec)
- Small coating thickness variation possible
- (need many sources to coat large mirrors 2 to 8-meters)
- No excessive line-power facilities
- No large transformers
- No large conductors needed to carry high amps
- Less outgassing during process
- Placement in hexagonal pattern improves coating uniformity

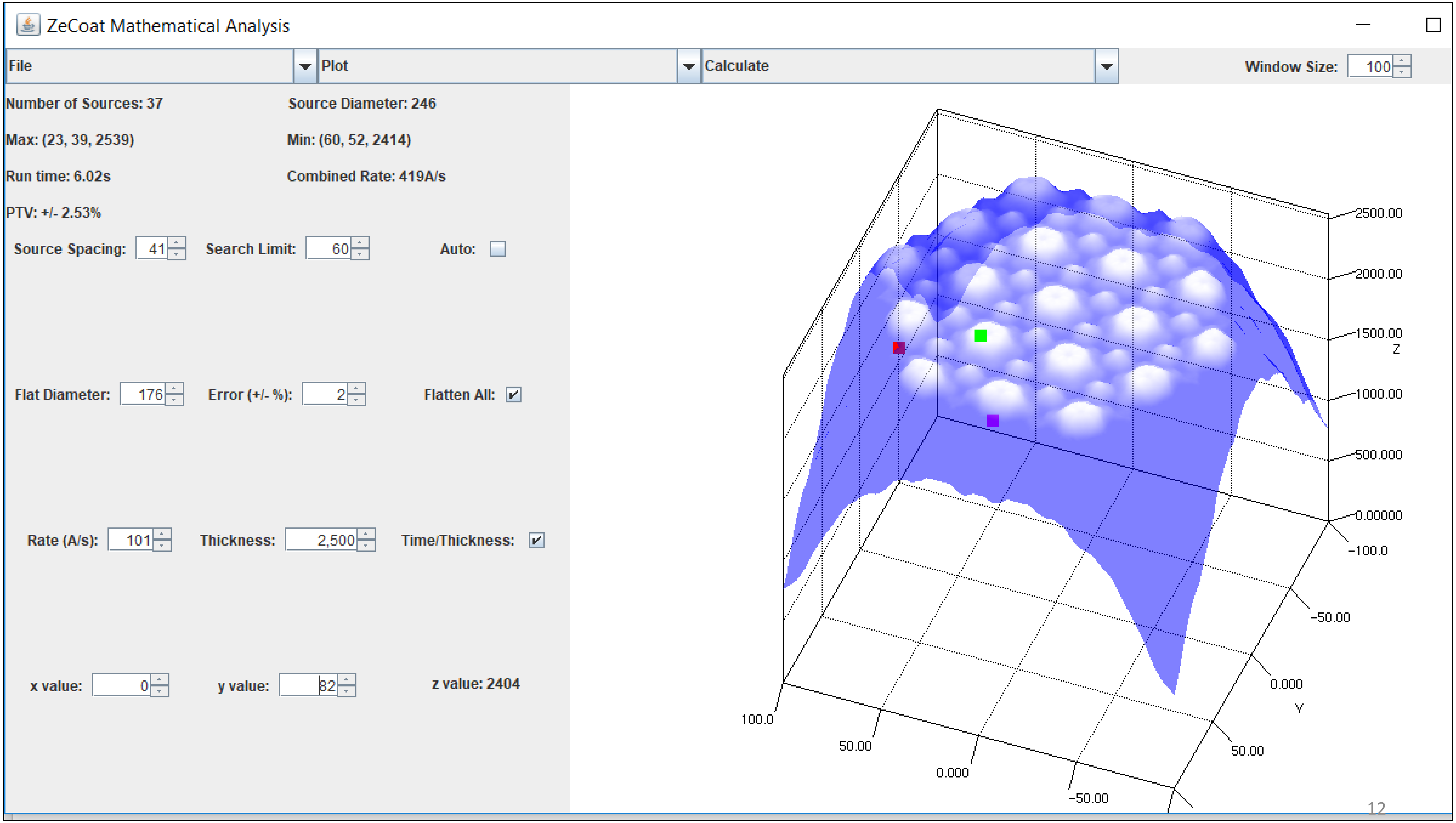


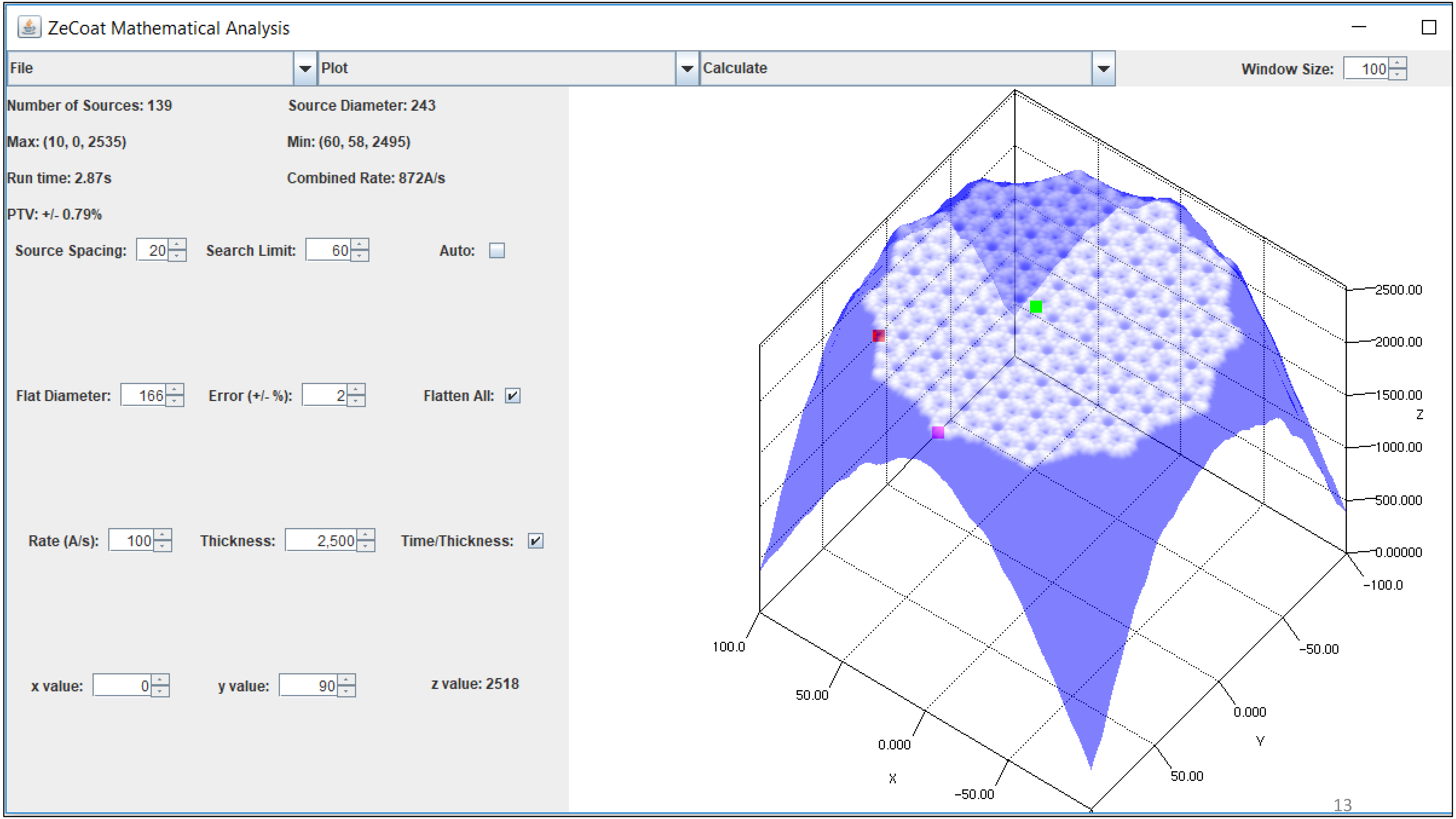
Battery-powered deposition unit for aluminum coating



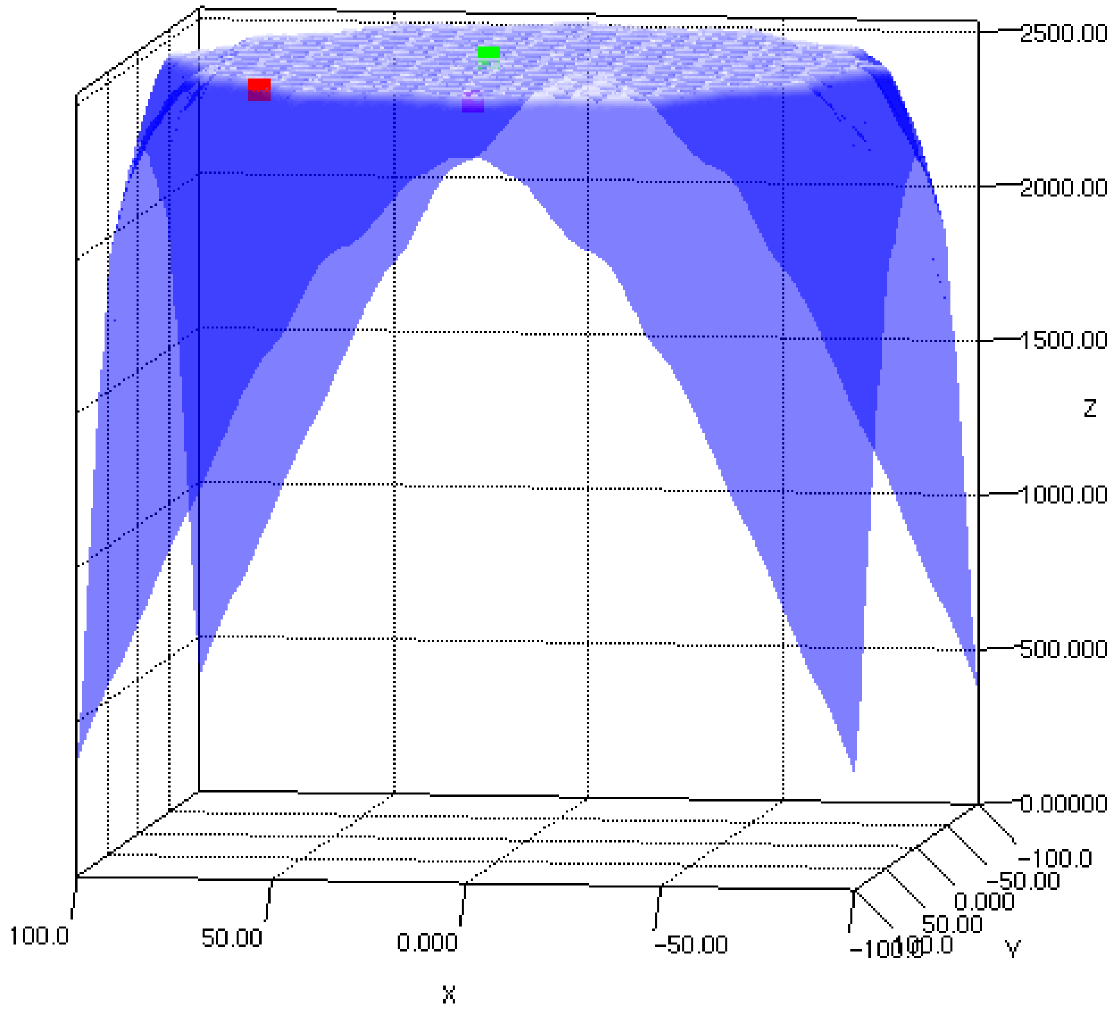
Polar Interpolation Thickness Distributions

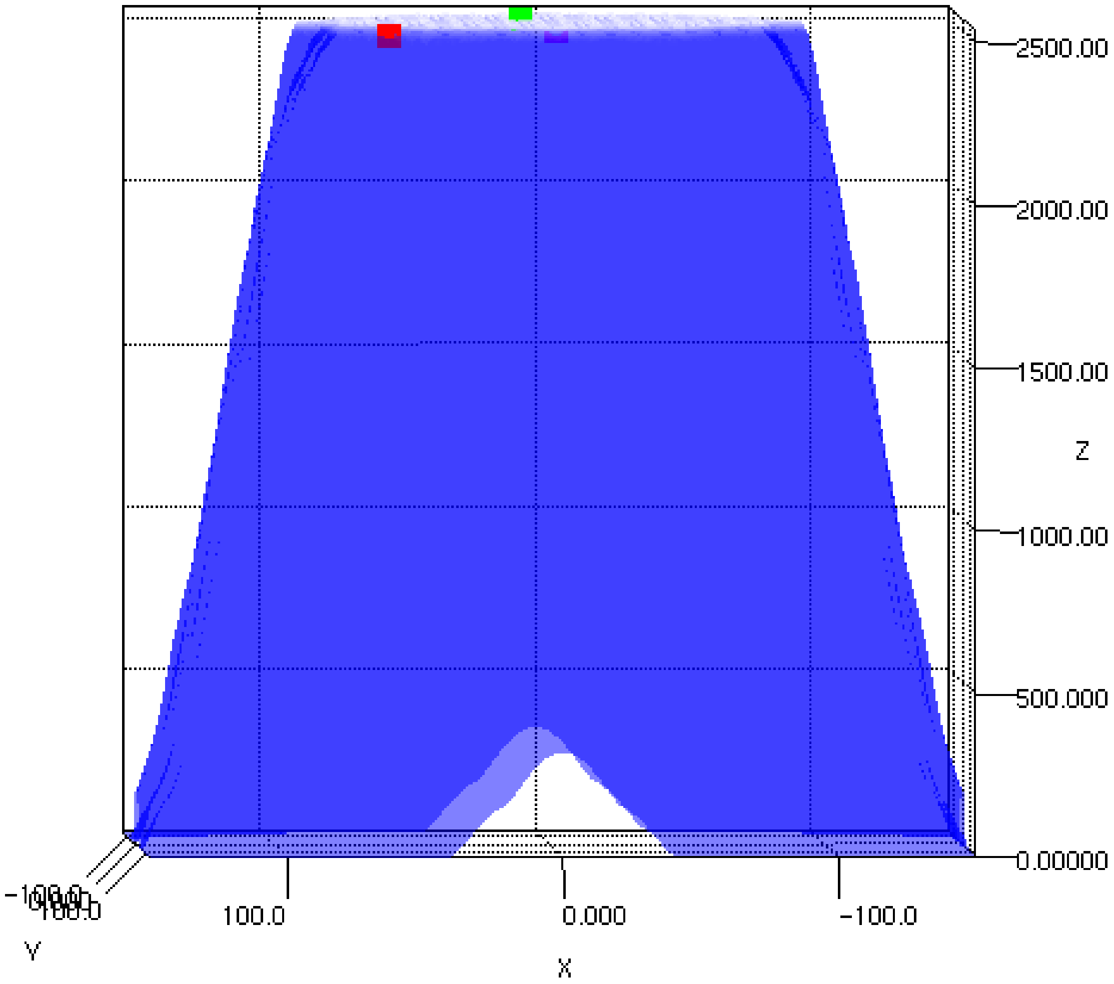



ZeCoat Mathematical Analysis
File
Plot
Calculate
Window Size: 100
Number of Sources: 37
Source Diameter: 246
Max: (23, 39, 2539)
Min: (60, 52, 2414)
Run time: 6.02s
Combined Rate: 419A/s
PTV: +/- 2.53%
Source Spacing: 41
Search Limit: 60
Auto:
Flat Diameter: 176
Error (+/- %): 2
Flatten All:
Rate (A/s): 101
Thickness: 2,500
Time/Thickness:
x value: 0
y value: 82
z value: 2404
2500.00
2000.00
1500.00
Z
1000.00
500.000
0.00000
-100.0
-50.00
0.000
Y
50.00
100.0
50.00
0.000
-50.00

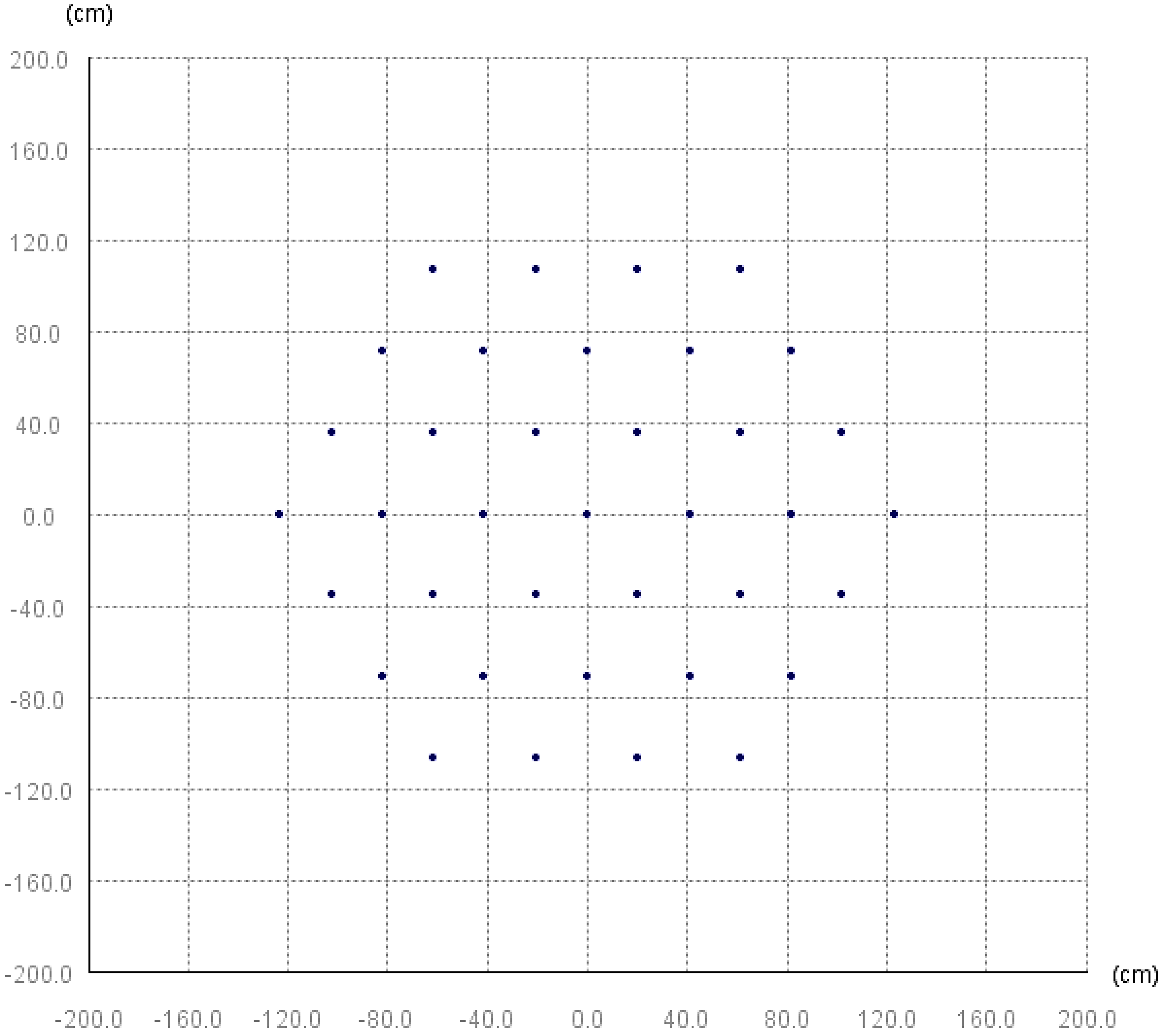

ZeCoat Mathematical Analysis
File
Plot
Calculate
Window Size: 100
Number of Sources: 139
Source Diameter: 243
Max: (10, 0, 2535)
Min: (60, 58, 2495)
Run time: 2.87s
Combined Rate: 872A/s
PTV: +/- 0.79%
Source Spacing: 20
Search Limit: 60
Auto:
Flat Diameter: 166
Error (+/- %): 2
Flatten All:
Rate (A/s): 100
Thickness: 2,500
Time/Thickness:
x value: 0
y value: 90
z value: 2518
2500.00
2000.00
1500.00
1000.00
500.000
0.00000
Z
-100.0
-50.00
0.000
50.00
Y
100.0
50.00
0.000
-50.00
X

Small plume results continued

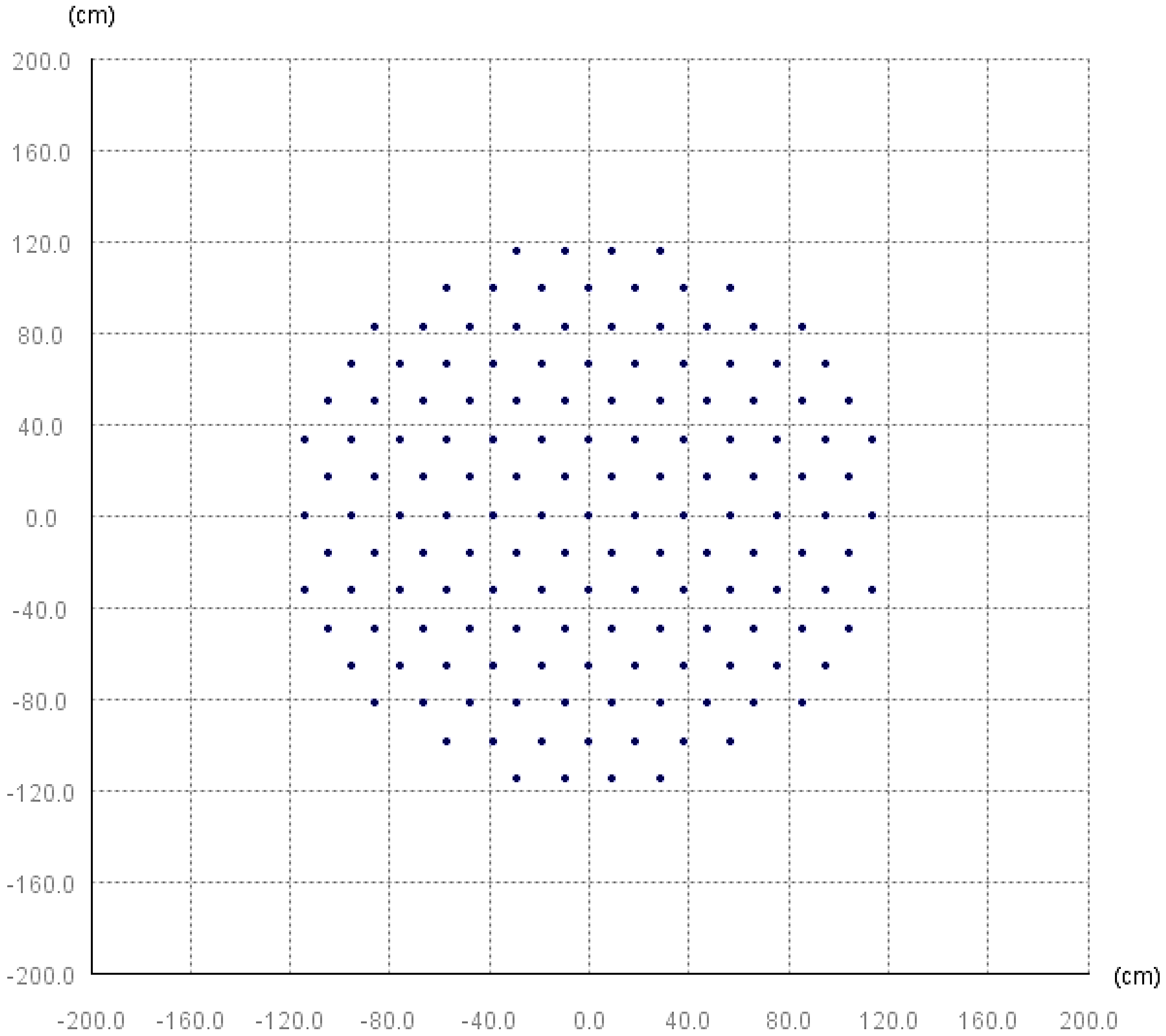




Evaporation source placement map



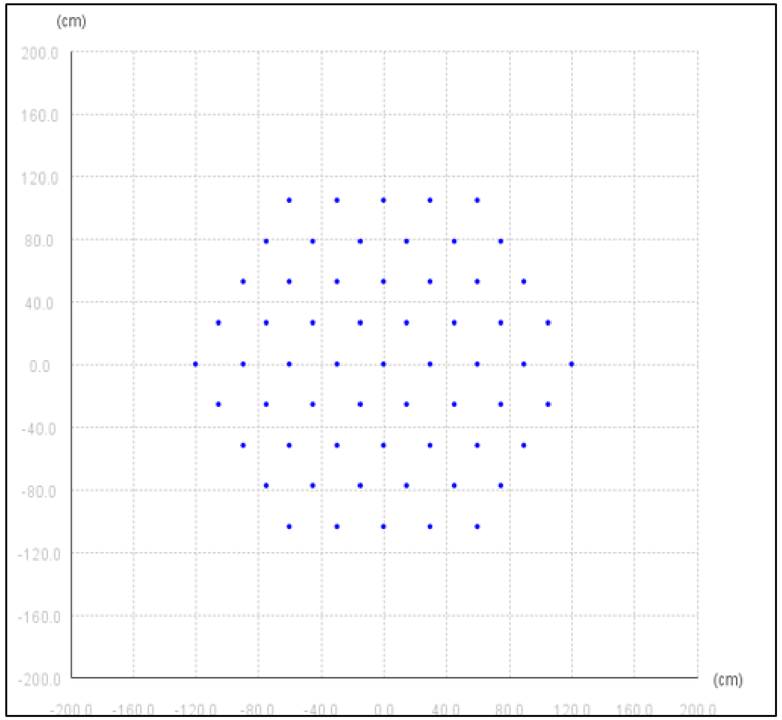
(37) plumes over 2.4-meters, 5% PTV, 1.64-m flat diameter

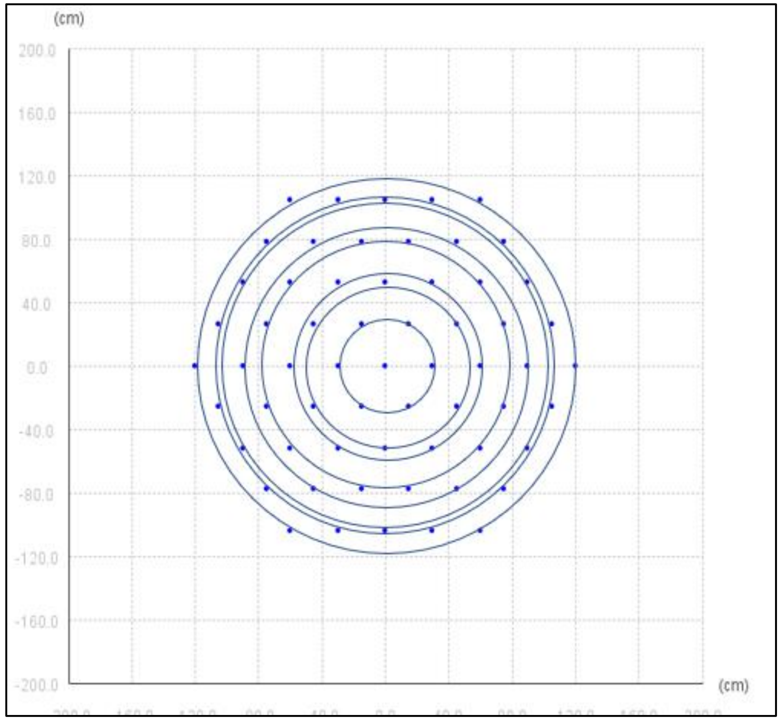


(139) plumes over 2.4-meters, 2% PTV, 1.8-m flat diameter

Multi-ring thickness optimization

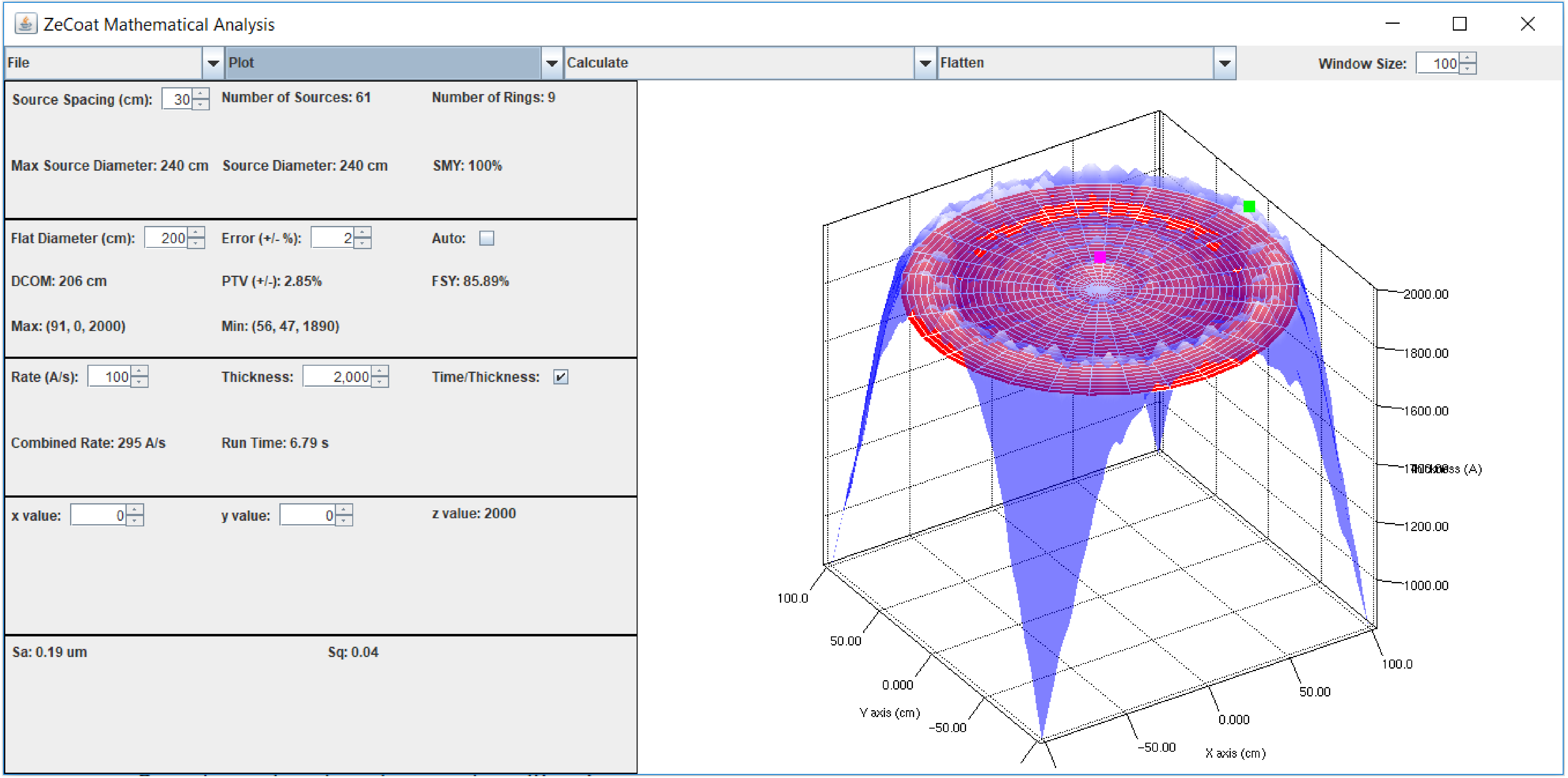
9-rings, 61-sources





Ring Number	Radius (cm)	Deposition Time (s)
1	0	6.789
2	30	2.258
3	52	2.047
4	60	1.188
5	79	1.082
6	90	3.078
7	104	5.758
8	108	6.000
9	120	4.547

2.4-m source diameter, 2.0-m flat area, +/- 2.85%,

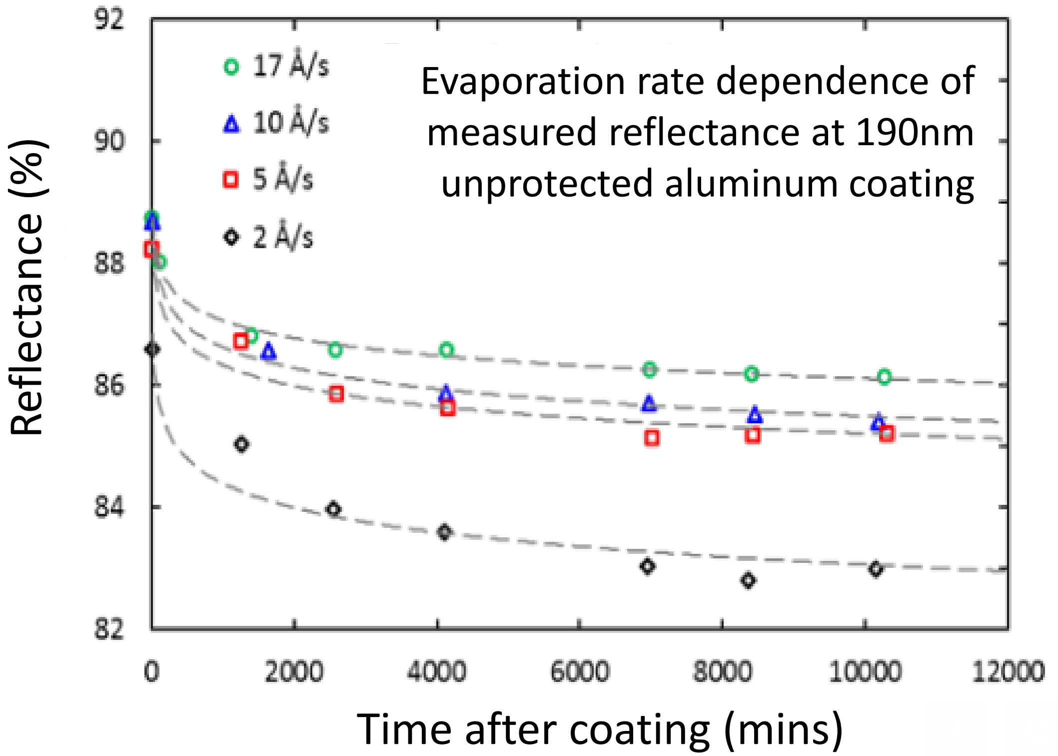

ZeCoat Mathematical Analysis
File
Plot
Calculate
Flatten
Window Size: 100
Source Spacing (cm): 30
Number of Sources: 61
Number of Rings: 9
Max Source Diameter: 240 cm
Source Diameter: 240 cm
SMY: 100%
Flat Diameter (cm): 200
Error (+/- %): 2
Auto:
DCOM: 206 cm
PTV (+/-): 2.85%
FSY: 85.89%
Max: (91, 0, 2000)
Min: (56, 47, 1890)
Rate (A/s): 100
Thickness: 2,000
Time/Thickness:
Combined Rate: 295 A/s
Run Time: 6.79 s
x value: 0
y value: 0
z value: 2000
Sa: 0.19 um
Sq: 0.04
2000.00
1800.00
1600.00
Thickness (A)
1200.00
1000.00
100.0
50.00
0.000
-50.00
Y axis (cm)
100.0
50.00
0.000
-50.00
X axis (cm)

Why do we need high evaporation rates to make FUV-quality aluminum?

Al evap. rate (A/sec)	Reflectance (%) @ 200nm	Reflectance (%) @ 400nm
40	82.7	91
65	87.6	91.5
125	90.2	91.8

~10^-6 torr vacuum

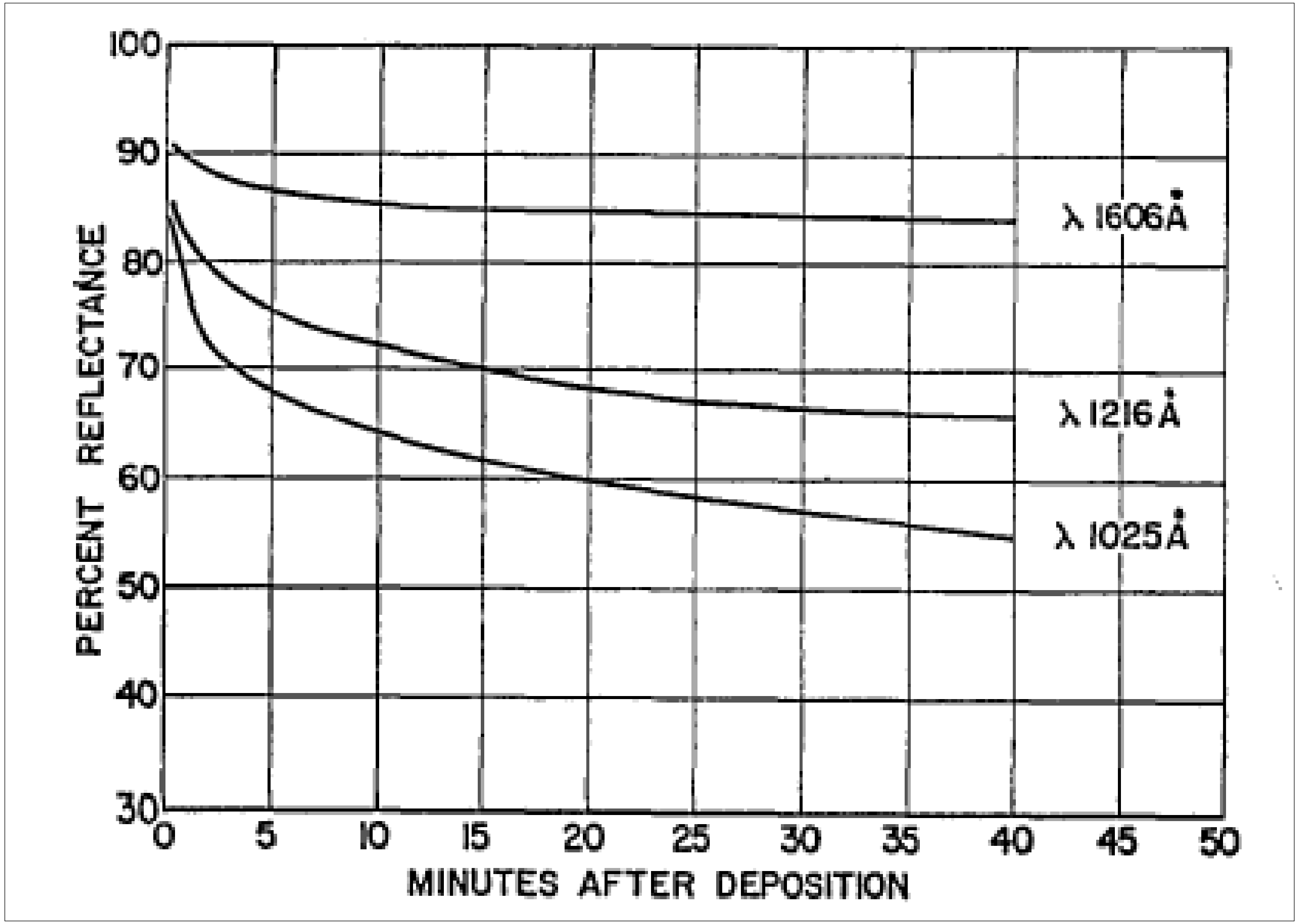
Reference: Dr. Andrew Phillips, University of California Observatories, 2015.



~10^-9 torr vacuum

Reference: Hennessy J, Balasubramanian K, Moore CS, et al; Performance and prospects of far ultraviolet aluminum mirrors protected by atomic layer deposition. J. Astron. Telesc. Intrum.

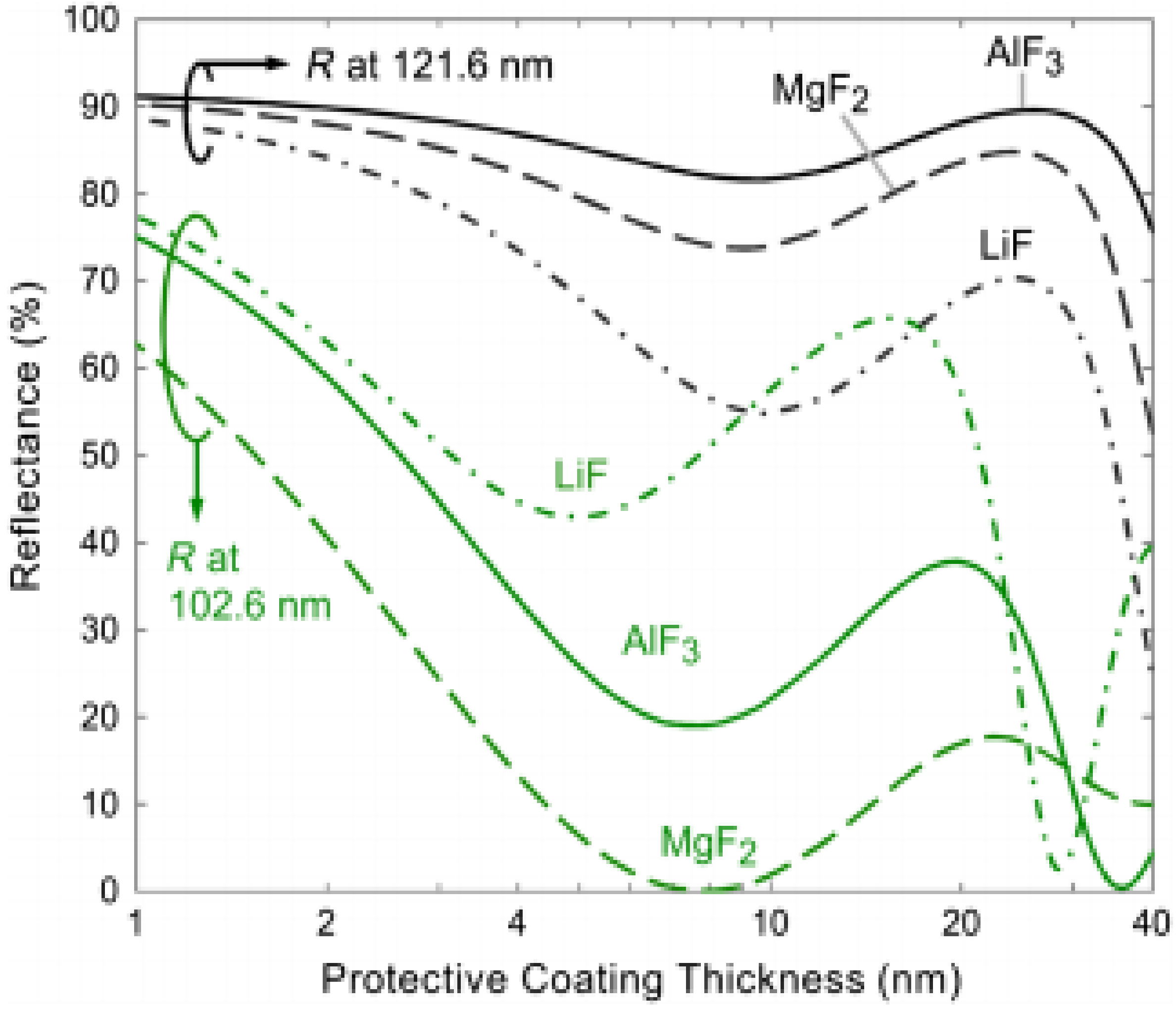
Importance of quickly protected an aluminum film once its made in the vacuum chamber



Oxidation of aluminum film in 5x10^-7 torr vacuum

R.P. Madden, L.R. Canfield, and G. Hass, "On the Vacuum-Ultraviolet Reflectance of Evaporated Aluminum before and during Oxidation", *Journal of the Optical Society of America* **Vol. 53 No. 5** (1963)

Fundamental limits of fluoride-protected aluminum coatings



The need for very thin protection schemes for telescopes operating below 105-nm

Reference: Hennessy J, Balasubramanian K, Moore CS, et al; Performance and prospects of far ultraviolet aluminum mirrors protected by atomic layer deposition. J. Astron. Telesc. Intrum.

Future plans

- 6-meter vacuum chamber capable of uniformly coating up to 5-meter HabEx mirror
- Moving ZeCoat to St. Louis, Mo. in spring of 2019
- New facility located directly on the Mississippi river and includes the use of a $45M barge dock
- 8,000 square feet with a 30’ (~ 9-m) tall high-bay for housing the 6-meter chamber

QUESTIONS?