



© 2025 Society of Vacuum Coaters all rights reserved, ISSN 0737-5921, ISBN 978-1-878068-45-3

Thin, Free-Standing Metal Films for Accelerator-Based Physics Experiments

John Greene, Connor Mohs, Claus Mueller-Gattermann
Argonne National Laboratory, Argonne, IL

Physical Vapor Deposition (PVD) has been routinely employed over the past half century for the production of thin isotopically enriched metal targets at facilities producing accelerated beams for nuclear physics studies. The Center for Accelerator Target Science (CATS) at Argonne National Laboratory (ANL) is tasked with the preparation of such targets for the Low-Energy Nuclear Physics Community in the United States as well as demands world-wide using a variety of techniques. We concentrate our efforts primarily on thermal evaporation of the isotopic metals required using state-of-the-art vacuum deposition systems. Thin films of the desired target material are deposited onto glass substrates with thicknesses ranging from sub-micron to many kilo-angstroms. To obtain free-standing foils, the glass is first treated with a parting agent for release from the substrate. Occasionally these deposits are, by necessity, evaporated onto already mounted thin backings foils which act only as a spectator during the accelerator physics experiments. The separated isotopic target starting materials are obtained from the National Isotope Development Center at Oak Ridge National Laboratory (ORNL) usually as metal powder. In some instances, when the metallic form is not available, certain chemical and metallurgical processes become necessary before deposition. Current work on the production of these targets and some examples will be presented.

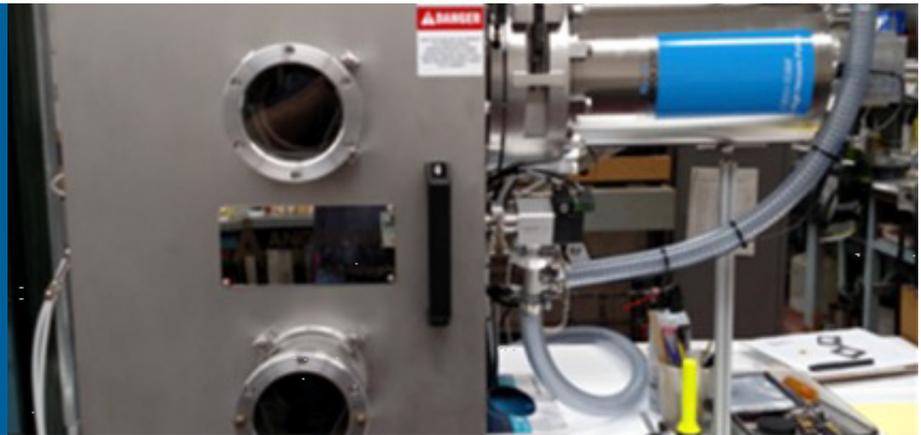
<https://www.svc.org>

DOI: <https://doi.org/10.14332/svc25.proc.0028>

THIS MATERIAL IS BASED UPON WORK SUPPORTED BY THE U.S. DEPARTMENT OF ENERGY, OFFICE OF SCIENCE, OFFICE OF NUCLEAR PHYSICS, UNDER CONTRACT NO. DE-AC02-06CH11357. THIS RESEARCH USED RESOURCES OF ANL'S ATLAS FACILITY, WHICH IS A DOE OFFICE OF SCIENCE USER FACILITY.



THIN, FREE-STANDING METAL FILMS FOR ACCELERATOR-BASED PHYSICS EXPERIMENTS



JOHN GREENE, CONNOR MOHS AND CLAUS MUELLER-GATERMANN

Center for Accelerator Target Science (CATS)

Physics Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439 USA



2025 SVC TechCon
Nashville, TN USA

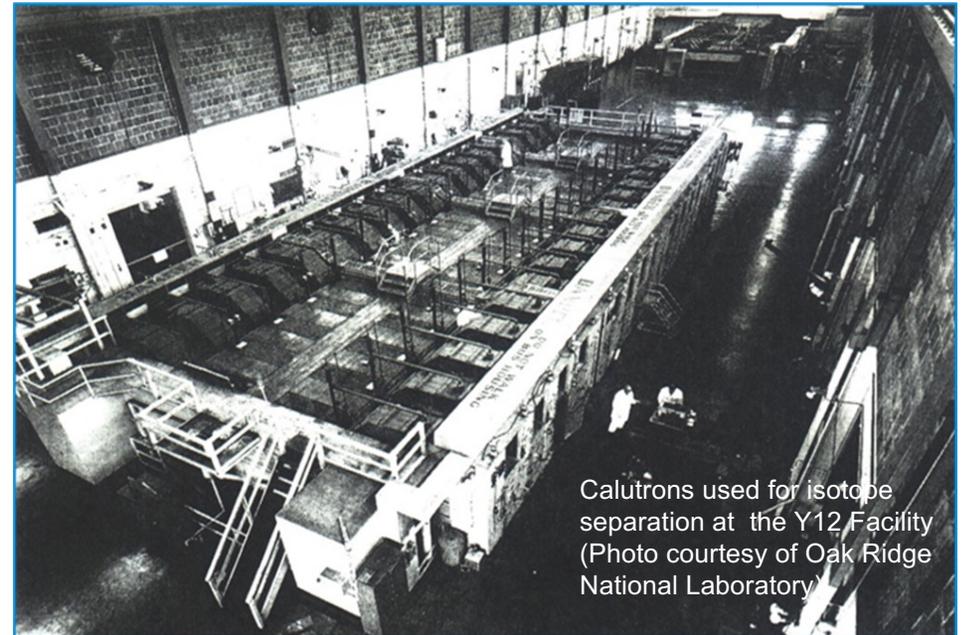
ABSTRACT

- Physical Vapor Deposition (PVD) has been routinely employed over the past half century for the production of thin isotopically enriched metal targets at facilities producing accelerated beams for nuclear physics studies. The Center for Accelerator Target Science (CATS) at Argonne National Laboratory (ANL) is tasked with the preparation of such targets. We concentrate our efforts primarily on thermal evaporation of the isotopic metals required using state-of-the-art vacuum deposition systems. Thin films of the desired target material are deposited onto glass substrates with thicknesses ranging from sub-micron to many kilo-angstroms. To obtain free-standing foils, the glass is first treated with a parting agent for release from the substrate.

ABSTRACT

(cont.)

- The separated isotopic target starting materials are obtained from the National Isotope Development Center at Oak Ridge National Laboratory (ORNL) usually as metal powder. In some instances, when the metallic form is not available, certain chemical and metallurgical processes become necessary before deposition. Current work on the production of these targets and some examples will be presented.



INTRODUCTION

Center for Accelerator Target Science - CATS

- Serve the low-energy community by producing targets whenever possible by either manufacturing them or by directing requests to other facilities best able to perform the task
- Train individual investigators and students in target making in order to provide a workforce capable to address present and future needs
- Carry out R&D activities dedicated to novel production techniques and optimization of existing ones
- Develop an inventory of existing targets that will serve as a pool available to the community

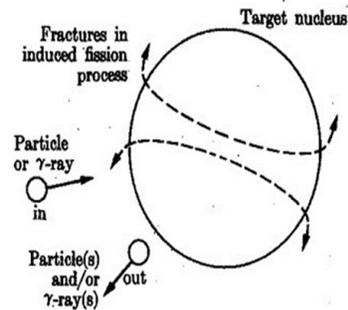


The CATS Facility Target Laboratory

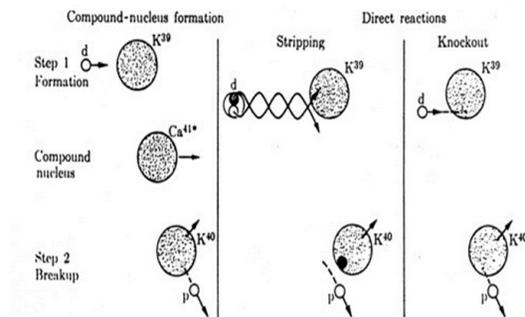
*"A unique asset of the ANL program is their target manufacturing capabilities. This expertise at ANL allows highly specialized targets to be prepared for various beam experiments at many laboratories. It is important that these capabilities be maintained given the continuing demands for such targets."
Report of the NSAC Subcommittee on Low Energy Nuclear Physics, November 15, 2001*

PHYSICS MOTIVATION

The low-energy nuclear physics research carried out at heavy-ion accelerator facilities consists of the production of an isotopically pure beam impinging on, to the extent possible, an isotopically pure target at energies above the Coulomb barrier for nuclear reaction and structure studies.



A direct approach for the study of low energy nuclear physics is particle bombardment of a target nucleus and observing the reactions.



Some simple examples of beam and target interactions.

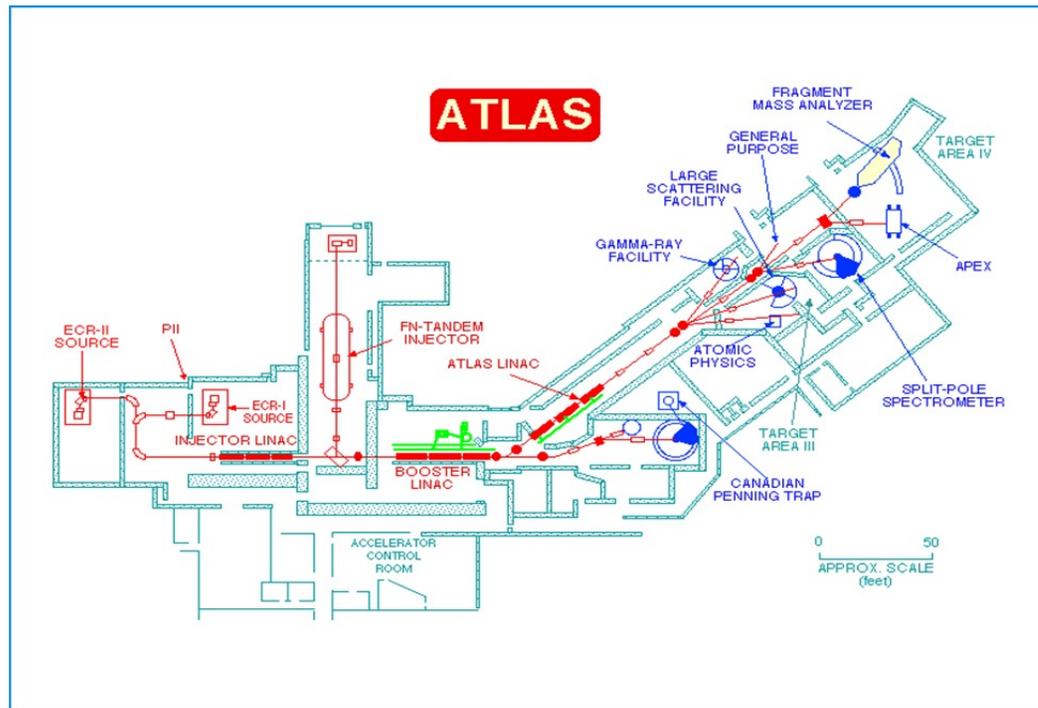
ACCELERATOR TARGET PREPARATION

- Within the Physics Division at ANL, CATS operates a target development laboratory that produces targets and foils of various thicknesses and on substrates, depending on the requirements, for experiments performed at the ATLAS accelerator facility. The targets are prepared from both naturally occurring materials and stable isotopes that are supplied either in pure, elemental form or as chemical compounds. Targets are made not only for ATLAS but also for other divisions at the Laboratory and for other laboratories and universities.

hydrogen 1 H 1.0079																		helium 2 He 4.0026																																
lithium 3 Li 6.941		beryllium 4 Be 9.0122																		boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180																									
sodium 11 Na 22.990		magnesium 12 Mg 24.305																		aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.06	chlorine 17 Cl 35.453	argon 18 Ar 39.948																									
potassium 19 K 39.098		calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.37	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selecnium 34 Se 78.96	bromine 35 Br 79.904	krpton 36 Kr 83.80																															
rubidium 37 Rb 85.468		strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	cadmium 46 Cd 112.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29																															
cesium 55 Cs 132.91		barium 56 Ba 137.33		lanthanum 57-70 * Lu 174.97	hafnium 71 Hf 178.49	tantalum 72 Ta 180.95	tungsten 73 W 183.85	rhenium 74 Re 186.21	osmium 75 Os 190.23	iridium 76 Ir 192.22	platinum 77 Pt 195.08	gold 78 Au 196.97	mercury 79 Hg 200.59	thallium 80 Tl 204.38	lead 81 Pb 207.2	bismuth 82 Bi 208.98	polonium 83 Po [209]	astatine 84 At [210]	radon 85 Rn [222]																															
francium 87 Fr [223]		radium 88 Ra [226]		actinides 89-102 ** Lr [260]	rutherfordium 103 Rf [261]	bohrium 104 Bh [262]	hassium 105 Hs [263]	meitnerium 106 Mt [264]	darmstadtium 107 Ds [265]	roentgenium 108 Rg [266]	copernicium 109 Cn [267]	nihonium 110 Nh [268]	flerovium 111 Fl [269]	tennessine 112 Ts [270]																																				
				<table border="1"> <tr> <td colspan="2">lanthanoids</td> <td>cerium 58 Ce 138.91</td> <td>praseodymium 59 Pr 140.91</td> <td>neodymium 60 Nd 144.24</td> <td>promethium 61 Pm [145]</td> <td>samarium 62 Sm 150.36</td> <td>europium 63 Eu 151.96</td> <td>gadolinium 64 Gd 157.25</td> <td>terbium 65 Tb 158.93</td> <td>dysprosium 66 Dy 162.50</td> <td>holmium 67 Ho 164.93</td> <td>erbium 68 Er 167.26</td> <td>thulium 69 Tm 168.93</td> <td>ytterbium 70 Yb 173.04</td> </tr> <tr> <td colspan="2">actinoids</td> <td>actinium 89 Ac [227]</td> <td>thorium 90 Th 232.04</td> <td>protactinium 91 Pa [231.04]</td> <td>uranium 92 U 238.03</td> <td>neptunium 93 Np [237]</td> <td>plutonium 94 Pu [244]</td> <td>americium 95 Am [243]</td> <td>curium 96 Cm [247]</td> <td>berkelium 97 Bk [247]</td> <td>californium 98 Cf [251]</td> <td>escherium 99 Es [252]</td> <td>fermium 100 Fm [257]</td> <td>mendeleevium 101 Md [258]</td> <td>nobelium 102 No [259]</td> </tr> </table>																lanthanoids		cerium 58 Ce 138.91	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04	actinoids		actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa [231.04]	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	escherium 99 Es [252]	fermium 100 Fm [257]	mendeleevium 101 Md [258]	nobelium 102 No [259]
lanthanoids		cerium 58 Ce 138.91	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04																																				
actinoids		actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa [231.04]	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	escherium 99 Es [252]	fermium 100 Fm [257]	mendeleevium 101 Md [258]	nobelium 102 No [259]																																			

ACCELERATOR TARGET PREPARATION

The ATLAS Accelerator Facility



ACCELERATOR TARGET PREPARATION

Isotopic Starting Material

16 1 s	I 117 2.2 m	I 118 8.5 m 13 m	I 119 19 m	I 120 53 m 1.35 h	I 121 2.12 h	I 122 3.6 m	I 123 13.2 h	I 124 4.15 d	I 125 59.41 d	I 13
40	Te 116 2.5 h	Te 117 1.1 h	Te 118 6.0 d	Te 119 4.7 d 16 h	Te 120 0.096	Te 121 154 d 16.8 d	Te 122 2.603	Te 123 0.908	Te 124 4.816	Te
114 m	Sb 115 32.1 m	Sb 116 60 m 16 m	Sb 117 2.8 h	Sb 118 5.0 h 3.5 m	Sb 119 38.5 h	Sb 120 5.76 d 15.9 m	Sb 121 57.36 d	Sb 122 4.2 m 2.70 d	Sb 123 42.64	Sb
113 115.1 d	Sn 114 0.65	Sn 115 0.34	Sn 116 14.53	Sn 117 13.6 d 7.68	Sn 118 24.23	Sn 119 290 d 8.59	Sn 120 32.59	Sn 121 50 a 27.0 h	Sn 122 4.63	Sn
12 14.4 m	In 113 99.49 m 4.3	In 114 49.5 d 71.9 s	In 115 95.7	In 116 2.2 s 54 m 14 s	In 117 1.94 h 43.1 m	In 118 6.5 s 4.4 m 5 s	In 119 18 m 2.3 m	In 120 47.3 s 42.2 s 3.1 s	In 121 3.8 m 23.1 s	In
111 12.80	Cd 112 24.13	Cd 113 12.22	Cd 114 28.73	Cd 115 44.8 d 53.36 h	Cd 116 7.49	Cd 117 3.21 h 2.42 h	Cd 118 50.3 m	Cd 119 2.2 m 2.7 m	Cd 120 50.8 s	Cd
110 24.6 s	Ag 111 7.65 d	Ag 112 3.12 h	Ag 113 1.1 m 5.37 h	Ag 114 4.5 s	Ag 115 18.0 s 20.0 m	Ag 116 8.2 s 2.7 m	Ag 117 5.3 s 73 s	Ag 118 2.8 s 3.7 s	Ag 119 6.6 s 7.1 s	Ag
109 13.43 h	Pd 110 11.72	Pd 111 5.5 h 23.4 m	Pd 112 21.1 h	Pd 113 1.6 m	Pd 114 2.4 m	Pd 115 50 s 25 s	Pd 116 11.8 s	Pd 117 4.3 s	Pd 118 1.9 s	Pd

TIN

Isotope	Natural abundance (at.%)	Isotopic enrichment* (at.%)
Sn-112	0.96	68-80
Sn-114	0.66	>61
Sn-115	0.35	>32
Sn-116	14.30	>95
Sn-117	7.61	>89
Sn-118	24.03	>97
Sn-119	8.58	>84
Sn-120	32.85	>98
Sn-122	4.72	>92
Sn-124	5.94	>94

INVENTORY FORM: oxide
Alternative Forms: metal, powder, or beads

TARGETS

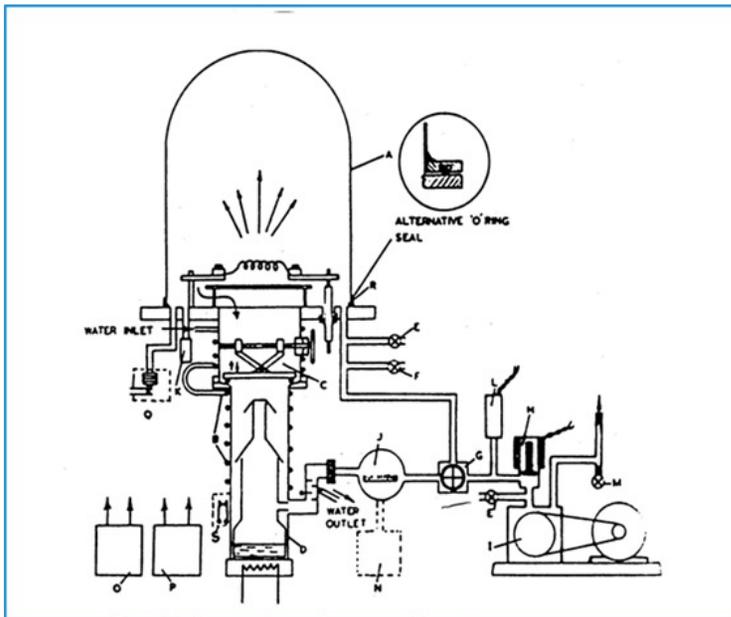
Isotopic or Normal
Standard Size: 2.5 cm by 2.5 cm

Form	Range of thickness (µg/cm ²)	Backing	Method of preparation
Element	10 to 1000	Metal	Evaporation
Element	100 to 4000	Self-supporting	Evaporation
Element	>4000	Self-supporting	Rolling
Element	Variable	Self-supporting	Cast or pressed

Other isotopic abundances, chemical forms, and/or targets considered on request.

*Typical isotopic distributions, p. C-6 of Appendix C.

PHYSICAL VAPOR DEPOSITION (PVD)



Resistance Heated Sources

The simplest vapor sources are resistance heated wires and metal foils of various types shown in Figure 4.9.

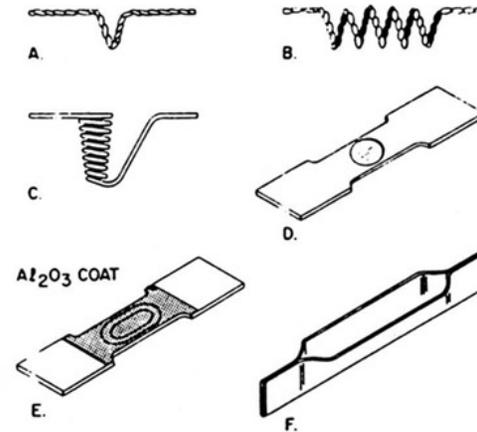


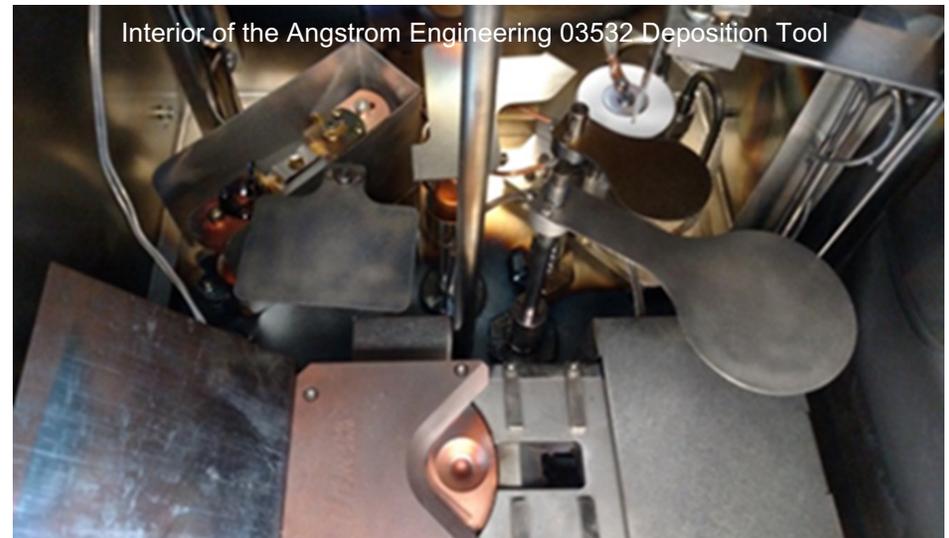
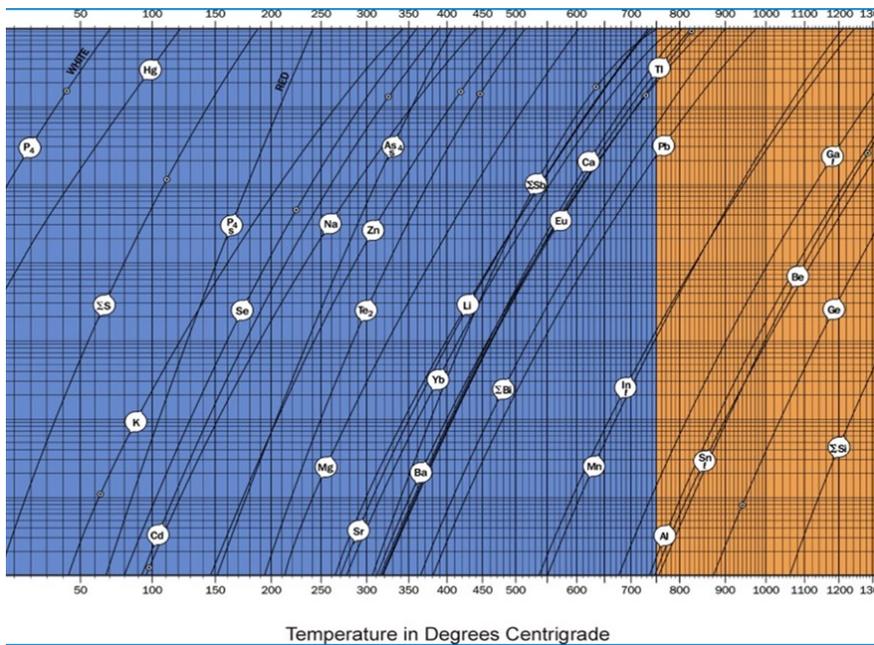
Figure 4.9: Wire and metal-foil sources. (A) Hairpin source. (B) Wire helix. (C) Wire basket. (D) Dimpled foil. (E) Dimpled foil with alumina coating. (F) Canoe type. (From *Handbook of Thin Film Technology*. Copyright © 1970, McGraw-Hill. Used with permission of McGraw-Hill Book Co.)

PHYSICAL VAPOR DEPOSITION (PVD) (cont.)

The target development laboratory includes state-of-the-art equipment for thin-film fabrication. The available techniques consist of multiple resistive heating, ion beam sputtering and electron beam evaporation. The evaporators are maintained under high vacuum and each chamber contains two quartz-crystal film-thickness deposition controllers with rate indicators. Included are movable shutters, quartz-lamp substrate heaters, water cooling and thermocouple temperature sensors, allowing for complete process monitoring during target deposition.



PHYSICAL VAPOR DEPOSITION (PVD) (cont.)



SUBSTRATES AND PARTING AGENTS

The role of the substrate and parting agent is crucial for the release of a free-standing evaporated foil. Many different compounds have been employed, taking care to provide the necessary conditions for stress free film growth. Parting agents consist mainly of soaps and surfactants (organic) as well as inorganic salts (crystalline) and even sucrose and common kitchen items!



SUBSTRATES AND PARTING AGENTS

(cont.)

- These releasing compounds dissolve during the foil floating process and are not found to be present in the film. They are prepared by hand application, dipping or even vacuum evaporated. For higher temperature depositions, the inorganic salts work best at withstanding the elevated temperatures encountered during processing.

D. Ramsay, Proc. of 1974 Ann. Int. Conf. of the INTDS Chalk River Nucl. Lab. p. 157.

Table 1
Substrates used in the growth of self-supporting films.

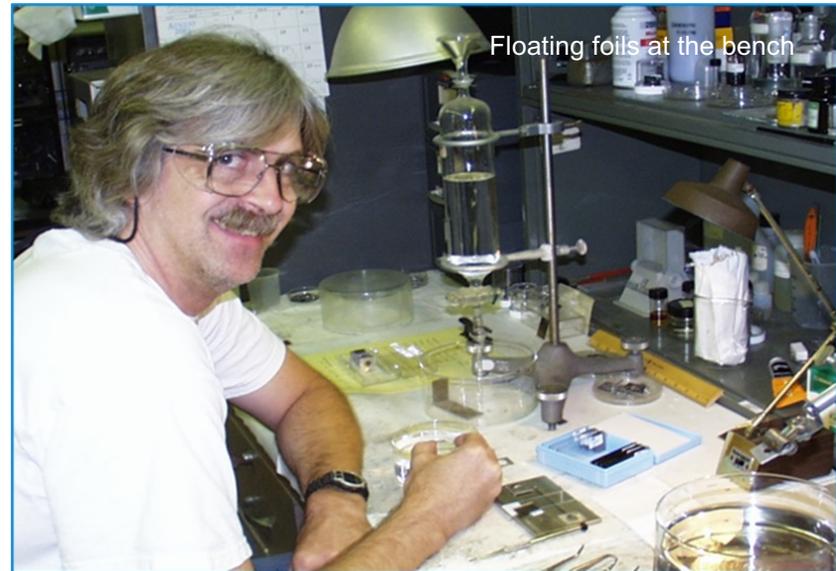
Element	Substrate	Element	Substrate
Aluminum	Teepol ^{a)}	Manganese	Aluminum Oxide
Antimony	Cesium Iodide	Molybdenum	Sodium Chloride
Beryllium	Barium Chloride	Neodymium	Barium Iodide
Bismuth	Cesium Iodide	Osmium	Sodium Chloride
Boron	Boron Oxide	Palladium	Cesium Iodide
Cadmium	Zinc Chloride	Potassium	Hexadecylamine
Calcium	Hexadecylamine ^{b)}	Praseodymium	Aluminum Oxide
Carbon	Teepol	Nickel	Copper
Chromium	Potassium Chloride	Rhodium	Potassium Iodide
Cobalt	Aluminum Oxide	Ruthenium	Aluminum Oxide
Copper	Teepol	Scandium	Aluminum Oxide
Erbium	Aluminum Oxide	Silicon	Potassium Chloride
Germanium	Barium Chloride	Silver	Teepol
Gold	Teepol	Tellurium	Teepol
Holmium	Calcium Iodide	Thulium	Calcium Iodide
Indium	Formvar ^{c)}	Tin	Teepol
Iron	Copper	Titanium	Calcium Iodide
Lead	Potassium Chloride	Vanadium	Potassium Iodide
Lithium	Hexadecylamine	Yttrium	Calcium Iodide
Magnesium	Zapon ^{d)}	Ytterbium	Copper

a) Teepol 610 (sodium secondary alkyl sulphate) Shell Chemical Co.
 b) S. H. Maxman, Rev. Sci. Instr. 35, 1572 (1964)
 c) Formvar 15/95E (polyvinyl formal) Monsanto Co., St. Louis, Missouri
 d) J. L. Gallant, Nucl. Instr. Meth. 102, 477 (1972)

RELEASING (FLOATING) THE FOILS

Using a steady hand and holding the slide at about a 45 degree angle, slowly lower the slide into a dish of clean water at room temperature. When the water level reaches the foil, it will begin to float on the water surface. When the foil has floated entirely off the slide, the slide is removed carefully so it is out of the way for the pickup process. Holding the target frame with forceps under the water at an angle of 90 degrees to the surface, lift the frame below the floating foil until an edge drapes over an edge of the frame. The target on the frame is lifted straight up out of the water and dried thoroughly.

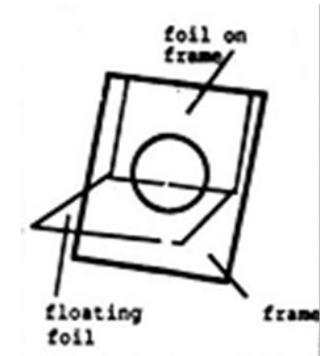
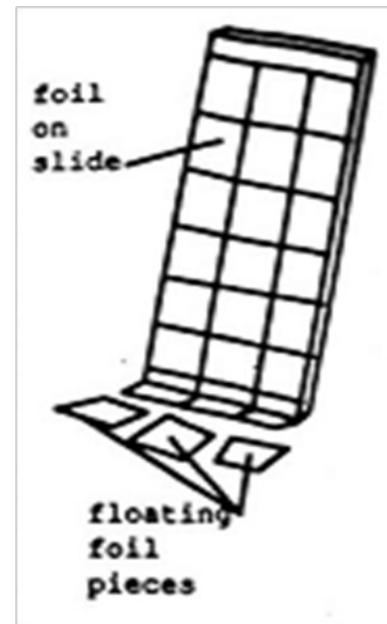
Courtesy of John Stoner – ACF Metals



RELEASING (FLOATING) THE FOILS (cont.)

Using a steady hand and holding the slide at about a 45 degree angle, slowly lower the slide into a dish of clean water at room temperature. When the water level reaches the foil, it will begin to float on the water surface. When the foil has floated entirely off the slide, the slide is removed carefully so it is out of the way for the pickup process. Holding the target frame with forceps under the water at an angle of 90 degrees to the surface, lift the frame below the floating foil until an edge drapes over an edge of the frame. The target on the frame is lifted straight up out of the water and dried thoroughly.

Courtesy of John Stoner – ACF Metals



CONCLUSION AND ACKNOWLEDGEMENTS





Conclusion

- CATS routinely provides free-standing metal foil targets for nuclear physics experimental studies
- Actively fulfilling ALL its Objectives
- Well positioned and ready for Future Opportunities

Acknowledgments

This work is supported by the U.S. Department of Energy,
Nuclear Physics Division, under Contract No. DE-AC02-06CH11357
Thank you for your attention!