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

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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.

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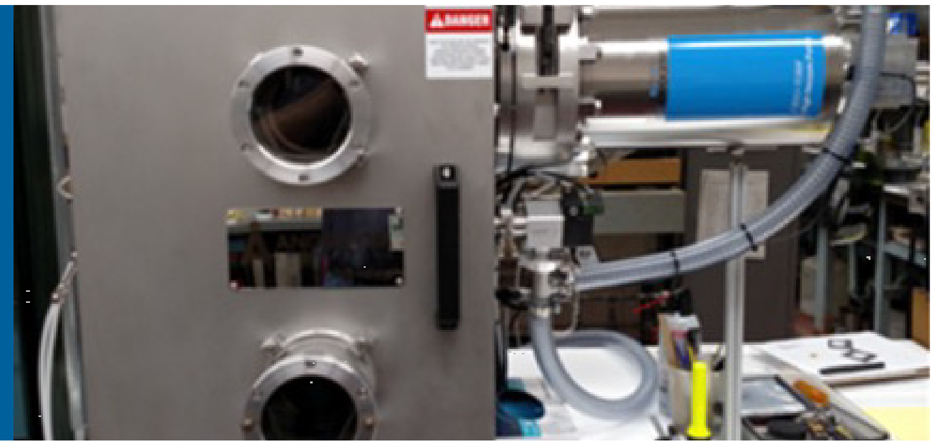
THIN, FREE-STANDING METAL FILMS FOR ACCELERATOR-BASED PHYSICS EXPERIMENTS



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ABSTRACT

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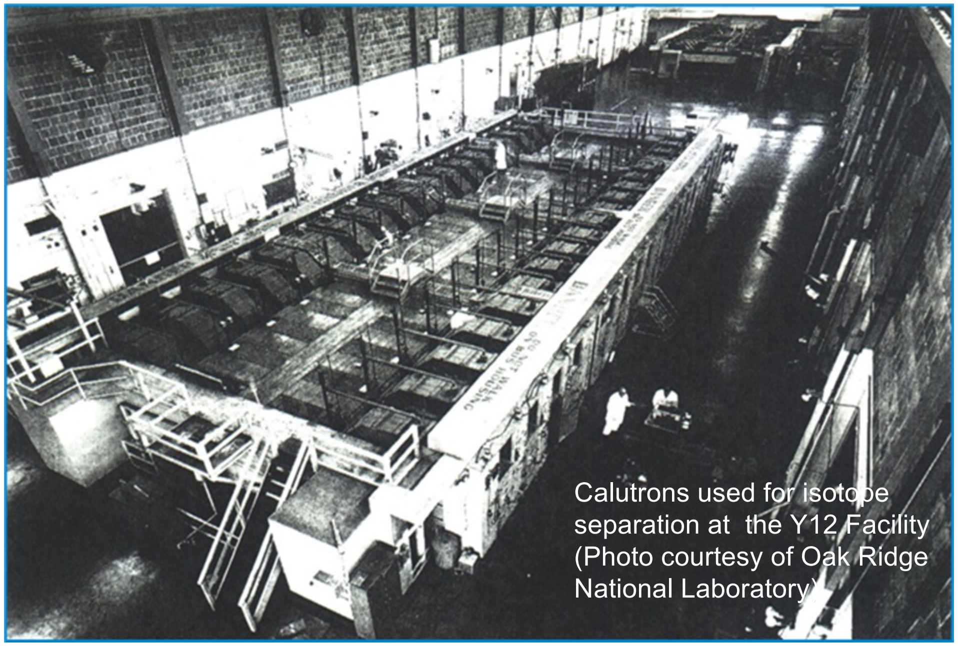
- The separated isotopic target starting materials are obtained from the National Isotope Development Center at Oak Ridge National Laboratory (ORNL) usually as metal powder. In some instances, when the metallic form is not available, certain chemical and metallurgical processes become necessary before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



Calutrons used for isotope separation at the Y12 Facility (Photo courtesy of Oak Ridge National Laboratory)

INTRODUCTION

Center for Accelerator Target Science - CATS

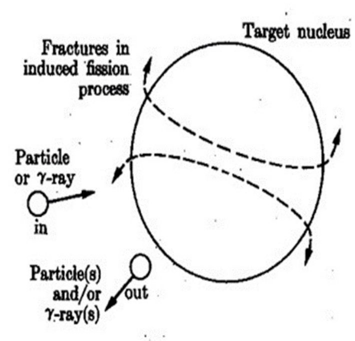
- Serve the low-energy community by producing targets whenever possible by either manufacturing them or by directing requests to other facilities best able to perform the task
- Train individual investigators and students in target making in order to provide a workforce capable to address present and 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

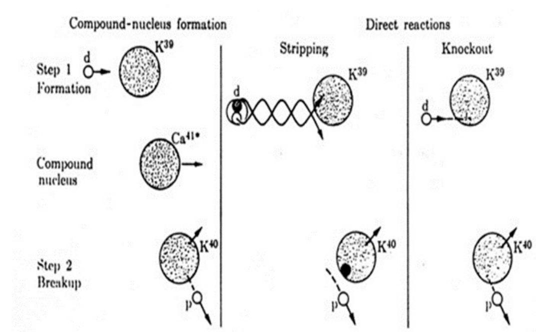
"A unique asset of the ANL program is their target manufacturing capabilities. This expertise at ANL allows highly specialized targets to be prepared for various beam experiments at many laboratories. It is important that these capabilities be maintained given the continuing demands for such targets."
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.



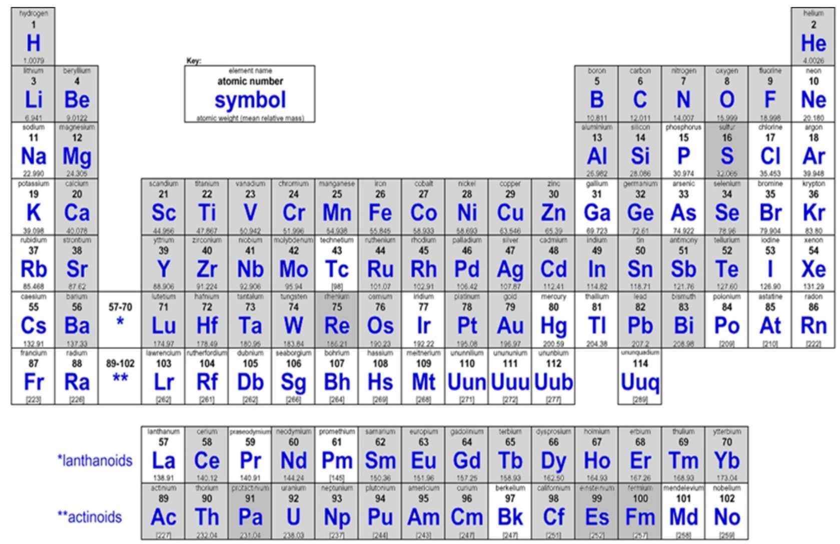
A direct approach for the study of low energy nuclear physics is particle bombardment of a target nucleus and observing the reactions.



Some simple examples of beam and target interactions.

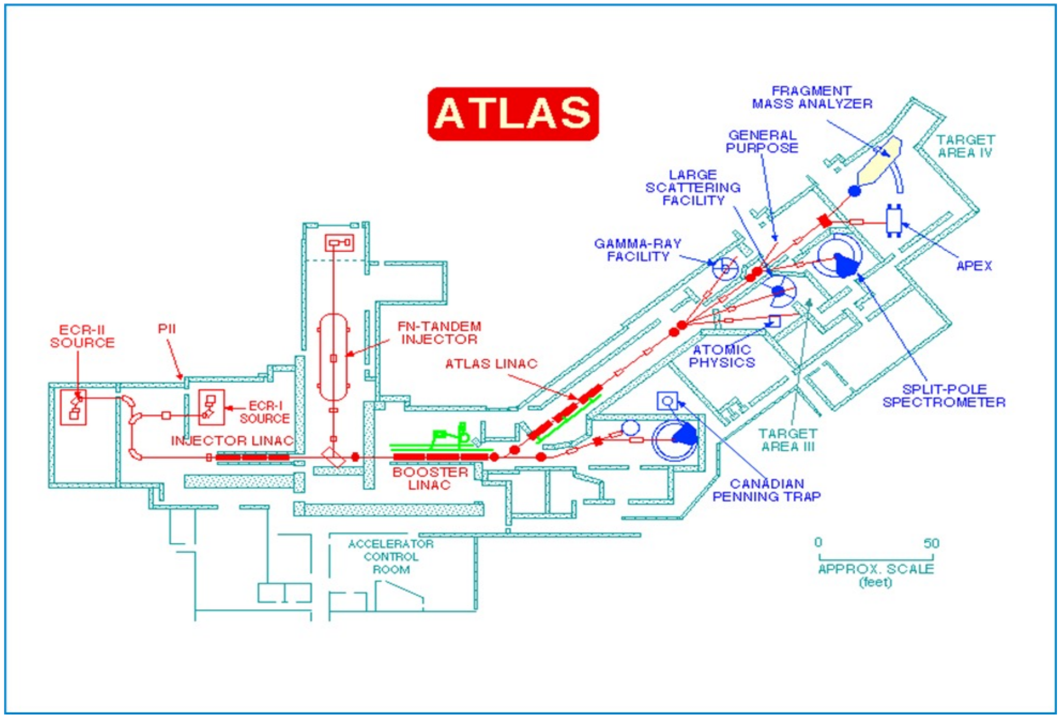
ACCELERATOR TARGET PREPARATION

- 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.



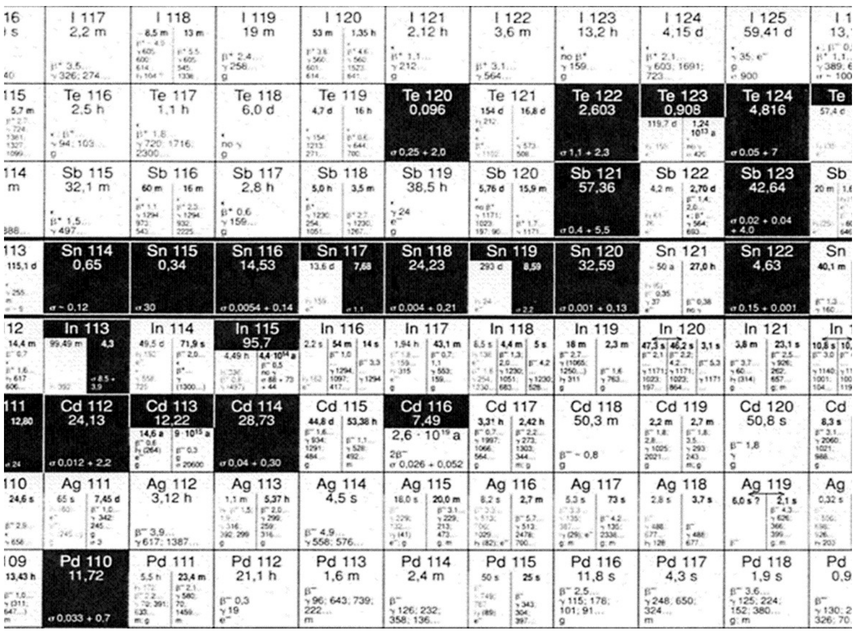
ACCELERATOR TARGET PREPARATION

The ATLAS Accelerator Facility



ACCELERATOR TARGET PREPARATION

Isotopic Starting Material



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

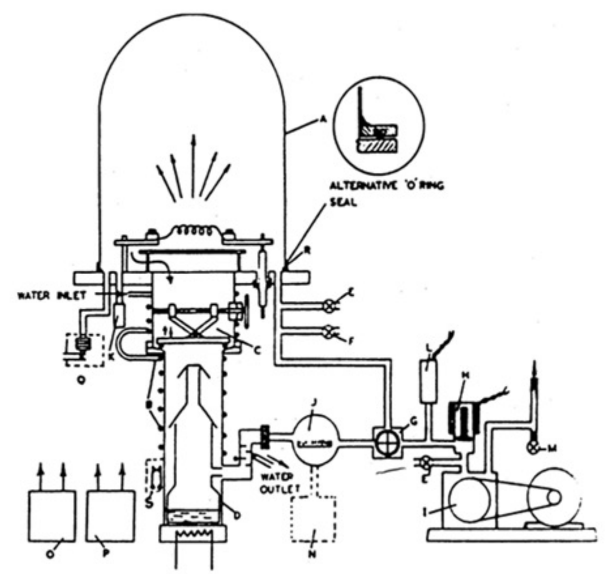
Isotopic or Normal
Standard Size: 2.5 cm by 2.5 cm

Form	Range of thickness ($\mu g/cm^2$)	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.

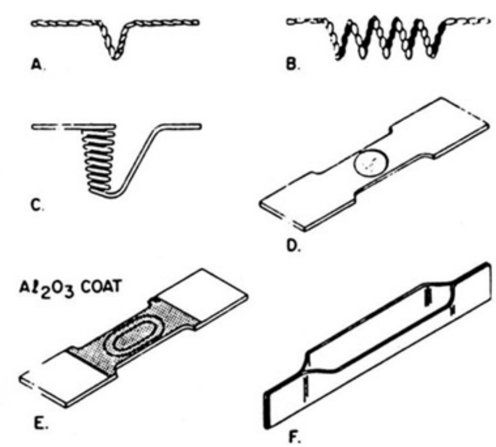
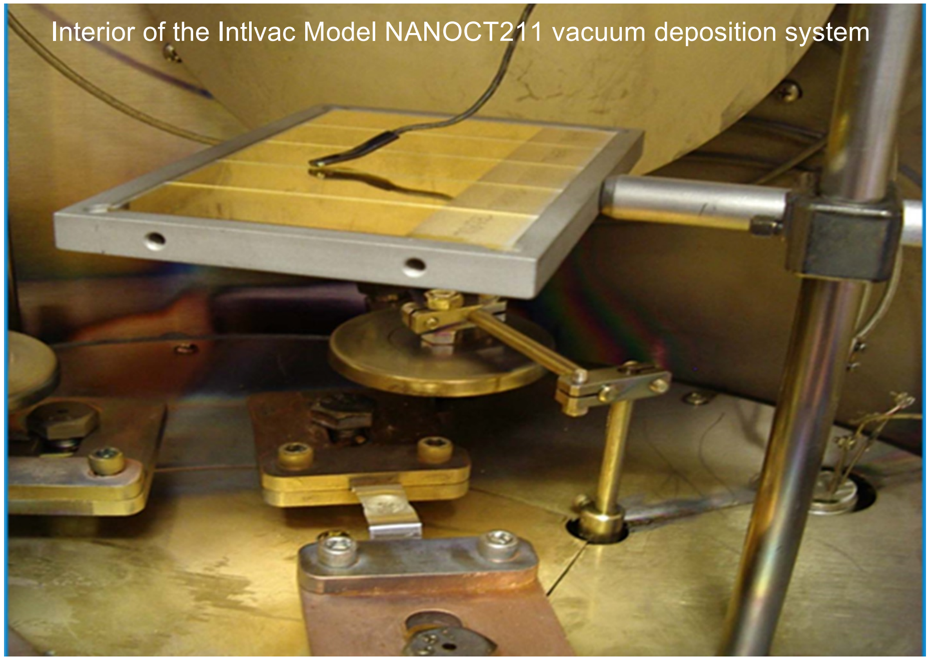


Figure 4.9: Wire and metal-foil sources. (A) Hairpin source. (B) Wire helix. (C) Wire basket. (D) Dimpled foil. (E) Dimpled foil with alumina coating. (F) Canoe type. (From *Handbook of Thin Film Technology*. Copyright © 1970, McGraw-Hill. Used with permission of McGraw-Hill Book Co.)

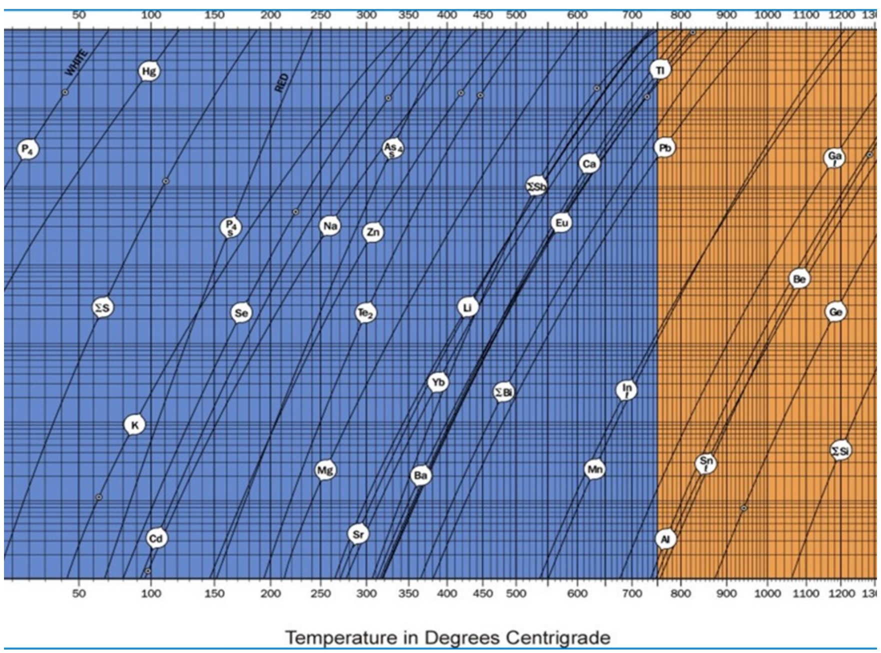
PHYSICAL VAPOR DEPOSITION (PVD)

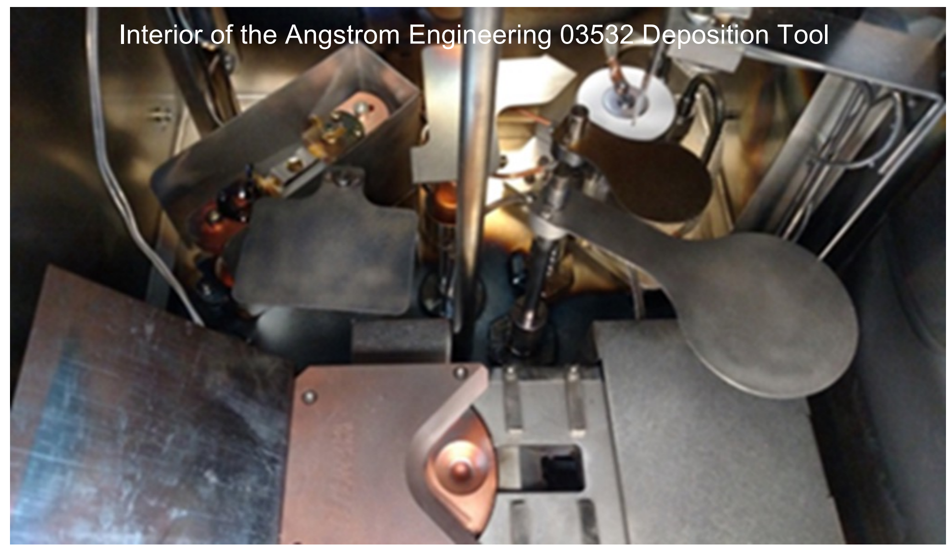
(cont.)

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.


Interior of the Intlvac Model NANOCT211 vacuum deposition system

PHYSICAL VAPOR DEPOSITION (PVD)
(cont.)




Interior of the Angstrom Engineering 03532 Deposition Tool

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

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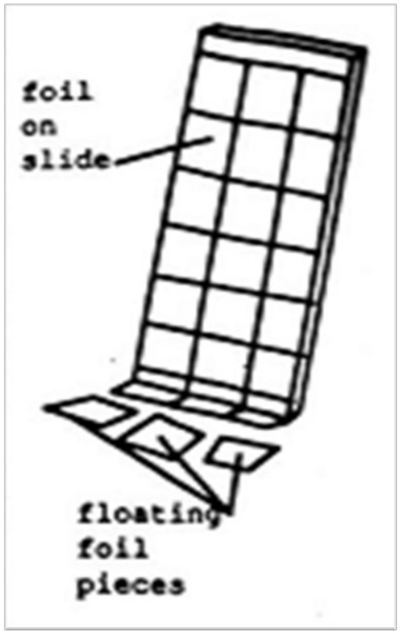

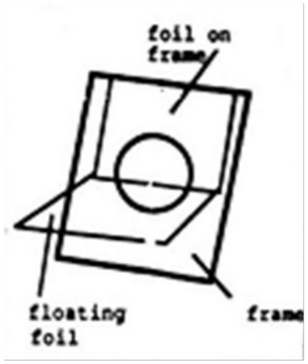

Courtesy of John Stoner – ACF Metals

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

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Thank you for your attention!