The Alchemy of Target Making

John P. Greene
Target Development Engineer

Notre Dame Physics Seminar
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Physics Division
Argonne National Laboratory
In the Beginning…

• Upon invention of the accelerator, the era of the “target maker” began; generally, the increase in sophistication of target making paralleled the increasingly complex developments in accelerator and nuclear physics. It is the target preparer who must provide the defined condition of the target sample – a complicated process involving the disciplines of chemistry, physics, metallurgy, ceramics, and material science.

• Targets prepared in the 1950’s were poorly defined and were frequently polynuclidic. With the advent of mass separators, in particular the calutrons, high purity mononuclidic materials became available for target preparations and precise nuclear reaction mechanisms could be studied.

• It became clear to the nuclear physics community that the cost and complexity associated with isotope target preparation required some centralization of the function. Only the relatively straightforward preparations could be economically performed in the small laboratories associated with the various accelerator sites. Not only was the impetus for this centralization the result of economics, but also of the necessity to preserve the rare and costly isotopes available for this use.

Courtesy of E.H. Kobisk Oak Ridge National Laboratory
Overview of Talk

- Introduction
- Some Target Making Basics
- But We Need the Isotope!
- Compounds, Alloys and Plastics
- Gas Targets / Secondary Beams
- More Complex Experiments
- Conclusion

"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

www.phy.anl.gov/targetlab/hompage.htm

This work is supported by the U.S. Department of Energy, Nuclear Physics Division, under Contract No.W-31-109-Eng-38.
Introduction

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

- The target development laboratory includes state-of-the-art equipment used for thin-film fabrication. The available techniques consist of multiple resistive heating, focused ion beam sputtering, glow-discharge plasma deposition, electron beam and electron bombardment evaporation, electro-deposition and mechanical rolling. The evaporators are maintained under high vacuum and each vessel contains a quartz-crystal film-thickness monitor with deposition rate indicators. Also included are movable shutters, quartz-lamp substrate heaters and thermocouple temperature sensors, allowing for complete process monitoring during target deposition.
Some Target Making Basics

- Physical Vapor Deposition (PVD)

Schematic of a typical vacuum deposition system

Resistance Heated Sources

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

- 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.)

www.rdmathis.com
Some Target Making Basics

- Physical Vapor Deposition (PVD)

For instance, Material Deposition Tables found in the Kurt J. Lesker catalog.

www.lesker.com
Some Target Making Basics

- Target Thickness and Uniformity

![Diagram of evaporation system](image)

Our evaporation system, a Varian NRC(1), is shown schematically in Figure 1. It uses an 18-inch glass bell jar, a NRC VH55 diffusion pump having a 2000-liter per second maximum pumping speed, a 400-liter per minute Welch 1397B roughing pump and a large-capacity liquid nitrogen cold trap. The liquid nitrogen cold trap improves the vacuum by a factor of ten as compared with a refrigeration-type trap. A Kronos crystal thickness monitor(2) was used in all evaporations.

Crystal Oscillators: The crystal oscillator monitor utilizes the piezoelectric properties of quartz. The resonance frequency induced by an a.c. field is inversely proportional to crystal thickness. In practice, the change in frequency of a crystal exposed to the vapor beam is compared to that of reference crystal.
Some Target Making Basics

• Target Thickness and Uniformity

For a dimple style source boat, the vapor flux can be approximated to cover an area of $\pi h^2$, where $h$ is the source to substrate distance. Thus, it can be determined how much material is needed for a given target thickness.

With a large source to substrate distance $h$, the thickness variation within the target area can be minimized. This comes at a cost of having to use more starting material in the boat, which can be expensive for separated isotope.

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Some Target Making Basics

• α-Particle Energy Loss Measurement

Alpha particle energy loss target thickness measurement system with laboratory computer.

The foil to be measured is placed within a mechanically-pumped vacuum chamber between the $^{249}$Cf source and a silicon surface-barrier detector. Small apertures are positioned above and below the target in order to collimate the alpha particles.
Some Target Making Basics

- Parting Agents

### Table 1

<table>
<thead>
<tr>
<th>Element</th>
<th>Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Tepol$^a$</td>
</tr>
<tr>
<td>Antimony</td>
<td>Caesium Iodide</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Barium Chloride</td>
</tr>
<tr>
<td>Bismuth</td>
<td>Caesium Iodide</td>
</tr>
<tr>
<td>Barium</td>
<td>Barium Oxide</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Zinc Chloride</td>
</tr>
<tr>
<td>Calcium</td>
<td>Naphazylamine$^b$</td>
</tr>
<tr>
<td>Carbon</td>
<td>Tepol</td>
</tr>
<tr>
<td>Chromium</td>
<td>Potassium Chloride</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Aluminium Oxide</td>
</tr>
<tr>
<td>Copper</td>
<td>Tepol</td>
</tr>
<tr>
<td>Erbium</td>
<td>Aluminium Oxide</td>
</tr>
<tr>
<td>Germanium</td>
<td>Barium Chloride</td>
</tr>
<tr>
<td>Gold</td>
<td>Tepol</td>
</tr>
<tr>
<td>Holmium</td>
<td>Calcium Iodide</td>
</tr>
<tr>
<td>Indium</td>
<td>Formvar$^c$</td>
</tr>
<tr>
<td>Iron</td>
<td>Copper</td>
</tr>
<tr>
<td>Lead</td>
<td>Potassium Chloride</td>
</tr>
<tr>
<td>Lithium</td>
<td>Naphazylamine</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Zapon$^d$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanguanese</td>
<td>Aluminium Oxide</td>
</tr>
<tr>
<td>Holmium</td>
<td>Sodium Chloride</td>
</tr>
<tr>
<td>Neodymium</td>
<td>Barium Iodide</td>
</tr>
<tr>
<td>Caesium</td>
<td>Sodium Chloride</td>
</tr>
<tr>
<td>Palladium</td>
<td>Caesium Iodide</td>
</tr>
<tr>
<td>Potassium</td>
<td>Hexaethanamine</td>
</tr>
<tr>
<td>Praseodymium</td>
<td>Aluminium Oxide</td>
</tr>
<tr>
<td>Nickel</td>
<td>Copper</td>
</tr>
<tr>
<td>Ruthenium</td>
<td>Potassium Iodide</td>
</tr>
<tr>
<td>Scandium</td>
<td>Aluminium Oxide</td>
</tr>
<tr>
<td>Silicon</td>
<td>Potassium Chloride</td>
</tr>
<tr>
<td>Silver</td>
<td>Tepol</td>
</tr>
<tr>
<td>Tellurium</td>
<td>Tepol</td>
</tr>
<tr>
<td>Thulium</td>
<td>Calcium Iodide</td>
</tr>
<tr>
<td>Tin</td>
<td>Tepol</td>
</tr>
<tr>
<td>Titanium</td>
<td>Calcium Iodide</td>
</tr>
<tr>
<td>Vanadium</td>
<td>Potassium Iodide</td>
</tr>
<tr>
<td>Yttrium</td>
<td>Calcium Iodide</td>
</tr>
<tr>
<td>Zirconium</td>
<td>Copper</td>
</tr>
</tbody>
</table>

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Use a mechanical arm or your own steady hand. Hold the slide, foil side uppermost, at about 45 degrees to the horizontal. Lower the slide slowly into a dish of clean (preferably distilled or deionized) water at room temperature. Foils will pick up ionic impurities from the water used to float them [Raih et al., Nucl. Instrum. Meth. 142, 39–44 (1977)]. Alternatively, the slide may be held fixed and the dish of water raised below it using a laboratory jack. The smoothest method, preferred for large foils, is to keep both slide and dish fixed, and siphon water from an auxiliary container into the dish. If the auxiliary container has smaller volume than the dish, it will not overflow the dish if your attention is distracted. Alternatively, the slide with foil uppermost may be laid horizontally on the bottom of a dish, and little drops of water placed with a medicine dropper on the intersections of the scribed lines on the foil. After a few minutes, the water will have crept under the foil and more water may be added. When the foil has released completely, water may be siphoned into the dish to lift the foil as needed.

When the water level reaches the foil, it will float on the water surface (Fig. 1). If the foil tends to stick, or is pulled below the water surface, you are doing it too fast. When the foil has floated entirely off of the slide, remove the slide carefully so it won’t be in your way for the pickup process. If desired, clean the undesired fragments from the water surface by picking them up with the corner of a paper towel, or sucking them up with a pipette tip, or by allowing them to flow into a little upright empty beaker that you first immerse gently in the water almost to its rim.

Sometimes foil pieces tend to stick together while floating. They can be separated conveniently by touching a boundary between foil pieces with a needle moistened in methanol (W. Lozowski, private communication, 1990).
ANL Target Laboratory Capabilities

- Resistive evaporation
- Electron beam deposition
- Ion beam & reactive sputtering
- Plasma & arc discharge
- Mechanical rolling
- Electroplating
- Painting, spreading and spray coating

“Because of the amount of research, development, and invention required in target preparation, a new group of scientists evolved having unique technical backgrounds in a wide variety of scientific disciplines. As a result, target makers derived the concept of the International Nuclear Target Development Society (INTDS) for the stated Purposes of enhanced communications, transmittal of technical developments, and personal involvement at an annual meeting where free discussions could be achieved.”

www.intds.org

Courtesy of E.H. Kobisk, Oak Ridge National Laboratory
Welcome to the homepage of the International Nuclear Target Development Society (INTDS).

We are a not-for-profit, educational organization that:

- Encourages the sharing of techniques developed, or being developed, to provide research-quality targets and reference samples, mostly for basic research in physics, chemistry, and related sciences.
- Publishes the technical reports, preparation and related topics, in a manner easily located in the scientific literature. Today a PC-based database of INTDS publications lists 786 articles and is searchable with 241 relevant keywords. Many of the articles were published as editions of Nuclear Instruments and Methods, and are proceedings of INTDS conferences. Twice a year we publish an INTDS Newsletter.
- Mentors people new to target and sample preparation.
- Provides modest financial support for hosts of INTDS conferences and for selected speakers.

We trace our roots to 1963 and the First Symposium on Research Materials for Nuclear Measurements, sponsored by the central Bureau of Nuclear Measurements (CBMN) in Geel, Belgium. We have biennial, autumn conferences that alternate between sites in Europe and North America. Check the interests page to determine if they’re similar to yours.

A resounding success! Bravo to John Greene (host), the ANL Organizing Committee, and the attendees of the 21st World Conference of the INTDS at Argonne National Lab, November 4-8, 2002. There were 38 presentations to approximately 70 colleagues from 14 countries. The INTDS proceedings will be published as vol. 521, no. 1 of NIM-A, due by the end of March 2004.

October 2004: The 22nd World Conference of the INTDS, "Preparation of Nuclear Targets and Samples for Advanced Scientific Measurements" will take place 19-22 October 2004 at the Gaithersburg, Maryland campus of the U.S. National Institute of Standards and Technology (NIST). To be placed on the conference mailing list for information and registration, e-mail David Gilliam. A more detailed announcement and call for papers will appear soon on this INTDS home page.

The conference will cover classical and innovative target and detector preparation related to the topics listed below.
ANL Target Laboratory Capabilities

• Resistive evaporation

Photograph inside the new evaporator after a gold deposition. Shown are the evaporation source boat, shutter, microscope slide substrates and thermocouple temperature sensor.

New Intelvac Nanochrome Vacuum Deposition System

• Large Area Chamber with Automatic Cyropumping System
• Dual Thermal Evaporation Sources
• Dual Deposition Controllers with Shutters
• Veeco Sputter Source for Ion Assisted Depositions
• Two Quartz lamps for radiant Heating
• Rotatable Substrate Fixture
• Intelvac Autosys Computer Control using LabView
**ANL Target Laboratory Capabilities**

- **Electron beam deposition**

  The Temescal Model STIH-270-1 Electron Beam Gun has four 7-cc evenly spaced crucibles with the contents of three being concealed for protection from stray beams and debris. This design prevents cross-contamination of the evaporants between the crucibles.

  The magnetic fields that direct and focus the electron beam are supplied by the main-field permanent magnet with two pole pieces and extensions and a hermetically sealed deflection electromagnet. The field of the permanent magnet, located inside the back of the gun is to confine the beam to the hearth area. The deflection coil is used to accomplish X-Y beam sweeping.
ANL Target Laboratory Capabilities

- Electron beam deposition

Photograph of electron-beam source showing turret for multiple evaporations.

Fig. 4. System for producing stress-free, self-supporting boron targets with a Vesco Veblen electron-beam-gun and a water-cooled copper anode.
ANL Target Laboratory Capabilities

- Electron bombardment deposition

Photograph of experimental arrangement for the reduction-distillation of gadolinium.

Fig. 3. Detail of the evaporation system of Erskine and Gemmel [5] using electron bombardment and having a water-cooled anode.
ANL Target Laboratory Capabilities

- Ion beam & reactive sputtering

Ion assisted evaporation uses a broad beam ion source to direct an energetic, reactive ion beam simultaneous with the evaporation of metal or dielectric materials (typically using an electron beam) onto a substrate. The ion sources are usually of the "gridless," end-Hall type. The ion beam is neutralized with an independent electron source.

Interior of the new evaporator chamber showing the dual thermal evaporation boats and Veeco sputter source.

Photograph showing the sputtering setup.
ANL Target Laboratory Capabilities

- Plasma & arc discharge

Fig. 1. Apparatus (not to scale) used to produce cracked-hydrocarbon foils. 1) Polycarbonate insulators, 2) anode support post (aluminum), 3) anode (brass), 4) cover plate (grounded), 5) neoprene gasket, 6) Pyrex glass vacuum jar, 7) plastic implosion shield, 8) electrode clamp (polycarbonate), 9) cathode (brass) and substrate, 10) post for cathode connection (brass), 11) polycarbonate insulators, 12) insulated high-voltage cable, 13) port cover (steel), 14) required, 15) aluminum ring and baseplate, 16) gate valve (10-cm aperture), 17) refrigerated baffle, 18) oil diffusion pump (10-cm aperture), 19) gas-inlet tubulation (polycarbonate), 20) anode support (3 required). Pressure gauging, gas inlet connection, auxiliary pumping connection, and high-voltage feedthrough are made via port covers (part 13).
ANL Target Laboratory Capabilities

• Mechanical rolling

With the sample in place within the stainless steel pack the rolling begins, slowly at first to prevent growing cracks within the sample. After several passes, the sample is rotated by 90 degrees and the gap decreased slightly.

New Type SE/EX rolling mill: acquired in 1997

Older model rolling mill now relocated to the Radioactive Materials Laboratory for rolling U and Th foils
ANL Target Laboratory Capabilities

- Electroplating

A photograph showing the experimental set-up in detail

Short teflon cell with conical interior bore

Photograph of a $^{239}$Pu target prepared by molecular plating.

Reference:


Figure 1. Electroplating setup.

ANL Target Laboratory Capabilities

• Painting, spreading and spray coating

- Close-up of the pipette and substrate when preparing a target by the “liquid drop” technique.
- CD$_2$ targets.
- Casting of the Formvar film using a glass rod on a glass plate substrate.
- Paasche airbrush used for spray coating.
- Spray coated films showing aggregates in the dispersion of the MoS$_2$ material.
Foils Other Than Targets

- Stripper foils
- Backing foils
- Energy degrader foils
- Charge resetting foils
- Catcher & stopper foils
- Absorbers & filters
- Windows

www.phy.anl.gov/atlas

• Targets Other Than ATLAS
**But We Need the Isotope!**

**TIN**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Natural abundance (at.%)</th>
<th>Isotopic enrichment* (at.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn-112</td>
<td>0.96</td>
<td>68-80</td>
</tr>
<tr>
<td>Sn-114</td>
<td>0.66</td>
<td>&gt;61</td>
</tr>
<tr>
<td>Sn-115</td>
<td>0.33</td>
<td>&gt;32</td>
</tr>
<tr>
<td>Sn-116</td>
<td>14.30</td>
<td>&gt;95</td>
</tr>
<tr>
<td>Sn-117</td>
<td>7.61</td>
<td>&gt;99</td>
</tr>
<tr>
<td>Sn-118</td>
<td>24.03</td>
<td>&gt;97</td>
</tr>
<tr>
<td>Sn-119</td>
<td>8.58</td>
<td>&gt;84</td>
</tr>
<tr>
<td>Sn-120</td>
<td>32.85</td>
<td>&gt;98</td>
</tr>
<tr>
<td>Sn-122</td>
<td>4.72</td>
<td>&gt;92</td>
</tr>
<tr>
<td>Sn-124</td>
<td>5.94</td>
<td>&gt;94</td>
</tr>
</tbody>
</table>

**INVENTORY FORM:** oxide

**Alternative Forms:** metal, powder, or beads

**TARGETS**

Isotopic or Normal

Standard Size: 2.5 cm by 2.5 cm

<table>
<thead>
<tr>
<th>Form</th>
<th>Range of thickness (µg/cm²)</th>
<th>Backing</th>
<th>Method of preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn</td>
<td>10 to 1000</td>
<td>Metal</td>
<td>Evaporation</td>
</tr>
<tr>
<td>Sn</td>
<td>100 to 4000</td>
<td>Self-supporting</td>
<td>Evaporation</td>
</tr>
<tr>
<td>Sn</td>
<td>&gt;4000</td>
<td>Self-supporting</td>
<td>Rolling</td>
</tr>
<tr>
<td>Sn</td>
<td>Variable</td>
<td>Self-supporting</td>
<td>Cast or pressed</td>
</tr>
</tbody>
</table>

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

*Typical isotopic distributions, p. C-6 of Appendix C.
But We Need the Isotope (as METAL)!

- Reduction of the Oxide

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>REDUCTANT AND METHOD</th>
<th>TEMP (°C)</th>
<th>BOAT TYPE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe₂O₃</td>
<td>H₂ in Tube Furnace</td>
<td>600-900</td>
<td>Quarts or Porcelain</td>
<td>CO₂ evolution limits power input and indicated rate of reduction.</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>Carbon Red.-Dist.</td>
<td>1000-1500</td>
<td>Graphite or Ta Crucible</td>
<td>Convert nitrate to oxide and reduce or use covered combustion boat when reducing nitrate to prevent losses.</td>
</tr>
<tr>
<td>Pb(WO₄)₂</td>
<td>H₂ in Tube Furnace</td>
<td>400-600</td>
<td>Vitreous C</td>
<td>See section on Red.-Dist. for details.</td>
</tr>
<tr>
<td>IrO₂</td>
<td>Ir or Th Red.-Dist.</td>
<td>1890-1950</td>
<td>Ta Crucible</td>
<td>See section on Red.-Dist. for details.</td>
</tr>
<tr>
<td>MgO</td>
<td>Lanthanum Red.-Dist.</td>
<td>800-1200</td>
<td>Ta Pinhole or Tube</td>
<td></td>
</tr>
<tr>
<td>Nd₂O₃</td>
<td>Ir or Th Red.-Dist.</td>
<td>1500-1900</td>
<td>Ta Crucible</td>
<td></td>
</tr>
<tr>
<td>Sm₂O₃</td>
<td>Lanthanum Red.-Dist.</td>
<td>900-1200</td>
<td>Ta Pinhole or Tube</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>Tantalum Red.-Dist.</td>
<td>1800-2000</td>
<td>C Crucible</td>
<td>Convert nitrate to carbonate with (NH₄)₂CO₃, then reduce to oxide at 850°C in Ta boat.</td>
</tr>
<tr>
<td>Sr(WO₄)₂</td>
<td>Lanthanum Red.-Dist.</td>
<td>900-1700</td>
<td>Ta Pinhole or Tube</td>
<td></td>
</tr>
<tr>
<td>Ti₂O₃</td>
<td>H₂ in Tube Furnace</td>
<td>300-325</td>
<td>Vitreous C</td>
<td>Oxide is volatile. Do not exceed 305°C. Use wet H₂ - bubble gas through water.</td>
</tr>
<tr>
<td>SnO₂</td>
<td>*</td>
<td>600-1000</td>
<td>Vitreous C</td>
<td>Heat at 450°C to reduce to metal. Then heat to 800°C for 1 hr. to prevent metal from becoming pyrophoric.</td>
</tr>
<tr>
<td>WO₃</td>
<td>*</td>
<td>450-800</td>
<td>Quarts</td>
<td></td>
</tr>
<tr>
<td>Tl₂O₃</td>
<td>Lanthanum Red.-Dist.</td>
<td>900-1200</td>
<td>Ta Pinhole or Tube</td>
<td>See section on Red.-Dist. for details.</td>
</tr>
<tr>
<td>ZnO</td>
<td>Carbon Red.-Dist.</td>
<td>600-800</td>
<td>Ta Pinhole</td>
<td>See section on electrolytic red. for details.</td>
</tr>
<tr>
<td>InO</td>
<td>Electrolytic</td>
<td></td>
<td></td>
<td>See section on electrolytic red. for details.</td>
</tr>
</tbody>
</table>


SnO₂ + 2H₂ → Sn + 2H₂O

heat

before (100 mg)  after (79 mg)

mp. Sn 232 C

Tube Furnace for Hydrogen reductions.

"The Alchemy of Target Making" - John P. Greene - Notre Dame Seminar
But We Need the Target (as METAL)!

- Pyrometallurgical Reduction Method

E.H. Kobisk and H.L. Adair, NIM 167 (1979) 153

Photograph of experimental arrangement for the reduction-distillation of $^{154}\text{Sm}$ onto 20 $\mu$g/cm$^2$ carbon backing foil.

$$154\text{Sm}_2\text{O}_3 + 2\text{La} \rightarrow 2^{154}\text{Sm} + \text{La}_2\text{O}_3$$

for (100 mg) oxide

heat

$^{154}\text{Sm}_2\text{O}_3 + 2\text{La} \rightarrow 2^{154}\text{Sm} + \text{La}_2\text{O}_3$

we need twice (78 mg) fresh La = 156 mg

Calculation of the free energy change for the metallothermic reduction of samarium

<table>
<thead>
<tr>
<th>Metallothermic reduction of samarium $^a$</th>
<th>FEC per mole Sm [kcal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3\text{Zr} + 2\text{Sm}_2\text{O}_3 \rightarrow 3\text{ZrO}_2 + 4\text{Sm}$</td>
<td>22.3</td>
</tr>
<tr>
<td>$3\text{Hf} + 2\text{Sm}_2\text{O}_3 \rightarrow 3\text{HfO}_2 + 4\text{Sm}$</td>
<td>19.1</td>
</tr>
<tr>
<td>$2\text{La} + \text{Sm}_2\text{O}_3 \rightarrow \text{La}_2\text{O}_3 + 2\text{Sm}$</td>
<td>6.7</td>
</tr>
<tr>
<td>$3\text{Th} + 2\text{Sm}_2\text{O}_3 \rightarrow 3\text{ThO}_2 + 4\text{Sm}$</td>
<td>0.003</td>
</tr>
</tbody>
</table>

$^a$ Calculations made for temperature at 1573 K.

mp. Sm 1072 C  
mp. La 920 C
**But We Need the Target (as METAL)!**

- **Pyrometallurgical Reduction Method**

  R. Pengo, et. al., NIM A303 (1991) 146

Photograph of experimental arrangement for the reduction-distillation of $^{148}$Nd onto a 1.5 mg/cm$^2$ “stretched” gold substrate.

We need (116 mg) oxide for (100 mg) metal:

$$2^{148}\text{NdO}_2 + 3\text{Hf} \rightarrow 4^{148}\text{Nd} + 3\text{HfO}_2$$

Using twice (90.3 mg) fresh Hf = 181 mg

Calculations of the free energy change for the metallothermic reduction of neodymium:

<table>
<thead>
<tr>
<th>Metallothermic reduction of neodymium $^*$</th>
<th>FEC per mole Nd [kcal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2\text{La} + \text{Nd}_2\text{O}_3 \rightarrow \text{La}_2\text{O}_3 + 2\text{Nd}$</td>
<td>12.9</td>
</tr>
<tr>
<td>$3\text{Sr} + 2\text{Nd}_2\text{O}_3 \rightarrow 3\text{ZrO}_2 + 4\text{Nd}$</td>
<td>7.8</td>
</tr>
<tr>
<td>$3\text{Hf} + 2\text{Nd}_2\text{O}_3 \rightarrow 3\text{HfO}_2 + 4\text{Nd}$</td>
<td>4.0</td>
</tr>
<tr>
<td>$3\text{Th} + 2\text{Nd}_2\text{O}_3 \rightarrow 3\text{ThO}_2 + 4\text{Nd}$</td>
<td>$-13.4$</td>
</tr>
</tbody>
</table>

* Calculations made for temperature at 2073 K.

Parr Pellet Press for compressing powdered samples into pellet or tablet form.

mp. Nd 1024 C    mp. Hf 2150 C
Compounds, Alloys, and Plastics

- Targets, Foils and Windows

Gold-coated Formvar foil mounted on the detector frame.

Havar window indium soldered to holder ring.

Practice Nd$_2$O$_3$ electrodeposition showing 3 mm target spot.

Photograph of the sputtered $^{24}$MgO and $^{26}$MgO deposits on Ta plate substrates.

1 mg/cm$^2$ Kapton foil targets cut from sheet.
**Gas Targets / Secondary Beams**

**PRODUCTION GAS CELL**

- Support tube
- Cooling liquid
- \( ^{17}O \)
- Window mounting
- \( H_2 \) chamber

*Fig. 1-55. A simplified cross section of the gas target.*

For \( H_2 \) or \( D_2 \) operation: uses 1.9 mg/cm\(^2\) HAVAR windows

Achieves target density: *(typically)* 1 mg/cm\(^2\) \( H \)

For \( ^{3}He \) or \( ^{4}He \) operation: uses 1.3 mg/cm\(^2\) Ti windows

Achieves target density: *(typically)* 1 mg/cm\(^2\) \( He \)

*Also needs charge resetting foils.*

A smaller version was developed as a gas target (\( He \)) using Ti windows

Achieved a target density of \(-30 \mu g/cm^2\) \( He \)

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**Beam Transport Schematic**

Titanium window attached using low-temperature epoxy.

**Gas cell and solenoid set-up at ATLAS.**
Gas Targets / Secondary Beams / Detectors

Gas Production Cells for Secondary Beams

- Robust Foils for High Beam Currents
- Havar for H\(_2\), D\(_2\) Fills
- Titanium for \(^3\)He, \(^4\)He Gas
- 20 µg/cm\(^2\) Carbon Charge Reset Foils

\(^3\)He Gas Target

- Specialized Ti and Havar Target Windows
- LN\(_2\) Cooled for Increased Gas Density
- Recent Efforts Towards Thinner Foil Windows
Gas Targets / Secondary Beams / Detectors

- Micro-channel Plate Detector Array

FMA micro-channel plate detector system.
Gas Targets / Secondary Beams / Detectors

- Solar Neutron Counter (U of C)

Development of a miniaturized low-energy solar neutron detector.
More Complex Experiments

- Experiments in Nuclear Astrophysics

- CH₂ and CD₂ Targets
- Large Area Metallized Plastic Foils
- Stopping Foils and Energy Degraders
More Complex Experiments – Target Wheels

“Thick” target wheels, \( \text{nat}^\text{C} \), Rolled \( \text{nat}^\text{Ni} \)
Isotopic rolled foil wheels (future)

New Target Wheel = 16 Sectors
Thin Target Wheels, \( ^{208}\text{Pb} \)
Charge Reset Foils

Large Area Aluminum Degrader Foil Ladder

Gas “Catcher” Cell
Havar Windows
\( ^{252}\text{Cf} \) Source

Chamber Cooling Entrance, Exit Windows

Detector Foils Degrader Foils
“Catcher” Foils
More Complex Experiments - RIA

2-Step Projectile Fragmentation
(High Pressure He Gas Stopper Cell)

- 100 kW
- HI Beam (~100 MeV/u)
- Cooled Tungsten Target
- Filter
- Stopper
- Gas Cell Catcher

- Ion Beam
- High-Power Target
- Filter

Secondary UC target
Liquid Li coolant
Beam
Primary tungsten target

Output ion beam

1-GeV p or d beam

Liquid lithium in
Liquid lithium out

“The Alchemy of Target Making” - John P. Greene - Notre Dame Seminar
Conclusion

• This hopefully gives you a little flavor of the importance of the target laboratory to the success of the experimental program, showing what goes into the preparation of the wide variety of targets and foils used at ATLAS.

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