Enriched Stable Isotopes and Technical Services at ORNL

Nuclear Science and Technology Division

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Isotope Development Group Activities

- **Calutrons**
  - Calutron operations, engineering, maintenance
  - Stable isotope enrichment not currently active
- **Products and Services**
  - Chemistry laboratories
  - Isotope Research Materials Laboratory
  - Stable isotope packaging and shipping
- **Nuclear Medicine Program**
  - Radioisotope development through clinical trial stages
- **Isotope Business Office (National Isotope Data Center)**
  - Administers contracts, sales, leases, and shipping of all ORNL, BNL, LANL, Y-12, PNNL and SRNL stable and radioactive isotopes for the DOE Isotope Program
- Production and distribution of enriched stable isotopes which is ISO 9001 registered through Underwriters Laboratories, Inc.
- National security (nuclear nonproliferation) training
- Technical support to other R&D projects (ORELA, USEC, DHS, DOE-NNSA, etc.)
What Is An Isotope And Why Enrich Them?

- Atoms of the same chemical element with same number of protons in the nucleus, similar chemical behavior
- Different number of neutrons in the nucleus, very different nuclear behavior
- Mass difference (neutrons) used to separate the isotopes from their natural mixture
- Natural U is 0.01% U-234, 0.71% U-235, and 99.28% U-238
- U-235 is fissionable and used in weapons and nuclear fuel
- U-238 is fertile and used to make Pu-239 and as shielding and projectiles
- Isotopes must often be enriched to enhance desired properties or avoid undesirable properties
- Calutrons (U of Cal-ifornia Cyclo-trons) produced first large-scale quantities of U-235 but were replaced by gaseous diffusion
- Stable isotope production started in November 1945
Y-12 National Security Complex Aerial View
## Y-12 Production Calutrons - 1945

<table>
<thead>
<tr>
<th></th>
<th>Alpha - I</th>
<th>Alpha – II</th>
<th>Beta</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Tracks</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Calutrons/Track</td>
<td>96</td>
<td>96</td>
<td>36</td>
<td>-</td>
</tr>
<tr>
<td>Total Calutrons</td>
<td>480</td>
<td>384</td>
<td>288</td>
<td>1,152</td>
</tr>
<tr>
<td>Beam Radii (feet)</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Beams per tank</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Total Ion Beams</td>
<td>960</td>
<td>1,536</td>
<td>576</td>
<td>3,072</td>
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</tbody>
</table>

Pilot Plant: 2 Alpha-II and 2 Beta calutrons
Isotope Enrichment Facility
Isotope Enrichment Facility

- Built in 1943 for U-235 enrichment (1 of 9 buildings)
- Second-pass for enrichment from 12-15% U-235 to greater than 90% for weapons use
- Top-off U-235 from early gaseous diffusion process
- IEF converted to stable and actinide isotope enrichment in the 1950s and early 1960s
- One of 2 production-scale calutron facilities in the world (other in Russia)
- Approximately 5 acres of floor space
- All stable isotope activities consolidated in the IEF in early 1990s (co-location resulted in ~40% savings), since moved to ORNL
- Originally staffed by 2,000 people, modern operations by a staff of 45 on a 3-shift/5-day rotating schedule (in operable stand-by since 1998)
- Enriched approximately 252 isotopes of about 58 elements
- One of 8 “Signature Facilities” of the Manhattan Project
- ANS Nuclear Historic Landmark
- DOE-NE requested and received an estimate (~$17M) to reestablish a smaller production-scale electromagnetic isotope enrichment capability at ORNL in February 2008
Isotope Enrichment Facility Calutrons
Schematic of a Calutron
Calcium Isotope Receiver
Examples of Stable Isotope Products and Applications

- Approximately 233 stable isotopes for multi-disciplinary research
- Rb-87 (naturally occurring radioisotope) used as a timing standard or atomic clock in geopositioning systems, cellular telephone applications, etc.
- Tl-203 for production of Tl-201 for cardiac imaging
- Cd-112 for production of In-111 for cancer detection and monitoring, kidney function assessment
- Zn-68 for production of Ga-67 for detection of abscesses, active inflammation, and cancer
- W-186 for production of W-188/Re-188 generators for cancer diagnostics and treatment
- Sr-88 for production of Sr-89 for bone cancer treatment
- Mo-98 for Mo-99/Tc-99m production– major medical isotope, concentration process licensed to a private industry
- Ni-62 for Ni-63 production – explosives detection, power sources
- Lu-176 for HSA Lu-177 production – medical applications
- Many medical radioisotopes start from a stable isotope precursor
WW-II Era Control Room

Current Control Room
# Isotopes Enriched by the Calutrons

This diagram illustrates the isotopes enriched by the Calutrons, with a key identifying elements separated in Calutrons and the number of isotopes collected, elements not separated in Calutrons, and stable elements with no naturally occurring stable isotopes.

- **Group IA**: Elements separated in Calutrons and number of isotopes collected
- **Group IB**: Elements not separated in Calutrons
- **Group II**: Stable elements with no naturally occurring stable isotopes

The diagram also indicates:
- Red diamond: Number of isotopes currently sold-out
- Red square: Number of isotopes sold-out, second pass high enrichment
- Yellow square: Number of isotopes with <20 year supply
- Yellow diamond: Number of isotopes with <20 year supply, second pass high enrichment

The diagram includes a periodic table with elements from Group IA to VIA, and Inert Gases from He to Rn.
Stable Isotopes are Used in Many Fields Either Directly or as Precursors to Radioisotopes

- **Basic Research**
  - Physics
  - Environment
  - Materials
  - Agriculture
  - Analytical Chemistry
  - Geosciences

- **National Security**
  - Communications
  - Detection
  - Nuclear Data
  - Global Positioning
  - Sources

- **Medicine**
  - Therapies
  - Imaging
  - Research
  - Dental

- **Industry**
  - Standards
  - Inspections
  - Testing
  - Sources
  - Nuclear Data

- **Enriched Stable Isotopes**
Stable Isotope Sales and Customers Vary Greatly

Sales can be highly variable and unpredictable with large contracts or single isotope sales taking total sales as high as $2-9M/year.

A wide variety of customers are served around the world; some single orders are for as many as 40-50 different isotopes.

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Technical Services</th>
<th>Stable Isotopes</th>
</tr>
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<tbody>
<tr>
<td>FY2003</td>
<td>$36,737</td>
<td>$373,948</td>
</tr>
<tr>
<td>FY2004</td>
<td>$53,349</td>
<td>$431,659</td>
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<tr>
<td>FY2005</td>
<td>$45,396</td>
<td>$313,208</td>
</tr>
<tr>
<td>FY2006</td>
<td>$72,553</td>
<td>$728,873</td>
</tr>
<tr>
<td>FY2007</td>
<td>$144,317</td>
<td>$687,204</td>
</tr>
<tr>
<td>Through 3Q 2008</td>
<td>$101,599</td>
<td>$1,087,996</td>
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</table>
Over the Years, Custom Products and Services Have Been Provided by the IDG for Most Elements and Their Respective Isotopes

<table>
<thead>
<tr>
<th>Period</th>
<th>Group IA</th>
<th>IA</th>
<th>IIA</th>
<th>IIB</th>
<th>IIB</th>
<th>IB</th>
<th>IIB</th>
<th>IIIA</th>
<th>IVA</th>
<th>VA</th>
<th>VIA</th>
<th>VIIA</th>
<th>Inert Gases</th>
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<tbody>
<tr>
<td>1</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IIA</td>
<td></td>
<td></td>
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<td></td>
<td>He</td>
</tr>
<tr>
<td>2</td>
<td>Li</td>
<td>Be</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>Na</td>
<td>Mg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>K</td>
<td>Ca</td>
<td>Sc</td>
<td>Ti</td>
<td>V</td>
<td>Cr</td>
<td>Mn</td>
<td>Fe</td>
<td>Co</td>
<td>Ni</td>
<td>Cu</td>
<td>Zn</td>
<td>Ga</td>
</tr>
<tr>
<td>5</td>
<td>Rb</td>
<td>Sr</td>
<td>Y</td>
<td>Zr</td>
<td>Nb</td>
<td>Mo</td>
<td>Tc</td>
<td>Ru</td>
<td>Rh</td>
<td>Pd</td>
<td>Ag</td>
<td>Cd</td>
<td>In</td>
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<td>6</td>
<td>Cs</td>
<td>Ba</td>
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<td>Hf</td>
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<td>W</td>
<td>Re</td>
<td>Os</td>
<td>Ir</td>
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<tr>
<td>7</td>
<td>Fr</td>
<td>Ra</td>
<td>Ac</td>
<td>Ce</td>
<td>Pr</td>
<td>Nd</td>
<td>Pm</td>
<td>Sm</td>
<td>Eu</td>
<td>Gd</td>
<td>Tb</td>
<td>Dy</td>
<td>Ho</td>
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<tr>
<td></td>
<td>Th</td>
<td>Pa</td>
<td>U</td>
<td>Np</td>
<td>Pu</td>
<td>Am</td>
<td>Cm</td>
<td>Bk</td>
<td>Cf</td>
<td>Es</td>
<td>Fm</td>
<td>Md</td>
<td>No</td>
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</table>
IEF Chemistry Laboratory

• Development and preparation of feed materials for calutrons
• Recovery and purification of enriched stable isotopes
• Custom chemical conversion services
  – Wet chemistry for alternate compound synthesis
  – Hydrogen reduction of some metals
  – Selected pyrochemical reductions
• Recovery and purification of leased isotopes upon return to ORNL
• Technical support to other ORNL, DOE, and private programs
Isotope Research Materials Laboratory

- Pyrochemical metal conversions
  - Reduction/distillation of Group IIA and selected rare earths
  - Calcium reduction on selected rare earth fluorides
  - Planned restoration of crystal bar reduction of Si, Ti, Zr, and Hf

- Custom physical form processing services
  - Metallurgical processing
  - Ceramic processing
  - High vacuum processing – thin films and coatings

- Maintenance and distribution of a significant inventory of isotopes in metal form

- Technical support to other ORNL, DOE, and private programs
Specific Chemical and Materials Processing Methods

CURRENT CAPABILITIES INCLUDE:
Inorganic chemical conversions
Arc melting and alloying
Arc melting and drop casting
Wire rolling
Metal and ceramic powder consolidation
Metal and ceramic hot-pressing
High-vacuum evaporation to produce thin films and coatings
Plasma sputtering to produce thin films and coatings

Pyrochemical conversions
Hot and cold rolling of metal foils
Crucible melting and casting
Wire swaging and drawing
Vanadium-encapsulated neutron dosimeters

CAPABILITIES CURRENTLY BEING RESTORED INCLUDE:
Ion beam sputtering to produce thin films and coatings (testing stage)
Crystal bar reduction processing (final component procurement stage)
Scanning electron microscopy/x-ray energy spectroscopy (procurement stage)
Pyrochemical Reduction/Distillation Is Used to Prepare a Wide Variety of High-purity Metals

Magnesium Beads Grown Inside Still by Reduction/Distillation
Arc Melter Used for Melting and Casting

Plutonium “Silver Dollar”

Enriched Pd-102 Button and Rod
Metallurgical Processing Lab

Swager, furnace, arc melter and rolling mills

Rolling of Pd-102 Rod
Ceramic Processing

Ceramic Wires – IR 100 Award Winner

In-core Neutron Dosimeters

Vacuum hot press and die

Hot-pressed oxide pellets
Vacuum Coatings and Thin Films

Evaporated U-235 Oxide Coatings

Evaporated Aluminum Foil

Cm-248 Deposit: Accelerator target for Element 109 Discovery
Materials Support to Other Programs

- Thermographic phosphor coatings on jet engine turbine blades for laser-based temperature measurement
- Coatings to improve adiabatic diesel engine brazed joints
- Particle beam neutralizer foils developed for US Army/SDI
- Coating for ion implantation studies
- Coating for high-temperature diffusion barrier development
- Hardened radioactive source materials development
- Preparation of diagnostic samples for nuclear weapons program
- Pm-147 single crystals and glasses for laser development
- HFIR target material preparation
- Innumerable chemistry and materials technical service jobs for other programs
Stable Isotope Packaging and Shipping

- Maintain an inventory of over 1,600 batches of stable isotopes
- Dispense isotopes in inventory form (generally powders) to fill customer orders
- Maintain analytical certification and MSDS files
- Package all stable isotopes for shipment in conformance with DOT and international shipping regulations
- Process lease agreements for stable isotopes
- Dispense non-electromagnetic separated isotopes (solids and gases) transferred to ORNL from Mound Laboratory
$360M* Worth of Stable Isotopes

(* list price)
Dispensing Stable Isotope Products
Isotope Business Office (National Isotope Data Center)

- Administer domestic and international contracts, quotes, sales, leases, billings, collections and shipments for the entire DOE Isotope Program: BNL, LANL, ORNL, PNNL, SRNL, Y-12
- Interface with hundreds of domestic and international customers
- Interface with Departments of Energy, Commerce, Justice, Homeland Security, and State
- Interface directly with DOE on a daily basis
- Coordinate irradiation services
- Ensure compliance in export control, NRC licensing and transportation
- Manage the Cf-252 Loan/Lease Program