Isotope Development

Nuclear Science and Technology Division

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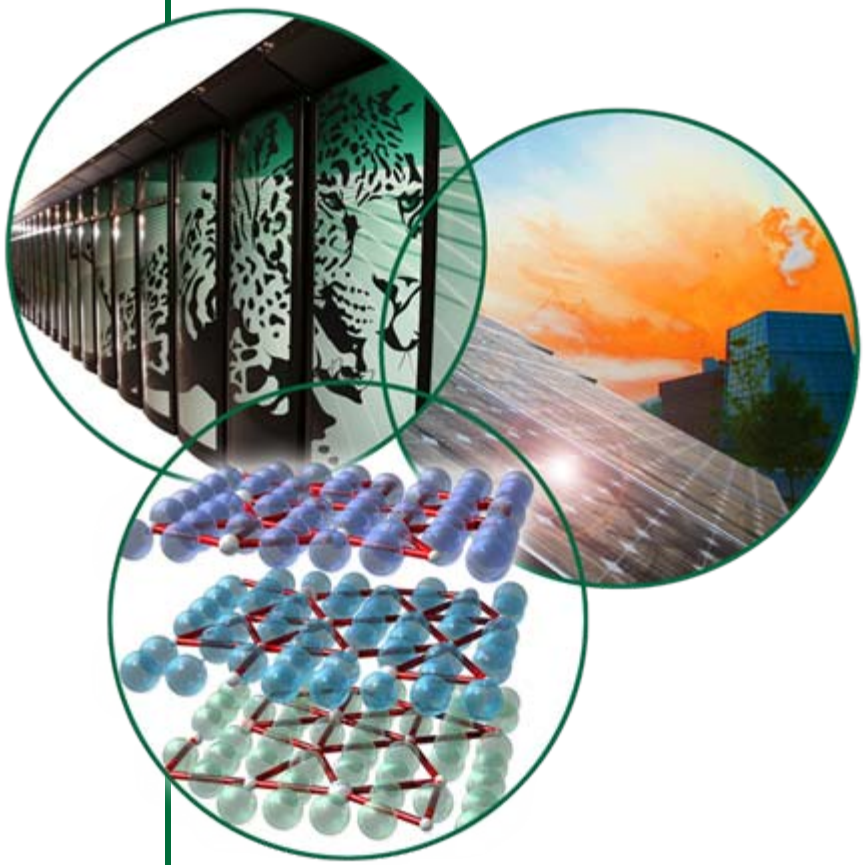
July 2009



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

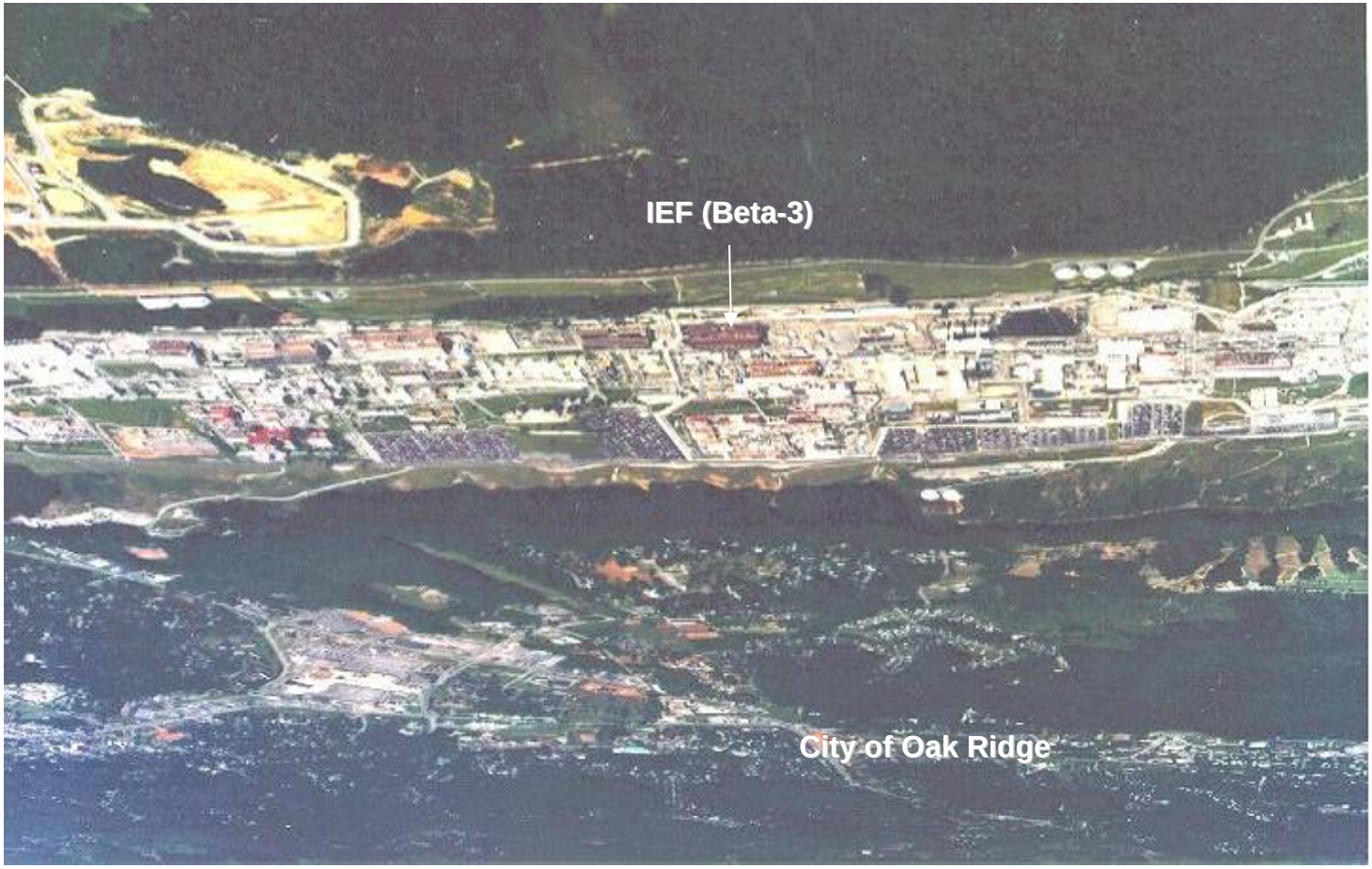
Isotope Development Group Activities

- **Calutrons**
  - **Calutron operations, engineering, maintenance**
  - **Stable isotope enrichment not currently active, new technologies are being developed**
- **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, BWXT 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-NA, 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 (1,152 calutrons and 3,072 ion beams) but were replaced by gaseous diffusion
- Stable isotope production started in November 1945

Y-12 National Security Complex Aerial View



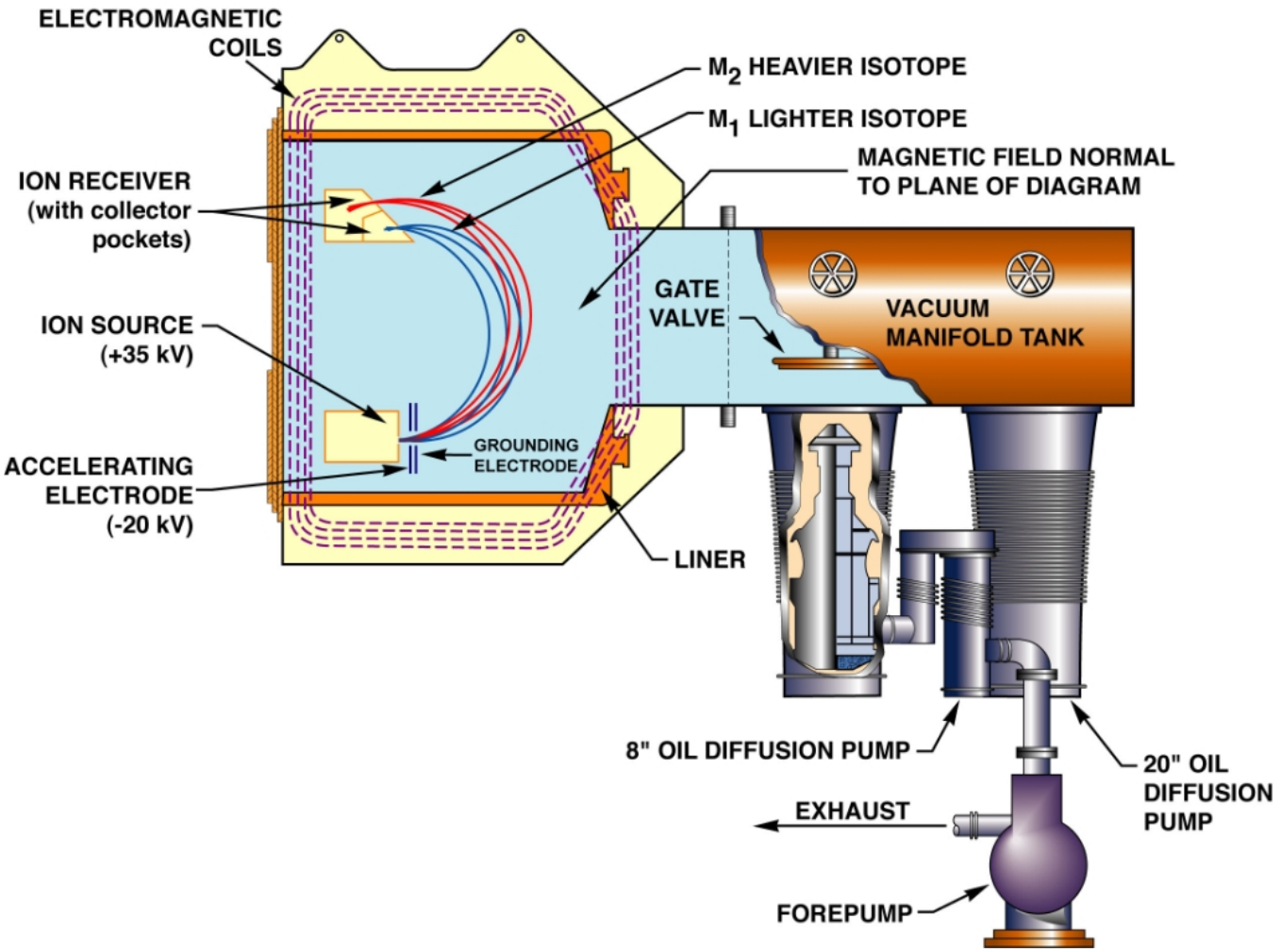
Isotope Enrichment Facility

Isotope Enrichment Facility

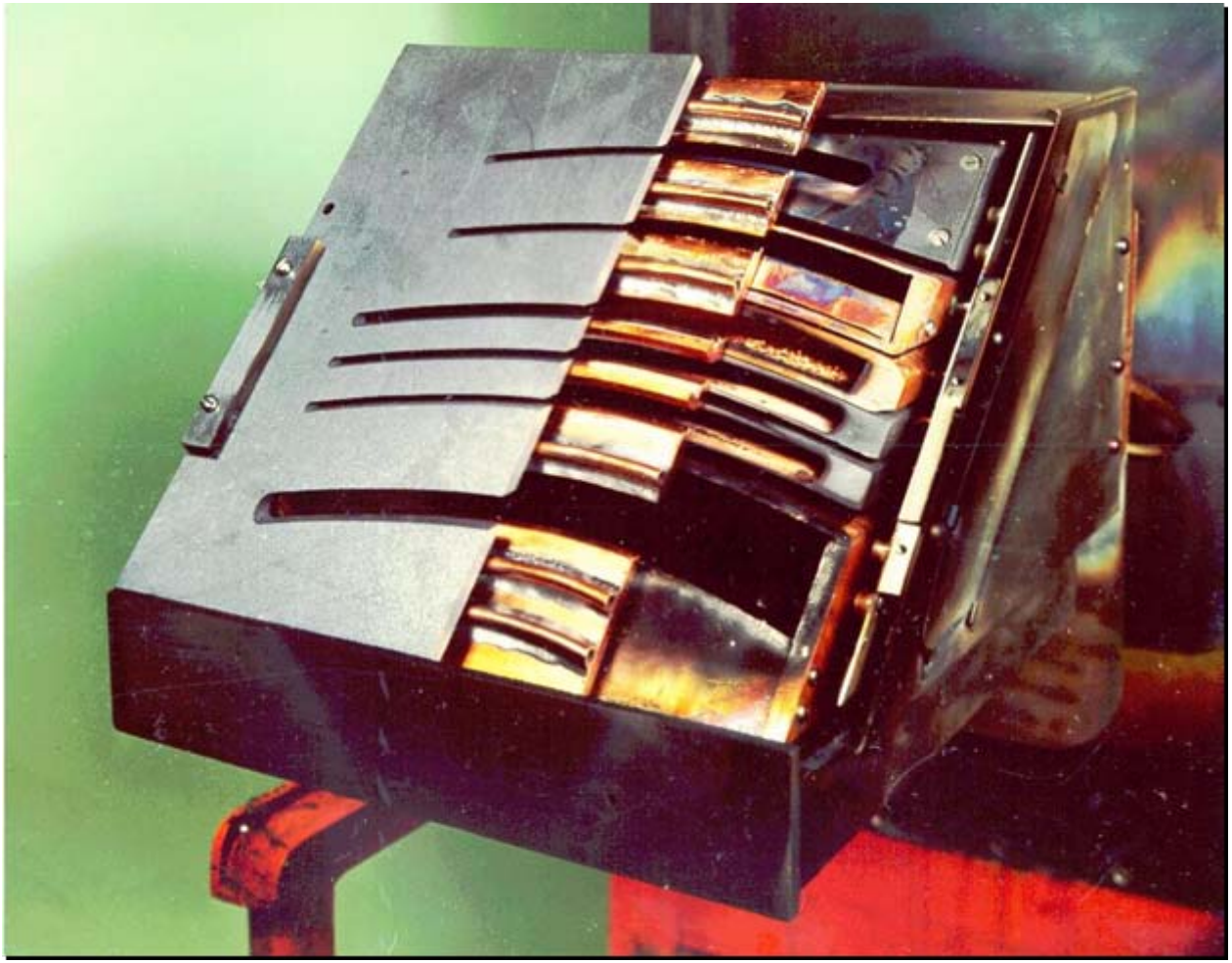
- Built in 1943 for U-235 enrichment (1 of 9 buildings)
- Second-pass for enrichment from 12-15% U-235 to greater than 90% for weapons use
- Top-off U-235 from early gaseous diffusion process
- IEF converted to stable and actinide isotope enrichment in the 1950s and early 1960s
- One of 2 production-scale 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 ($17.5M) to reestablish a smaller electromagnetic isotope enrichment capability at ORNL in February 2008

Isotope Enrichment Facility Calutrons

Schematic of a Calutron



Calcium Isotope Receiver



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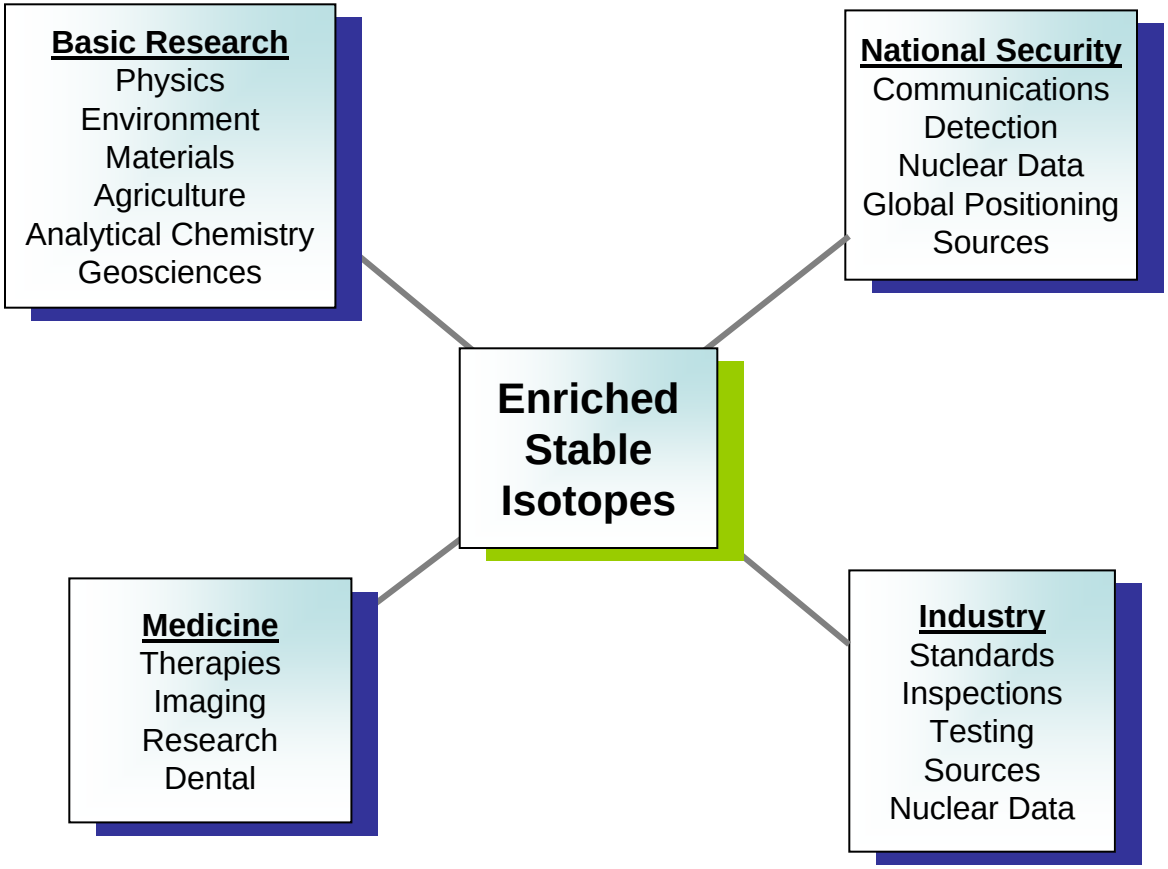
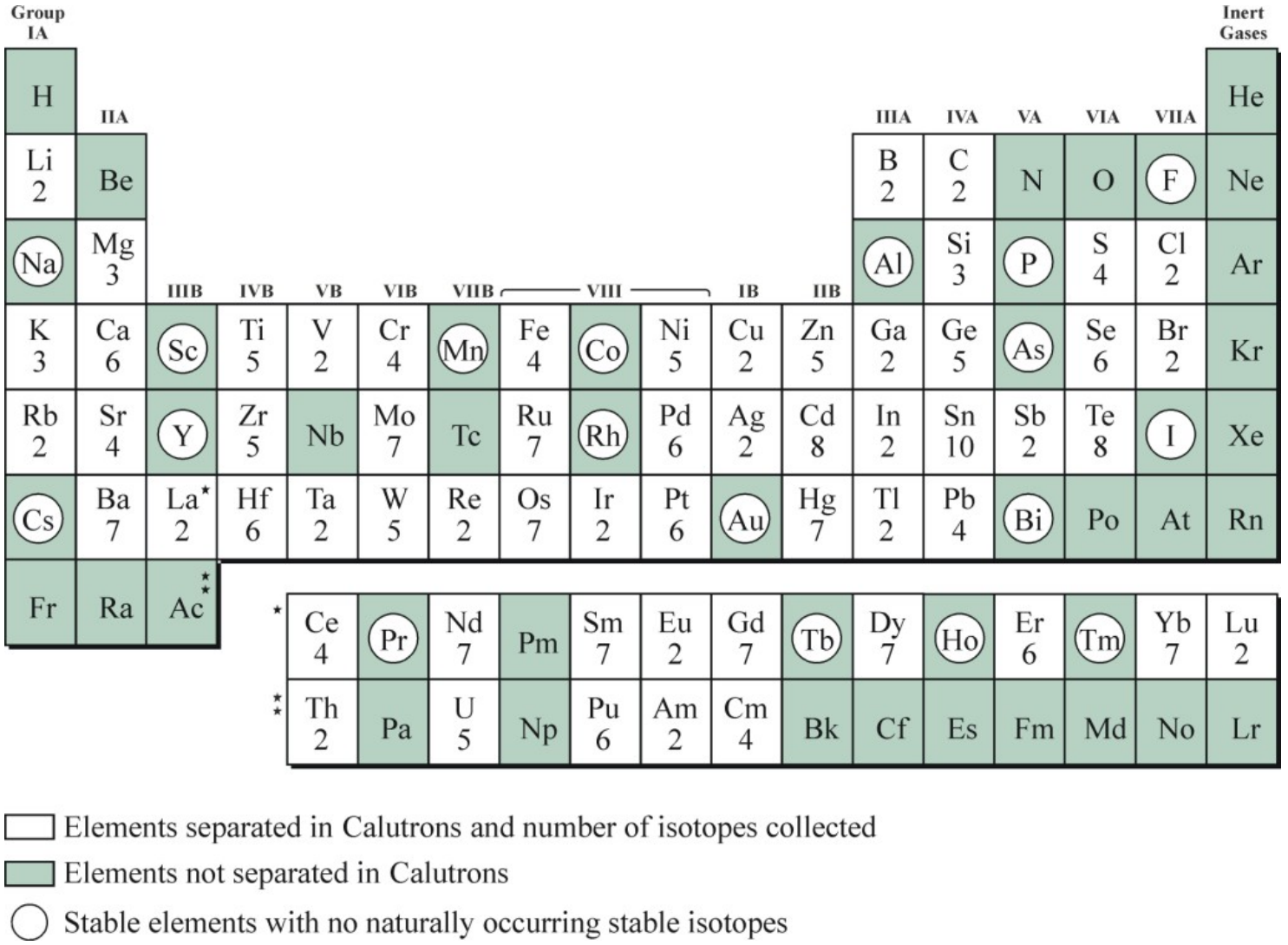
WW-II Era Control Room

Current Control Room

Stable Isotopes are Used in Many Fields Either Directly or as Precursors to Radioisotopes



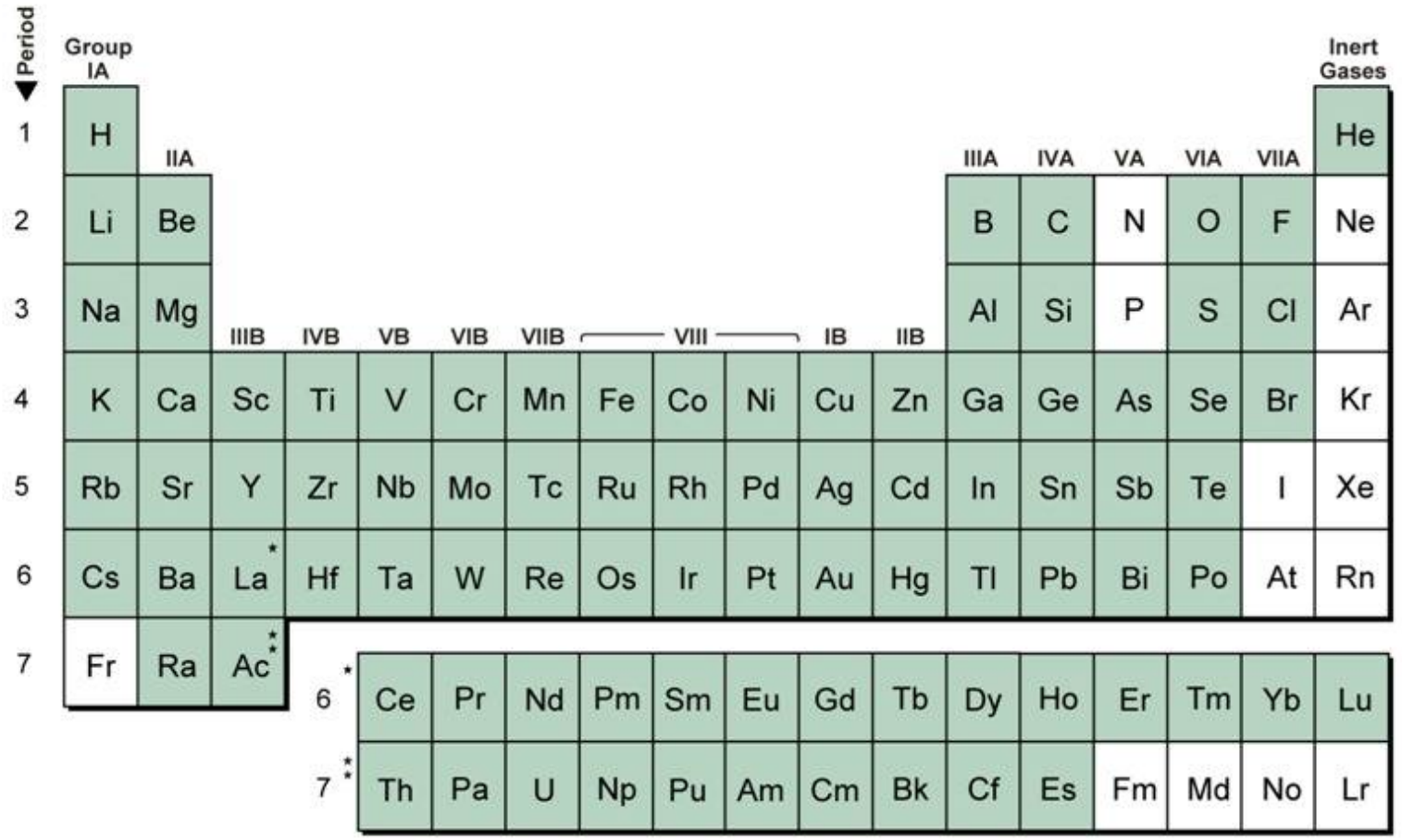
Isotopes Enriched by the Calutrons



Examples of IDG 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

Over the Years, Custom Products and Services Have Been Provided by the IDG for Most Elements and Their Respective Isotopes



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IEF Chemistry Laboratory

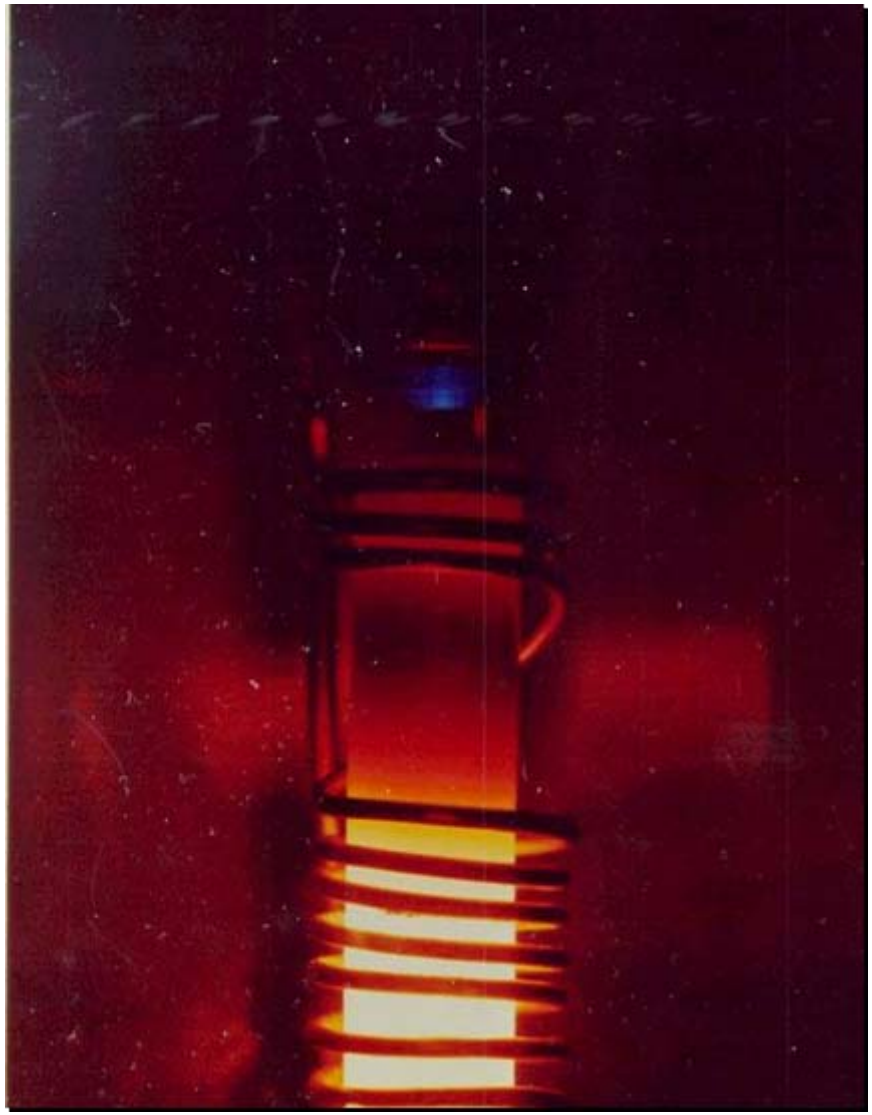
- Development and preparation of feed materials for calutrons
- Recovery and purification of enriched stable isotopes
- Custom chemical conversion services
  - Wet chemistry for alternate compound synthesis
  - Hydrogen reduction of some metals
  - Selected pyrochemical reductions
- Recovery and purification 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, Federal and private industry programs

Pyrochemical Reduction/Distillation Is Used to Prepare a Wide Variety of High-purity Metals

Magnesium Beads Grown Inside Still by Reduction/Distillation



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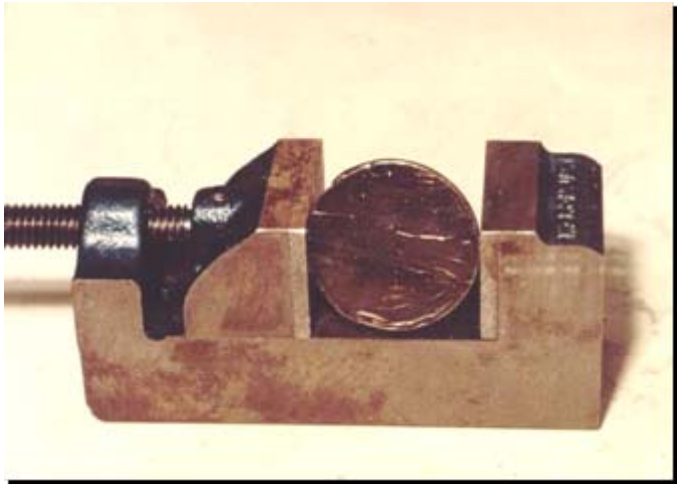
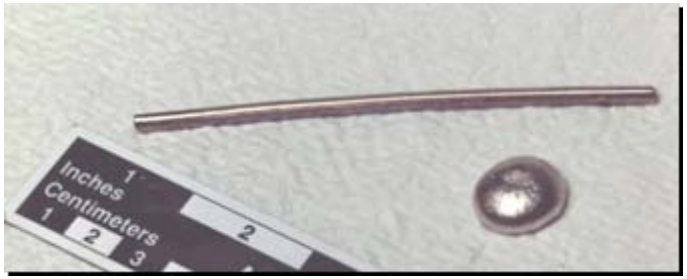
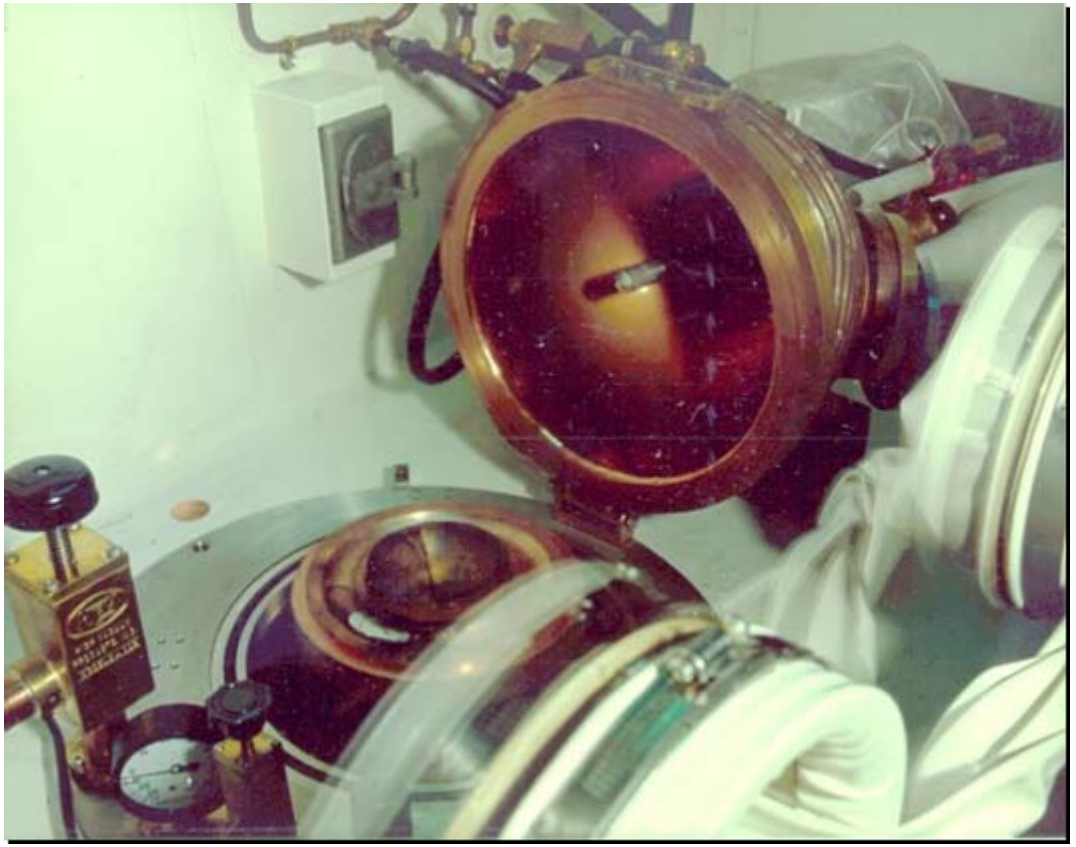
Arc Melter Used for Melting and Casting



Plutonium “Silver Dollar”

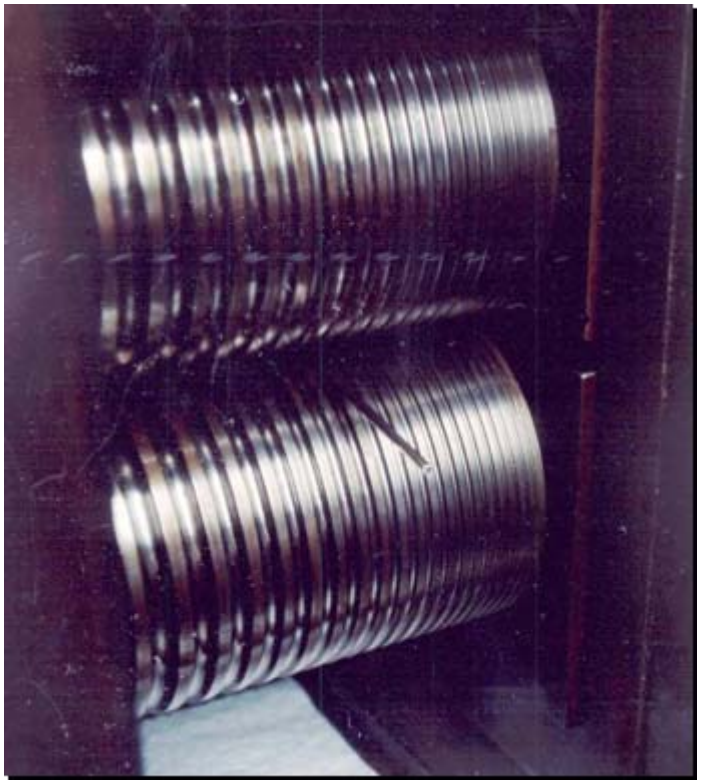


Enriched Pd-102 Button and Rod



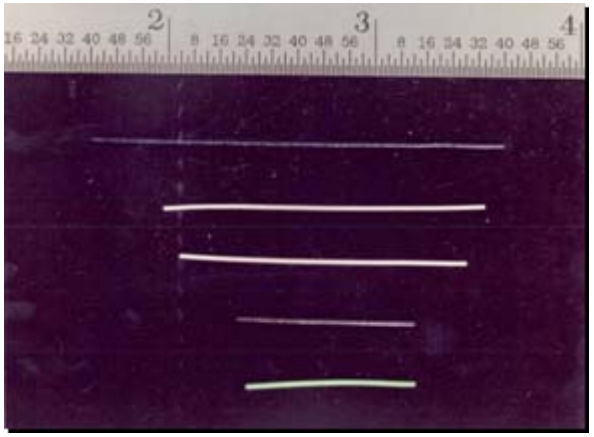
Metallurgical Processing Lab

Swager, furnace, arcmelter and rolling mills

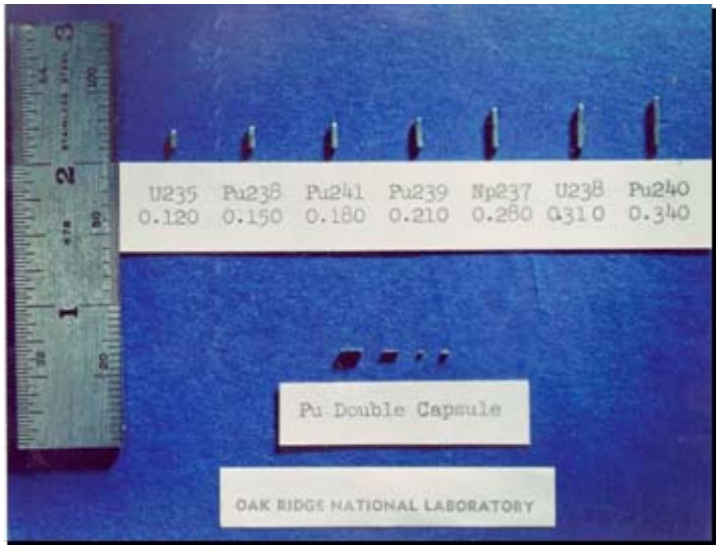


Rolling of Pd-102 Rod

Ceramic Processing



Ceramic Wires – IR 100 Award Winner



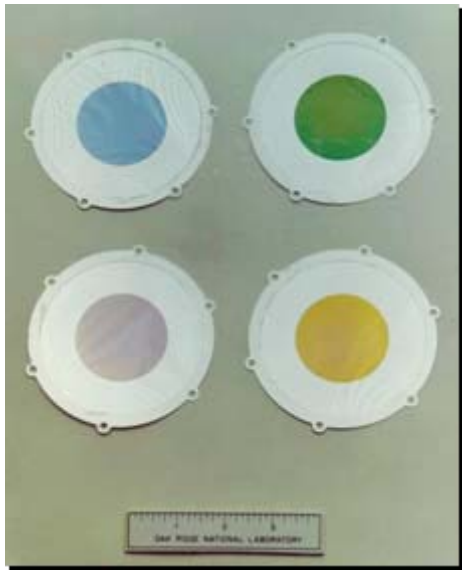
In-core Neutron Dosimeters

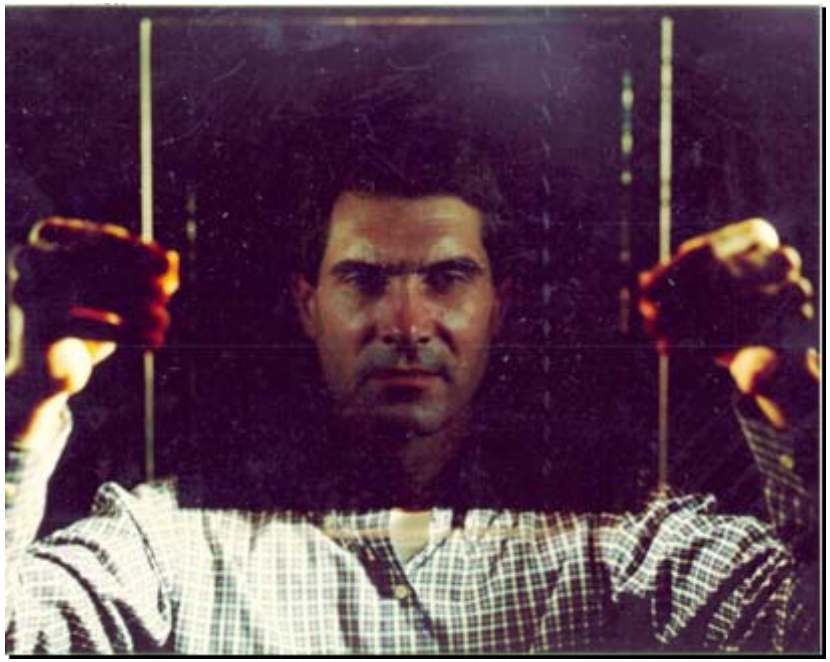
Vacuum hot press and die

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

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Materials Support to Other Programs

- Development of CERMETS as an advanced high level waste form for spent fuel reprocessing waste immobilization and storage
- 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 2,000 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)

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Dispensing Stable Isotope Products

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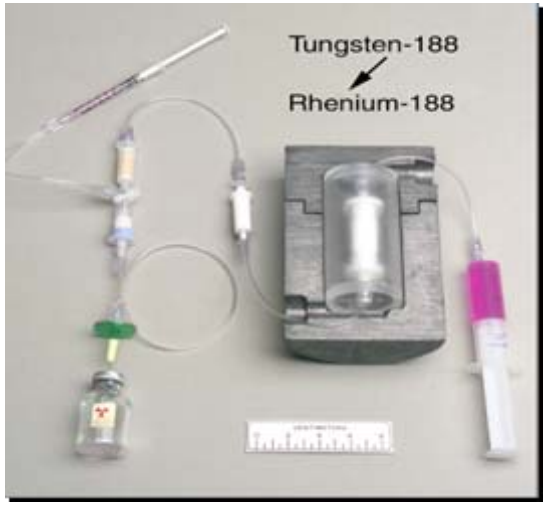
Nuclear Medicine Program

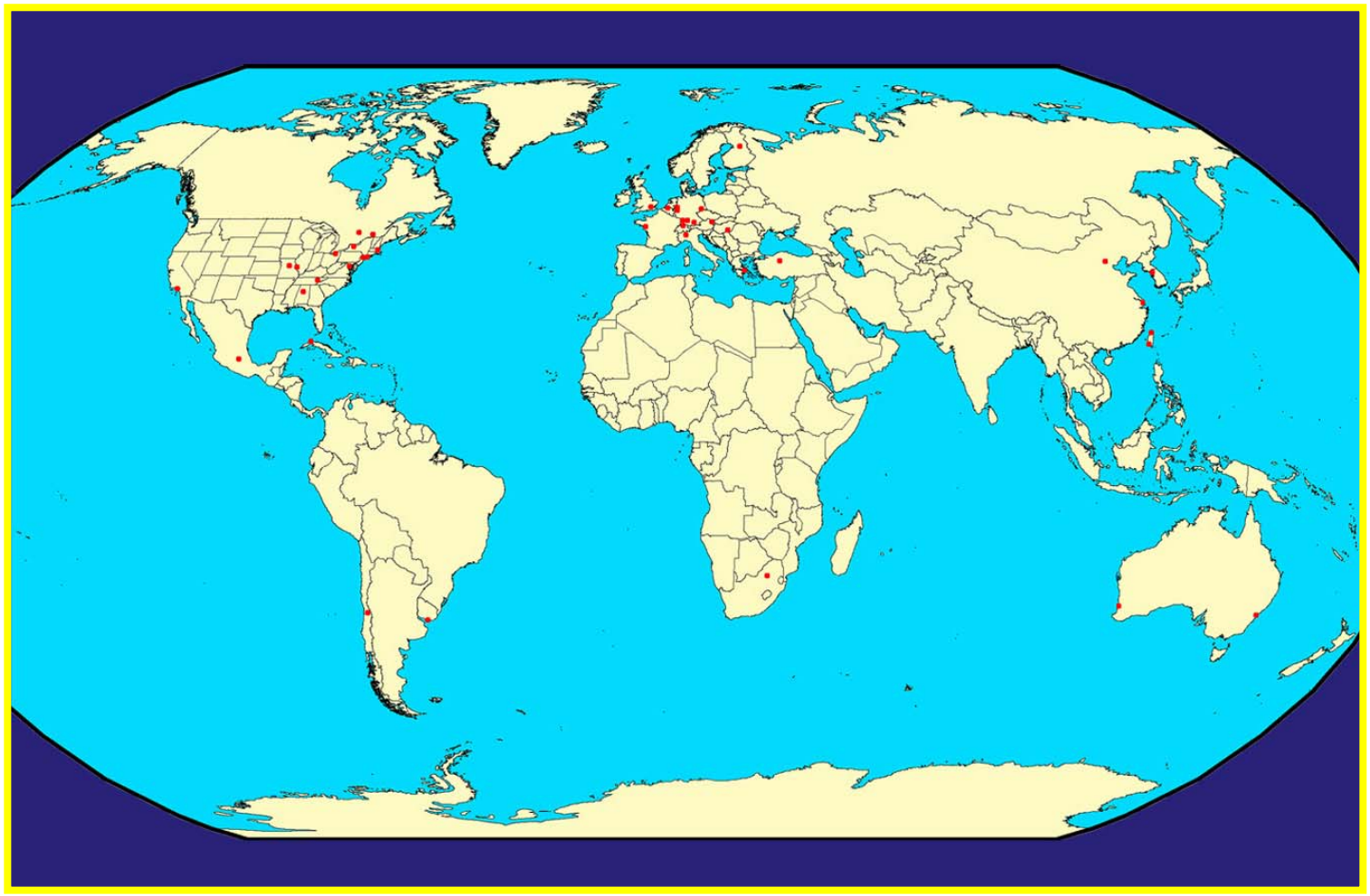
- Use unique characteristics of the ORNL High Flux Isotope Reactor (HFIR) for nuclear medicine applications
- Use hot cells and glove boxes in both radiological and nuclear facilities to process radioisotopes
- Animal facility for development testing
- Cancer therapy, pain palliation, arthritis treatment, anti-restenosis, diagnostics
- Development of W-188/Re-188 generator and clinical trials
- Development of U-233/Th-229 process chemistry and Ac-225/Bi-213 generator and clinical trials
- Identifying and developing new isotopes for medical applications
- Instituting current Good Manufacturing Processes (cGMPs) and Drug Master File under the FDA for W-188/Re-188 process and plan to extend to other nuclear medicine products
- Currently developing new product line – high specific activity Lu-177

HFIR's Very High Flux is Essential for the Production of Tungsten-188

- Double neutron capture on calutron-enriched tungsten-186
- Palliation of bone pain from cancer metastasis
- Therapy of refractory liver cancer
- Bone marrow ablation in leukemia patients to "rescue" with stem cells
- Treatment of rheumatoid arthritis
- Inhibition of coronary restenosis after angioplasty



Over 50 Clinical Trials in Progress Using Rhenium-188 from HFIR-produced Tungsten-188 from Calutron-Enriched Tungsten-186



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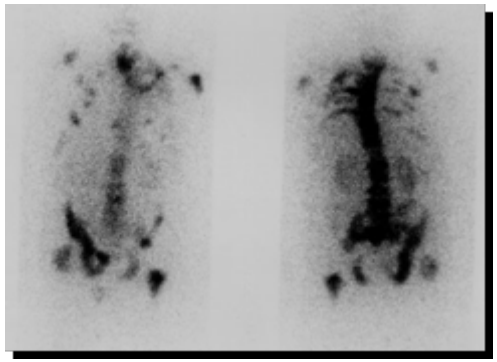
Some Medical Applications of Re-188



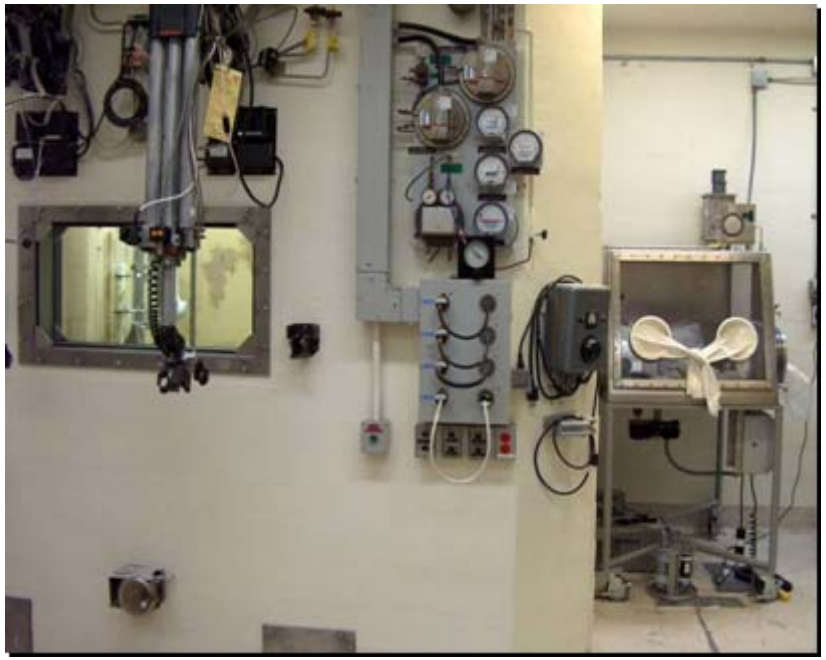
Use of rhenium-188 from the ORNL tungsten-188/rhenium-188 Generator System for palliative treatment of bone cancer from prostate cancer metastases (Courtesy of H.-J. Biersack, M.D., Clinic for Nuclear Medicine, Bonn, Germany)

Rhenium-188-impregnated patches can effectively treat non-melanoma basal cell and squamous cell skin carcinoma cancers precluding the tissue scarring often encountered after surgical removal (Sedda, *et al., Experimental Dermatology*, 33, 745, 2008)

Alpha-Emitters Play an Important Role in Nuclear Medicine

- Large amount of energy with short range
  - Bi-213: 8 MeV alpha particles
  - 6-10 cell diameters (~100 µm)
  - Kills everything in its path
  - Generators can provide on-site source of short half-life alpha-emitting isotopes
- Site-specific therapy of cancers and micrometastic diseases
  - Radiolabeled biomolecules provide the targeting
    - Chelating agents, antibodies, peptides
    - Fullerene carbon cage “Buckeyball” being developed for enhanced stability of targeting agent.

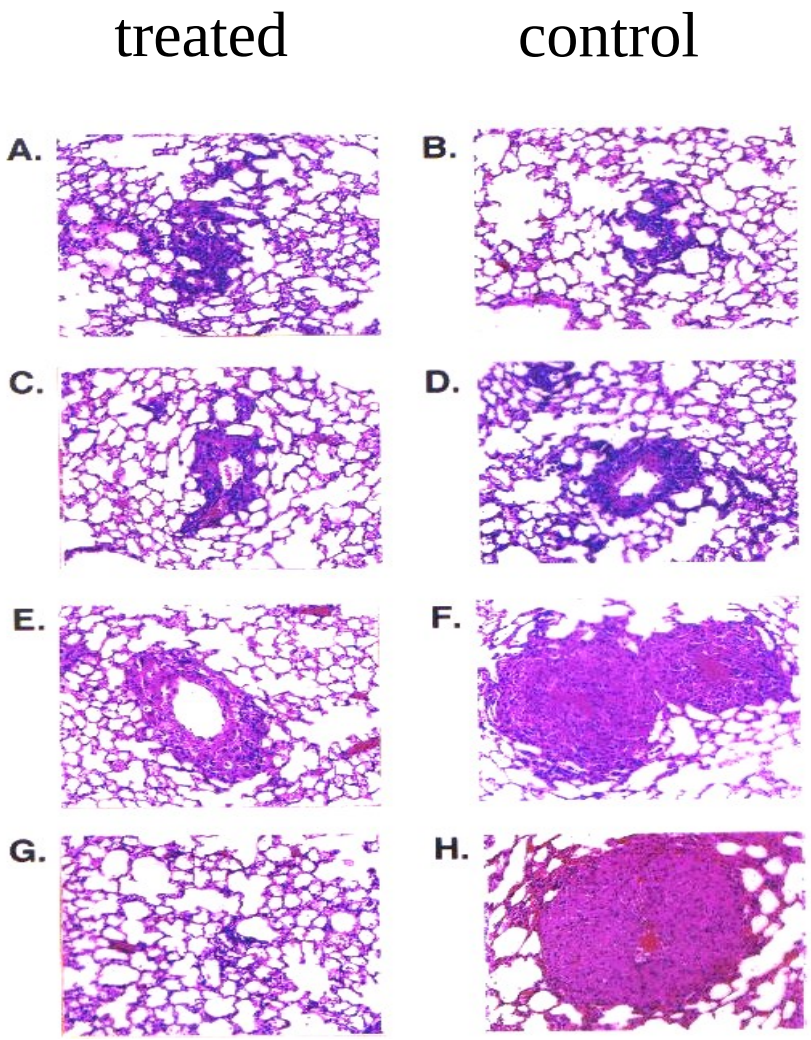
Th-229/Ac-225 Processing Facility in REDC



Cave A containing Th-229 Cow

Actinium-225 Gloveboxes

Example of Monoclonal Antibody 201B Labeled With Bi-213 Radioimmunotherapy



Isotope Business Office

- Administer domestic and international contracts, quotes, sales, leases, billings , collections and shipments for the entire DOE Isotope Program: BNL, LANL, ORNL, PNNL, SRNL, BWXT 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/SC-NP on a daily basis
- Coordinate irradiation services
- Ensure compliance in export control and NRC licensing for all ORNL radioactive shipments
- Support administration of the Cf-252 Lease Program