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Accelerator Production of the Medical Radioisotope ^{99}Mo

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Use and Distribution of ^{99m}Tc

- ^{99m}Tc is used for diagnostic imaging.
 - Decays with a 141 keV internal transition (IT) γ .
 - 6-hour half life.
- ^{99m}Tc is the daughter product of the longer lived ^{99}Mo .
 - 66-hour half life.
 - Allows distribution using radionuclide generators.
- The source of over 99% of the world's supply of ^{99m}Tc from ^{99}Mo is produced from the fissioning of ^{235}U .
- Most of this production uses Highly Enriched Uranium (HEU) targets.

Integrated SPECT/CT Imager

Global Production of ^{99}Mo

Past major suppliers of ^{99}Mo to the US:

NRU, Chalk River (60%)

HFR, Petten (40%)

NRU and HFR produce 95% of the world supply of ^{99}Mo .

Current Global State of ^{99}Mo Production
<http://www.radiopharm.com/SupplyUpdate/index.html>

- ^{99}Mo is currently produced in nuclear reactors as a fission product from HEU targets (fission yield is 6%).
- There is currently a critical shortage of ^{99}Mo in the US.
 - The US is completely reliant on foreign suppliers for ^{99}Mo .
 - Two major production reactors are currently offline.
 - The crisis is likely to continue or worsen due to the age of the major production reactors and the lack of alternatives.

M³ Effort in ⁹⁹Mo Production

- **NNSA Office of Materials Management and Minimization (M³) is working on implementing projects to demonstrate the viability of non-HEU based technologies for large-scale production, which include the following technology pathways:**
 - LEU targets (mostly foreign production support)
 - LEU solution reactors (B&W)
 - Neutron capture (GE/Hitachi on hiatus)
 - Accelerator production.
 - DT accelerator driven U solution (Shine/Morgridge)
 - Electron accelerator production (NorthStar)

NorthStar Electron Accelerator Production

- The NorthStar process uses an electron accelerator to create a high flux of bremsstrahlung photons in enriched ^{100}Mo targets to create ^{99}Mo through the photonuclear reaction $^{100}\text{Mo}(\gamma, n)^{99}\text{Mo}$.
 - Reaction threshold is 9 MeV.
 - Peak cross section is 150 mb at 14.5 MeV.
- We are exploring electron beams in the 35-42 MeV range.

Average bremsstrahlung photon spectra produced with 20, 35, and 42 MeV electron beams in a Mo target compared to the photonuclear cross section of ^{100}Mo .

Scaled Accelerator Tests at Argonne National Laboratory in Chicago, IL.

Thermal Test Setup

Present Target Design Concept

- Multiple Mo-100 disks held in a holder with gaps in between for coolant flow.
- The beam strikes the target from each end. Exploits target symmetry and doubles production for a given target mass.
- No x-ray converter, x-rays are produced in the Mo-100 target directly.
- The ANL test target disks are 12 mm in diameter, 1 mm thick, with 1 mm gaps, and there are 25 disks in a target.
- Production facility disks are currently 29 mm in diameter, 0.5 mm thick, with 0.25 mm gaps.

NorthStar Target Testing at ANL

Target Side View

Single sided target for thermal and production tests at ANL

12 mm diameter, 1 mm thick disks, 25 disks in a target for testing at ANL.

Target Assembly for the Thermal Test with Pressed Powder Natural Mo Disks

Target mounted to insertion stalk, with thermocouples

Once Through Gaseous Helium Target Cooling

He bottles, about 1 minute of full power beam time per bottle

Target assembly in the beam path holding 4 instrumented targets

NorthStar Target and Helium Cooling Loop Design Installed at ANL

Gaseous Helium Flow Loop Using a Roots Blower

The roots blower is used to move the He through the loop and across the targets. The PV is used to increase the base pressure of the system to 300 psi.

Pressure Vessel (PV)

Electric motor

Roots Blower

January 2015 Thermal Test

Mock Target Window OTR and IR Testing

IR Camera Image

IR Camera Image

Optical Transition Radiation (OTR) Beam Position and Profile Measurement

To address the beam steering and beam profile monitoring, LANL developed an OTR system looking at the exit window for measuring the ANL beam profile and position during the irradiation.

Beam image
x and y profile measurements

Front Window Oxidation

- Oxidation of the beam window has been complicating the IR temperature measurements.
- A scratch on the window caused during installation is also complicating our beam profile measurements.
- These can be mitigated with proper handling and leaving the window under vacuum after irradiation.

Thermal Target After Irradiation

Disks 2-5 were Mo Powder pressed and sintered disks from ORNL.

Disks 1&4 had thermocouples.

Disks 6-25 were Mo cut from rod-stock.

Disks 6-8 thermocouples.

Thermal Test Results

Peak Window and Target Disk Temperature: 23MeV @ 275 psi Inlet
($\dot{m} = 94 \text{ g/s}$)

Calculated temperatures in blue, along with measured temperatures in orange. For the window, the light blue bar is the calculated value, the dark orange bar the IR camera measurement.

Beam Position Monitor

Used for detecting the beam position with capacitive pickups

Production Facility Beamline Design Concepts

Side view of one accelerator

Top view of an accelerator pair

LANL Support for SHINE Medical Technologies

SHINE Medical Technologies will produce fission product ^{99}Mo in a subcritical accelerator driven low enriched uranium salt solution

Uranium Solutions

A rapid and robust method for uranium analysis in solution is required to meet US NRC regulations.

Left to right.

- *Uranium metal standard dissolved in HNO_3 ,*
- *A sample of this solution converted to solid $\text{UO}_3 \cdot x\text{H}_2\text{O}$, and*
- *Resulting solid material dissolved in 1 M H_2SO_4 to yield a standard solution*

Blue Room Experiments at LANSCE

Use pf LANSCE Target 2 (Blue Room) to achieve longer sample irradiations with higher neutron fluxes to produce higher concentrations of ^{99}Mo for separations chemistry experiments.

DT Accelerator Production of ^{99}Mo : Blue Room Irradiations

Blue Room Experiment

Experimental Validation Low Enriched Uranium Irradiation Generation of 70 mCi ^{99}Mo

Removing the Drain Lines from the Shipping Container

Mo-99 Separation Column

Target 4 Solution Irradiation Experiments

- New irradiations capability at LANSCE
- “90 Up” flight path
- 10^9 n/cm²/sec thermal neutron flux
- Used for uranium solution irradiations and Mo-99 separations
- Shipped solutions to TA-48 for separation chemistry experiments
- 3 irradiations were part of a loop test to reirradiate uranium sulfate solution to test solution reuse
- 1 irradiation supported an LDRD-ER for uranium recovery from uranium nitrate solutions.

Target 4 Sample Retrieval

Mo-99 Separations Experiments

Batch studies

Column studies

Questions?