

Reactor-Based Mo-99 Supply System (RB-MSS) Using Selective Gaseous Extraction: Update

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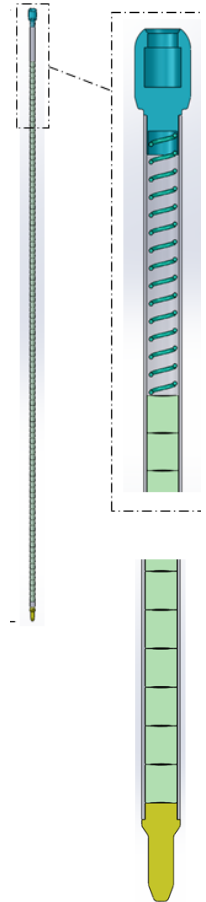
General Atomics, MURR, and Nordion Are Working Together To Produce Mo-99 from LEU

- **NNSA is funding a cooperative agreement to GA with Nordion providing the cost share**
 - **MURR** and **Nordion** are key partners
 - Project meets NNSA required yield of > 3000 6-day Ci/wk
 - Commercialization scheduled for the first half of 2018
- **The technical approach relies on an innovative selective gas extraction (SGE) step**
 - The SGE process minimizes liquid waste
 - Mo-99 is extracted in the gas phase from irradiated targets
 - Fast processing results in high yields
- **The project maximizes use of existing facilities and infrastructure**
- **Mo-99 produced by SGE will work seamlessly in all existing Tc-99m generators**



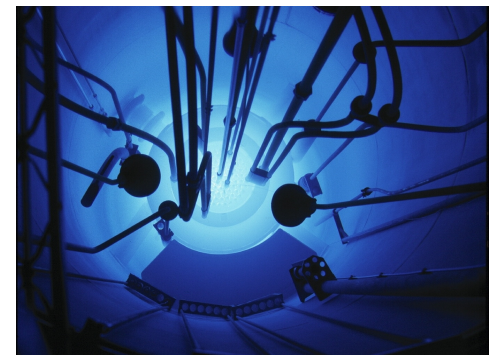
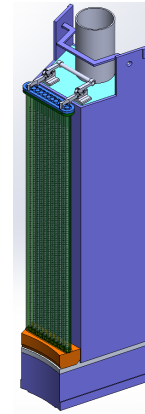
The Technical Approach Has Been Adjusted To Expedite Time To Market

- **Mo-99 is generated by fission of LEU in a nuclear reactor**
 - SGE is performed on the irradiated material
 - Existing purification methods are used to produce the final Mo-99 product
- **To achieve high Mo-99 yield, the SGE process step, originally in situ, was shifted to batch mode**
 - Reduces timeline by implementing conventional irradiation conditions
 - No longer utilizes a reusable target; reuse of target material may be revisited in the future
- **The target is an assembly of rods filled with UO₂ pellets**
 - The assembly is located inside the reflector region
 - The stationary assembly allows for insertion and removal of target rods to meet Mo-99 production quantities

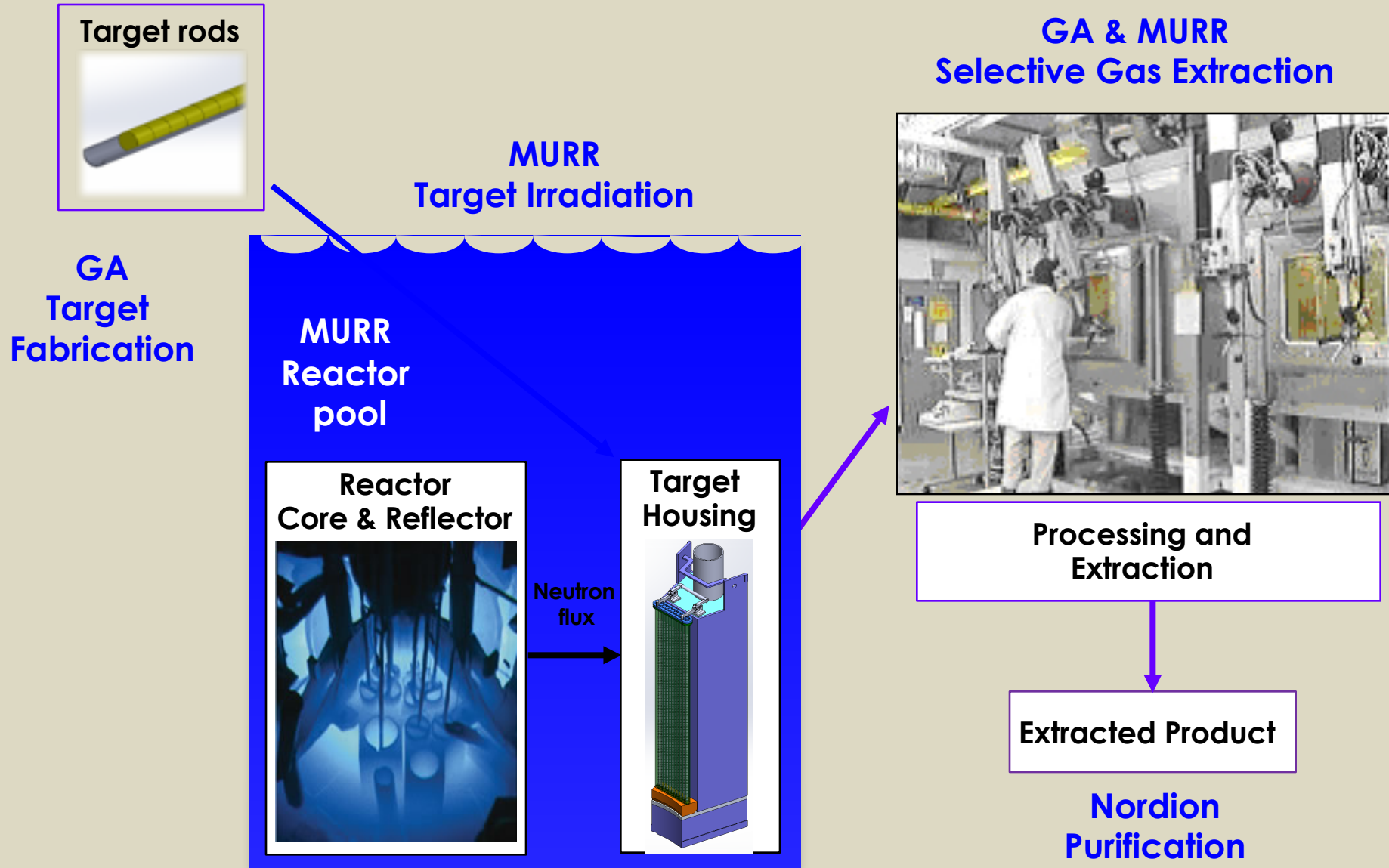


Each Team Member Has Demonstrated Expertise Well Matched To Their Role In the Project

- **GA fabricates pellets, target assembly, and collection systems**
 - Develops and manufactures Mo-99 target and custom assembly parts
 - Optimizes SGE extraction conditions
- **MURR irradiates dense UO₂ pellets and performs first stage extraction of Mo-99**
 - Adapts reflector to accommodate Mo-99 targets
 - Submits licensing amendment for use of SGE target
- **Nordion performs final purification at their cGMP facilities**
 - Submits DMF to FDA
 - Provides product to Tc-99m manufacturers



Mo-99 Technology Development Involves Steps At All Three Team Member Facilities



The Project is Well Underway and Process Steps Are Being Demonstrated

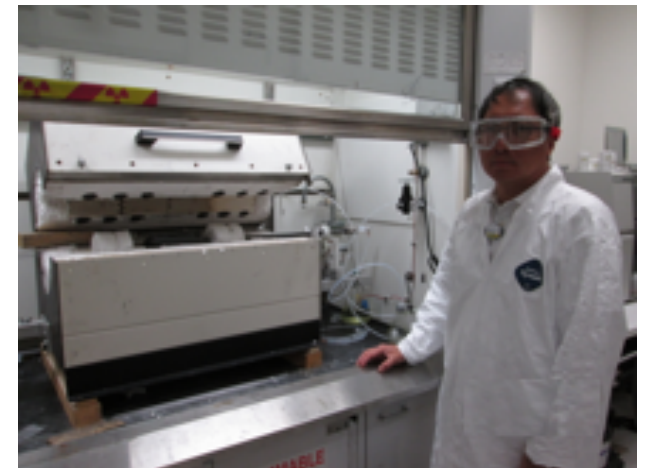
- **Physics modeling of production/extraction and thermal-hydraulics analyses have been performed**
- **Main engineering tasks of target assembly are complete**
- **Bench-top experiments to optimize and validate the physics have produced needed yield**
 - GA performs experiments on pellets
 - MURR performs tests on irradiated target material
- **MURR has defined equipment required for the target manipulations and hot cell processing**

In-house GA Experiments Determined Key Parameters for Pellet Fabrication and SGE Processing

- **Pellet fabrication is progressing well**
 - Process has been scaled-up to 1/10th scale
 - Bench top to pilot scale pellet fabrication is in progress
- **Use of activated Mo-99 has enabled optimization of SGE processing parameters**
 - Rapid, high-yield of Mo-99 has been demonstrated
 - Gas process parameters have been optimized
- **Loading and sealing fuel rod is straightforward**



Pellet Press

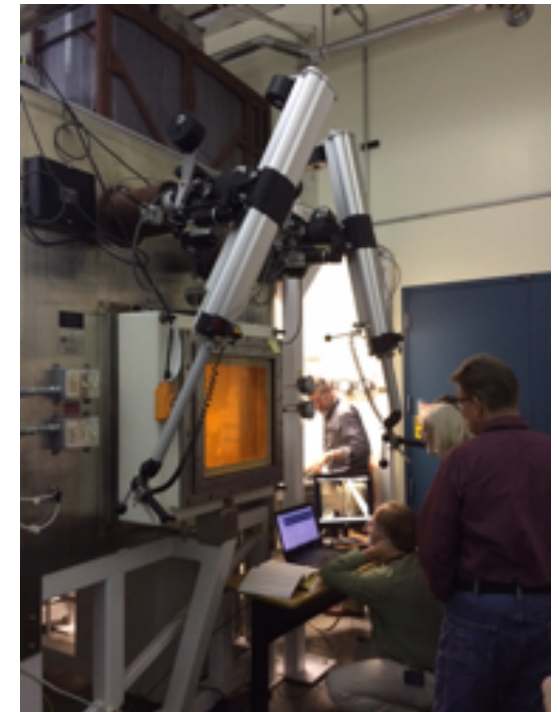
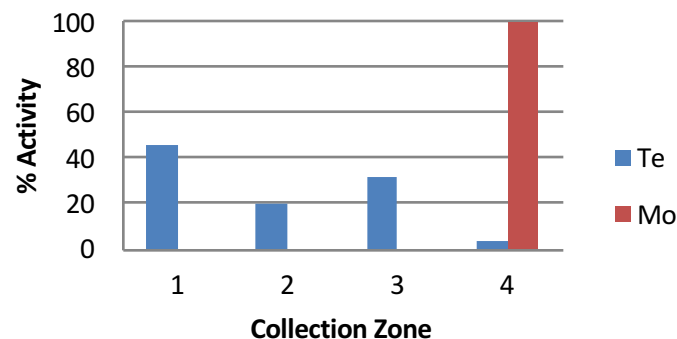


SGE Test Equipment



MURR Has Successfully Extracted Mo-99 From Irradiated Target Material

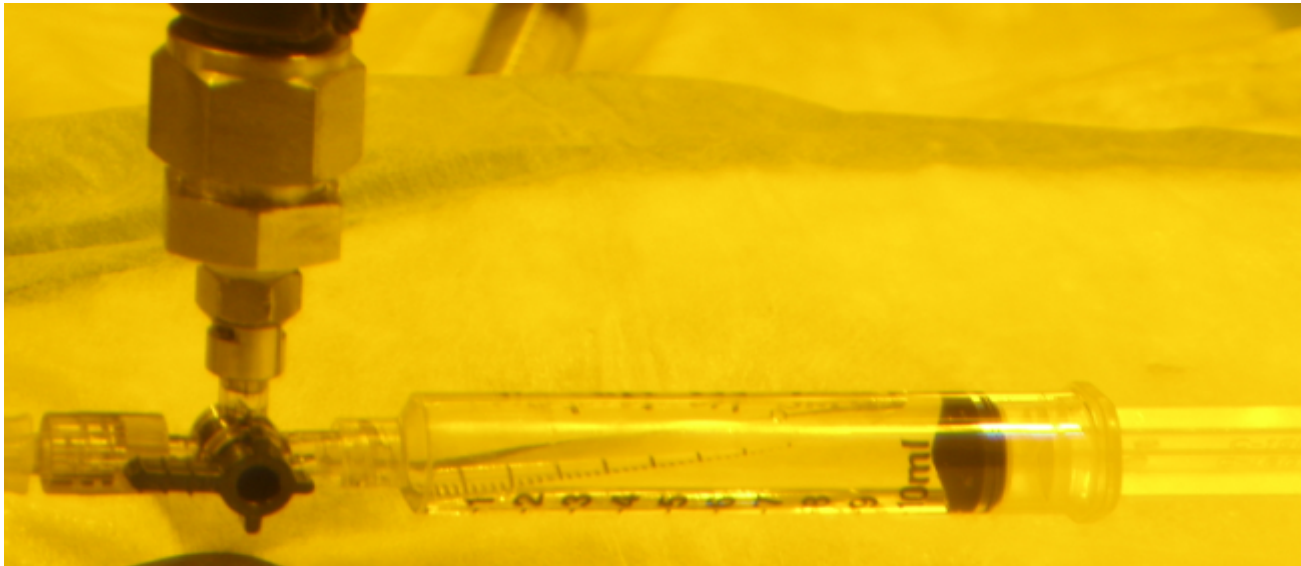
- GA supplied target capsules containing prototype UO_2 pellets were irradiated
- Irradiated material was transferred to hot cells for testing
- Extractions verified processing conditions determined from GA experiments



Nordion Has Characterized First Mo-99 Received from MURR

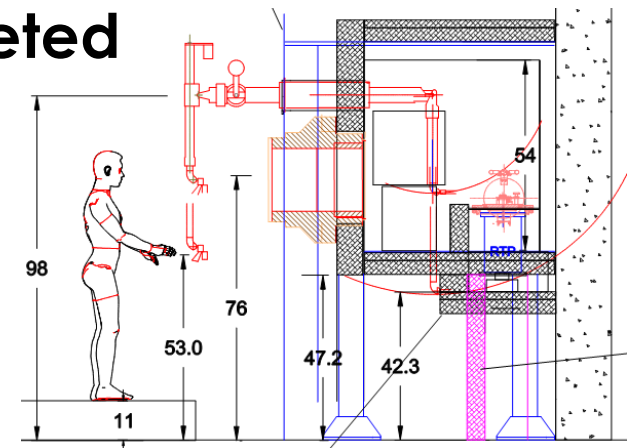


- Test samples from MURR extraction have been examined in Nordion cGMP facilities
- MURR extraction activities complement Nordion's purification process making use of existing facilities and process
- Excellent final product quality
- Reliable supply with required capacity



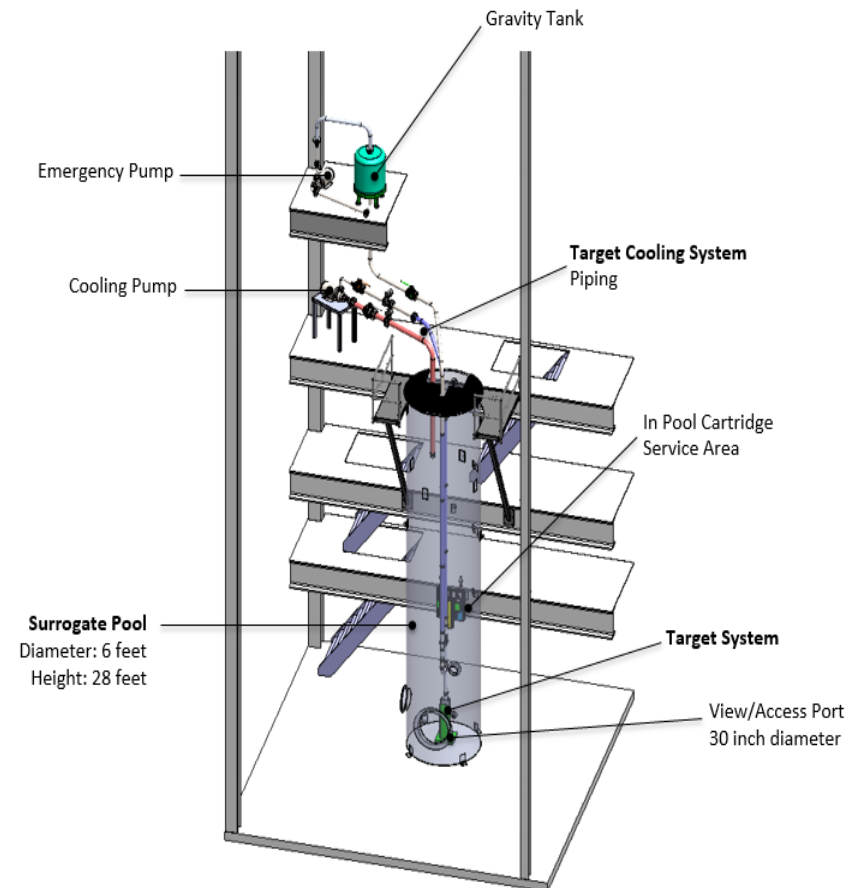
Major Technical Objectives Have Been Completed in Phase 1

- **Critical technical milestones have been met**
 - Fuel form and dimensions defined – one enrichment
 - Processing conditions for SGE have been optimized
 - Mo-99 has been successfully extracted from targets irradiated at MURR
 - Extraction yield is well above required
- **Preliminary designs reviews are all completed**
 - Target and assembly
 - Cooling system
 - Target transfer and pellet removal systems
 - Mo-99 collection systems
- **Major equipment purchases are all defined and procurements are in progress**
 - Pellet fabrication equipment
 - Hot cells
 - SGE equipment



Next Phase Activities Address Scale-up and Qualification

- **Upcoming activities include:**
 - Surrogate testing of target cooling system at GA
 - Submission of License Amendment to US NRC
 - Pellet manufacturing scale-up
 - Fabrication of full-size prototype target rods
 - Target material qualification testing
 - Supporting data for FDA submissions by Nordion and customers
 - Licensing of spent target material shipping casks



Loss of Cooling Test at GA

NRC License Amendments and Other Agreements/Approvals Are In Progress

- **NRC License Amendment Applications**
 - MURR is actively engaged with the NRC and preparing a License Amendment application for NRC review
- **Uranium Lease and Take Back**
 - LEU lease agreement between MURR and NNSA is signed
 - Delivery of 20 kg LEU for prototype target fabrication is imminent
 - Take-back agreement is being worked with EM and NNSA
- **FDA Approvals**
 - Process and product validation will use full-scale samples
- **Shipping Cask Approvals**
 - CNSC license amendment for shipping raw Mo-99
 - NRC license amendment application for Type B waste



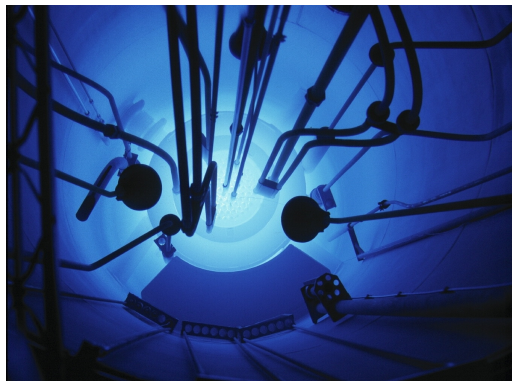
Licensed Shipping Container

The Project Leverages World-Class Capabilities and Existing Nuclear Infrastructure

General Atomics

Target and Reactor Systems Design and Manufacturing

- Experts in reactor design: GA TRIGA® research reactors in operations around the world for over 50 years
- Developer of LEU technology utilizing novel selective gas extraction process



Missouri University Research Reactor

Premiere Reactor Operator and Research Center

- 35+ years of successful and innovative radio-pharmaceutical R&D and collaborations with industry
- 10 megawatt facility; the largest university research reactor, operating 52 weeks a year



Nordion

Premier Isotope Producer and Distributor

- Experts in Mo-99 purification into medical grade product since 1975
- Global leading supplier of Mo-99 with extensive marketing, sales & distribution expertise



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