NNSA National Nuclear Security Administration

NNSA’s Office of Conversion

DOE Workshop on Federal Isotope Supply and Demand

November 9, 2016

— PERMANENT THREAT REDUCTION —

M3

MATERIAL MANAGEMENT AND MINIMIZATION

CONVERT, REMOVE, DISPOSE

Material Management and Minimization

Achieving Permanent Threat Reduction by Managing and Minimizing Nuclear Materials

Convert

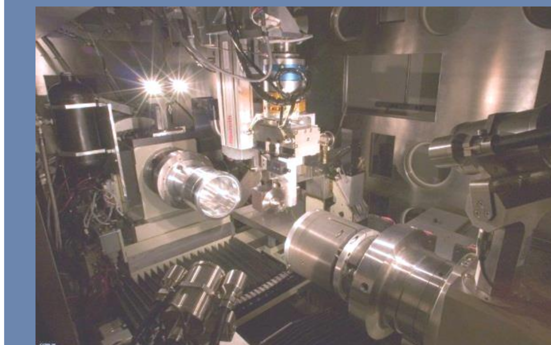
Convert research reactors and isotope production facilities to non-weapons-usable nuclear material both domestically and abroad

- Research Reactor Conversion
- Mo-99 Program

Remove

Remove or confirm the disposition of excess weapons-useable nuclear material at civilian facilities across the globe and consolidate those materials that remain

- International Nuclear Material Removal and Consolidation
- International Nuclear Material Down-blending



Dispose

Dispose of and manage excess weapons-useable nuclear material, from both domestic stockpiles and material returned from abroad, and implement the Plutonium Management Disposition Agreement (PMDA) with Russia

- HEU and Plutonium Disposition
- Uranium Supply for Peaceful Uses

REACTOR CONVERSION

Research Reactor Conversion Program

Objective: Minimize the use of HEU in civilian applications by converting or verifying the shutdown of research reactors Worldwide.

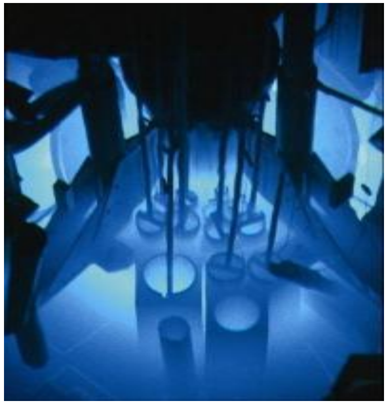
Status: 148* civilian research reactors to be converted or shutdown; 96** (65%) converted or verified as shutdown (as of Oct 2016)

*The M^3 program target is 156 facilities, including 8 radioisotope production facilities
**The M^3 metric total of 97 includes 1 radioisotope production facility that has shutdown

The M^3 Reactor Conversion Program includes:

- High-density LEU fuel qualification and fabrication for U.S. high-performance research reactors.
- Technical support and cooperation with Korean, European, and Russian partners in the development and qualification of new high-density LEU fuels.
- Conversion of civilian HEU-fueled research reactors worldwide to the use of LEU fuel.

Kazakhstan's VVR-K Critical Assembly was converted to LEU fuel in 2012



NNSA is working on a new high-density LEU fuel that will enable the conversion of the Missouri University Research Reactor (MURR)

Reactor Conversion Program Mission Drivers

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Long standing U.S. National Security policy to minimize and, where possible, eliminate the use of HEU in civilian applications (RERTR program initiated in 1978):

- The Energy Policy Act of 2005, the Foreign Relations Authorization Act, and the Nuclear Nonproliferation Act of 1978 direct the U.S. to pursue the elimination of HEU for use in research reactors, in international commerce, and encourage multilateral cooperation to develop and to use low-enriched alternative nuclear fuels. This legislation is tied to export law as well.
- President Obama's April 2009 Prague Speech called for a U.S.-led international effort to secure vulnerable nuclear material worldwide
- July 2009 Obama-Medvedev Joint Statement on Nuclear Security noting importance of continued progress on reactor conversion.

Nuclear Security Summit Communiqués (2010, 2012 and 2014) issued by President Obama and over 40 heads of state.

"Nuclear terrorism continues to be one of the most challenging threats to international security… We stress the fundamental responsibility of States… to prevent non-state actors from acquiring such materials and from obtaining information or technology required to use them for malicious purposes… We encourage States to take measures to minimize the use of HEU, including through the conversion of reactors from highly enriched to low enriched uranium (LEU) fuel, where technically and economically feasible"

Conversion – A Vital Role in Permanent Threat Reduction

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Conversions result in permanent threat reduction by:

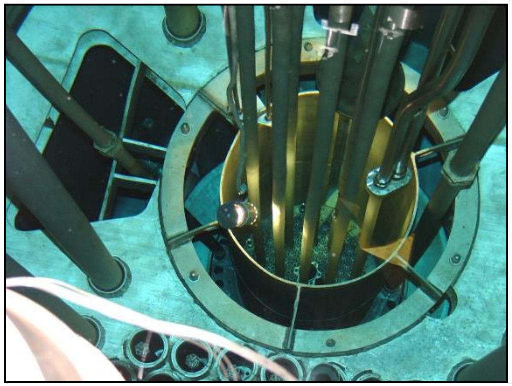
- Eliminating the demand for HEU in civilian applications
- Allowing for the full cleanout of HEU from a site (without conversion all HEU cannot be removed)
- Reducing HEU in supply chain including transit and fuel and target fabrication (where HEU is most vulnerable to theft or diversion)
- Avoiding HEU security costs

To date:

- Conversion efforts have eliminated, from civilian commerce, enough HEU for approximately 15 nuclear weapons per year
- Additionally, conversion efforts have helped facilitate the removal of over 140 weapons worth of HEU

(left) Poland's Maria reactor converted to LEU fuel in 2012

(right) Portugal's RPI reactor converted to LEU fuel in 2007



(left) Vietnam's Dalat reactor converted to LEU fuel in 2007

Principles of LEU Fuel Development

To be **ACCEPTABLE** for LEU conversion of a specific reactor, a fuel assembly must be qualified, commercially available, and suitable for use in that reactor, then BOTH the **reactor operator & regulator must agree to ACCEPT the fuel for conversion.**

- **QUALIFIED**
  - Fuel assembly that has been successfully irradiation tested and is licensable by the regulator from the point of view of fuel irradiation performance

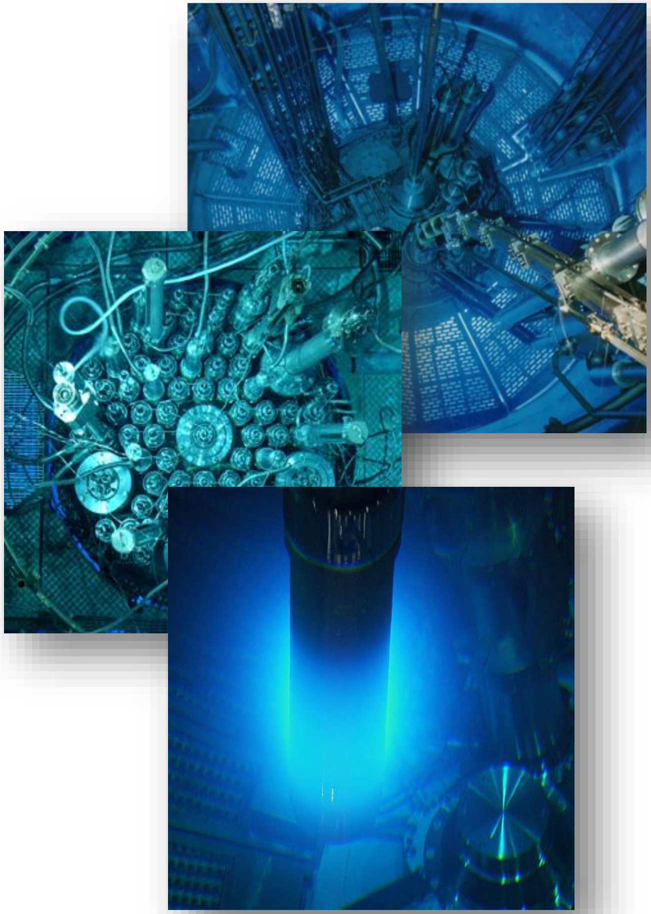
- **COMMERCIALLY AVAILABLE**
  - Fuel assembly that is available from a commercial manufacturer

- **SUITABLE**
  - Satisfies criteria for LEU conversion of a specific reactor
    - Safety criteria are satisfied
    - Reactor operations and performance are maintained
    - Critical research reactor mission needs are met

International LEU Fuel Development

Europe

- European Fuel Development focuses on U-Mo dispersion fuel for the RHF, BR2, and JHR reactors; Germany's FRM2 reactor will need U-Mo monolithic fuel for conversion.
- Europe launched HERACLES in 2013 to focus on U-Mo dispersion fuel qualification for EU High Flux Reactor (HFR) conversions. The U.S is a co-sponsor of HERACLES.
- EMPIRE experiment to include dispersion miniplates and some monolithic plates. Insertion into ATR in mid-2017. Irradiation to last until October 2017 (pending final ISOP).



Russia

- U-Mo High Density Dispersion Fuel Qualification (IRT-3M LTAs) for IRT Conversions at conditions lower than the EU HFR
- Irradiation complete July, 2016; PIE Report ~February 2017; fuel expected to be qualified in 2017.

RHF
JHR
Orphee

BR2

FRM2

Korea

- KAERI is collaborating with DOE-NNSA/M3 on Irradiation testing of LEU U-7Mo for the KIJANG Research Reactor (KJRR).
- Lead Test Assemblies to finish irradiation testing in ATR in late 2016.

Reactor Conversion Program: Results and Next Steps

Since 2009, all U.S. HEU research reactors that can convert with existing qualified LEU fuels have been converted

- To convert the 6 remaining U.S. High Performance Research Reactors, M3 is developing a new high density U-Mo fuel and fuel fabrication capability

MNSR LEU Core

Recent Conversions:

- China Prototype MNSR
- Kazakhstan VVR-K
- Jamaican Slowpoke reactor

Upcoming Conversions:

- Ghana MNSR
- Nigeria MNSR
- Remaining MNSRs
- Japan KUCA cores

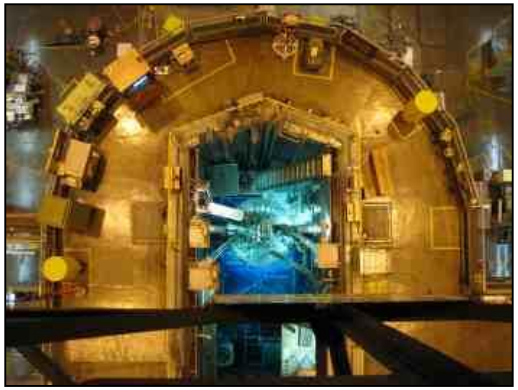
Jamaica's SLOWPOKE Reactor with LEU fuel

Molybdenum-99

(Mo-99)

What is Mo-99?

- Molybdenum-99 (Mo-99) is the parent product of Tc-99m, a radioisotope used in approximately 50,000 medical diagnostic tests per day in the U.S.
- Primary uses include detection of heart disease, cancer, study of organ structure and function, and other applications
- Mo-99 has a short half life (66 hours) and cannot be stockpiled
- U.S. demand is approximately 50% of the world market
  - The current global demand is ~9,000 6-day curies per week
  - Global demand has dropped since 2010
- Large-scale quantities of Mo-99 are produced at only five processing facilities worldwide, in cooperation with eight research reactor facilities
- Most Mo-99 is produced today with highly enriched uranium (HEU) targets
- Shortages of Mo-99 in 2009 and 2010 due to the unexpected shut down of two major production facilities highlighted the need to accelerate new, non-HEU Mo-99 Production in the United States



SAFARI-1 Reactor (South Africa)

Example of a Tc-99m Generator
(Image courtesy of Lantheus Medical Imaging, Inc.)

International and Domestic Approaches

Objective: To accelerate the establishment of reliable supplies of the medical isotope molybdenum-99 (Mo-99) produced without highly enriched uranium (HEU)

INTERNATIONAL EFFORTS

Assisting global Mo-99 production facilities to convert to use LEU targets

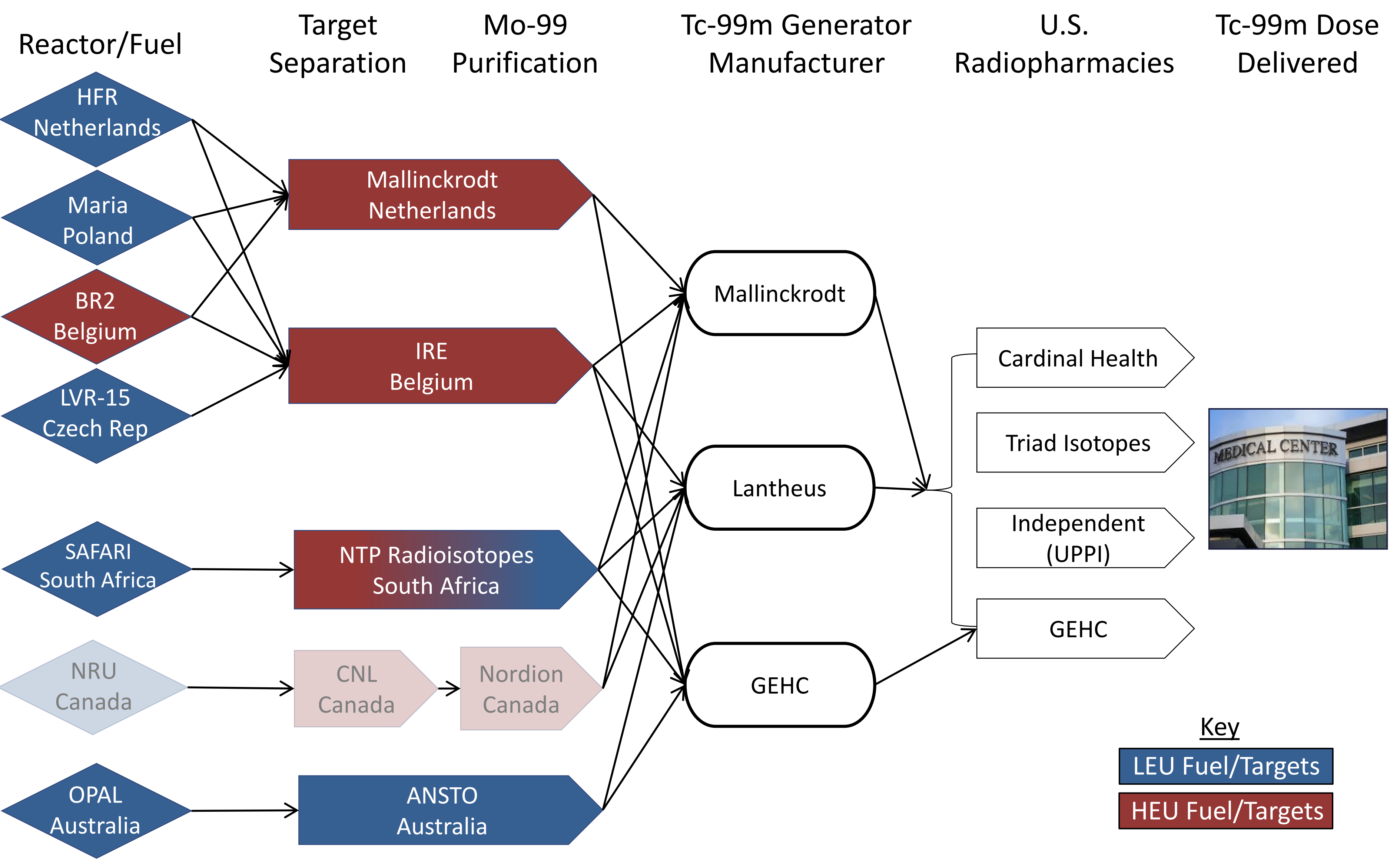
U.S. DOMESTIC EFFORTS

Accelerating the establishment of commercial non-HEU-based Mo-99 production in the United States

Achieve HEU minimization

Establish reliable supplies of Mo-99 produced without HEU

Current U.S. Mo-99 Supply Matrix



Transition Strategy for Reliable Non-HEU-Based Mo-99 Supply*

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HEU | Non-HEU

Prior to October 2016

- ANSTO (Australia)
- NTP Radioisotopes (South Africa)
- Mallinckrodt (Netherlands)
- IRE (Belgium)
- CNL-Nordion (Canada)

Nov 2016 to Mar 2018

Canada Contingency Production

- ANSTO (Australia)
- NTP Radioisotopes (South Africa)
- Mallinckrodt (Netherlands)
- IRE (Belgium)
- NEW Pending
- NEW Pending

Future Global Mo-99 Supply – Additional Producers

- ANSTO (Australia)
- NTP Radioisotopes (South Africa)
- Mallinckrodt (Netherlands)
- IRE (Belgium)
- NEW Pending
- NEW Pending
- NEW Pending

- NNSA Cooperative Agreement Partners
- Other Potential U.S. Mo-99 Production
- Increased International Mo-99 Production

*Existing large-scale Mo-99 producers and U.S.-based potential producers only. Capacity of producers not represented.

2016 OECD-NEA Study

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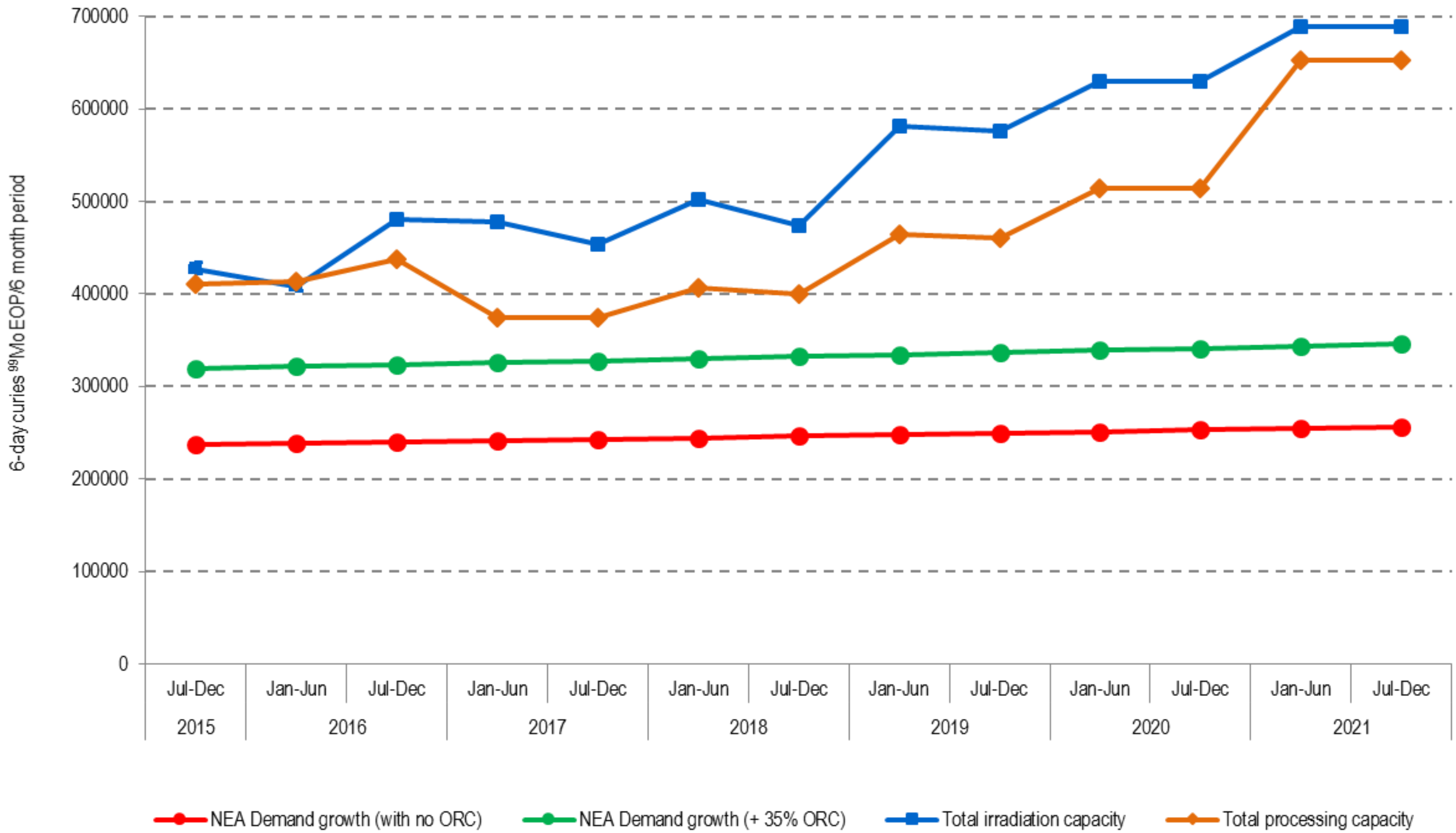
Current Mo-99 Demand and Irradiation and Processing Capacity "Scenario C"



Source: OECD-NEA Report "2016 Medical Isotope Supply Review: ^{99}Mo/^{99m}Tc Market Demand and Production Capacity Projection 2016-2021", June 2016

ORC: Outage Reserve Capacity
NRU CC: National Research Universal (Research Reactor) Contingency Capacity

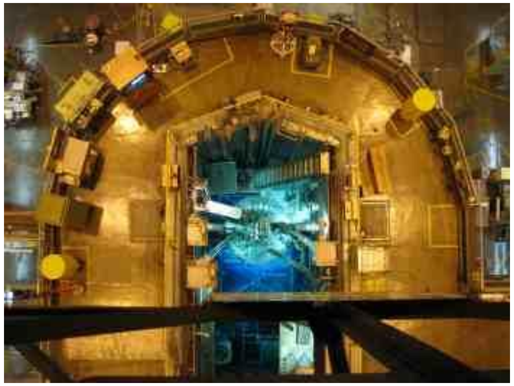
Assisting International Conversion from HEU Targets to LEU Targets

- Four-party joint statement at the 2012 Nuclear Security Summit on the minimization of HEU and the reliable supply of medical radioisotopes
  "…Belgium, the Netherlands, and France, in cooperation with the United States, reaffirm their determination to support conversion of European production industries to non-HEU-based processes by 2015….."

- OECD-NEA Joint Declaration on the Security of Supply of Medical Radioisotopes

- NNSA offers support to international Mo-99 producers to convert Mo-99 production from HEU targets to LEU targets:
  - South Africa
    - To date, NNSA has contributed approximately $21M toward the conversion of the NTP Radioisotopes Mo-99 production facility, and to address the HEU in Mo-99 waste residue. This support assisted the South African producer to become the world's first large-scale commercial supplier of Mo-99 produced with LEU targets in 2010.
  - Belgium
    - NNSA has contributed $9.4M toward the conversion of the IRE isotope production facility.
  - The Netherlands
    - NNSA has contributed $4.6M toward the conversion of the Mallinckrodt isotope production facility.
  - Canada
    - The NRU reactor in Canada is expected to cease regular isotope production in October 2016.

Nuclear Security Summit Seoul 2012



SAFARI-1 Reactor (South Africa)

NNSA Cooperative Agreement Partners

RadioGenix™ – NorthStar ^{99m}Tc Generating System

SHINE Medical Technologies Accelerator-Driven LEU Subcritical Assembly for Medical Isotope Production

Since 2009, NNSA has partnered with U.S. commercial entities to accelerate domestic Mo-99 production. NNSA's cooperative agreements are:

- awarded under a 50% - 50% cost-share cooperative agreement, per the American Medical Isotopes Production Act and the Energy Policy Act.
- limited to $25M in NNSA contributions per project, consistent with the OECD-NEA policy guidelines.

Neutron Capture Technology:

NNSA has awarded a total of $25 million to NorthStar Medical Radioisotopes to develop its neutron capture technology.

Accelerator Technology:

NNSA has awarded a total of $5.7 million to NorthStar Medical Radioisotopes to develop its accelerator-based technology.

Accelerator with LEU Fission Technology:

NNSA has awarded a total of $15 million to Morgridge Institute for Research ($10.7M) and SHINE Medical Technologies ($4.3M), to develop its accelerator with LEU fission technology.

LEU Target Technology:

NNSA has awarded a total of $9.7 million to General Atomics to develop its LEU selective gaseous extraction technology.

Other Important Mo-99 Updates

- Canada’s NRU Contingency Plan
- Uranium Lease and Take-Back Program
- Nuclear Science Advisory Committee
  - Mo-99 Subcommittee Report finalized October 2016
- National Academy of Sciences Report
  - Published September 2016