Annual Assessment of the NNSA-Material Management and Minimization (M3) ^{99}Mo Program

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Outline

- Charge and Subcommittee process
- Background – the ^{99}Mo issue
- Overview of the NNSA Material Management and Minimization ^{99}Mo program
- Findings and comments
- Recommendations

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Charge to NSAC

- What is the current status of implementing the goals of the NNSA-M^3 Mo-99 Program? What progress has been made since the 2018/2019 NSAC assessment?
- Is the strategy for continuing to implement the NNSA goals complete and feasible, within an international context?
- Are risks identified in implementing those goals being appropriately managed?
- Has the NNSA-MMM Program addressed concerns and/or recommendations articulated in the 2018/2019 NSAC assessment of the Mo-99 Program appropriately and adequately?
- What steps should be taken to further improve NNSA program effectiveness in establishing a domestic supply of Mo-99?

Subcommittee Members

- Ronald Crone, Idaho National Laboratory
- Mitch Ferren, Oak Ridge National Laboratory
- Silvia Jurisson, University of Missouri - Columbia
- David Hertzog, University of Washington
- Suzanne Lapi, Chair, University of Alabama at Birmingham
- Steve Mattmuller, Kettering Medical Center
- Alan Packard, Boston Children’s Hospital
- Thomas Ruth, TRIUMF

Expertise of the Subcommittee

Committee Expertise		
Nuclear Medicine	Radioisotope Production	Radiopharmacy and Clinical Use
Alan Packard Suzanne Lapi Silvia Jurisson	Mitch Ferren Suzanne Lapi Thomas J. Ruth	Steve Mattmuller Alan Packard
Nuclear and Radio Chemistry	Commercial Isotope Sales	Project Management
Silvia Jurisson Suzanne Lapi Thomas J. Ruth	Mitch Ferren Suzanne Lapi	David Hertzog Ron Crone

Subcommittee Process

- The Subcommittee met in Arlington, VA on February 3-4, 2020.
- We were briefed by:
  - NNSA (both open and closed sessions)
  - DOE-EM
  - All active cooperative agreement partners (closed sessions).
- The second day was devoted to closed meetings and a second NNSA session responding to questions raised by the committee.

Background

- ^{99m}Tc is the daughter of ^{99}Mo and is widely used for nuclear medicine diagnostic imaging.
- Today,^{99}Mo is mainly produced by fission of ^{235}U (until recently using Highly Enriched Uranium (HEU).
- There is U.S. government interest in reducing the use of HEU.
- American Medical Isotopes Production Act (AMIPA) aims establish a technology-neutral program to provide assistance to commercial entities to accelerate production of ^{99}Mo (without the use of HEU).
- Until recently, there was no U.S. producer of ^{99}Mo.

Image courtesy of J. McConathy, UAB

NNSA ^{99}Mo Objectives and Strategy

The organization and goals of the NNSA-M3 program with respect to ^{99}Mo remain unchanged since the previous review: to achieve HEU minimization and to assist in establishing reliable domestic supplies of ^{99}Mo produced without the use of HEU.

The NNSA-M3 program seeks to achieve these objectives through assisting global ^{99}Mo production facilities to convert to the use of low-enriched uranium (LEU) targets and reactor fuel and by accelerating the establishment of commercial non-HEU-based ^{99}Mo production in the United States

A stated objective during this review is to bring online two U.S. producers, each capable of producing 3000 6-day Ci/week of ^{99}Mo.

Changes in the international context (OECD)

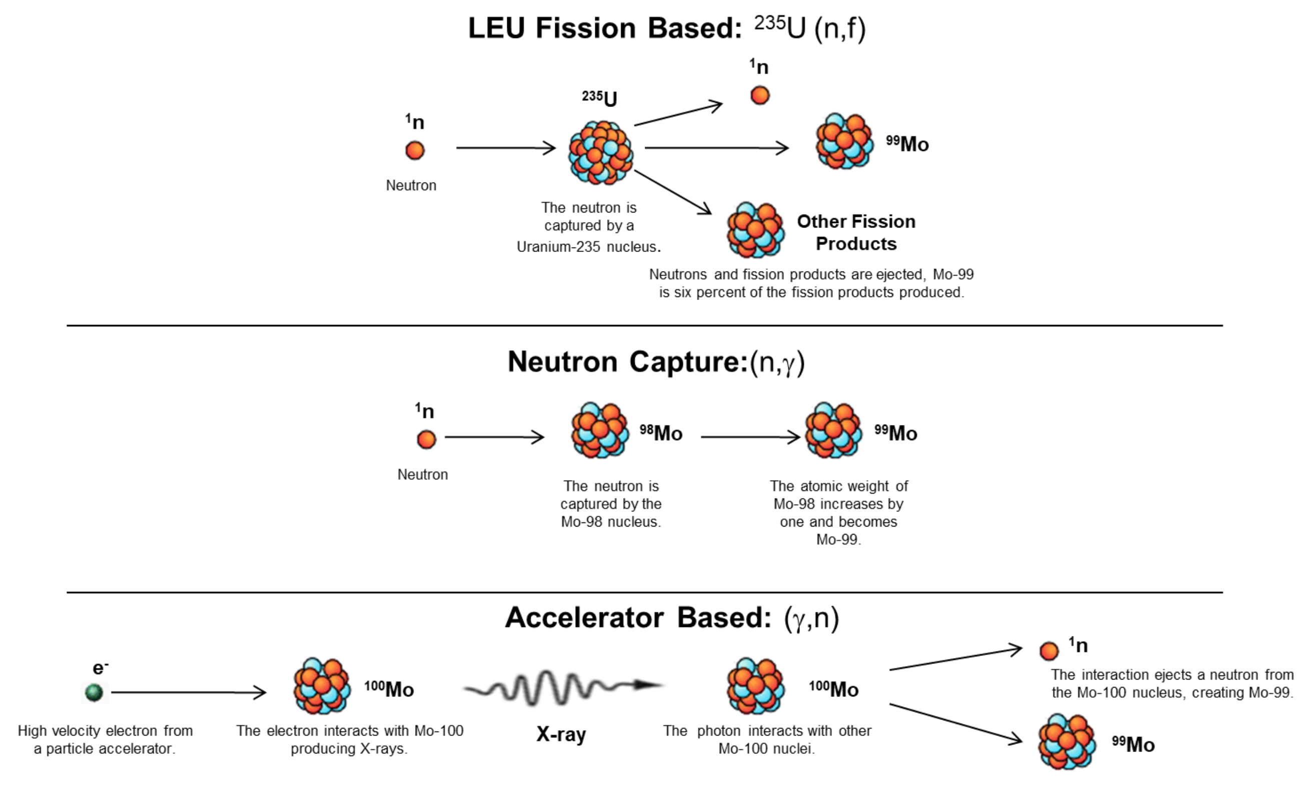
"The Supply of Medical Radioisotopes: 2019 Medical Isotope Demand and Capacity Projection for the 2019-2024 Period".

- Global demand growth has been maintained as in earlier reports.
- The conclusion on supply is similar to the previous report, "When facilities are well-maintained, well-scheduled and when unplanned outages are avoided, total irradiator and processor capacity should be sufficient." ……… "However, when no additional processing capacity is added above the present level, the capability to manage adverse events will remain low and will be further reduced with time."

Changes in the international context (OECD)

- Sporadic problems led to some shortage situations in some markets.
- Almost all international projects, including those supported by NNSA, have reported delays.
- Longer term OECD projections point to the possibility of a significant overcapacity internationally as additional facilities come on-line.

NNSA and U.S. Domestic ^{99}Mo Implementing a Technology-Neutral Program



Previous NNSA Co-operative Partners

	Neutron Capture Technology	Accelerator Technology	Accelerator with LEU Fission Technology	LEU Target Technology
Cooperative Agreement Partner	NorthStar Medical Radioisotopes	NorthStar Medical Radioisotopes	SHINE Medical Technologies	General Atomics
Funded	$25 million	$25 million	$25 million	$25 million
Cooperative Agreement Status	Completed	Period of Performance extended to 2021	Completed	Terminated by General Atomics
Anticipated Market Entry*	November 2018	2020	2020	N/A

*Market entry dates provided by CA partners in 2018

New NNSA Co-operative Partners

	Neutron Capture Technology	Accelerator with LEU Fission Technology	LEU fission with proprietary targets	Photonuclear LEU fission
Cooperative Agreement Partner	NorthStar Medical Radioisotopes	SHINE Medical Technologies	Northwest Medical Isotopes	Niowave
Funded	$15 million	$15 million	$15 million	$15 million
Cooperative Agreement Status	Active	Active	Active	Active
Anticipated Market Entry*	November 2018	2022	2023	2024/2025

*Market entry dates provided by CA partners in 2020

NorthStar neutron capture project:

- They initiated direct customer/commercial shipments for patient use in 4Q2018.
- Plan to be able to produce 30-35% of the US market needs by late 2020 using the neutron capture process at MURR

NorthStar accelerator project:

- Electron linac via the $^{100}Mo(\gamma,n)$ reaction.
- Construction of their accelerator facility was initiated in 2019, and the first accelerator is scheduled to be delivered in 2020.

SHINE Accelerator with LEU Fission project:

- Have initiated construction of their production facility
- Met several significant financing milestones.
- They will be able to achieve first production of ^{99}Mo by late 2021 with sales starting in 2022

Northwest Medical Isotopes project:

- Will use existing research reactors (MURR and Oregon State University (OSU)) to irradiate proprietary LEU targets.
- Aim to produce ^{99}Mo on a small scale (Ci level) by 2021.

Niowave project:

- Produce ^{99}Mo and other isotopes via photonuclear fission of LEU.
- They have already purchased LEU for their pilot studies and aim to produce 99Mo on a small scale (Ci level) by 2021.

The CA partners acknowledge the importance of the assistance from the national labs.

General Conclusions

- The Subcommittee found that since the review in 2017, NNSA has moved the NNSA-M^3 program forward, consistent with the specific AMIPA requirements.
- The continuation of ^{99}Mo produced by NorthStar into the market and the resulting ^{99m}Tc into patient procedures is an important step forward.
- As reported last year, there continue to be issues related to the long-term financial viability of any producers that succeed in entering the market.
  - Some of these are related to ULTB and/or FCR

What is the current status of implementing the goals of the NNSA-MMM ^{99}Mo Program? What progress has been made since the last assessment?

- The program is continuing to make progress towards improving the reliability of domestic ^{99}Mo supply.
- NorthStar has begun to deliver ^{99}Mo to the U.S. market. With additional approvals, they estimate they will be able to produce 30-35% of the US market needs by 2020 (using the neutron capture process at MURR).
- Shine aims to have ^{99}Mo into the U.S. Market by 2022.
- New cooperative agreements with new (Northwest and Niowave) and existing CA partners have been initiated.
- The ULTB program is still underdeveloped, however CA partners appear to be finding alternative paths forward including purchasing material.

Is the strategy for continuing to implement the NNSA goals complete and feasible, within an international context?

- The Subcommittee finds the dual goals of the NNSA program to be on track to realize both a significant domestic ^{99}Mo supply and a global conversion to non-HEU sources.
- The national laboratory program has been very effective and should be continued with a focus on R&D specific to advancing ^{99}Mo production
- The ULTB program has not been effectively implemented. This is both a combination of the fact that it is not needed by most of the CA partners and because of the difficulty of establishing the costs of the “take-back”, in particular, full-cost recovery by DOE-EM, and the open-ended cost provisions.
- The significant U.S. production of ^{99}Mo and entrance of NorthStar into the U.S. market – even with their unique generator system – does establish that the NNSA program of CA partner support can work.

Are the risks identified in implementation being appropriately managed?

- NNSA has identified a comprehensive set of risks; these were discussed in previous reports and no new risks have been identified.
- Some of these risks are beyond the direct control of the NNSA. All risks within the scope of their program are now being well managed.

Response to 2018/2019 Recommendations

- NNSA continues to highlight the need for potential ULTB customers to engage with DOE/NNSA at least two years prior to its first LEU delivery needs.
- DOE-EM did not provide the committee a waste takeback model and contract template as requested by the Subcommittee in the last report.
- The Subcommittee believes NNSA has addressed the concerns and recommendations within the scope of their program.
- FCR for ^{99}Mo should continue to be a worldwide goal; however, the difficulty of accomplishing this task cannot be overstated.

Steps to further improve the NNSA program effectiveness in establishing the domestic supply of ^{99}Mo

- The Subcommittee still believes that the Uranium Lease and Take Back (ULTB) program requires significant attention in order to provide Cooperative Agreement (CA) partners well-defined, predictable, and stable costs for disposition and storage of waste from leased low enriched uranium (LEU).
- Additionally, the Subcommittee encourages NNSA to focus their strategy and resources on the stated objective during this review, which is to bring online two U.S. producers, each capable of producing 3000 6-day Ci/week of ^{99}Mo.

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Recommendation 1

- The limitations of the ULTB program continues to be one of the biggest risks to the program's success. The ULTB contract templates should be reviewed and revised as necessary; in particular, with respect to reducing the continuing significant uncertainties in the Take Back aspects of the DOE-EM program. The results of this review should be presented to the NSAC ^{99}Mo Subcommittee at the next program assessment.

Recommendation 2

- The NNSA stated during this review that a program objective was to have at least two US producers, each capable of producing 3000 6-day Ci/week of ^{99}Mo. The third FOA for this program is anticipated in 2020. After 10 years of significant investment in this program, the NNSA should focus their strategy on prioritizing future awards such that time-to-market, consistent with the stated objective, is considered as the most important review criteria. This strategy should be reflected in the approach to allocation of CA funding and national laboratory resources.

Acknowledgements

- Thanks to our committee members who did a great job.
- Thanks to NNSA and all the CA partners.
- Thanks to Brenda May for her support in organizing our meeting!

Back up slides

U.S. Department of Energy
and the
National Science Foundation

October 4, 2019

Professor David Hertzog
Chair, DOE/NSF Nuclear Science Advisory Committee
Department of Physics
University of Washington
Seattle, Washington 98195

Dear Professor Hertzog:

This letter is to request that, in accordance with direction given to the DOE in the National Defense Authorization Act (NDAA) for FY2013, the Nuclear Science Advisory Committee (NSAC) standing Subcommittee on Mo-99 conduct its annual assessment of the effectiveness of the National Nuclear Security Administration, Office of Material Management and Minimization (NNSA-MMM) Domestic Molybdenum-99 (Mo-99) Program (formerly known as the Global Threat Reduction Initiative).

The American Medical Isotopes Production Act of 2012 (Act), formerly known as S. 99 and H.R. 3276, was incorporated into the National Defense Authorization Act (NDAA) for FY2013. On January 2, 2013, President Obama signed the NDAA into law, enacting this legislation. A stipulation of the NDAA under section 3173 – *IMPROVING THE RELIABILITY OF DOMESTIC MEDICAL ISOTOPE SUPPLY* is that:

"...the Secretary [of Energy] shall...use the Nuclear Science Advisory Committee to conduct annual reviews of the progress made in achieving the [NNSA MMM] program goals and make recommendations to improve effectiveness."

The Department of Energy (DOE) and National Science Foundation (NSF) very much appreciate NSAC's five previous assessments as described in reports transmitted to the agencies on May 8, 2014, July 30, 2015, November 3, 2016, March 19, 2018, and April 17, 2019.

We request that NSAC reconvene the Subcommittee to provide a sixth annual assessment addressing the following charge elements:

- What is the current status of implementing the goals of the NNSA-MMM Mo-99 Program? What progress has been made since the 5th NSAC assessment?
- Is the strategy for continuing to implement the NNSA goals complete and feasible, within an international context?
- Are the risks identified in implementing those goals being appropriately managed?
- Has the NNSA-MMM Program addressed concerns and/or recommendations articulated in the 2018/2019 NSAC assessment of the Mo-99 Program appropriately and adequately?

- What steps should be taken to further improve NNSA program effectiveness in establishing a domestic supply of Mo-99?

It is requested that this assessment be submitted by spring of 2020.

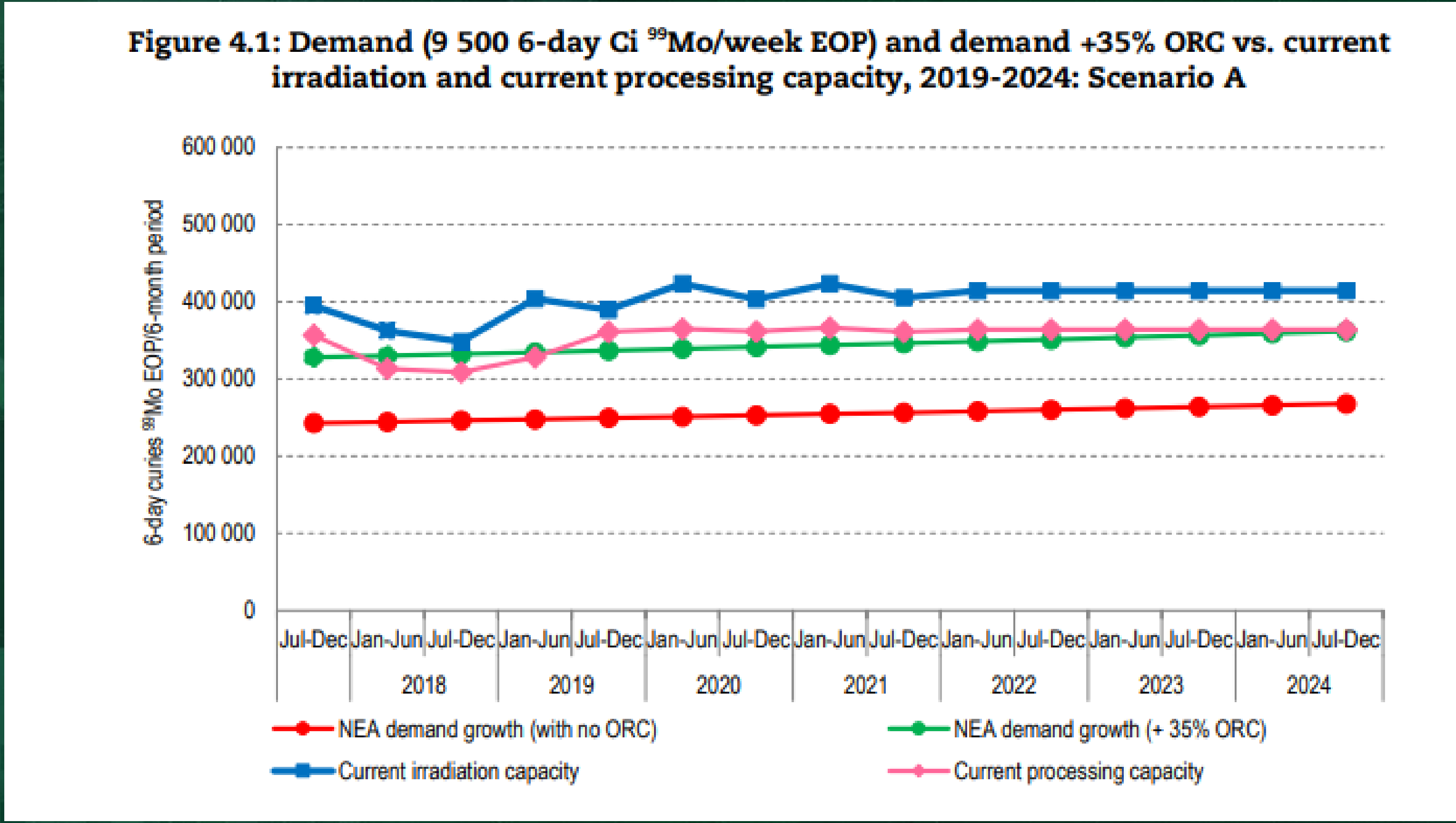
We are aware that this charge represents an additional burden on your time. However, the involvement of NSAC is essential to inform the Agency regarding the effectiveness of efforts to steward Mo-99, and isotope essential for the health and well-being of the Nation.

Sincerely,

Christopher Fall
Director
Office of Science

Anne L. Kinney
Assistant Director, Directorate for
Mathematical and Physical Sciences
National Science Foundation

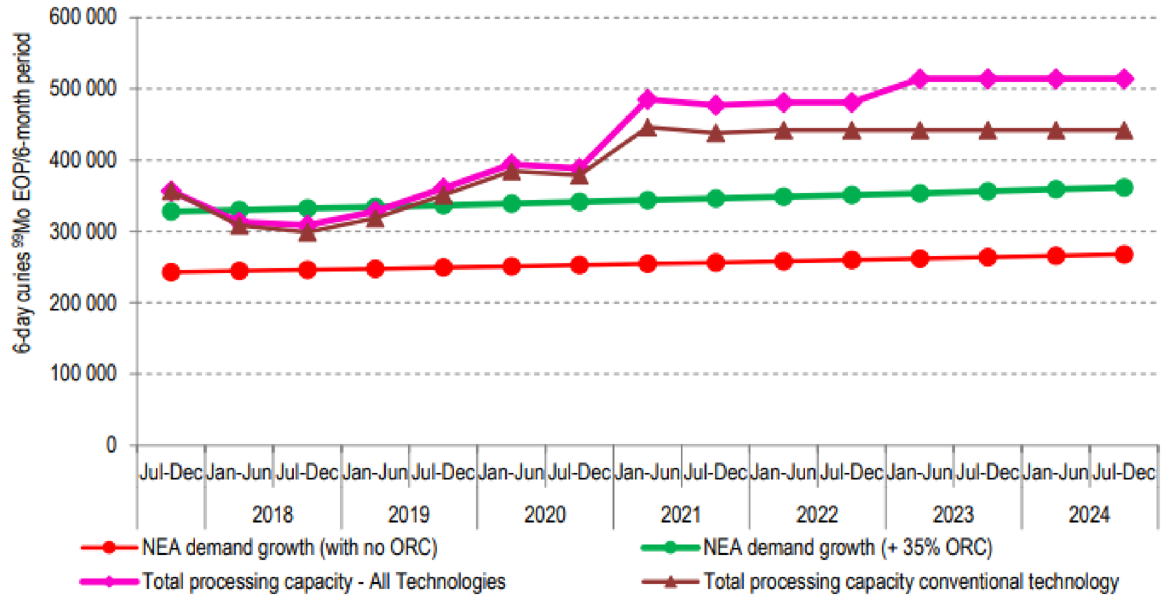
OECD



https://www.oecd-nea.org/med-radio/docs/sen-hlgmr2019-1.pdf

OECD

Figure 5.2: Current demand (9 500 6-day Ci ^{99}Mo/week EOP) and demand +35% ORC vs. processing capacity – total and processing capacity – conventional only, 2019-2024: Scenario B



https://www.oecd-nea.org/med-radio/docs/sen-hlgmr2019-1.pdf

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Table 1. Current irradiators

Reactor (Fuel)	Current targets[6]	Normal operating days/year	Anticipated ^{99}Mo production weeks/year	Expected available capacity per week (6-day Ci ^{99}Mo)	Expected first full year of ^{99}Mo production[7]	Expected available capacity per year (6-day Ci ^{99}Mo) by 2024	Estimated end of operation
BR-2 (HEU)	HEU/LEU	147	21	6 500	NA	136 500	At least until 2026
HFR[1] (LEU)	HEU/LEU	275	39	6 200	NA	241 800	2026
LVR-15 (LEU)	HEU/LEU	210	30	3 000	NA	90 000	2028
MARIA (LEU)	LEU	200	36	2 200	NA	79 200	2040
OPAL (LEU)[2]	LEU	300	43	2 150	NA	92 450	2057
RA-3 (LEU)	LEU	230	46	500	NA	23 000	2027 or earlier based on RA 10 introduction
SAFARI-1 (LEU)	LEU	305	44	3 000	NA	130 700	2030
RIAR[3] (HEU)	HEU	350	50	540	NA	27 000	At least until 2025
KARPOV[3] (HEU)	HEU	336	48	350	NA	16 800	At least until 2025
MURR[4] (HEU)	Natural Mo in CRR	339	52	750	2019	39 000	2037
OPAL[5] (LEU)	LEU	300	43	+1 350	2020	58 050	2057

Notes: 1). HFR capacity increased to 6 200 per week from 2017, 2). OPAL extra irradiation capacity now operating at 12 plates, 3). RIAR and KARPOV material needs to comply with specific requirements to be available in some markets; the KARPOV facility will be relicensed in 2020 to continue its operation; RIAR weekly production varies depending on RBT-6/RBT-10 availability, 4). MURR irradiations for the NorthStar system started in 2018, 5). OPAL extra irradiation capacity at 12 plates in the new ANM ^{99}Mo facility started 2019, first full year 2020, 6). HEU >20% enriched Uranium, LEU <20% enriched Uranium, 7). NA = Not Applicable

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https://www.oecd-nea.org/med-radio/docs/sen-hlgmr2019-1.pdf

What is ^{99}Mo?

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. (over 18 million per year 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

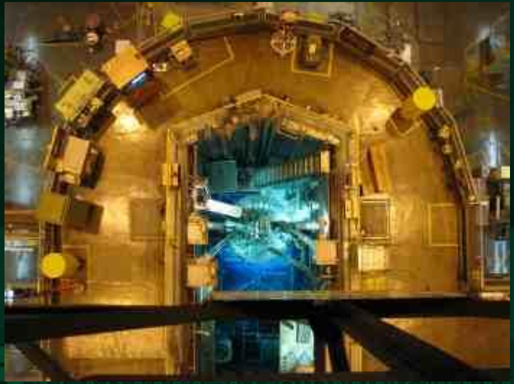
U.S. demand is approximately 50% of the world market

- The historic global demand is ~12,000 6-day curies per week.
- Since the 2009-2010 shortages, global demand has been ~10,000 6-day curies per week.

Mo-99 is produced at only 5 processing facilities worldwide, in cooperation with 8 research reactor facilities

- Processing facilities located in Canada (HEU), The Netherlands (HEU), Belgium (HEU), South Africa (HEU and LEU), and Australia (LEU)
- Research reactors used for irradiation located in Canada, The Netherlands, Belgium, France, Poland, Czech Republic, South Africa, and Australia

Tc-99m generator and labeling kits



SAFARI-1 Reactor (South Africa)

The American Medical Isotopes Production Act of 2012

- The Act was incorporated in the National Defense Authorization Act for Fiscal Year 2013 and enacted on January 2, 2013.

- Intended to help establish a reliable domestic supply of Mo-99 produced without the use of HEU and includes a number of short, medium, and long-term actions.

    - Requires the Secretary of Energy to establish a technology-neutral program to provide assistance to commercial entities to accelerate production of Mo-99 in the United States without the use of HEU
    - Requires annual public participation and review
    - Requires development assistance for fuels, targets, and processes
    - Establishes a Uranium Lease and Take Back program
    - Requires DOE and NRC to coordinate environmental reviews where practicable
    - Provides a cutoff in exports of HEU for isotope production in 7 years, with possibility for extension in the event of a supply shortage
    - Requires a number of reports to be submitted to Congress