



**IAEA**

International Atomic Energy Agency  
*Atoms for Peace and Development*

# Molybdenum 99 Production Overview

***WOSMIP 2022***

June 9, 2022

*John N Dewes*

*International Atomic Energy Agency*

# A Brief History of Mo-99/Tc-99m



- First practical medical use in the 1960s
- Early on neutron capture ( $\text{Mo-98}(n,\gamma)\text{Mo-99}$ ) dominated
- Cintichem process from 1968 on and the rise of fission production
- Tc-99m used in ~80% of all nuc. med. procedures worldwide

# IAEA Support for Mo-99/Tc-99m Technology



## Department of Nuclear Sciences and Applications

- Radioisotope Products and Radiation Technology Section
- Focuses on Technology Development, Application

## Department of Nuclear Energy

- Research Reactor Section
- Focuses on HEU Minimization

# Radioisotope Products and Radiation Technology Section Activities Relevant to Mo-99

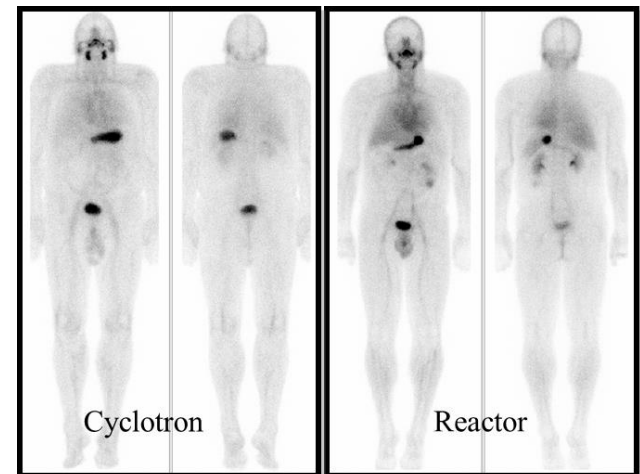
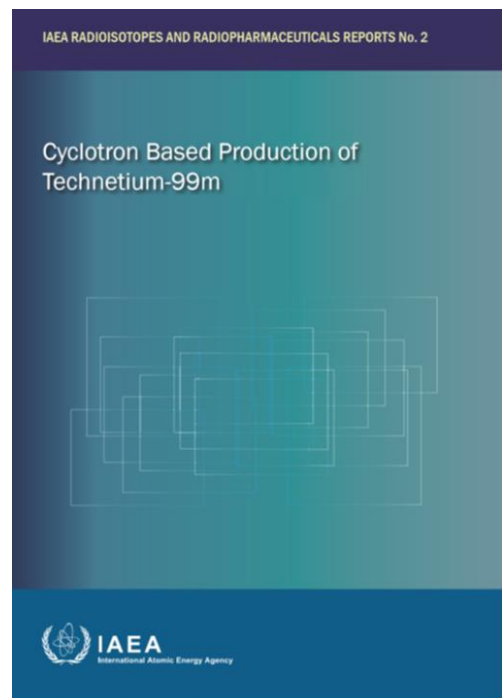
- ❖ Research and Development
- ❖ Implementation of Technologies
- ❖ Education / Training / Qualification

## Areas:

- Production of radioisotopes and radiopharmaceuticals
- Accelerator-based radiation technologies for industry, environment, and cultural heritage
- Sealed radiation sources for NDT and other applications

# Accelerator-based Alternatives to Non-HEU production of Mo-99/Tc-99m

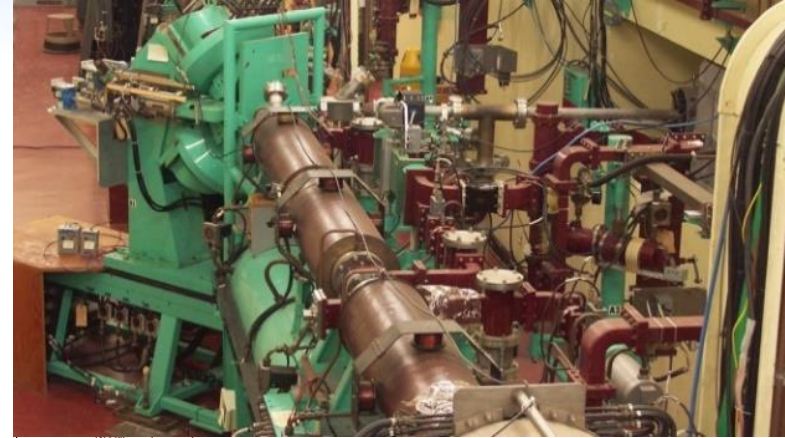
- 2011-2015
- 18 participants from 16 Member States
- Production of Tc-99m in cyclotron - very successful
- Technology to produce several (>30) Ci Tc-99m per run in medical cyclotrons of energies below 24 MeV proven; clinical trials under way; regulatory approvals sought
- Monograph approved in Europe
- Self-sufficiency in hospitals/towns/country
- Good option for hospital or radiopharmacy; local productions
- Target specifications; reuse of targets etc. need consideration



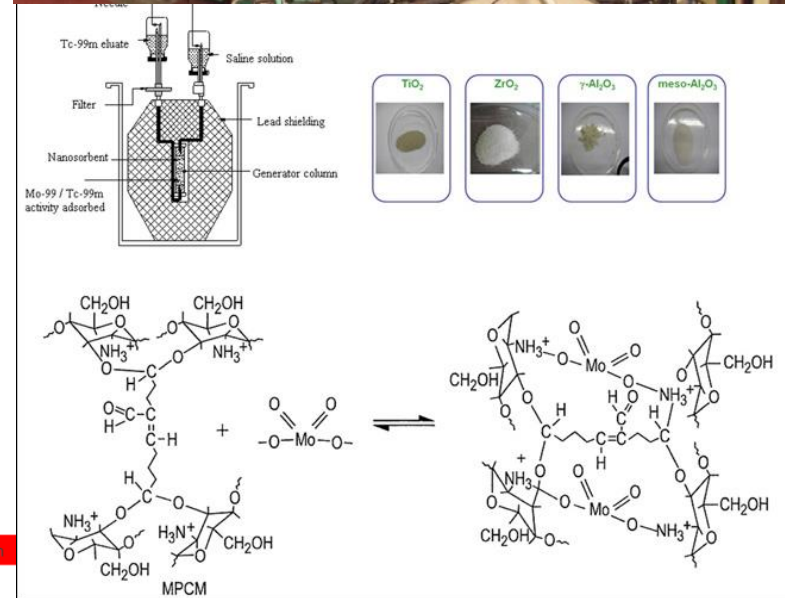
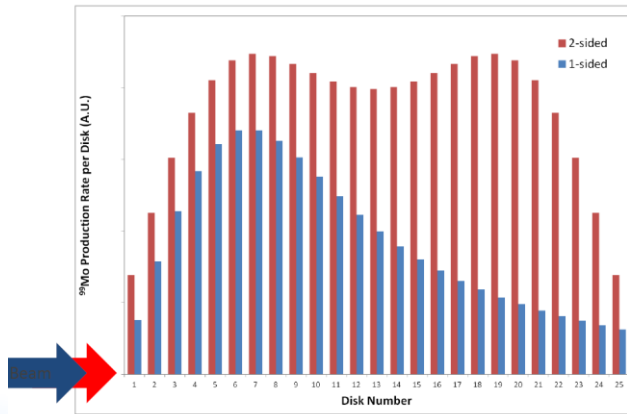
*Comparison of cyclotron- and reactor-based Tc-99m pertechnetate for the Univ. of Alberta Clinical Trial (cancer thyroid patients imaged post-thyroidectomy)*

# CRP: Photonuclear Route for Producing Tc-99m and Tc-99m Generators

- First Meeting: December 2017
- 18 Approved Proposals
- Aimed as use of low specific activity Mo-99 for generator preparation and accelerator production of Mo-99 (Mo-100 ( $\gamma, n$ ) reaction)
- Third RCM November 2021
- Publication to Follow



Two Sided Irradiation, 35 MeV Production



<https://www.iaea.org/newscenter/news/new-crp-new-ways-of-producing-tc-99m-and-tc-99m-generators>

**TABLE 1. IAEA PUBLICATIONS RELATED TO Tc-99m RADIOPHARMACEUTICALS**

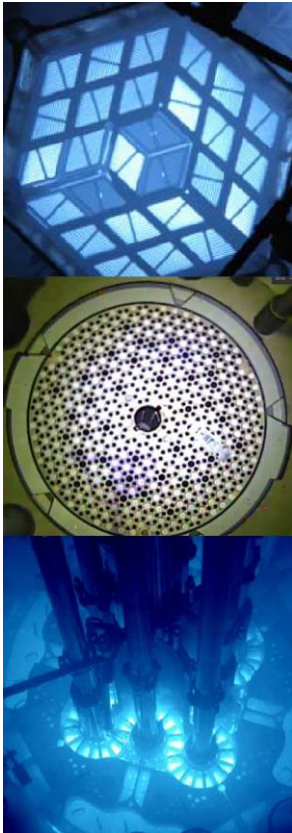
\*TRS = [Technical Reports Series](#) ; RRR = [Radioisotopes and Radiopharmaceuticals Reports](#); NES = [Nuclear Energy Series](#); Tec-Doc = Technical Document.

| Title   | Date of publication | CRP code | Reference | Format*    |
|---|---------------------|----------|-----------|------------|
| Development of Kits for 99mTc Radiopharmaceuticals for Infection Imaging  | 2004                | F22032   | [18]      | TECDOC     |
| 99mTc labelled peptides for imaging of peripheral receptors   | 2001                | F22023   | [19]      | TECDOC     |
| Labelling of Small Biomolecules Using Novel Technetium-99m Cores  | 2007                | F22038   | [20]      | TRS        |
| “Technetium-99m Radiopharmaceuticals: Manufacture of Kits”  | 2008                | n.a.     | [21]      | RRS        |
| Technetium-99m Radiopharmaceuticals: Status and Trends”   | 2010                | n.a.     | [22]      | <u>RRS</u> |
| Non-HEU Production Technologies for Molybdenum-99 and Technetium-99m  | 2013                | n.a.     | [23]      | NES        |
| Cyclotron Based Production of Technetium-99m  | 2017                | F22062   | [24]      | <u>RRR</u> |
| <u>Feasibility of producing molybdenum-99 on a small-scale using fission of low enriched uranium or neutron activation of natural molybdenum (iaea.org)</u> | 2015                | T12018   | [25]      | TRS        |
| Development of 99mTc Radiopharmaceuticals for Sentinel Node Detection and Cancer Diagnosis  | 2015                | F22045   | [26]      | RRS        |

**A new IAEA TECDOC, *PROGRESS ON Tc-99m RADIOPHARMACEUTICALS (under preparation 2022)?***



# Research Reactor Section Support for HEU Minimization



30+ years of IAEA support on international efforts to reduce HEU in international civilian activities

We assist countries, upon request with

- Conversion to LEU
- New Fuel Specification and Procurement
- HEU Removals
- Non-HEU Mo-99 Production



# Non-HEU Mo-99/Tc-99m Production

IAEA supports Member States to ensure sustainability of production of Mo-99/Tc-99m and other radioisotopes

## Technologies:

- Conversion of Major Mo-99/Tc-99m Producers – HEU to LEU targets
- Non-HEU Production of Mo-99 (Mo-98 activation)
- Accelerator-based alternatives to Non-HEU Production of Mo-99/Tc-99m

## Production Support:

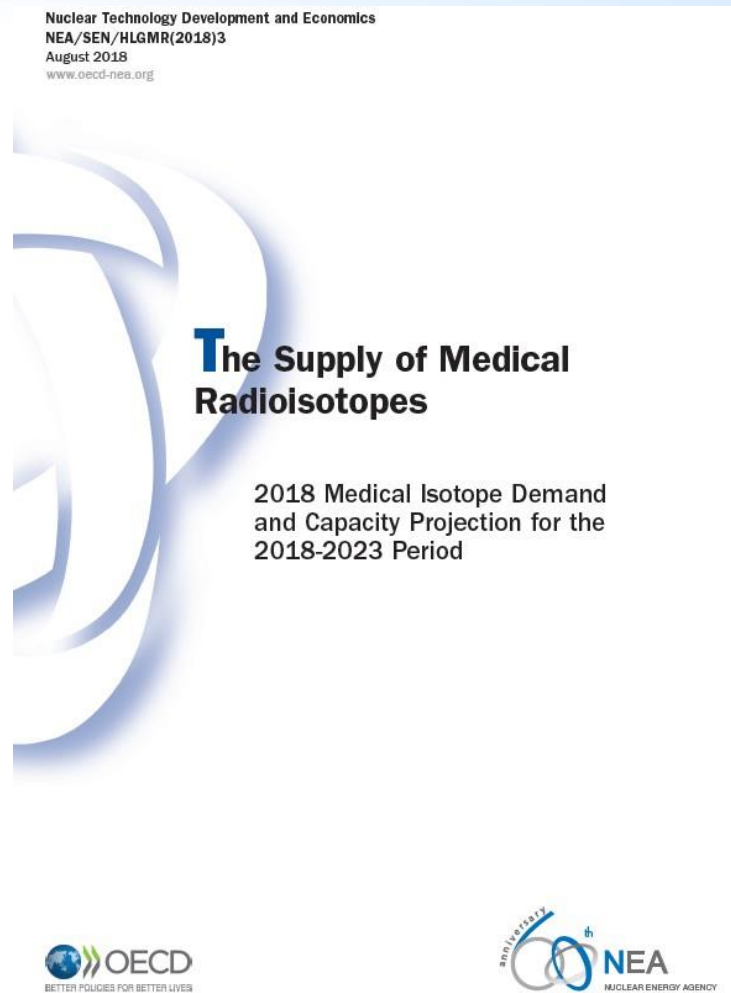
- 2018 OECD Isotope Supply Review
- 2018 and 2020 Technical Meetings on Global Capabilities for Production and Manufacture of Non-HEU Mo-99 Targets
- 2022 Technical Meeting on Management of Wastes / Residuals from Mo-99 Production
- Planned October 2022 Mo-99 International Symposium
- US Molybdenum-99 Program Support



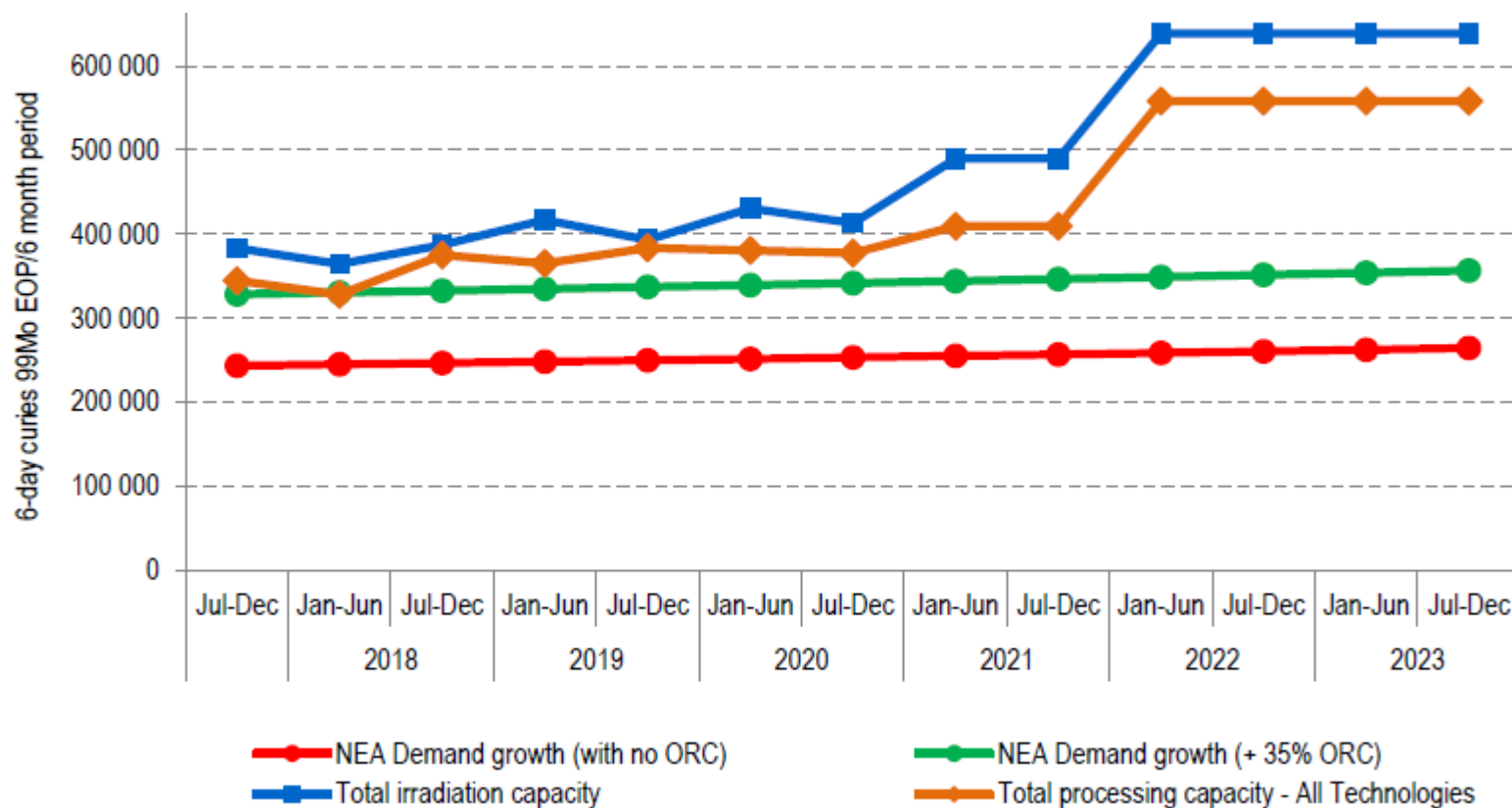
# OECD: 2018 Medical Isotope Supply Review



- Global Demand
- Irradiation Capacity
- Processing Capacity
- Supply



# OECD: 2018 Medical Isotope Supply Review



# OECD Key Takeaways, Current Status



- Positive developments with conversion to LEU and first licensing for alternative generators by NorthStar, SHINE
- Extended unplanned outage at NTP has pushed processing capacity below the NEA demand +35% outage reserve guideline
- Other Irradiators Have Stepped Up
- Supply situation will continue to require careful planning to minimize security of supply risks and react effectively in the event of unplanned outage

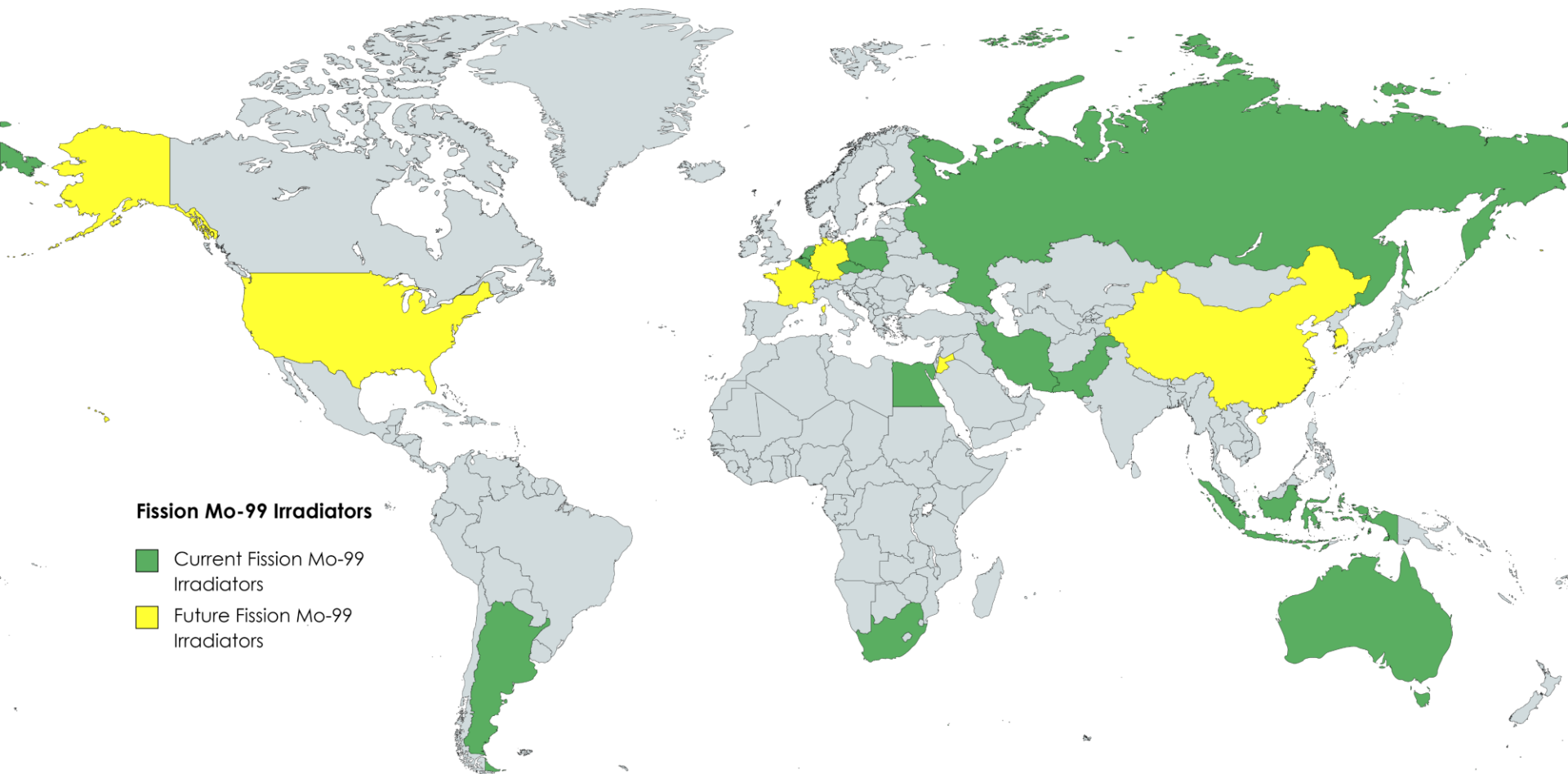
# US Molybdenum 99 Program



- Established by US Congress in Response to Shutdown of Maple Reactors in Canada
- Designed to Establish Commercial Supply of Non-HEU Based Mo-99/Tc-99m Production in the USA
- Cooperative Agreements Made with Three Companies
- Led to January 2022 End of US Exports of HEU for MIP

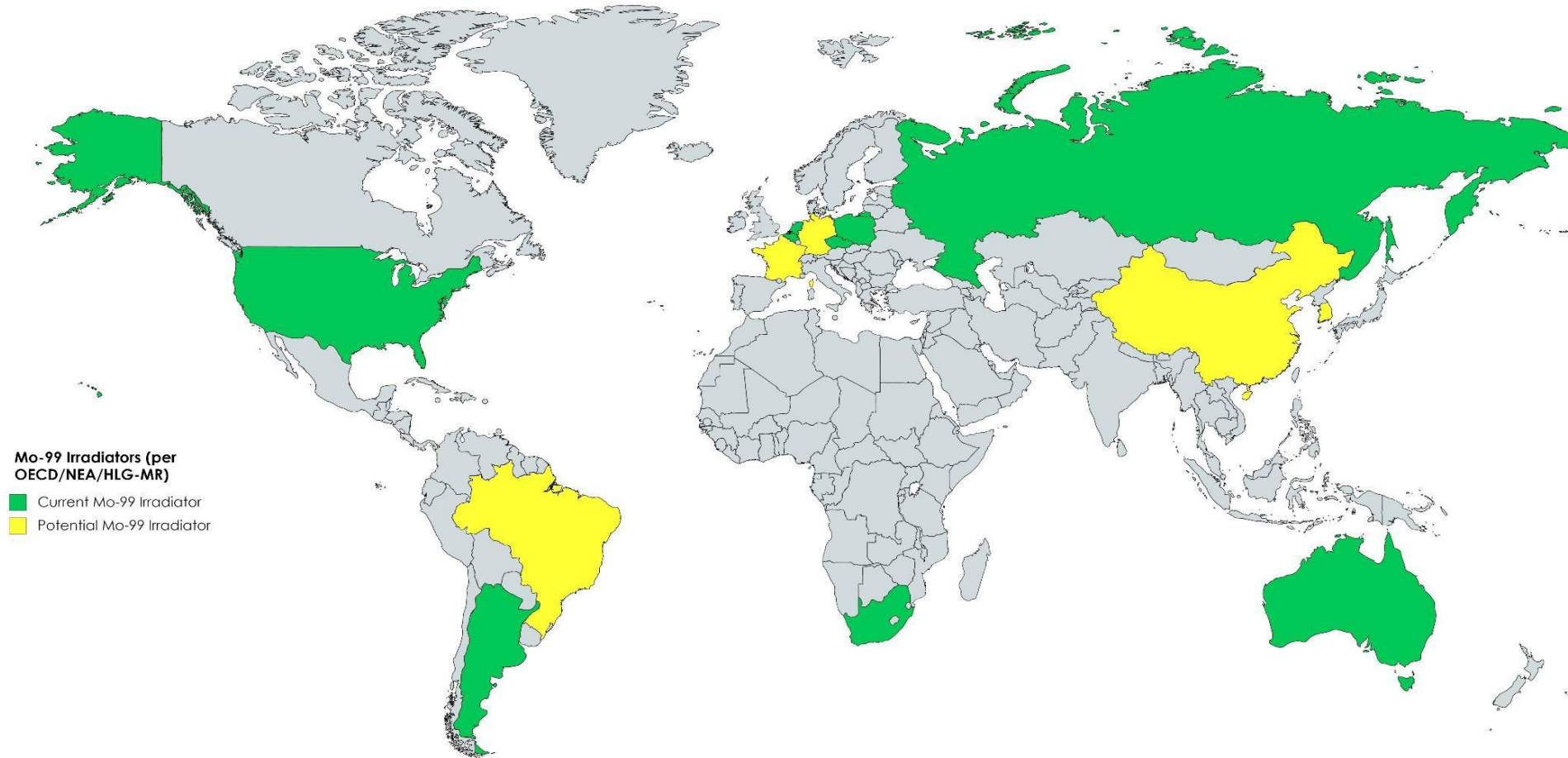
|   |   |  |
|---|---|--|
| The logo for NIOWAVE, consisting of a blue circle with a white atomic symbol inside, followed by the word "NIOWAVE" in bold blue capital letters. | The logo for NorthStar Medical Radioisotopes, LLC, featuring a stylized black and white graphic of a star or comet above the word "NorthStar" in a serif font, with "MEDICAL RADIOISOTOPES, LLC" in a smaller sans-serif font below it. | The logo for SHINE, featuring a blue square with a white stylized 'S' shape inside, followed by the word "SHINE" in bold blue capital letters. |
| Accelerator with LEU fission  | Two technologies: <ul style="list-style-type: none"><li>➤ Neutron capture with enriched Mo-98 targets</li><li>➤ Accelerator with Mo-100 targets</li></ul>   | Accelerator with LEU fission   |

# Fission Mo-99 Target Irradiators





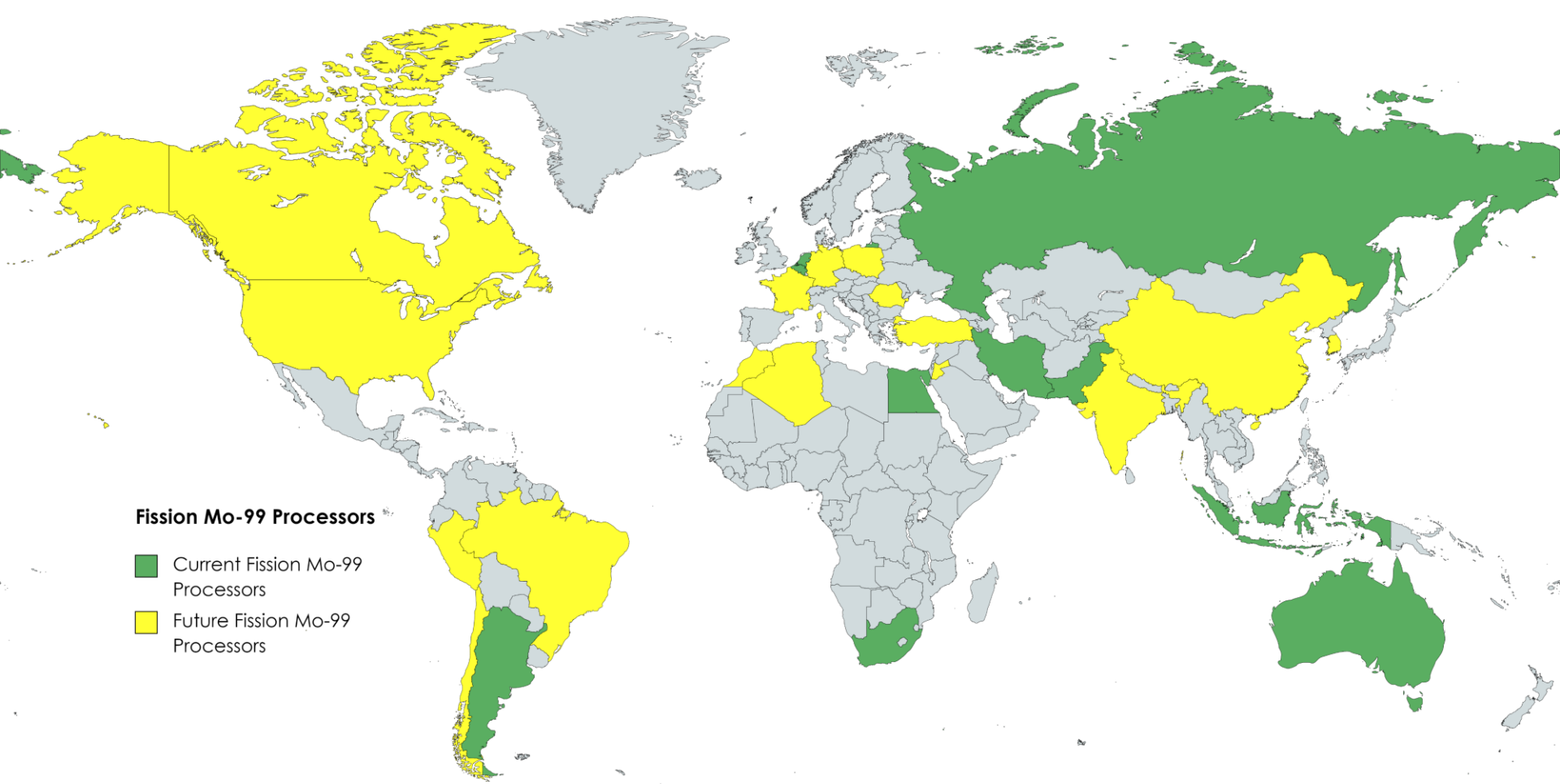
# Fission Mo-99 Target Irradiators - 2018



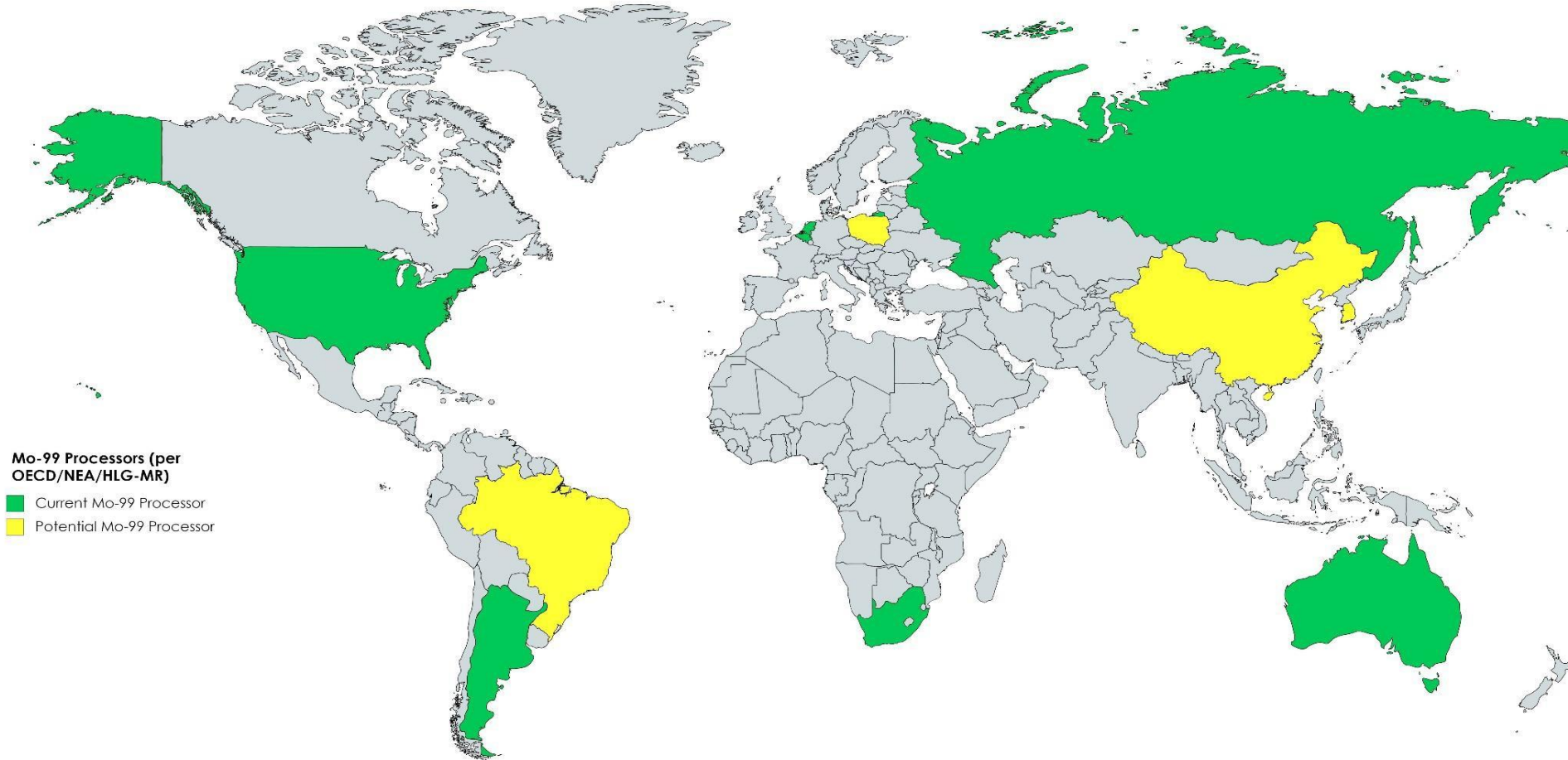
Mo-99 Irradiators (per  
OECD/NEA/HLG-MR)

- Current Mo-99 Irradiator
- Potential Mo-99 Irradiator

# Fission Mo-99 Target Processors



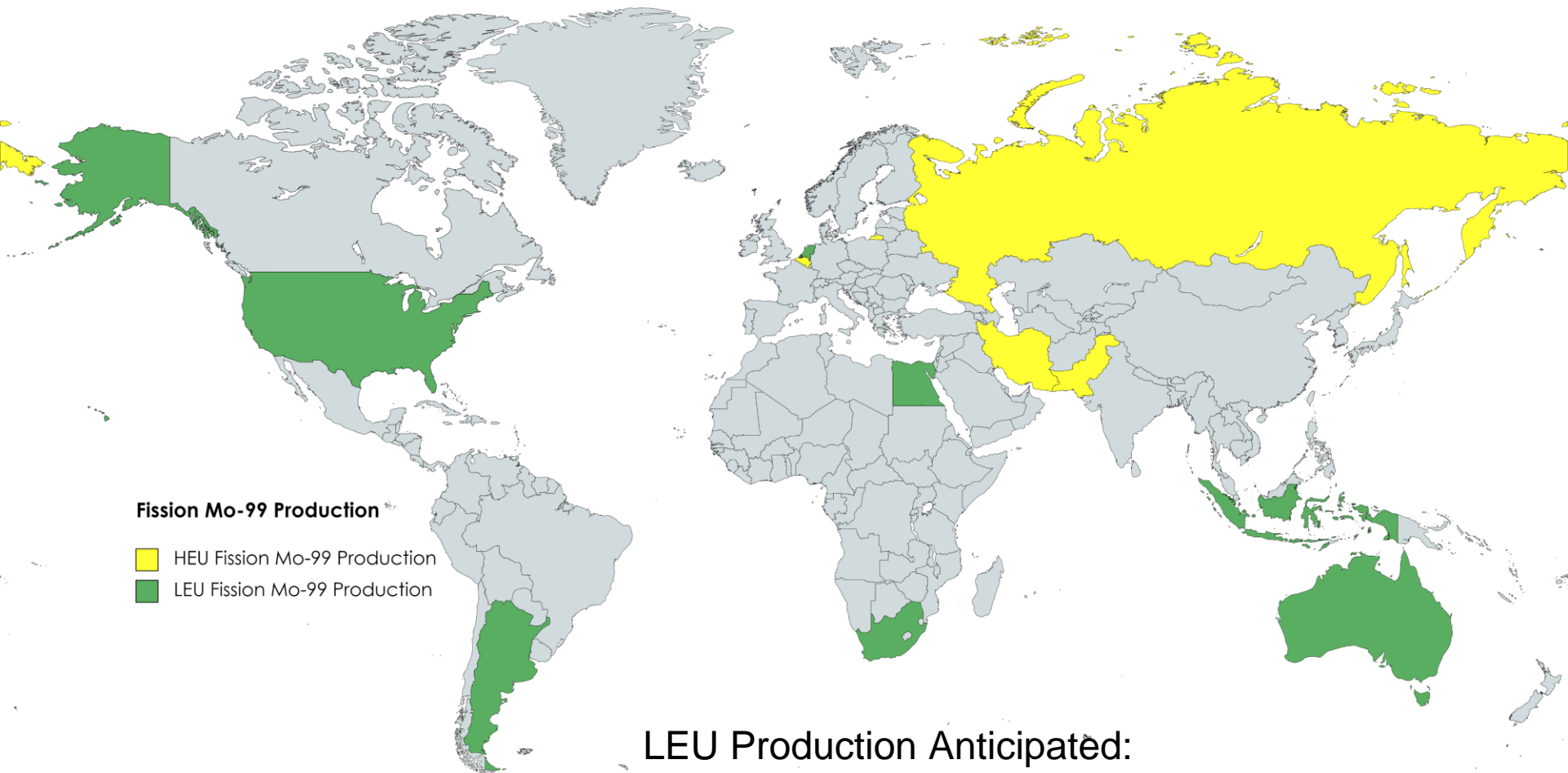
# Fission Mo-99 Target Processors - 2018



Mo-99 Processors (per  
OECD/NEA/HLG-MR)

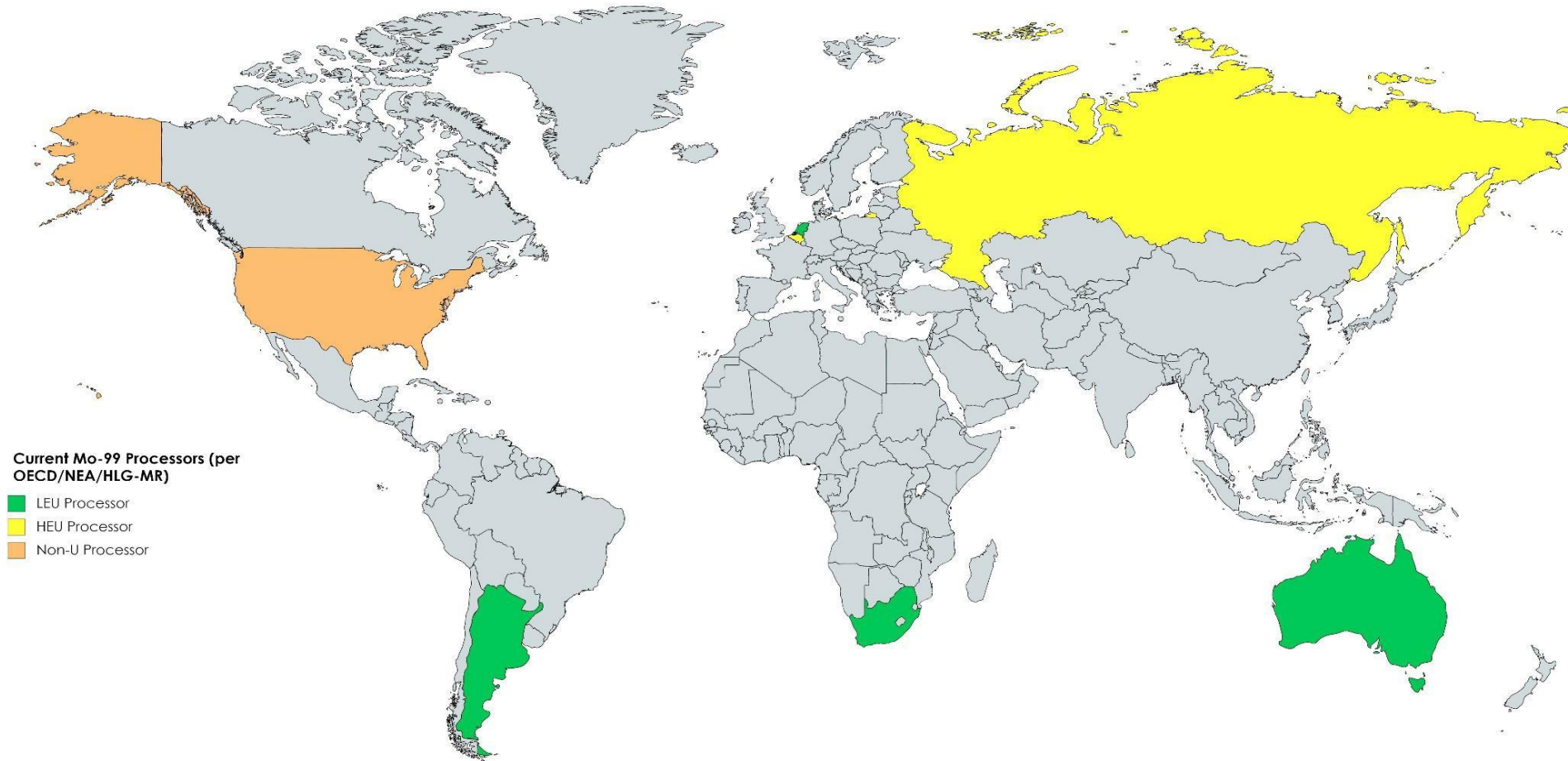
- Current Mo-99 Processor
- Potential Mo-99 Processor

# Most World Mo-99 Process Capacity Now non-HEU



LEU Production Anticipated:  
Belgium 2022  
Russia 2024  
Pakistan, Iran – Under Study

# Most World Mo-99 Process Capacity Now non-HEU - 2018







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# IAEA CRP: Sharing and Developing Protocols to Further Minimize Radioactive Gaseous Releases to the Environment in the Manufacture of Medical Radioisotopes

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# Coordinated Research Project (CRP)

- CRP on Sharing and Developing Protocols to Further Minimize Radioactive Gaseous Releases to the Environment in the Manufacture of Medical Radioisotopes, as Good Manufacturing Practice
- Request received from Australia, Belgium, the Netherlands, Republic of Korea, and the USA in May 2014
- Request proposed the IAEA initiate a CRP on the topic of technologies to reduce emissions from medical isotope production facilities
- Research Coordination Meetings Held in 2015, 2017, and 2018

# SPECIFIC RESEARCH OBJECTIVES

- To identify the steps and factors of the MIP process that need proper gaseous emission monitoring and trapping, including those radioisotopes coming from the fission of Uranium.
- To evaluate the impacts of emissions on health and safety and on the international and national monitoring of nuclear explosions without affecting production capabilities by using ATM.
- To validate ATM and quantify the uncertainty based on MIP stack data and monitoring data.
- To develop research activities focusing on efficient methods of treatment and process of the radioactive gaseous emission to the atmosphere (plant operation, gas trapping and decay time) that could mitigate the radioactive gaseous emissions.
- To evaluate and develop stack measurement systems for radioactive gases and explore data exchange methodologies and formats.

# Recommendations From the Final Report



- CRP showed that the cooperation between IAEA and CTBTO is productive and should be continued
- New adsorption materials and mitigation technologies should be further explored, in combination with modelling adsorption/desorption cycles to allow cost and space efficient systems for reducing emissions, potentially in a new CRP
- Further study of global medical isotope production which can lead to potential releases impacting treaty verification (e.g. radio Xe & I)
- Collection and sharing of data such as
  - Stack monitoring and environmental monitoring
  - Atmospheric dispersion and transport modelling
- Study on worldwide background levels of I-131

# Proposed Contents for the Guidelines

## Introduction

## Origin of Radioactive Gaseous Emissions

Xe, Kr, I

Fission process: dissolution, purification, waste treatment

## Trapping/Delay – Technology for New and Existing Facilities

Noble Gases

I-131

## Stack Monitoring

Detectors, efficiency, resolution, detection limits

Fixed and mobile

Data Sharing with CTBTO

## Monitoring Stations

## Transport Modelling – Validation of ATM

Near range (installation)

Long range

## Recommended Emission Values (safety and background)

# Current Status

- The work performed during this CRP will be shared and made accessible to Member States beyond those involved in the CRP
- Draft of Publication is Expected early 2023
- Depending of Format, Publication is Expected in 2024-25





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*Thank you!*

