Eurasia Research Reactor Coalition
– a potentially significant source of (n,γ) Mo-99

P. Chakrov¹, A. Carrigan², K. Alldred², J. Ritchie³
1) Institute of Nuclear Physics, Almaty, Kazakhstan
2) International Atomic Energy Agency, Vienna, Austria
3) Pacific Development Services Inc., Carson City, USA

Mo-99 Topical Meeting
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Outline

• EARRC reactors
• EARRC history
• Why \((n,\gamma)\) Mo-99?
• Examples of Tashkent and Almaty reactors
• From local to global supply
• Why coalition?
• Production capacity estimate
• Transportation options
• Potential customers
### EARRC reactors

- **Almaty, Kazakhstan**
  - **WWR-K**
  - 6 MW, $10^{14}$ cm$^{-2}$s$^{-1}$

- **Tashkent, Uzbekistan**
  - **WWR-SM**
  - 10 MW, $10^{14}$ cm$^{-2}$s$^{-1}$

- **Kiev, Ukraine**
  - **WWR-M**
  - 10 MW, $10^{14}$ cm$^{-2}$s$^{-1}$

- **Řež, Czech Republic**
  - **LVR-15**
  - 10 MW, $10^{14}$ cm$^{-2}$s$^{-1}$

- **Budapest, Hungary**
  - **BRR**
  - 10 MW, $10^{14}$ cm$^{-2}$s$^{-1}$

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**Russian design light water research reactors**

All have $1...1.5 \times 10^{14}$ n$_{th}$/cm$^2$s$^{-1}$ in suitable positions

All equipped with irradiation facilities and hot cells

- **Pitesty, Romania may join:**
  - **TRIGA**
  - 14 MW, $1...2 \times 10^{14}$
EARRC history

• December 2007, Vienna – IAEA meeting on strategic planning for research reactors – idea of “Central Asia RR Coalition” (Almaty, Kazakhstan + Tashkent, Uzbekistan) for isotope production

• May 2008, Almaty – Seminar on isotope production –
  + Kiev, Ukraine

  + Prague, Czech Republic + Budapest, Hungary
  + isotope trading companies
  ➔ “EURASIA RESEARCH REACTOR COALITION” (EARRC) Memorandum of Understanding

• 2009-2012 – 6 meetings, focus on (n,gamma)Mo-99
Why \((n,\gamma)\) Mo-99?

Mo-99:
- Important public mission
- Global demand for diversification of supply sources
- Opportunity to increase self-reliance of coalition reactors

\((n,\gamma)\) Low specific activity… but:
- No use of HEU
- No processing of irradiated uranium
- No gaseous fission products
- Almost no radioactive waste
- Minimum infrastructure required
- Existing experience, a number of technologies available
  - Proliferation resistant and safe
  - All coalition reactors are capable to produce significant quantities without significant investment
Example 1:

WWR-SM reactor (Tashkent, Uzbekistan)

- enriched $^{98}$Mo (n, gamma) $\sim 3...4$ Ci/g
- (large) alumina column generators 5.5....18.5 GBq
- 30% of former USSR production
- proven pharmaceutical quality
Example 2:

WWR-K reactor (Almaty, Kazakhstan)

- natural Mo \((n,\gamma)\) \(0.8\ldots1.1\) Ci/g
- supported by IAEA TC and CRP
- central gel generator since 2001
- portable gel generators (India design) since 2010
  (Kazakhstan design) since 2013
- proven pharmaceutical quality
Proven quality (portable gel generator, Almaty)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(^{99m}\text{Tc from gel generator})</th>
<th>European Pharmacopeia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of radionuclide impurities, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(^{99}\text{Mo})</td>
<td>(\leq 0.02)</td>
<td>(\leq 0.1)</td>
</tr>
<tr>
<td>other radionuclide impurities</td>
<td>(\leq 0.002)</td>
<td>(\leq 0.01)</td>
</tr>
<tr>
<td>Content of inactive impurities, µg/ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>(\leq 2.0)</td>
<td>(\leq 2.0)</td>
</tr>
<tr>
<td>Mo</td>
<td>(\leq 5.0)</td>
<td></td>
</tr>
<tr>
<td>Zr</td>
<td>(\leq 5.0)</td>
<td></td>
</tr>
<tr>
<td>Radiochemical purity, %</td>
<td>(\geq 99.0)</td>
<td>(\geq 95.0)</td>
</tr>
<tr>
<td>pH</td>
<td>(4.0 - 7.0)</td>
<td>(4.0 - 8.0)</td>
</tr>
<tr>
<td>Sterility</td>
<td>Sterile</td>
<td>Sterile</td>
</tr>
<tr>
<td>Pyrogenity</td>
<td>Pyrogen free</td>
<td>Pyrogen free</td>
</tr>
</tbody>
</table>

Generator activity is up to 1 Ci at the end of production (1 day after irradiation) with natural molybdenum irradiated 6 days in \(1 \cdot 10^{14} \text{n/(cm}^2\text{s)}\)

18 GBq (0.5 Ci) \(^{99m}\text{Tc}\) guaranteed on first day after delivery to clinic

85% of \(^{99m}\text{Tc}\) activity in first 5 ml of eluate \(\rightarrow 3 \text{ GBq/ml}\) in clinic

Construction of GMP production facility to be completed in 2013 (50 gen-s/lot)
LSA \((n,\gamma)\) Mo-99 - from local to global supply

Local/regional production:
- Dozens of Curies
- Proven quality and reliability
- Specific activity is not so important
- Natural molybdenum suitable – cheap and easily available (solvent extraction, gel, ion exchange)

Critical issues for international supply:
- Thousands of Curies
- Reliability of supply
- Market - distribution chain and regulatory approvals
- Transportation container (large volume) / logistics
- Economics is strongly dependent on specific activity
- Enriched Mo-98
  - supply source
  - recovery – technology, logistics, approvals
Why Coalition?

• Possibility to resolve all “critical issues”
• Large joint production capacity
• Diversified and robust supply network
• More interest from potential customers
• More interest from potential partners
• More efficient joint R&D
EARRC – status of $^{99}\text{Mo}/^{99m}\text{Tc}$ production

• Existing regular production

✓ WWR-SM (Tashkent, Uzbekistan)
  Enriched Mo-98, alumina column generator

✓ WWR-K (Almaty, Kazakhstan)
  Natural Mo, gel generator

• Experiments and calculations

✓ LVR-15 (Řež, Czech Republic)
✓ WWR-M (Kiev, Ukraine)
✓ BRR (Budapest, Hungary)
✓ TRIGA (Pitesti, Romania)

→ Different results, strongly depending on specific irradiation conditions (target size and design, neutron spectrum)
Irradiation capacity estimate

With the existing spectrum in the available irradiation position, each reactor can produce

- using natural Mo
  - (as-irradiated) 2000 Ci/week with ~ 1 Ci/g
  - (6-day pre-calibrated) 440 Ci/week with ~0.22 Ci/g;
- using enriched $^{98}\text{Mo}$ ~ 4 times more.

6 reactors – 6 times more (>2500 6-day Ci/week with natural Mo-98).

Optimization of irradiation conditions may increase the specific activity.
Potential to increase a specific activity

Neutron spectrum in irradiation positions in WWR-K

Mo-98 n capture resonance areas

Neutron spectrum in irradiation positions in WWR-K
Transportation efficiency estimate for LSA Mo-99

Specific Mo-99 activity (for natural molybdenum target):

- at the end of irradiation: 1.1 Ci/g
- at shipment (one day after end of irradiation): 0.86 Ci/g
- 6 day pre-calibrated: 0.19 Ci/g

Useable volume of transport container: \(\approx 500 \text{ cm}^3\)

<table>
<thead>
<tr>
<th></th>
<th>Molybdate solution</th>
<th>MoO₃ powder</th>
<th>Sintered MoO₃ pellet</th>
<th>Metal Mo pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo density in the shipped material, g Mo/cm³</td>
<td>0.2</td>
<td>1</td>
<td>2.5</td>
<td>10</td>
</tr>
<tr>
<td>Packing density in transport container, %</td>
<td>100</td>
<td>100</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Mo-99 activity in the container at shipment, Ci:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>actual activity</td>
<td>86</td>
<td>430</td>
<td>860</td>
<td>3400</td>
</tr>
<tr>
<td>6 day precalibrated</td>
<td>19</td>
<td>95</td>
<td>190</td>
<td>750</td>
</tr>
</tbody>
</table>
Findings from transportation efficiency estimate

- For large quantities (hundreds of Curies) transportation of liquid LSA Mo-99 solution is not feasible
- Metal target is preferable for transportation, but even low density MoO$_3$ powder traditionally used in various (n,γ) technologies gives about 100 Ci (6 day) in one container (500 cm$^3$)
- Solid form requires material dissolution at customer’s facility
  - Material and geometry should fit the specific customer’s technology
  - Target material and geometry to be defined by customer
Transportation containers

- For LSA material, large volume container is needed, licensed for Mo-99 in solid form

<table>
<thead>
<tr>
<th>OPTIONS</th>
<th>UK-80</th>
<th>MIDUS</th>
<th>GANUK-GA-01</th>
<th>TRUPAC-3200-W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity volume, cm(^3)</td>
<td>1889</td>
<td>760</td>
<td>487</td>
<td>790</td>
</tr>
</tbody>
</table>

- Transport optimization program is underway
Potential customers

• Not producers of chromatographic generators
• Not traditional radiopharmacies
• But the new establishments/projects developing technologies for production and/or use of non-fission, both reactor and accelerator-based, Mo-99

OECD-NEA: Reserve production capacity should be sourced…

The White House: Preferentially procuring, through certain U.S. government entities, Mo-99-based products produced without the use of HEU, whenever they are available…

After transportation container is certified,

EARRC is a readily available and reliable source of non-HEU Mo-99 for those who pursue technologies based on low specific activity Mo-99 … and a reserve production capacity