Medical Isotope Production in Liquid-Fluoride Reactors

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Flibe Energy was formed in order to develop liquid-fluoride reactor technology and to supply the world with affordable and sustainable energy, water and fuel.
FLUORIDE FUEL FOR A MOLTEN SALT REACTOR

$^7\text{LiF} - \text{BeF}_2 - ^{233}\text{UF}_4$
The Molten-Salt Reactor Experiment was an experimental reactor system that demonstrated key technologies.
Fissile elements

Control and adjust the concentration of U

Fission gases

Xe is a strong neutron absorber

Metal particles

Noble plate out on the vessel wall

Dissolves fission products

Lanthanides are strong neutron absorbers
Lanthanide Fission Products
<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
<th>Mass Number</th>
<th>Electron Configuration</th>
<th>Atomic Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niobium</td>
<td>92</td>
<td>92.90638</td>
<td>[Kr]4d⁴5s²</td>
<td>92.7589</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>42</td>
<td>95.94</td>
<td>[Kr]4d⁵5s²</td>
<td>95.7092</td>
</tr>
<tr>
<td>Technetium</td>
<td>43</td>
<td>98</td>
<td>[Kr]4d⁵5s²</td>
<td>98.728</td>
</tr>
</tbody>
</table>

Note: The table includes the electron configuration, atomic weight, and atomic number for each element.
Figure 5.1. Comparison of the measured to theoretical amounts of noble metals on the primary heat exchanger.
THE MIGRATION OF A CLASS OF FISSION PRODUCTS (NOBLE METALS) IN THE MOLTEN-SALT REACTOR EXPERIMENT

R. J. Kedl
Fig. 11.7. Compartment model for noble-metal fission transport in MSRE.
Addressing Molten Salt Contamination
Salt Purification by NF3 Fluorination

Nitrogen trifluoride (NF3) could be used to purify salts from any oxide or sulfide contamination as well as to remove noble metals. NF3 is much less aggressive towards container materials.

\[
\begin{align*}
3\text{BeO} + 2\text{NF}_3 & \rightarrow 3\text{BeF}_2 + \text{N}_2 + 1.5\text{O}_2 \\
3\text{Li}_2\text{O} + 2\text{NF}_3 & \rightarrow 6\text{LiF} + \text{N}_2 + 1.5\text{O}_2 \\
\text{Mo} + 2\text{NF}_3 & \rightarrow \text{MoF}_6 + \text{N}_2 \\
\text{Tc} + 2\text{NF}_3 & \rightarrow \text{TcF}_6 + \text{N}_2
\end{align*}
\]
Molybdenum-99 is a fairly common fission product product.

About 5% of the fission reactions in uranium-233 generate molybdenum-99.
Vastly Simplified 99Mo Production in LFTR

1. Natural thorium
2. LFTR blanket salt: No enrichment losses, no fabrication losses
3. Thorium converted to U-233
4. LFTR fuel salt: over time, all U-233 fissions; ~5% of fission generates Mo-99; ~25% lost to decay before removal from reactor
5. Fission product extraction and separation
6. Delivery to technetium generator factory
Fluoride salts are safe and versatile

Chemically stable in air and water

Unpressurized liquid with 1000°C range of temperature
Large power reactors make vast amounts of Mo-99...which unfortunately is utterly inaccessible... due to high pressure operation and the use of solid nuclear fuel.
Unique Technology Intersection

Power-generating reactors
- LWR, HWR, HTGR, LMFBR, FHR, GFR

Medical-isotope-generating reactors
- NRU, HFR, OPAL, BR2, Safari, TRIGA, SHINE, TRIUMF

LFTR
North American Competition for $^{99}$Mo Production

- $^{235}$U ($n, f$) $^{99}$Mo in solid uranium targets (LEU or HEU)
  - NorthWest Medical Isotopes, Corvallis, Oregon
  - Coqui Pharmaceuticals, Coral Gables, Florida
  - Eden Radioisotopes, Albuquerque, New Mexico
  - General Atomics, San Diego, California
- $^{98}$Mo ($n, \gamma$) $^{99}$Mo in solid molybdenum targets
  - NorthStar Medical Isotopes, Madison, Wisconsin
  - GE Hitachi Nuclear Energy, Wilmington, North Carolina
- $^3$H ($d, n$) $^4$He in subcritical aqueous uranium solution
  - SHINE Medical Technologies, Monona, Wisconsin
- $^{100}$Mo ($e^- \rightarrow \gamma, n$) $^{99}$Mo in solid molybdenum target
  - NorthStar Medical Isotopes, Madison, Wisconsin
- $^{100}$Mo ($p, 2n$) $^{99m}$Tc in solid molybdenum target
  - TRIUMF, Vancouver, British Columbia
Small MSR would produce globally-significant 99Mo
100 MWt Facility for Assured Power Generation
Program on Technology Innovation: Technology Assessment of a Molten Salt Reactor Design
The Liquid-Fluoride Thorium Reactor (LFTR)
My Own Little Medical Radioisotope Experience