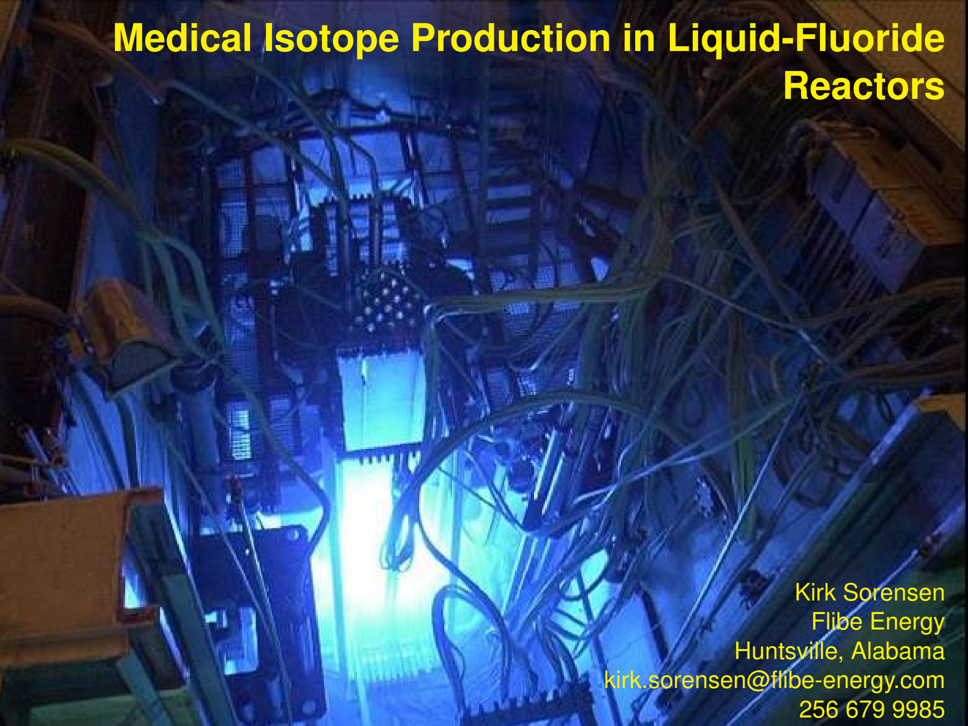
# Medical Isotope Production in Liquid-Fluoride Reactors



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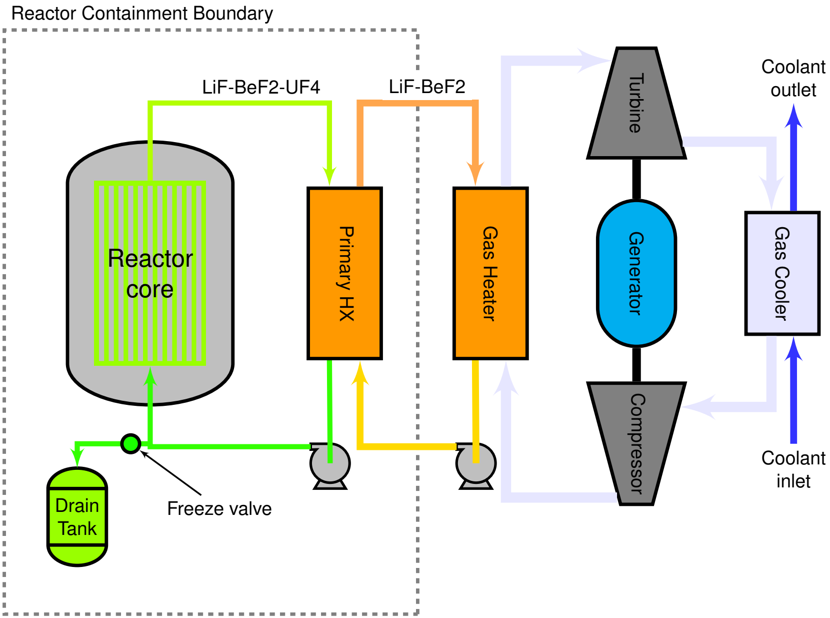
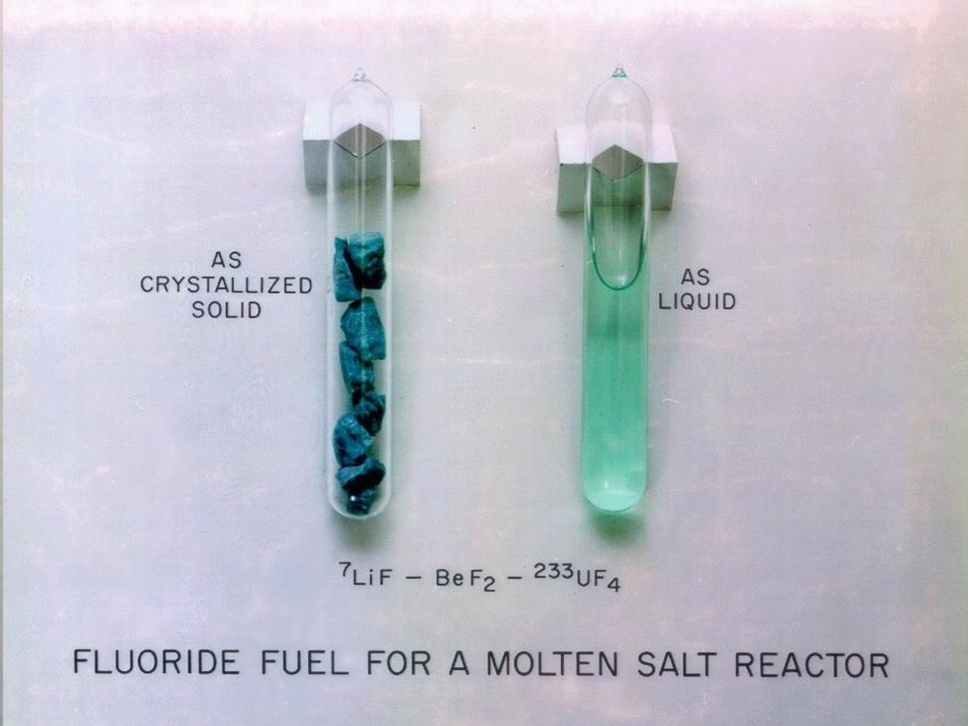
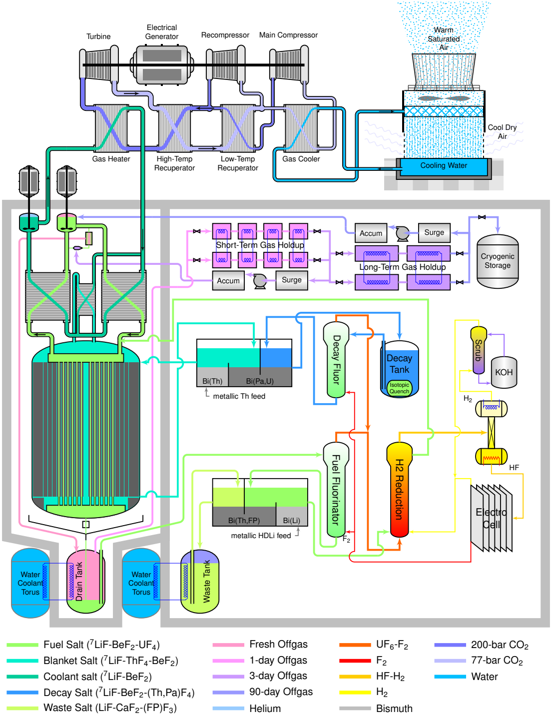
Flibe
ENERGY

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.

# Liquid-Fluoride Reactor Concept

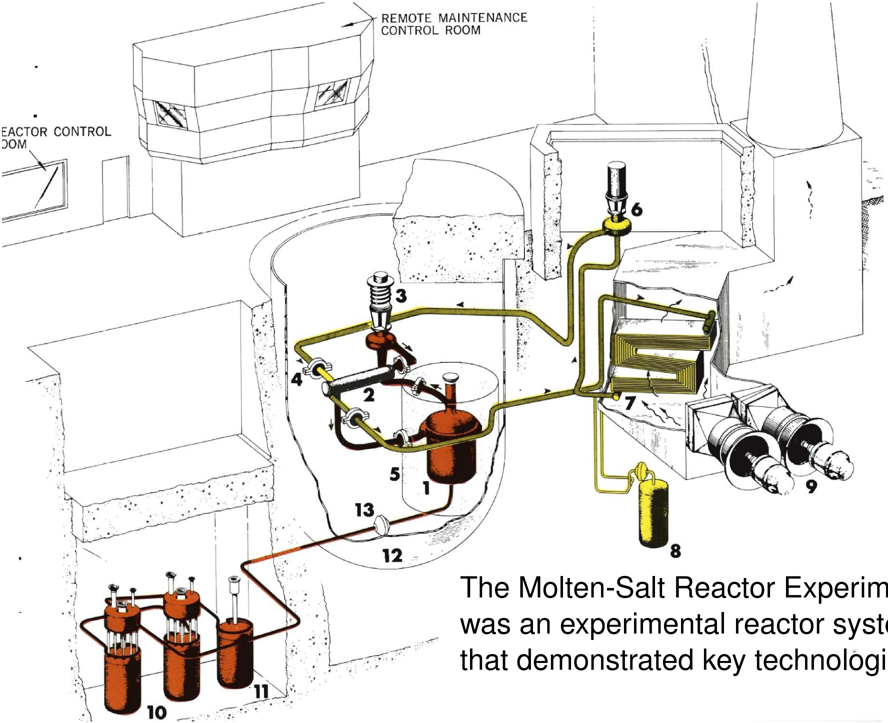



AS
CRYSTALLIZED
SOLID
AS
LIQUID
$^7LiF - BeF_2 - ^{233}UF_4$
FLUORIDE FUEL FOR A MOLTEN SALT REACTOR

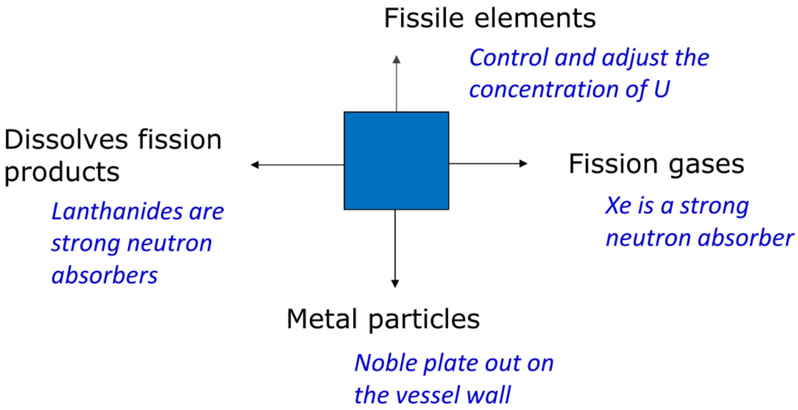


Turbine
Electrical Generator
Recompressor
Main Compressor
Warm Saturated Air
Cool Dry Air
Cooling Water
Gas Heater
High-Temp Recuperator
Low-Temp Recuperator
Gas Cooler
Accum
Surge
Short-Term Gas Holdup
Long-Term Gas Holdup
Cryogenic Storage
Accum
Surge
Decay Fluor
Decay Tank
Isotopic Quench
Bi(Th)
Bi(Pa,U)
metallic Th feed
Scrub
KOH
$H_2$
HF
Fuel Fluorinator
H2 Reduction
Electro Cell
Bi(Th,FP)
Bi(Li)
metallic HDLi feed
$F_2$
Water Coolant Torus
Drain Tank
Water Coolant Torus
Waste Tank
Fuel Salt ($^7LiF-BeF_2-UF_4$)
Blanket Salt ($^7LiF-ThF_4-BeF_2$)
Coolant salt ($^7LiF-BeF_2$)
Decay Salt ($^7LiF-BeF_2-(Th,Pa)F_4$)
Waste Salt ($LiF-CaF_2-(FP)F_3$)
Fresh Offgas
1-day Offgas
3-day Offgas
90-day Offgas
Helium
$UF_6-F_2$
$F_2$
$HF-H_2$
$H_2$
Bismuth
200-bar $CO_2$
77-bar $CO_2$
Water

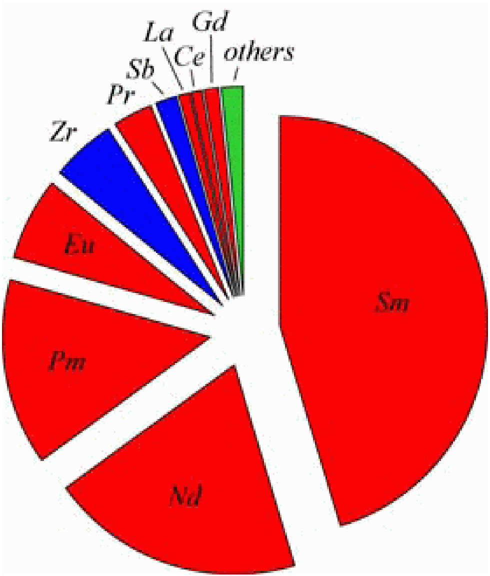

UNITED STATES AIR FORCE
Convair
Crusader
XB-36H
U.S. AIR FORCE
15712



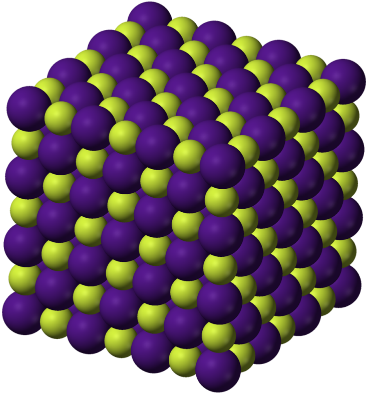

The Molten-Salt Reactor Experiment was an experimental reactor system that demonstrated key technologies.

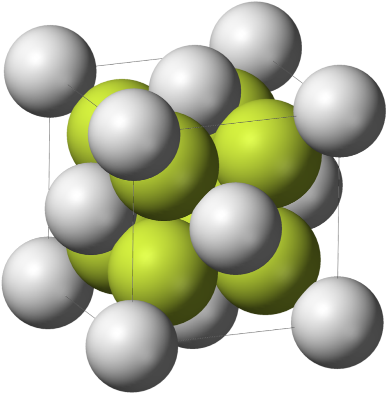

Fissile elements
Control and adjust the concentration of U
Dissolves fission products
Lanthanides are strong neutron absorbers
Fission gases
Xe is a strong neutron absorber
Metal particles
Noble plate out on the vessel wall

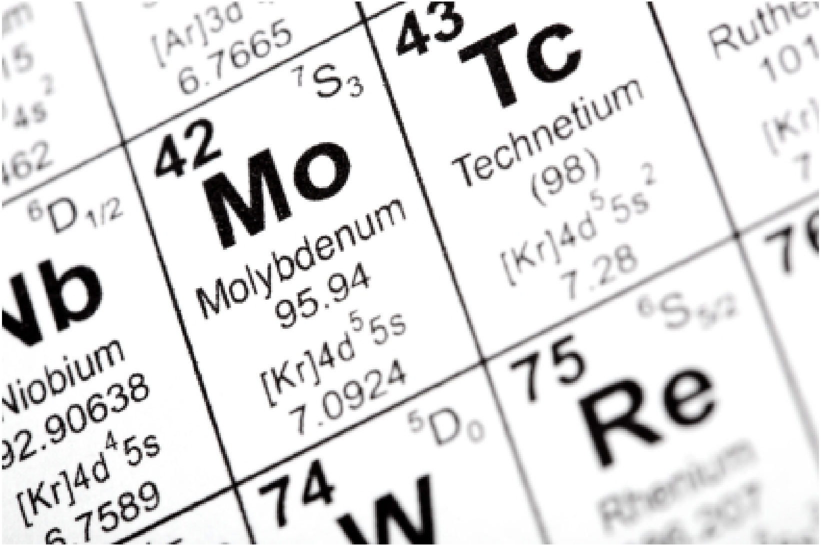
# Lanthanide Fission Products



# Alkali- and Alkaline-Earth Fission Product Fluorides






[Ar]3d
6.7665
$^7S_3$
43
Tc
Technetium
(98)
[Kr]$4d^5 5s^2$
7.28
$^6D_{1/2}$
42
Mo
Molybdenum
95.94
[Kr]$4d^5 5s$
7.0924
Nb
Niobium
92.90638
[Kr]$4d^4 5s$
6.7589
$^6S_{5/2}$
75
Re
$^5D_0$
74
W

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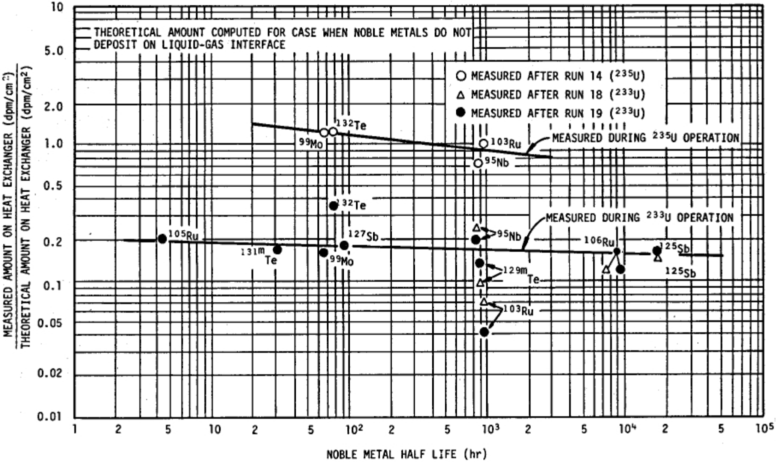


FIGURE 5.1. COMPARISON OF THE MEASURED TO THEORETICAL AMOUNTS OF NOBLE METALS ON THE PRIMARY HEAT EXCHANGER

ORNL-TM-3884

# THE MIGRATION OF A CLASS OF FISSION PRODUCTS (NOBLE METALS) IN THE MOLTEN-SALT REACTOR EXPERIMENT

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OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

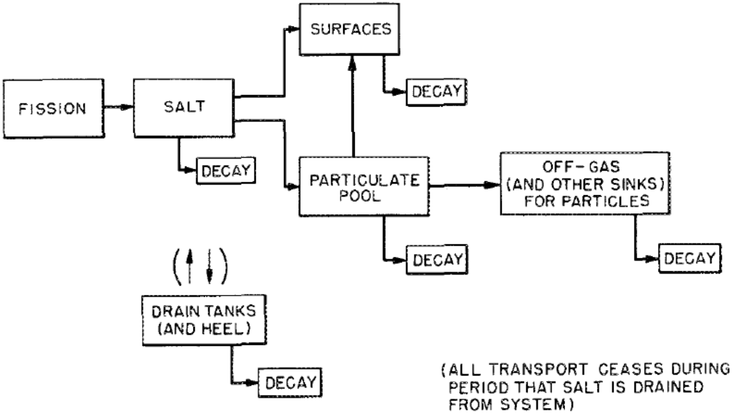
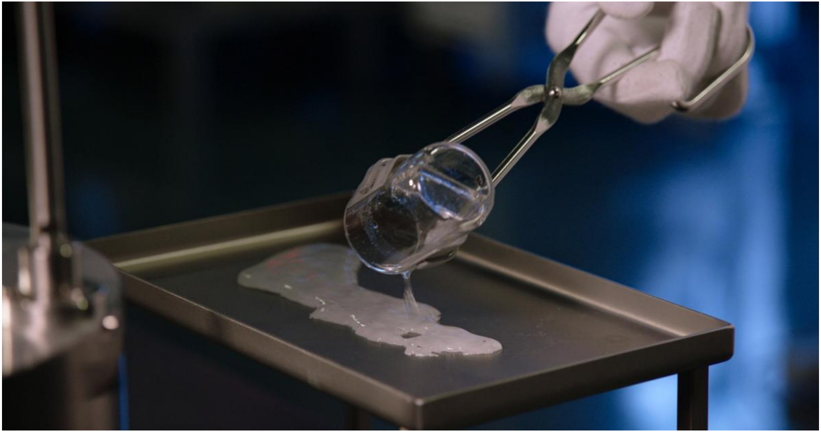



Fig. 11.7. Compartment model for noble-metal fission transport in MSRE.

# Addressing Molten Salt Contamination

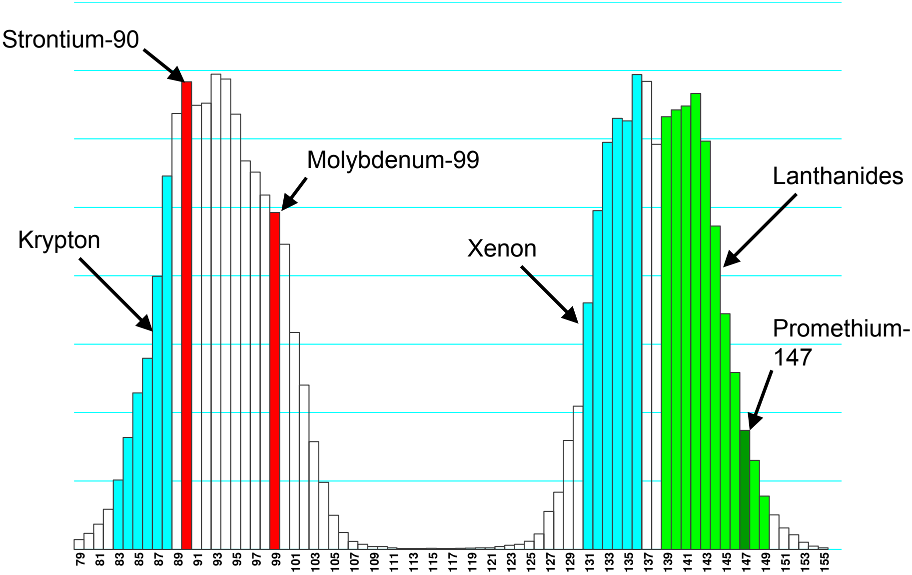


# Salt Purification by NF3 Fluorination

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.

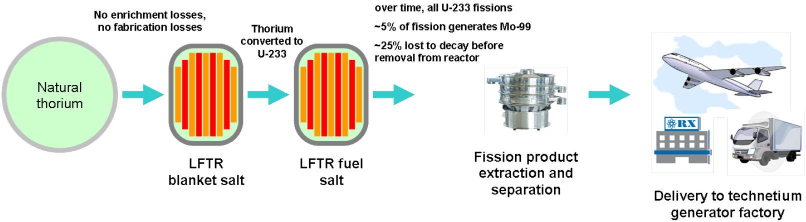
$$3BeO + 2NF_3 \rightarrow 3BeF_2 + N_2 + 1.5O_2$$
$$3Li_2O + 2NF_3 \rightarrow 6LiF + N_2 + 1.5O_2$$
$$Mo + 2NF_3 \rightarrow MoF_6 + N_2$$
$$Tc + 2NF_3 \rightarrow TcF_6 + N_2$$

# Molybdenum-99 is a fairly common fission product

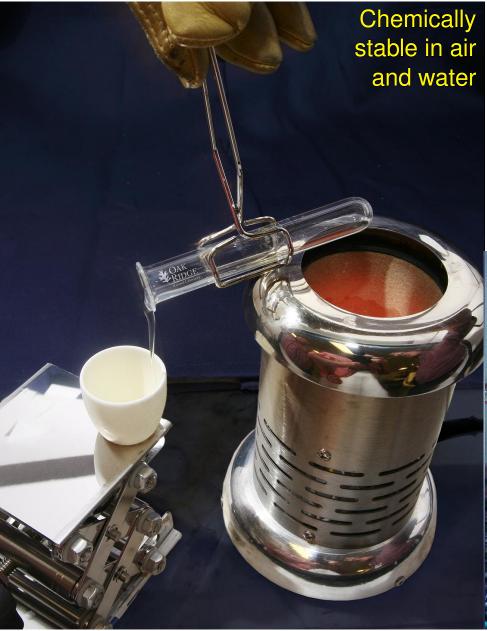


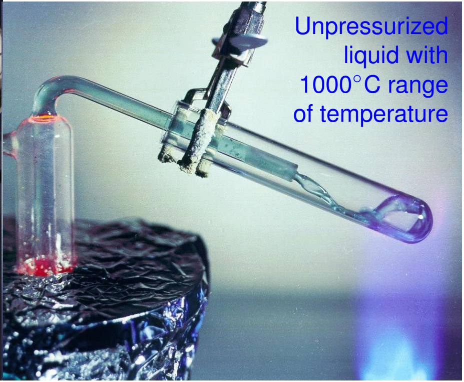

About 5% of the fission reactions in uranium-233 generate molybdenum-99.

# Vastly Simplified 99Mo Production in LFTR



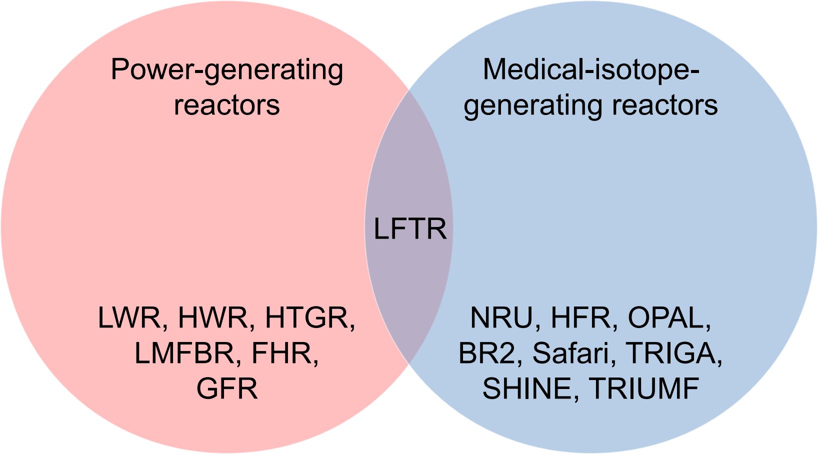
# Fluoride salts are safe and versatile



# Large power reactors make vast amounts of Mo-99

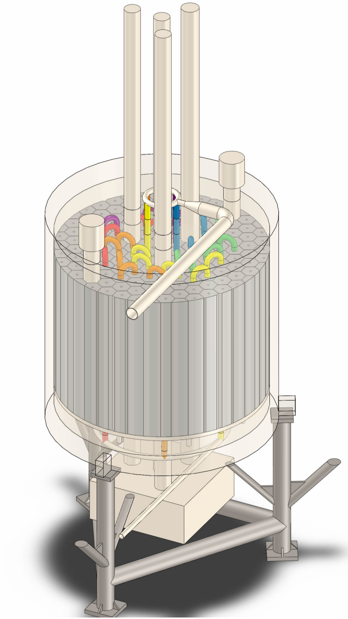

# Unique Technology Intersection



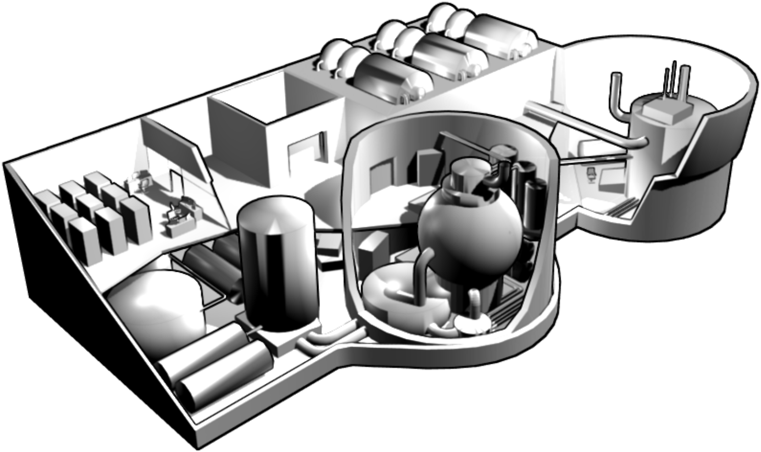
# North American Competition for $^{99}$Mo Production

- $^{235}$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 $(e^- \to \gamma, n)$ $^{99}$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

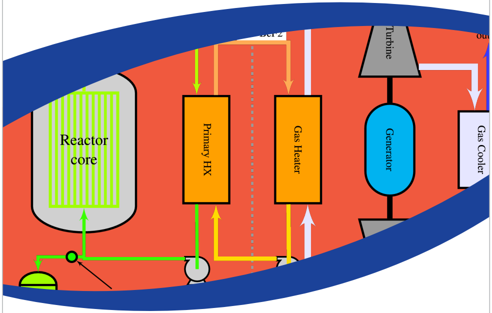


ELECTRIC POWER RESEARCH INSTITUTE

2015 TECHNICAL REPORT

# Program on Technology Innovation: Technology Assessment of a Molten Salt Reactor Design

## The Liquid-Fluoride Thorium Reactor (LFTR)



# My Own Little Medical Radioisotope Experience