Overview of LFTR: Materials and Components

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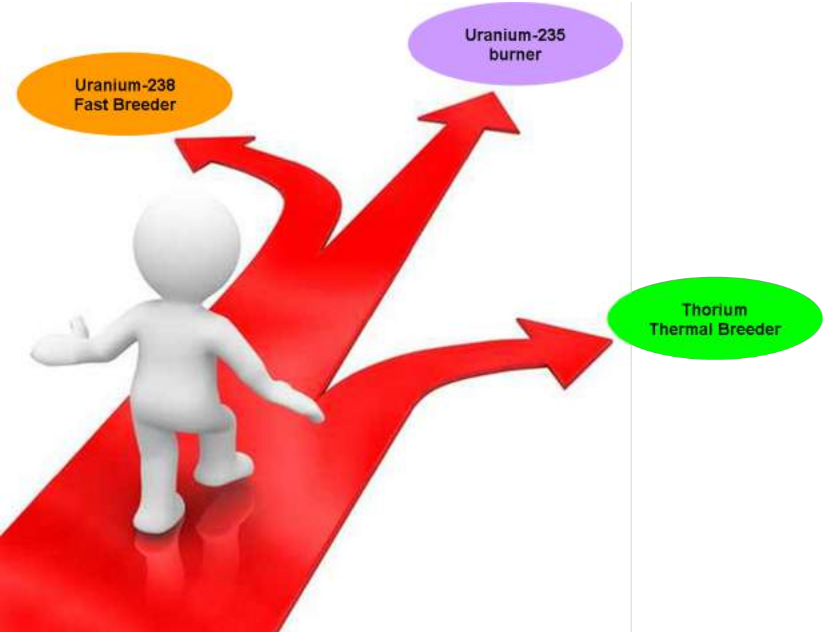
Three Nuclear Options

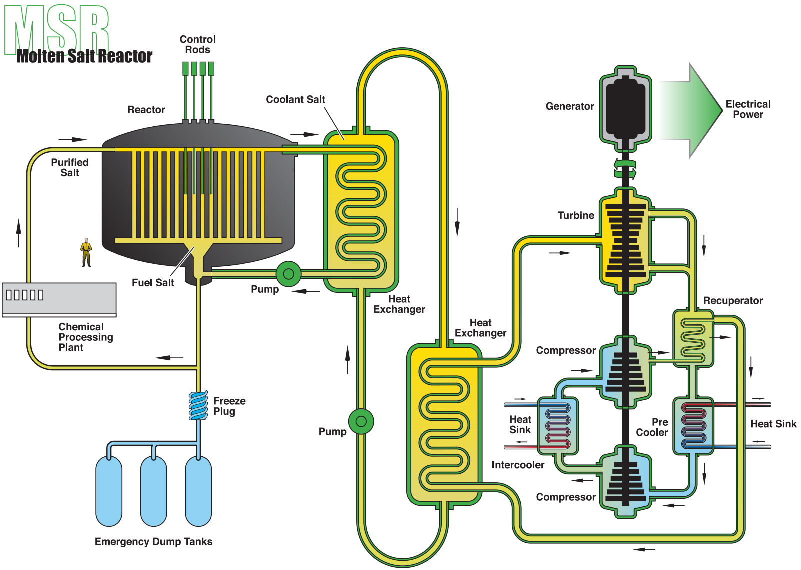


Flibe ENERGY

The Thorium Reactor Company

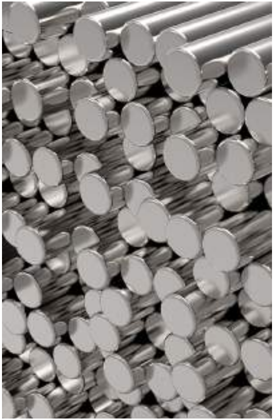
Located in Huntsville, Alabama

Gen-4 Molten Salt Reactor Concept



The MSRE successfully operated for over 20,000 hours, from 1965-1969.

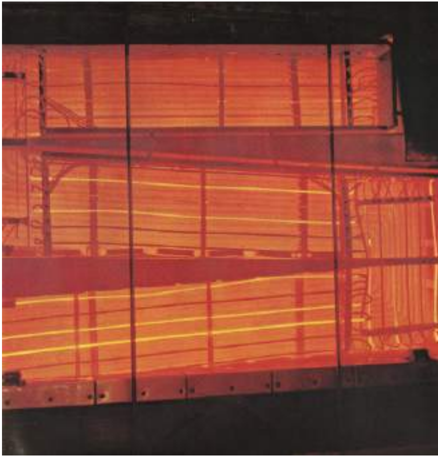
MSR Material Compatibility



At ORNL, scientists and engineers made excellent materials decisions, culminating in the MSRE's demonstration of materials compatibility in a neutron environment between FLiBe salts, graphite, and Hastelloy N.

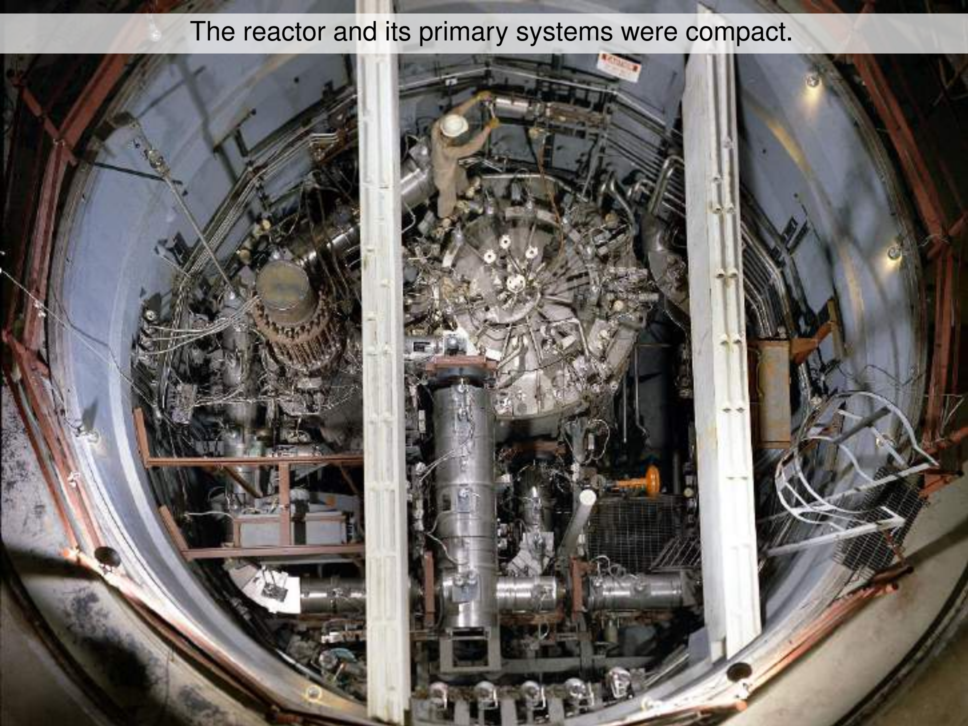
The feasibility of a nuclear reactor that used LiF-BeF_2 fluoride salt as a coolant with UF_4 as a nuclear fuel was demonstrated in the United States in 1965.

The nuclear fuel heated a coolant salt in a simple heat exchanger.



The reactor had the potential for high performance because it could generate high temperatures at low pressure in a compact unit.

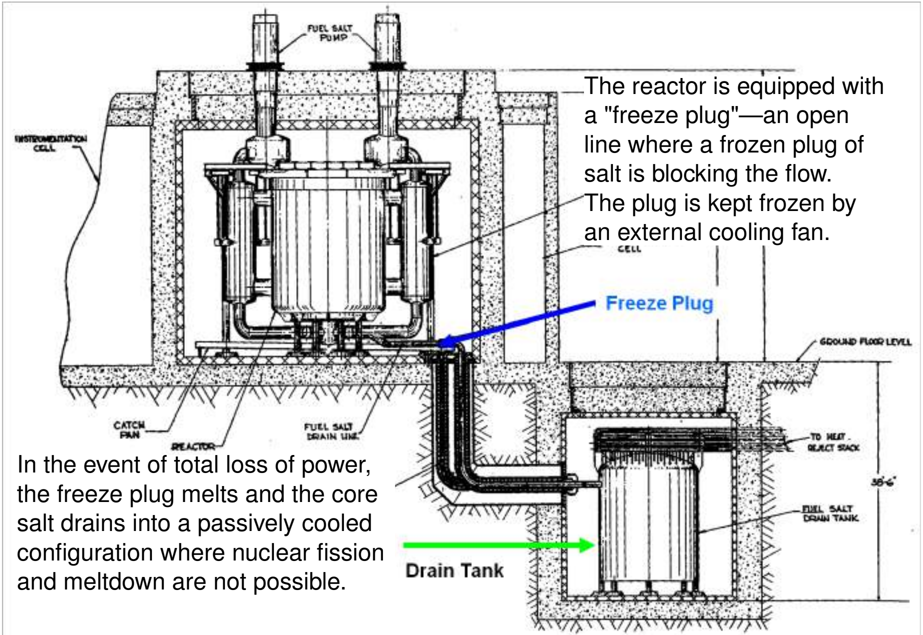
The reactor and its primary systems were compact.



Operators enjoyed the fact that the reactor was inherently safe and easy to control.

Successful operation for over 20,000 hours was demonstrated.

Liquid fuels enhance safety options



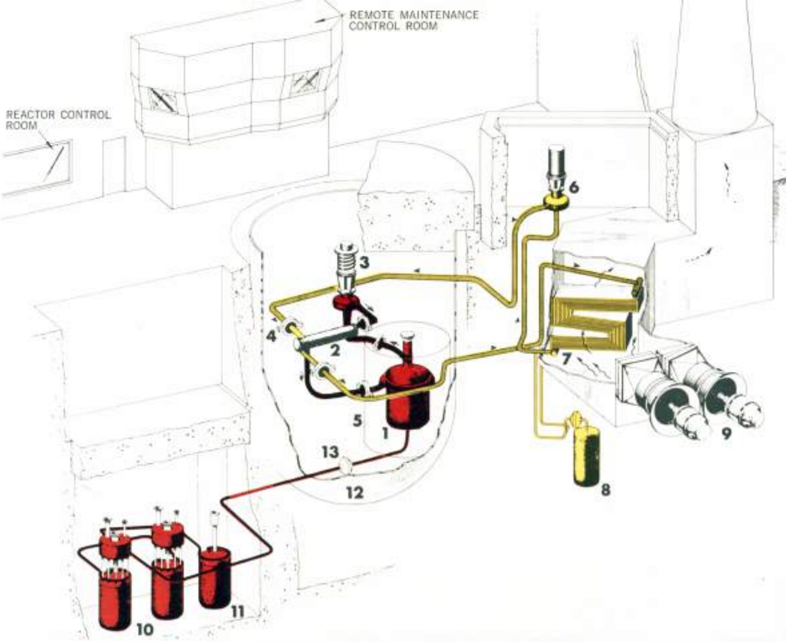
The reactor is equipped with a "freeze plug"—an open line where a frozen plug of salt is blocking the flow. The plug is kept frozen by an external cooling fan.

In the event of total loss of power, the freeze plug melts and the core salt drains into a passively cooled configuration where nuclear fission and meltdown are not possible.

Drain tank

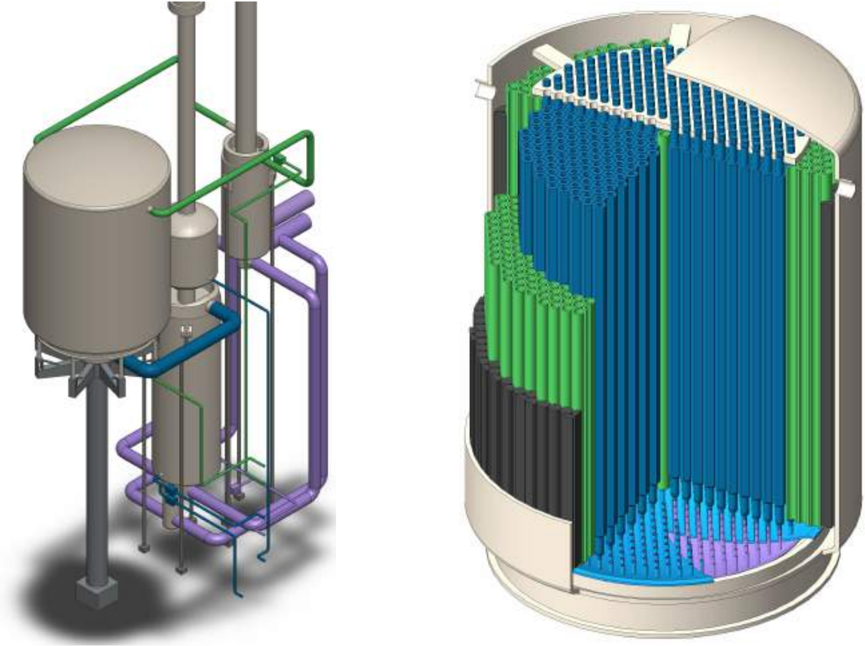
MSRE salt drain tank design shown,

- Design constraints
  - fuel salt drain tank must be designed to be prepared to receive the entire inventory of hot fuel salt immediately after shutdown
  - insignificant neutron flux, strongly subcritical due to no graphite
- Non-emergency use parameters
  - to help keep drain tank at operating temperature, plan to utilize volume for decay of noble gases
  - cooling requirement for noble gas decay is similar to fission-product decay heating immediately after shutdown
  - small amount of fuel salt held up in drain tank for decay, prior to transfer to chemical processing system
- Drain tank represents the "emergency core cooling system"

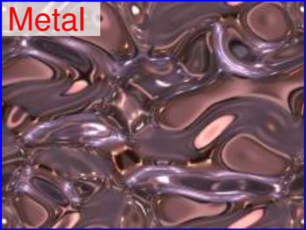


1. Reactor Vessel, 2. Heat Exchanger, 3. Fuel Pump, 4. Freeze Flange, 5. Thermal Shield, 6. Coolant Pump, 7. Radiator, 8. Coolant Drain Tank, 9. Fans, 10. Fuel Drain Tanks, 11. Flush Tank, 12. Containment Vessel, 13. Freeze Valve.

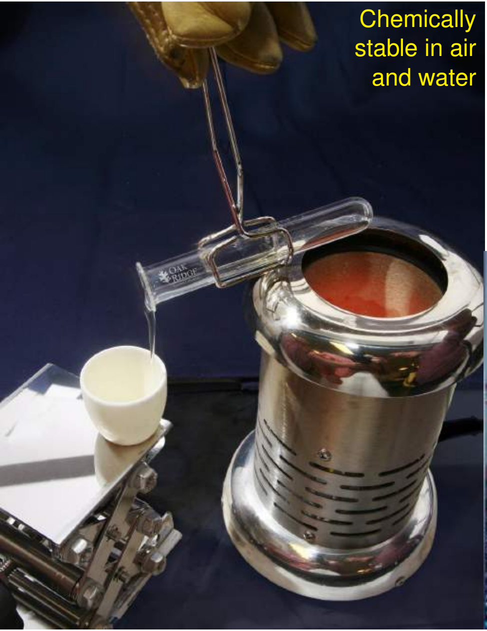
Two-Fluid MSBR Reactor Module and Core Cutaway

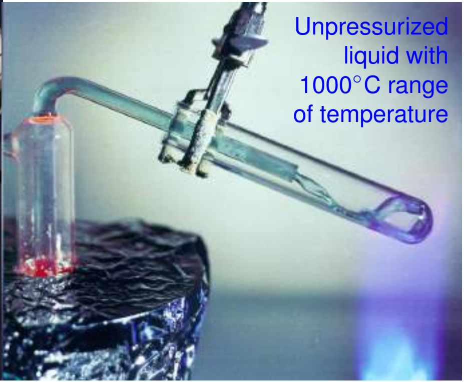


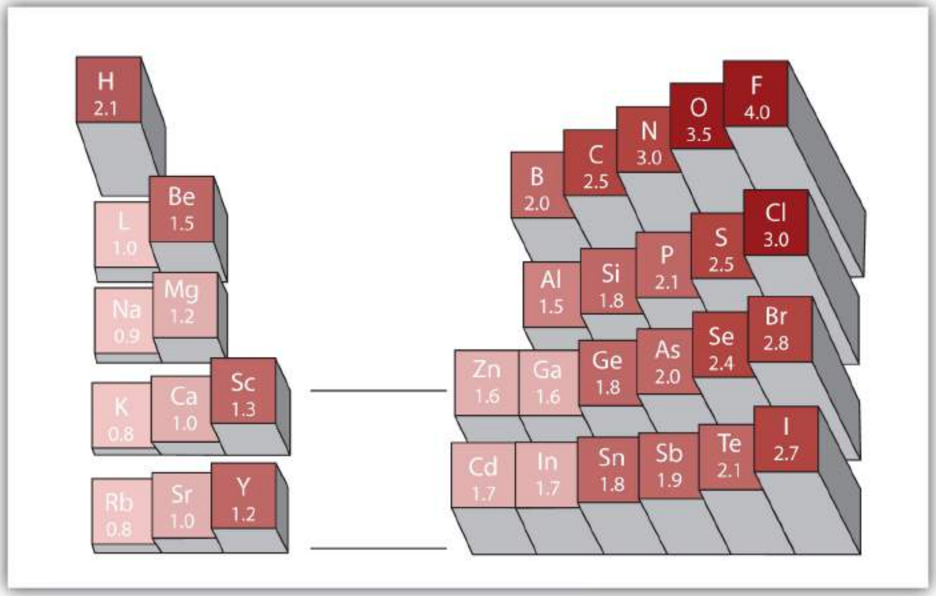
Coolant Choices for a Nuclear Reactor

	atmospheric pressure operation	high-pressure operation
moderate temperature (250-450°C)	Metal 	Water 
high temperature (650-900°C)	Salt 	Gas 

Fluoride salts are safe and versatile

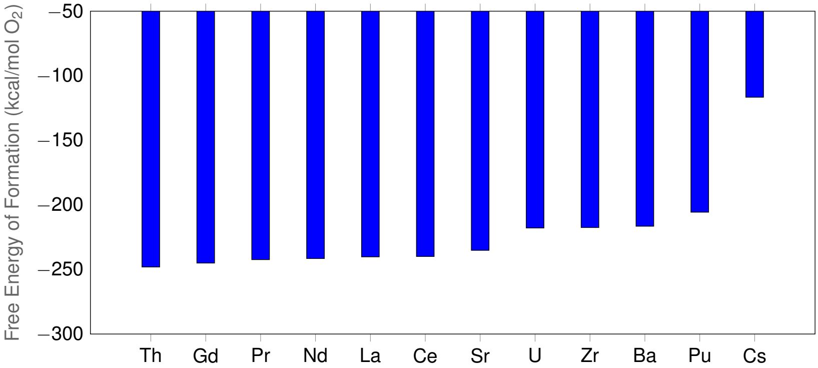




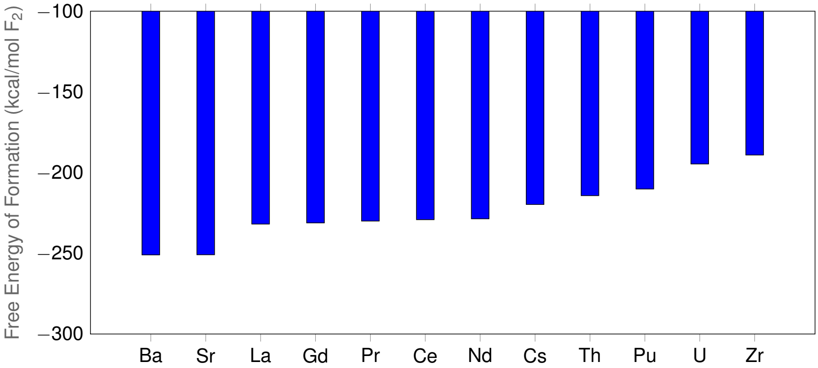


Fluorine has extremely high electronegativity, allowing fluoride salts to retain most fission products.

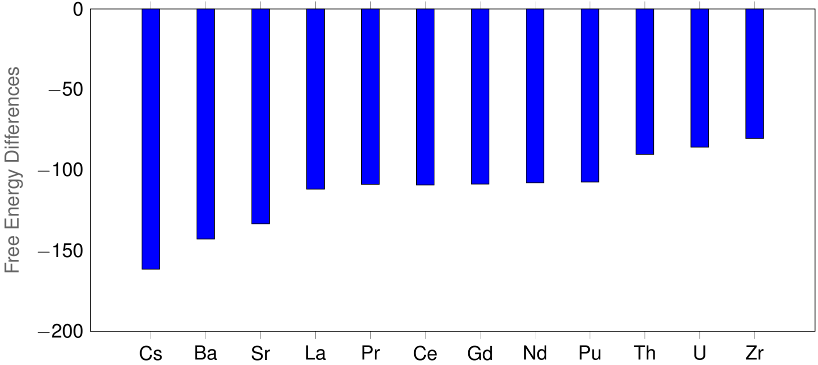
Free energies of formation of oxides at 1000 K



Free energies of formation of fluorides at 1000 K

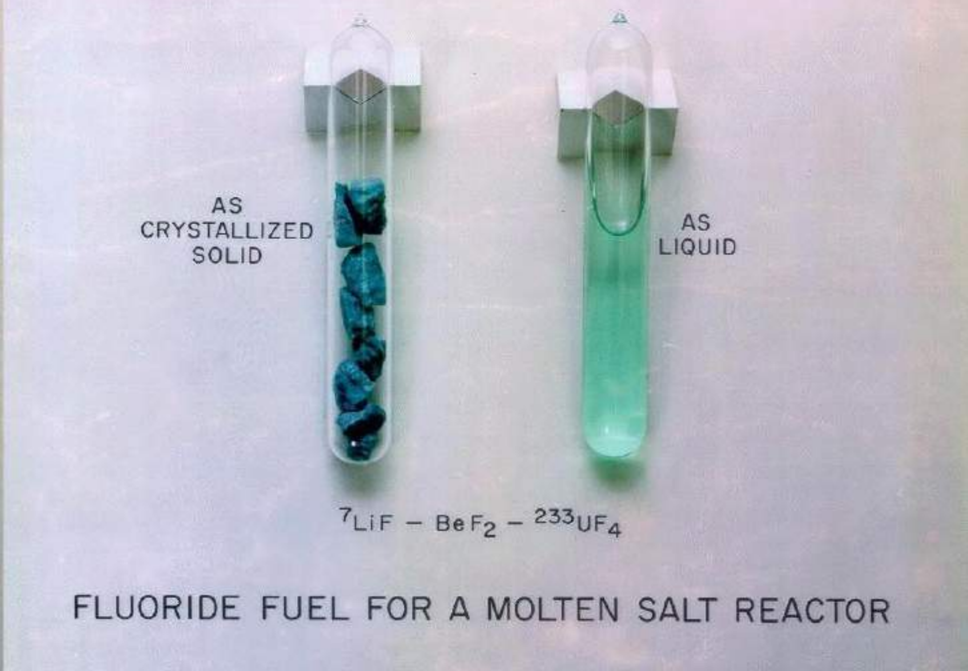


Free energy differences (oxides/fluorides) at 1000 K



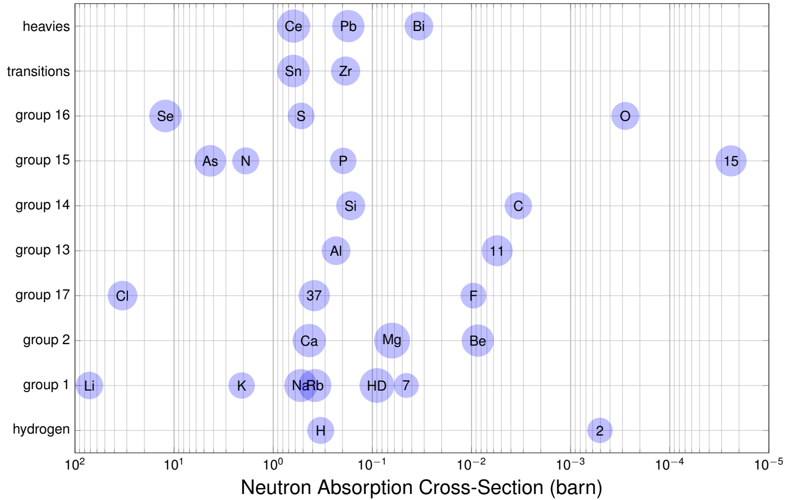
In fluoride form, all actinides and alkaline fission products – most notably cesium and strontium – remain in fluoride salt form in the presence of air, and don't form volatile species. **In molten salts, the first barrier to fission product release is the chemical form of the fuel salt, rather than the mechanical integrity of the fuel pin.**

LiF-BeF_2 fluoride salt is an excellent carrier for uranium (UF_4) nuclear fuel.



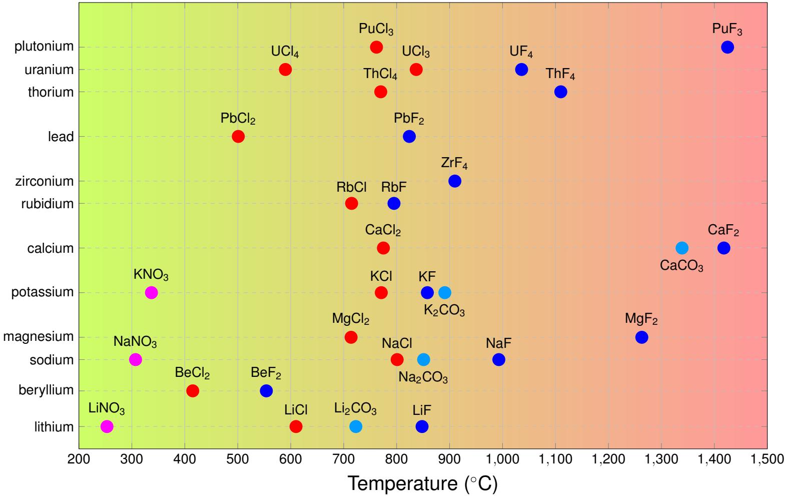
Element Absorption Cross-Sections

Only a few elements have neutron absorption cross sections low enough to be of interest, along with suitable chemistries.

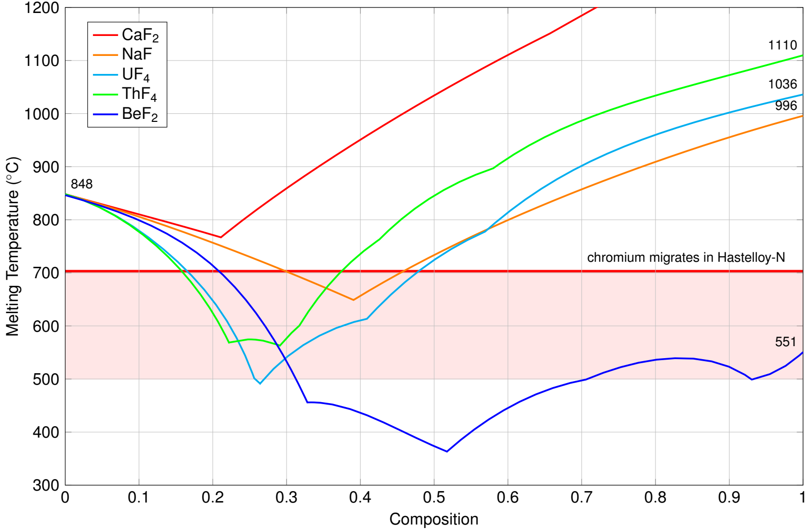


Melting Temperatures of Salt Constituents

Individual fluoride salt components tend to have melting points too high (>600°C) to be useful in practical reactors.



Lithium Fluoride Melting Temperatures



Neutron reactions in LiF-BeF2 salt

$$^{7}_{3}\mathrm{Li} \xrightarrow[0.045\ \mathrm{b}]{n,\gamma} {}^{8}_{3}\mathrm{Li} \xrightarrow[0.842\ \mathrm{sec}]{\beta^-} {}^{8}_{4}\mathrm{Be} \xrightarrow[67\ \mathrm{asec}]{\alpha} {}^{4}_{2}\mathrm{He}$$

$$^{9}_{4}\mathrm{Be} \xrightarrow[0.160\ \mathrm{b}]{n',2n} {}^{8}_{4}\mathrm{Be} \xrightarrow[67\ \mathrm{asec}]{\alpha} {}^{4}_{2}\mathrm{He}$$

$$^{19}_{9}\mathrm{F} \xrightarrow[0.009\ \mathrm{b}]{n,\gamma} {}^{20}_{9}\mathrm{F} \xrightarrow[1.1\ \mathrm{sec}]{\beta^-} {}^{20}_{10}\mathrm{Ne}$$

$$^{9}_{4}\mathrm{Be} \xrightarrow[0.009\ \mathrm{b}]{n,\gamma} {}^{10}_{4}\mathrm{Be} \xrightarrow[1.6\ \mathrm{Myr}]{\beta^-} {}^{10}_{5}\mathrm{B}$$

$$^{6}_{3}\mathrm{Li} \xrightarrow[941\ \mathrm{b}]{n,\alpha} {}^{3}_{1}\mathrm{H} \xrightarrow[12.3\ \mathrm{yr}]{\beta^-} {}^{3}_{2}\mathrm{He}$$

$$^{7}_{3}\mathrm{Li} \xrightarrow[68\ \mu\mathrm{b}]{n',2n} {}^{6}_{3}\mathrm{Li} \xrightarrow[941\ \mathrm{b}]{n,\alpha} {}^{3}_{1}\mathrm{H} \xrightarrow[12.3\ \mathrm{yr}]{\beta^-} {}^{3}_{2}\mathrm{He}$$

$$^{9}_{4}\mathrm{Be} \xrightarrow[0.051\ \mathrm{b}]{n',\alpha} {}^{6}_{3}\mathrm{Li} \xrightarrow[941\ \mathrm{b}]{n,\alpha} {}^{3}_{1}\mathrm{H} \xrightarrow[12.3\ \mathrm{yr}]{\beta^-} {}^{3}_{2}\mathrm{He}$$

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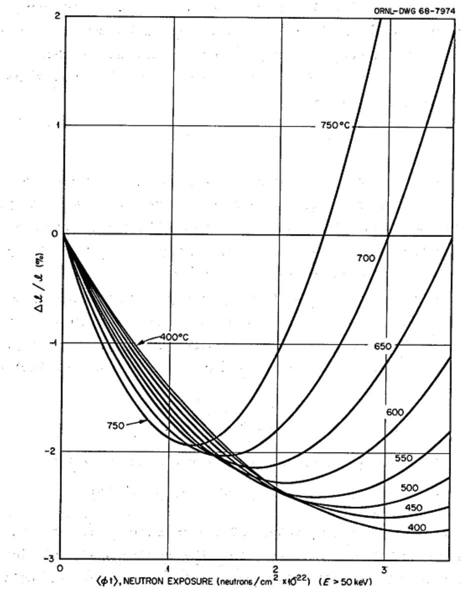
Residual lithium-6 forms tritium in a neutron flux, and even if it could be eliminated, fast neutron reactions in lithium-7 and beryllium recreate lithium-6. Tritium shall be captured to the maximum degree practical at each stage in the reactor system, with the summation of these capture techniques minimizing tritium release to a degree that is acceptable from a licensing basis.

Graphite undergoes dimensional change

Under sustained irradiation, the lattice structure of graphite changes. First it contracts, then it expands steadily. This effect is enhanced by an increase in temperature. Ultimately, it leads to a need for graphite replacement.



To meet the challenges of liquid-fluoride salt mixtures, metallurgists at Oak Ridge developed a high-nickel alloy they called "INOR-8", but which is now more commonly known as "Hastelloy-N".

Structures Fabricated from INOR-8

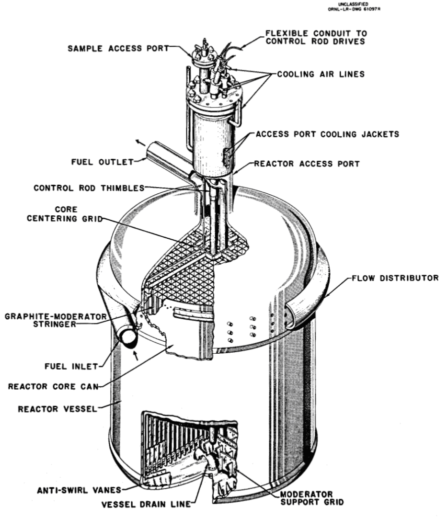
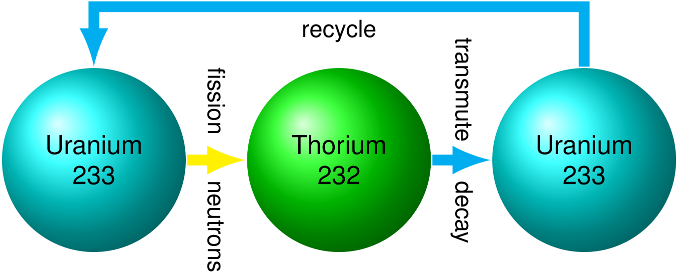


Fig. 2.2. Reactor Vessel.

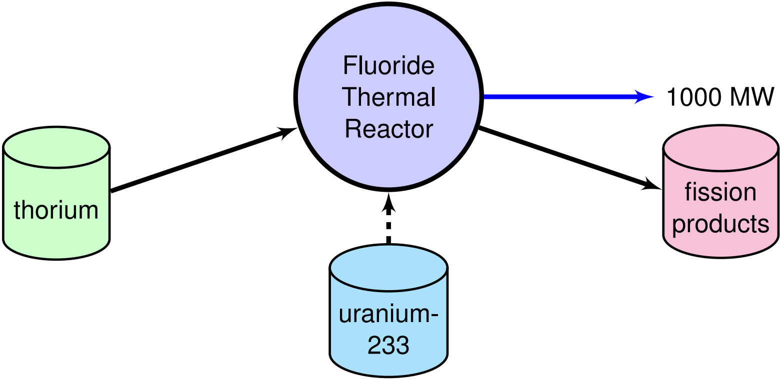
From this material they fabricated all the structures that would be in contact with the fluoride salt mixture.

Sustainable Use of Thorium is the Ultimate Goal

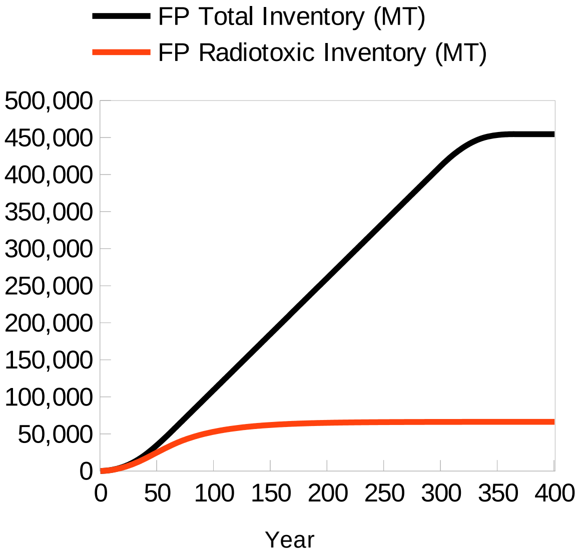


Uranium-233 alone produces sufficient neutrons per thermal neutron to match or exceed its consumption. In this way, U-233 is the "catalyst" to sustainable energy production from thorium and can almost eliminate transuranic production.

Fluoride Thermal Reactor Material Flows



Potential Steady-State Waste Profile



Conclusions

- Flibe Energy is developing the Liquid Fluoride Thorium Reactor (LFTR)
- Two-fluid MSR with chemical processing, off-gas treatment and sequestration, and sCO2 PCS
- FLiBe salts (HD Li), graphite channels also moderate, and thin-walled Hastelloy N vessel and piping for low pressures and corrosion
- Minimal stored energy or driving forces for radionuclide release, inherent safety features
- Fuel cycle potential: no mining, no enrichment, minimal fissile inventories, minimal fissile transportation, no excess fissile production, minimal fission product inventory during operation, steady-state and manageable waste stream