Materials Behavior and Aging in MSR's

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GEDEON-PRACTIS WORKSHOP
THE MOLTEN SALT REACTORS (MSR)
PYROCHEMISTRY AND FUEL CYCLES FOR INNOVATIVE NUCLEAR SYSTEMS
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Major Materials in MSR's

Not included in discussion are other components such as pumps, valves, sampling devices.

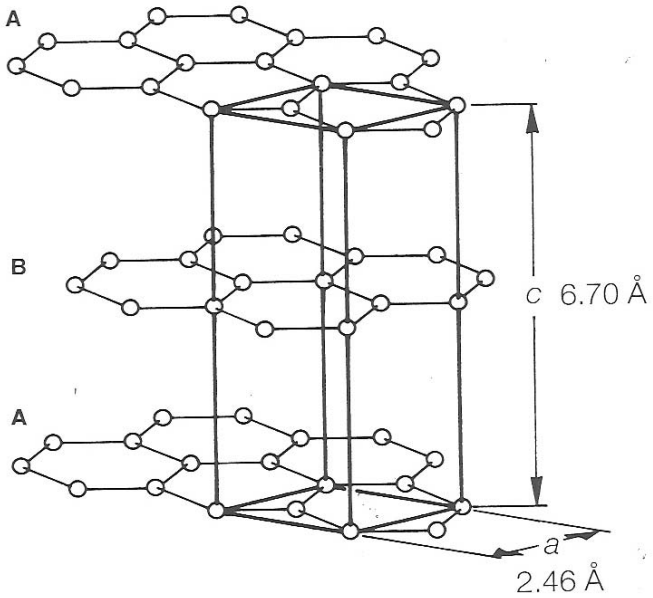
- **Moderator Graphite** **(T.D. Burchell)**
  - **In the MSRE CGB grade with pores sealed by gas phase carbon deposition**
- **Metal Container** **(M. L. Grossbeck)**
  - **Nickel based alloy commonly used**
- **Molten Salt** **(D.F. Williams/ L.M.Toth)**
  - **Various mixtures considered**

Radiation Damage in Graphite is Understood, but not Solved

(1) T.D. Burchell, Carbon Materials for Advanced Technologies, Chapter 13 “Fission Reactor Applications of Carbon” Pergamon 1999, ISBN-0-08-042683-2

(2) T.D. Burchell, “Radiation Effects in Graphite and Carbon Bases Materials” Material Research Society Bulletin, Vol. XXII (2), pp. 29-35, Feb. 1997

- **Dimensional Changes**
- **Stored Energy**
- **Reduced Conductivity**
- **Electrical Resistivity Decrease**
- **Embrittlement**

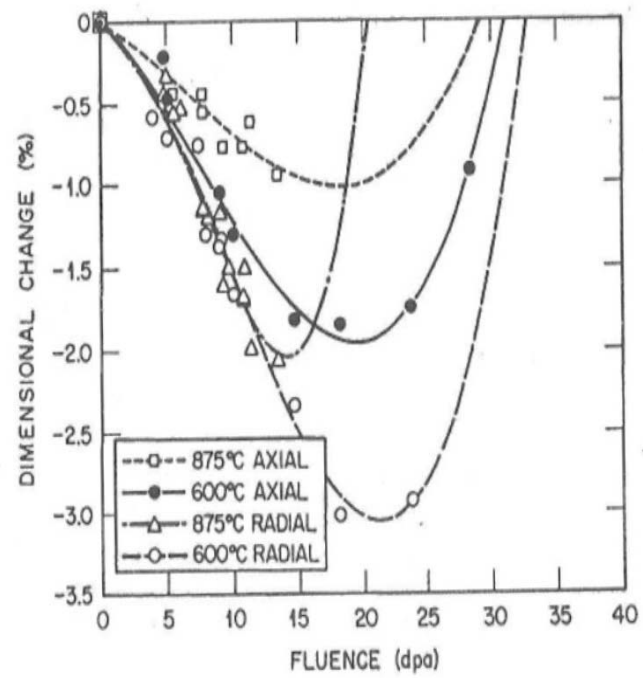


Dimensional Changes in Graphite

A startling realization as a result of laboratory studies during the time of MSRE operations

- **Greatest in crystallographic** a **axis direction**
- **Reactor systems can tolerate up to 2% dimensional change**
- **Radiation exposures of $3X10^{23}$ n/cm^2 or approx 300 dpa expected**
- **Thus, periodic replacement of graphite will be necessary**
- **Design of graphite shape helps**
- **Improved graphites show better performance, but not enough to help significantly**

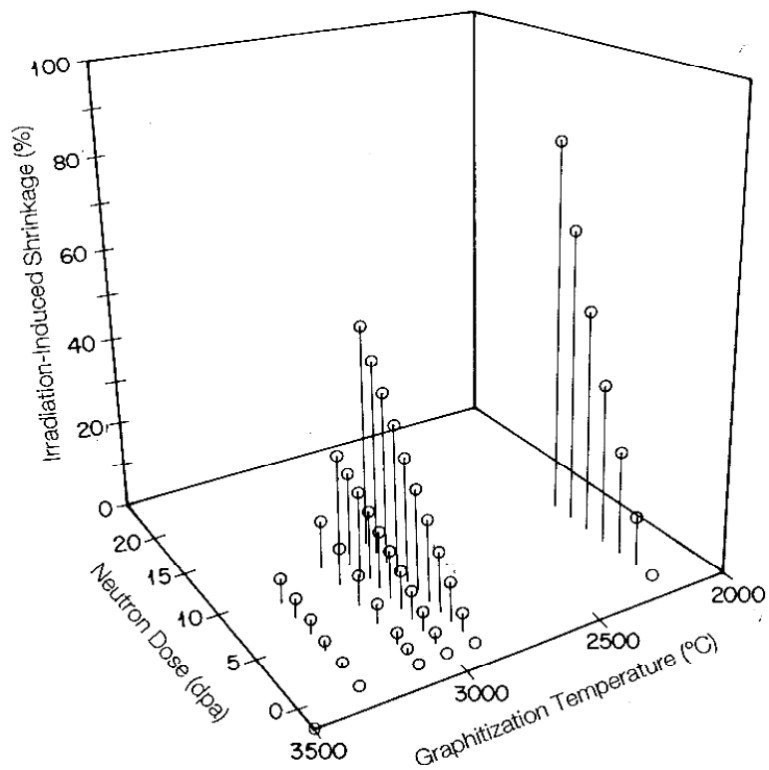
Taken from ref. 1,2



Higher Graphitization Temperature Helps Reduce Dimensional Changes

- **Crystallographic "a" direction shrinkage shown for pyrolytic graphite**
- **Shrinkage is linear with dose**
- **Magnitude decreases with increasing graphitization temperature**
- **Temperature effect due to reduced vacancy trapping sites because of induced improvements in crystal.**

Taken from ref. 1,2

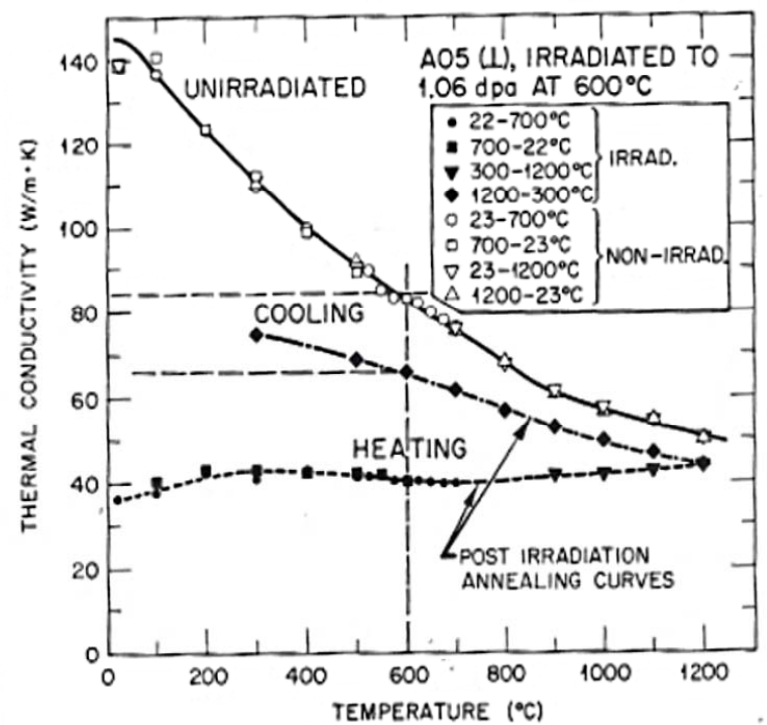


Radiation Damage Decreases Thermal Conductivity of Graphite

Taken from ref 1,2

Due to:

- **Submicroscopic interstitial clusters containing ~4 C atoms**
- **Vacant lattice sites**
- **Vacancy loops in basal plane of graphite**



Metal Containment Concerns

- Corrosion
  - Redox controlled
  - Lower Redox potential recommended
- Fission Product Effects
  - Te found to be a problem
  - Corrected by two methods
- Radiation Damage
  - Atom displacement
  - Helium production

Metal Containment is Typically Nickel-Based Alloy at Temperatures < 850° C

- Hastelloy N proved very satisfactory until Te problem
- Modified Hastelloy N reduced Te cracking and shows better radiation resistance

Hastelloy N

Element	Standard	Modified
Ni	bal	bal
Mo	16	12
Cr	7	7
Fe	4	0.5
Mn	0.5	0.2
Si	0.5	0.1
C	0.05	0.05
Ti + Nb		2
Re		0.01

Radiation Damage to Hastelloy N

- In MSRE at 650° C no swelling or hardening was observed
- Helium was formed by (n, ’) reactions of thermal neutrons with Ni and B
- Loss of ductility in tensile and creep tests at 650° C.
- Embrittlement attributed to helium gas bubbles at grain boundaries.

Alloy Development Produced Modified Hastelloy N that was more Radiation Resistant

- **Addition of Nb increased creep strength and fracture strain.**
- **Ti also proved beneficial.**
- **Overall improvement for operation at higher neutron fluxes is yet to be determined.**

Alternate Materials to Hastelloy N

- **Certain improved SS may offer enhanced radiation resistance but require more reducing conditions.**
  - **Less helium will be generated with resistant SS in fusion program containing fine dispersion of carbide particles.**
- **Refractory metals such as Mo and TZM have proved to be corrosion resistant at 1000° C**
  - **Radiation effects on these refractories must be further examined.**

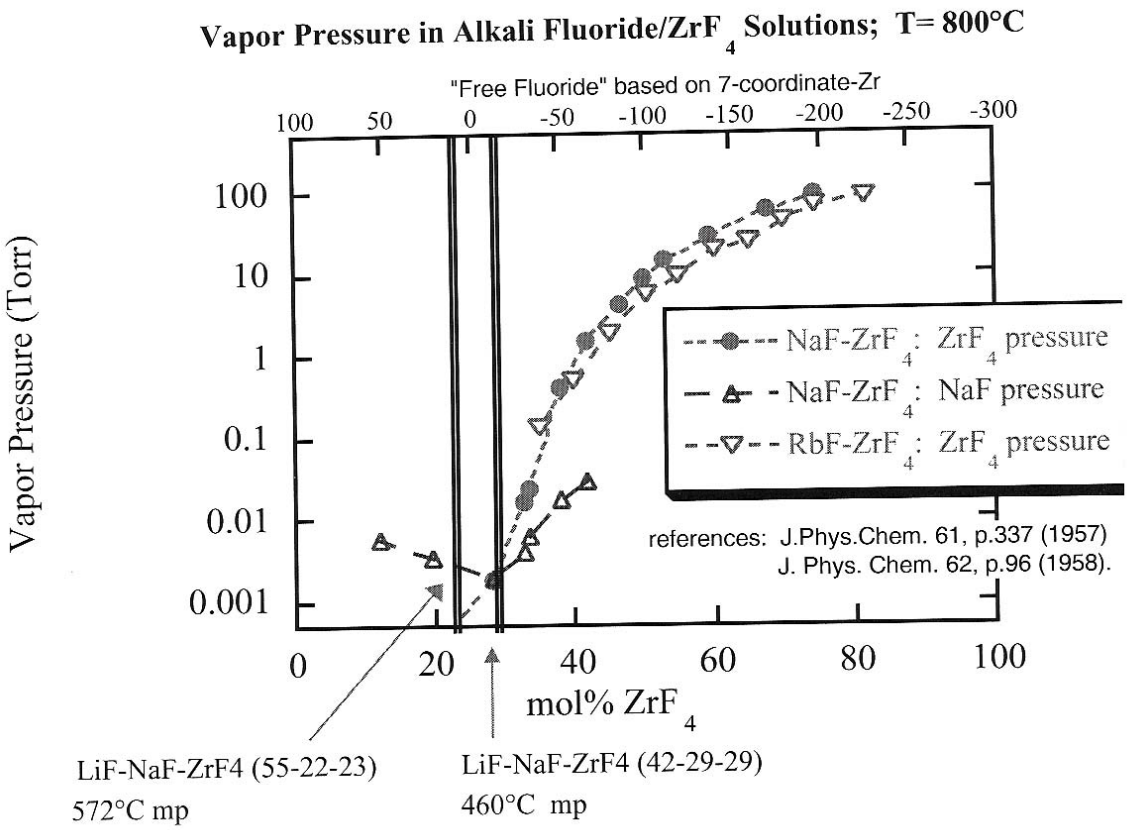
Molten Salt Selection
(When you don't want to use FLiBe)

- **FLiBe is considered best overall.**
  - Good acid/base properties
  - Low Vapor pressure
  - Small neutron cross section
  - Good redox properties
- **FLiNaK (LiF-NaF-KF[46.5-11.5-42 mol %])**
  - Better solubility properties w.r.t. fuel and fp's
  - Poorer corrosion properties

Molten Salt Selection (cont.)

- ZrF_4 rich melts
  - $NaF\text{-}ZrF_4$ eutectic at 51-49 mol % has too high a VP.
  - Addition of LiF makes melt more basic and decreases VP.
  - Processing is more complex due to easy reduction of Zr(IV).

LiF-NaF-ZrF4 (42-29-29 mol %) Solves the Vapor Pressure problem



Selection of Molten Fluoride Has Great Affect on Ease of Processing

We must, therefore, look at the entire system in selecting salt composition

- ZrF_4 -containing melts will show Zr(IV) reduction before that of the Ln-An components
- Acid-base conditions will affect metal transfer process in liquid salt/metal extractions.

Conclusions

- MSRE proved much in operating a molten fluoride reactor
- MSRE showed a number of problems, many of which have already been solved
- Operation at higher power levels introduces many problems not encountered or addressed by MSRE