LS-VHTR Overview: Factors Impacting Refueling

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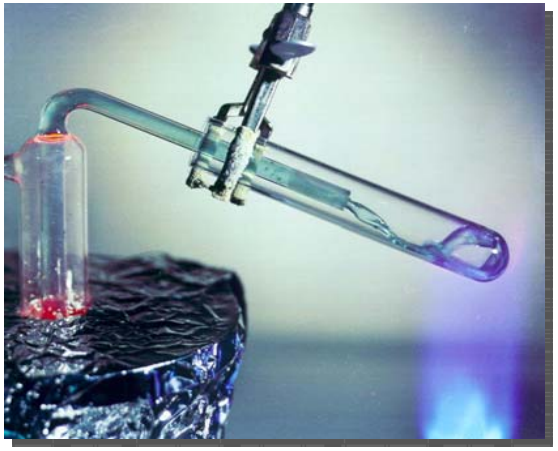

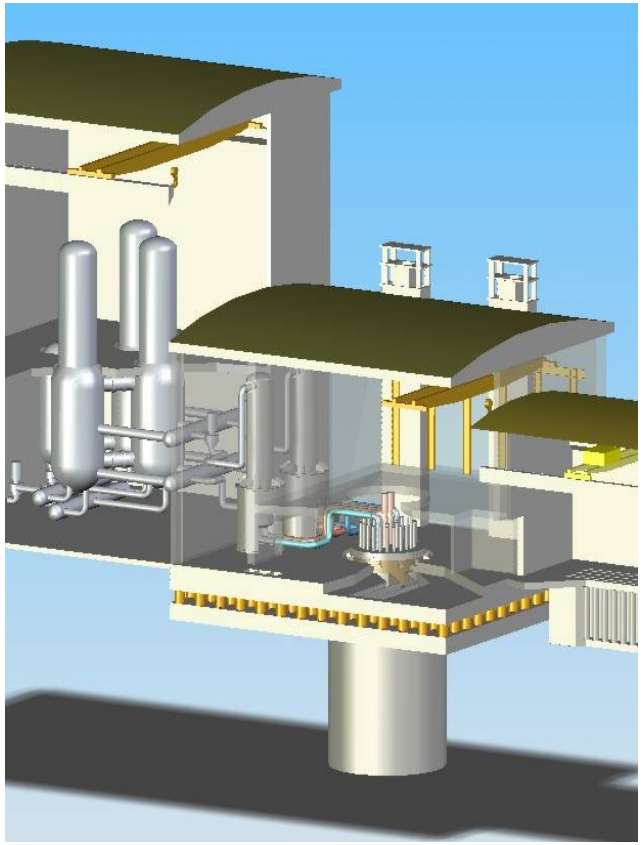

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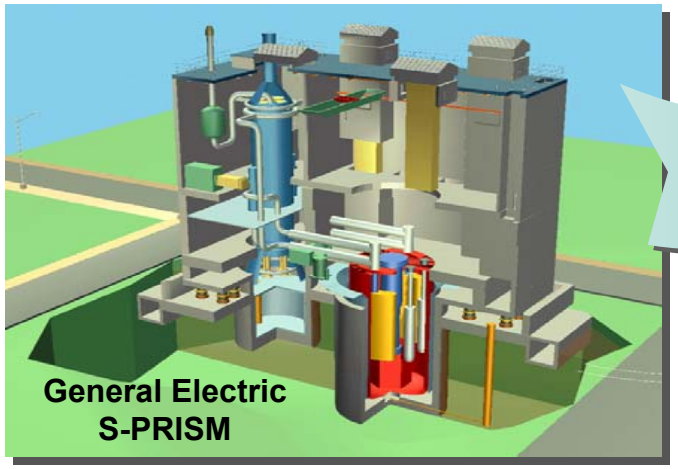
Basis for Refueling Studies

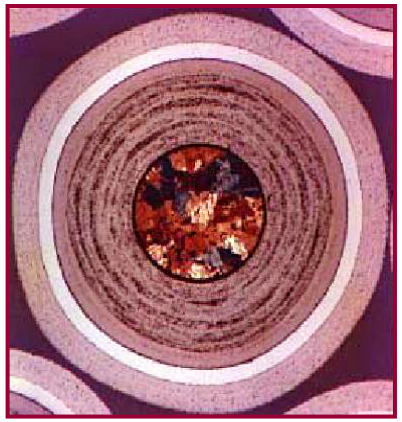
- **Use previous experience**
  - **Molten salt reactors**
  - **High-temperature reactors**
  - **Sodium-cooled reactors**
- **Adopt new technologies if it offers unique advantages (instrumentation, etc.)**
- **Understand options**

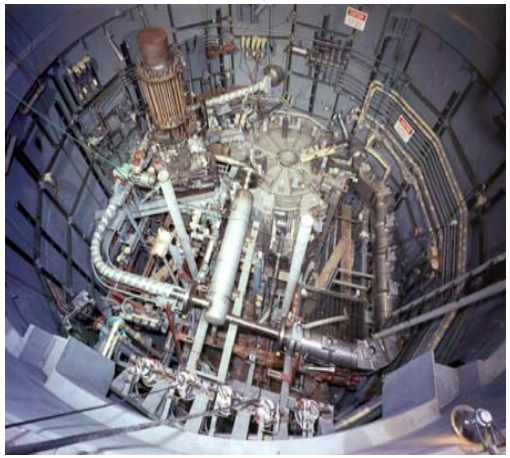
Strategies for Refueling to be Based on Experience



Sodium-Cooled Fast Reactor Plant Design and Refueling Experience

High-Temperature Reactor Core Designs and Refueling Experience





Operational Experience with Molten Salt Reactors

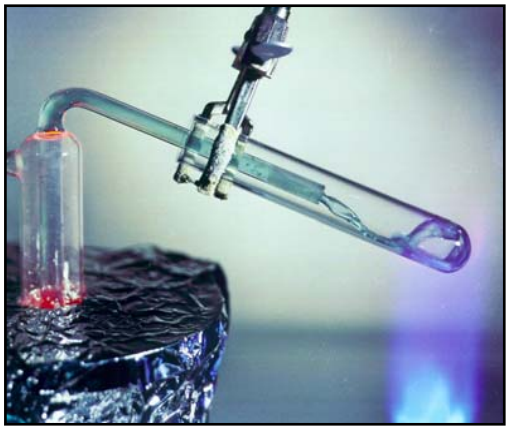
Coolant: Liquid Salt

There is Nuclear Reactor Experience with Four High-Temperature Coolants

(Lessons Learned That are Applicable to the LS-VHTR)

Fluoride Salt→

←Helium



Sodium→

←Carbon Dioxide

Liquid-Salt-Cooled Systems are Intrinsically High-Temperature Systems

- **Useful salts for nuclear applications have freezing points between 350 and 500ºC**
- **Minimum refueling temperatures from 400 to 550ºC**
- **Options to drain salt but this increases refueling times and complicates safety case**

Summary of AHTR Salt Options

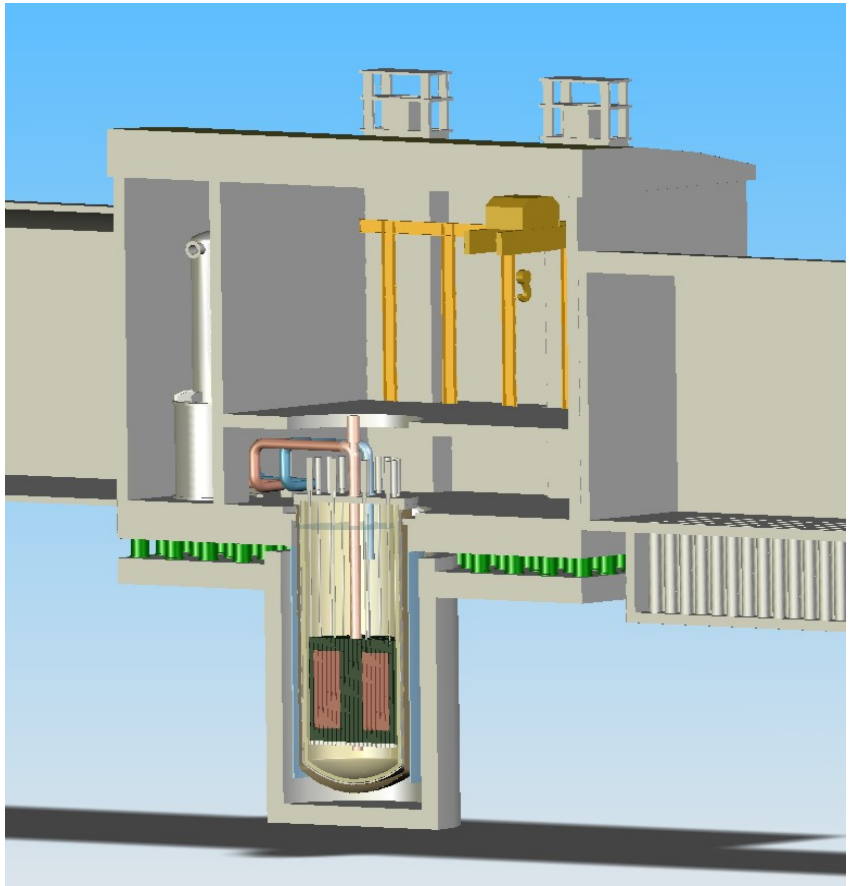
Fluoride Salt	Composition (mole %)	Melting Point (ºC)	Density (g/cm^3)	Notes
LiBe	67-33	460	1.94	Best Neutronics, Be toxicity, High Li Cost, Experience: MSRE, No gamma emitters, Low density (fuel buoyancy)
NaBe	57-43	340	2.01	Low MP, Be toxicity, Low density (fuel buoyancy)
LiNaZr	26-37-37	436	2.79	Small addition of expensive Li (2 wt %), Low toxicity
NaZr	59.5-40.5	500	3.14	Inexpensive, Low toxicity, Experience: Aircraft Nuclear Propulsion Salt
NaRbZr	33-23.5-43.5	420		Inexpensive, Max freeze protection with minimum Rb, Max Zr without high ZrF_4 vapor pressure, Neutronic questions

Implications of Liquid-Salt-Cooled Systems On Refueling

- **Refueling temperatures between 400 and 550ºC**
- **Fuel may have a lower density than the salt (salt and fuel dependent)**
  - **Similar issue in lead-cooled fast reactors**
  - **Multiple options to hold fuel in place**
    - **Ballast**
    - **Hold-down mechanisms (incorporated into many reactors)**
- **Must chose materials compatible with salts**

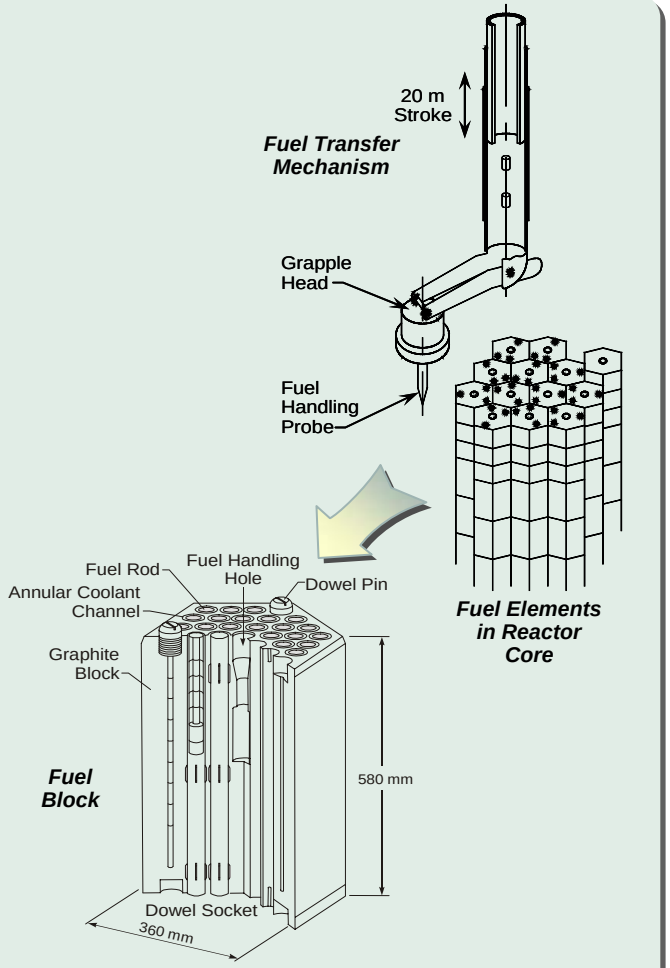
Fuel: Graphite-Matrix Coated-Particle

LS-VHTRs and High-Temperature Gas-Cooled Reactors Use the Same Fuels

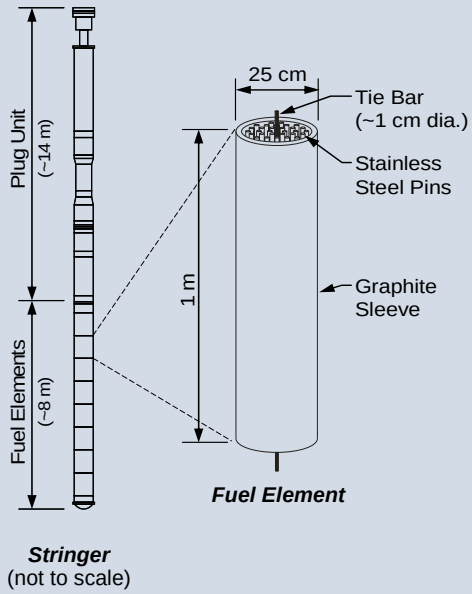


- **Three classes of gas-cooled reactor fuels and core designs**
  - **Prismatic fuel**
  - **Pebble-bed fuel**
  - **Pin/Assembly fuel**
- **LS-VHTR**
  - **Same three fuel and core design options**
  - **Three strategies for refueling**

High-Temperature Core Configurations



Prismatic Fuel Block



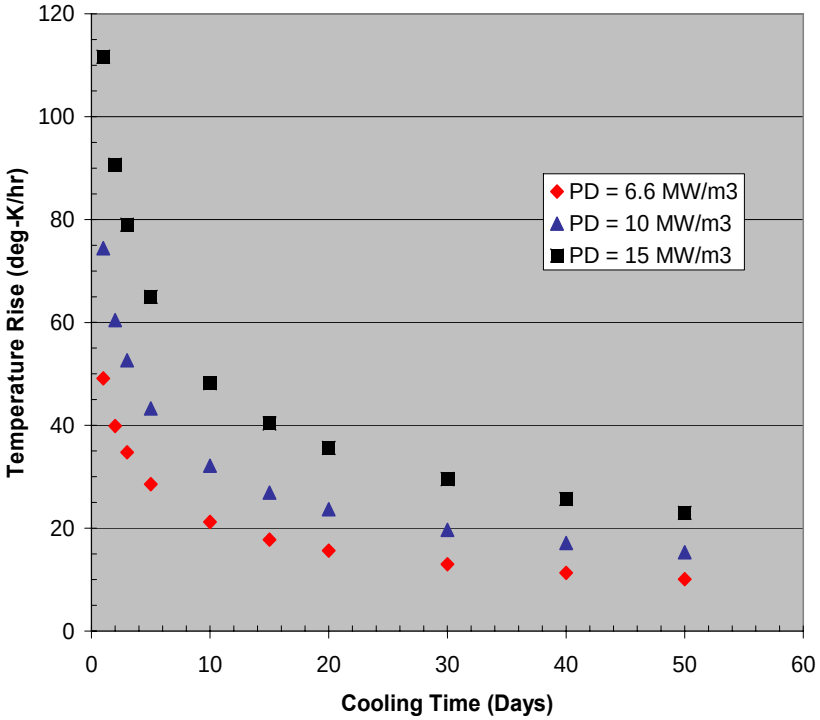
Stringer

Pebble Bed

Coated-Particle-SNF Heat-up Rate is Slow Relative to Other Types of SNF

(ANL to Provide Detailed Information)

- **Assumptions**
  - **150 GWd/ton**
  - **Prismatic fuel**
  - **Fully insulated**
- **Implications**
  - **Slow heat-up rates after 1 day**
  - **Not a significant refueling constraint (different than with fast reactor fuel)**

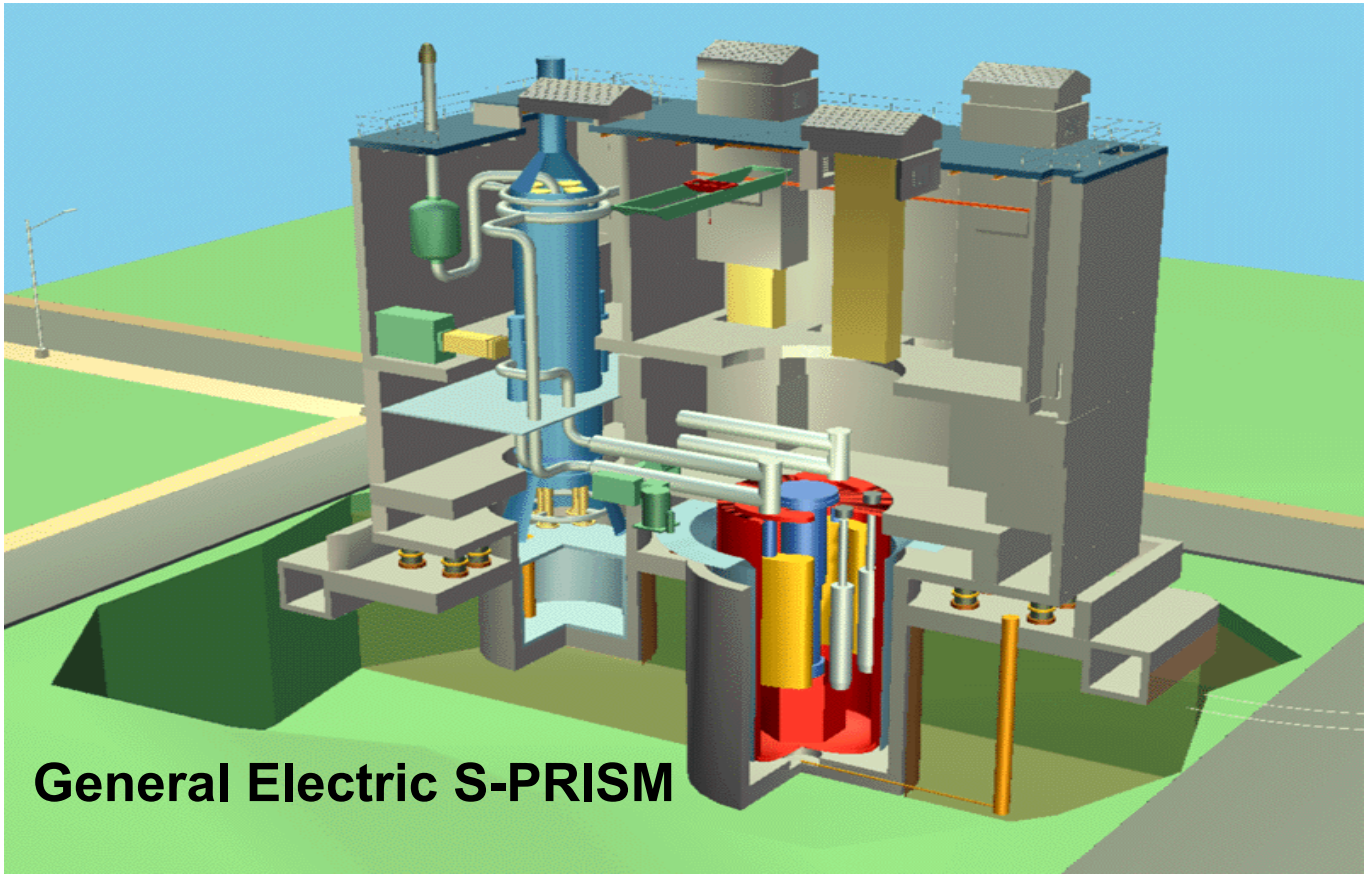


ANL-GenIV-069

Plant: Similar to Sodium-Cooled Fast Reactor

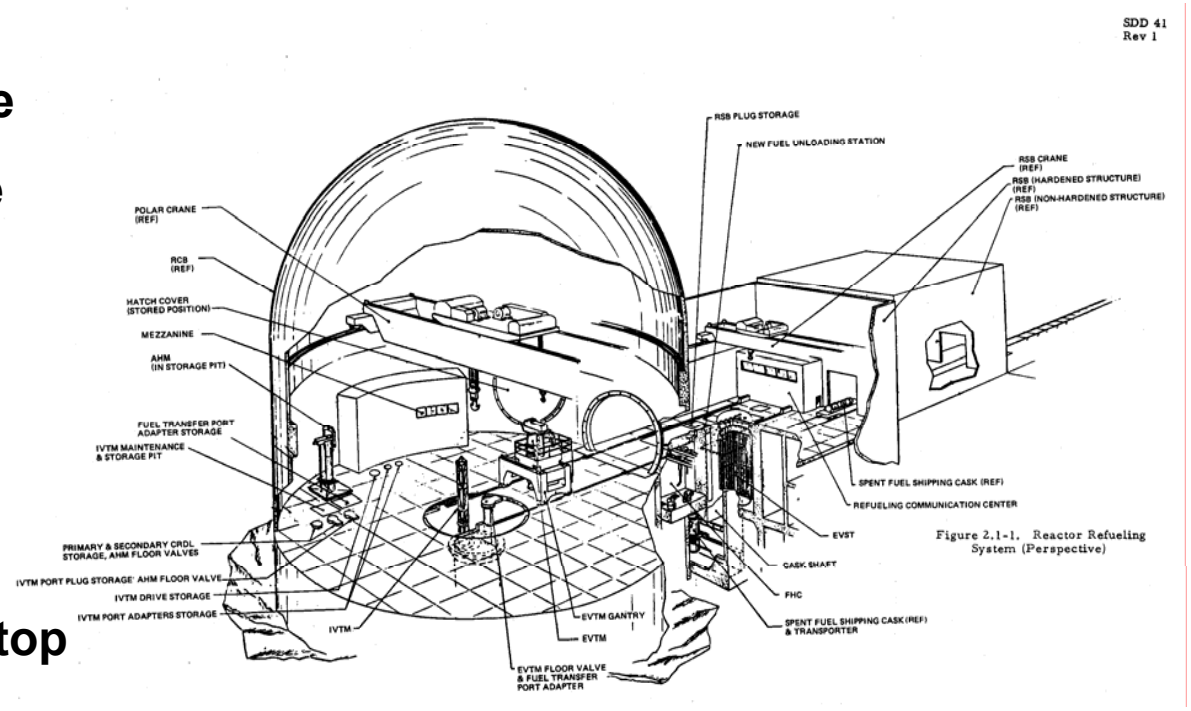
AHTR Facility Layouts are Based on Sodium-Cooled Fast Reactors

Low Pressure, High Temperature, Liquid Cooled



LS-VHTRs and LFRs have Common Refueling Characteristics

- **Common characteristics**
  - **High-temperature**
  - **Inert atmosphere**
  - **Low pressure**
- **LS-VHTR Implications**
  - **Flat lid**
  - **Rotating plug at top**
  - **Full vertical access to core**



CRBRP Refueling System

Relevant Refueling Experience

	High-Temperature Reactors				
Reactor	**HTGR**	**Pebble**	**AGR**	**LMR**	**MSR**
Fuel form	Prismatic graphite	Pebble bed	Metal-pin (assembly)	Metal-pin (assembly)	Liquid
Refuel Temp.[a] (ºC)	<100	750 (950)[b]	640 (750)[b]	370 (540)[b]	700
Pres. (bar)	1	40 (11)	43	1	1
Coolant environment	Helium	Helium	Carbon dioxide	Sodium	Molten salt
Visibility	Clear	Clear	Clear	Opaque	Clear
Ass./ MW(e)	4.5		0.5	0.5	0
Reactors	2	3	14	>20	2
Refueling	Off-line	Online	Online	Off-line	Online

[a]LS-VHTR between 450 and 550ºC.
[b]Peak temp. shown parenthetically.