Wielenga Innovation Static Salt Reactor
WISSR Progress and Potential

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NUCLEAR ENGINEERING &
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Wielenga Innovation Foundation, Inc.

- Non-Profit Corporation for creativity and innovation
- Open research project: WISSR, WISST
- Website: WiFound.org, Wielenga.org
  - WISSR: www.wifound.org/nuclear-reactor
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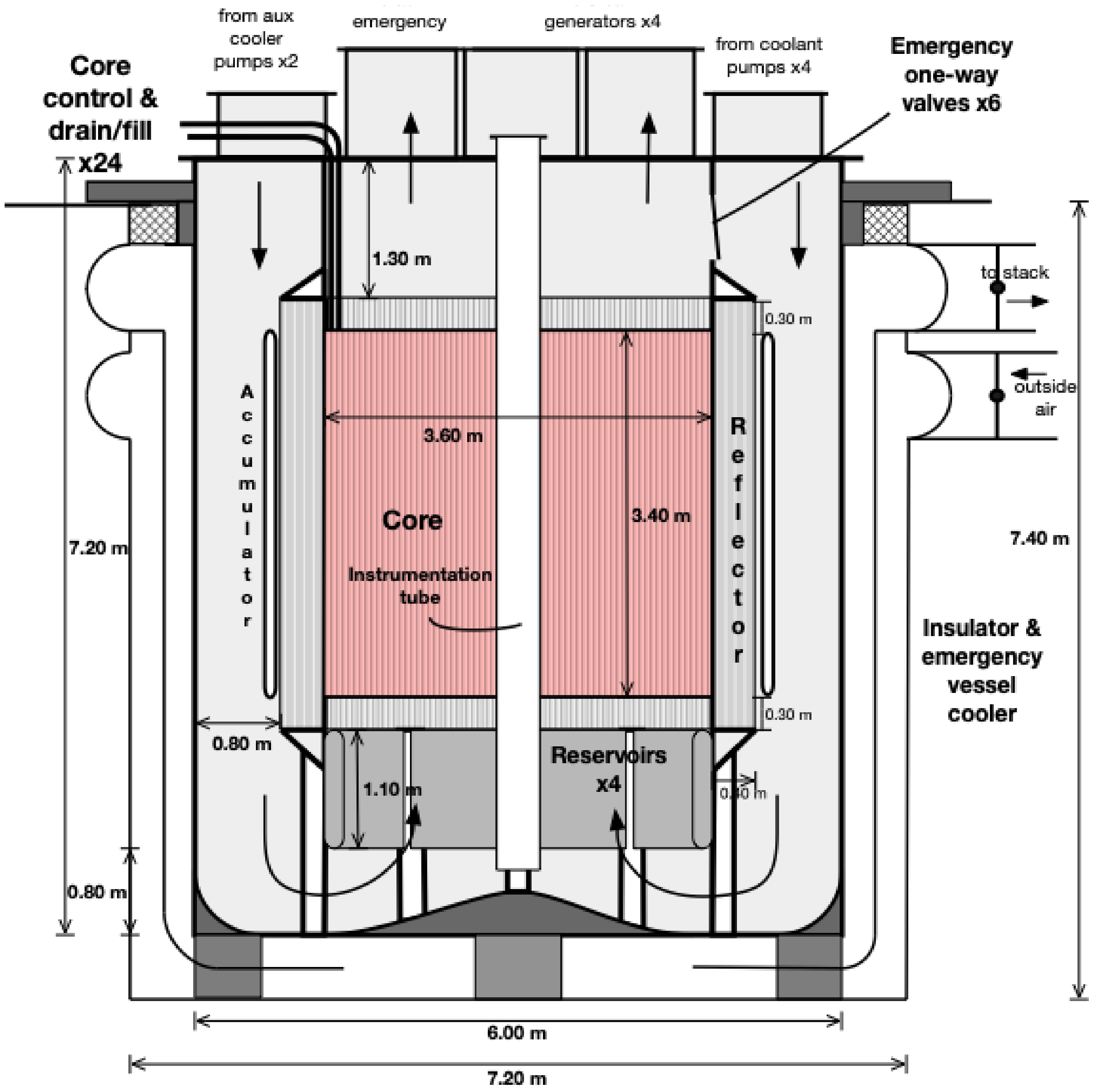
Overview

- Two versions:
  - WISSR: annular chambers
  - WISTR: tank with helical tube cooling
- Thermal analysis on WISSR
- Throttle control worth on both
- Pressure supported fuel movement on temperature change
- Fuel cycle analysis on both with no fuel recycling
- Corrosion mitigation
- Fuel recycling method with NASICON



WISSR Reactor layout

- Molten salt fuel
- Thin annular cylinders
- 4 Regions
- Surrounding reflectors
- Fuel level is pressure controlled
- 1 throttle to 4 fixed chambers
- 4 Fuel reservoirs below
- Accumulator: shuffling/shutdown
- Molten salt coolant
- Coolant flows down outside and up through core
- Vessel below ground
- Emergency air cooling

WISSR - approach

- Utility scale power: 500 - 600 MWe
- Molten salt reactor
  - Variable fuel control
  - Static molten salt U/TRU fuel
  - Flowing molten salt coolant
  - Fast spectrum – chloride salts
  - Recycled fuel – TRU from pyroprocessed LWR waste
  - Easily fueled – online refueling, reprocessing
  - High temperature -> efficiency
- Economic to build
  - Road transportable core – factory made
  - Stainless steel construction
  - Low pressure – thinner walls

✓ Fuel salt

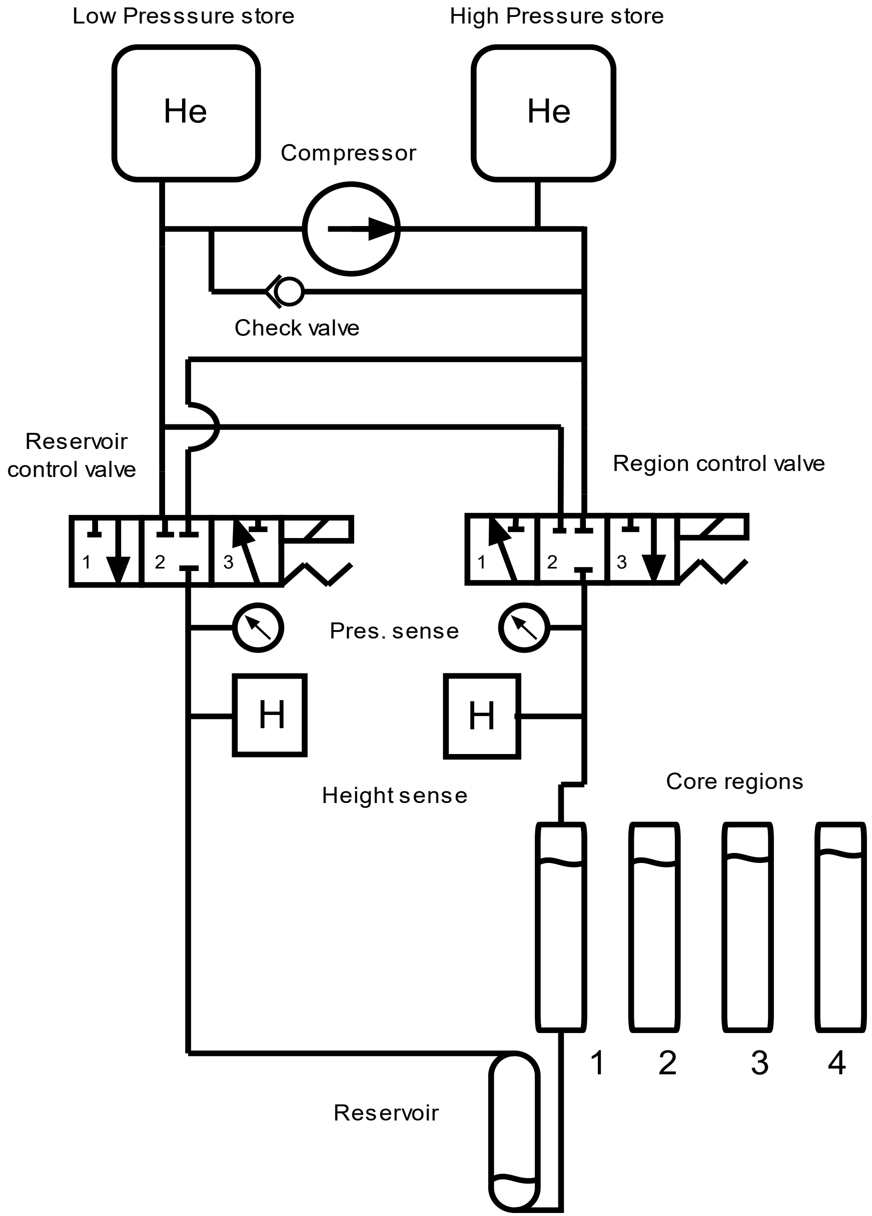
- $55NaCl-45(U,TRU,RE)Cl_3$
  - TRU recovered from 10-year cooled PWR used fuel of 50 MWd/kg burnup
  - Assumed weight fractions in recovered fuel
    - U: TRU: RE (rare earth) = ~20%: ~71%: ~9%

✓ Coolant salt

- $60NaCl-40MgCl_2$
  - Melting point: 741K
- $15.11NaCl-38.91KCl-45.98MgCl_2$
  - Melting point: 675K

Safety

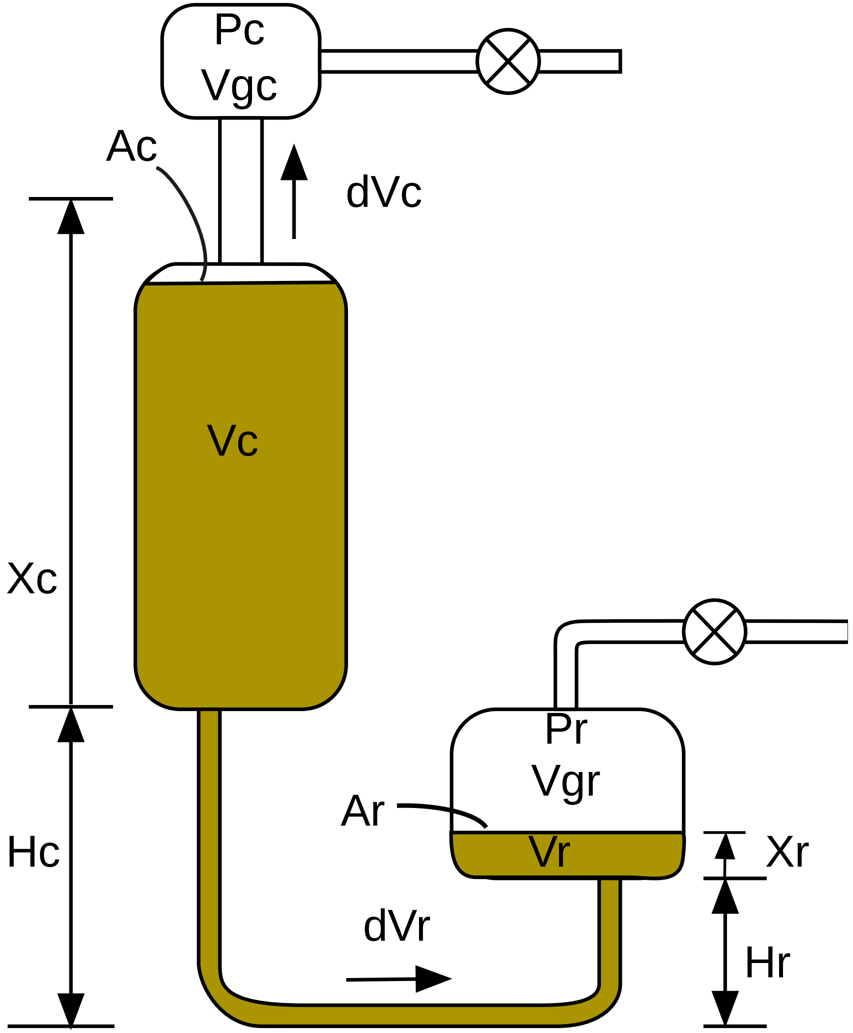
- Controllable
  - Negative thermal, Doppler, overall reactivity coefficients
  - Liquid control via pressurized helium
  - No mechanicals in reactor, simple mechanical gas valves outside
  - Scrams on power loss, throttles go to zero
- Redundant systems
  - 4 independent throttles and reservoirs
  - Redundant helium pressure supplies
- Severe emergency dilutes fuel with coolant



Throttle control

- Annular cylinders in core, 4 regions
- Reservoirs below
- Differential gas pressure controls levels
- Valve settings:
  - 1. Increase reactivity
  - 2. Normal running
  - 3. Reduce reactivity (default)
- Power loss drains throttle fuel
- Redundant systems

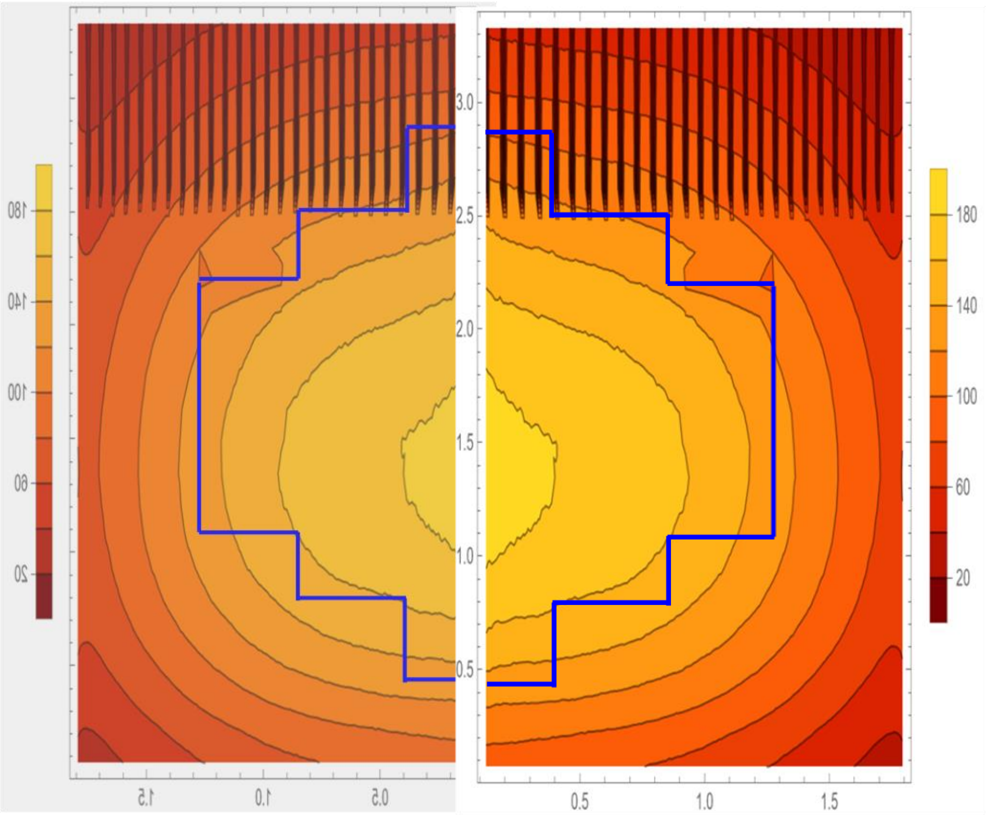
Pressure Supported Fuel movement



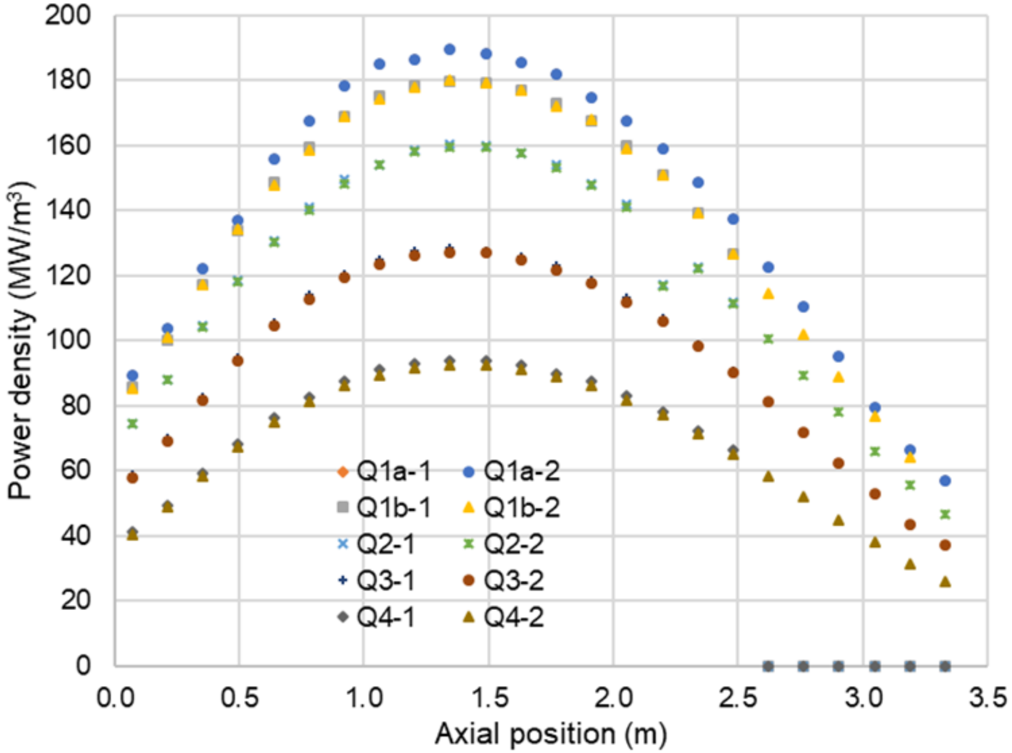
- Results:
  - Fuel moves up very little
  - Most expansion moves toward reservoir
  - Leaving 1% space in top of core – results in no danger of overtopping
  - All modeled reactors had similar characteristics
- To increase movement toward reservoir
  - Increase gas space above reservoir
  - Increase the interface area in reservoir

Neutronics Analysis Results

- Critical TRU fraction in HM: 45.5 w/o
  - k-eff: 1.00459±15 pcm



- Power distribution
  - Peak power density: 190 MW/m^3
  - Radial peaking factor: 1.50
  - Axial peaking factor: 1.34
  - Total peaking factor: 2.01



WISSR Neutronics Analysis Results

- Reactivity feedback coefficients
  - Fuel Doppler coefficient @ 1200K: -0.21±0.03 pcm/K
  - Fuel salt density coefficient: -7.0±0.2 pcm/K
  - Coolant temperature coefficient: 4.0±2.1 pcm/K
- Fuel depletion
  - Reactivity loss: -10.3 pcm/day
  - Fuel salt charge rate to compensate reactivity loss: 6.8 kg/day
- Reactivity control requirement: 2839 pcm
  - Power defect: 2038 pcm
  - 15% overpower: 306 pcm
  - RMS total uncertainty: 408 pcm

- Throttle fuel worth

Region	Bottom 3/4		Top 1/4	
	value	std	value	std
1a	398	21	63	21
1b	2150	21	283	21
2	2294	22	291	21
3	1698	21	167	21
4	916	20	89	20
All	8628	24	1067	21

- Shutdown margin
  - 1a & 1b & 4 with the largest worth chamber stuck: 259 pcm
  - 2 & 3 with the largest worth chamber stuck: 717 pcm

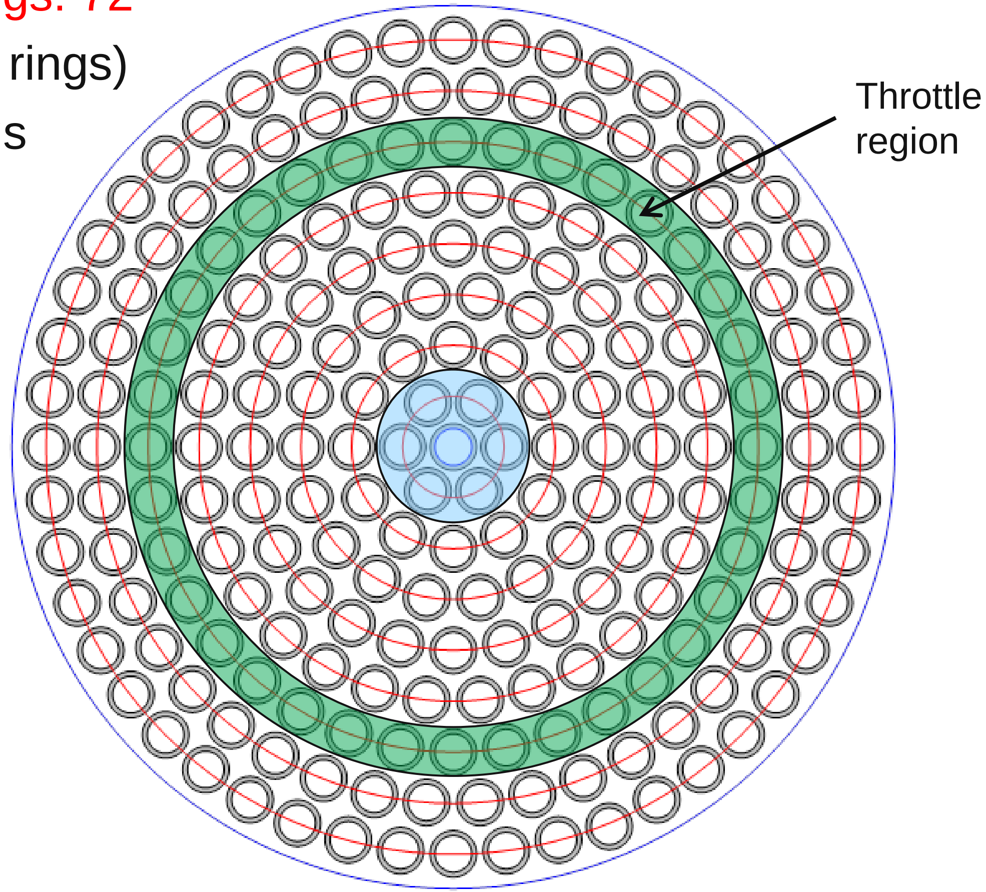
WISTR - helical coolant tubes in a fuel tank

- Tank fuel connections easier
- No concern regarding chamber width changes
- Helix reduces stress on tubes from thermal expansion
- Concentrates cooling at hot spot
- Increases tube separation at tube sheet

Configuration of WISSR Tank Design

- Coolant tubes are arranged in a modified circular lattice.
- Design parameters
  - Tube diameter: 1.5 cm; Radial pitch: 2.5 cm; No. of tube rings: 72
  - Instrument channel radius: 3.75 cm (replace innermost two rings)
  - Annular fuel region occupies integer number of circular rings
  - Throttle regions act as region splitter, located at the outer boundary of each region to reduce peak power (75% filled)
  - Total number of tubes: 15330
  - 1.25 cm gap between lattice and tank wall filled with fuel

Region	# tube rings	Outer radius (cm)	Throttle inner radius (cm)	# tube rings in throttle
R1a	16	43.75	36.25	3
R1b	18	88.75	81.25	3
R2	15	126.25	118.75	3
R3	11	153.75	148.75	2
R4	10	180.00	173.75	2



WISTR - Control Worth of Throttle Fuel at BOL

- Reference throttle fuel height is set at 75%
- Estimated with DIF3D calculations using ISOTXS generated for the chamber design at BOEC
  - Cross sections will be regenerated for new equilibrium core configuration
- Reactivity worth of throttle regions at BOL for the tank design:

Throttle region	Fuel volume (m^3)	Reactivity Worth (pcm)	
		Top 25%	Bottom 75%
R1a	0.39	148	1115
R1b	0.83	269	2285
R2	1.21	285	2574
R3	0.98	147	1401
R4	1.64	158	1447
Collective	5.05	1006	8822

Required reactivity control capacity estimated for the chamber design (NET paper)

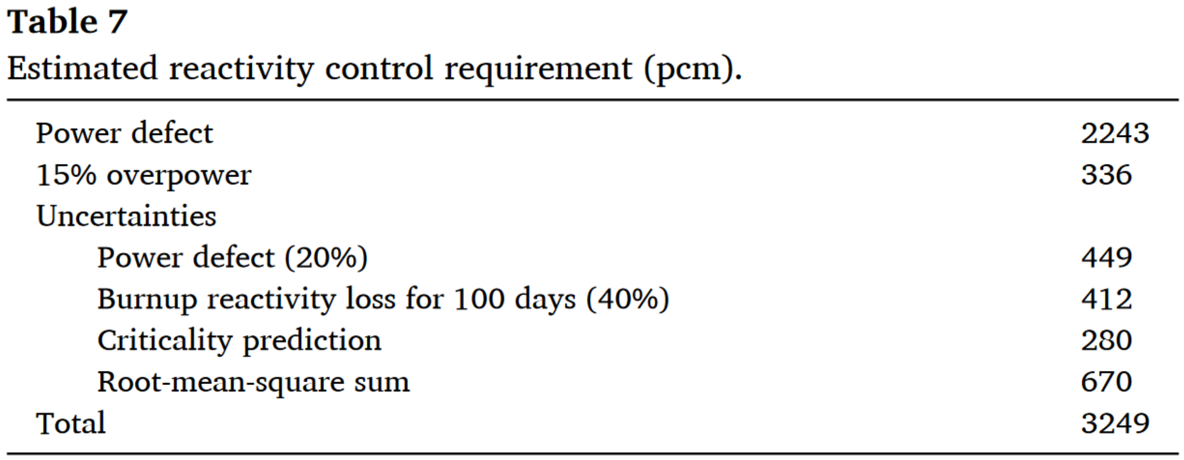


Table 7
Estimated reactivity control requirement (pcm).

Power defect	2243
15% overpower	336
Uncertainties	
Power defect (20%)	449
Burnup reactivity loss for 100 days (40%)	412
Criticality prediction	280
Root-mean-square sum	670
Total	3249

If the most reactive region (R2) is stuck at 100% throttle fuel level, the remaining throttle regions can provide ~6680 pcm reactivity reduction.

Comparison of Equilibrium Cycle Performance

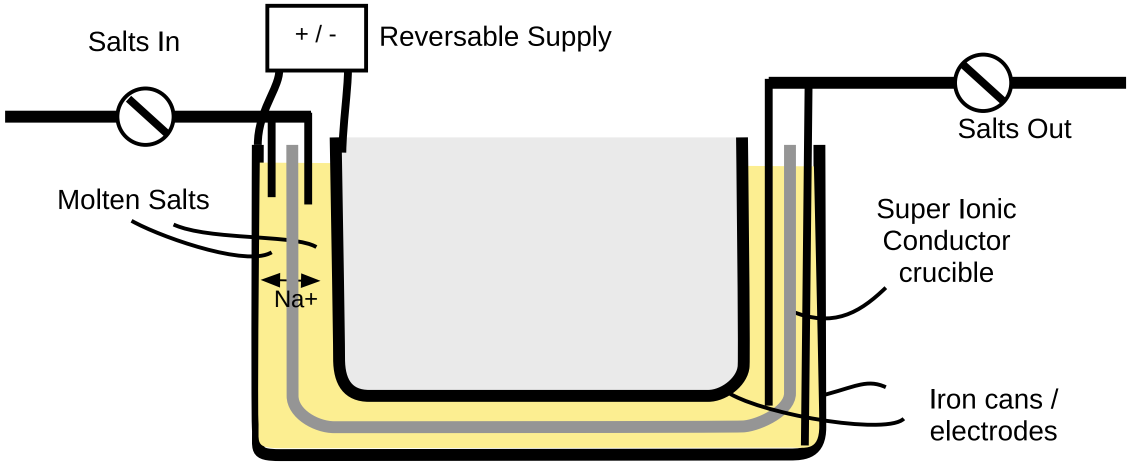
Core design	Chamber	Tank
TRU fraction of fresh fuel (at%)	60.4	35.8
Equilibrium cycle length (day)	102.6	183.6
HM feed rate (kg/day)	6.5	8.2
TRU feed rate (kg/day)	4.2	3.2
Equil. HM discharge burnup (atom%)	19.6	15.5
Burn rate of HM (kg/day)	1.27	1.27
Burn rate of TRU (kg/day)	1.04	0.67
TRU conversion ratio	0.18	0.45
TRU destruction rate (%/cycle)	24.6	21.1

Handling corrosion with "passivation"

- Principle: Pick least active metal in salt as sacrificial element
- For fuel, sacrificial metal is Uranium
  - Does not reduce TRU chlorides to metal
  - Corrodes before the iron, chromium and nickel in stainless steel
  - Uranium wire feed into fuel tank
- For coolant, sacrificial metal is Magnesium
  - Does not reduce sodium or potassium
  - Corrodes before the iron, chromium and nickel in stainless steel
  - Magnesium rod in cool part of coolant stream (near pump)

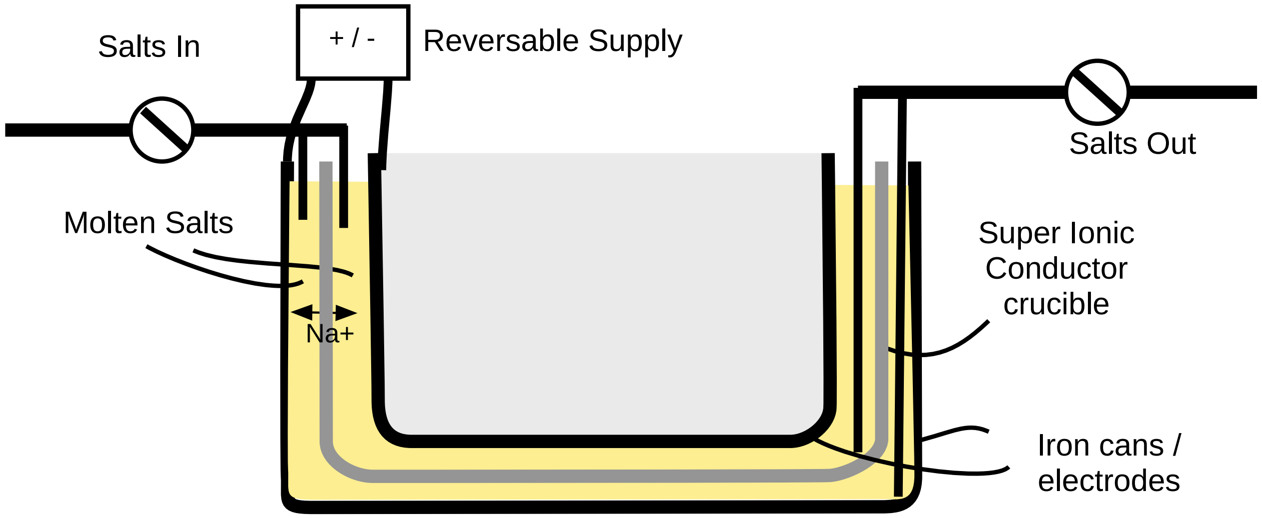
Recycling approach

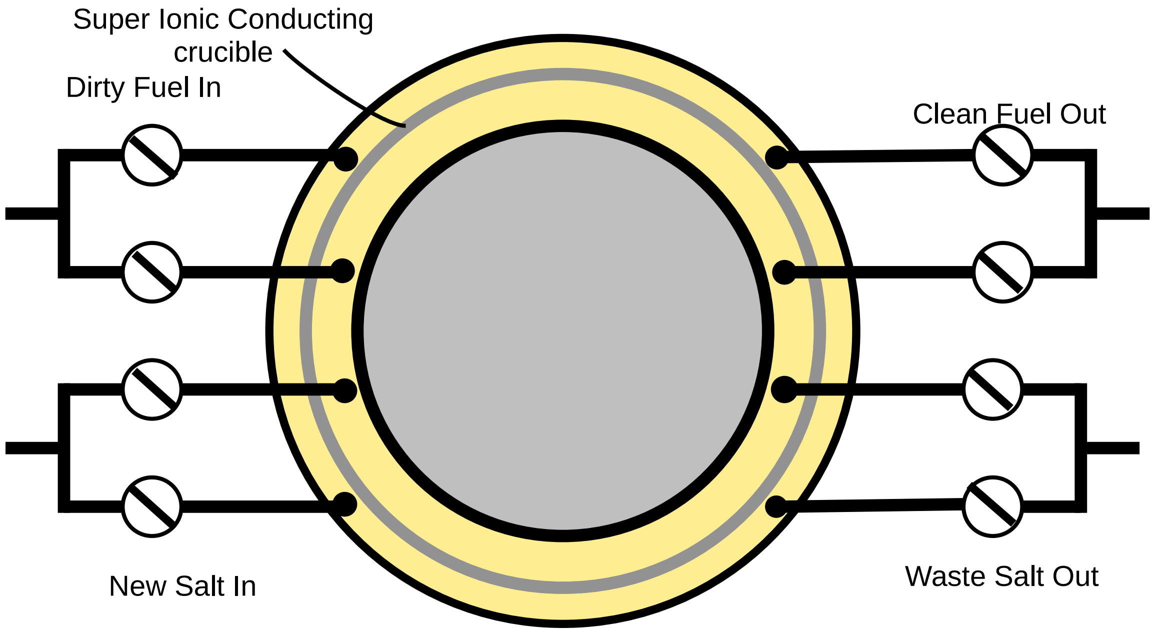
- Based on Sodium Super-Ionic Conductor - NASICON
- Conducts Na^+ ions through beta-alumina ceramic
- With NaCl molten salt on both sides, an electric potential makes one side reducing (from excess sodium) and one side oxidizing (from excess chlorine)



- Reduce TRU and Uranium to metallic on reduction side but stop when lanthanides are reached
- Remove salt and treat as waste
- Chlorinate metallic TRU and Uranium to salt in fresh salt, it becomes fuel salt
- Remainder is waste
- Possible liquid electrodes – cadmium or bismuth
- Tabletop size for WISSR and WISTR (4 – 5 liters / day)

Recycler schematic





Summary

- A new static molten salt reactor concept WISSR has been developed
  - Controls a nuclear reactor by moving a molten salt fuel into or out of the core
  - Fast spectrum TRU-burner reactor
  - Many safety features
  - Compact 500 MWe core design
  - NaCl, (TRU, U, RE)Cl_3 fuel
  - NaCl-KCl-$MgCl_2$ coolant
- Two configurations:
  - Annular chambers (WISSR),
  - Tank w/ helical tubes (WISST)
- Corrosion mitigation: use least active salt metal to “passivate” system
- Compact fuel recycling: salt -> metal -> salt using NASICON
- Open research: get involved!