ELYSIUM
MOLTEN CHLORIDE SALT
FAST REACTOR
(MCSFR)

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How to Achieve Disruptive Technological Change

Step 1: Believe Disruption is Possible
Background

- 32 years at Knolls Atomic Power Laboratory
- MARF Prototype Operations/Trained students
- Reactor Design/Support for 9 Ship Classes
  - Los Angeles, Trident, CGN, CVN, Seawolf, Virginia, Columbia, NR-1, Astute, Other
- Start up testing for 15 reactors
  - Los Angeles, Trident, NR-1, Virginia
- Jupiter Icy Moons Orbiter
- All coolants and other cooling methods investigated

- Elysium Team has over 300 years of reactor design experience covering all engineering disciplines
Our Technology
Elysium Molten Salt Reactor Concept

- Rated electric output 1000 MWe (~40% efficiency)
- Chloride fuel salt
- Fast spectrum neutron flux
- Fuel flexibility with DU, LEU, SNF, RGPu, WGPu, Th, Unat
- Core outlet temperature of > 600 °C
- Core inlet temperature of ~ 500 °C
- Low reactor operating pressure
- Structural components made from code qualified materials
- Superheated Steam Rankine power cycle

We chose a reactor design that is both compelling but can also be developed in a shorter period of time
Our Technology

Elysium Molten Salt Reactor – Flexible Power

- Max. Power
  - 1000 MWe, 8 Loops, 8 Heat Exchangers, 8 Pumps
  - Full Flow Pumps
  - Power System: 1 large turbine or 8 smaller turbines

- 250 Mwe, 2 Loops, 2 Heat Exchangers, 2 Pumps
  - Full Flow Pumps
  - Power System: 1 or 2 turbines

- 125 Mwe, 2 Loops, 2 Heat Exchangers, 2 Pumps
  - 50% Flow Pumps

- 25 Mwe, 2 Loops, 2 Heat Exchangers, 2 Pumps
  - 10% Flow Pumps
  - Super-Heated or Super-Critical Steam Rankine power cycle

Elysium Reactor is highly Scaleable
Our Technology

Elysium Molten Salt Reactor – Alternate Configuration

Elysium Reactor is highly Scaleable

Not preferred
Initially
Difficult Maintenance
**Our Technology**

**Chloride Salt Chemistry**

**Fuel Salt Functions**
- Solvent for nuclear fuel
- Working fluid for transporting nuclear heat to the intermediate loop
- Prevent release of fission products

**Chloride-based fuel and intermediate salts**
- Chloride salts melt 300°C lower than similar Fluoride salts in the absence of Li and Be
- Avoids the use of Li-7 and the associated problems with tritium production, supply chain issues, and proliferation concerns with Li-6
- Does not require use of developmental alloys

**High solubility of actinides**

**Corrosion**
- Lower for Chlorides vs Fluorides
- Better options for control (passive and/or active)

**Purification systems with high technical readiness**
- Actinides are easier to separate from lanthanides in a Chloride salt
- Only use very simplified version with simple removal of some of the fission products
Design to Prevent Diversion or Illegal Utilization
- Chloride salt allows fission product removal without separating Actinides
- Uranium & Plutonium always mixed AND always with some fission products
- Continuous monitoring of fuel addition and fission product waste stream inventories
- No spent fuel removed from reactor - No opportunity for diversion of fissile material

Physical Protection consistent with IAEA Guidelines
- Purification (cleanup) systems contained within low pressure containment
  - No fuel salt outside the high radiation boundary
- Containment structures designed to mitigate external threats
  - Designed to withstand aircraft impact
  - Below grade construction
  - Restricted plant access
Fuel Cycle Options

Fuel Option 1

Normal Option

- Fissile x10 = Fertile
- High Assay LEU 10-20% enriched
  - High fuel load due to fast reactor, open core, etc.
- Feed-In starts as mostly 20% enriched
  - Decreases slowly over years to natural
  - Pu builds over time
  - U235 concentration decreases
  - Continuously changing ratios of U235, Pu, U238
- Reach steady state concentration
  - 10% Pu
  - 90% U238
- Actinides go into the core, but never leave, except...
Fuel Cycle Options

Fuel Option 2

Pu & SNF

- WGPu 8 tons/reactor startup
  - 34 tons in US, 4 reactors started
  - Plutonium Management & Disposition Agreement with Russia
  - 53 tons 7 reactors started
- RGPU > 10 tons/reactor startup
- SNF ~ 68 tons, less if using RGPU
- Feed-In Fuel 3 kg/day or 1 ton/year of SNF
- Pu & SNF core / Th blanket > U-233

Pu & Thorium core / Th blanket

HEU & SNF

- HEU 12 tons/reactor startup
  - 1370 tons – 114 reactors started
Fuel Cycle Options

Fuel Option 3

U233 & Thorium
- U233 8 tons/reactor startup
  - U233 Made in Blanket of Fuel Cycle Option 2
  - Feed-In Fuel 3 kg/day or 1 ton/year of Thorium
Elysium’s process requires fewer and easier processing steps than existing reprocessing technologies AND requires no separation of proliferation sensitive material:

$\text{PUREX} \gg \text{IFR Pyro-processing} \gg \text{Elysium Conversion}$
Notional MCSFR II

- Passive Safety
  - Pump w/o electricity - Path Identified
  - Pumped Draining - Path Identified
  - Drain faster than a Freeze Seal - Path Identified
- Use Waste as Fuel
  - Use AlloThanium Fuel
- Discharge No Fuel
- Minimize Proliferation Concerns
- Thot = 1300 C (~2400 F); 60%+ Efficiency – Path Identified
- Don’t shut down for Natural Disasters
  - Disasters are when your safe power is needed MOST - Path Identified
MCSFR Summary

- Molten Chloride Fast Reactor
- Passively Safe
- Power Levels
  - 20 Mwe – 2 Hx/2 pumps/reduced flow
  - 250 Mwe – 2 Hx/2 pump/full flow
  - 1000 Mwe – 8 Hx/8 pumps/full flow
- Fuel Cycle
  - Closes Fuel Cycle
  - Closes LWR Fuel Cycle
  - Fuel Flexible - consumes ALL actinides
  - Splitting or Breeding for Startups
- Proliferation Safe even with
  - Conversion of SNF & Pu to MCSFR fuel
    - No separation
  - Positive Breeding for new reactor fuel
    - No separation
- Tank/Blanket region can breed
  - Thorium > U-233/U-238 denatured
  - U-238 > Pu-239/Pu-240 denatured
QUESTIONS?
Backup Slides
EFFICIENT UTILIZATION OF NUCLEAR FUEL

• Breeding ratio ≤ 1.0
  • Fuel production without the need to reprocess
  • ~3kg/day addition of low enriched, and eventually natural uranium

• Actinides remain in fuel salt until consumed
  • Closed Fuel Cycle
  • Fuel salt can be transferred to subsequent units at the end of reactor useful lifetime

• Reactor initially fueled with LEU, but can use:
  • Spent fuel LWR’s for make-up feed fuel
    • Simpler and more proliferation resistant than current MOX reprocessing
  • Plutonium from weapons stockpiles or separated Plutonium from LWR
    • Could be used at beginning of core life to consume faster than feed-in fuel
  • Thorium
Our Technology

Reduction of Environmental Burden

No long term waste repository
- Actinides remain in reactor for burning
- Shorter half-life (~300 yrs)
- Cl-36 production is a potential issue
  - Volume will be small
  - Designed to reuse Cl
  - Vitrification of fission products for storage

Insignificant carbon footprint for production emissions

Reduced need for cooling water and possibility of air cooling

Start Up after Plutonium is Gone

- Divide by 2
- Back Fill with LEU

Or................
Positive Breeding Option

• Positive Breeding Ratio
  • Temperature Rises over time to keep fissile in core constant
  • Discharge Fuel into storage tank in Containment
  • Ship to new reactor

• But, what about Proliferation
  • Fuel is not separated
  • U, Pu, MA, FP all together, denatured and protected by FP radiation
After SNF and Plutonium Waste are gone

- Mine uranium, use as is UO₂
- Extract U from Seawater & Coal ash
- Recover Thorium & Uranium
  - Iron Ore tailings
  - Phosphate tailings
  - Rare Earth tailings
    - Allows American Rare Earth Production