Moltex technology

An overview for the National Academies of Sciences, Engineering, and Medicine committee on fuel cycles and waste aspects of advanced nuclear reactors

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By Rory O’Sullivan, Chief Executive Officer, North America
Why Moltex was founded

Overnight capital cost of nuclear over time

Koomey & Hultman (2007)
What are the options for low-cost nuclear?

Gas cooled fast reactor
- Costly high pressure system and expensive new solid fuel system

TRISO fuelled reactors
- Excellent safety but published fuel cost estimates show cannot compete with gas/coal

Sodium fast reactor
- Highly dependent on engineered safety

Lead cooled fast reactors
- Better than sodium, but new materials needed

Molten salt reactor
- MAYBE? Step change in intrinsic safety at lower cost than TRISO

Supercritical water
- Not credibly cheaper
Reducing risk

Hierarchy of controls

- **Elimination**: Physically remove the hazards
- **Substitution**: Replace the hazards
- **Engineering controls**: Isolate people from the hazards
- **Admin controls**: Change the way people work
- **PPE**: Protect the worker with personal protective equipment

Moltex approach

Post-Chernobyl
Two ways to use molten salt fuel

Conventional MSRs

- Intensely radioactive fuel salt pumped at pressure round an engineered system which can never be approached by a human being

Stable Salt Reactor platform

- Fuel salt placed in fuel assemblies
- New concept, patent now granted worldwide
Why is this a new idea?

- “Static” molten salts in fuel pins rejected by ORNL because convection of fluids would be unreliable in an aircraft – but convection is essential for heat transfer in unpumped fluids

- Decision not revisited for ground-based reactors

Aircraft reactor experiment which led to molten salt reactor experiment
Fuel pin comparison
Technology benefits

1. **Costs less**
   Moltex’s design is smaller, simpler and inherently safe, making it low-cost to build and operate.

2. **Reduces waste**
   Moltex recycles waste from existing nuclear power stations, and uses it to produce more clean energy.

3. **Enables renewables**
   Moltex can store energy and supply it to the grid as needed, enabling intermittent renewables.

4. **Cogeneration**
   Moltex can produce heat for heavy industry and hydrogen production.
Advanced reactor design

**REACTOR CORE**

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<table>
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<tbody>
<tr>
<td>Thermal power</td>
<td>750 MWth</td>
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<tr>
<td>Refueling cycle</td>
<td>Online refueling</td>
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<tr>
<td>Thermal or fast neutrons</td>
<td>Fast</td>
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**FUEL**

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<tbody>
<tr>
<td>Chemical composition</td>
<td>55%XCl₃ : 45%KCl where X = Pu-U-An-Ln</td>
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<tr>
<td>Physical form</td>
<td>Stable molten salt in pins</td>
</tr>
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**CLADDING**

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<tr>
<td>Material</td>
<td>Stainless steel</td>
</tr>
<tr>
<td>Physical form</td>
<td>Each fuel assembly has hexagonal pins inside a hexagonal wrapper</td>
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**COOLANT**

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<tr>
<td>Chemical composition</td>
<td>MgCl₂ / NaCl</td>
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<tr>
<td>Physical form</td>
<td>Molten salt flowing through reactor core</td>
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Refuelling

Cross between SFR and CANDU

- Online refuelling
- Hex fuel assemblies with channel like BWR
- Vertical lift like PWR/SFR
- Cycle duration (between refuelling) – 6-12 days
- Assembly average residence time – 6.3 years
SSR-W fuel

Chloride fuel with high impurity level

PuCl₃, 22.2%

LnCl₃*, 6.6%

AnCl₃**, 2.3%

UCl₃, 23.9%

KCl, 45.0%

Pu vector is approximately 2/3 fissile based on CANDU spent fuel composition. U vector is below natural enrichment levels.

*Ln=Lanthanides; **An=Actinides

Corrosion control in fuel pins by addition of Zr metal
Low-cost thermal energy storage at grid scale from solar industry
Impact of GridReserve on capital cost

- Rest of plant costs are **high confidence** as similar to CCGT and CSP plants and not subject to nuclear regulation. Errors, optimism bias, etc. in nuclear island costs have relatively little impact on total cost.
- GridReserve triples the capacity for double the cost
- GridReserve is a fraction of the cost of lowest future battery cost
- Only possible with high temperature reactors
Stage 1 – Chemical decladding of used fuel
WATSS: WAste To Stable Salt

Stage 2 – Electroreduction of oxide pellets to alloy form and separation of fission products
Stage 3 – Conversion of alloy to fuel salt. Clean uranium remains.
Stage 4 – Fuel salt poured into SSR-W fuel assembly
WATSS waste streams for first fuel load

- **Stage 1**: CANDU fuel bundle 100%
  - Zr in cladding recycled in coolant 21%

- **Stage 2**: Depleted fuel pellets 79%
  - Uranium + actinide alloy 78.5%

- **Stage 3**: U alloy 77.9%

- **Stage 4**: Fission products 0.5%
  - Fuel salt 0.6%

**Process**
- Long-lived waste
- Low-activity uranium
- Potential reuse
WATSS waste streams during SSR-W operation

- CANDU fuel bundle 100%
- Deciad fuel pellets 79%
- U + actinide alloy 78.5%
- U alloy 77.9%

- Spent SSR-W fuel 100%
- Remaining fuel 93%
- Extraction of fission products 7%
- Top up fuel salt 7%
- Back to SSR-W

- Zr in cladding recycled in coolant 21%

- Mixing New SSR-W fuel 100%

- Process
- Long-lived waste
- Low-activity uranium
- Potential reuse
WATSS: Key advantages

• SSR-W reactor burns Pu and higher actinides

• Much of the cost of traditional pyro-processing is in separating Pu from other chemically similar actinides and lanthanides (rare earth elements)
  • This high purity separation is required for any oxide or metal fuel fabrication
  • The WATSS recycling process is therefore simpler and cheaper

• Residual waste streams contain no higher actinides
  • Makes storage/disposal easier and cheaper
US spent fuel disposition

50 GW
Cogeneration

SSR-U
Thermal spectrum reactor

SSR-W
Fast spectrum reactor

HTE
Low-cost electricity

LTE
Industrial process heat

Hydrogen

Industrial processes

High temperature industrial processes

Ammonia

Synthetic fuels

Fuel cells

Heavy transport

Heating
Challenging licensing issues

Regulatory challenges associated with waste management

• Lack of standards and regulations around nuclear fuel recycling

• US export controls around reprocessing make international collaboration extremely challenging

Moltex implementation plan for commercializing nuclear energy system

• Step 1: Perform laboratory scale tests to obtain critical parameters for the operation, process design and reactors design

• Step 2: Perform real tests at hot cell scale

• Step 3: Commission and operation of industrial scale as part of the FOAK facility in Point Lepreau nuclear site
Current US activities

Rapid construction studies with c. U$4M grant from ARPA-E

• Accelerated construction methods by Purdue University
• Hazard and operability study with EPRI
  • Expert working groups identifying all fault scenarios and failure modes (expanded PIRT)
• Fast reactor physics with Argonne National Laboratory
  • Transient and static analysis of all major fault groups
• Oak Ridge salt studies
  • Fission product vapor and from salts
  • Dose release for severe accidents
  • Molten salt / concrete interactions in severe accidents
SSR-W milestones

2021-2024
• Laboratory scale tests conducted and engineering design completed
• CNSC Vendor Design Review phase 2 completed

2025-2027
• Hot cell tests performed and detailed design completed
• Licences to prepare site and construct obtained

2028-2031
• FOAK facility at Point Lepreau commissioned and constructed
• First SSR-W core ready for commercial operation
Summary of key points

• Molten salt fuel in essentially conventional fuel assemblies is a genuinely new concept that eliminates many of the novel challenges of an MSR.

• Eliminates conventional nuclear hazard which radically simplifies safety case

• GridReserve enables lower cost renewables

• The SSR-W can reduce legacy waste from the first nuclear era

• Canada, UK and US governments aligned on nuclear policy

• Moltex has a utility partner and is progressing demonstration, planning expansion into US market
Thank you

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