Experimental Facilities and Plan for a Prototype SFR

IAEA Technical Meeting on Existing and Proposed Experimental Facilities for Fast Neutron Systems

10-12 June 2013

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Outline

I STELLA

II Under Sodium Viewing

III Sodium-CO2 Interaction Test
I STELLA
National Plan for SFR Development

- 2017: Safety Analysis Report for Prototype SFR
- 2020: Design Approval
- 2028: Completion of Construction
STELLA Program

- STELLA (Sodium Integral Effect Test Loop for Safety Simulation and Assessment)
  - Phase 1: STELLA-1, Individual component test
    - Performance evaluation of key sodium components
    - Heat exchanger design codes V&V
  - Phase 2: STELLA-2, Integral effect test
    - Verification of dynamic plant response after reactor shutdown
    - Construction of test DB to support specific design approval for the prototype SFR

- Schedule

[Diagram showing the schedule with timelines and milestones for each phase.]
Scope of Experiment

- Reference design
  - Prototype Gen-IV SFR

- DHR performance
  - DHX
    - Straight-tube type sodium-to-sodium HX
  - AHX
    - Helical-tube type sodium-to-air HX
  - FHX
    - Fin-tube type sodium-to-air HX
  - DHR operation
    - Passive & Active DHRS
    - Natural circulation characteristics
Overall Characteristics of STELLA-1

- **Main test loop**
  - Test components
    - Sodium-to-sodium heat exchanger (DHX)
    - Sodium-to-air heat exchanger (AHX)
    - Mechanical sodium pump (PHTS pump)
  - Electrical loop heaters, EM pumps, Flow meters, Expansion tanks, Sodium storage tank

- **Sodium purification system**
  - Cold trap, Plugging meter, etc.

- **Auxiliary Systems**
  - Gas supply & Vacuum system
  - Power supply system
  - Fire protection system

- **Major Characteristics**

<table>
<thead>
<tr>
<th>Working fluid</th>
<th>Liquid sodium</th>
<th>Total electric power</th>
<th>2.5 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sodium inventory</td>
<td>~ 18 ton</td>
<td>Heat capacity of HXs</td>
<td>1.0MW</td>
</tr>
<tr>
<td>Design temperature</td>
<td>600°C</td>
<td>Design pressure</td>
<td>10 bar</td>
</tr>
<tr>
<td>Max. flowrate for HX test</td>
<td>10 kg/s</td>
<td>Max. flowrate for Pump test</td>
<td>125 kg/s</td>
</tr>
</tbody>
</table>

Overall Size (W × L × H): 15m × 8m × 22m
STELLA-1 Loop Constitution by tests

INDEX
- Cold Loop
- Hot Loop
- Pump Loop
- AHX Air Cooling Loop

Test matrix (schematic)
- AHX test (Forced-draft air)
- AHX test (Natural-draft air)
- DHX test
- DHX-AHX Natural Circulation Test
- Mechanical sodium pump test
STEELA-2 Facility Design

- **Integral effect test**
  - Verification of dynamic plant response after reactor shutdown

- **Top-tier requirements**
  - Preservation of overall system behavior in the prototype plant
    - Evaluation of important design issues
    - Reproducibility of major T-H phenomena accompanying natural circulation flow
    - Minimization of scaling distortion

- **Design requirements** (preliminary)
  - Scale (Height: 1/5, Volume: 1/125)
  - Identical working fluid and temperature conditions
  - Simulated electric power
    - 7% of the scaled nominal power
  - Use of the PIRT for simulating representative transients

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**Major characteristics (For example)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scaling Ratio (Model/Prototype)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference reactor (Prototype)</td>
<td>PGSFR</td>
</tr>
<tr>
<td>Working fluid</td>
<td>Sodium</td>
</tr>
<tr>
<td>Sodium mass</td>
<td>~17 ton</td>
</tr>
<tr>
<td>Core power</td>
<td>1.9 MW</td>
</tr>
<tr>
<td>Reactor vessel height</td>
<td>~3.7 m</td>
</tr>
<tr>
<td>Reactor vessel diameter</td>
<td>~2.3 m</td>
</tr>
<tr>
<td>Temperature distribution</td>
<td>1:1</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>1 bar</td>
</tr>
</tbody>
</table>

**Key design parameters of the facility**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scaling Ratio (Model/Prototype)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Ratio</td>
<td>1/5</td>
</tr>
<tr>
<td>Area Ratio</td>
<td>1/25</td>
</tr>
<tr>
<td>Volume Ratio</td>
<td>1/125</td>
</tr>
<tr>
<td>Temperature Rise/Drop Ratio</td>
<td>1/1</td>
</tr>
<tr>
<td>Velocity Ratio</td>
<td>1/2.24</td>
</tr>
<tr>
<td>Time Ratio</td>
<td>1/2.24</td>
</tr>
<tr>
<td>Gravity Acceleration Ratio</td>
<td>1/1</td>
</tr>
<tr>
<td>Core Power Density Ratio</td>
<td>2.24</td>
</tr>
<tr>
<td>Power Ratio</td>
<td>1/55.9</td>
</tr>
<tr>
<td>Flow rate Ratio</td>
<td>1/55.9</td>
</tr>
<tr>
<td>Pressure Drop Ratio</td>
<td>1/5</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Option 1: Simulation of whole plant system

- **Whole Plant System Concept**
  - Including IHTS with L/D Scale Ratio of 1/1

- **Main Systems**
  - Reactor vessel & internals, 2 PHTS pumps, 4 IHXs
  - 2 IHTS Loop, 2 IHTS Pumps, 2 UHXs for simulating SGs
  - 4 DHXs, 2 AHXs, 2 FHXs, Expansion tanks

- **Electric core simulator**
  - Heater rods (assembly arrangement)
  - Preservation of the relative core $\Delta P$

- **Auxiliary systems**
  - IHX gas ($N_2$) cooling system
  - Heat loss compensation system
  - Power supply system
  - Gas supply system
  - Fire protection system

- **Instrumentation / Control / Monitoring systems**
**Option 2: Simulation of key safety system**

**System Constitution**
- Main vessel w/o IHTS Loop and sodium Pumps
- Active and Passive DHRS (DHX coupled with AHX or FHX)
- Simulation of sodium pool inside main vessel using electric loop heaters (or rod heaters)
  - No restriction of the heater rods configuration
  - No core simulator
Discussions on the STELLA program

- Scope of experiment for licensing
  - Licensing requirements: Interactions with Regulatory body
  - Demonstration of Integral effects including decay heat removal performance
    - Whole system (option 1) vs. Key safety system (option 2)
    - Identification of major thermal-hydraulic phenomena and their priorities
  - Scope of Integral effect test facility design
    - Full-height scale vs. Reduced-height scale
    - Scaling ratio: Length, Volume, Aspect ratio, etc.
    - Similarity conditions between model and prototype
      ✓ Methods to minimize scaling distortion
Under Sodium Viewing
Feasibility test facility of prototype ultrasonic waveguide sensor module in water

- **Feasibility Test Facility**
  - 10 m long prototype ultrasonic waveguide sensor module
  - H-beam frame
    - Dimension: 13 m x 4 m x 6 m
    - Vertical installation of prototype WG sensor module
  - Ultrasonic C-scan system and Scanner
  - Development of C-scan software program
    - Using LabVIEW graphic language
    - Scanner control, image mapping and signal processing

- **Feasibility Test in Water**
  - C-scan resolution tests of 10 m prototype waveguide sensor module in water
    - Detection and identification of loose parts in reactor core mock-up
    - C-scan resolution: 0.8mm slit detected
Performance test facility of under-sodium ultrasonic waveguide sensor module in sodium

- **Performance Test Facility**
  - Design and construction of sodium test facility
    - Glove box system
    - Open-type sodium test tanks
    - Ar purification system

- **Under-Sodium Waveguide Sensor Module**
  - Under-sodium waveguide sensor coated with Be and Ni layers
    - Be coating for the effective radiation of ultrasonic beam in sodium
    - Ni coating for the improvement of sodium wetting

- **Basic Performance Tests in Sodium**
  - Ultrasonic wave propagation and sensitivity test
  - C-scan imaging resolution test
Plan for under-sodium viewing facility of under-sodium ultrasonic waveguide sensor

- Performance Verification and Comparison Tests
  - Performance enhancement of under-sodium ultrasonic waveguide sensor
  - Comparison tests of under-sodium waveguide sensors and immersion sensors

Under-Sodium Viewing Applications

Immersion Ultrasonic Array Sensor (JAEA)  Rod Waveguide Sensor (ANL)  Plate Waveguide Sensor (KAERI)
Sodium-CO2 Interaction Test
Mechanism of Na-CO₂ interaction

- Structure & Configuration of Na-CO₂ HX (PCHE)

- Modular-type PCHE unit

- Top-view

- Sodium inlet plenum

- Gas inlet plenum

- Gas exit plenum

- Sodium header

- Sodium inlet

- CO₂ gas in

- CO₂ gas out

- Sodium out

- CO₂ interaction

- Micro crack

- ~1 bar

- 200 bar
Potential design issues

- Damage propagation on the pressure boundary in Na-CO₂ HXs
  - thermal, mechanical and chemical effects on neighboring structures

- Potential channel plugging in Na-CO₂ HXs

- Slow loss of CO₂ inventory
  - Pre-determined leak rate (micro-crack)
    - $m_f^{CO₂} : 250 \sim 500 \text{cc/min} (\sim 1 \text{g/sec CO}_2)$
    - "Small leak" condition of SWR
  - Subsonic flow (controllable flow)
  - Major concerns
    - Leak hole (path) size & leak rate
    - Potential leak hole plugging by reaction product

Potential wastage scenario:

- Surface degradation
- Potential wastage scenario

Wastage test

Plugging test


## Test Facility Overview

### Progress Review
- Test program setup and Test facility design (2012~2013FY)
- Construction of experimental facilities (~2013FY)
- Main experiments & Assessment of Test results (~2014)

### CO₂ upstream pressure in the gas tank and feeding tube
- Injection pressure : ~ 20 MPa (Realistic condition)

### Sodium temperatures
- 300°C ~ 550°C at intervals of 50°C
- 600°C test for Auto-combustion condition

### Sodium velocity
- 0.5 inch/sec (Inside test section around the target assembly)
- 5.0 lpm of liquid sodium flow

### Injection nozzle size : 100 microns
- CO₂ leak rate : 1.6 ~ 1.7 liter/min (chocking condition)
- Test time : 30sec ~ 1min (CO₂ feeding only)

### Target assembly
- Square plate (40 by 40 mm, 2mm thick.)
- Material : Mod.9Cr-1Mo steel / STS316 / Alloy800
- Distance : 1 mm (Reference design) & 5mm
- Impinging angle to the Horizon: 45° only

### Primary assumption
- Slow loss of CO₂ inventory into flowing sodium

### Sodium temperatures
- 300°C ~ 550°C at intervals of 50°C
- 600°C test for Auto-combustion condition

### Sodium flow conditions
- Flowrate : 0.05 ~ 0.1 lpm
- Sodium channel velocity : 0.72 m/sec (nominal condition)

### CO₂ flowrate
- 50scc/min, Pre-determined leak rate (micro-crack) by MFC

### Injection nozzle size : 100 microns
- Test time : 30sec ~ 1min (CO₂ feeding only)

### Test channel assembly
- Venturi type single sodium channel (Half-circular shape)
- Channel diameters (mm) : 2.0 (nominal), 3.0, 4.0, 5.0
- Channel length (m) : 1.0
3D drawings for the Test Facility

3D-view

Side-view

Front-view
Experiment Planning for Prototype SFR (1/2)

- Identify and list up experiments to perform
- Ranking by priority
- Detail planning

<table>
<thead>
<tr>
<th>Category</th>
<th>Experiment</th>
</tr>
</thead>
</table>
| Reactor Physics                 | Critical experiment for a U core  
|                                 | Critical experiment for a mixed U/TRU core  
|                                 | Critical experiment for a TRU core  
| Thermal Hydraulics and Safety   | Test for heat exchanger characteristics (DHX, AHX, FHX)  
|                                 | Heat transfer and flow characteristics test for SG  
|                                 | Sodium pump performance test (mechanical pump, EM pump)  
|                                 | Reactor thermal behavior characteristics test  
|                                 | Cold trap performance test  
|                                 | Integral effect test (STELLA-2)  
|                                 | Simulation test for primary pipe rupture  
|                                 | Source term evaluation test          |
## Experiment Planning for Prototype SFR (2/2)

<table>
<thead>
<tr>
<th>Category</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Structure and Main Component</td>
<td>Dynamic characteristics test for UIS  &lt;br&gt; Performance test for CRDM  &lt;br&gt; Performance test for IHX structure  &lt;br&gt; Performance test for ISI (USV and sensors)</td>
</tr>
<tr>
<td>Metal Fuel</td>
<td>Performance test for metal fuel slug  &lt;br&gt; Performance test for fuel rod and cladding  &lt;br&gt; Performance test for fuel assembly</td>
</tr>
<tr>
<td>MMIS</td>
<td>Performance test for digital MMIS safety system  &lt;br&gt; Safety communication structure and characteristics test  &lt;br&gt; Power control system characteristics test</td>
</tr>
</tbody>
</table>