Advanced SFR Concept Design Studies at KAERI

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Outline

I  Introduction
II Development of advanced SFR concept
III R&D Activities
IV Summary
Introduction
Long-term Plan for SFR and Pyroprocess

- **SFR**
  - Advanced Design Concept
  - System Performance Test
  - Standard Design
  - Detailed Design
  - Metal Fuel Irradiation Test
  - Licensing Technology Development
  - Demonstration Plant

- **Pyroprocess**
  - Mock-up Facility (Nat. U, 10t/Yr)
  - Eng.-scale Facility (10t/Yr)
  - Prototype Facility (100t/Yr)
  - Prototype Facility Operation

Timeline:
- '07: Advanced Design Concept
- '11: System Performance Test
- '16: Standard Design
- '20: Detailed Design
- '26: Metal Fuel Irradiation Test
- '28: Demonstration Plant

Key Dates:
- Viability & Economics
- Licensibility
- Construction
Technology Goals and R&D Activities

Technology Goals of Gen IV Reactor System

<table>
<thead>
<tr>
<th>Sustainability</th>
<th>Proliferation Resistance</th>
<th>Economics</th>
<th>Safety</th>
</tr>
</thead>
</table>
| - Burner CR: 0.5-0.8 | - No Blanket | - FOAK  
- 4 $/kWh  
- 2,000 $/kWe | - CDF < 10⁻⁵/R·Y  
- Grace time of more than three days |

R&D

- Burner core development
- Breakeven core development
- Development of MA bearing metal fuel
- Size optimization
- Core and structure optimization
- S-CO₂ Brayton cycle system
- Integrated components
- High temp LBB

PDRC concept validation  
⇒ Passive safety  
⇒ Inherent safety

Core concept without blankets  
Construction cost ~ $2,300/kWe  
PDRC Concept  
Analysis codes

Conceptual Design of Advanced SFR
II

Development of Advanced SFR Design Concept
KALIMER-600 System

Key Design Features

- 600MWe, Pool-type Reactor
- Fuel: U-TRU-Zr
- Core I/O Temp: 390/545°C
- DHR System: PDRC
- 2-loop IHTS/SGS
- Net Efficiency: 39.4%

Heat transport system of KALIMER-600
Advanced Concept (1200MWe)

Key Design Features

- 1200MWe, Pool-type Reactor
- Fuel: U-TRU-Zr metal
- Core I/O Temp: 390/545°C
- DHR System: PDRC
- 2-loop IHTS/SGS
- Net Efficiency: 39.4%

Conceptual NSSS Layout

Heat transport system of advanced pool type SFR
### Breakeven Core Design

#### Core Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>KALIMER-600</th>
<th>Advanced SFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (MWe)</td>
<td>600</td>
<td>1,200</td>
</tr>
<tr>
<td>Core height (cm)</td>
<td>94</td>
<td>80</td>
</tr>
<tr>
<td>No. of fuel regions</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Fuel rod outer diameter (mm)</td>
<td>9.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Clad thickness (IC/MC/OC, mm)</td>
<td>1.02/0.72/0.59</td>
<td>0.6</td>
</tr>
<tr>
<td>Cycle length (EFPM)</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Charged TRU enrichment (IC/MC/OC, wt%)</td>
<td>14.94</td>
<td>13.16/ - /16.79</td>
</tr>
<tr>
<td>Average discharge burnup (MWD/kgHM)</td>
<td>80.4</td>
<td>100.1</td>
</tr>
<tr>
<td>Fissile Pu Loading (ton/GWe)</td>
<td>6.23</td>
<td>5.07</td>
</tr>
<tr>
<td>Sodium void reactivity ($)</td>
<td>7.51</td>
<td>7.25</td>
</tr>
<tr>
<td>Axial Moderator Layer (cm)</td>
<td>14.9 cm Graphite</td>
<td>None</td>
</tr>
</tbody>
</table>
## TRU Burner Core Design Parameters

<table>
<thead>
<tr>
<th>Core Design Parameters</th>
<th>TRU Burner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (MWe)</td>
<td>600</td>
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<tr>
<td>Core height (cm)</td>
<td>89</td>
</tr>
<tr>
<td>No. of fuel regions</td>
<td>3</td>
</tr>
<tr>
<td>Fuel rod outer diameter (mm)</td>
<td>7.0</td>
</tr>
<tr>
<td>Clad thickness (IC/MC/OC, mm)</td>
<td>1.01/0.93/0.73</td>
</tr>
<tr>
<td>Cycle length (EFPD)</td>
<td>332</td>
</tr>
<tr>
<td>Charged TRU enrichment (wt%)</td>
<td>30.0</td>
</tr>
<tr>
<td>Conversion ratio (fissile/TRU)</td>
<td>0.74/0.57</td>
</tr>
<tr>
<td>Burnup reactivity swing (pcm)</td>
<td>3,496</td>
</tr>
<tr>
<td>Average discharge burnup (MWD/kgHM)</td>
<td>127.9</td>
</tr>
<tr>
<td>Sodium void reactivity (EOEC, $)</td>
<td>7.50</td>
</tr>
</tbody>
</table>
Heat Transport System Design

- Improvement of safety and economics from KALIMER-600

- Consideration of Economics
  - Reduction of construction costs by increasing IHTS capacity
  - 600MWe/Loop

- Safety Improvement
  - Elimination of sodium-water reaction by Double wall tube steam generator
  - Secure redundancy and diversity by adopting
    - Passive RHRS(PDRC)
    - Active RHRS(IRACS)
PDRC Design Features

- **System Design Features**
  - Elimination of active components
  - Operation by natural circulation
  - No operator action
  - Major components
    - AHX, DHX, expansion vessel and piping

- **Design Improvement**
  - Prevention of sodium freezing in PDRC loop
    - Partial contact of DHX with sodium
    - Enhancement of local convection by DHX skirt
Mechanical Structure System

- **Cost competitive NSSS**
  - Increasing the reactor capacity
  - Minimizing number of loops
  - Simplifying systems & components
  - New ISI, LBB

- **Structural Design**
  - Reactor vessel size minimization
  - 2 loop layouts with large size equipments
  - Simplified IHTS piping with large piping diameters (135m/loop)
  - Integrated components (ISI)
  - LBB on RV & IHTS Piping

- **Future Work**
  - Structural design evaluation

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R&D Activities
PDRC Experiment

- **Objectives**
  - Assessment of initial & long term cooling capability by natural circulation
  - Verification of design concept
  - Establishment of database for validating system analysis code

- **Test scope**
  - Confirmation of basic design issues
    - Verification of heat removal capability by transient mode
    - Prevention of sodium solidification
    - Countermeasures for a postulated RV fracture
  - Dynamic simulation of natural circulation cool-down during key design basis events
S-CO$_2$ Brayton Cycle System

- **Objectives**
  - Enhancement of plant economics
  - Elimination of SWR

- **Status**
  - Establishment of system design concept coupled to advanced SFR
  - Development of MMS-LMR code for evaluation of system control logic
  - Performance test of air foil type PCHE

- **Future Work**
  - Evaluation of system transients
Na-CO₂ Interaction Test

- **Objective**
  - Investigation of Na-CO₂ interaction and its kinetic features

- **Surface reaction tests with well-manipulated conditions**
  - Confirmation of temperature dependency on reaction mechanism
  - Estimation of kinetic parameters

- **Future Work**
  - Validation of reaction models
Under-sodium Viewing Technology

- **Objective**
  - Development of ultrasonic waveguide sensor for under-sodium viewing

- **Experimental facility**
  - Manufacture of 10m long waveguide sensor module and feasibility test in water
    - 2mm resolution
  - Fabrication of double rotating scanner w/ radiation beam steering function
  - Development of C-scan program (Under-Sodium MultiVIEW)

- **Future Work**
  - Setup of mockup facility
  - Performance test in water and sodium
Metal Fuel Technology

- **Metal Fuel**
  - Selected for the Advanced SFR
  - To meet requirements of Gen IV

- **Practicality**
  - Requires Radiation shielded environment
  - Fuel fabrication technology
  - FMS cladding alloys
  - Advanced fuel casting system
    - Induction furnace
    - Gravity casting

- **Future Work**
  - Fuel irradiation test in HANARO
Validation of SFR Neutronics Code

- **Objectives**
  - Validation of reactor core analysis code (K-CORE) with critical experiments

- **Status**
  - Evaluation of BFS critical assemblies by using up-to-date nuclear data files, ENDF/B-VII.0, JEFF-3.1, JENDL-3.3, JENDL-AC2008
  - Calculation results for the BFS-73-1, BFS-75-1, BFS-55-1

- **Future Work**
  - Sensitivity and Uncertainty evaluation code
  - Development of adjusted multi-group cross section library

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**C/E k-effective**

**Sodium void reactivity**
Structural Integrity Evaluation

- **Objectives**
  - Development of SIE ASME-NH Computer Program Compliance to ASME-NH Rules for Elevated Temperature Design
  - Engineering Cost Reduction by Fast and Accurate Structural Integrity Evaluations

- **Status**
  - Complete SIE ASME-NH 1.0 Version with Design Material DB
  - Easy user interface program

- **Future Work**
  - Update Design Material DB
  - Design Procedures for Inelastic Analysis Method

![Diagram showing the process flow of Structural Integrity Evaluation]

Procedures for ETD by SIE ASME-NH

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Safety Analysis Code

- **Objectives**
  - To have a flexible modeling capability and enhanced accuracy for the safety evaluation of a SFR

- **Status**
  - Simulation of SHRT tests for the validation of MARS-LMR code
  - Simulation of Natural Circulation Test of Phenix EOL tests for code evaluation
  - Analysis of accidents for KALIMER

- **Future Work**
  - Simulation of KAERI Experiments
  - Accident analysis of Demonstration Reactor of Korea
Sodium Technology

Double wall tube test
Leak detection test

Analysis of SWR Phenomena
Wastage characteristics

Sodium velocity measurement
Low and local velocity measuring sensors

Acoustic leak detection
Performance test of SWR detection system
Summary

- Advanced SFR to satisfy the Gen IV technology goals
  - sustainability, safety and reliability, economics, proliferation resistance, and physical protection

- Advanced concept design studies from KALIMER-600
  - Breakeven vs. Burner
  - Heat transfer system
  - Mechanical Design

- Various R&D activities
  - To support the development of Advanced SFR concepts
  - PDRC Experiments
  - SCO2 cycle studies
  - Under-sodium viewing
  - Metal Fuel
  - Development and Validation of Analysis codes
    - Neutronics, Structure integrity evaluation, Safety, Performance
  - Sodium technology