Advanced SFR Concept Design Studies at KAERI

International Conference on Fast Reactors and Related Fuel Cycles (FR09), Kyoto, Japan

7 December 2009

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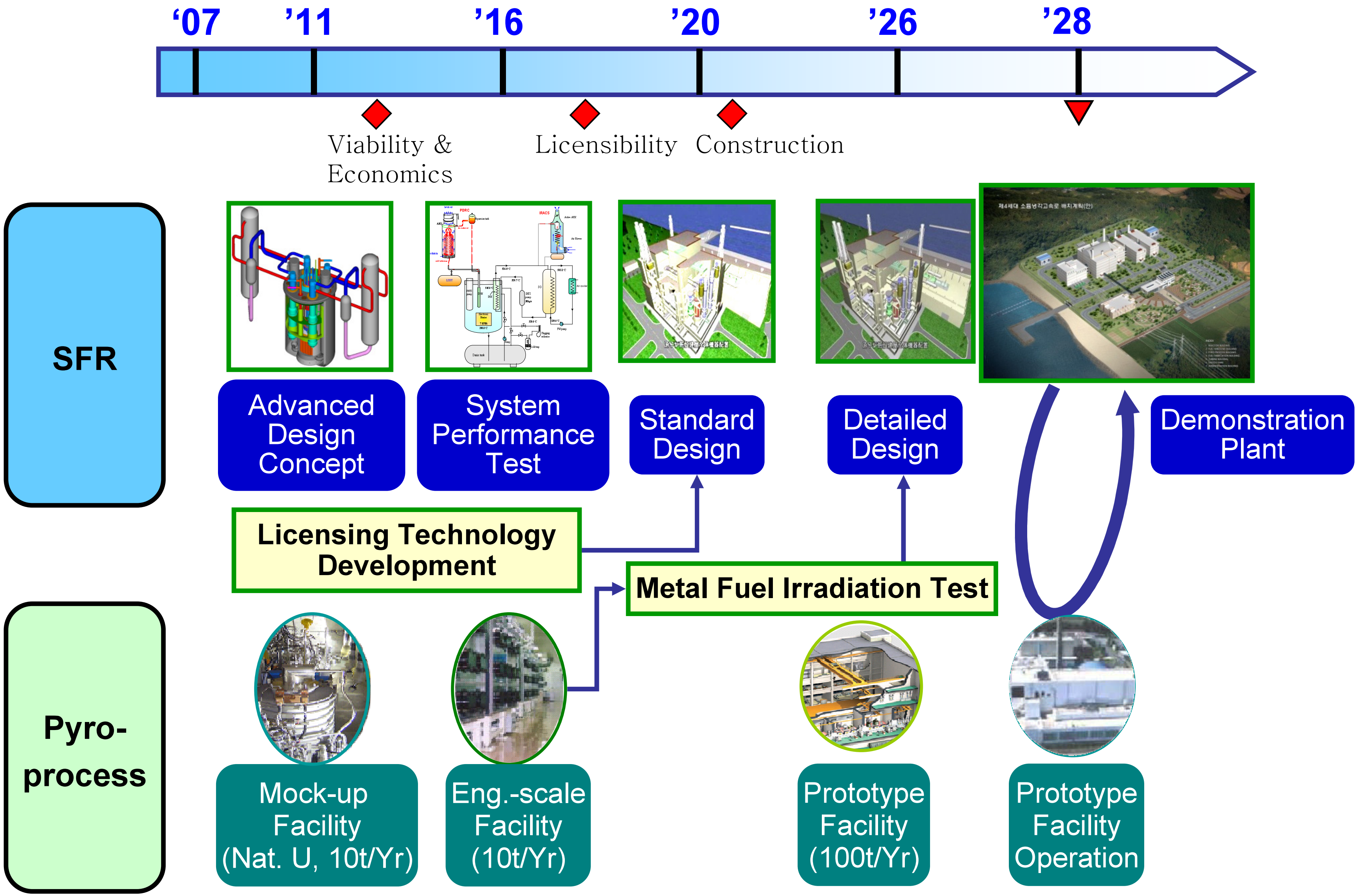
Outline

- I Introduction
- II Development of advanced SFR concept
- III R&D Activities
- IV Summary

I Introduction

Long-term Plan for SFR and Pyroprocess



Technology Goals and R&D Activities

Technology Goals of Gen IV Reactor System

Sustainability	Proliferation Resistance	Economics	Safety
▪ Burner CR: 0.5-0.8 ▪ Breakeven CR: 1.0	▪ No Blanket	▪ FOAK - 4 ¢/kWh - 2,000 $/kWe	▪ CDF < 10^{-6}/R·Y ▪ Grace time of more than three days

R & D

Sustainability / Proliferation Resistance	Economics	Safety	
– Burner core development – Breakeven core development – Development of MA bearing metal fuel	- Size optimization - Core and structure optimization - S-CO_2 Brayton cycle system - Integrated components - High temp LBB	PDRC concept validation ⇒Passive safety	Validation of analysis codes ⇒Inherent safety

Conceptual Design of Advanced SFR

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

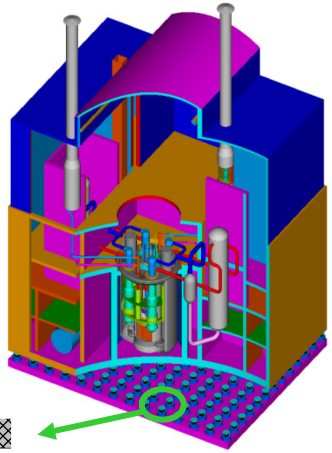
II

Development of Advanced SFR Design Concept

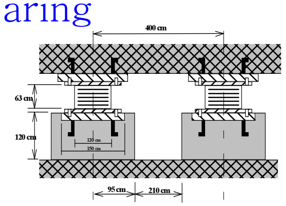
KALIMER-600 System

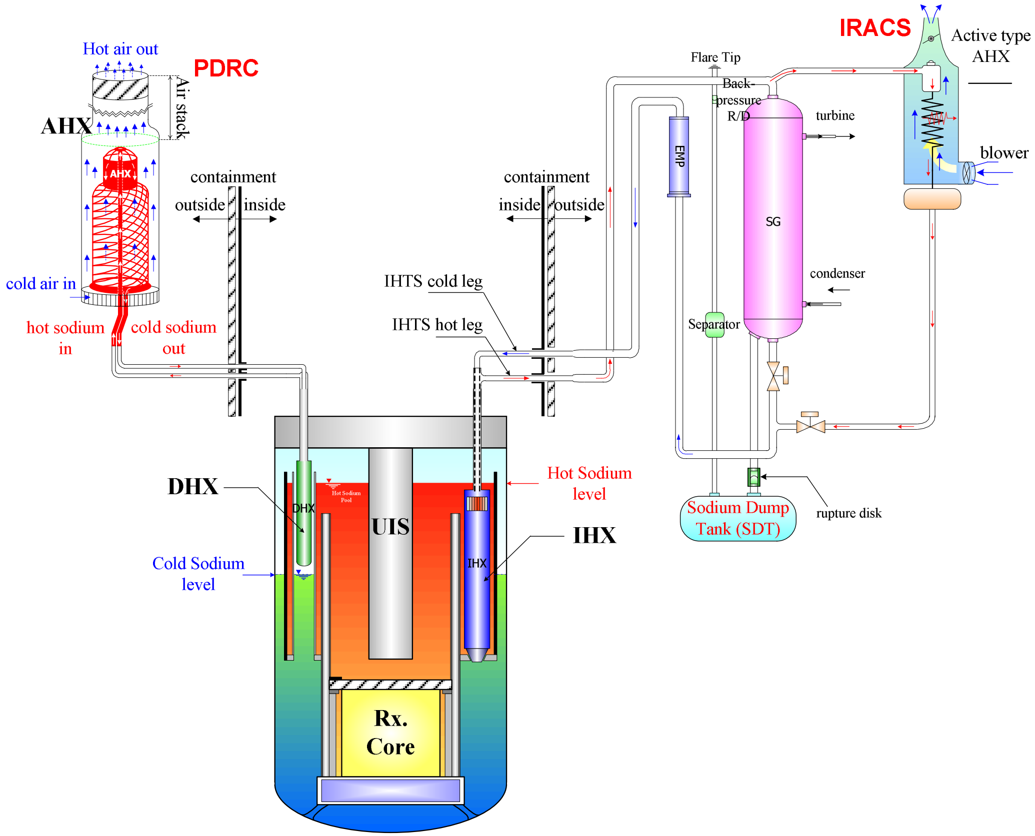
Key Design Features

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



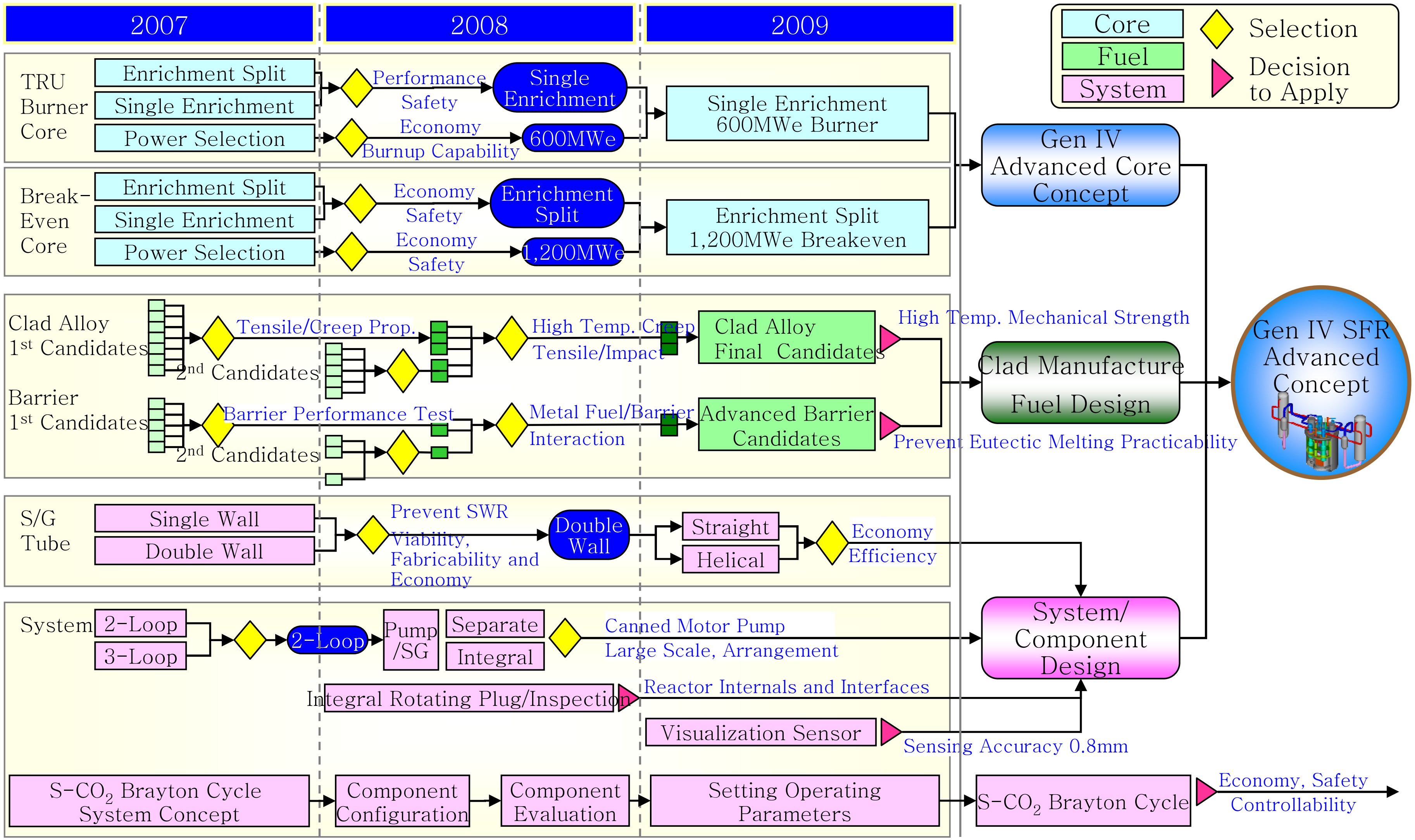
2-D Seismic Bearing





Heat transport system of KALIMER-600

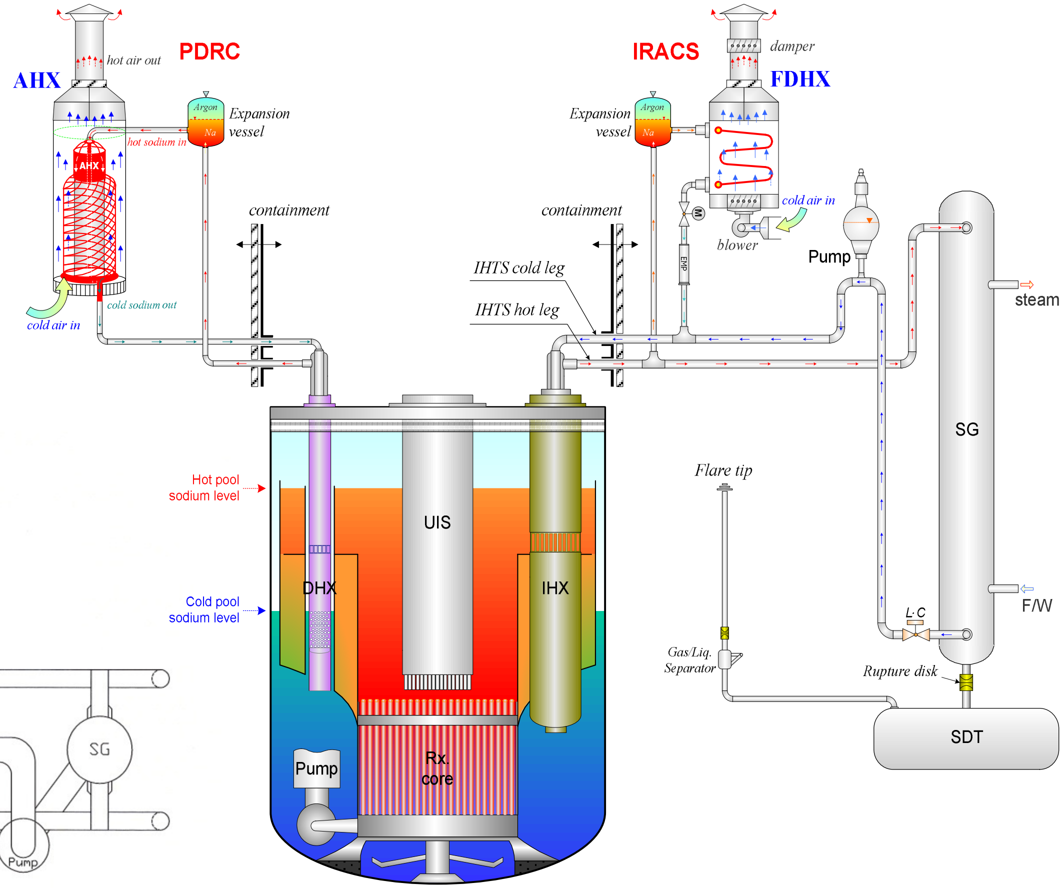
Design Studies of Advanced Concept



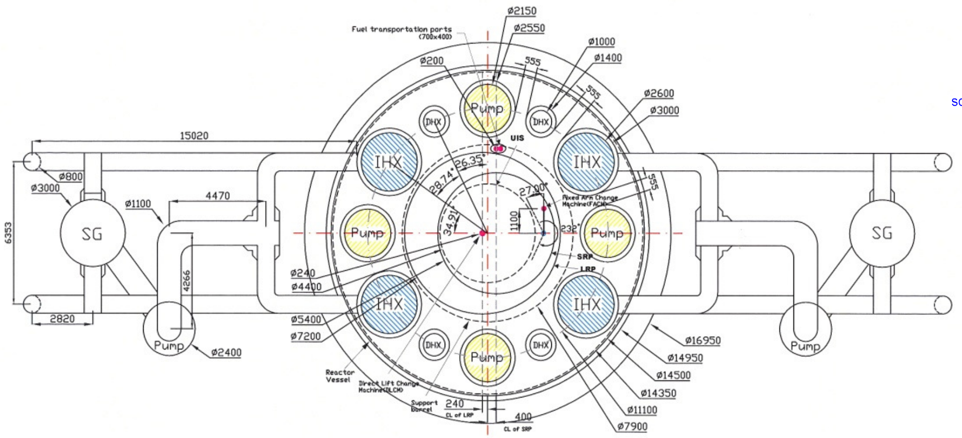
Advanced Concept (1200MWe)

Key Design Features

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

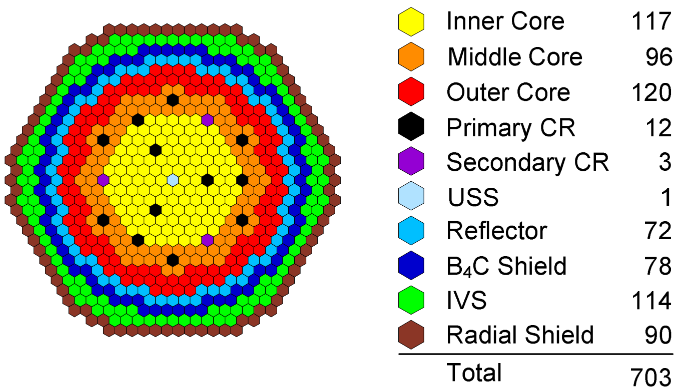


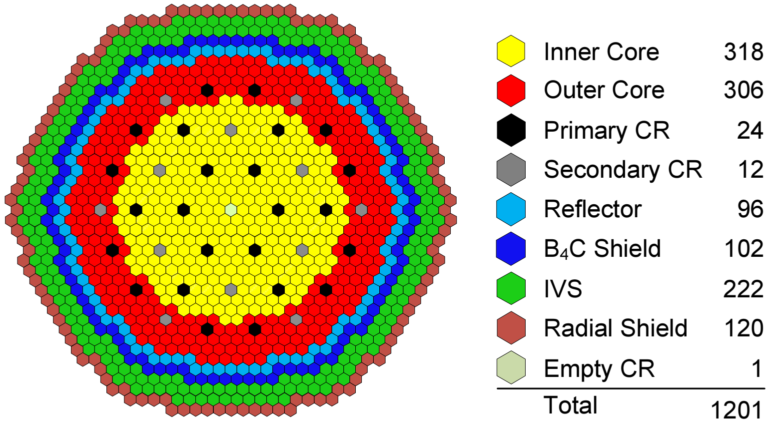
Heat transport system of advanced pool type SFR



Conceptual NSSS Layout

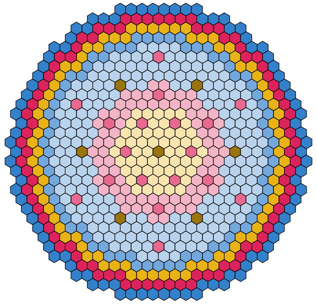
Breakeven Core Design





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

TRU Burner Core Design

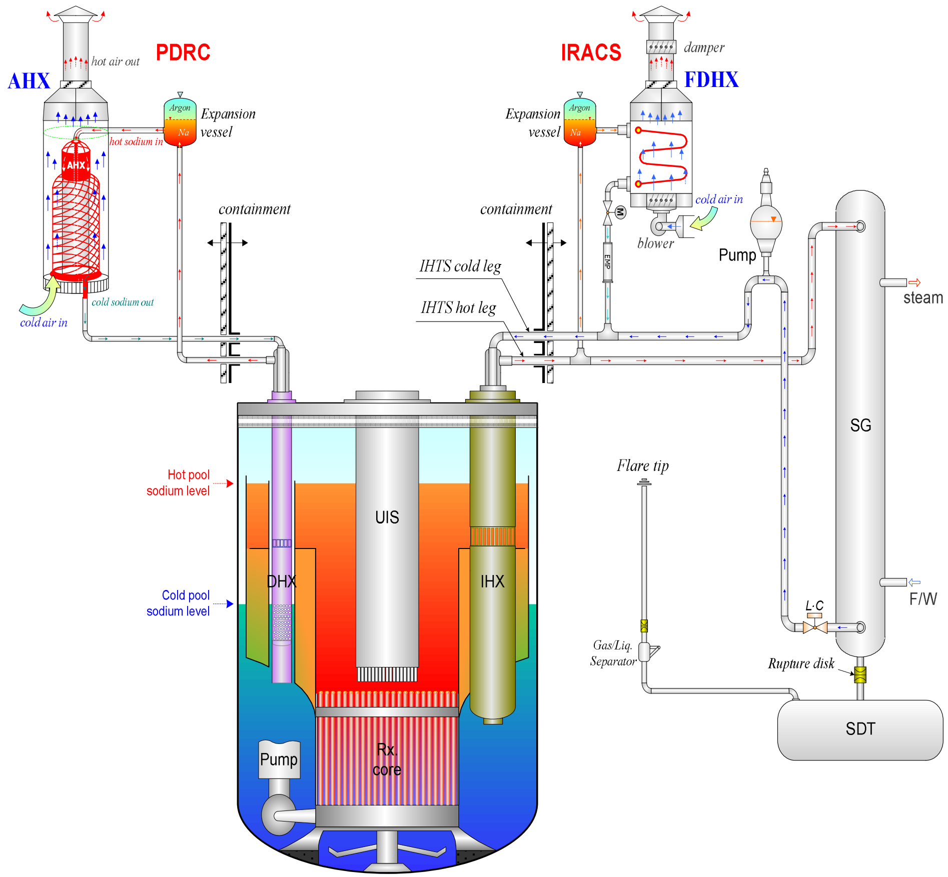


	Inner Core	54
	Middle Core	72
	Outer Core	198
	Primary CR	18
	Secondary CR	7
	Reflector	72
	B_4C Shield	78
	IVS	84
	Radial Shield	90
	Total	673

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

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)



Heat transport system of advanced pool type SFR

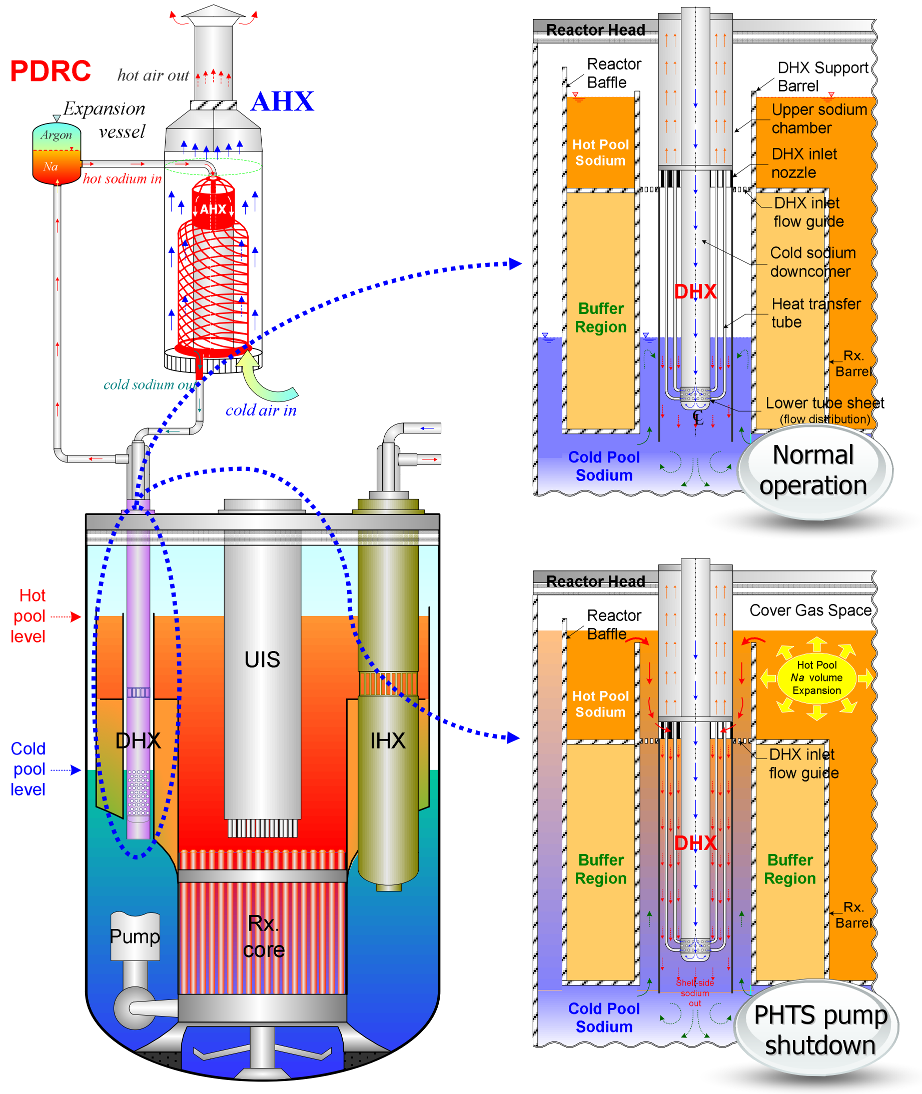
PDRC Design Features

❑ 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



PDRC design concept

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Mechanical Structure System

❑ Cost competitive NSSS

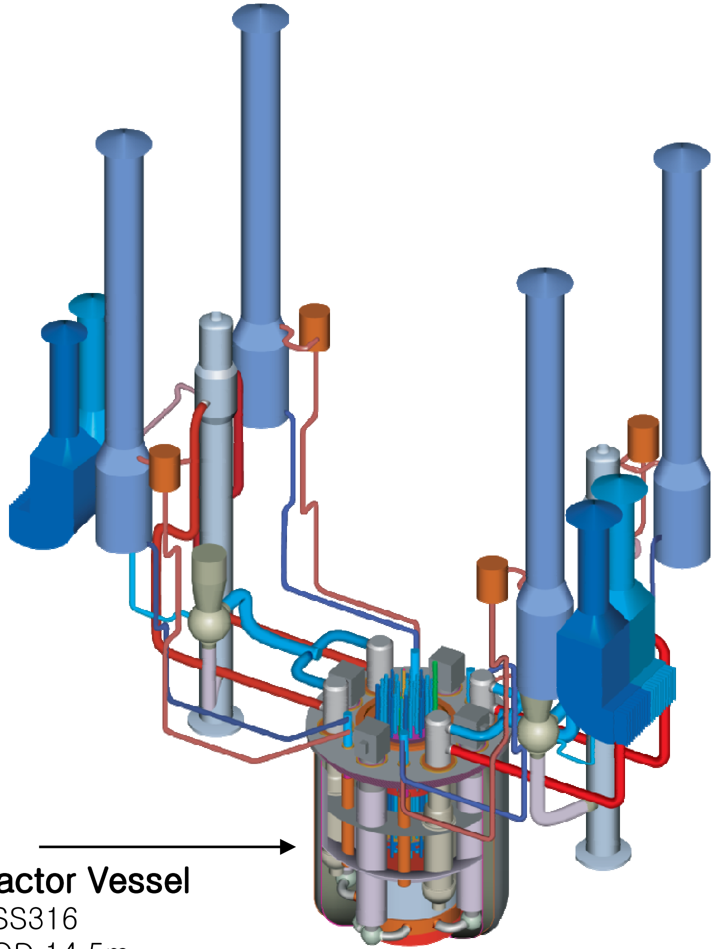
- Increasing the reactor capacity
- Minimizing number of loops
- Simplifying systems & components
- New ISI, LBB

❑ 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



Reactor Vessel
- SS316
- OD 14.5m
- Length 18.0m
- Thickness 0.05m

Conceptual NSSS Design

III R&D Activities

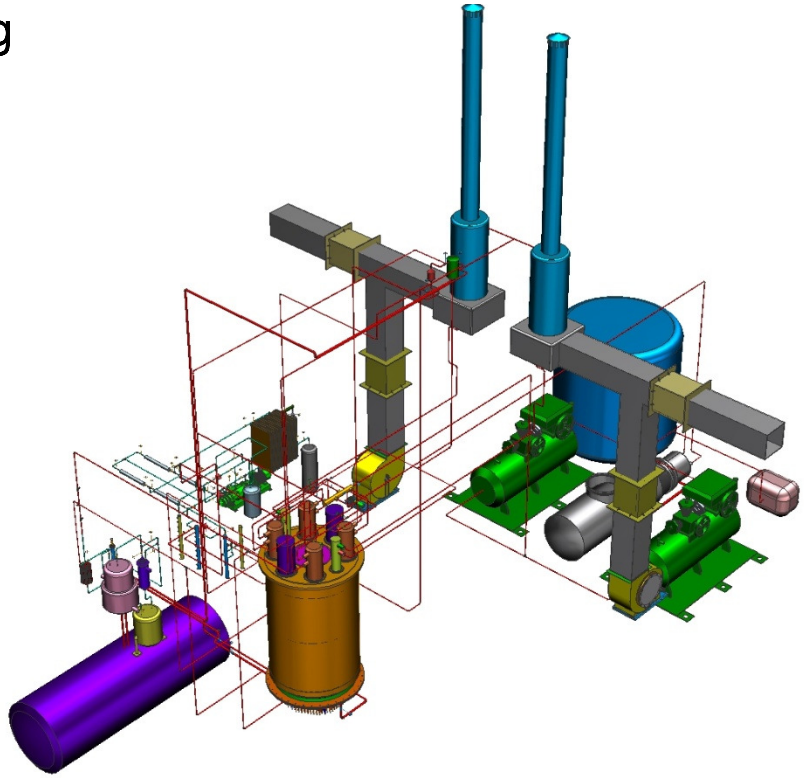
PDRC Experiment

❑ 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



Layout of Experimental Facility

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S-CO_2 Brayton Cycle System

❑ Objectives

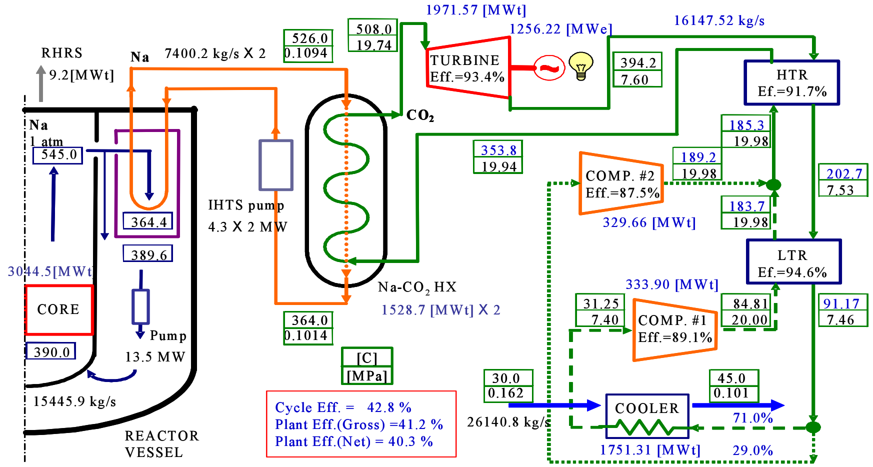
- Enhancement of plant economics
- Elimination of SWR

❑ Status

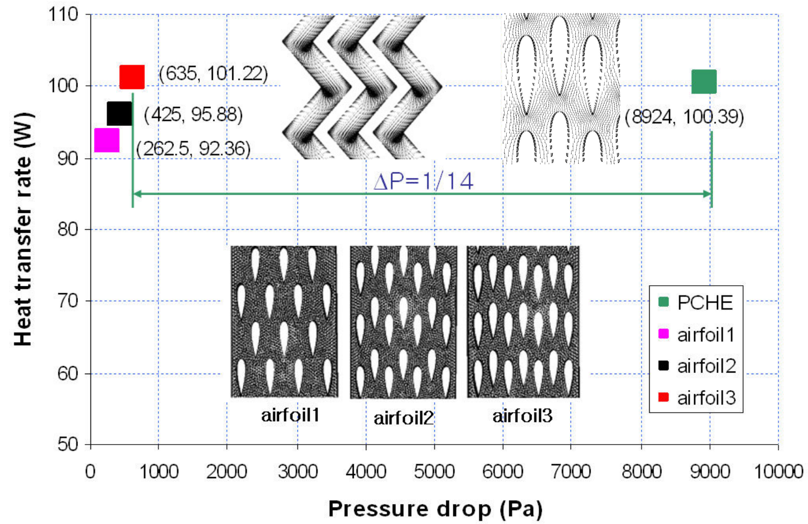
- Establishment of system design concept coupled to advanced SFR
- Development of MMS-LMR code for evaluation of system control logic
- Performance test of air foil type PCHE

❑ Future Work

- Evaluation of system transients



S-CO_2 Brayton cycle for SFR



Performance of air foil type PCHE

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Na-CO_2 Interaction Test

❑ Objective

– Investigation of Na-CO_2 interaction and its kinetic features

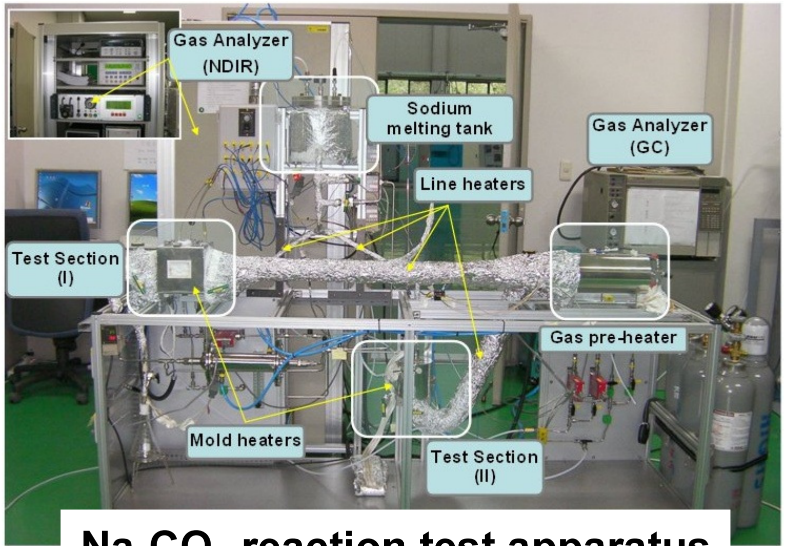
❑ Surface reaction tests with well-manipulated conditions

– Confirmation of temperature dependency on reaction mechanism

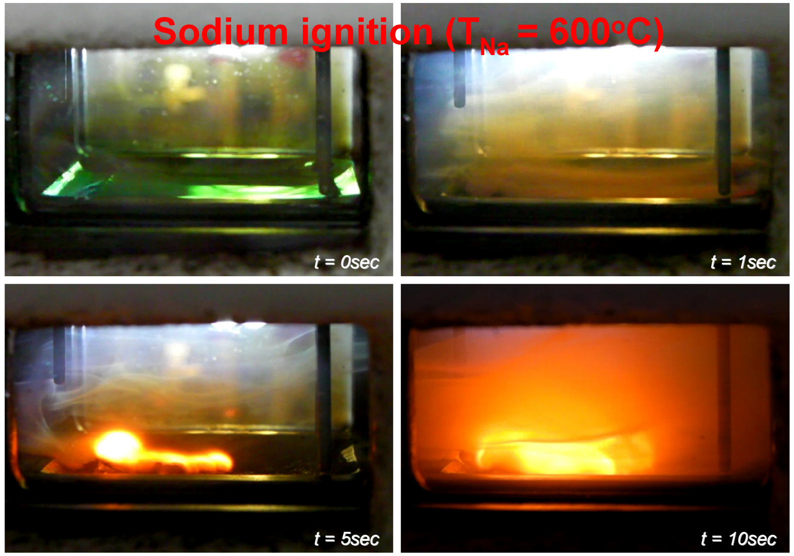
– Estimation of kinetic parameters

❑ Future Work

– Validation of reaction models



Na-CO_2 reaction test apparatus



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

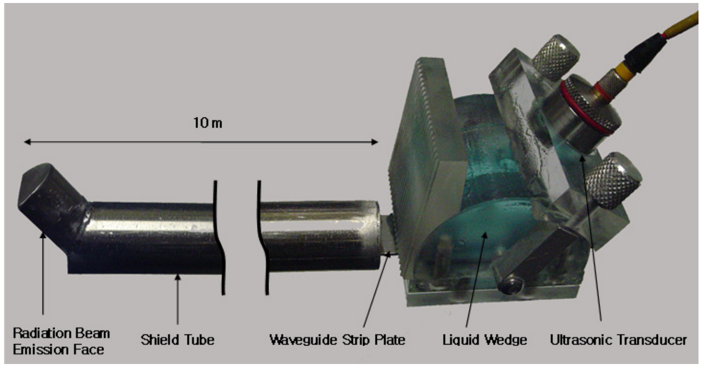
– Fabrication of double rotating scanner w/ radiation beam steering function

– Development of C-scan program (Under-Sodium MultiVIEW)

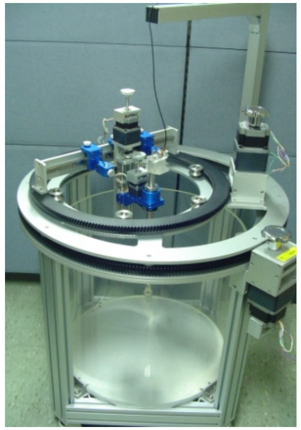
❑ Future Work

– Setup of mockup facility

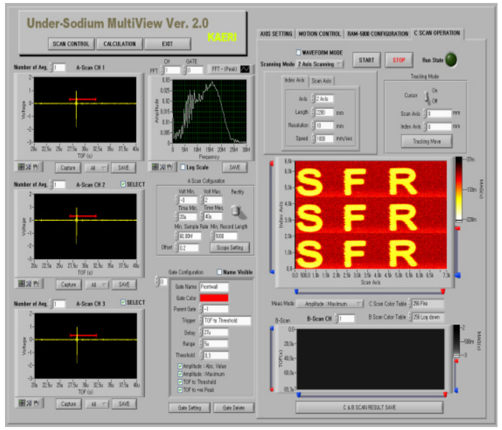
– Performance test in water and sodium



Ultrasonic Waveguide Sensor module



Double rotating scanner

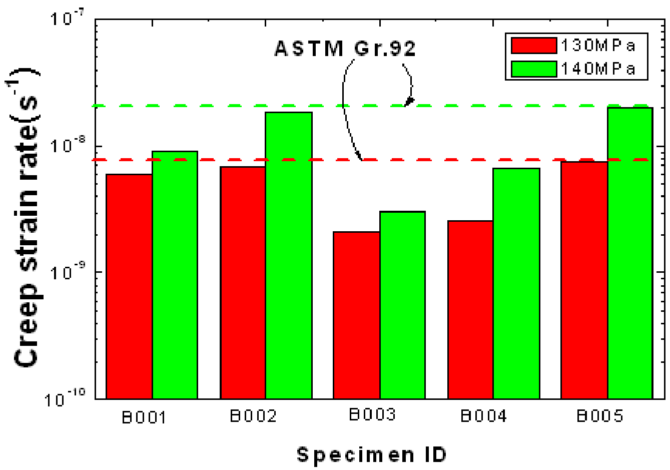


Under-Sodium MultiVIEW

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

Fuel casting system



Creep Strain Rate of New Cladding Alloys

Validation of SFR Neutronics Code

❑ Objectives

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

❑ Status

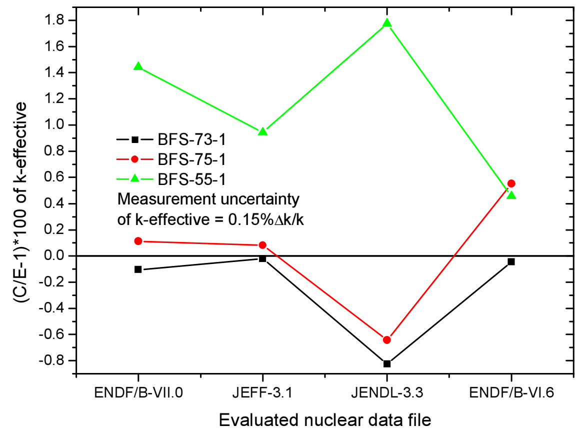
– Evaluation of BFS critical assemblies by using up-to-date nuclear data files, ENDF/B-VII.0, JEFF-3.1, JENDL-3.3, JENDL-AC2008

– Calculation results for the BFS-73-1, BFS-75-1, BFS-55-1

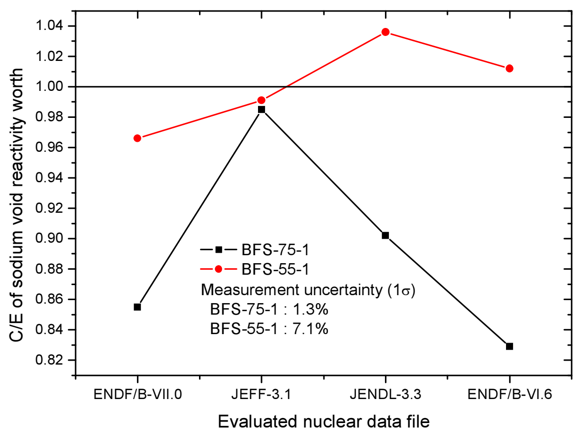
❑ Future Work

– Sensitivity and Uncertainty evaluation code

– Development of adjusted multi-group cross section library



C/E k-effective



Sodium void reactivity

Structural Integrity Evaluation

❑ Objectives

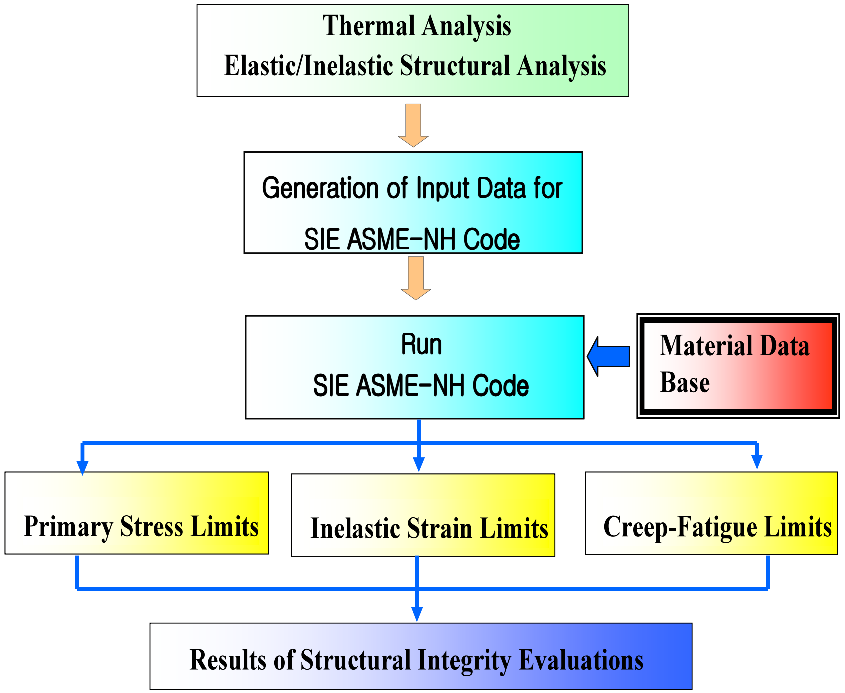
- Development of SIE ASME-NH Computer Program Compliance to ASME-NH Rules for Elevated Temperature Design
- Engineering Cost Reduction by Fast and Accurate Structural Integrity Evaluations

❑ 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



Procedures for ETD by SIE ASME-NH

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

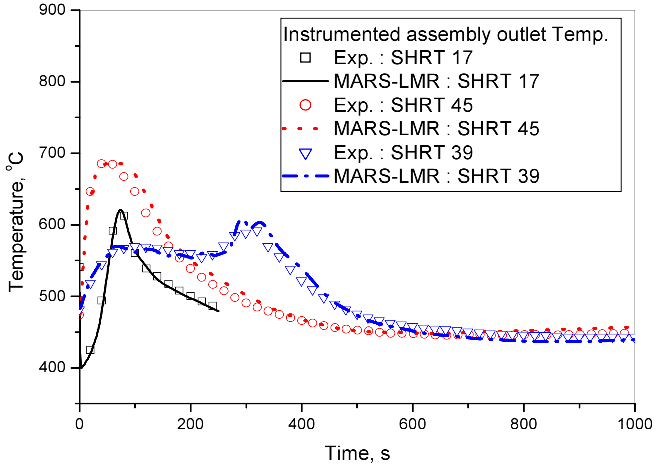
– Simulation of Natural Circulation Test of Phenix EOL tests for code evaluation

– Analysis of accidents for KALIMER

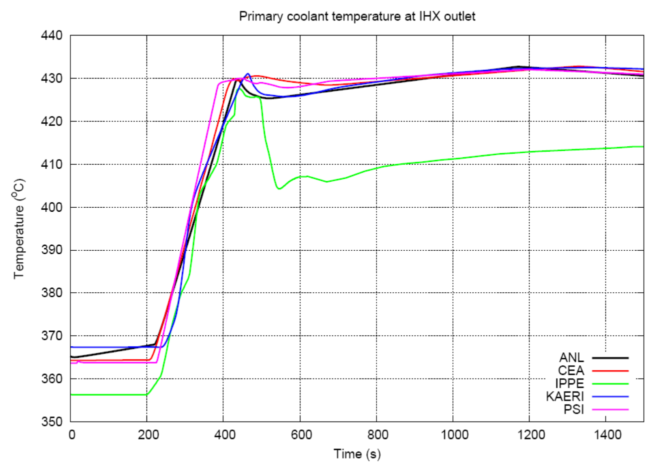
❑ Future Work

– Simulation of KAERI Experiments

– Accident analysis of Demonstration Reactor of Korea



Simulation of SHRT tests



Benchmark calculation of Phenix EOL test

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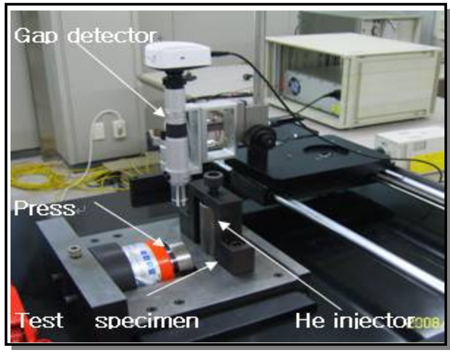
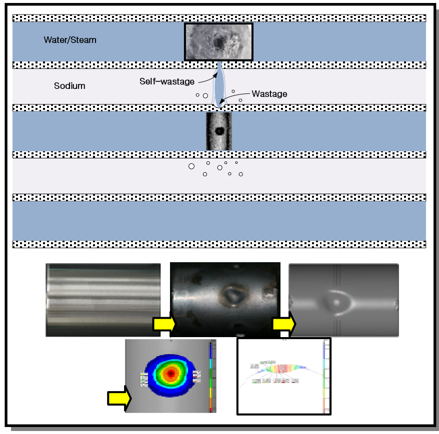
Sodium Technology



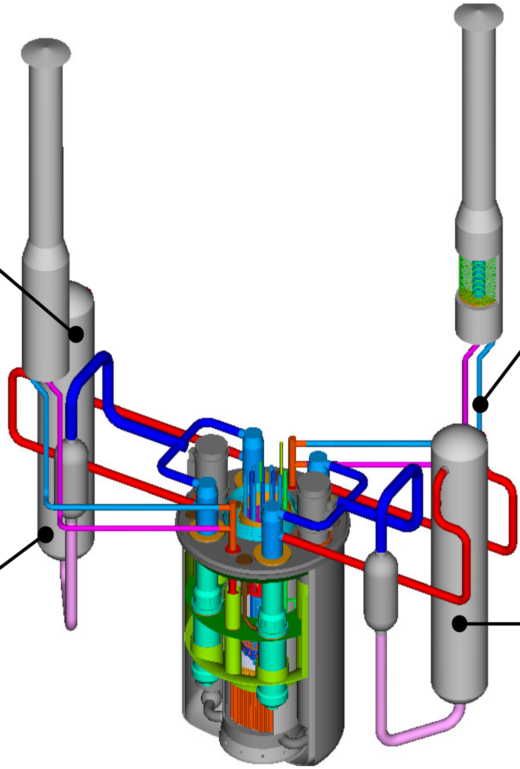
Double wall tube test

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