Korean Strategy for Sustainable Nuclear Energy Development

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Outline

I Status of Nuclear Energy in Korea

II R&D Programs at KAERI

- II-1 Sodium Fast Reactor
- II-2 Pyroprocessing
- II-3 Reactor System Development
  - Small Integral Reactor : SMART
  - Research Reactor

III Summary

I

Status of Nuclear Energy in Korea

Nuclear Power Plants in Korea

◆ **Plants Under Construction**

− ***OPR1000*** *: Shin-Wolsung (#2)*

− ***APR1400*** *: Shin-Kori (#3,4), Shin-Ulchin (#1,2)*

- 4 additional APR1400 units by 2022

Units [MWe]

Site	In Operation	Under Construction	Total (2018)
(Sin)Kori	6 (5,137)	2 (2,800)	8 (7,937)
(Sin)Wolsong	5 (3,779)	1 (1,000)	6 (4,779)
Yonggwang	6 (5,900)	-	6 (5,900)
Ulchin	6 (5,900)	2 (2,800)	8 (8,700)
Total	23 (20,716)	5 (6,600)	28 (27,316)

***** ***Shin-Kori #2 & Shin-Wolsong #1 started commercial operation in July, 2012***

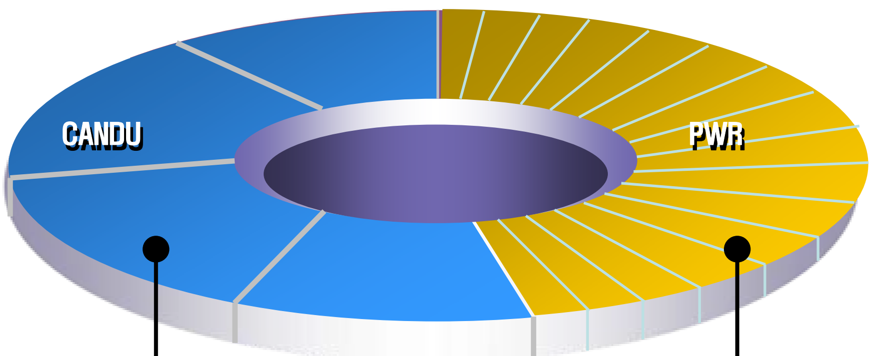
***** ***Nuclear installed capacity is 25.4 %.***

Spent Fuel Generation

Attribute

- High radioactivity and heat : emits about 12 kW/ton after 1 yr cooling
- High radiotoxicity : 300,000 yrs will be taken to be natural uranium level
- Energy resource : contains 1% Pu and 93% Uranium

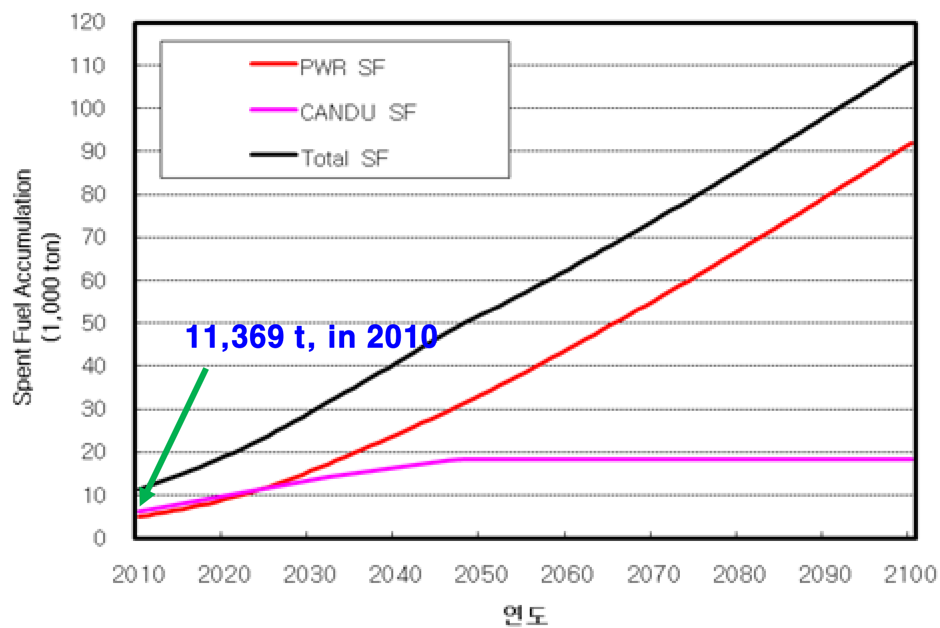
Annual Spent Fuel Generation 760t/yr



- 95 t/yr,unit
- 4 units
- 380 t/yr

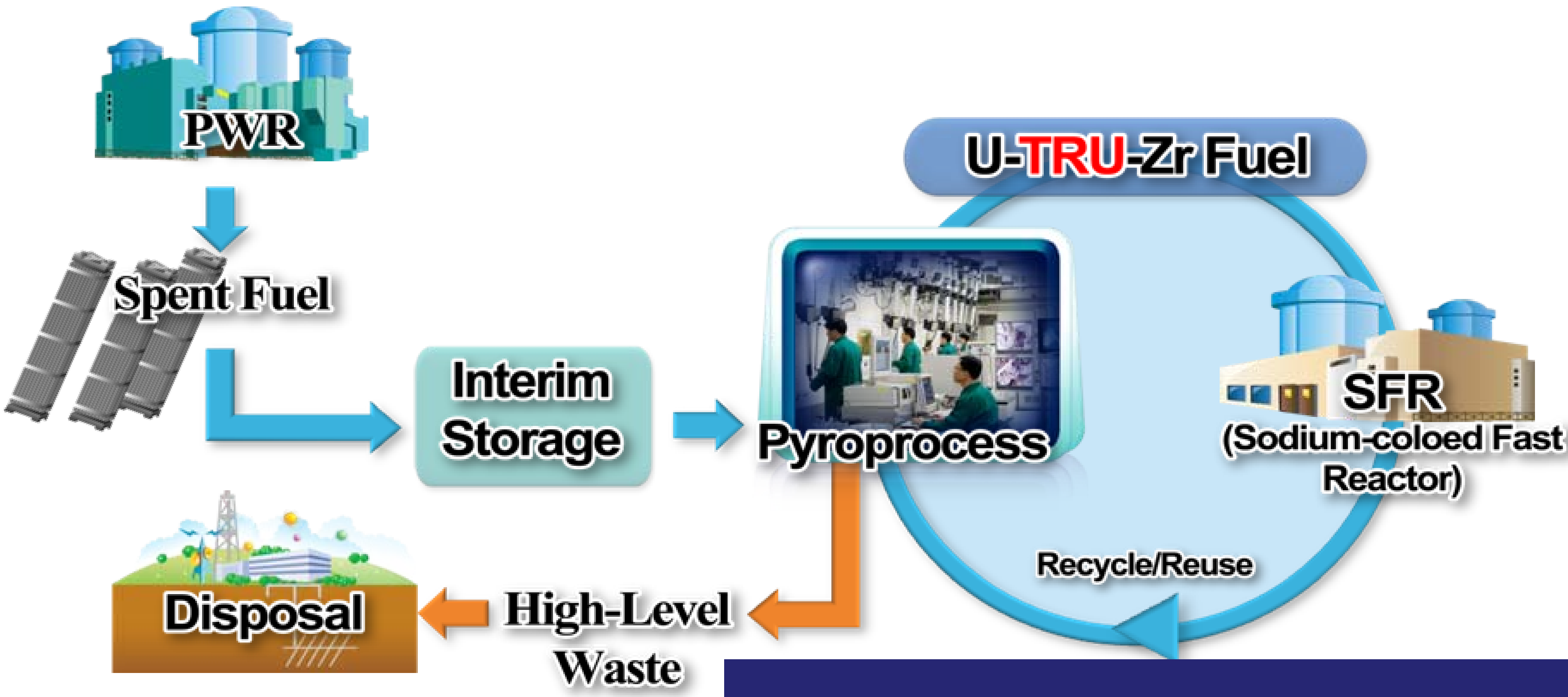
- 20 t/yr, unit
- 19 units
- 380 t/yr

Projection of Spent Fuel Generation



Korean Advanced Nuclear Energy System

Korean, Innovative, Environment-Friendly, and Proliferation-Resistant System for the 21st C (KIEP-21)



- Saves disposal space by a factor of ~100
- Reduce radiotoxicity to the level of natural uranium in roughly 300 years rather than 300,000 years
- Increases U utilization
- Ensures intrinsic proliferation resistance

II-1

Sodium Fast Reactor

Prototype SFR

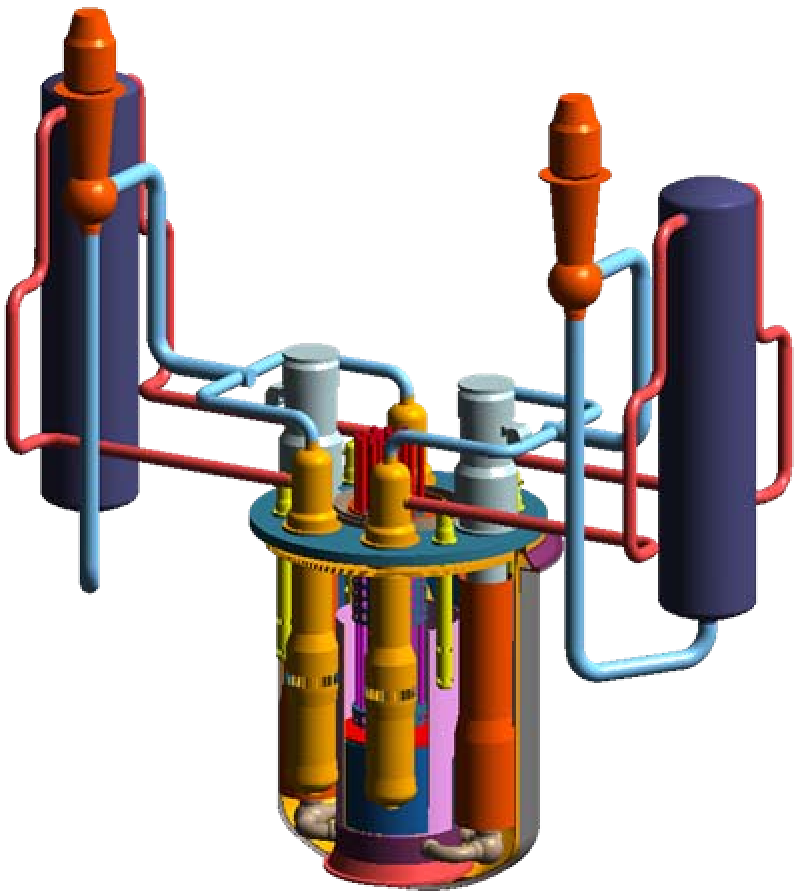
❖ Objectives

– Irradiation test of TRU fuels

– Acquisition of design, construction, and operation technologies

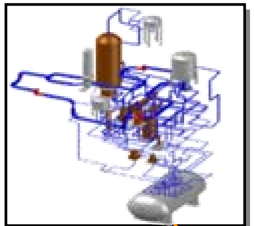
❖ Key Design Features (Draft)

- 150 MWe
- Pool-type Reactor
- Fuel : U-Zr -> U-TRU-Zr Metal
- Clad : FMS
- Core I/O Temp : 390/545 ℃
- DHR System : PDRC/ADRC
- 2-loop IHTS/SGS
- Single or Double Wall SG Tube
- Superheated Rankine or S-CO_2 Cycle



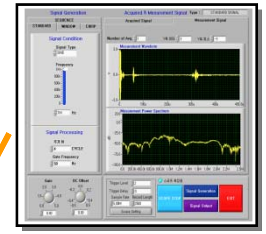
SFR R&D Activities

STELLA-1 Installation

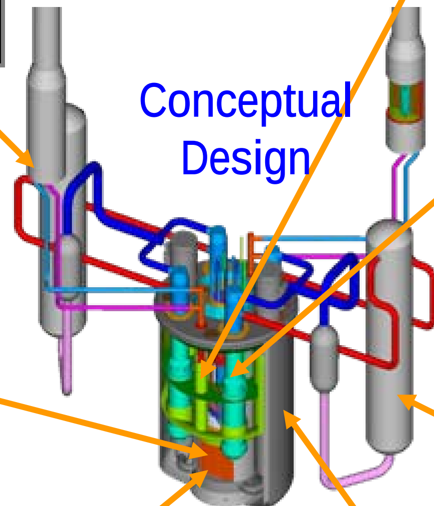


- Design and manufacture completed
  - ✓ Heat exchangers and mechanical pump
  - ✓ Main component: tank, heater, cold trap, electro-magnetic pump, etc

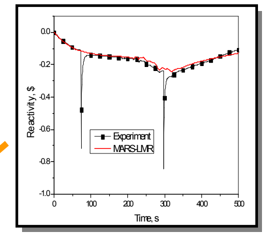
Under-Sodium Viewing Technology



- Waveguide Sensor Module
- Performance Tests in Sodium

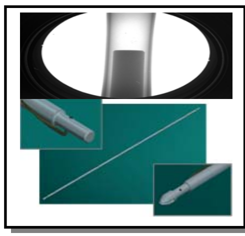


Validation of Safety Analysis Code Models



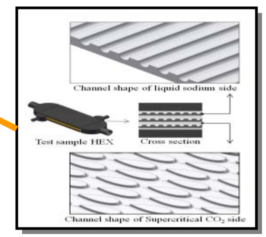
- Analysis of Phenix End of Life Test
- Reactivity model evaluation with EBR-II test

Metallic Fuel

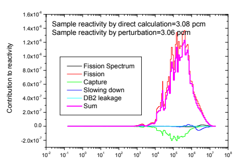


- Fuel Rod Fabrication((7.0mm OD, 1000mm L)
- HT9 Cladding Fabrication

New Compact Heat Exchanger for S-CO_2 Brayton Cycle



- Development of a new compact Na/CO_2 heat exchanger
- Construction of test facility



V&V of core neutronics code system

- Sensitivity analysis code development (APSTRACT)
- Generation of adjusted cross section
- Reactor physics experiment in collaboration with IPPE

V/V of COMMIX code model by water mockup facility

- Measurement of velocity field by PIV
- Measurement of pressure loss of components in flow path

Large-scale Sodium T/H Test Program - STELLA

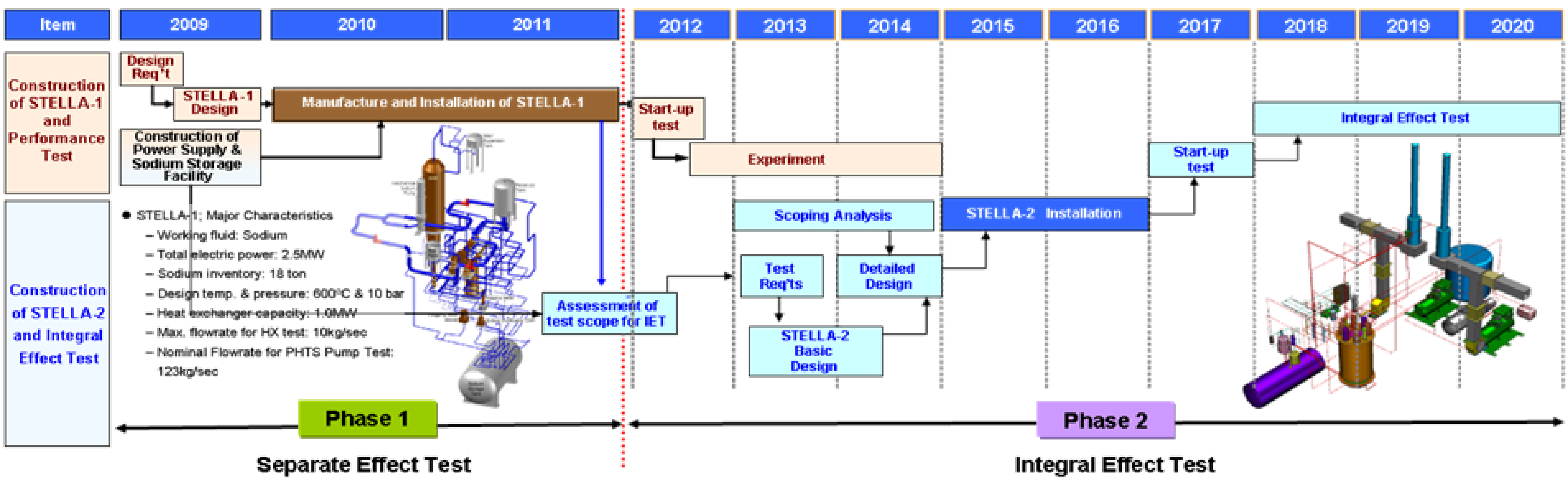
- **Objective**
  - Performance evaluation of major components & verification of heat exchanger design codes
  - Integral effect test to support standard design approval for the prototype SFR
- **Current status**
  - STELLA-1 construction is completed
  - Start-up test is in progress
- **Schedule**

Recent view of STELLA-1 facility

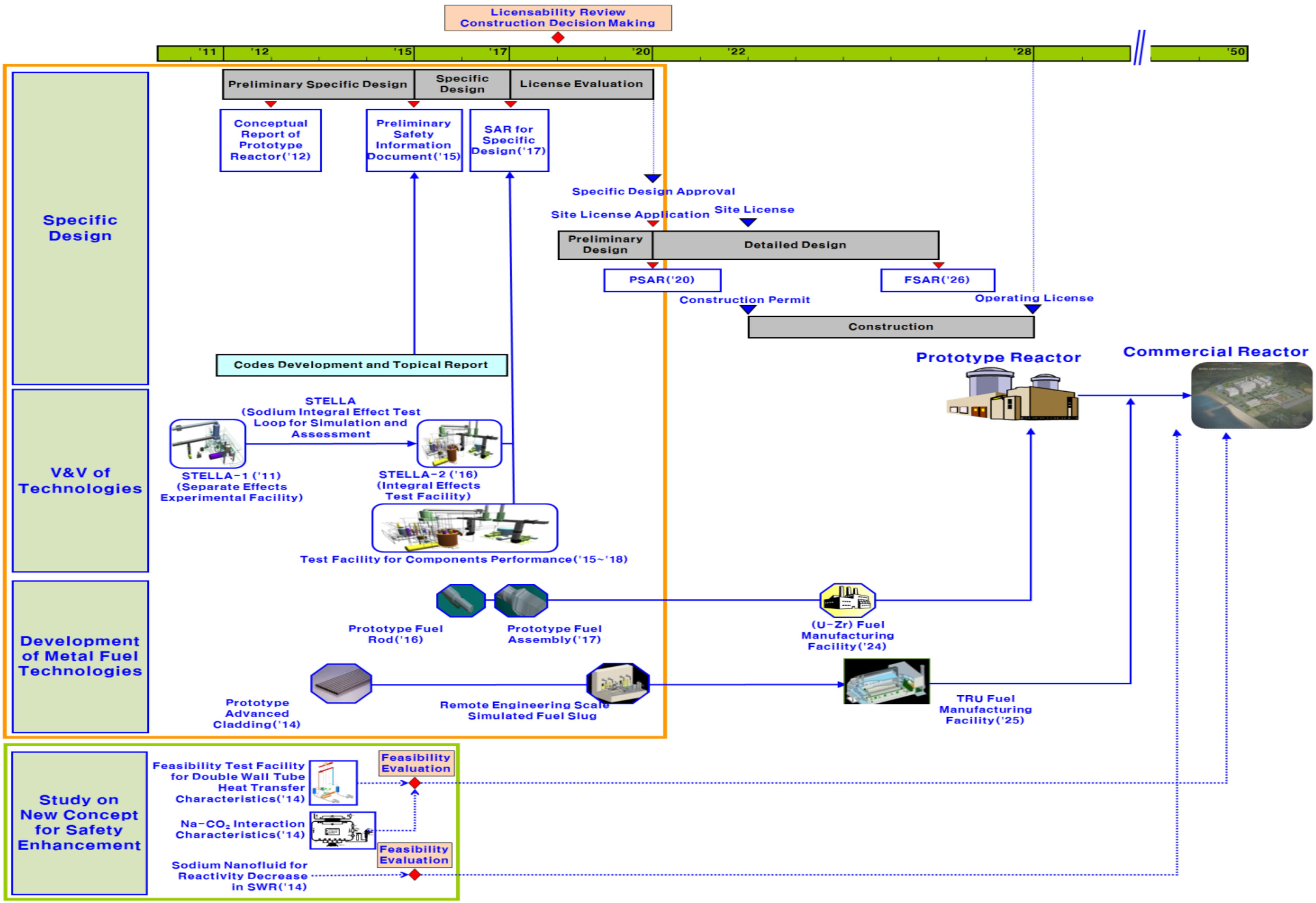
DHX

AHX

Mechanical pump



Prototype SFR Development Schedule



II-2 Pyroprocessing

Why Pyroprocessing?

- ❖ Pyroprocess produces Pu with actinides(U, Np, Am) together.
  - Have a good intrinsic barrier of proliferation resistance
- ❖ The product is handled in shielded area.
  - Easy to use containment & surveillance

(Comparison of Characteristics of PR and Safeguards)

<table>
<tr><th colspan="3">Characteristics Items</th><th>Pyroprocess</th><th>Wet Reprocess</th></tr>
<tr><td rowspan="3">Proliferation Resistance</td><td colspan="2">Radiation field</td><td>Very High</td><td>Low</td></tr>
<tr><td colspan="2">Impurity</td><td>High</td><td>Low</td></tr>
<tr><td colspan="2">Spontaneous neutron generation</td><td>High</td><td>Low</td></tr>
<tr><td rowspan="4">Safeguards</td><td rowspan="2">Material control & Accounting</td><td>Measurement error</td><td>High</td><td>Low</td></tr>
<tr><td>Sampling error</td><td>High</td><td>Low</td></tr>
<tr><td colspan="2">Containment & surveillance</td><td>Good</td><td>Low</td></tr>
<tr><td colspan="2">Near real time accounting</td><td>Difficult</td><td>Easy</td></tr>
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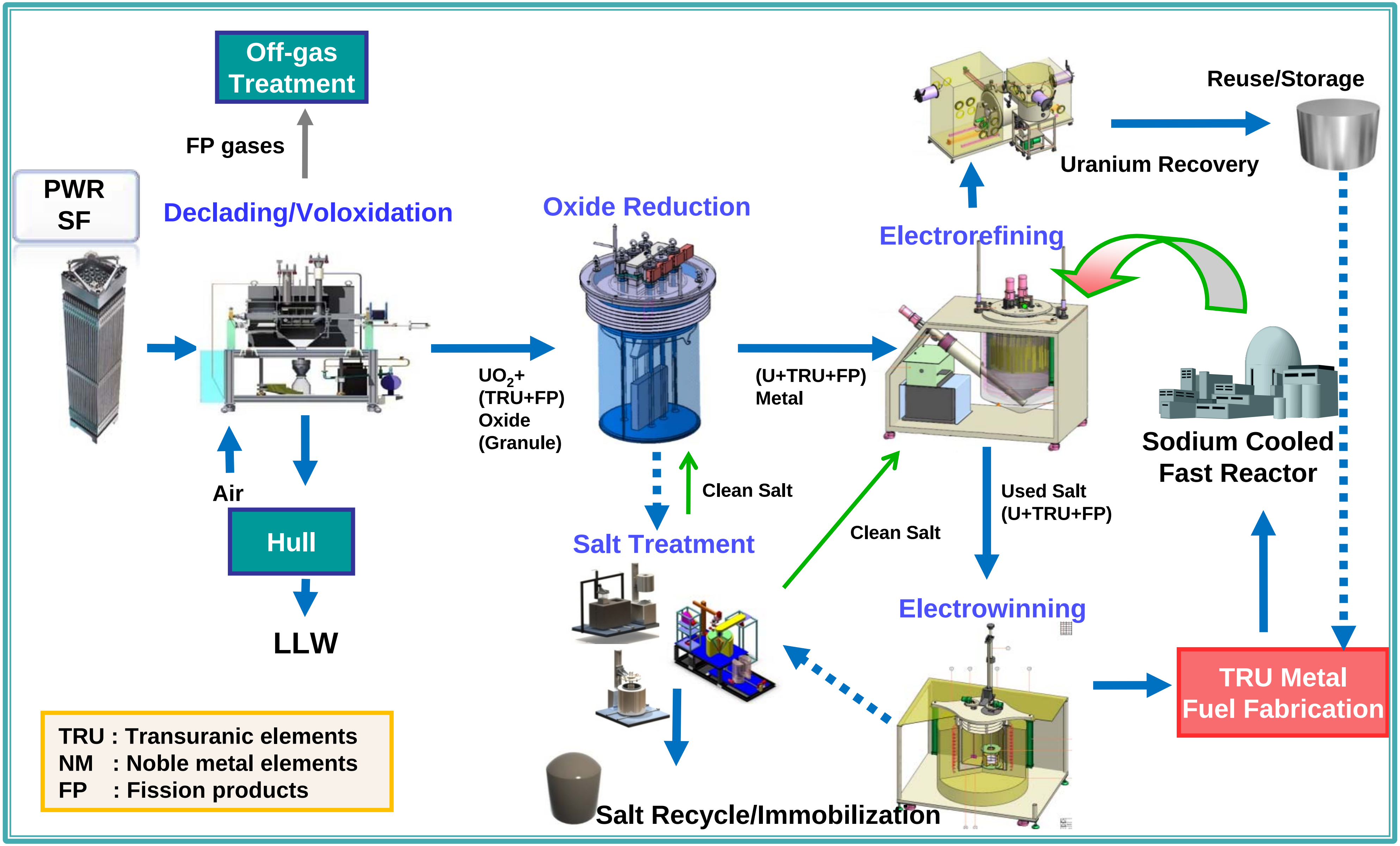
KAERI'S R&D Areas in Pyroprocessing



Process Technology Development

- **Objectives**
  - Increase throughput (graphite cathode, planar electrode)
  - Simple and easy remote operability
  - Enhance interconnection between unit processes
  - Reduce waste volume (by new technology such as crystallization)

- **Improvement**
  - High performance electrolytic reduction process
  - Graphite cathode employment to recover U in electrorefining system
  - Application of residual actinides recovery (RAR) system
  - Crystallization method applied to recover pure salt from waste mixture

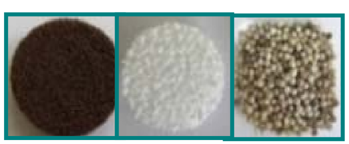
Waste Treatment Technology Development

- ❖ Optimization of waste treatment process
- ❖ Minimization of high-level waste amounts by recycling
- ❖ Integrated management of waste forms for final disposal

Key Tech. Development ('97 ~ '11)	Engineering-scale Demo. ('12 ~ '16)	Scale-up & Design (KAPF) ('17 ~ '25)
Lab.-scale test	Eng.-scale test (PRIDE), Active Test(DFDF/ACPF)	

Volume reduction of Waste

- ❑ **Gaseous Waste** : Cs,Tc, I
  - − Selective off-gas capturing
  - − Immobilization of spent filters
- ❑ **Metal Waste** : Hull, NFBC
  - − Zr recovery from hull

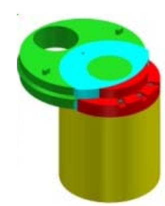
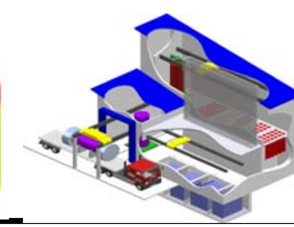



Recycling of Salt Waste

- ❑ **LiCl & LiCl-KCl Salt Waste**
  - − Removal of FPs form salt waste ➲ recycling of the purified salt
  - − Fabrication of high-integrity waste forms : SAP & ZIT

Integrated Waste Management

- ❑ **Packaging & Transp.**
- ❑ **Decay Storage**
  - − Logistics study
  - − Design and safety analysis

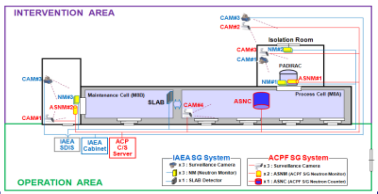



Nonproliferation System Development

◆ Objectives

- Development of PR/Safety Enhanced Hot Cell design and Safeguards Technology for an Engineering-scale Pyroprocessing Facility

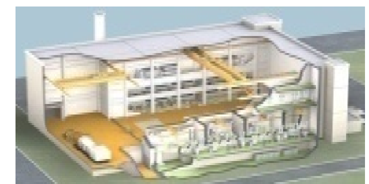
	2002	2007	2012	2017	2022
Milestone	ACPF Safeguards Implement. →	PRIDE SG System Dev. →	REPF 3S by Design →	KAPF 3S by Design →	



ACPF (Lab. Scale, SF)

PRIDE (Eng. Scale, Simfuel)

REPF (Eng.-scale, SF)



KAPF (Prototype)

◆ International Collaboration

- **IAEA** (ROK-IAEA MSSP)
- **US** (Joint Fuel Cycle Study)
- **INPRO/GIF** (PR/PP)

ACPF Facility

ACPF(Advanced spent fuel Conditioning Facility)

- **Purposes**
  - Demonstration of lab-scale electrolytic reduction process using spent fuel
- **General Features**
  - Inside dimension of Hot Cell: 11mL x 2mW x 4.3mH
  - Environment : Air cell
  - Location: Basement of IMEF at KAERI
- **Near-term schedule**
  - Refurbishment work is planned to install inert compartment area in hot cell

Hot Cell Area

Operation Area

PRIDE Facility

❑ Purpose

- Test facility to evaluate performance (cold-run) and scale-up issues of full-spectrum pyroprocessing technology
- Equipment design improvement
- Material measurement & flow study
- Personnel training & operation experience

❑ Schedule

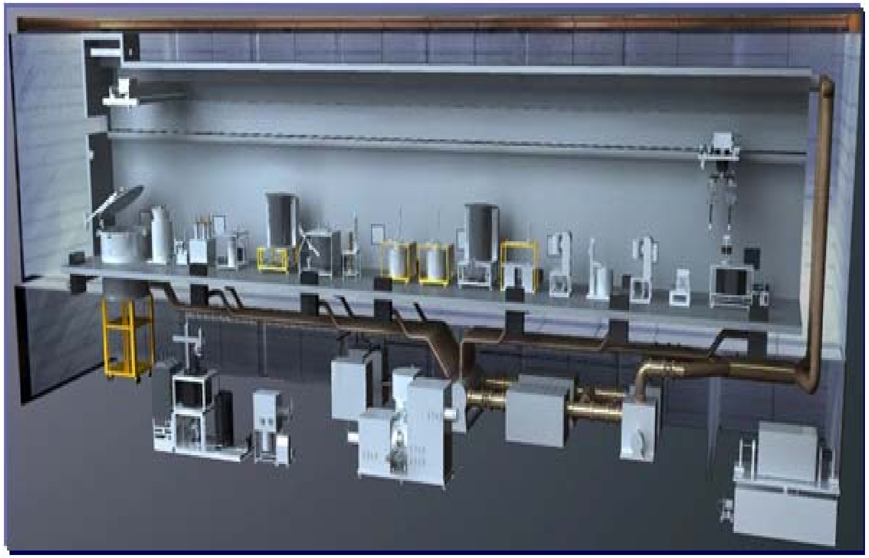
- Design : 2007 ~ 2008 (2 years),
- Construction : 2009 ~ 2011 (3 years)

❑ Main Features

- Test facility with depleted uranium and surrogate upto Engineering Scale
- Completely sealed argon-filled hot cell for electrochemical recycling work
- Full Remote Operation and Maintenance Concepts
- Argon Cell Size: 40m(L) × 4.8m(W) × 6.4m(H)

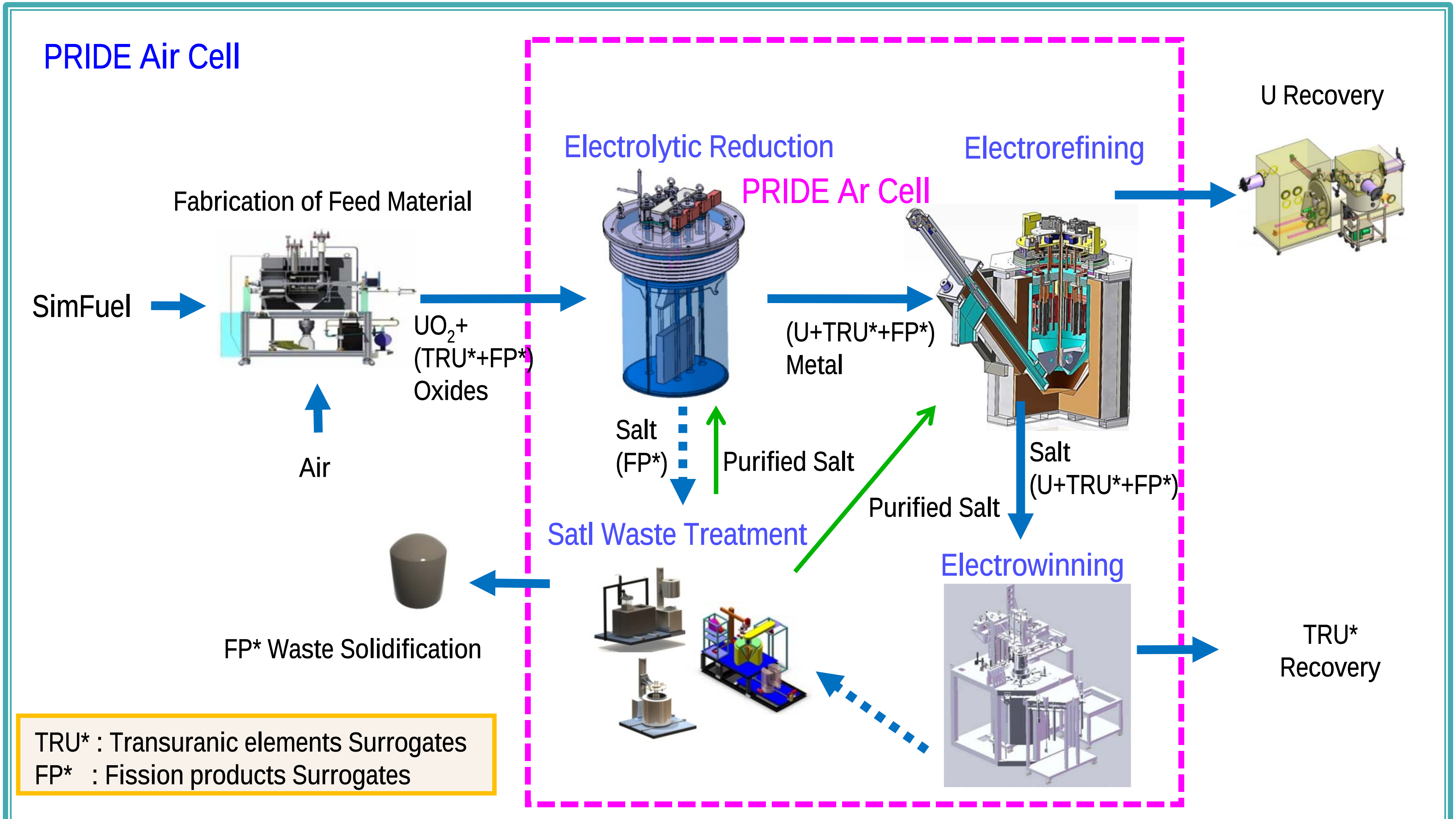
- PRIDE : PyRprocessing Integrated inactive Demonstration

PRIDE Building



Schematic View of Argon Cell

PRIDE Process Flow



Joint Fuel Cycle Study between ROK and USA

Purpose

- To support future evaluations of the technical feasibility, economic feasibility, and nonproliferation acceptability of electrochemical recycling process

R&D activities

- Electrochemical Recycling Feasibility Study Safeguards and Security Technology
- Joint Study of Fuel Cycle Alternative

Approach

- Stepwise approach is proposed to complete 10-year ROK-US joint study
  - Phase I : Scientific feasibility assessment (2 yr)
  - Phase II : Process validation (4 yr)
  - Phase III : Process demonstration (4 yr)

II-3

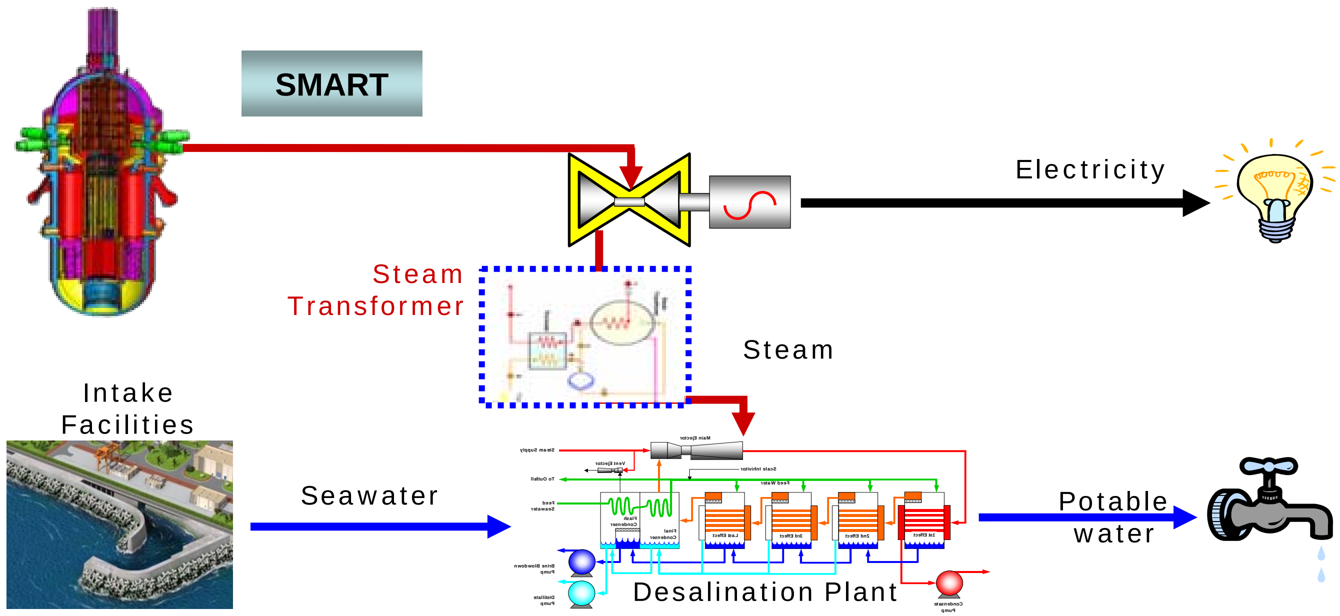
Reactor System Development :

- Small Integral Reactor : SMART

Integral Reactor SMART

330MW$_{th}$ Integral PWR

Electricity Generation, Desalination and/or District Heating



Plant Data

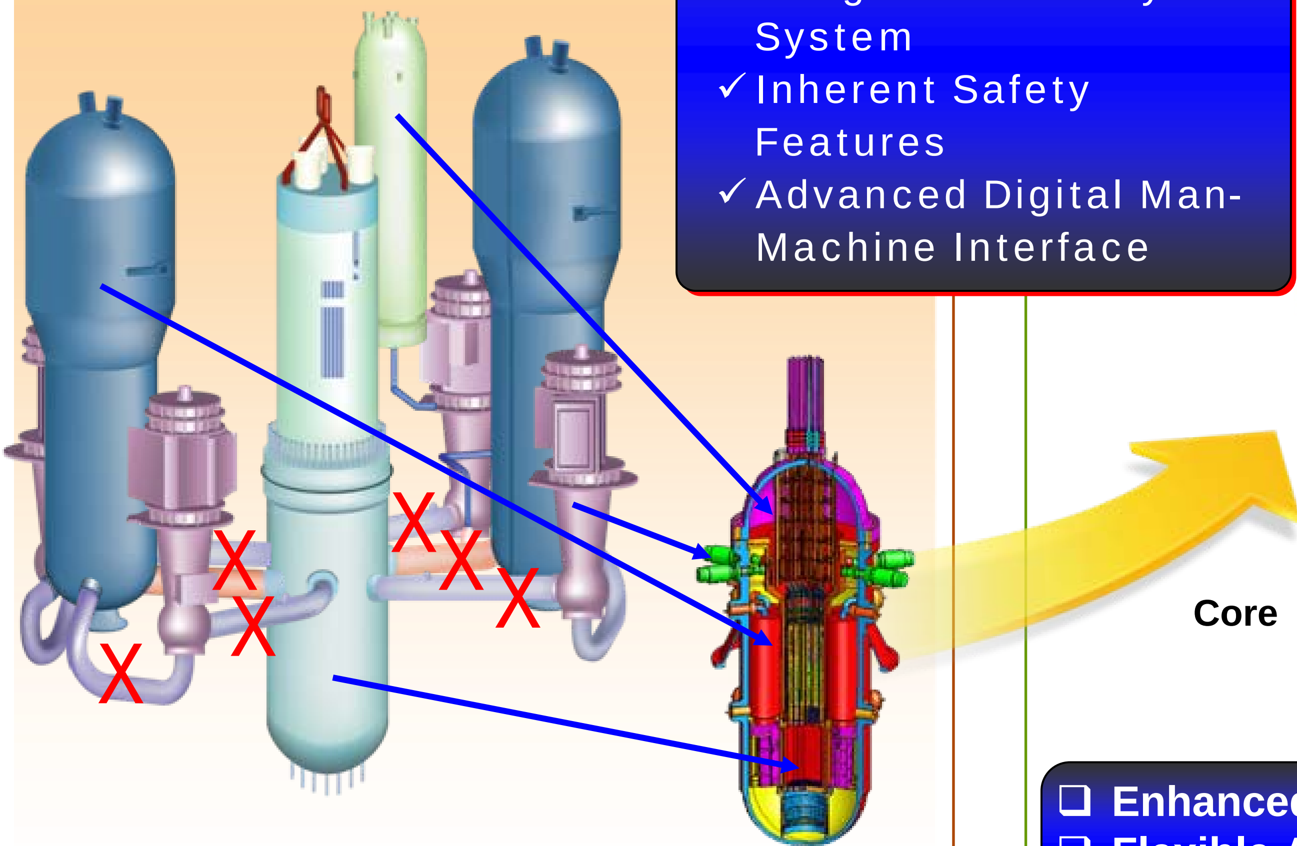
- **Power : 330 MWt**
- **Water : 40,000 t/day**
- **Electricity: 90 MWe**

***S**ystem-integrated **M**odular **A**dvanced **R**eac**T**or*

- ❑ **Electricity and Fresh Water Supply for a City of 100,000 Population**
- ❑ **Suitable for Small Grid Size or Localized Power System**

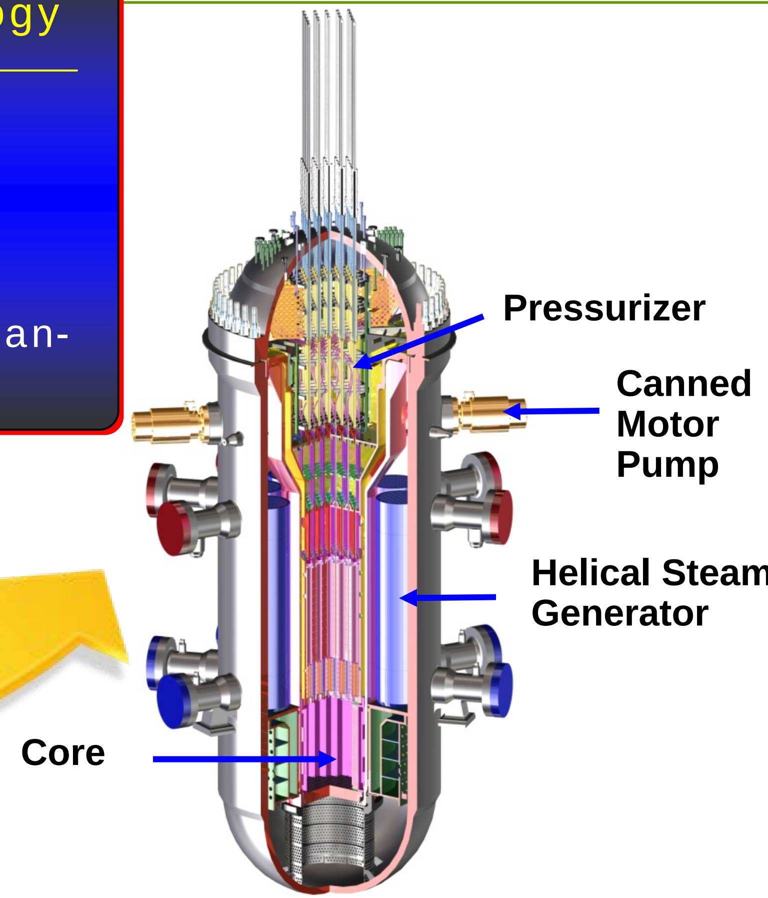
SMART Characteristics

Loop Type PWR



Advanced Technology

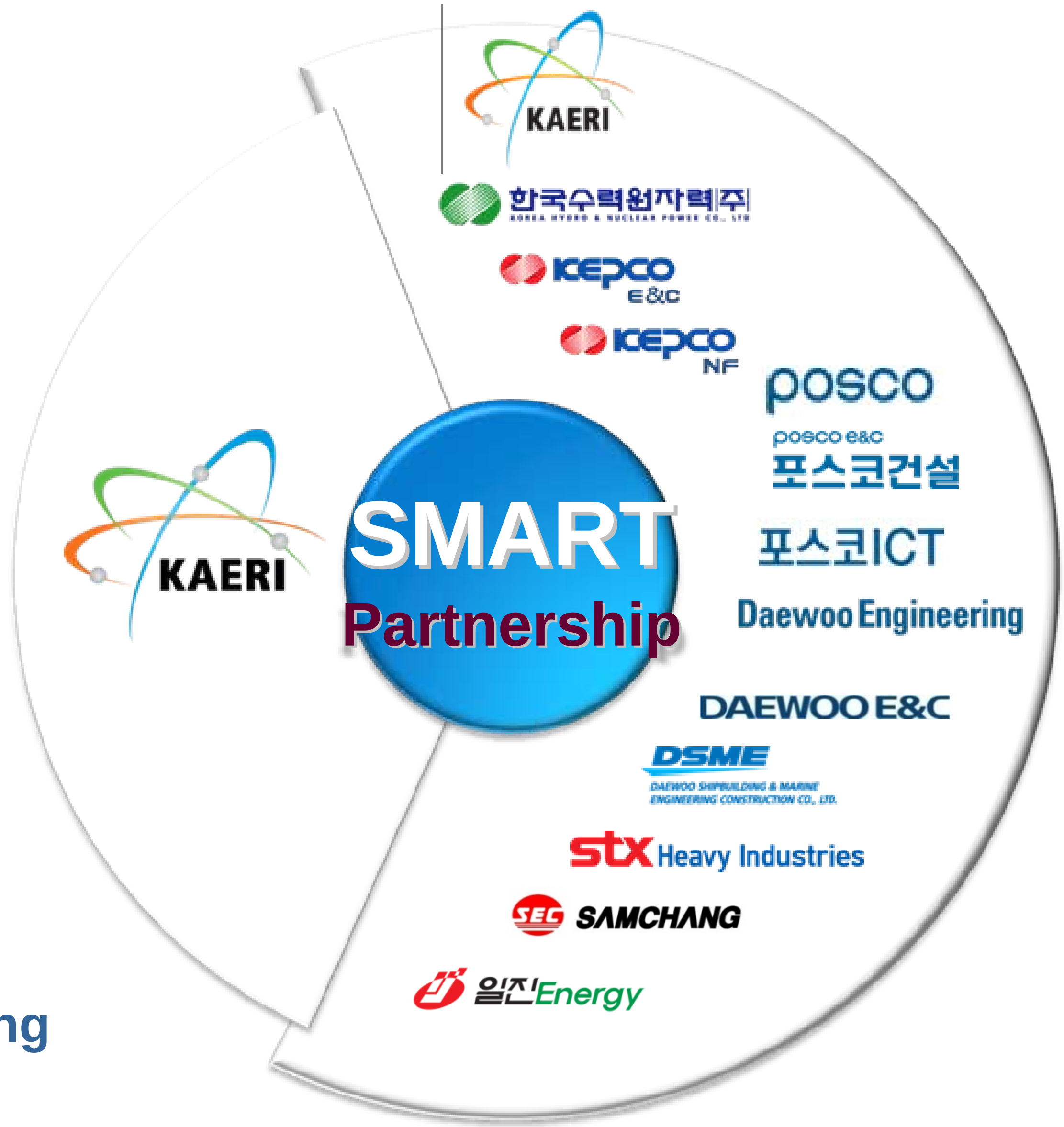
- ✓ Integrated Primary System
- ✓ Inherent Safety Features
- ✓ Advanced Digital Man-Machine Interface



- ❑ **Enhanced Reactor Safety: No LBLOCA**
- ❑ **Flexible Applications: Grid, Heat**
- ❑ **Early Deployment: Proven Technology**

Partnership for SMART Project

- **Achievements**
  - 15 years (1997- 2012) development effort with 300 m$ investment
  - Development partnership with 13 Korean organization
  - SDA (Standard Design Approval) issued in July 2012 by the Korean regulatory body
  - Construction of SMART in Korea and oversea cooperation is under planning



II-3

Reactor System Development :

- Research Reactor

Facilities for New Research Reactor

- **Outline : till 2017 with 200 m$ investment**
- **Reactor Development**
  - 20 MW, Pool type
  - Bottom mounted CRDM
- **RI Production Facility**
  - Fission Mo technology
- **LEU Fuel Manufacturing Facility**
  – Atomized U-Mo plate-type fuel
- **Irradiation Service Facility**
  – NTD wafer production
- **Radwaste Treatment Facility**

Cf. Hanaro at KAERI :

- 30 MW, Pool type, U-Si fuel
- Thermal, cold neutron research facilities
- Materials & fuel irradiation facilities
- RI & NTD production

III Summary

Peaceful Use of Nuclear Energy

- **Reactor System Development**
  - Large power reactor (OPR-1000, APR-1400)
  - Small integral reactor (SMART)
  - Research reactor (HANARO, New reactor)
  - Sodium-cooled fast reactor with Pyroprocessing

- **SFR & Pyroprocessing is Key Elements for the Sustainable Nuclear Energy Utilization**

KAERI