PRIDE
(PyRoprocess Integrated inactive DEMonstration facility)

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Hansoo Lee
Nuclear Power Plants in Korea as of ‘12.08

- 23 units in operation
  - 19 PWRs
  - 4 PHWRs

- Planned (National Energy Committee, 2008)
  - 10 APR+ (~2030)
  - Target: 59% share in 2030

Electricity generation in 2010
KEPCO in Brief, 2011.03

- Fissile 66.5%
- Nuclear 31.3%
- Hydro 1.4%
- Alternatives 0.8%
R&D on SNF Management

- On-site SF storage limit will be reached from 2016
- Spent fuel management policy will be determined after formulating a nation wide consensus through full spectrum open discussions

Ongoing Projects on SF Management (MKE-KRMC)
- Expert Consensus Development Project
- Development of Long-term Project Plan
Pyroprocessing – SFR closed fuel cycle

- Waste: 1/20
- HLNW disposal area: 1/100
- Time to natural background: 1/1,000
- U usage: 100

- U, TRU recovery
- Cs, Sr separation
- TRU, I, Tc transmutation
- U recycle

* TRU (Transuranics) : Pu + MA
* MA (Minor Actinides) : Np, Am, Cm

SNF → Interim storage → pyroprocessing → U, TRU → SFR

HLW → Interim storage → pyroprocessing → Cs, Sr → LILW Repository

I, Tc

PWR

CANDU

SFR

HLW repository

U–TRU–Zr fuel

Long-term storage

HLW

Cs, Sr
TRU*: Transuranic elements s.m.
FP*: Fission products s.m.

PRIDE Process Equipments

**PRIDE Air Cell**
- Fuel fabrication
- Simulated fuel
- Air
- \( \text{UO}_2^{+} \) (TRU*+FP*) oxide

**PRIDE Ar Cell**
- Oxide reduction
- Electrorefining
- Salt (U+TRU*+FP*)
- Purified salt
- Electrowinning
- TRU* recovery
- U recovery

Waste treatment

FP* solidified waste

Salt (U+TRU*+FP*)
**Head-end process: Decladding/Voloxidation**

**SIMFUEL pellet**
- Burnup: 55,000 MWd/tU
- Cooling time: 10 yrs.

**Simulated SIMFUEL pellet**

**Thermal Granulation**

**Granule Recovery**

**Recycling**
- Particle size:
  - > 20mm, < 1 mm

**Lab-scale (200g-U/batch) voloxidation test by Rotary motion**
- Recovery ratio of >1mm granules: ~84%
- Electro-reduction ratio of UO₂ granules to U: > 99%

**Lab-scale (200g-U/batch) off-gas trapping test**
- Development of off-gas filters for trapping Cs, Tc(Re), I
- Hot test of selective off-gas trapping for high temp voloxidation

**To electrolytic reducer**
Oxide Reduction (Electrolytic Reduction)

**Head-end**

**Electrolytic Reducer**

**Cathode Processor**

**Electrorefining**

**Salt Treatment**

Eng-scale (20g-U/batch) Oxide Reduction test implemented
- Current: 150-300A
- Operating voltage: <3.1V
- Cathode Processor
- Salt powder Recovery: >99%

SF: Spent Fuel
MS: LiCl-Li₂O molten salt
Electrorefining

**U-chlorinator**
- UCl₃

**Oxide Reduction**
- Reduced SF
- 30 kg/batch, 30 mol% UCl₃
  - Cl₂+Cd -> CdCl₂
  - CdCl₂+U -> UCl₃ + Cd

**Electrorefiner**
- 50 kg/batch
  - Graphite cathode
  - Bucket receiver

**Salt Recycle**
- Salt distiller
  - 33 kg U+Salt / batch
    - 850°C
    - 0~5 torr

**Electrowinning**
- 300 kg-salt / camp.
  - Pu/U > 3.0
  - Salt + TRU/RE/U

**Deposit (U+Salt)**
- 65 kg/batch
  - Dendrite: 50 kg
  - Salt: 15 kg

**Ingot casting furnace**
- 50 kg/batch
  - Gas-cooled induction heater
  - Tilting & turntable crucibles

**Salt transfer**
- 33 kg U+Salt / batch

**Used salt (TRU/RE)**
- 50 kg/batch
  - Graphite cathode
  - Bucket receiver
Electrowinning

Salt from electrorefiner

TRU/U/RE/Salt
- Pu/U > 3.0

Mesh type LCC
U > 14%

Cd mass recovery > 99%

CdCl₂ injection

Cleaned salt
To electrorefiner

LCC Electrowinning

TRU/U/RE/Cd
- HM > 10wt%
- RE/TRU < 0.25

Cd-TRU Distillation

CDCl₂ injection

Residual Actinide Recovery

RE/Salt (TRU < 100 ppm)

Salt purification

TRU/U/RE (Cd < 50 ppm)

TRU/RE/Cd

Fuel Fabrication

Metal Fuel
Salt Treatment

Clean salt to ERD

LiCl purification system

Salt from electro-reduction

Cs/Sr in LiCl

LiCl recovery > 90%

Layer Crystallization

LiCl purification system

Salt from RAR

REE in LiCl-KCl

LiCl-KCl recovery > 95%

LiCl-KCl purification system

REEO+Salt

Salt Distillator

Oxide precipitation

Waste Solidification System

Waste loading Cs/Sr ~ 25%
REE ~ 40%

REE oxides

Wasteform for final disposal

SAP/ZIT Process

REE oxides

SAP wasteform ZIT wasteform

Salt Distillator

Salt Treatment

LiCl recovery > 90%

LiCl-KCl recovery > 95%
Approach for Pyroporcess Modeling & Simulation

(3 level Architecture for M&S)

PyroFlow
(With ExtendSim platform)

Plant level model
by Discrete Event System

dynamic in/out
calculation of
unit process is
possible
macroscopically

Plant-level-model

Unit operational model

Basic unit process model

1. Processed qty of grouped element in unit process
2. Number of batch operations
3. Accumulated qty in buffers
4. Generated qty of product and waste
5. Equip op status (op, failure, idle)
PRIDE Process Equipments

High Capacity Electrolytic Reduction Technology

High-throughput Electrorefining Technology

LCC electrowinning and RAR Technology

Waste Salts Treatment Technology

Development of Integrated Process and Mass Flow Diagram

PRIDE Integrated Pyroprocess

PRIDE Ar Cell (2nd Fl.)

Test and Modification of Lab-scale Process

PRIDE Air Cell

Developing Lab-scale Pyro Core-technologies

- PRIDE Process Equipments
- Metal Product
- Design and Installation of Eng.-scale Integrated Pyroprocess
- Development of Integrated Process and Mass Flow Diagram
- PRIDE Integrated Pyroprocess
- Waste Salts Treatment Technology
- High-throughput Electrorefining Technology
- LCC electrowinning and RAR Technology
- Waste Salts Treatment Technology
- Development of Integrated Process and Mass Flow Diagram
- PRIDE Integrated Pyroprocess

TRU: Transuranic elements
NM: Noble metal elements
FP: Fission products
Key technologies

- Structure & Component Design
- Operation Utilities Design
- Remote Handling System Design
- Remote Handling & Operation Technology
- System Operation & Remote Maintenance
- Safety Analysis & Design Optimization

ACPF : Advanced spent fuel Conditioning Process demonstration Facility
PRIDE: PyRoprocess Integrated inactive DEMonstration facility

PRIDE Technology Development

Start of PYRO Facility Design Research (2001)

α-γ Type Hot Cell (ACPF)

Design and Construction of ACPF

Design of PRIDE and Cell Operation Equipments

Construction of PRIDE and Install Operation Equipments

PRIDE Facility

Large Argon Cell and auxiliary systems
Long-term Plan for Pyroprocess Technology Development

**Long Term R&D Plan**

- **Lab scale exp. (~ 2012)**
  - Lab-scale Demonstration
- **Engineering scale (2012 ~ 2016)**
  - PRIDE Operation
  - Integrated Process Demonstration
- **Engineering scale (2016 ~ 2020)**
  - PRIDE Improvement
  - Integrated Process Improvement and Demonstration
- **Future activity (2020 ~ )**
  - Facility

**PRIDE**
- (Inactive with Eng. scale)
- Integrated Process Demonstration
- Electroreduction Improvement and Demonstration
- Process operation Fuel irradiation test

**ACPF/DFDF**
- (Active)
- Electroreduction Demonstration

**JFCS**
- (Active)
  - Integrated Process Demonstration
PRIDE (PyRoprocess Integrated inactive Demonstration facility)

- **Purposes**
  - Test facility to evaluate performance (cold-run) and scale-up issues of full-spectrum pyroprocessing technology

- **General Features**
  - Pyroprocess test & demonstration with depleted uranium or surrogate up to engineering scale
  - Inside dimension of argon cell: 40mL x 4.8mW x 6.4mH

- **Near-term schedule**
  - Test in-cell handling systems and utilities
  - Test engineering scale process equipments and remote operability
Scenarios for Development of equipments

Evaluating Remote Operability/Maintainability of 3D Models of Equipments

3D models of Equipments in Pyroprocessing

Design

Evaluating remote Operability/Maintainability of Constructed Equipments

Construction

Installation

Remote handling systems
- Two MSM
- One BDSM
- One Overhead Crane
- One Flexible window

Simulation

Digital Mock-up of PRIDE

Evaluation

Evaluation Mock-up of PRIDE
1. Simulator – Digital Mock-up of PRIDE

- A full scale digital mock-up (virtual facility) of the PRIDE
- Provide an efficient means for simulating and verifying the conceptual design, design developments, arrangements and rehearsal of pyroprocessing equipment in a virtual environment in advance

Constitution

- PRIDE & process equipments model
  - Electrolytic reduction
  - Electro-refining
  - Electro-winning
  - Salt waste treatment

Analysis: workspace, operability

Digital Mock-up of PRIDE

Motion simulation

Target Devices
  - Dual arm servo MSM
  - Mechanical MSM
  - Crane, Bridge transporter

3D models of process equipments and remote handling devices
2. PRIDE Mock-Up Area

- **Usage**
  - Useful means for testing and evaluating the **operability and maintainability** of constructed pyroprocessing equipments **in advance** at the same operating conditions of the PRIDE from the remote handling viewpoint before they are installed in the PRIDE Upgrade from PC-based control system
  - Utilization in **improving the completeness and reliability** of the pyroprocessing equipments to be used at the PRIDE

- **Features**
  - 1/8 scale-downed mock-up of the PRIDE in length with the same width and height as ones of the PRIDE, but air atmosphere
  - Configuration of 5.0x4.8x6.4 (LxWxH) m

- **Consisting of**
  - One BDSM
  - Two pairs of MSM
  - One overhead crane (two tons)
  - One flexible viewing window
3. Remote handling evaluation in a mock-up

Evaluation of Remote Operability and Maintainability

A Case of ‘Rare Earth Precipitation apparatus’

Accessibility & Arrangements

Arrangement of optimal location (Visibility should be secured)

Test of accessibility from the front face (using MSM)

Test of accessibility for the rear side (using BDSM)

Remote Operability-1

Moving of Material container using a crane and MSM

Part insertion for a chemical treatment using a crane and BDSM (Vision is secured remotely)

Motorized lid is closed by remote operation

Remote Operability-2

Bolt fastening and releasing using an portable machine tool

Hook handling for lifting

Part disassembly and extraction

Simulator (Digital Mock-up of PRIDE)

Mock-up of PRIDE
PRIDE Facility Brief Overview

Main Cell Operation Equipments (side view)

- Argon Cell Crane & Trolley Hoist
- Dual Arm Servo Manipulator
- Master-Slave Manipulator
- Argon cooling and circulation systems
- Small Transfer Lock System
- Large Transfer Lock System
- Feed-throughs
- Gravity tube
V. PRIDE 시설

2nd Floor

OR
Salt distil

ER
Salt trans

Salt distil

EW
Cd distil

RAR

precip
salt recovery

cryst salt recovery

1st Floor

Waste solidif.

U-Chlorinator

Ingot casting furnace

pretreatment
Current Status

- Installation cell operation and remote equipments: ‘11.10 ~ ‘12.02
- Installation of BDSM: ~ ‘12.03
- Installation argon system and HVAC: ‘11.10 ~ ‘12.02
- Manufacturing process apparatus and installation on PRIDE: ~ ‘12.05
- PRIDE construction is completed: ‘12.07

Schedule

- PRIDE start-up test in progress: ‘12.08 ~
- PRIDE operation and utility systems operational and functional performance test: ‘12.08 ~ ‘13.02
- BDSM operational and functional performance test: ‘12.08 ~ ‘13.02
- Process equipment’s operational and functional test: ‘12.08 ~ ’13.02
- Process equipment remote handling test: ’12.08 ~ ‘13.02
- Process equipment’s salt test: ‘13.03 ~
## PRIDE Program

### Program

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### achievements

- Utility Operation experience
- Equipment design improvement
- Material Measurement – online offline monitoring
- Material Flow Check
- Applicability of the other concepts
- Personnel Training
Thank you for your attention

Clean Energy! Clean Korea!