Improving Safeguards Approaches for the Future Aqueous Reprocessing

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Future Nuclear Energy World

- Nuclear power growth (number of reactors, advanced-reactors, fast reactors etc)
- Needs of nuclear fuel cycles (large scale fuel cycle, Pu recycle)
- Needs to develop safer, more economical systems
- Needs of proliferation-resistant nuclear systems against the increase in nuclear diversion risk
Proliferation Resistant NFC

- *Impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State*
- *Demonstrate NFC for peaceful purpose*

- **Intrinsic Features:**
  - No isolated Pu, Limited accessibility, etc

- **Institutional (Extrinsic) Measures:**
  - *International Safeguards* [Comprehensive Safeguards Agreement + Additional Protocol], Bilateral Agreements, Export Control, etc

- **Complementary measures; as additional confidence building**
  - *Transparency* (e.g. information sharing on nuclear activities with neighbor countries, public)
Proliferation Resistance Strategy

GEN IV PR&PP Experts Group

- Develop and demonstrate a methodology for the systematic evaluation with respect to proliferation resistance (PR) and physical protection (PP)
- Member: USA, CA, JPN, EC, FRA, UK, ROK, IAEA

Proliferation Resistance Measures
- Proliferation Technical Difficulty (TD)
- Proliferation Cost (PC)
- Proliferation Time (PT)
- Fissile Material Type (MT)
- Detection Probability (DP)
- Detection Resource Efficiency (DE)

Example of PR&PP aspects of the Fuel

Characteristics
- Highly radioactive
- Radiation dose
- High heating rate
- Low decontamination

From PR&PP
- Hard to access
- Difficult to handle
- Difficult to divert
- Low grade Pu

Unattractive for diversion
Advanced Aqueous Reprocessing for FR Cycle

- Japan
  *FaCT Project*: Fast reactor Cycle Technology Development
  **NEXT**: New Extraction system for TRU recovery

- US
  *AFCI, GNEP*
  **UREX+**: Uranium Extraction Process

- France
  *GANEX*: Grouped Actinides Extraction
Advanced Aqueous Reprocessing

- FR Spent Fuel
  - More Pu than LWR SF
    (Approx. x10 Pu LWR-SF)

- No isolated Pu

- Lower DF and/or TRU Mixture
  - Heat and Radiation
  - Limited Access

“NEXT” Process

- Disassembling/decladding
- Dissolution/clarification
- Crystallization
- Co-extraction
- Co-stripping (U/Pu/Np recovery)
- Solvent regeneration
- MA recovery
- Extraction chromatography
- Adjusting Pu content
- Concentration
- U/Pu/Np
- U
- If necessary
- High level liquid waste

- New technologies
- Conventional technologies

Ref. 2006 JAEA/NPSTC International Forum

The University of Tokyo
Safeguards in Proliferation Resistance

Clandestine nuclear Weapon program

Detect program

Hidden Nuclear Facility

Detect Activity

Technical difficulty

Acquisition of nuclear weapon

Detect by process surveillance

Detect by NRTA, Accountancy & C/S

Detect by PIV + IIV

Technical difficulty

SG based on CSA

SG based on AP

Intrinsic

E.g. Civil nuclear reprocessing

Fail

Yes

No

Fail

Yes

No

Fail

Yes

No

Fail
An Approach to Robust Proliferation Resistant System

1. Pursue technical solutions to meet the Safeguards requirements in light of timeliness, accuracy and efficiency as much as reasonably achievable.

2. Evaluate it from the perspective of Proliferation Resistance (PR).

3. Take additional PR measures if necessary.
Items to be considered to meet SG requirement (Technical solutions)

The below-shown ideas may be essential for future NFC’s “Safeguards by Design”;

(1) Small process inventory,
(2) Real time process monitoring with remote monitoring - C/S, NDA etc for NRTA, for detection of process condition change etc
(3) More accurate interim inventory verification in practically possible frequency (e.g. monthly)
(4) Accountancy-friendly operational mode for NRTA (e.g. computerized)
Inventory at IIV

Case A
- In-process Inventory: 200 kgPu
- Accountancy-vessels’ Inventory: 200 kgPu

Case B
- In-process Inventory: 15 kgPu
- Accountancy-vessels’ Inventory: 75 kgPu

Throughput: 12,000 kgPu/year

Safeguards by Design
(1) Small process inventory: Case Study on Reprocessing

Input Accountancy

Case A, B
- 60 kgPu/batch
- 200 batch/year

Case A
- 200 kgPu/batch
- 60 batch/year

Case B
- 15 kgPu/batch
- 800 batch/year

Extractors

Pu evaporator

Output Accountancy
### Safeguards by Design

#### (1) Small process inventory: Case Study on Reprocessing

**To Estimate Flow $\sigma_{MUF}$**

**Assumption**
Errors for volume measurement, sampling, conc. Measurement : ITV

**To Estimate Inventory $\sigma_{MUF}$**

**Assumption**
Error for volume measurement : 1%
Error for sampling : 0.5%
Error for conc. Measurement : 10%

Errors in Volume Measurement and DA analysis in Reprocessing (ITV2000)

<table>
<thead>
<tr>
<th></th>
<th>Input Pu</th>
<th>Output Pu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Random, Relative %</td>
<td>Systematic Relative %</td>
</tr>
<tr>
<td>Volume</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Sampling</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Pu-conc. (IDMS)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Results of Case Study A&B

(1) Small process inventory: Case Study on Reprocessing
(2) Installation of real time process monitoring for NRTA and for detection of process condition change (with remote monitoring):

- C/S
- Common use of operator’s process monitors/sensors (with authentication for independency)
- NDAs including neutron, gamma monitors
- Solution monitoring other new ideas e.g. electrochemical monitors + density measurement: U, Pu, H\(^+\) (idea for reprocessing case)
(3) More accurate interim inventory verification: idea for reprocessing case

1. Increase in number of vessels that are capable of measuring NM at accountancy level (input, output, major buffer vessels)

2. Transfer and centralize NM to the major vessels

3. Slight interruption for taking samples

4. Determine total amount of NM by IDMS (Isotopic Dilution Mass Spectrometry) without measuring solution volume
## Improvement of \( \sigma \)MUF with IDMS
- Direct determination for Pu amount -

(Without volume measurement)

<table>
<thead>
<tr>
<th>Case</th>
<th>Flow</th>
<th>Total Inventory (Process+Accountancy)</th>
<th>Errors (Flow &amp; Inventory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case A</td>
<td>60 kgPu x 200 batches</td>
<td>200 kgPu x 60 batches</td>
<td>ITV2000</td>
</tr>
<tr>
<td></td>
<td>(12,000 kgPu/year)</td>
<td>400 kgPu</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case C</td>
<td>15 kgPu x 800 batches</td>
<td>170 kgPu</td>
<td>Volume:0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sampling &amp; Measurement: ITV 2000</td>
</tr>
</tbody>
</table>
Improvement of $\sigma$MUF with IDMS

- Direct determination for Pu amount -

Image of accountancy performance

Control of NM with $\sigma$MUF < 1SQ-Pu may be realized by monthly IIV.
(4) Accountancy-friendly operational mode (computerized)

Safeguards System Simulator

**Principle process**
- Chopper
- Dissolver
- Crystallization
- Rapid Contactor
- Chromatography
- Conversion
- Furnace
- Fabrication

**Conceptual design**
- Apparatus
  - Vessel 1
  - Vessel 2

**Engineering Design**
- Stage 1
- Stage 2
- Stage N

**System arrangement**

**Operational mode**

**Operational model**

**Multi-objective function module**
- Initial investment
- Operational cost
- Person-day of inspection
- Inspection evaluation

**Virtual Visualization Core**
- Facility operation module
  - Operational model
  - Safeguards equipment
  - DA, NDA apparatus
  - Waste loss
  - Proliferation resistance

**Virtual Visualization Core**

**Operational model**

\[ Q_j = f_1(x_1, x_2, x_3, x_4, x_5...) + f_2(x_1, x_2,...) + ... \]

**Optimized design**

**Nuclear Material Accountancy Core**
- Nuclear material transfer module
  - \( \rho \) (Pu); Density
  - M(Pu); Mass
  - \( u, v, w \); Velocity
  - \( T \); Temperature
  - p; Pressure
  - C(Pu); Concentration

**Chemical separation & MA module**
- Aqueous, Organic
- Radioactivities
- Nuclides concentration
- Chemical reaction

**Multivariate Multi-scale Core**
- Process monitoring module
  - Statistical analysis
  - Wavelet analysis
  - PCA

**Improved detection probability**

**Nuclear Material Accountancy Core**

**Multivariate Multi-scale Core**
An Idea towards Future SG/PR for Advanced Fuel Cycle

Virtual design

Incorporated into the design

Laboratory and engineering scale

Demonstration Scale

Commercial

Advanced Safeguards and PRPP system

[Safeguards by Design]

Advanced technologies: Accurate IIV with tracer technique, NRTA, etc

Element such as monitors/sensors, in-plant measurement tools, Tracer technique

Accountancy-friendly process operational mode

Reasonable practice of PRPP

Evaluation Simulator for SG system

Evaluation Simulation

Proliferation resistance evaluation methodologies

Milestone Concept Elemental technology Equipment System Field test Demonstration

Advanced accountancy system on DIV, CS, Process Monitoring

Rapid and efficient Safeguards: remote monitoring, NRTA with real-time monitors Unattended mode, SNRI, Verification of SSAC’ lab

Accountancy-friendly process operational mode
Measures for confidence building:

- State-State, State-International Organization:
  - Safeguards; information sharing through IAEA
- State-State: information sharing through transparency-framework
- Non-government organizations:
  - through cooperative project
- System for information Sharing on e.g. Safeguards with citizens.
Conclusions

- Safeguards will play the essential role among measures for Proliferation Resistance.
- Future NFC requires Safeguards system with a timely, accurate and efficient manner (also economically efficient), which may only be realized by “Safeguards by Design”.
- Additional PR measures can be taken if necessary.
- “Transparency” should be pursued for mutual confidence building for peaceful use of nuclear energy.
Thank you for your attention