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Improving Safeguards Approaches for the Future Aqueous Reprocessing

Naoko INOUE, Yusuke KUNO

Dept. of Nuclear Engineering & Management,

School of Engineering,

The University of Tokyo

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

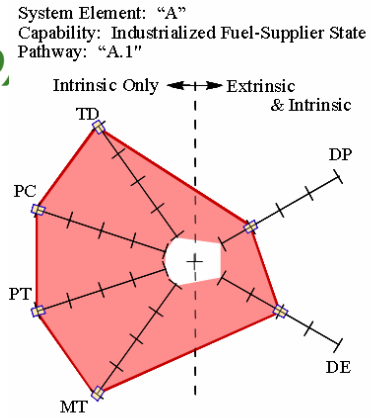
GEN IV PR&PP Experts Group

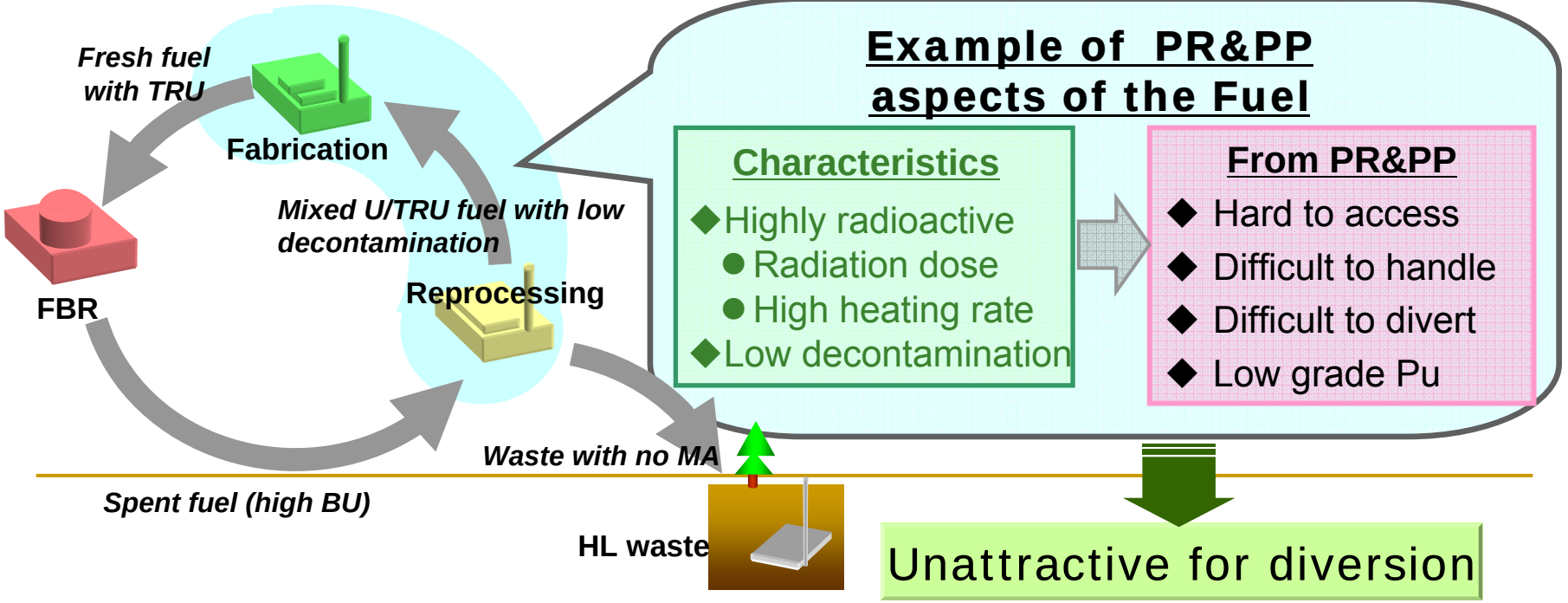
➢Develop and demonstrate a **methodology** for the systematic evaluation with respect to **proliferation resistance** (PR) and **physical protection** (PP)

➢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)***





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

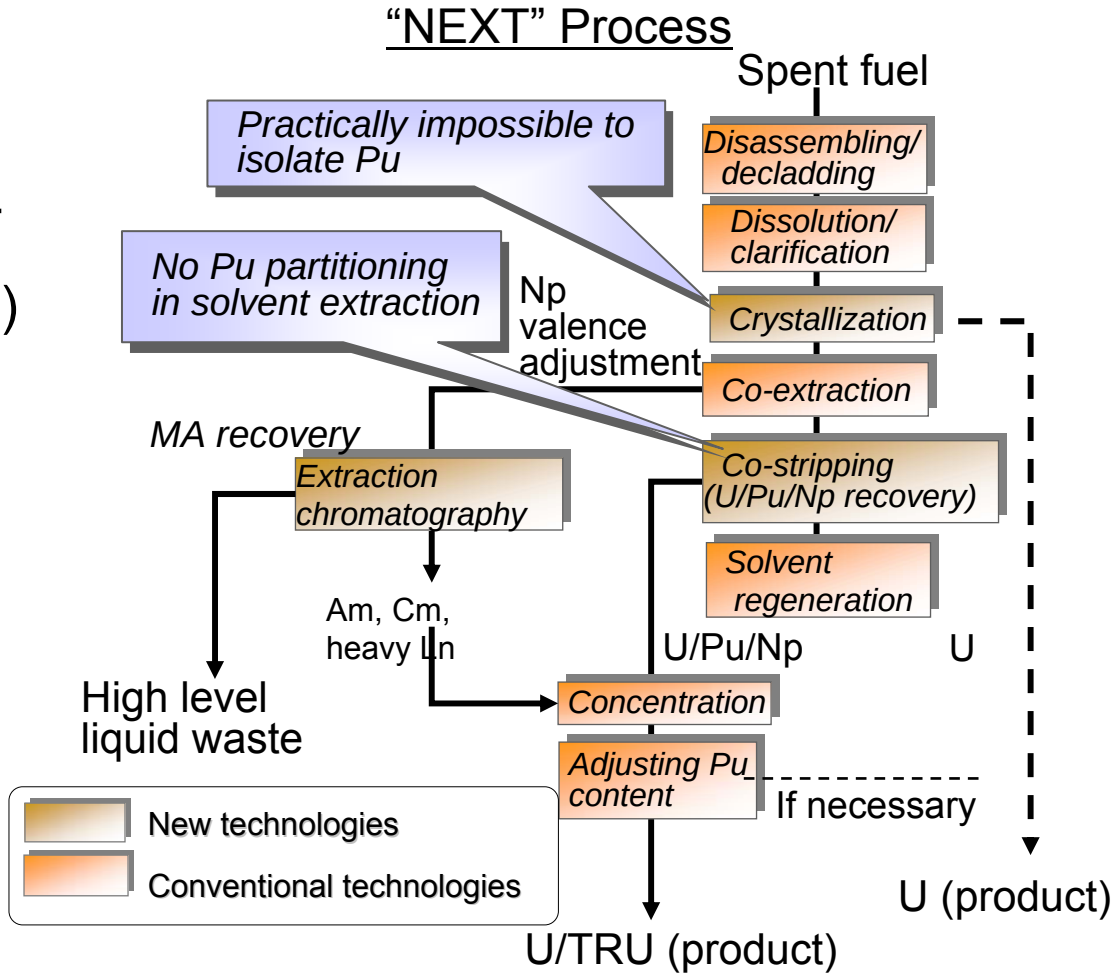
- France

  GANEX: Grouped Actinides Extraction

Advanced Aqueous Reprocessing

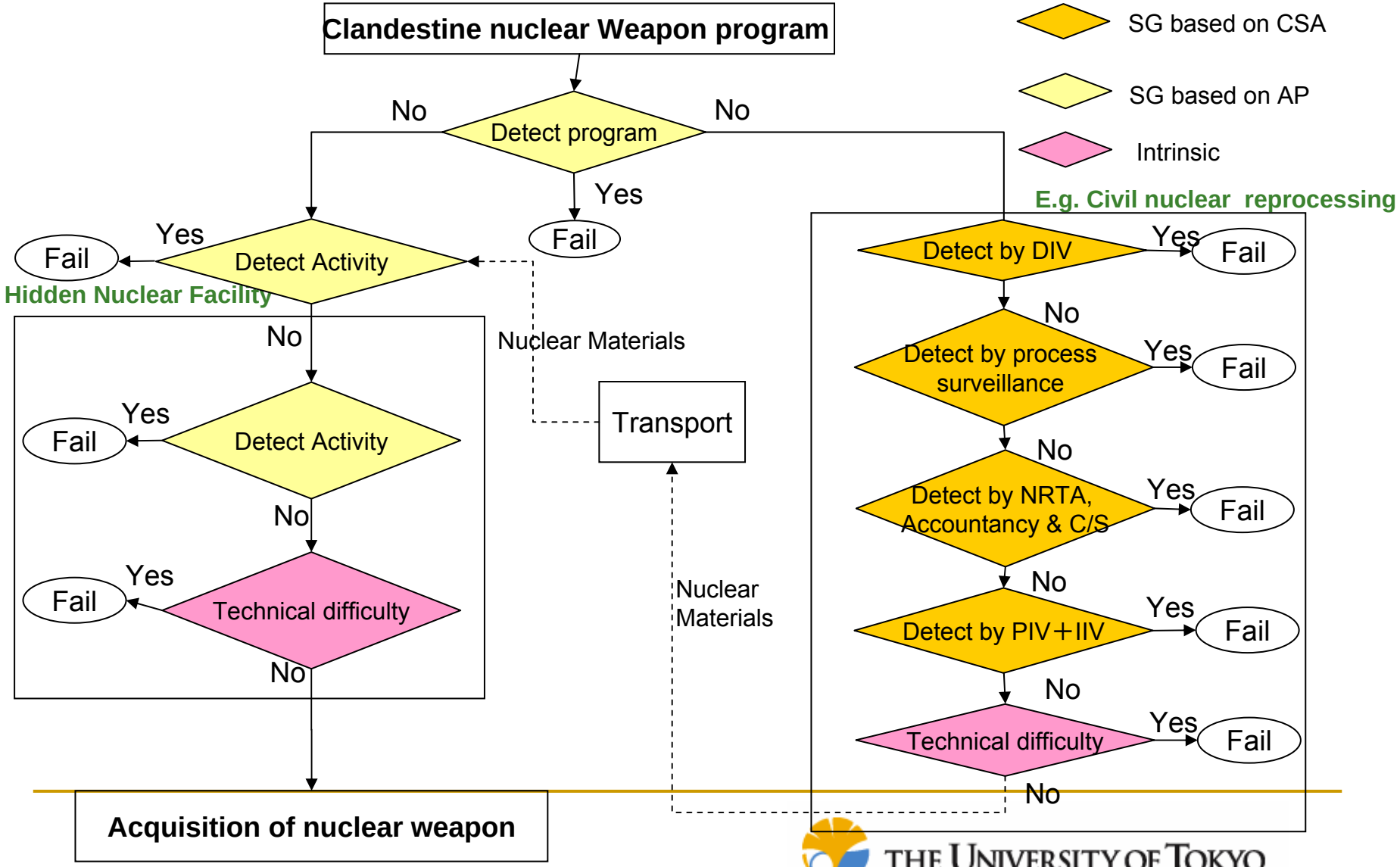
- FR Spent Fuel
  - More Pu than LWR SF

  (Approx. x10 Pu LWR-SF)
- No isolated Pu
- Lower DF and/or TRU Mixture
  - Heat and Radiation
  - Limited Access



Ref. 2006 JAEA/NPSTC International Forum

Safeguards in Proliferation Resistance



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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**";

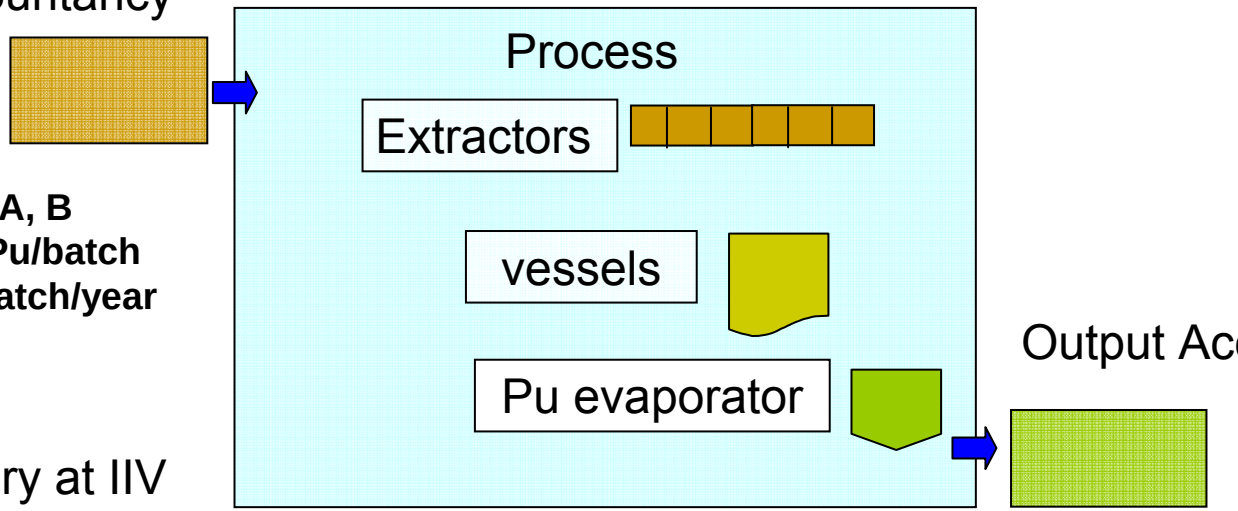
(1) Small process inventory,
(2) Real time process monitoring with remote monitoring - C/S, NDA etc for NRTA, for detection of process condition change etc
(3) More accurate interim inventory verification in practically possible frequency (e.g. monthly)
(4) Accountancy-friendly operational mode for NRTA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

Safeguards by Design

(1) Small process inventory: Case Study on Reprocessing

Throughput : 12,000 kgPu/year

Input Accountancy



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

Output Accountancy

Case A
200 kgPu/batch
60 batch/year

Case B
15 kgPu/batch
800 batch/year

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

Safeguards by Design

(1) Small process inventory: Case Study on Reprocessing

To Estimate Flow σ_{MUF}

Assumption

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

To Estimate Inventory σ_{MUF}

Assumption

Error for volume measurement : 1%

Error for sampling : 0.5%

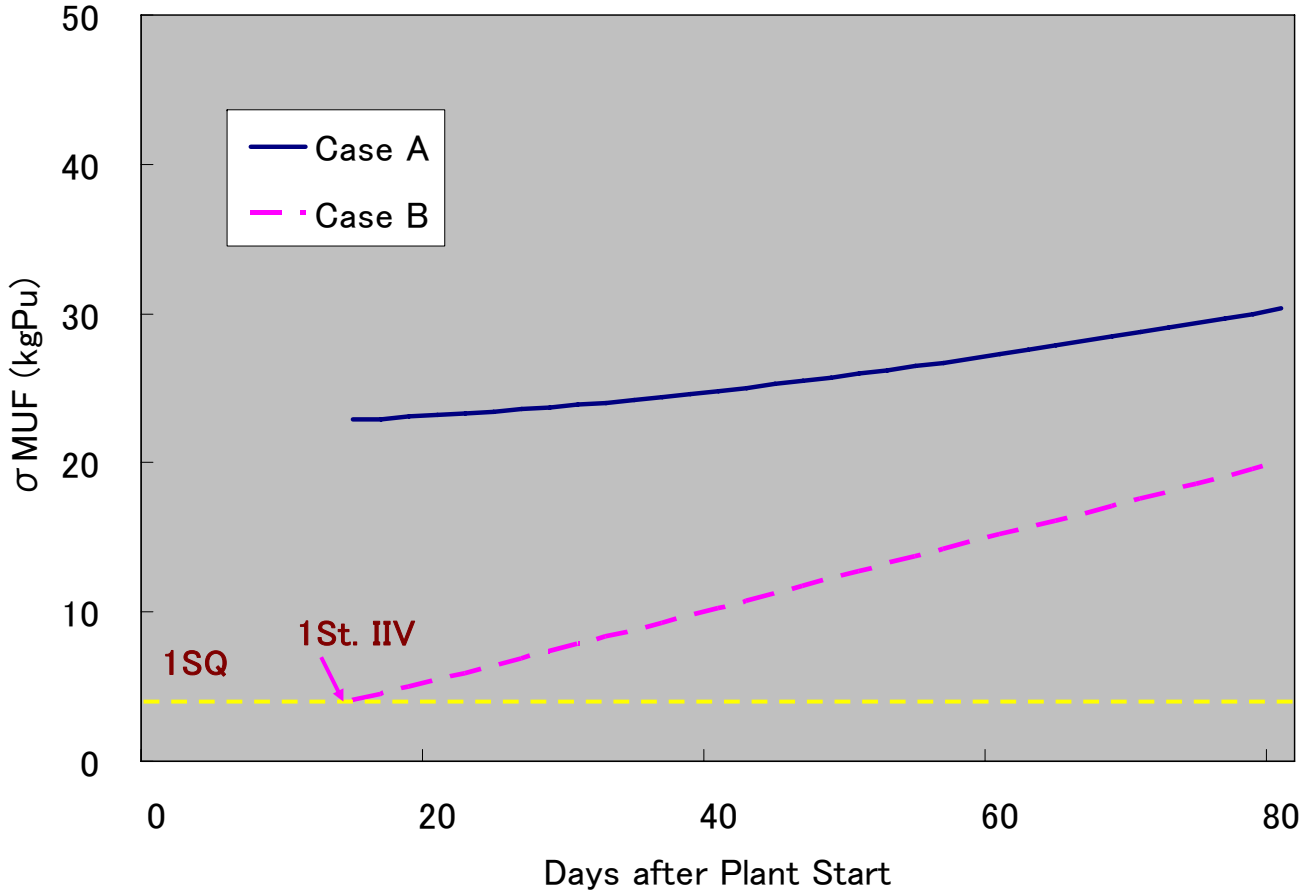
Error for conc. Measurement : 10%

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

	Input Pu		Output Pu	
	Random, Relative %	Systematic Relative %	Random, Relative %	Systematic Relative %
Volume	**0.3**	**0.2**	**0.3**	**0.2**
Sampling	**0.3**	**0.2**	**0.2**	**nd**
Pu-conc. (IDMS)	**0.2**	**0.2**	**0.15**	**0.1**

Results of Case Study A&B

(1) Small process inventory: Case Study on Reprocessing



Safeguards by Design

(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)*

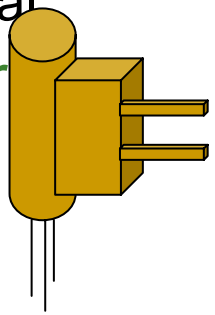


Image of U･Pu Real-Time Monitor composed of 3 Pt electrodes

Safeguards by Design

(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 σMUF with IDMS

- Direct determination for Pu amount -

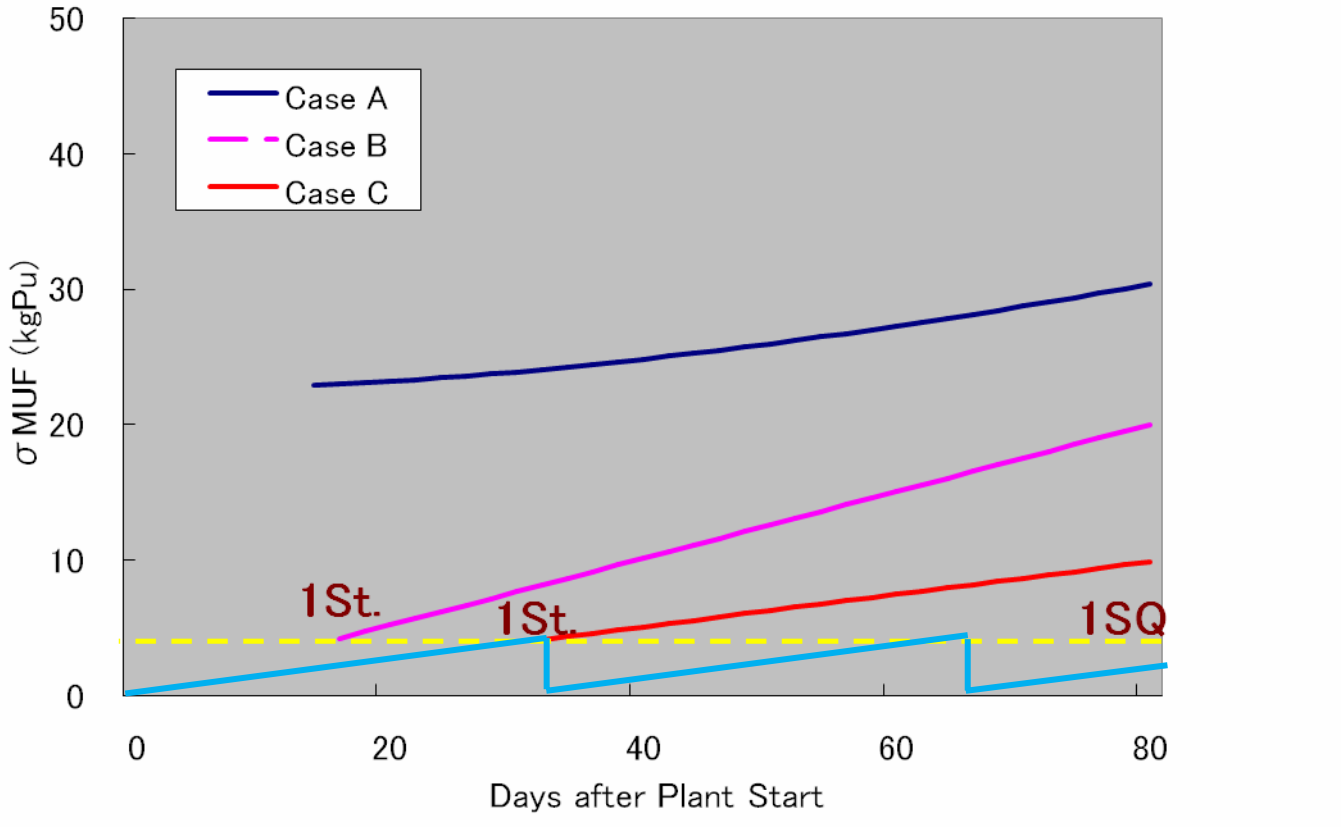
(without volume measurement)

	Flow		Total Inventory (Process+Accountancy)	Errors (Flow & Inventory)
	Input	Output		
Case A	60kgPu x 200 batches (12,000 kgPu/year)	200 kgPu x 60 batches	400 kgPu	ITV2000
Case C		15 kgPu x 800 batches	170 kgPu	Volume:0% Sampling & Measurement: ITV 2000

Improvement of σMUF with IDMS

- Direct determination for Pu amount -

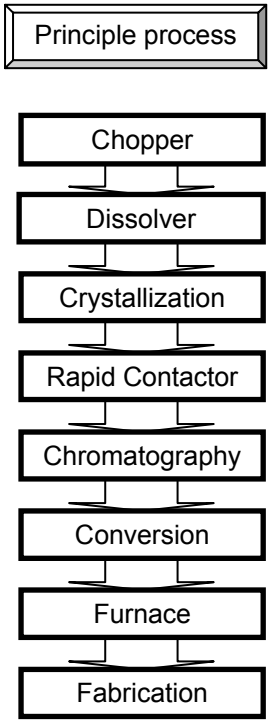
Image of accountancy performance

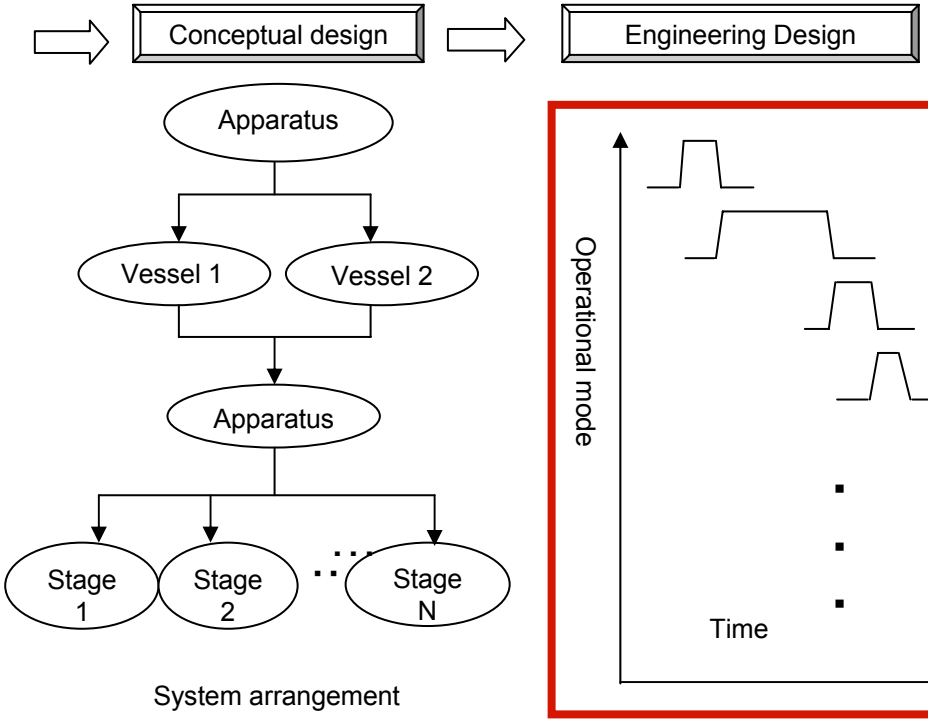


Control of NM with σ'MUF< 1SQ-Pu may be realized by monthly IIV.

(4) Accountancy-friendly operational mode (computerized)

Safeguards System Simulator





Nuclear Material Accountancy Core

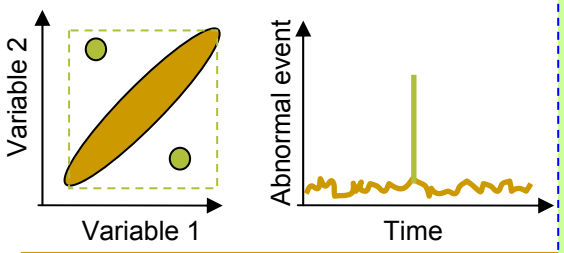
Nuclear material transfer module
- ρ (Pu); Density
- M(Pu); Mass
- u,v,w; Velocity
- T; Temperature
- p; Pressure
- C(Pu); Concentration

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

Multivariate Multi-scale Core

Process monitoring module
- Process monitoring
- Statistical analysis
- Wavelet analysis
- PCA

Improved detection probability



Multiple Optimization Core

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

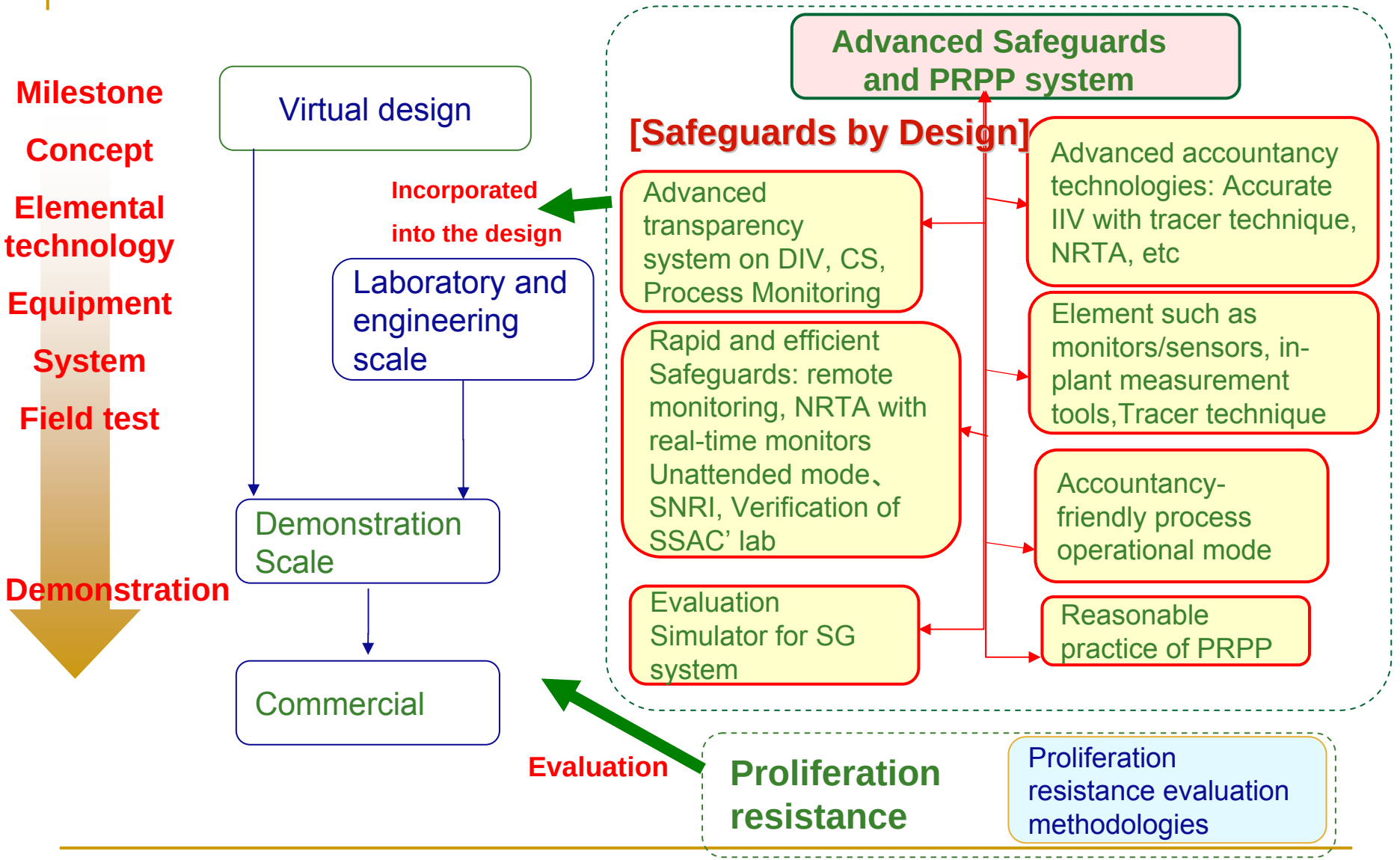
Virtual Visualization Core

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

$$Q_j = f1(x1, x2, x3, x4, x5...) + f2(x1, x2, ...) + ...$$

Optimized design

An Idea towards Future SG/PR for Advanced Fuel Cycle



Transparency

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