Role of Safeguards in Proliferation Resistance for the Future Nuclear Fuel Cycle Systems

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Japan's Nuclear Energy Policy

Basic Goals of the Framework for Nuclear Energy Policy
(adopted October 2005 by the Cabinet) http://www.enecho.meti.go.jp/english/report/rikkoku.pdf

(a) Continuing to meet **at least 30 to 40% of electricity** supply even after 2030 by nuclear power generation,

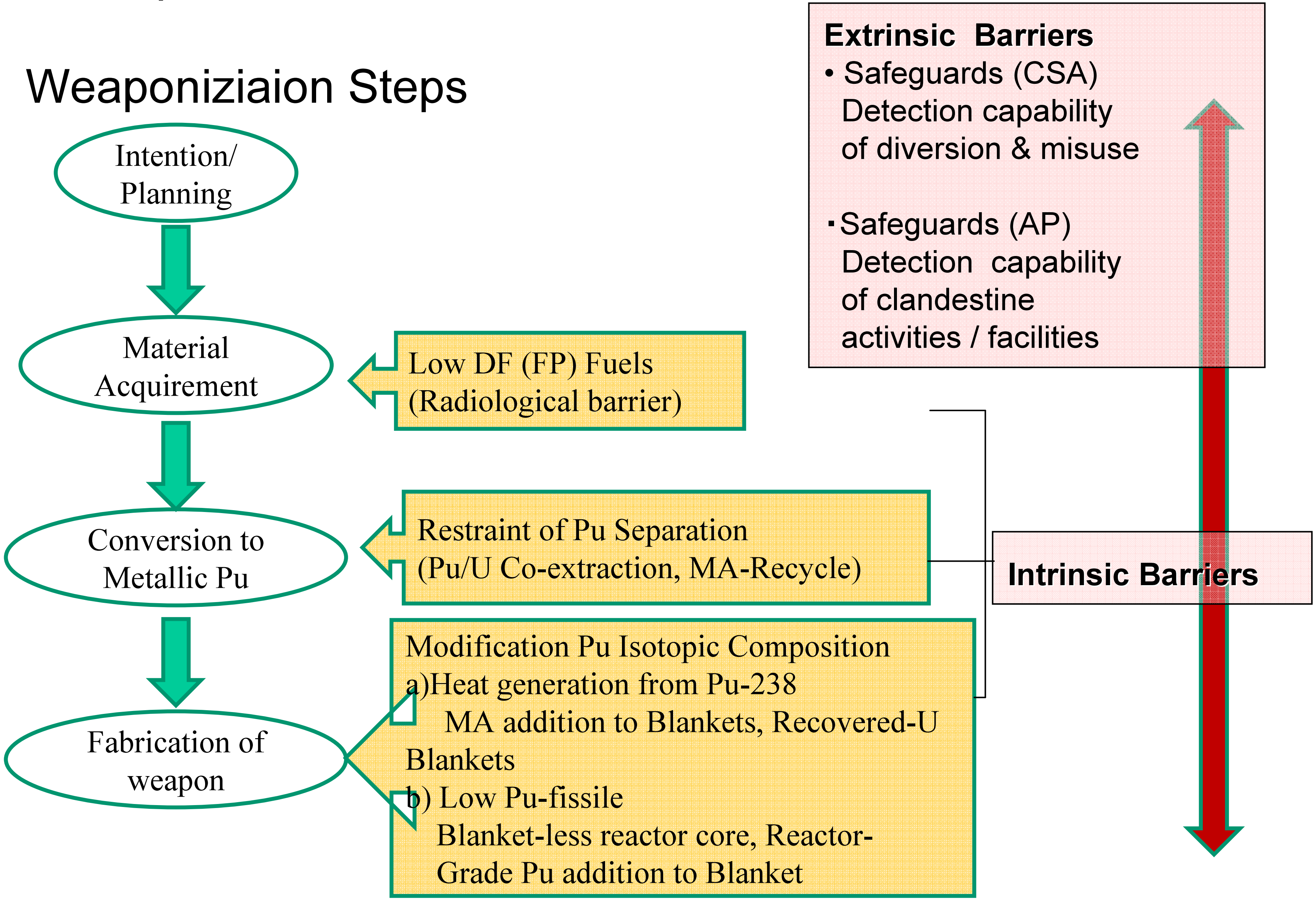
(b) Further **promoting the nuclear fuel cycle (NFC)**, and

(c) Aiming at commercializing practical **FBR cycle** in 2050.

Nuclear non-proliferation

- Accordingly larger amount of plutonium than that in the present time should be recycled.
- It is essential to incorporate Proliferation Resistance (PR) technologies and Safeguards into its early design stages of NFC, in order to demonstrate robust proliferation-resistant future NFC in an efficient, effective and economically viable manner.
- Present Safeguards system in Japan, namely, International Safeguards under CSA and AP is very effective measures, among many PR measures. However, more effective and efficient Safeguards should be considered for future NFC.

Example of Barriers for Proliferation Resistance



Key Proliferation Resistance Measures to be considered during designing NFC

INPRO
- States' Commitments（UR 1）
- Attractiveness of NM and Technology（UR 2）
- Difficulty and Detectability of Diversion（UR 3）
- Multiple Barriers（UR 4）
- Optimization of design（UR 5）

GEN IV
- Technical Difficulty（TD）
- Proliferation Costs（PC）
- Detection Probability（PT）
- Material Type（MT）
- Detection Probability（DP）
- Detection Resource（DR）

→

Key PR Measures（Barriers）

1. Detection of Diversion and Misuse
2. Difficulty to Modify Process for Separation of Pu
3. Material Type Barriers

Reasonably Economical Designing

↓ **Effect**

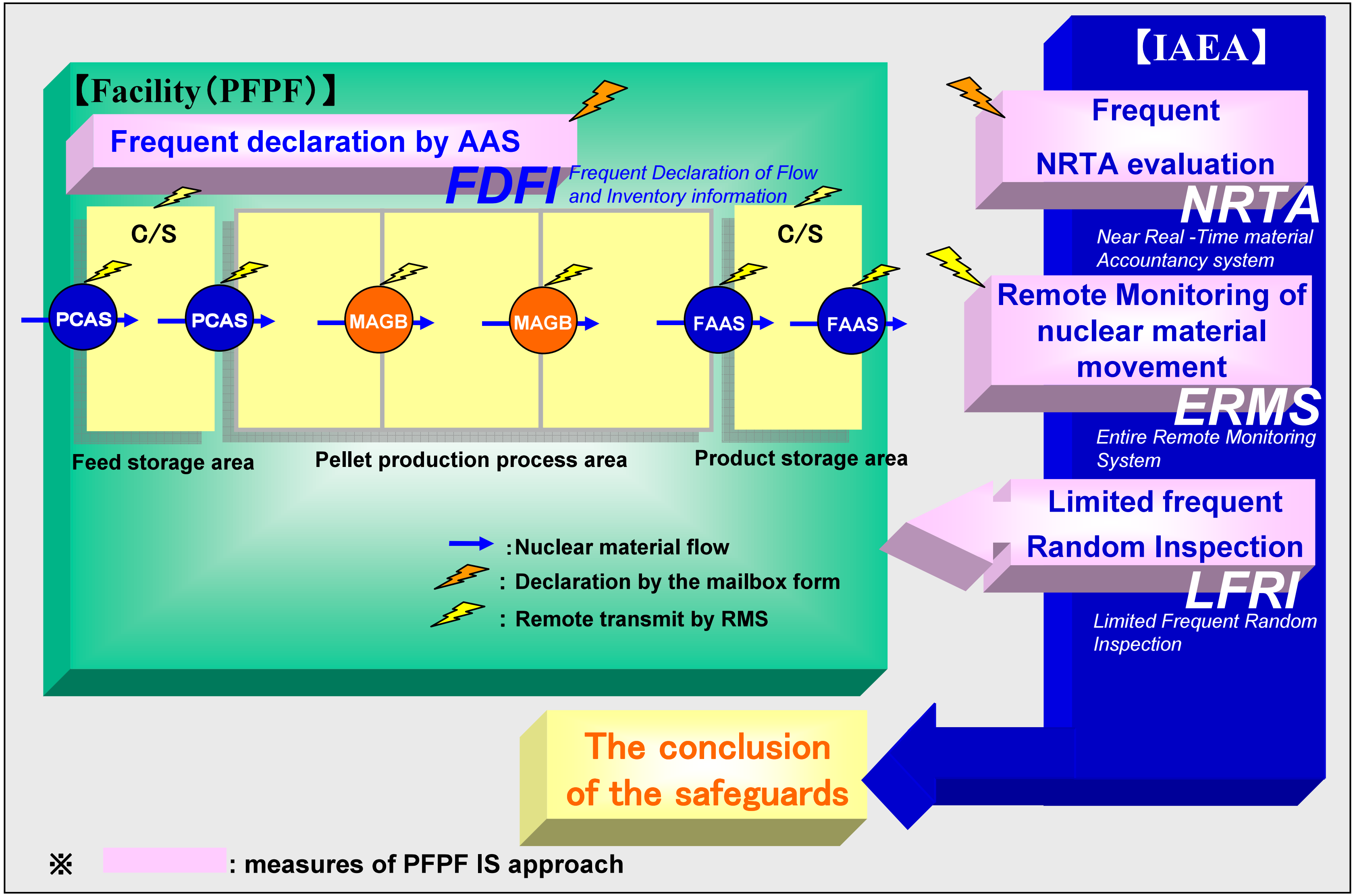
- Detect Diversion/Misuse in Timely Manner (SG by Design)
- Delay Diversion/Production of Nuclear Weapon
- Deterrence

Proliferation Resistance – ***Detection***: Based on Institutional Systems

High detection probability by Safeguards (SG) and other techniques:

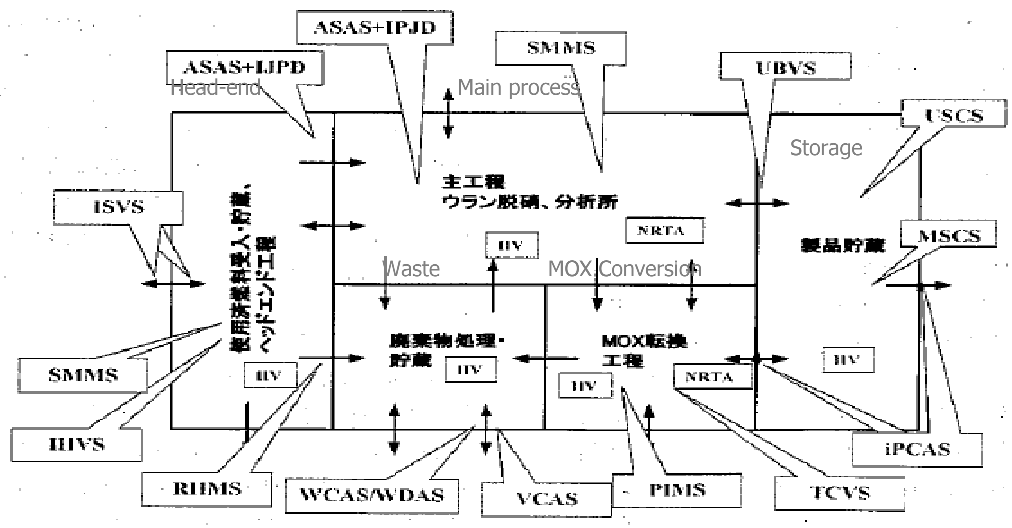
- Design information
- Material accountability
- Containment/Surveillance (C/S)
- Detect-ability of material diversion and misuse
- Operational transparency
- Etc.

IS Approach at Pu Fuel Production Facility



SG for Large Scale Reprocessing（SG Approach in RRP）

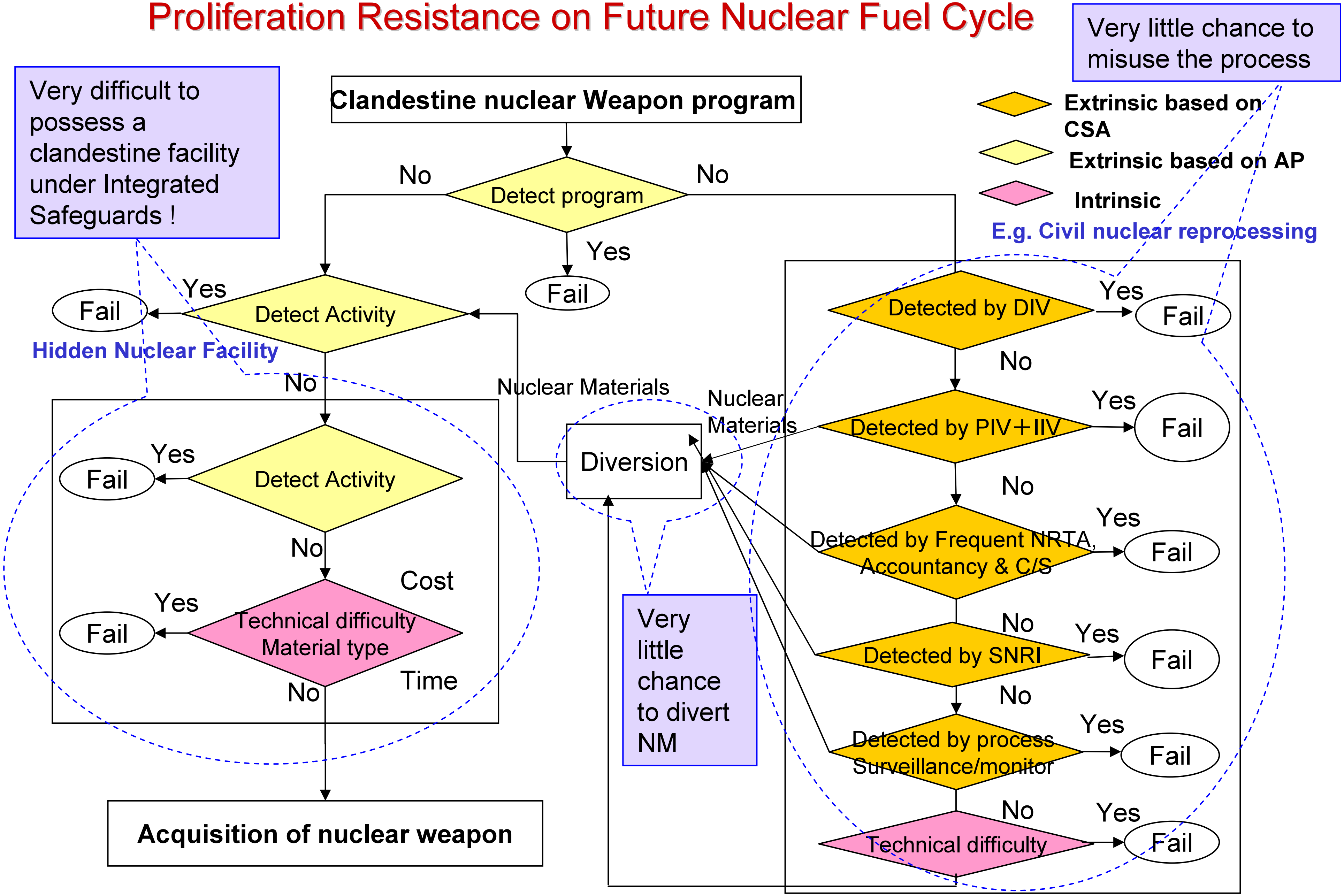
- DIQ/DIV
- Dual C/S（Surveillance Cameras, Radiation Detectors）
- Process Monitoring（Hull Monitoring, Solution Monitoring、PIMS etc）
- NRTA
- Unattended Mode Inspection, Centralized Collection of Inspection Data
- Various NDAs
- Advanced Accountancy System
- On-Site-Laboratory (Rapid Verification Measurement)



注）
ＩＳＶＳ：Integrated Spent fuel Verification System
ＩＨＶＳ：Integrated Head-end Verification System
ASAS：Automatic Sampling Authentication System
WCAS：Waste Crate Assay System
VCAS：Vitrified Canister Assay System
TCVS：Temporary Canister Verification System
MSCS：MOX Storage C/S System
USCS：Uranium Storage C/S System
SMMS：Solution Monitoring and Measurement System
RHMS：Rokkasho Hulls Drum Measurement System
ＩＪＰＤ：Inspector Jug Passage Detector
WDAS：Waste Drum Assay System
ＰＩＭＳ：Plutonium Inventory Measurement System
iPCAS：Improved Plutonium Canister Assay System
UBVS：Uranium Bottle Verification System

Example

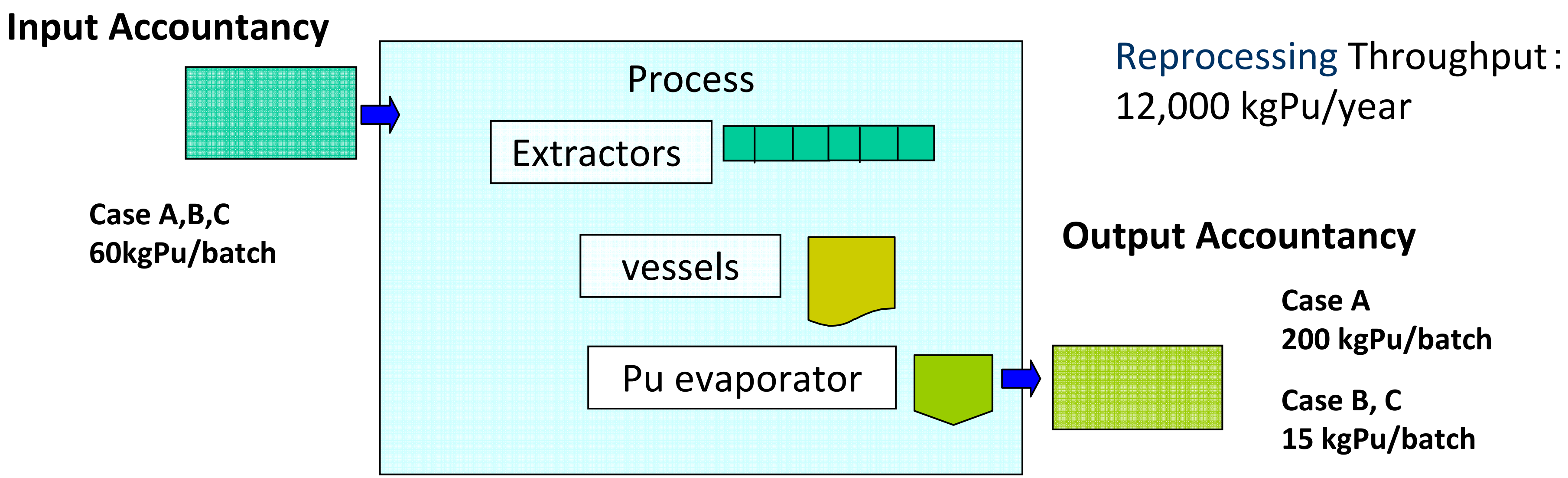
Proliferation Resistance on Future Nuclear Fuel Cycle



What are the real challenges in diversion risk for future Japanese NFC ?

- Present Japanese NFC is under Integrated Safeguards, where either clandestine facilities or diversion of nuclear materials / misuse of NFC should be found at very high probability.
- This is unattractive enough to deter from taking nuclear weapon option, although Japan politically decides not to take it.
- Challenge will be to design NM accountancy future NFC (e.g. reprocessing, MOX fuel fabrication facility) where significantly/much higher amount of Pu than that in present time should be processed.

Case study how to realize nuclear material accountancy



	Flow		Total Inventory (Process+Accountancy)	Errors (Flow & Inventory)
	Input	Output		
Case A	**60 kgPu x 200 batches** (12,000 kg Pu/year)	**200 kg Pu x 60 batches**	**400 kg Pu**	**ITV2000 (for accountancy tanks)** + **Process control level measure**
Case B		**15 kg Pu x 800 batches (smaller Pu tank)**	**90 kg Pu (very small inventory)**	
Case C			**170 kg Pu**	Sampling & Measurement: **All: ITV 2000** Volume:0% (total Pu is directly obtained without volumer measurement , i.e. by IDMS-tracer techniques)

Assumption for calculation

To Estimate ***Inventory*** σ_{MUF} : process-control measurement (Case A & B)
level

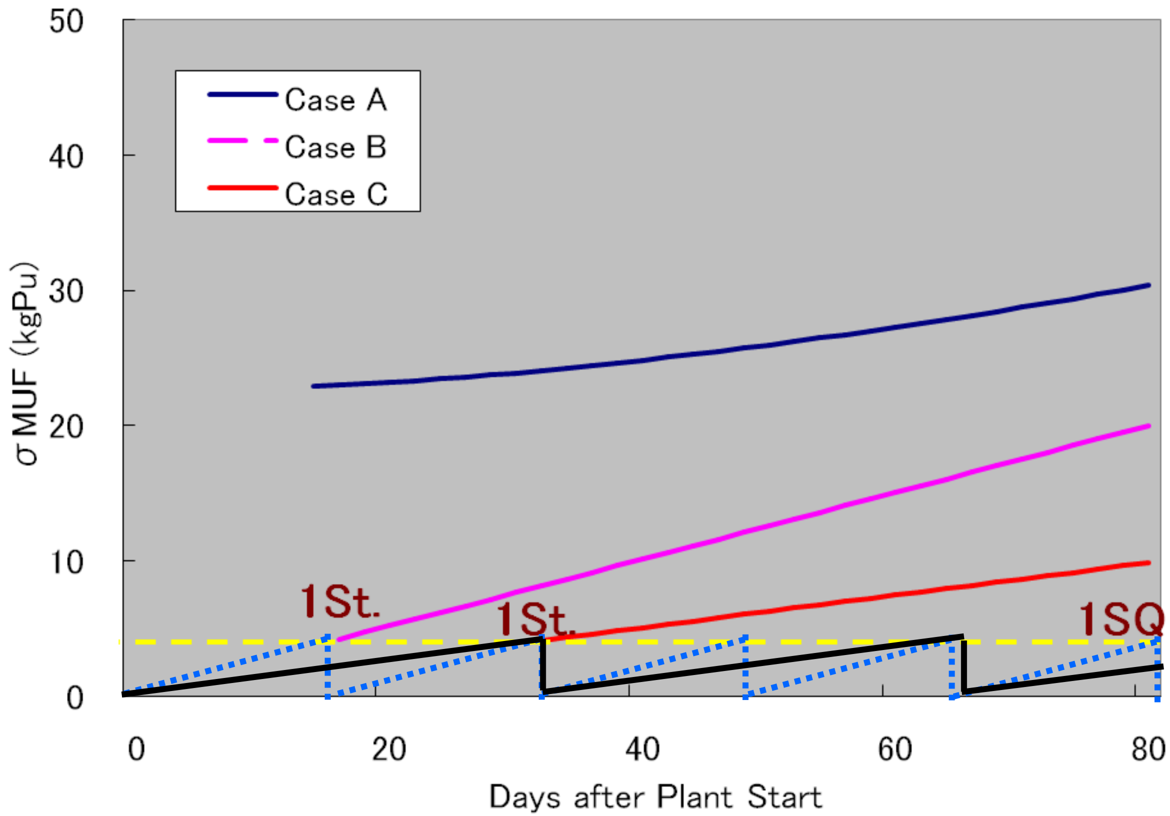
Error for volume measurement : 1%
Error for sampling : 0.5%
Error for conc. Measurement : 10%

ITV 2000 *to Estimate* ***Flow*** σ_{MUF} *(Case A & B), both* ***flow*** *and* ***Inventory*** σ_{MUF} *(Case C)*

ITV 2000	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

Improvement of σ'_{MUF}

Image of accountancy performance



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

To have Safeguard-ability for future NFC

Example,

①Essentials of Nuclear Material Accountancy / Safeguards

- Small process inventory
- More accurate accountancy measurement for input/output
- More accurate measurement even for inventory for IIV (≒PIV(PIT)
- Frequent IIV for timeliness requirement
- Short notice randomized inspection

⇒ needs to design accountancy-friendly process and operational mode

②Improvement of Detectability

- NRTA→RTA
- Real time process monitoring with remote monitoring - C/S, NDA, sensors for detection of misuse of process: solution volume + concentration, possibly with isotopics
- More sophisticated monitors/sensors for Pu/U/(H^+)

Key: "Safeguards by Design"

When Intrinsic measures work if a complete package of Safeguards is implemented?

Simply put, “in the case of break-through of institutional system (abrogation)”

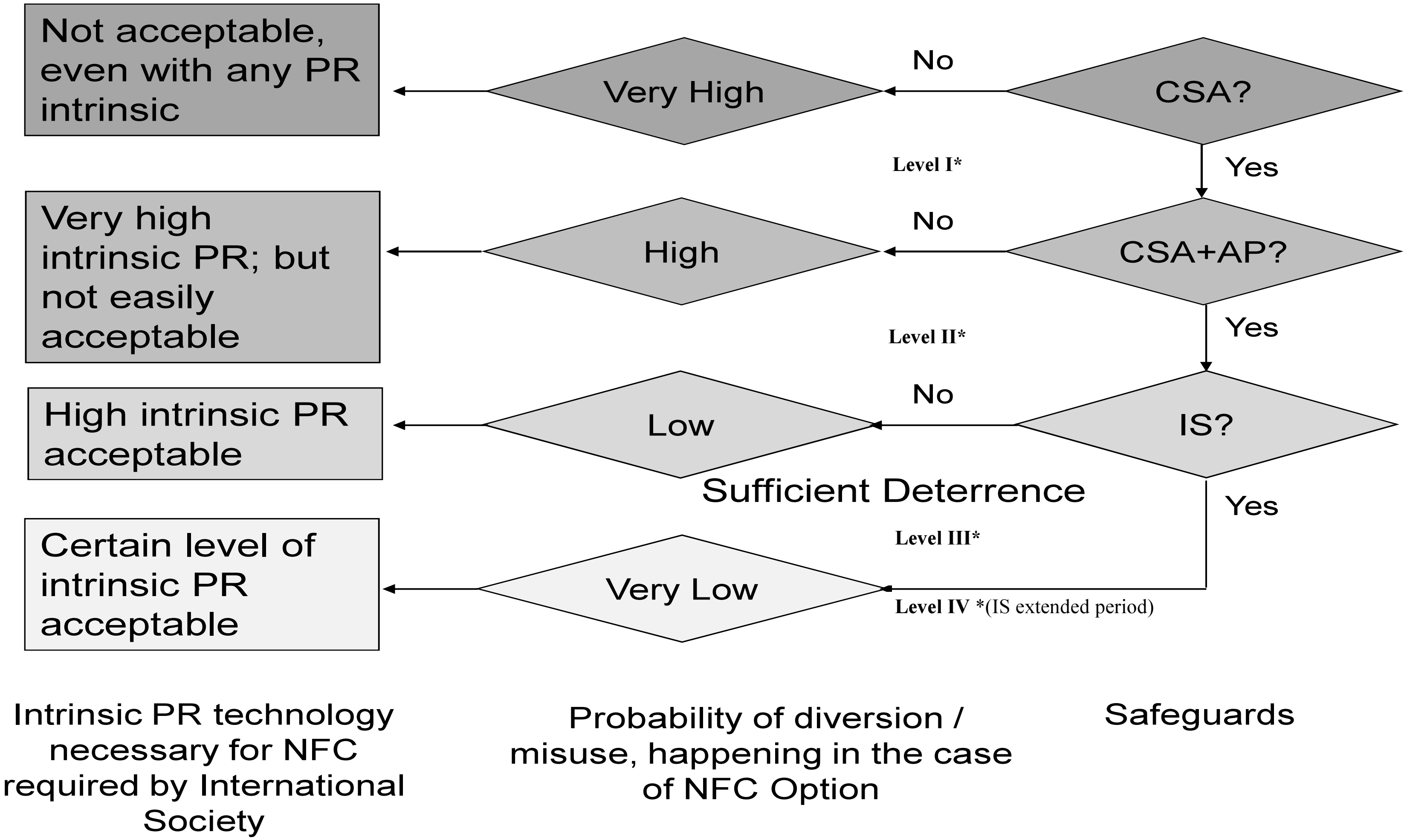
What probability should be considered for such an abrogation for State that is in Integrated Safeguards?

How long is sufficient for the “lengthy delay”?
Worthy to invest such intrinsic measures?

Intrinsic Measures for Future NFC?

- Strong intrinsic measures, such as technical difficulty or material type barrier should be studied because those would be effective for the cases of State's break-out (abrogation) from institutional framework or terrorist attack.
- However, if the study on the strong intrinsic measures results in not being economically viable, then there may be no other choice than finding a certain rational level of intrinsic measures, that are to be reasonably acceptable for international communities.
- Here, it is essential that these intrinsic measures should always be combined with the above-mentioned advanced ideas to provide sufficient safeguardability/detectability to meet institutional requirements and a strong PP system.
- This kind of study may be a future Japanese challenge.

Safeguards and Intrinsic PR Technologies



* Classification of Level I-IV was proposed by J.Carlson and R.Leslie: "Safeguards Intensity as a Function of Safeguards Status", the 46th INMM Annual Meeting, Phoenix, Texas, July 2005

Figure of Merit on Various Reactors, Arranged from the Previous Study*

Reactor Type (*Materials in SF)	Figure of Merit (FOM) :$1 - \log_{10}(x)$ $x = m$ [1/800 + h/4500 + n (produce fizzle yield)] + $[d/500]^{1/\log_{10}2}$ FOM: B>2, C:1-2, D: 0-1 B,C,D: DOE Graded Safeguards
WG-Pu	B
LWR**	C
LWR/MOX**	C
LMFBR Core** LMFBR Blanket**	C B
LWR (High BU)***	C
Pu (10% 238Pu) Pu (80% 238Pu)	C D

*J-S.Choi and Y.Kuno: "Degrading the Plutonium Produced in Fast Breeder Reactor Blankets", GLOBAL2009, September 6-11, Paris.
** Conditions on fresh fuel and BU etc for the calculation are referred to M. Benedict, T. Pigford, H. Levi, Nuclear Chemical Engineering, 2nd. Edition, McGraw-Hill, 1981.
*** "Considerations of material characteristics in FR recycling systems," J. A. Stillman, ANL, Feb. 25, 2005.

Level of Intrinsic PR Measures

- The degrading criteria can be based on;
  1) quality of plutonium similar to those produced in current operating reactors.
  2) a quantitative Figure-of-Merit (FOM) related to the intrinsic properties of nuclear materials.
- Materials of LWR spent fuels (SF), MOX (LWR) SF, and Pu materials containing 10% of ^{238}Pu, as regarded very high PR, are uniformly in accordance with grade C of US DOE Graded Safeguards (US DOE M 474.1-1B).
- In this context, material-type PR measure for blanket fuel whose FOM value is staying in grade C could correspond to the "certain level" for the case attaining SG Level III, IV
- Grade D may fit to the "very high" and high level" of intrinsic PR.

Conclusion

- A large amount of plutonium should be handled in the future fast reactor nuclear fuel cycle (FR-NFC).
- Robust measures for nuclear PR may have to be taken to prevent nuclear proliferation.
- To optimize the balance of extrinsic and intrinsic barriers is essential for NFC design.
- International Safeguards including Comprehensive Safeguards Agreement and Additional Protocol is the most effective institutional barrier among other institutional measures in non-proliferation regime.
- Particularly, in the countries where Integrated Safeguards (IS) is implemented, it seems unlikely that abrogation of institutional systems or diversion of nuclear materials in such countries occurs.
- A new concept of differentiation in the intrinsic measures depending upon the level of Safeguards could be applied from the viewpoint of plant design rationalization.

Thank you for your attention