2023 KNS Fall Conference

비핵화 검증을 위한 획득경로분석 모델 개발

Simulation Model Development for Acquisition Path Analysis

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Simulation Model Development for Acquisition Path Analysis

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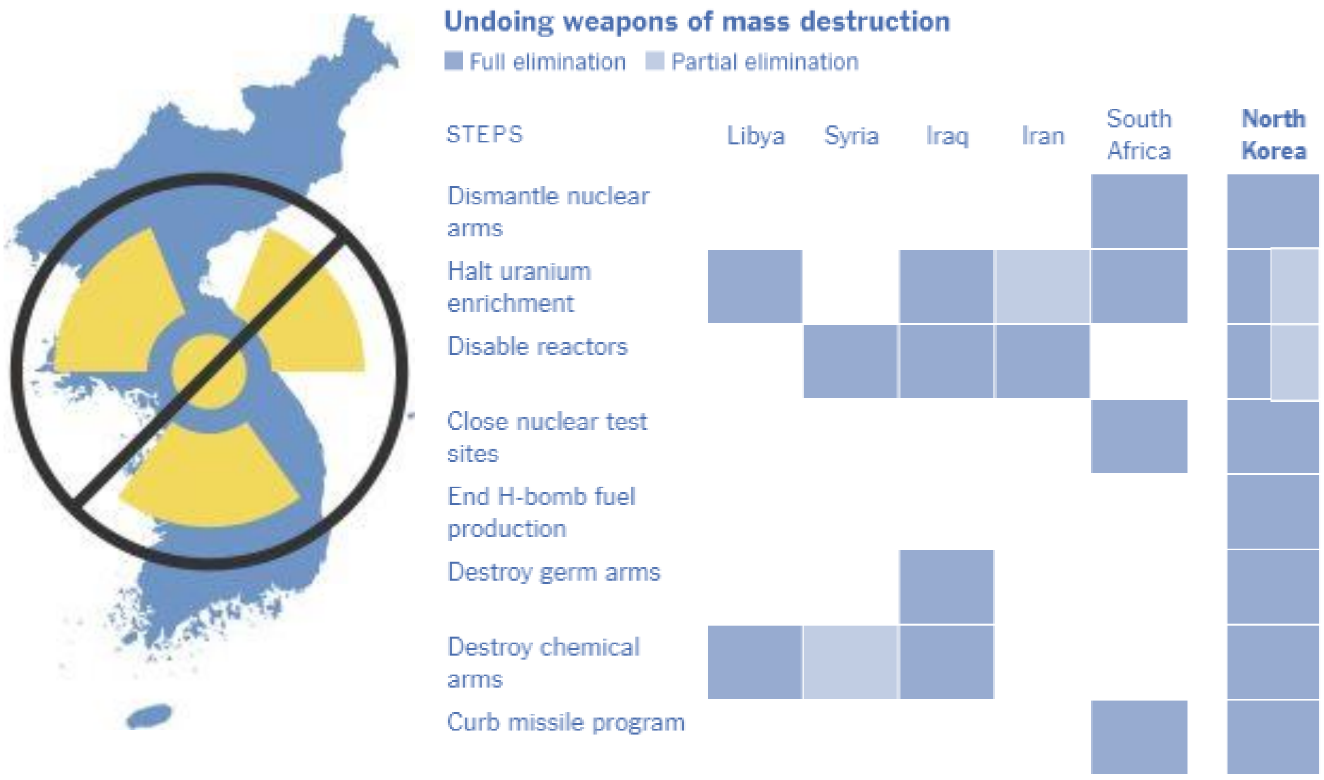
The Nine Steps Required to Denuclearize North Korea



출처 : https://www.nytimes.com/interactive/2018/06/11/world/asia/north-korea-nuclear-weapons-talks.html

NUCLEAR NON-PROLIFERATION TREATY -NPT-

191 States Parties

Non-States Parties:
India, Israel, Pakistan, South Sudan
North Korea has initiated a procedure to withdraw.

The NPT recognizes five nuclear-weapon States:
China, France, Russia, the United Kingdom and the United States

Entry into force: **1970**

IAEA
International Atomic Energy Agency

Aim: **limiting the quantity of nuclear weapons** worldwide

> A cornerstone of **collective security**
> An irreplaceable component of **peacekeeping**

Three pillars

Non-proliferation	Disarmament	Peaceful uses of nuclear energy
Not transferring nuclear weapons, or **assisting in manufacture or acquisition**	Pursuing **negotiations** in good faith on **nuclear disarmament measures**	Facilitating access to **peaceful applications** of nuclear energy
Many States have given up nuclear weapons, like South Africa and Ukraine	**The global nuclear warhead stock has been reduced** from 70,000 in the 1980s to **15,000 today**	Civilian applications of nuclear energy have been fostered: worldwide, **more than 450 reactors** produce electricity

Safeguards

HOW ?

출처 : https://www.diplomatie.gouv.fr/en/french-foreign-policy/security-disarmament-and-non-proliferation/disarmament-and-non-proliferation/combating-the-proliferation-of-nuclear-weapons/article/nuclear-non-proliferation-treaty-npt-our-dossier

Type of IAEA Safeguards Agreements

Comprehensive Safeguards Agreements (CSAs) (INFCIRC/153) With 180 States (99 with SQPs)

NNWS

IAEA
International Atomic Energy Agency

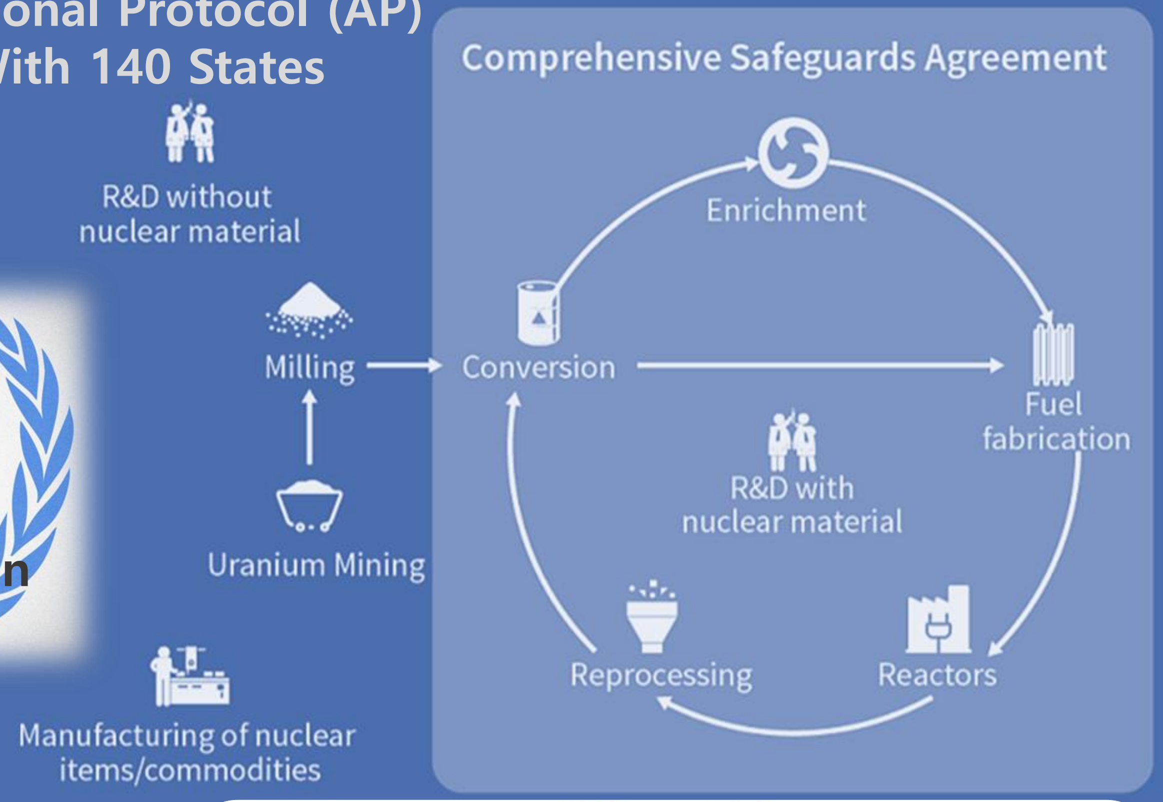
Voluntary Offer Agreements (VOAs) With 5 States

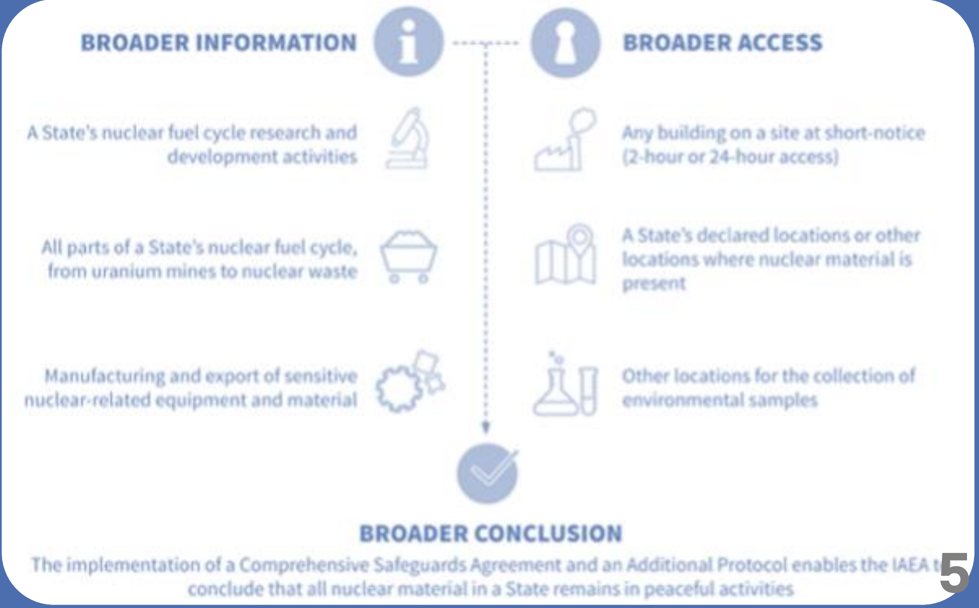
NWS

Item-specific Safeguards Agreements (INFCIRC/66) With 3 States
(India, Israel, Pakistan)

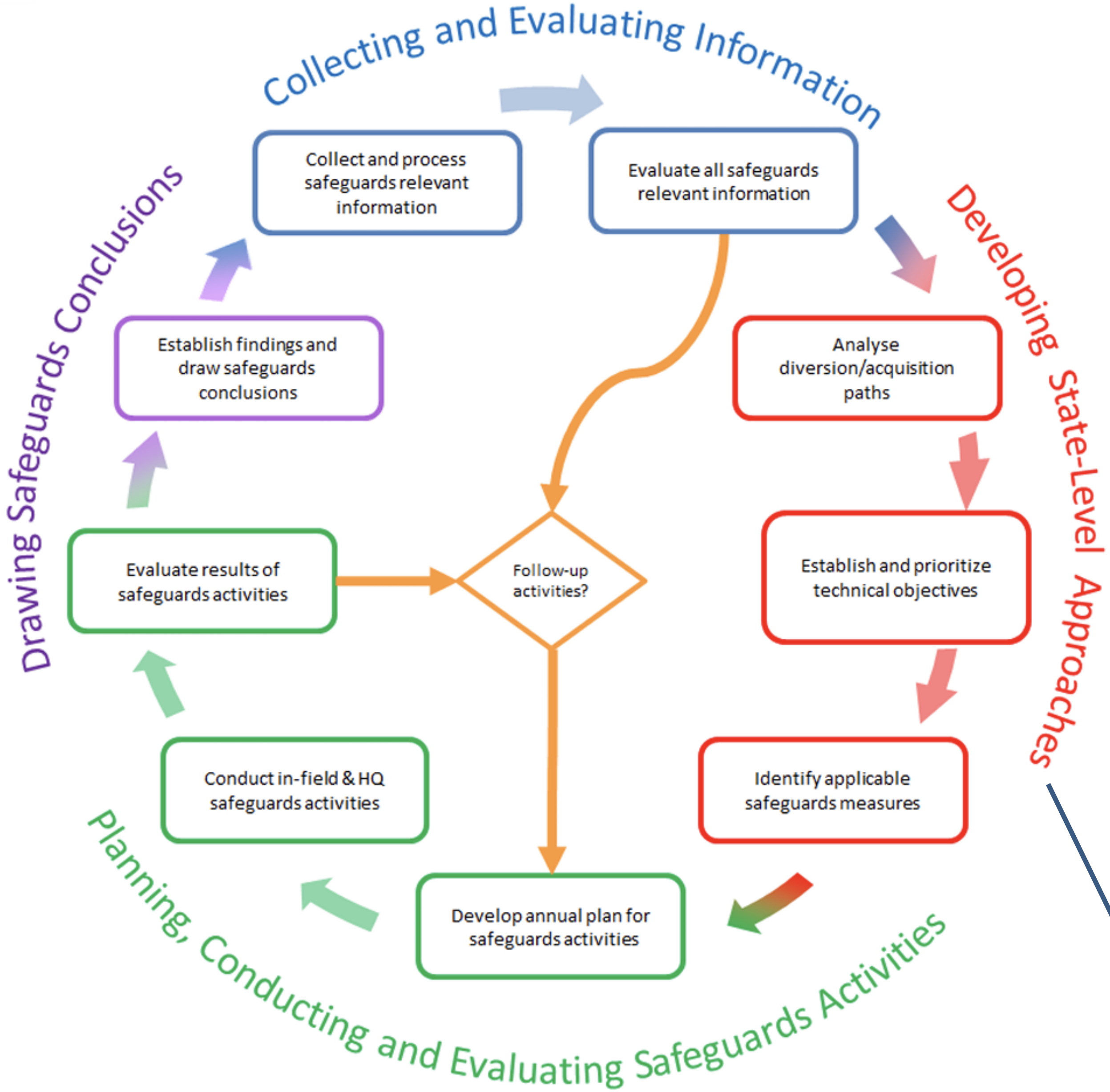
Non-NPT States

Additional Protocol (AP) With 140 States



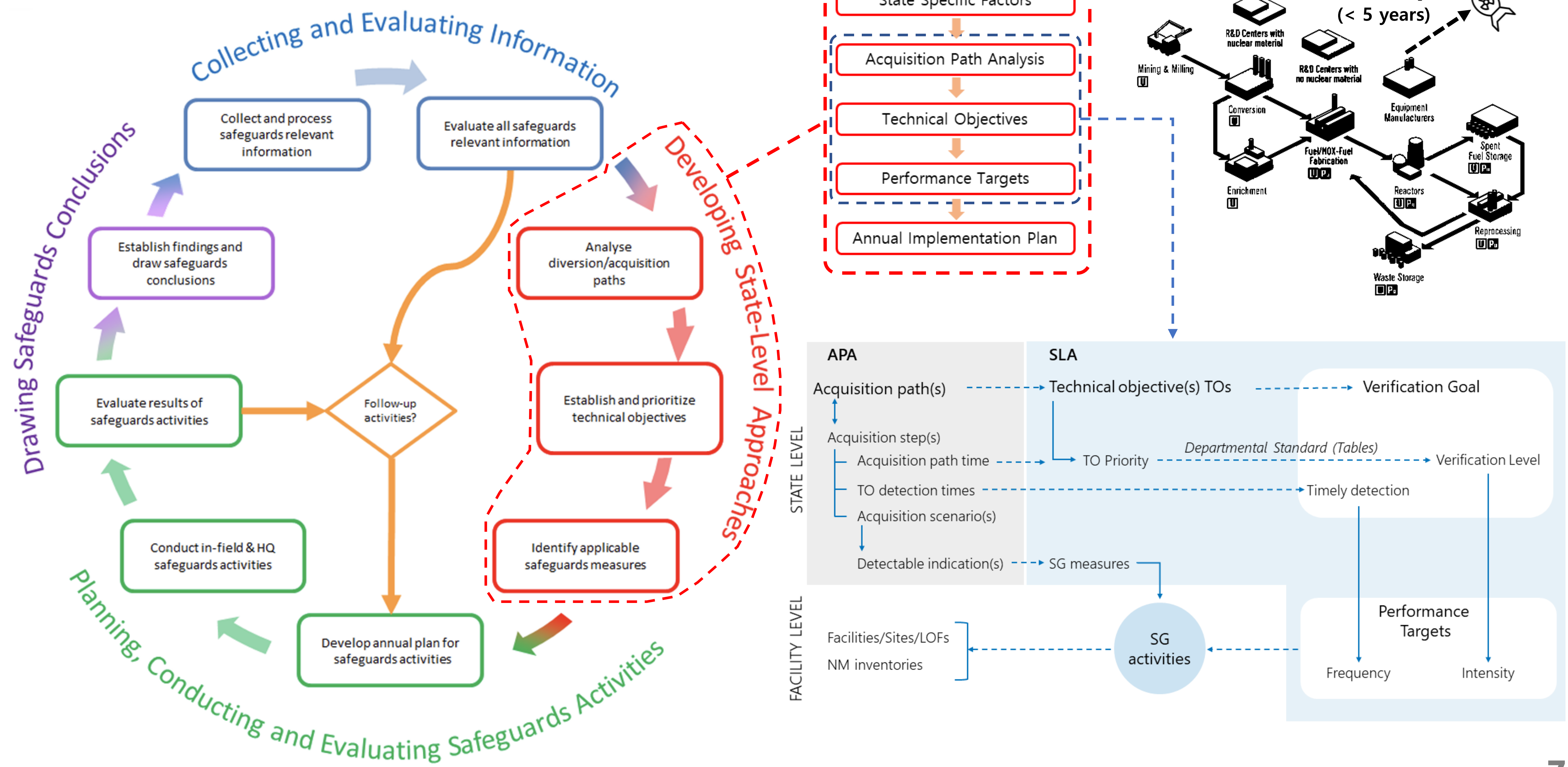


IAEA State-Level Approach (SLA)



출처 : IAEA. (2013). **The Conceptualization and Development of Safeguards Implementation at the State Level**. *IAEA GOV/2013/38*. 12 August 2013.

IAEA State-Level Approach (SLA)



출처 : 유호식, 임동혁, 이승민. (2022). **개선된 SLA 이행절차 및 사례연구**. *KINAC-TR-002/2022*. 2022년 1월.

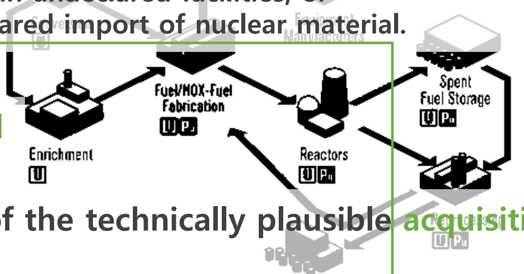
IAEA State-Level Approach (SLA)

- State Specific Factors
- Acquisition Path Analysis
- Technical Objectives
- Performance Targets
- Annual Implementation Plan

State Specific Factors:
- Types of safeguards agreement
- Nuclear fuel cycle and related technical capabilities of the State
- Technical capabilities of the SSAC
- Ability of the IAEA to implement certain safeguards measures in the State
- Scope of cooperation between the State and the IAEA
- IAEA's experience in implementing safeguards in the State

Acquisition Path Analysis:
- Declared facilities and locations outside facilities (LOFs) with inventories and flows of nuclear material
- Declared sites
- Exports and imports of nuclear material
- Research and development activities
- Exports and imports of non-nuclear material and equipment
- Uranium mines and concentration plants
- Nuclear-related industrial capabilities
- Holdings of pre-34(c) source material
- Exempted nuclear material
- Radioactive waste containing nuclear material

- P: Indigenous production of pre-34(c) nuclear material;
- D: Diversion of declared nuclear material in declared facilities or LOFs;
- M: Undeclared production or processing of nuclear material in declared facilities or LOFs;
- F: Undeclared production or processing of nuclear material in undeclared facilities; or
- I: Undeclared import of nuclear material.



NFC Model
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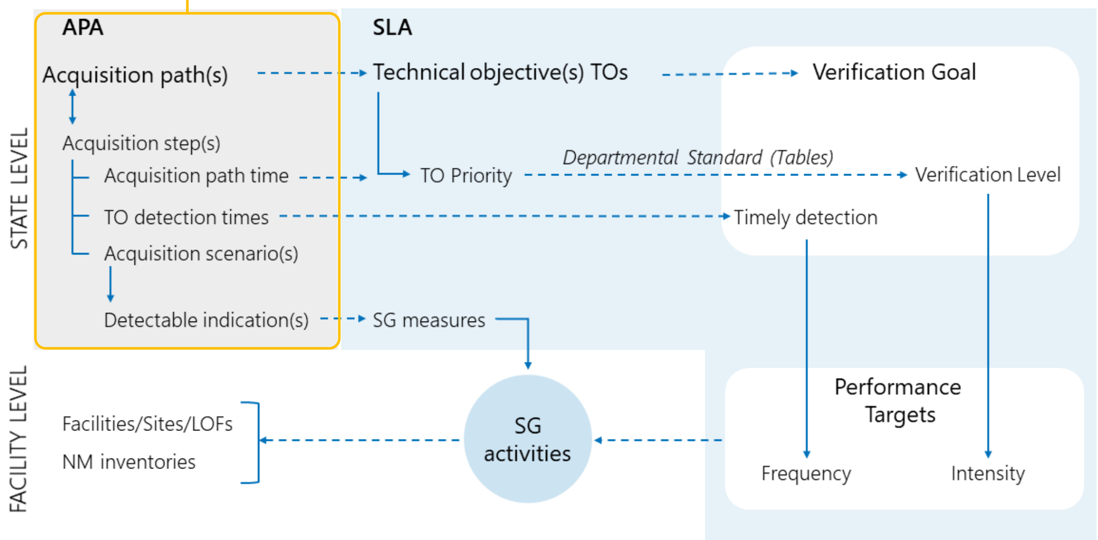
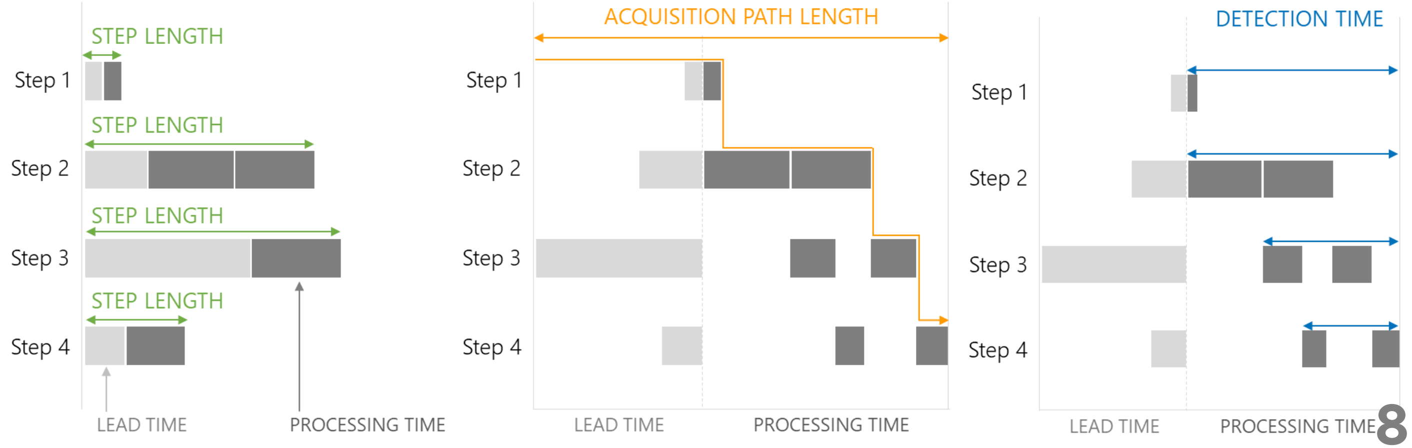
- Identification of the technically plausible acquisition paths
- Identification of the possible proliferation scenarios to accomplish the steps
- Assessment of the time needed to accomplish each identified acquisition path

Holder – Proficient – User – Emerging – None

- Step length = Lead time + Processing time
  (Lead time: Time from R&D to construction)
- Acquisition path length = Max(Lead time) + Sum(Processing time)
- Detection time = Time from start to accomplish path



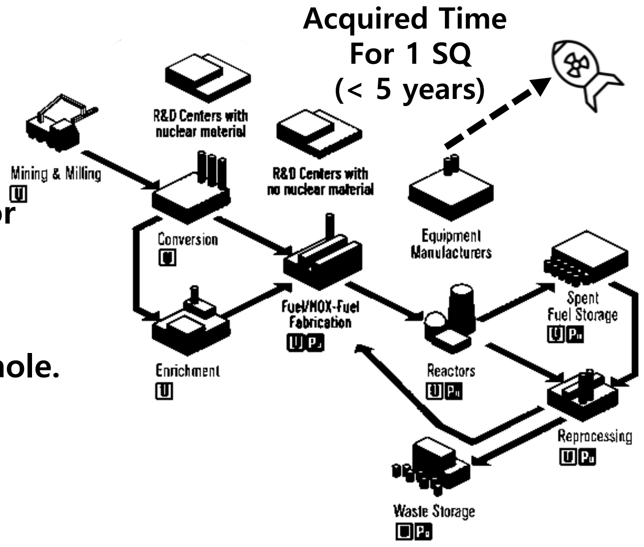


IAEA State-Level Approach (SLA)

State Specific Factors
↓
Acquisition Path Analysis
↓
Technical Objectives
↓
Performance Targets
↓
Annual Implementation Plan

Generic safeguards objectives are (TOs are established to fulfil this):

- to detect any diversion of declared nuclear material at declared facilities or locations outside facilities (LOFs);
- to detect any undeclared production or processing of nuclear material at declared facilities or LOFs where nuclear material is customarily used; and
- to detect any undeclared nuclear material or activities in the State as a whole.



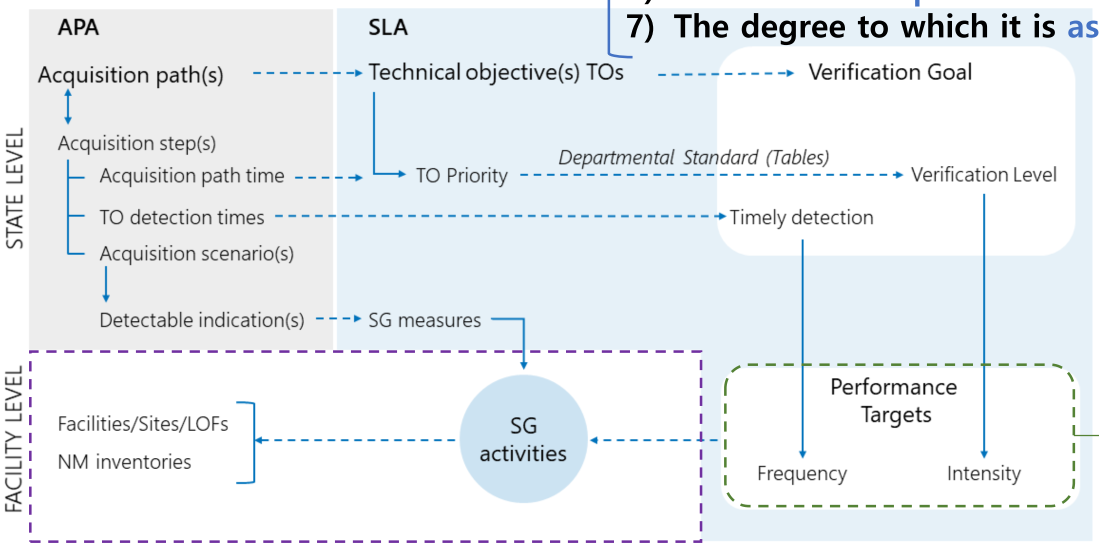
Technical objectives can be established:

- to detect specific steps on an acquisition path,
- to confirm the assessment of State-specific factors,
- to confirm supporting key assessments from State evaluation, or
- to address significant issues, inconsistencies, and anomalies.

Technical objectives should be prioritized as High, Medium, or Low based on the following:

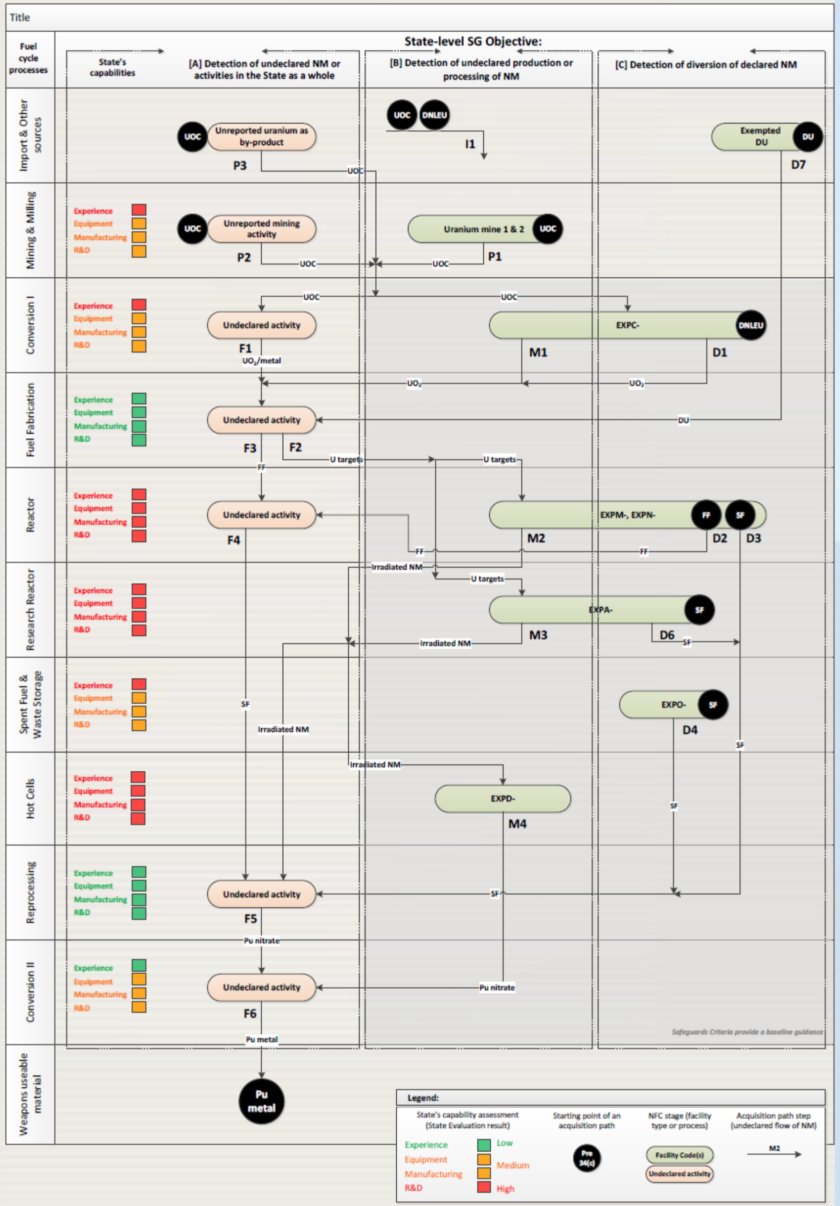
1) The state's technical capability as recorded in the APA
2) The sensitivity of acquisition path steps
3) The speed with which a path could be completed as determined by the APA
4) The degree of insufficient information to complete a full assessment during APA
5) The IAEA's ability to detect various proliferation scenarios
6) The number of paths covered by a technical objective
7) The degree to which it is associated with a technically plausible path

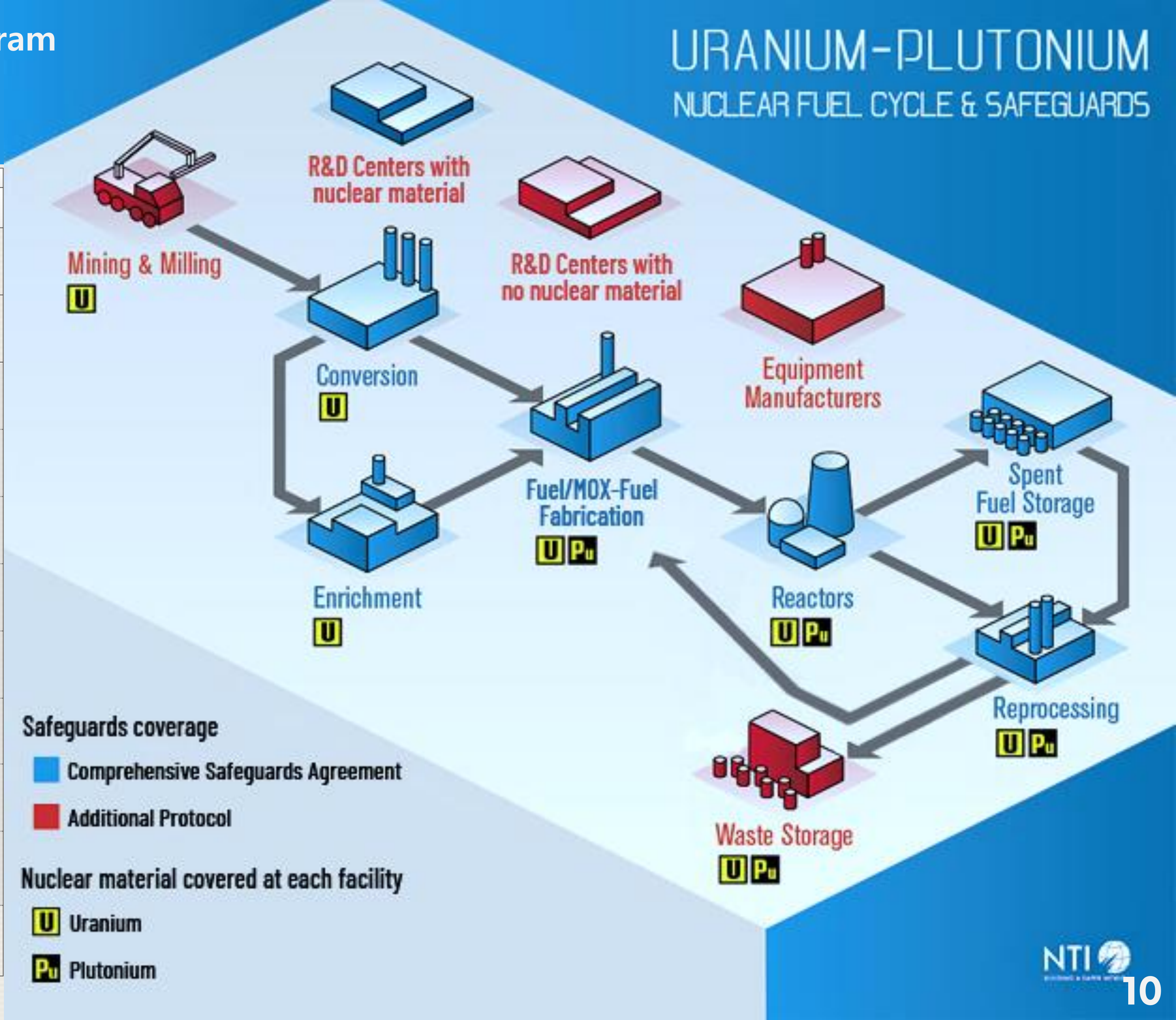
	TO(1)			TO(2)			TO(n)		
	L	M	H	L	M	H	L	M	H
1)			v		v		v		
2)		v				v			v
3)	v				v			v	
4)		v				v	v		
5)			v	v					v
6)		v				v		v	
7)	v					v	v		
T		v				v	v		



Nuclear Fuel Cycle Diagram For IAEA Safeguards

APA tool proposed by IAEA





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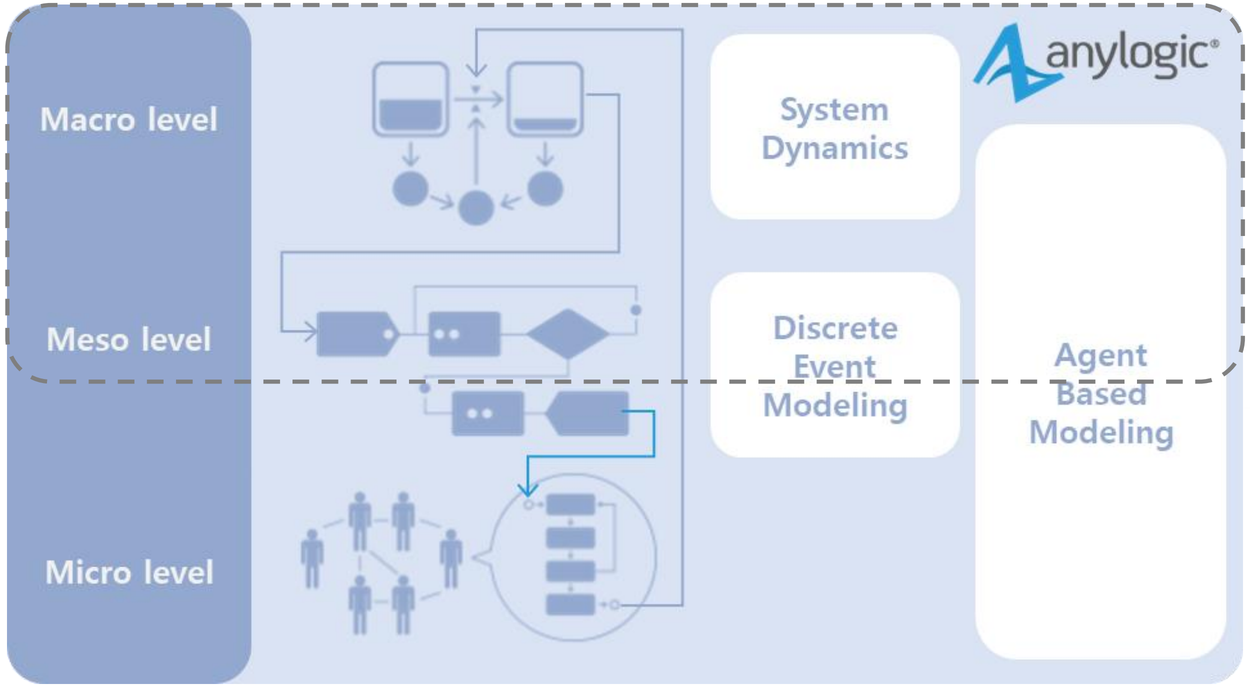
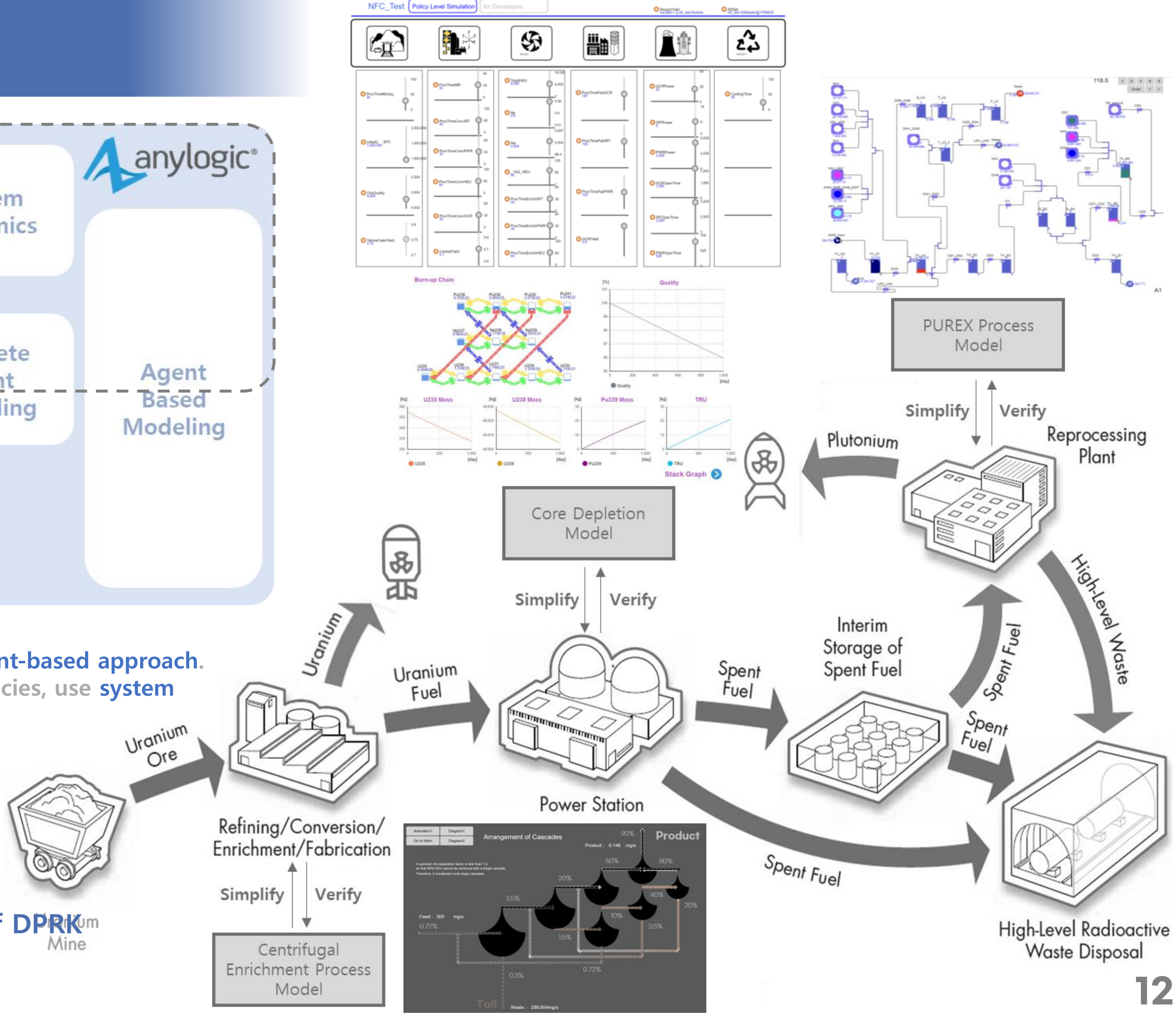
Simulation Tool (AnyLogic)



Multi-method modeling environment

- If there are many independent objects, use an **agent-based approach**.
- If there is only information about global dependencies, use **system dynamics**.
- If a system is easily described as a process, use a **discrete event approach**.
- Having **access to all methods simultaneously** gives the flexibility needed to successfully solve the problem

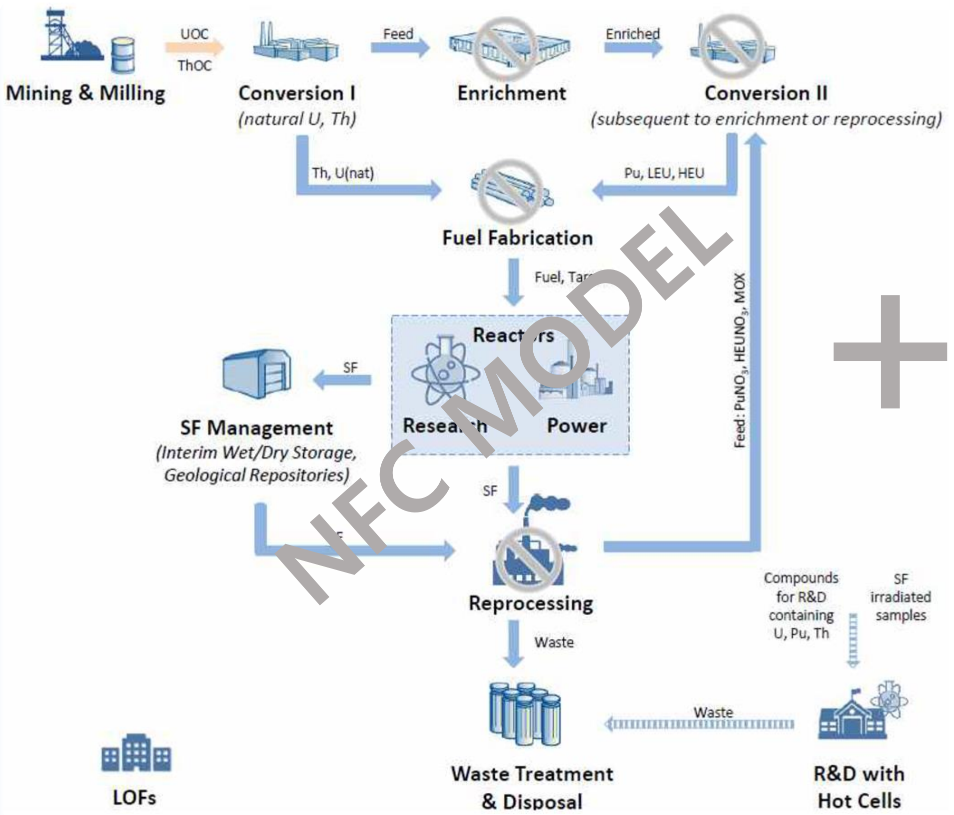


Nuclear Fuel Cycle Model of DPRK
Developed by KINAC

Scope of Modeling

Required Input Data
- Nuclear Fuel Cycle
- Nuclear Material Inventories
- Technical Capabilities

State Specific Factors
↓
Acquisition Path Analysis
↓
Technical Objectives
↓
Performance Targets
↓
Annual Implementation Plan



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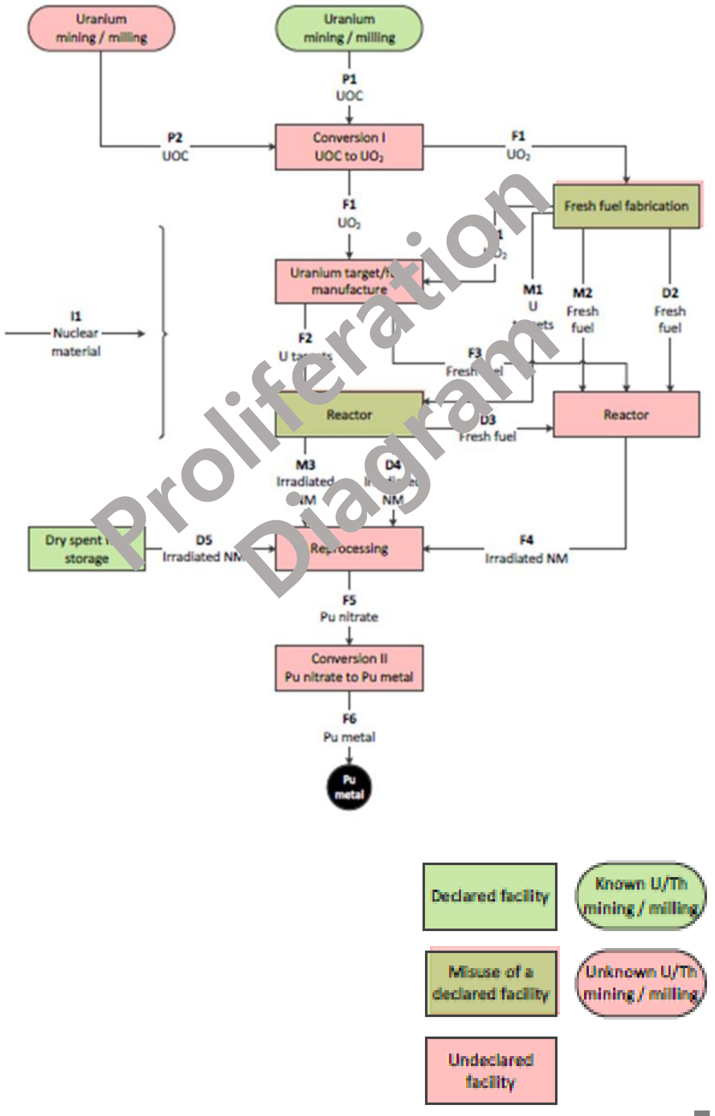

Required Output
- The set of technically plausible acquisition paths
- The possible proliferation scenarios
- The time needed to accomplish each identified acquisition path

Proliferation Scenarios

	Declared Facility (Diversion)		Undeclared Import	Declared Facliity (Misuse)		Undeclared Facility
Mine	NU U Mine P1-1		NU Import I1	**P1-1**		NU U mine P1-2
Conversion 1	NU Conversion D2-1	NU LOF D2-2	NU Import I2	Conversion M2		Conversion F2
Enrichment	NU Enrichment D3		NU Import I3	Enrichment M3-1	LOF M3-2	Enrichment F3
Conversion 2	EU, DU Conversion D4-1	EU, DU LOF D4-2	EU, DU Import I4	Conversion M4		Conversion F4
Fabrication	FF Fabrication D5		FF Import I5	Fabrication M5		Fabrication F5
Reactor(Irr)	FF Power Reactor D6-1	FF Research Reactor D6-2		Power Reactor M6-1	Research Reactor M6-2	Power Reactor F6
Storage	SF Interim Storage D7-1	SF LOF D7-2	SF Import I7			Interim Storage F7
Reprocessing	SF Reprocessing D8-1	SF Hot cell D8-2	SF Import I8	Reprocessing M8-1	Hot cell M8-2	Reprocessing F8
Conversion3	EU, MOX Conversion D9-1	EU, MOX LOF D9-2	EU, MOX Import I9	Conversion M9		Conversion F9
Product		Pu Metal			HEU Metal	

Proliferation Scenarios

- P: Indigenous production of pre-34(c) nuclear material;
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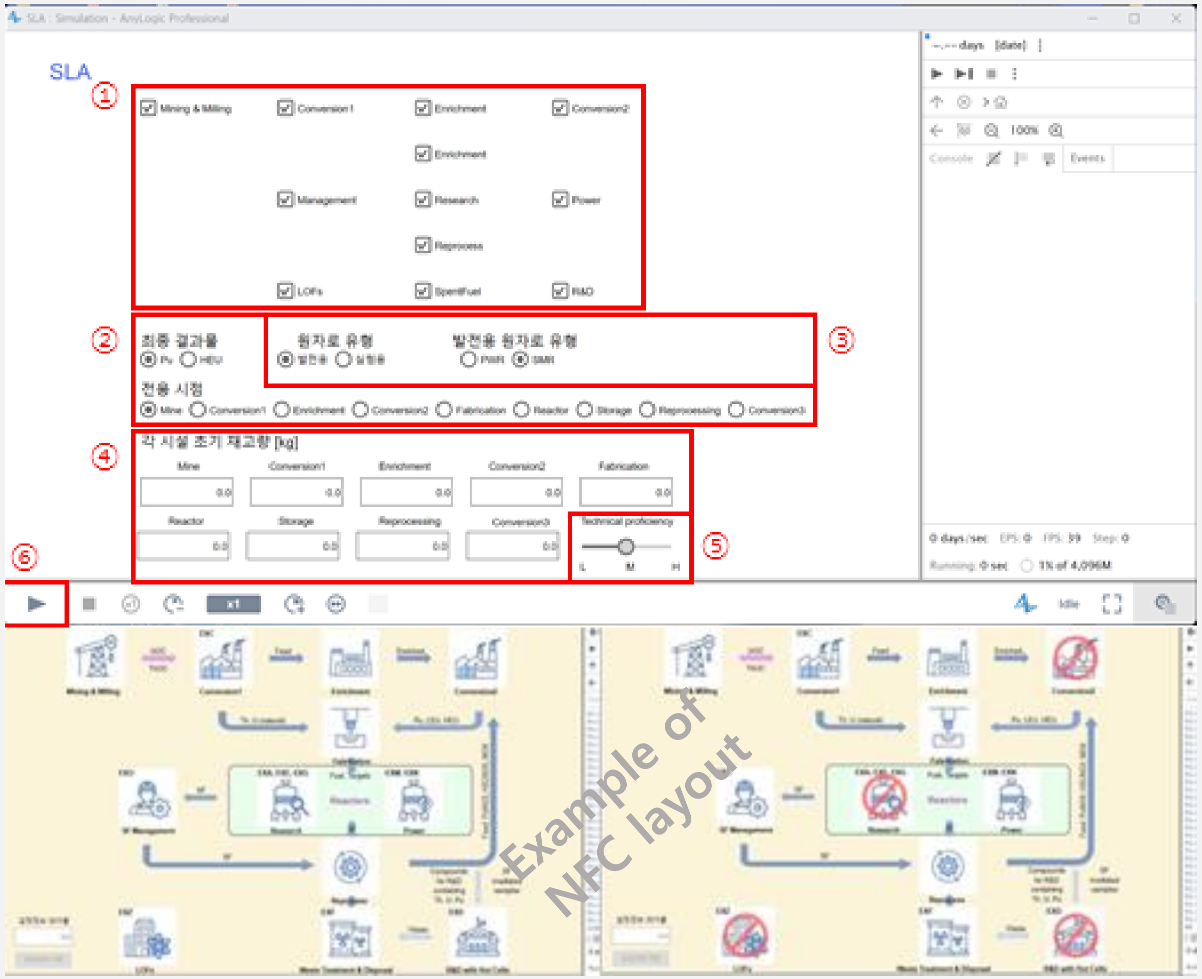
Nuclear Fuel Cycle

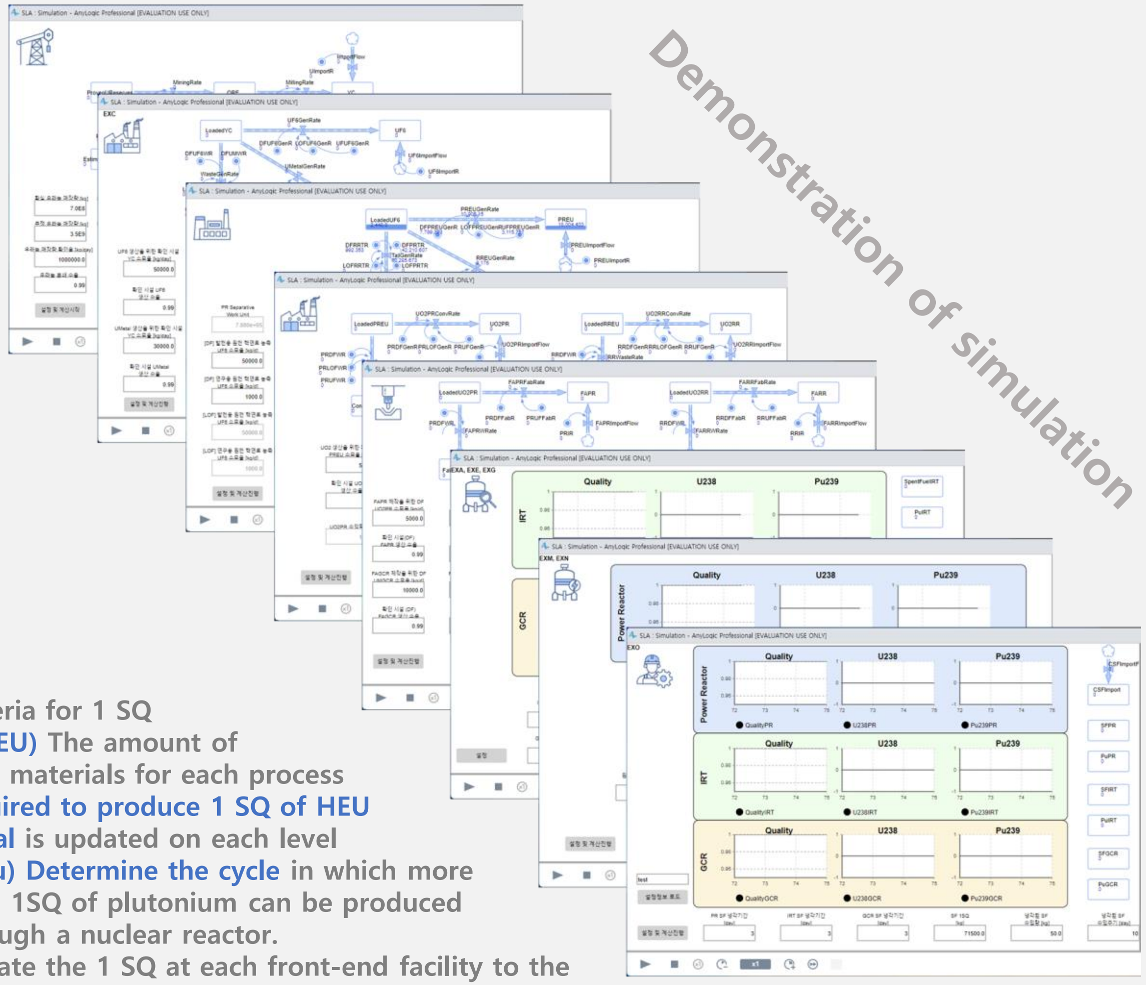
- Divided into 9 levels according to the nuclear fuel cycle sequence
- If alternative facilities exist, they are classified with a '–(hyphen)' sign
- When using NU as nuclear fuel, level 2 and level 3 are skipped
- The acquisition path related to DU assumes neutron irradiation through a nuclear reactor
- Although there will be a combination of different proliferation scenarios, this model assumes one malicious activity at every single facility.

Level	Start	Process	End
1	P1-1, I1, P1-2	-	
2	D2-1, D2-2, I2	M2, F2	
3	D3, I3	M3-1, M3-2, F3	
4	D4-1, D4-2, I4	M4, F4	HEU
5	D5, I5	M5, F5	
6	D6-1, D6-2	M6-1, M6-2, F6	
7	D7-1, D7-2, I7	F7	
8	D8-1, D8-2, I8	M8-1, M8-2, F8	
9	D9-1, D9-2, I9	M9, F9	
10	-	-	Pu

Example of developed simulation model



① Existence of the declared facilities
② Type of acquired nuclear material (HEU, Pu)
③ Type of reactors (PWR, IRT, GCR)
④ Inventory of declared nuclear material at each facility
⑤ Technical capabilities (H, M, L)
⑥ Run



- Criteria for 1 SQ
  - (HEU) The amount of feed materials for each process required to produce 1 SQ of HEU metal is updated on each level
  - (Pu) Determine the cycle in which more than 1SQ of plutonium can be produced through a nuclear reactor.
  Update the 1 SQ at each front-end facility to the amount required to operate the determined cycle.
- If a declared facility exists, enter the facility information.
- If a declared facility does not exist, a facility with a capacity of 1SQ per year is assumed.
- Assume one facility as one material balance area.
- If there is nuclear material inventory, the inventory amount is deducted from 1SQ, the target production of the previous facility.

Model Assessment & Results

Input Data and Assumption
- Target State: DPRK
- Declared Facilities
  - Mining and Milling
  - Conversion
  - Enrichment
  - Deconversion
  - Fabrication
  - Reactor
  - Reprocessing
  - Conversion (to metal)
- Declared Nuclear Material: Nothing
- Technical Capability: High
- Type of Reactor: Graphite Cooled Reactor

광산	재고량	시설용량	회수율	변환1	재고량	시설용량	회수율
	0 [MTU]	11700 [MTU/yr]	95 [%]		0 [MTU]	500 [MTU/yr]	95 [%]

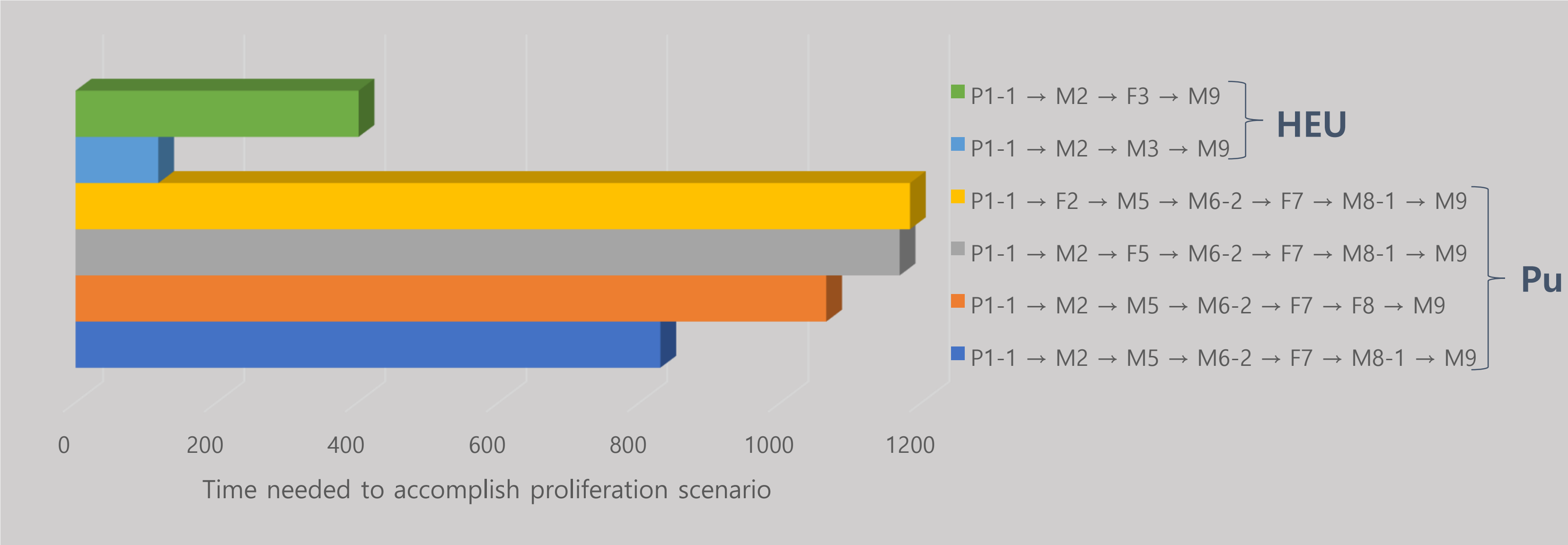
농축	재고량	N_F	N_P	N_W	시설용량
	0 [kg]	0.7 [%]	90 [%]	0.3 [%]	16,000 [kg-SWU]

변환2	재고량	시설용량	회수율	가공	재고량	시설용량	회수율
	0 [MTU]	500 [MTU/yr]	95 [%]		0 [MTU]	350 [MTU/yr]	95 [%]

원자로	재고량	열출력	장전량	캠페인	연소도
	0 [MTU]	25 [MWth]	50 [MTU]	18 [mon]	270 [MWd/MTU]

재처리	재고량	시설용량	회수율	변환3	재고량	시설용량	회수율
	0 [kg]	110 [MTU/yr]	95 [%]		0 [kg]	500 [MTU/yr]	95 [%]

대상 핵물질	Pu	목표 유의량 [kg]	8
경로 집합수 [#]	1,296	최소 소요시간 [day]	829.25
최소 소요경로	P1-1 → M2 → M5 → M6-2 → F7 → M8-1 → M9		
대상 핵물질	HEU	목표 유의량 [kg]	25
경로 집합수 [#]	12	최소 소요시간 [day]	117.31
최소 소요경로	P1-1 → M2 → M3 → M9		



Results and Discussion
- The acquisition path that utilizes all declared facilities is the shortest
- Acquisition time underestimated since model assumed nuclear material inventory does not exist (Presence of low-enriched uranium in the uranium enrichment process can significantly shorten the acquisition path)
- Input variable may differ from reality, leading to inaccuracy (Especially, reactor campaigns set as fixed variables can cause significant differences in the acquisition path)
- When loading NU, 1 SQ of Pu can be acquired in 1 cycle, so there is no need to consider the scenario of loading DU
- The acquisition path for HEU is dramatically lower in terms of time required and number of paths compared to the acquisition path for Pu. Therefore, it can be empirically confirmed that the risk of HEU's proliferation scenario is higher

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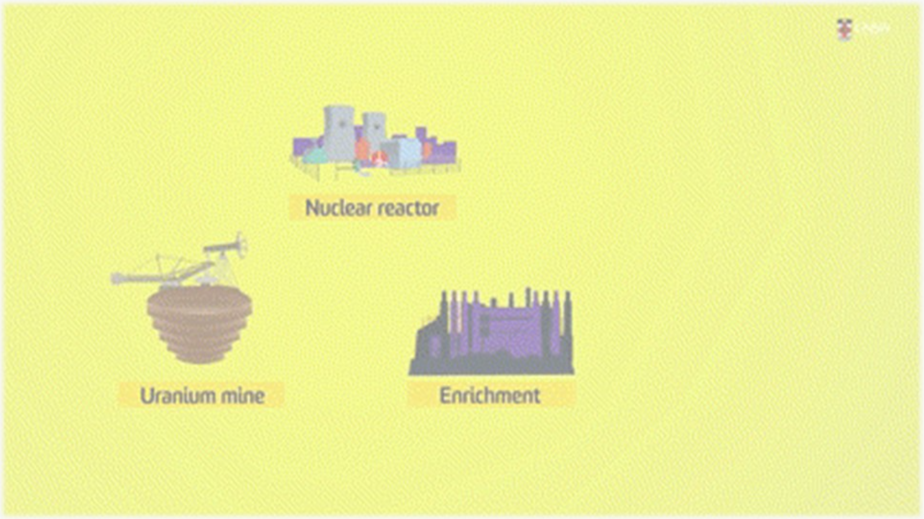
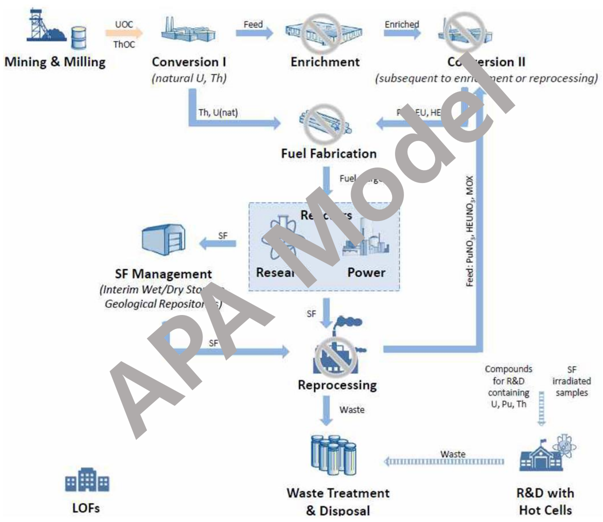
Conclusion and Required Improvements

- Verification of denuclearization has similar purposes and procedures to the IAEA's safeguards implementation activities.
- Therefore, benchmarking the IAEA's safeguards implementation activities would be a more realistic alternative to denuclearization verification.
- Especially in cases where part of sensitive nuclear fuel cycle facilities are permitted for commercial purposes, such as Iran's JCPOA, a quantitative proliferation scenario evaluation is needed to minimize proliferation risk.
- However, the following required improvements were derived to improve the model's accuracy and reliability.
    - ✓ Considering complex proliferation scenarios
    - ✓ Specification of material balance area and supplementation of input data
    - ✓ Improving model by considering nuclear material inventory of various uranium enrichment
    - ✓ Considering the case of operating the reactor only in campaigns optimized for Pu 1 SQ production
    - ✓ Visualization to intuitively understand the acquisition path
    - ✓ Improving UI
    - ✓ Development of an alternative methodology to determine TO priorities

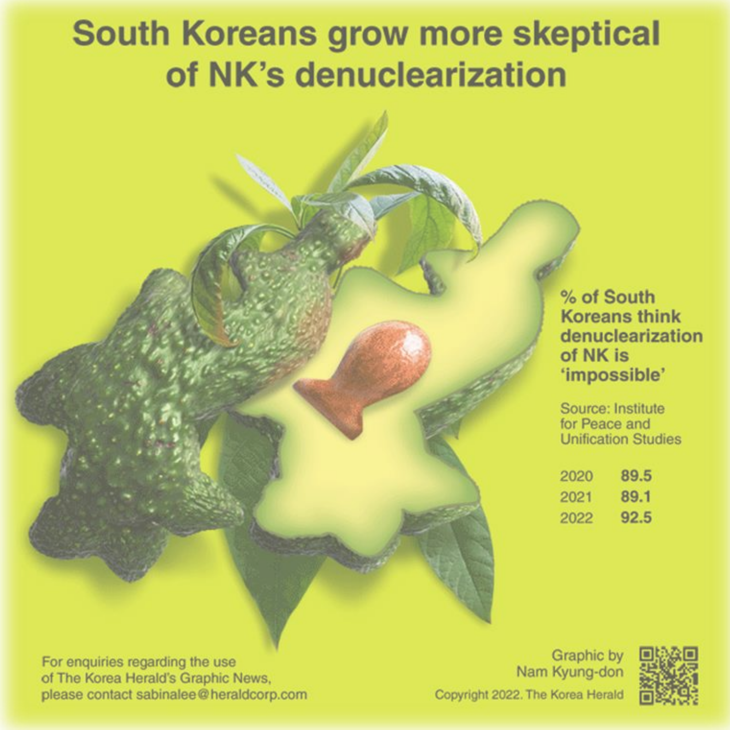


Implications and Applicability

Verification of Denuclearization



Verification of Annual Implementation Plan



원자력안전위원회 IAEA International Atomic Energy Agency

Nuclear transparency guaranteed by the international community

QUESTION

감사합니다

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