Identification of Requirements for Material Balance Evaluation based on a Benchmark Scenario

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Background

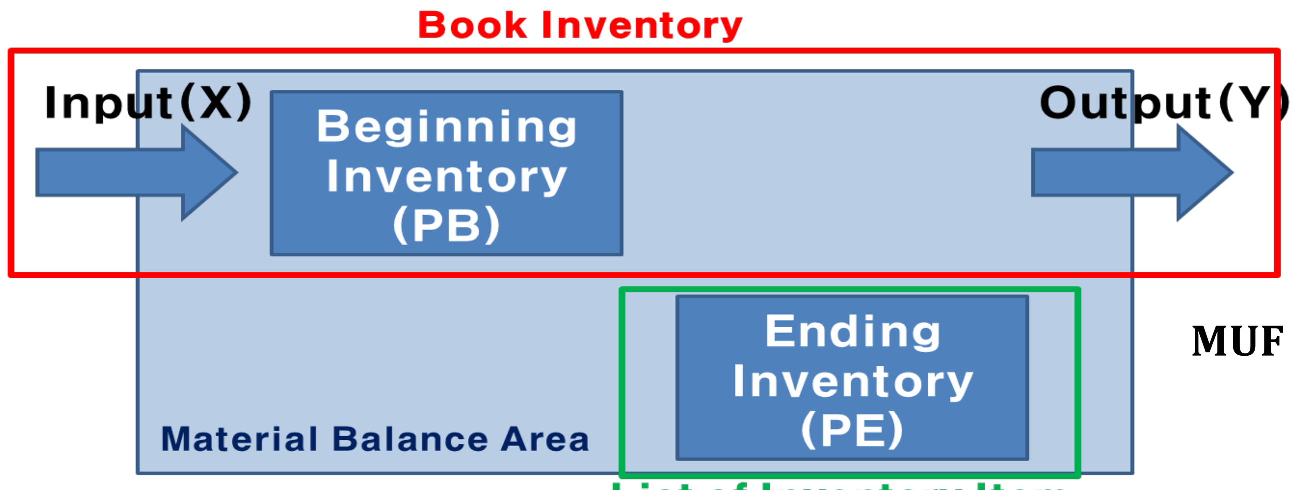
- The ROK has been conducting independent national inspection since 2015
- KINAC is performing independent national inspections to domestic nuclear facility based on a domestic notification(NSSC No. 2017-83)[1]
- However, current national inspection does not satisfy a requirement of the notification, material balance evaluation (MBE)
- The requirements has to be identified prior to develop an independent domestic MBE method

Objective

- Identify requirements for domestic MBE based on a benchmark scenario, IAEA's method and domestic characteristics of material accountancy

Methods

- MBE evaluates whether the material unaccounted for (MUF) of a facility is originated from measurement uncertainty or not
  - MUF is defined as the difference between the book inventory and list of inventory item (LII)



$$MUF = PB + X - Y - PE$$

where,
MUF: Element/isotope material unaccounted for, X: Material inflow, Y: Material outflow,
PB: Physical inventory at the beginning of an MBP, PE: Physical inventory at the end of an MBP.

- Calculate σ_{MUF} using the information of facilities' accounting system and error propagation[2, 3]

$$\sigma_{MUF} = \sqrt{V(MUF)},\quad V(MUF) = V_r(MUF) + V_g(MUF) + V_s(MUF)$$

$$V_r(MUF) = \Sigma_{k=1}^{K} x_k^2 \left(\frac{\delta_{rq}^2}{n_k m_k} + \frac{\delta_{rt(E)}^2}{r_k m_k c_k} + \Sigma_{g(k)=1}^{G(k)} \left(\frac{\delta_{rt(I)}^2}{r_{g(k)} m_{g(k)} c_{g(k)}} + \frac{\delta_{rp}^2}{r_{g(k)} m_{g(k)}} \right) \right)$$

$$V_g(MUF) = \Sigma_q\, \delta_{gq}^2\, \Sigma_i\, M_{qi}^2 + \Sigma_p\, \delta_{gp}^2\, \Sigma_i\, M_{pi}^2 + \Sigma_{t(E)}\, \delta_{gt(E)}^2\, \Sigma_i\, M_{t(E)i}^2 + \Sigma_{t(I)}\, \delta_{gt(I)}^2\, \Sigma_i\, M_{t(I)i}^2$$

$$V_s(MUF) = \Sigma_q\, M_q^2 \delta_{sq}^2 + \Sigma_p\, M_p^2 \delta_p^2 + \Sigma_{t(E)}\, M_{t(E)}^2 \delta_{st(E)}^2 + \Sigma_{t(I)}\, M_{t(I)}^2 \delta_{st(I)}^2$$

x_k: Mass of Stratum k,
δ: Relative uncertainty,
n_k: Item per batch in stratum k,
$m_{k/g(k)}$: Number of batches in tratum k(g(k)),
$r_{k/g(k)}$: Sample per batch in stratum k(g(k)),
$c_{k/g(k)}$: Analysis per sample in stratum k(g(k)),
$M_{X(i)} = \Sigma_{k=1}^{K} A_k x_{kX(i)}$
A_k: 1(gain), -1(loss).

- Evaluate the calculated MUF and σ_{MUF} using a hypothesis testing method (z-test) [3]
  - $z_\alpha = 3$ in nuclear safeguards

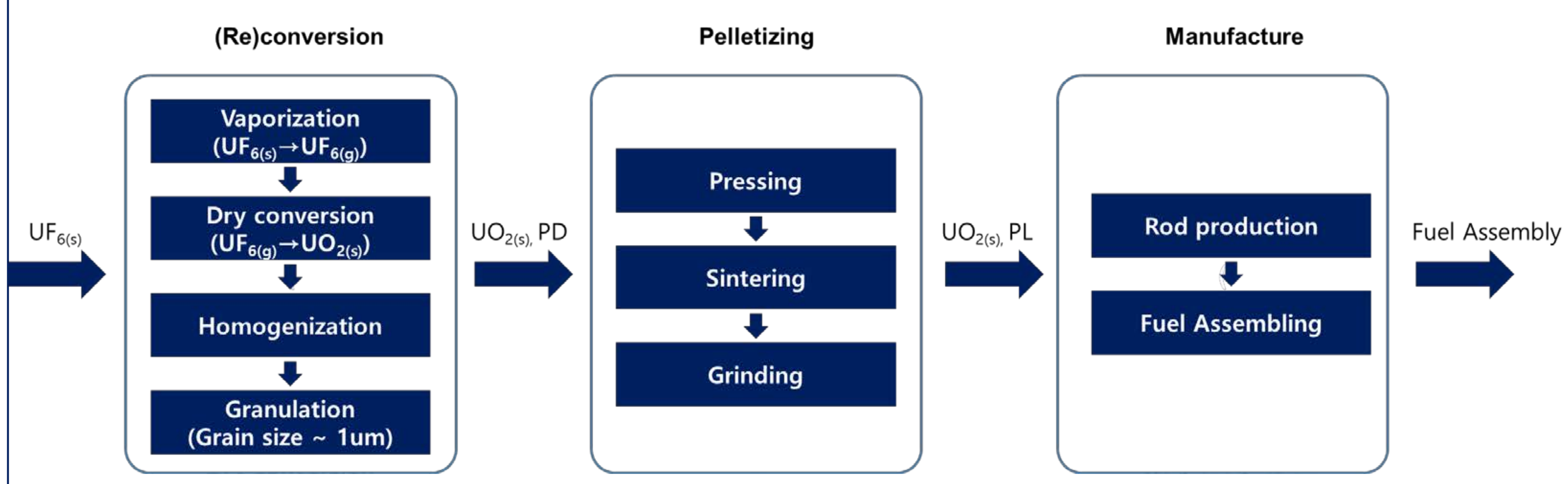
MUF Originated from

$H_0: MUF = 0,\ \text{if } |\mathrm{MUF}| \le z_\alpha \sigma_{MUF}$ → Measurement uncertainty (Normal)

$H_1: MUF \ne 0,\ \text{if } |\mathrm{MUF}| > z_\alpha \sigma_{MUF}$ → Another sources (Abnormal)

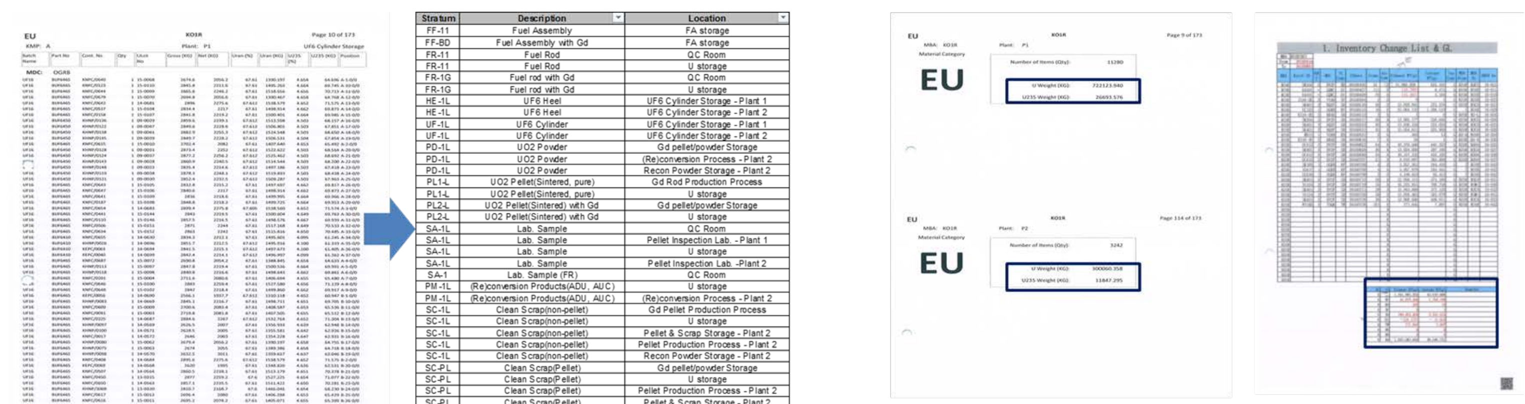
Benchmark Scenario

- Process of a benchmark fuel fabrication plant



- Stratification rule※ for the facility and calculated MUF

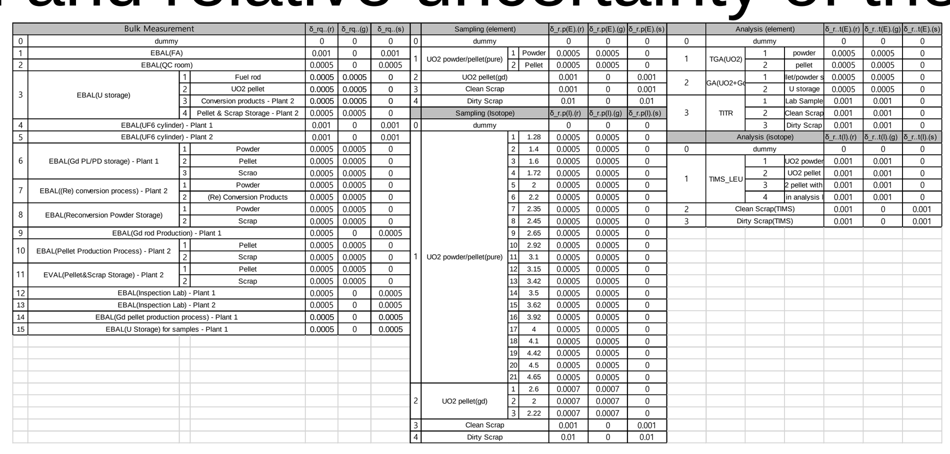
※ Classification of nuclear material by physical and chemical characteristics



	Measured Inventory	Book Inventory	MUF (kg)
U Weight (KG):	1,022,096.481	1,023,082.848	986.367
U235 Weight (KG):	38,572.800	38,548.731	-24.069

- Measurement system and relative uncertainty of the benchmark facility [4]

Definition	Measurement Method1)2)		
	Mass	Element	Enrichment
UF6	EBAL	–	–
(Re)conversion products			
UO2 Powder		TGA	TIMS
UO2 Pellet&Scrap before Sintering		–	–
UO2 Pellet&Scrap after Sintering		TGA	TIMS
Uranium Nitrate		–	–
Fuel Rod			
Fuel Assembly			
Scrap (Clean&Dirty)		TITR	TIMS
Solid Waste		–	–
Liquid Waste			
Laboratory Sample		TITR	TIMS



Results

- Calculate σ_{MUF}(element), σ_{MUF}(isotope)
  - Most of the σ_{MUF} originated from systematic error
  - Especially systematic error of bulk measurement

u(MUF,Element) (kg)	V(MUF,Element) (kg^2)	Vr(MUF)	Vg(MUF)	Vs(MUF)
494.940	244965.257	9818.667	12948.345	222198.244

u(MUF,Element) (kg)	V(MUF,Element) (kg^2)	Vr(MUF)	Vg(MUF)	Vs(MUF)
18.667	348.463	1.681	29.349	317.433

Vs(q)	Vs(p)	Vs(t(E))
205893.827	16304.417	0.000

Vs(q)	Vs(p)	Vs(t(E))	Vs(t(I))
298.584	15.331	0.000	3.518
118.958	0.000	0.000	0.000
0.046	0.000	0.000	3.399
0.000	3.399	0.000	0.119
101.505	11.933		
78.069			
0.000			
0.000			
0.000			
0.006			
0.000			
0.000			
0.000			
0.000			
0.000			
0.000			

- Evaluate the calculated σ_{MUF}

	Measured Inventory	Book Inventory
U Weight (KG):	1,022,096.481	1,023,082.848
U235 Weight (KG):	38,572.800	38,548.731
MUF (kg)	**σ(MUF) (kg)**	**Significance(3σ)**
986.367	494.9396499	No
-24.069	18.66716368	No

→ **MUF is originated from measurement uncertainty**

Conclusion

- The KINAC plans to identify requirements for domestic MBE method using a benchmark scenario prior to develop the method
- Results indicated the "**detailed information on measurement system**", "**uncertainty of the measurement system**" and "**stratification rule**" are required to develop and operate domestic MBE

References

[1] Subparagraph 7 of Article 4 of Regulations on the Safeguards Inspection of Special Nuclear Materials of the ROK, NSSC notification No. 2017-83, 2017.
[2] IAEA, IAEA Safeguards Technical Manual part F Statistical Concepts and Techniques, IAEA-TECDOC-261, Vol. 3, 1982.
[3] IAEA, Statistical Concepts and Techniques for IAEA Safeguards, IAEA-SG-PR-2016, 1998
[4] IAEA, International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Materials, IAEA-STR-368, 2010.