

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

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## Background

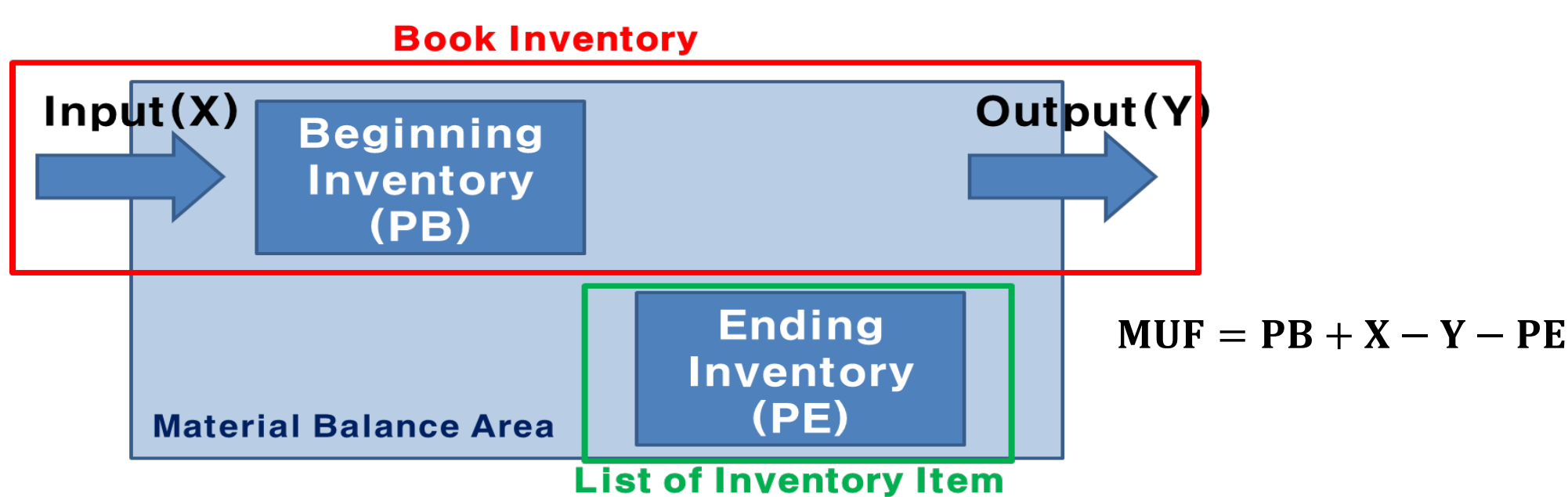
- The ROK has been conducting independent national inspection since 2015
- KINAC is performing independent national inspections to domestic nuclear facility based on a domestic notification(NSSC No. 2017-83)[1]
- However, current national inspection does not satisfy a requirement of the notification, 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 accountability

## 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)



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  $\sigma_{MUF}$  using the information of facilities' accounting system and error propagation[2, 3]

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

$$V_r(MUF) = \sum_{k=1}^K x_k^2 \left( \frac{\delta_{r,q}^2}{n_k m_k} + \frac{\delta_{r,E}^2}{r_k m_k c_k} + \sum_{g(k)=1}^{G(k)} \left( \frac{\delta_{r,t(l)}^2}{r_{g(k)} m_{g(k)} c_{g(k)}} + \frac{\delta_{r,p}^2}{r_{g(k)} m_{g(k)}} \right) \right)$$

$$V_g(MUF) = \sum_q \delta_{g,q}^2 \sum_i M_{q1}^2 + \sum_p \delta_{g,p}^2 \sum_i M_{p1}^2 + \sum_{t(E)} \delta_{g,t(E)}^2 \sum_i M_{t(E)i}^2 + \sum_{t(I)} \delta_{g,t(I)}^2 \sum_i M_{t(I)i}^2$$

$$V_s(MUF) = \sum_q M_q^2 \delta_{s,q}^2 + \sum_p M_p^2 \delta_{s,p}^2 + \sum_{t(E)} M_{t(E)}^2 \delta_{s,t(E)}^2 + \sum_{t(I)} M_{t(I)}^2 \delta_{s,t(I)}^2$$

$x_k$ : Mass of Stratum k,  
 $\delta$ : Relative uncertainty,  
 $n_k$ : Item per batch in stratum k,  
 $m_{k/g(k)}$ : Number of batches in stratum 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)),  
 $M_{X(I)} = \sum_{k=1}^K A_k x_{kX(I)}$   
 $A_k$ : 1(gain), -1(loss).

- Evaluate the calculated MUF and  $\sigma_{MUF}$  using a hypothesis testing method (z-test) [3]

-  $Z_\alpha = 3$  in nuclear safeguards

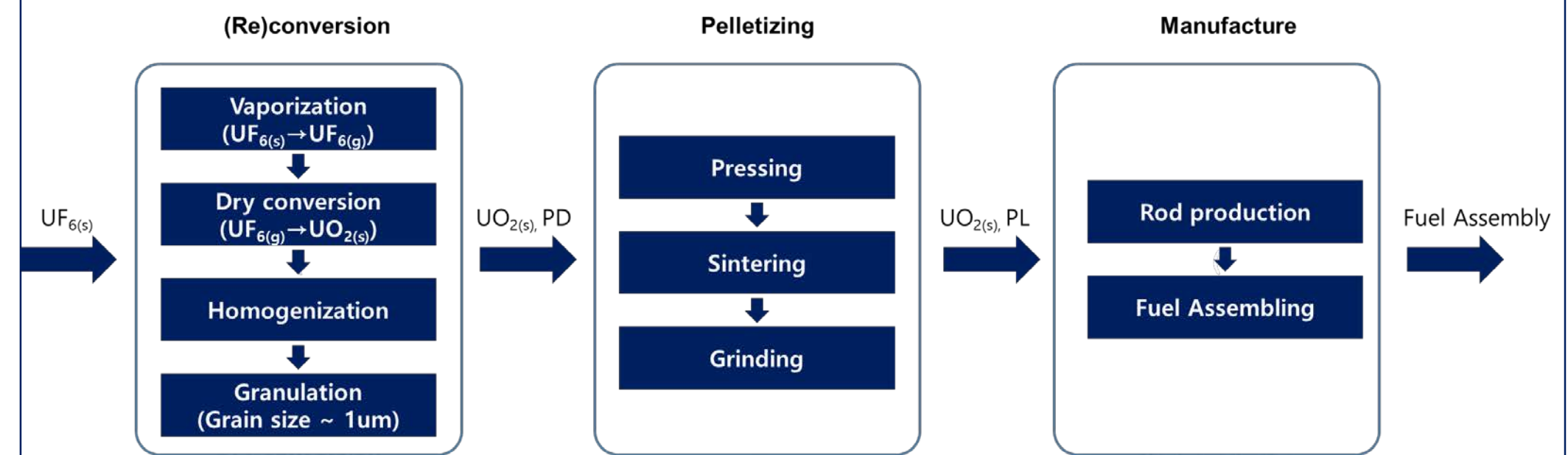
MUF Originated from

$H_0: MUF = 0$ , if  $|MUF| \leq Z_\alpha \sigma_{MUF}$  → Measurement uncertainty (Normal)

$H_1: MUF \neq 0$ , if  $|MUF| > Z_\alpha \sigma_{MUF}$  → Another sources (Abnormal)

## Benchmark Scenario

- Process of a benchmark fuel fabrication plant



- Stratification rule<sup>※</sup> for the facility and calculated MUF

※ Classification of nuclear material by physical and chemical characteristics

Stratum	Description	Location
U1	Fuel assembly	Fuel storage
U2	Fuel assembly	UO <sub>2</sub> storage
U3	Fuel rod	UO <sub>2</sub> storage
U4	Fuel rod	UO <sub>2</sub> storage
U5	Fuel rod	UO <sub>2</sub> storage
U6	Fuel rod	UO <sub>2</sub> storage
U7	Fuel rod	UO <sub>2</sub> storage
U8	Fuel rod	UO <sub>2</sub> storage
U9	Fuel rod	UO <sub>2</sub> storage
U10	Fuel rod	UO <sub>2</sub> storage
U11	Fuel rod	UO <sub>2</sub> storage
U12	Fuel rod	UO <sub>2</sub> storage
U13	Fuel rod	UO <sub>2</sub> storage
U14	Fuel rod	UO <sub>2</sub> storage
U15	Fuel rod	UO <sub>2</sub> storage
U16	Fuel rod	UO <sub>2</sub> storage
U17	Fuel rod	UO <sub>2</sub> storage
U18	Fuel rod	UO <sub>2</sub> storage
U19	Fuel rod	UO <sub>2</sub> storage
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U21	Fuel rod	UO <sub>2</sub> storage
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U25	Fuel rod	UO <sub>2</sub> storage
U26	Fuel rod	UO <sub>2</sub> storage
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U95	Fuel rod	UO <sub>2</sub> storage
U96	Fuel rod	UO <sub>2</sub> storage
U97	Fuel rod	UO <sub>2</sub> storage
U98	Fuel rod	UO <sub>2</sub> storage
U99	Fuel rod	UO <sub>2</sub> storage
U100	Fuel rod	UO <sub>2</sub> storage

	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 Method <sup>[2]</sup>		
	Mass	Element	Enrichment
UF6	—	—	—
(Re)conversion products	—	—	—
UO <sub>2</sub> Powder	—	TGA	TMS
UO <sub>2</sub> Pellet&Scrap before Sintering	—	TGA	TMS
UO <sub>2</sub> Pellet&Scrap after Sintering	—	TGA	TMS
Uranium Nitrate	—	—	—
Fuel Rod	—	—	—
Fuel Assembly	—	—	—
Scrap (Clean&Dry)	—	TITR	TMS
Solid Waste	—	—	—
Liquid Waste	—	—	—
Laboratory Sample	—	TITR	TMS

## Results

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

u(MUF,Element) (kg)	V(MUF,Element) (kg <sup>2</sup> )	Vr(MUF)	Vg(MUF)	Vs(MUF)
494.940	244965.257	9818.667	12948.345	222198.244
18.667	348.463	1.681	29.349	317.433

- Evaluate the calculated  $\sigma_{MUF}$

	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)	$\sigma$ (MUF) (kg)	Significance(3 $\sigma$ )
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.