The Introduction of the verification technology and method for UF6 Cylinders

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1. Introduction

This paper provides the NDA technology and method to verify the contents of the UF6 cylinder at the nuclear fuel fabrication plant. The method is to meet the Agency's safeguards goals. The KNFC (Korea Nuclear Fuel Co. Ltd.) imports UF6 cylinders that are enriched at the foreign enrichment plants, according to requirements by KHNP (Korea Hydro & Nuclear Power Co. Ltd.). Then they are stored in the UF6 storage before transferring in the vaporization process. Therefore, the verification of uranium enrichment of UF6 cylinders is very important issue for the International Atomic Energy Agency (IAEA) and Korea Institute of Nuclear Nonproliferation and Control (KINAC) to verify all foreign receipts of low enriched uranium (LEU) needed for all LWRs. This paper introduces the technology and method necessary for verification of UF6 Cylinders for safeguards purposes and verification results for national safeguards inspection.

2. The Measurement of Uranium Enrichment

The important information for the quantitative nondestructive assay (NDA) of nuclear material is the full-energy peak measured from a sample because uranium and plutonium samples have a wide variety of isotopic compositions. This measurement is used to establish the fraction of fissile ^{235}U, commonly referred to as the uranium enrichment.

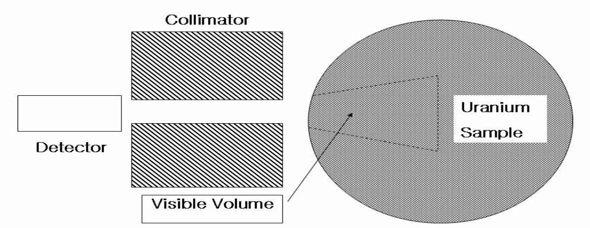

Fig 1. The basic elements of a gamma-ray uranium0enrichment measurement setup

The primary radiation used in passive NDA of uranium samples is gamma radiation, which is usually dominated by emission from ^{235}U decay. The 186-keV gamma ray is the most frequently used signature to measure ^{235}U enrichment because it is the most prominent single gamma ray from any uranium sample enriched above natural uranium levels. The basic measurement procedure involves viewing a uranium sample through a collimated channel with a gamma-ray detector (Figure 1).

Table 1. Mean free paths and infinite thickness for 186-keV photons in uranium compounds.

Uranium Compound	Density (g/cm³)	Mean Free Path (cm)	"Infinite" Thickness (cm)
Metal	18.7	0.04	0.26
UF6 (solid)	4.7	0.20	1.43
UO2 (sintered)	10.9	0.07	0.49
UO2 (powder)	2.0	0.39	2.75
U3O8 (powder)	7.3	0.11	0.74
Uranyl nitrate	2.8	0.43	3.04

The "visible volume" of the sample is determined by the collimator, the detector geometry, and the mean free path of the 186-keV radiation in the sample material. Because of that, the mean free path and infinite-thickness values for the 186-keV gamma-ray should be reflected in commonly encountered uranium compounds (Table 1). The cylinder containing UF6 in solid forms vary in size and wall thickness. The large, high-density wall thickness of the cylinders means that minor variation in wall thickness can result in significant variation in gamma-ray count rate. Therefore, wall thickness of the cylinders must be measured by a thickness-gauge and reflected in measurement program to reduce the measurement error.

3. Verification of UF6 Cylinders in KNFC

3.1 Verification Criteria required by IAEA

IAEA started to perform SNRI (Short Notice Random Inspections) at KOR- from the beginning of 2007. An annual PIV and small number of SNRIs a year will be scheduled under Traditional Safeguards at the KOR- by Agency. All of nuclear material at KOR- is subject to the verification of PIV and 100% of nuclear transfer in or out the KOR- is subject to the verification of SNRIs.

All of UF6 cylinders subjected to the verification are verified with random medium detection probability for gross, partial and bias defects. And Inventory changes involving UF6 are reported to Agency through the mailbox declaration.

3.2 Measurement

UF6 cylinders are needed to be verified for partial defect. The partial defect means a fractional difference between the declared amount of nuclear material and the real amount of the material actually present.

Prior to the actual verification of UF6 cylinders, thickness measurements were performed on each cylinder wall. The thickness was utilized by the software in correcting for the attenuation of the 186-keV signal.

The actual verification of UF6 is divided into two parts. One is the verification of enrichment (Method F), the other is the verification of weight (Method B). The procedure of the verification and evaluation for partial defect is as follows;

- Measurement of weight by load cell
- Verification of enrichment with a single count time of 300 sec
- Calculation of d ([Declared weight of ^{235}U – Measured weight of ^{235}U] / Declared weight of ^{235}U)
- Comparison between |d| and 3δ
  (if |d|≤ 3δ, results are satisfied)

3.3 UF6 Enrichment Verification System

The measurement system used in this work is the IMCG verifier (Inspection Multi-Channel Analyzer with Germanium Detector) produced by Canberra Industries.

Table 2. Measurement System

Detector	Low Energy Germanium (LEGe)
MCA	Inspector 2000 portable multi-Channel Analyzer
Software	IMCA 2000 operated in the GENIE 2000 environment, communication with MCA via USB
Computer	TOSHIBA, Window XP
Ultrasonic Thickness Gauges	Krautkramer Branson Model DM4 E

The highly automated system includes total computer control of the MCA, automatic data storage, and analysis through a preset region of interest containing the 186-keV peak.

3.4 Result

During the Physical Inventory Verification(PIV) at KNFC in 2006, 31 UF6 cylinders were measured to verify the ^{235}U enrichment by using the detector system described in Table 2 (Table 3)

Table 3. Summary of UF6 cylinders ^{235}U enrichment measurement results by IMCG in 2006-PIV

Operator's declared value			Inspector's measured value		Evaluation	
Enrichment of ^{235}U	Weight of ^{235}U	Weight (kg/g)	Weight (kg/g)	^{235}U	Error	ldl<3δ
(wt%)	(kg/g)	Gross	Net	Enrichment(%)	|d|(%)	(Yes/No)
3.803	52.644	2678.000	2045.1	3.739	1.8	Y
3.798	57.458	2869.5	2235.9	3.925	3.2	Y
3.8	23.933	1545.8	930.8	3.805	0.1	Y
3.812	54.446	2112.869	2112.9	3.771	1.1	Y
4.5	67.655	2223.7	2222.7	4.501	0	Y
4.5	67.533	2219.7	2220.6	4.525	0.6	Y
3.796	54.614	2128.651	2129.651	3.641	4.2	Y
3.796	54.648	2130.198	2128.698	3.653	4	Y
3.791	54.591	2130.559	2130.559	3.79	0	Y
3.799	54.706	2130.605	2129.605	3.702	2.7	Y
3.828	55.105	2129.651	2128.151	3.822	0	Y
4.503	67.294	2210.3	2209	4.474	0.7	Y
4.503	66.158	2173	2172	4.548	0.9	Y
4.503	67.78	2226.7	2226.3	4.462	0.9	Y

The verification results are summarized in Table 3 and the results by MMCG in 2005-PIV are summarized in Table 4 to compare with the accuracy of the equipments (IMCG and MMCG). In results by IMCG, measurement errors were significantly reduced. Also these results satisfied the criteria of safeguards inspection.

Table 4. Summary of UF6 cylinders ^{235}U enrichment measurement results by MMCG in 2005-PIV

Operator's declared value			Inspector's measured value		Evaluation	
Enrichment of ^{235}U	Weight of ^{235}U	Weight (kg/g)	Weight (kg/g)	^{235}U	Error	ldl<3δ
(wt%)	(kg/g)	Gross	Net	Enrichment(%)	|d|(%)	(Yes/No)
3.812	54.35	2109.19	2110.694	3.9443	3.5	Y
3.812	54.38	2110.56	2112.6	3.7848	0.6	Y
3.804	54.149	210.7	2108.79	3.7498	1.4	Y
3.794	54.103	2110.147	2109.65	3.8303	0.9	Y
3.794	54.044	2108.240	2109.24	3.833	1.1	Y
4.501	64.393	2116.0	2115	4.438	1.5	Y
4.499	64.61	2124.1	2123.1	4.7908	6	Y
4.5	68.702	2258.971	2258.97	4.6748	3.7	Y
4.495	67.085	2208.12	2207.62	4.5421	1	Y
4.495	67.071	2207.67	2208.17	4.529	0.8	Y
4.594	67.068	2207.715	2208.22	4.5224	0.7	Y
4.494	67.097	2208.67	2208.17	4.8152	6.6	Y
4.514	67.26	2204.0	2204.3	4.3917	2.8	Y

4. Conclusions

The verification of UF6 contents is very important issue for the Safeguards inspection purpose at the nuclear fuel fabrication plant. This paper shows the technology and method necessary for verification of UF6 contents.

Korea Institute of Nuclear Nonproliferation and Control (KINAC) replaced MMCG by IMCG to verify enrichment of UF6 cylinders to improve the quality of verification. As a result, the accuracy of the verification result and efficiency of the verification are evaluated to be increased. It is also expected that IMCG system is able to be applied to other types of nuclear materials to improve the quality of verification.

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