Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

A Study on MUF (Material Unaccounted For) Evaluation Plan

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1. Introduction

Material Unaccounted For (MUF) refers to the difference between the book inventory and the physical inventory of material in a Material Balanced Area (MBA) during the Material Balanced Period (MBP) [1], [2].

The following equation is generally referred to as MUF equation:

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

where PB is the beginning physical inventory, X is the sum of increases to inventory, Y is the sum of decreases from inventory, and PE is the ending physical inventory[2][3]. Theoretically, MUF should be zero but if not, it might indicate that materials have been diverted [1].

MUF depends on the type of facility. For an item facility, MUF should always be zero because materials in an item facility are not re-measured and consequently the values assigned to items in item facilities should remain the same. For bulk facilities, however, non-zero MUF is possible and even expected. It may be caused by diversion, but it may also be caused by measurement error, holdup in processing equipment, unmeasured inventory, re-measurement of inventory, unmeasured losses, and operator's mistake in recording data, all of which occur with some degree of regularity in bulk facilities [1].

The purpose of the Material Unaccounted For (MUF) evaluation is to decide whether the MUF can be explained by the accumulation of measurement uncertainties. However, the MUF evaluation has not been introduced in national inspection owing to the lack of evaluation tool and well-defined procedure.

This study aims at developing the plan for the MUF evaluation to improve the management of nuclear material in bulk facilities. The procedure of MUF evaluation is briefly described and the MUF evaluation tool is also introduced.

2. The procedure of MUF evaluation

The first step in MUF evaluation is to construct the material balance table (MBT). The MBT is a stratified list of all material in each of the four components of the material balance equation in a given material balance area (MBA). A separate MBT is prepared for each element and isotope using the data from Physical Inventory Listings (PILs), Inventory Change Reports (ICRs) and inspection reports over a specified material balance period (MBP). The static material that was not measured (or re-measured) during the MBP must be removed from the MBT. It cannot contribute to standard deviation of MUF (σ_{MUF}) and it should not be included in the calculation of σ_{MUF}. Therefore, static material should be identified prior to MUF evaluation so that it can be eliminated from the σ_{MUF} calculations.

Once the material in the MBT has been stratified and static material has been removed, the next step in the evaluation process is extending the MBT to include measurement uncertainties and operator–inspector differences. Every stratum measured by the operator must be assigned an estimated operator measurement uncertainty to calculate σ_{MUF} and every verified stratum must also be assigned a measurement uncertainty to calculate standard deviation of Operator-Inspector difference (σ_D). Operator-Inspector difference data must be matched with each stratum that was verified to estimate stratum differences, D_S, and overall material balance difference, D. After preparing and extending the MBT, the following step is to calculate the statistic MUF, D and the inspector's estimated MUF (IMUF) and to estimate the measurement uncertainty associated with each statistic. The estimated σ_{MUF} is compared with International standards for judging operator's measurement system. If the calculated σ_{MUF} exceeds the international standards, the operator's measurement systems may be inadequate.

The last step of MUF evaluation is the test of the hypothesis that a non-zero value of a statistic is caused only by measurement uncertainty.

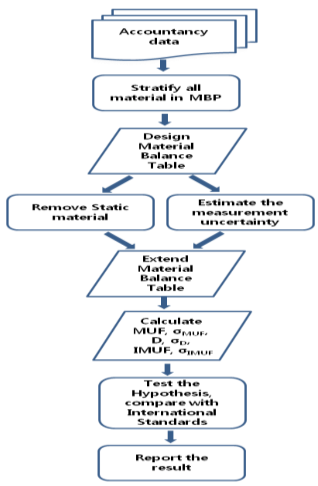

Fig.1.The procedure of MUF evaluation

3. MUF Evaluation Tool

An MUF evaluation tool was designed by SAS (Statistical Analysis System) Analytics programming solution to assist the national inspectors in carrying out MUF evaluation for bulk facilities. This tool is intended to run on a personal computer and assists in constructing MBT and calculating various statistics and uncertainties for MUF evaluation such as MUF, σ_{MUF}, D, σ_D, IMUF and σ_{IMUF}. The SAS code for MUF evaluation is shown in Fig. 2.

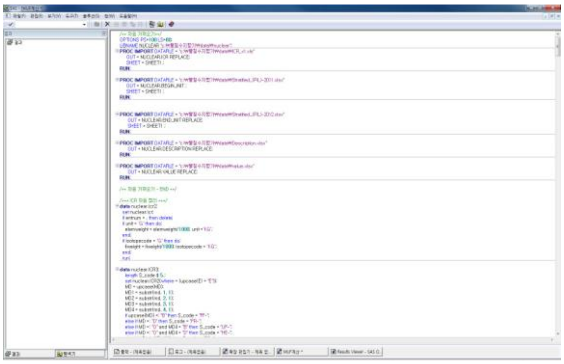

Fig.2. SAS code for MUF evaluation

The applicability of the evaluation tool has been verified through the simulated MUF evaluation on nuclear materials in nuclear fuel fabrication facility during the last two material balance periods. Actual data from physical inventory verification (PIV) by national inspectors were used in the simulation. Fig. 3 and Fig. 4 show the results of MUF evaluation of low enriched uranium in KO1R (PWR fuel fabrication facility).

STRATURM ID	NUMBER OF BATCHES	NUMBER OF ITEMS	ELEMENT WEIGHT (KG)
BEGINNING INVENTORY			
FF-	1	44	19480.417
FR-	3	7621	12813.056
HE-	1	123	142.844
PD-	3	66	18239.299
PL-	3	2305	66402.473
SA-	4	174	8.345
SC-	5	857	10070.867
SD-	3	16	663.710
UF-	1	257	366764.984
T O T A L			494585.995
ENDING INVENTORY			
FF-	1	548	242879.525
FR-	2	6536	11504.518
HE-	1	193	186.490
PD-	1	154	56777.088
PL-	2	1433	56995.742
SA-	1	288	13.973
SC-	6	242	12336.345
SD-	4	74	2325.656
UF-	1	129	184787.356
T O T A L			567806.693
RECEIPTS			
PD-	1	1	169.647
SA-	2	4	0.028
SD-	1	1	40.600
UF-	14	268	386498.093
T O T A L			386708.368
SHIPMENTS			
FF-	720	720	312787.346
FR-	4	5	1.090
SA-	4	10	0.086
WS-	1	397	147.608
T O T A L			312936.130
MUF			551.540

Fig.3. MBT of Low Enriched Uranium

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1) GENERAL MBA PARAMETERS DURING THE MBP:

   Throughput(THR.) (KG)          567806.7
   AVG (KG)                       5604.252
   SQ  (KG)                         75.000
   Total material(PB+PE+R+S) (KG) 1762037
   Sigma International(INT.) =    1703.420

   Sigma MUF:
   Random error variance          3575.817
   Systematic error variance      878790.9
   Total error variance           882366.7
   Sigma MUF                       939.344

2) MUF EVALUATION AND CONFIDENCE LIMITS ON MUF:

    MUF      Sigma MUF    Sigma MUF     T       Critical      Statistical
    (KG)     (KG)         in of THR.    Test    value(α)      significant

    551.540  939.344        0.165       0.587  <  1.96          NOT

          LOWER LIMIT(L) = MUF - 1.96 × SIGMA MUF = -1289.57
          UPPER LIMIT(U) = MUF + 1.96 × SIGMA MUF = 2392.654
          M = GOAL AMOUT (KG)                     = 5604.252

          Ordering : L < 0 < U < M  ⇒ MUF < 2σ

3) STATEMENT ON FACILITY MEASUREMENT SYSTEM

    Sigma MUF      Sigma INT.

    939.344       1703.420

   -The facility measurement system based on
    Operator error estimates of the
    uncertainty of MUF is acceptable
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Fig.4. MUF evaluation result of Low Enriched Uranium

As t-test value is smaller than 1.96, the hypothesis of MUF = 0 is not rejected. D and IMUF are also estimated in the same manner and the result is that there is no difference between the MUF declared by operator and verified by inspector. It eventually draws the conclusion that the MUF can be explained by the measurement uncertainty.

Through simulated evaluation, it is found that national inspectors are able to carry out MUF evaluation in a short time of PIV by the help of the MUF evaluation tool, which generates statistics data and MUF evaluation results from operator's accountancy data and inspector's verification results.

4. Conclusions

The MUF evaluation plan was studied to improve the management of nuclear material in bulk facilities. This study paved the way for introduction of MUF evaluation in national safeguards inspections by developing the evaluation tool and procedure, which is expected to enhance the credibility and transparency of domestic nuclear activities.

REFERENCES

[1] Material Balance Evaluation, IAEA General STR-326, IAEA, 2002.
[2] IAEA Safeguards Glossary, International Nuclear Verification series 3, IAEA, 2003.
[3] Nuclear Material Accounting Handbook, IAEA Service series 15, IAEA, 2008.