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Uncertain to Unambiguous—Shipper Receiver Evaluations			
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The purpose of this document is to briefly outline the general methodology of the shipper receiver difference evaluation calculations with emphasis on elements of the calculation that may be overlooked by personnel new to the concepts trying to develop the calculation. This document applies to facility personnel who may be interested in developing or cost-scheduling a project to develop such a calculation as well as other stakeholders such as corporate or regulatory oversight personnel interested in evaluating or encouraging the development and routine use of such statistical models and calculations.			
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1.0 INTRODUCTION

This paper is intended to facilitate discussions regarding the need for and potential cost-benefit (or risk reduction) of performing statistical evaluations of individual shipper receiver differences as well as historical trend analyses. Other analyses corollary to these evaluations is an understanding of individual measurement systems and material types that pose the most risk to the SNM accountancy system, especially for those which the receiver routinely accepts the shipper's values upon receipt confirmation.

1.1 Purpose, & Scope

The purpose of this document is to briefly outline the general methodology of the shipper receiver difference evaluation calculations with emphasis on elements of the calculation that may be overlooked by personnel new to the concepts trying to develop the calculation. This document applies to facility personnel who may be interested in developing or cost-scheduling a project to develop such a calculation as well as other stakeholders such as corporate or regulatory oversight personnel interested in evaluating or encouraging the development and routine use of such statistical models and calculations.

1.2 Limits of Applicability

This document is not a comprehensive discussion of the statistical methodology of the calculation of the SRD, individual shipper receiver difference evaluations, or shipper receiver difference trending. It should not be used as the sole resource for completing such a calculation at a specific facility for a specific material type, but as a guide to finding resources and planning for such a development. This document does not propose to comply with the regulations or requirements of any location or facility.

2.0 SUMMARY OF TERMS & DEFINITIONS

Most material control and accounting definitions are interchangeable among facilities using the language of IAEA, EURATOM, and US Nuclear Regulatory Commission (USNRC) regulations, handbooks, or guidance documents. For example, special nuclear material (SNM) and material balance area (MBA) are two terms commonly in use by nuclear industry personnel around the world. This section simply attempts to relate a few USNRC terms to those used by the IAEA in order to facilitate a clear understanding among a wide variety of readers, especially regarding shipper receiver differences and measurement error variances.

A. Material Balance Period

This is sometimes called an inventory period. It marks the dates on a calendar between which a material balance is calculated, corrected for the inventory difference and reconciled (for grams U and ^{235}U, obligations, material type blending, etc.) between the facility and regulatory authorities through a central reporting database. Financial accounting normally follows this since SNM is likely the highest valuable commodity possessed and used by the facility. In the US, commercial fuel cycle facilities licensed by the NRC to process uranium enriched to $\leq 5\%$ ^{235}U, this is normally 1 calendar year plus or minus 30 days unless a special inventory is required at a shorter frequency.

B. Measurement System

A measurement system is the combination of method, material, matrix, and machine used to describe how a certain material type obtains a measured attribute within its inventory stratum. For example, a bulk method normally results in a net weight of material. This bulk system may be one level indicator and volumetric calibration curve and laboratory density method associated with one bank of uranyl nitrate tanks, or it may be a type of weighing device calibrated to weigh pellets on trays across all production lines using the same size and type of tray and measurement control protocol. Conversely, it could be one titrator that measures various material types in various chemical/physical forms from various sampling systems across the plant—each material type having their own "system" designation.

C. Systematic Error Variances and Relative Standard Deviations (RSDs)

The systematic error variance of a measurement system typically includes the major bias contributors for that system. For a given measurement system (*i*), these tend to be calibration error (or the uncertainty of the standard certification, S_0, for systems with point calibrations which are usually reported at $2 \cdot \sigma$), readability (Δ) error variance, and the standard error of all in-control standard measurements from the measurement control program.

$$\sigma_{sys_i} = \sqrt{\frac{S^2_{stds_i}}{n_{stds_i}} + \left(\frac{S_{0_i}}{2}\right)^2 + \frac{\Delta_i^2}{12}}$$

The systematic variances may be pooled over multiple standard types within a single measurement system and/or pooled across like-kind measurement systems. For example, the high and low control standard measurements (and readability, etc.) across all pellet scales may constitute σ_{sys} for pellet tray weighing.

D. Random Error Variances and Relative Standard Deviations (RSDs)

Random error variances are calculated using replicated measurements. This could be analyses of multiple samples from the same UO2 powder blend or pellet lot or repeated weighings of unknown-weight items or control standard weights. The standard deviation (or, equivalently, the root mean square error from a one-way ANOVA) of paired differences or replicate ranges is used to estimate the random variance. For samples, some facilities use repeated measurements of replicate samples to perform a fully nested ANOVA to separate the sampling mean square error (reproducibility) from the analytical mean square error (repeatability) and propagate them independently from one another. Most facilities allow the sampling and analytical random error to remain confounded and propagate thusly.

The random variances may be pooled across like-kind measurement systems. For example, standard deviation of standard weighings across all pellet scales may constitute σ_{Rnd} for pail weighing.

E. Shipper Receiver Difference Limit of Error (LOE) Model

The concept of performing shipper receiver difference evaluations can be as simple as a weight check of each UF_6 cylinder received against the stated shipper gross weight, or it can be a full suite of weighing, sampling, and analysis for element and isotope for every cylinder, pail, or other SNM item received.

Obviously, the best method is a full set of verification measurements for each batch and container received whether or not the receiver is recording their own values or the shipper's. This is normally quite expensive and labor intensive for routine receipts, such as UF_6 cylinders at a fuel cycle facility (which is the context of this document). The full measurement scheme would identify not only security or safeguards-significant abrupt issues, but also lab-to-lab biases and trends that may indicate that the shipper or receiver has an undetected bias that may threaten one or both accountancy systems. The full suite of measurements would follow this model for each item, batch, shipment, or series of shipments (SRD_i), whatever discrete amount of SNM is being evaluated.

$$\mathbf{Variance}\left(\mathbf{Receiver}_{\mathbf{grams\ U235}}\right) = C^2_{\mathbf{Receiver}_{SRD_i}} \cdot \left(\frac{RSD^2_{RND_{Weighing}}}{n_{weighings_{Batch}}} + \frac{RSD^2_{RND_{U\ Sampling\&Analysis}}}{n_{U\ anlayses_{Batch}}} + \frac{RSD^2_{RND_{Iso\ Sampling\ \&\ Analysis}}}{n_{Iso\ analyses_{Batch}}} + RSD^2_{SYS_{Weighing}} + RSD^2_{SYS_{U\ Analysis}} + RSD^2_{SYS_{ISOAnalysis}}\right)$$

where

$$C^2_{Shipper_{SRDi}} = \sum \left(\text{grams }^{235}U_{Receiver_{SRD_i}}\right)^2$$

and where

i = items, batches of items, shipments of items, or a series of shipments of items, whatever quantity is being evaluated

The shipper's coefficient ($C^2_{Shipper_{SRD_i}}$) in squared sum of grams ^{235}U for the item, batch, shipment, or other quantity for which a Shipper Receiver Difference is being calculated (SRD_i). This is the same formulation used to calculate the shipper's coefficient. Moreover, the formula applies to the variance of the entire shipment, or the entire series of shipments being evaluated. Thus, the LOE for the batch uses the same formulation as that for a shipment or series of shipments, where the coefficient changes based on the total SNM masses being compared. Just take the square of the sum of SNM grams ^{235}U as if the entire SNM mass was received and is being evaluated at once.

Also, the RSD is the relative standard deviation (systematic and random) for weighing, sampling, and analytical measurement error. Note that the random error variances are divided by the number of measurements, assuming that the average of these measurements are recorded as the results of record or used as the verification. This is the receiver's values only. Presumably, this variance (prior to taking the square root) can be doubled if the assumption that the shipping facility's measurement systems perform similarly to the receiving facility's measurement system performances. The coefficient can still be calculated based on shipper's values, but RSDs & number of measurements may be assumed equal. Audits and benchmarking are good methods of validating this for stakeholders or for ascertaining shipper's RSDs if they are not routinely provided.

$$\mathbf{LOE}_{SRD_i} = \mathbf{2} \cdot \sqrt{\mathbf{Variance}_{\mathbf{SRD}_i}\left(\mathbf{Shipper}_{\mathbf{grams\ U235}}\right) + \mathbf{Variance}_{\mathbf{SRD}_i}\left(\mathbf{Receiver}_{\mathbf{grams\ U235}}\right)}$$

Again, the SRD variance given above is the full measurement model used at the reference plant for this document. There are specific local requirements for the full verification measurement of every received UF_6 cylinder, which provides a definitive data set for SNM accountancy and incredible investigative tools to identify both safeguards and financial risks and impacts. See the toolbox for individual SRD evaluations discussed in § 4.2 for discussion of simpler models.

3.0 ASSUMPTIONS & INPUTS

3.1 Assumptions

There is a plethora of statistical assumptions that underly any measurement uncertainty analysis. Reference [1] would be the place to begin to apply statistical concepts to the measurement error variance and shipper receiver difference evaluations of a given material type, container configuration, and batching scheme where evaluations can be made regarding the nature and validity of those assumptions. This document attempts to generally outline the major basis of the limit calculations (or equivalently, hypothesis tests).

That major basis is the assumption—or perhaps assertion—that measurement uncertainty is the only contributor to shipper receiver differences. This assumption is important in flagging non-measurement SRD contributors. If human error, unmeasured losses, uncorrected measurement biases, or malicious diversions occur, these would be unaccounted-for SRD contributors and would also be unaccounted-for in a measurement uncertainty propagation, giving them higher probability of being flagged by a test or limit calculated using only measurement uncertainties.

Another assumption or basis for the evaluation is a propagation to grams ^{235}U, when in actuality a similar formulation can be used for net weight comparisons or uranium element masses. In fact, at the reference plant for this document the uranium masses are tracked and trended alongside the ^{235}U masses to isolate issues with net weight and uranium element anomalies or biases from purely isotopic assay issues.

3.2 Inputs

3.2.1 <u>Statistical Methodological Guidance</u>

The USNRC statistical guidance is a publication called NUREG/CR-4604, "Statistical Methods in Nuclear Material Accounting" (Reference [1]). It was commissioned by the NRC and generated by Bowen and Bennett of Pacific Northwest Laboratory (PNL) in 1988. It covers many foundational statistical concepts then moves into concepts specific to nuclear material accountancy—from error modeling to determination of individual measurement system uncertainties to error variances to calculation of limits of error to historical trending. It also includes other helpful topics such as variable and attribute sampling plans as well as measurement control strategies. Specifically, chapters 14 and following are most relevant to the discussion in this document, but the preceding chapters contain a fairly comprehensive treatment of the statistical bases and concepts.

3.2.2 Regulatory Requirements

Facilities around the world follow various local, regional, and international safeguards regulations and guidance handbooks. In the US, the applicable regulation is Title 10, Code of Federal Regulations part 74 (Reference [2]). These regulations further delineate between facilities who process highly enriched uranium and those who process commercial grade uranium. For the commercial fuel cycle facilities within the scope of this document, 10 CFR 74.31 specifies the use of the shipper receiver difference as a loss detection tool. A general rule is presented there that a statistically significant shipper receiver difference that also exceeds 500 grams ^{235}U is to be considered safeguards significant and resolved. This 500 grams ^{235}U rule is used in commercial-grade SNM licensees to indicate the line where other anomalies such as item control discrepancies where resolution should also be sought, and NRC notifications made. A confirmed loss of any amount is also pursued, and NRC notified, but the 500-gram rule is a good indicator for the seriousness of anomalous internal or external transactions that could—but do not necessarily—indicate a loss, diversion, or theft. Any batch or shipment SRD that exceeds the limit of error is investigated, but on a graded approach that puts the most resources on the highest risks. This is why the evaluations shown in this document are in grams ^{235}U, because the 500-gram rule is used among the US commercial fuel cycle facilities.

4.0 CALCULATION DISCUSSION

This document does not contain a detailed calculation of an SRD evaluation. Each SRD calculation is very specific to the material type, container type, and operation of the subject facility and includes sensitive information. However, a discussion of the most important considerations is still helpful especially in understanding terms, definitions, and considerations.

4.1 SRD Methodology Overview & Data Requirements

4.1.1 Evaluation Method Discussion

The general methodology adopted among USNRC licensees is to evaluate shipper-receiver differences by batch as well as by shipment—each consignment is reported to the NRC on one or more nuclear material transaction forms (Form 741, similar to an Inventory Change Document). Normally each detail line of the form contains a batch.

The simplest version may be the cases where a fuel fabrication facility receives 30B UF_6 cylinders which are weighed and sampled by the supplier such that each cylinder is also a batch. Thus, the number of items is also the number of batches, and one batch normally receives one gross weight (with the tare weight previously established and accepted by all), uranium element analysis, and one isotopic abundance analysis. Therefore, if four 30B cylinders are received on one consignment and reported on a nuclear material transaction form, each on its detail line, then each cylinder's shipper net weight, uranium weight, and ^{235}U weight is compared to the corresponding value from the receiver, where the LOE of the individual cylinder is calculated for the shipper and receiver as well as the combined LOE for both shipper & receiver (summed in quadrature) for each cylinder. See the SRD LOE definition in § 2.0.E for the general formulation. If the uranium or ^{235}U grams difference exceeds the combined

The concept is to isolate any flagged shipper receiver difference issues. The evaluation (SRD_i) draws a box around the problem. Item by item evaluations for smaller items whose batches span many items may become prohibitive, and error variances may not be easily applied. However, similar checks on net weights using only weighing error are good for isolating suspected anomalous items.

4.1.2 <u>Data Requirements</u>

The shipper-defined batch is the base unit for conducting Shipper Receiver Difference evaluations. USNRC requires resolution of SRDs on a shipment basis unless a facility is required by the IAEA to resolve such SRDs on a batch basis, which the reference plant for this document performs. Batch differences rarely exceed the 500-gram difference even for very large batches. However, differences that exceed the Limit of Error for a batch are investigated as a best practice.

Therefore, for a single shipment, the shipper's batch identification and measurement results are required as well as data sufficient to ascertain the net weight of the SNM compounds being transported. The SNM net weights may be summarized or aggregated into the batch level reporting, but it is not advisable to aggregate multiple batches into fewer composite or weighted average batches. While this is mathematically possible for receipts that contain multiple small batches but the experience at the reference facility is that issues that arise or flagged differences become difficult to isolate.

Some Shipper Receiver Difference evaluations for routinely received materials are performed in applications with automated calculation procedures and stored in database tables, and others are performed manually with spreadsheet calculations. Historical trending is easier to perform when historical SNM masses and SRD variances can be summed directly from a single table rather than opening multiple files and manually extracting (or with macros) this data. Therefore, if manual Shipper Receiver Difference evaluations are being performed in a spreadsheet, it is advisable to add single entries into a separate sheet for trending purposes as batch or shipment Shipper Receiver Difference evaluations are performed.

4.2 Individual SRD Evaluation Toolbox

In USNRC regulated facilities, each shipment is evaluated against a combined shipper-receiver Limit of Error and an absolute 500-gram-^{235}U limit. In IAEA-selected facilities and other facilities that choose to do so, similar batchwise comparisons are also made, which aids in isolation of significant SRDs on a shipment basis. The key to this is the SRD variance, which is the sum of random and systematic variances in the appropriate units (grams U or grams ^{235}U). Twice the square root of this variance is the Limit of Error for the SRD evaluation (by batch or shipment or series of shipments).

4.2.1 Individual Shipment Evaluations

This is a straightforward process once random RSDs are obtained for the appropriate measurement systems used to ascertain the SNM masses. RSDs may be taken from annual SEID or σ-MUF calculations if they are performed, or otherwise specially calculated on some frequency and used in the interim. The SRD coefficients are simply the square of the sum of SNM masses—this document recommends using grams ^{235}U as the basis. These shipper's and receiver's coefficients are multiplied by the relative variances as shown in § 2.0.E to obtain an SRD variance in the desired units. The Limit of Error is simply twice the square root of the combined shipper & receiver variances. If shipper variances are unavailable and it is reasonable to assume that the RSDs are not very different between the shipper and receiver (both use mass spectrometry and gravimetry and state-of-the-art scales, e.g.), then the receiver's variance may simply be doubled. The combined Limit of Error is the basis for making decisions for statistical significance, and the absolute 500-gram ^{235}U threshold is the basis for determining that a statistically significant difference is also of Safeguards significance.

In facilities not required to perform Shipper Receiver Difference evaluations using the full suite of measurements for percent element and isotopic abundances of all received items, the grams ^{235}U may still be used as the basis for the coefficient, only eliminate the sampling and analytical RSD terms from the variance model. This will scale the impact of weighing variance to its acceptable impact to the grams ^{235}U difference. In this way, the weight differences can be evaluated in terms of their impact to the grams ^{235}U.

However, while any true loss or diversion in transit would likely also be associated with a net weight discrepancy, a shipper's laboratory analytical bias whose values are summarily accepted by the receiver, will be reflected directly in their material balances with no way to detect or isolate it. While this would often be less than would impact a single material balance, years' worth of receipts from the same facility with the same bias would certainly have problematic security and financial implications of SNM accountancy. This document recommends randomly selecting at least 15 batches to analyze in replicate (at least two samples each batch analyzed in duplicate) throughout a material balance period to ensure 1) there is not an ongoing lab-to-lab bias affecting one or more SNM accountancy systems, 2) the shipper's sampling uncertainties approximate those assumed or established by the receiver, and 3) that there is enough data to calculate a valid error variance for sampling and analysis of routinely received material types. Replicate samples analyzed in duplicate (at least two replicates and at least two duplicate analyses) can be used to establish the repeatability of the measurement (duplicates) and the reproducibility of the shipper's mixing/sampling processes using a fully nested ANOVA or gauge R&R study in any statistical software package.

4.2.2 In-Transit Loss Detection Limit Based on a Lower Limit of a Goal Quantity

For non-US facilities, this document recommends that stakeholders develop an abrupt anomaly (one consignment, e.g.) goal quantity in absolute terms that would indicate the need to hold received items and pursue resolution. This may be statistically driven, financially driven, security related, or some combination of all those things. Then, use the SRD variance to build a lower, one-sided limit based on an expansion factor such as 2 (> ~95% confidence), or 1.3 (≈ 90% confidence), or some similar criterion that all stakeholders agree is reasonable. This formulation hypothesizes that the threshold is exceeded until the evaluation proves that it is not, which are reversed from the limit-of-error strategy. The LOE says with your specified confidence (or risk tolerance) "We can't see with any higher resolution than this, and the difference appears smaller than what we can confidently see." The abrupt loss strategy says with your specified confidence, "This absolute difference is important to us, and we have proved that the difference does not exceed it."

4.3 Historical SRD Evaluation Toolbox

A few things to note about historical SRD evaluation and trending. The beginning of the trending period is very important. If a known and ongoing bias is being investigated, then the trend should be reset at the first sign that improvements have been made to verify. Otherwise, attempt to choose a beginning time that either marks a well-behaved period of SRDs or some system change likely to induce or fix a trend: key personnel changes, key measurement system updates, events involving losses or gains of substantial SNM quantities. The receipt of new material types (routinely) or the advent of a new supplier are excellent times to begin a trend.

The variance of each batchwise SRD is key. A cumulative SRD will almost never sum to zero as expected, so the question is how seriously to take a non-zero cumulative SRD. Small facility-to-facility biases are the rule, not the exception. Each measurement system provides a well-educted opinion no matter how tightly the calibrations and control protocol are controlled.

Two categories of historical evaluations are performed at the reference facility for this document: 1) All shippers versus the receiver, and 2) Each shipper versus the receiver. Two types of each-shipper's historical trends are performed, both based on cumulative results. One is a cumulative SRD with cumulative Limits of Error, and the other is a scoring method that ranks the shippers based on agreement with the receiver. The all-shipper method is another cumulative SRD with cumulative Limits of Error but done with all shippers together versus treating each shipper in isolation. The discussion of all shippers cumulative SRD analysis also applies to the each-shipper version with no differences in calculation or presentation, only the scope of the data. Therefore, the each-shipper cumulative analysis is not specifically presented.

4.3.1 <u>All-Shippers Cumulative SRD Analysis</u>

Not included in Reference [1] but developed locally at the facility where this document was generated, the cumulative ID analysis is a simple tool using the historical SRDs and SRD variances. These are cumulatively summed sequentially such that all SRDs and variances are summed from the beginning of the trend period to the present. Each year, this cumulative trend is performed over the material balance period, then that data is added to a long-term analysis that spans many years. The square root of the cumulative variances for each iteration is multiplied by an expansion factor of ±2 to provide upper and lower expanded limits that equates to the actual Limit of Error for a shipment that was received containing all the material over the series at once. Each row of the table is the next batch received and the associated variance, which are summed and used to establish a chart that shows the cumulative SRD and associated LOE for each row. The LOEs tend to extend outward from zero as more and more sequential batch evaluations are summed. This not only establishes the boundary for statistical significance, but also serves to scale the graph appropriately—not according to the cumulative SRD itself, but according to our ability to see the cumulative SRD. Figure 4.3.1-1 shows a Material Balance Period worth of grams ^{235}U Shipper Receiver Differences with no error bars, and Figure 4.3.1-2 shows the same data with error bars.

Figure 4.3.1-1: Cumulative Grams ^{235}U Difference All Shippers

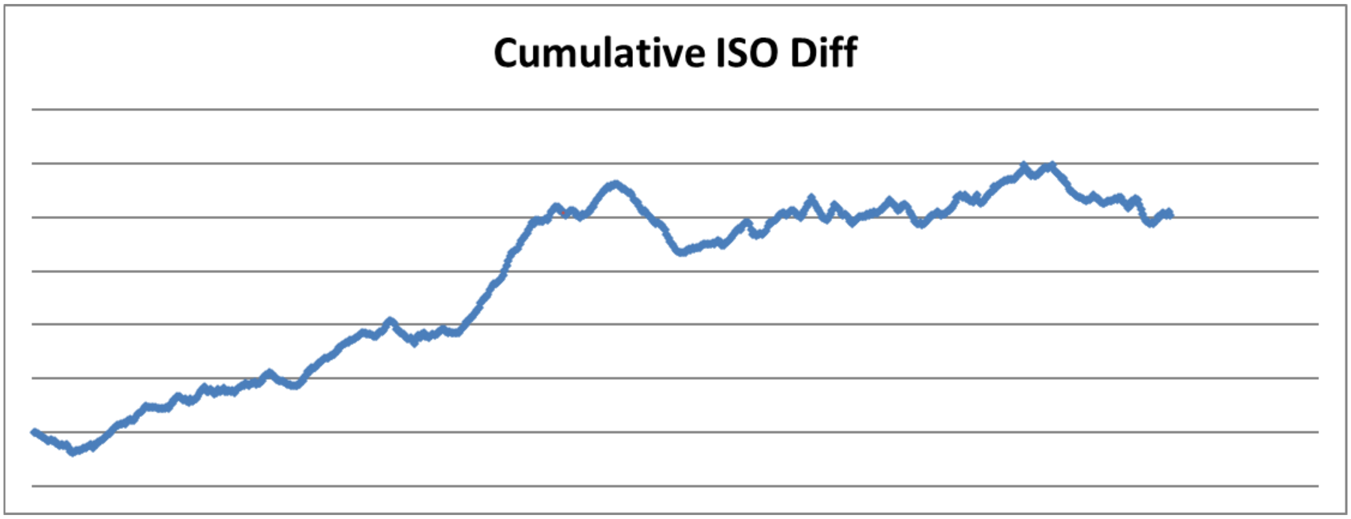
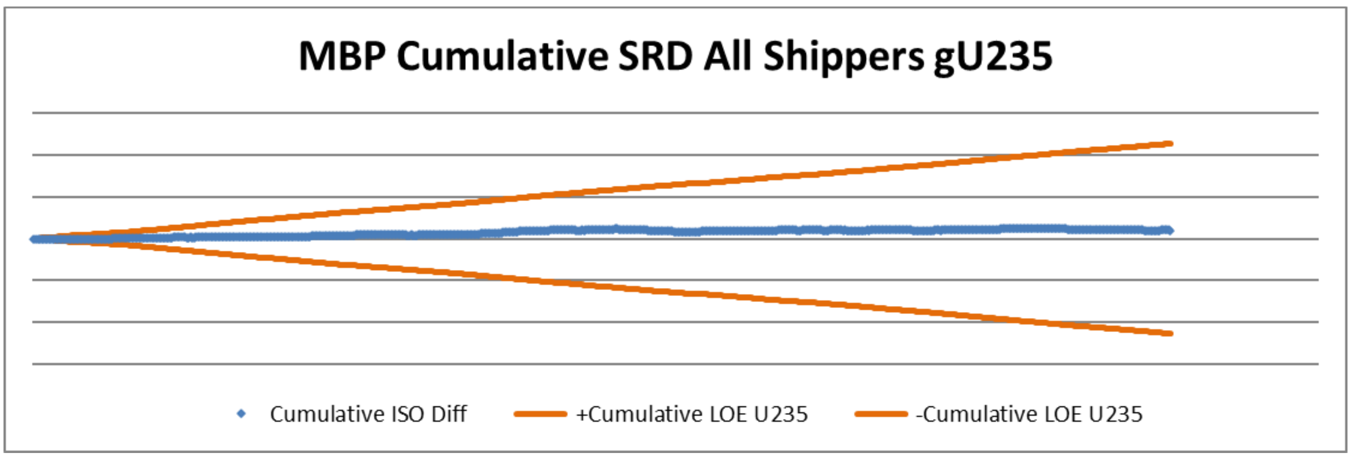


Figure 4.3.1-2: Cumulative Grams ^{235}U Difference All Shippers with Cumulative LOEs

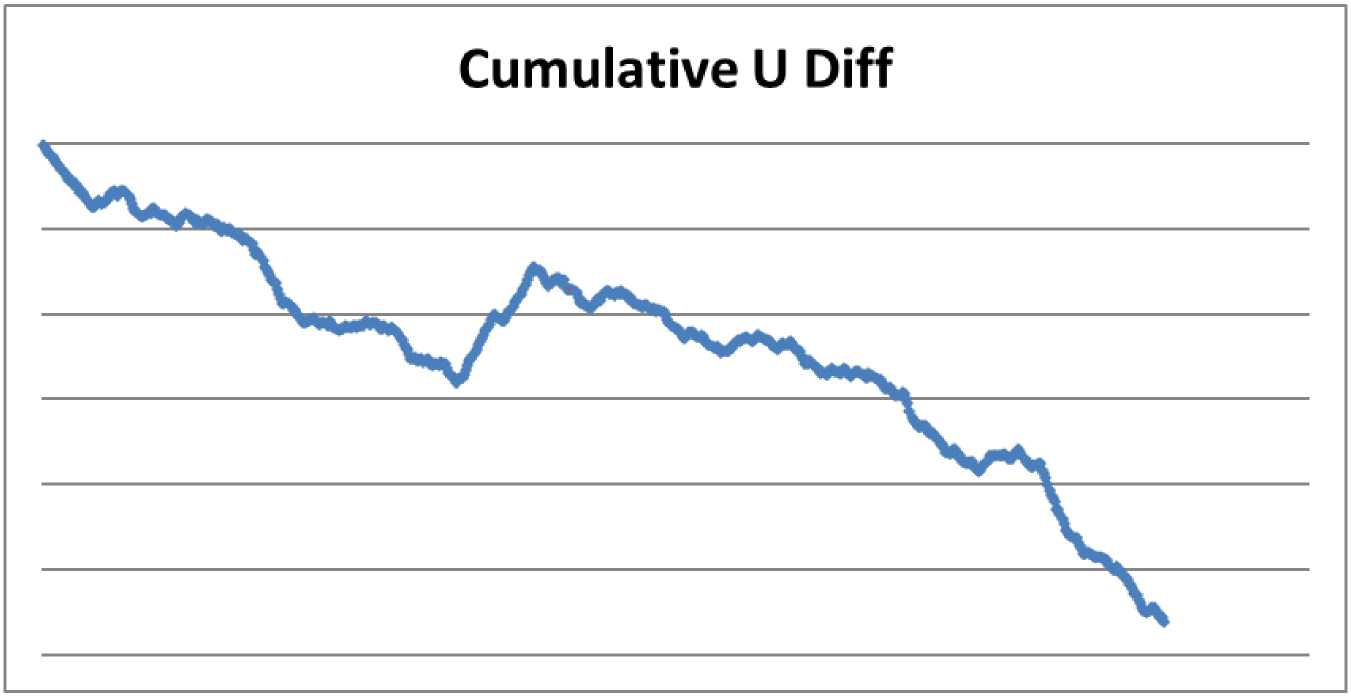


This method is easily interpreted. Both the calculation method and the result can be consumed by stakeholders of any background, technical or non-technical. The expanding limits serve to scale the chart appropriately, not only serving as a definitive limit but also a visual aid to show the stakeholders how seriously to take a non-zero cumulative trend.

This all-shipper-versus-receiver analysis shows us how much of the inventory difference (or MUF) can be attributed to Shipper Receiver Differences, especially if shipper's validated values are routinely booked in the SNM accountancy space. But even if receivers values are routinely booked or booked when some limit is violated, this still shows what may be an issue on the receiver's end. If UF_6 weighing is biased but rod weighing is unbiased, this will still induce material unaccounted-for, and this trend analysis may be the only reason to suspect the UF_6 weighing even in a facility that routinely calibrates and controls the scale.

This exercise can be done with net weights and grams U differences as well, as shown in figures 4.3.1-3 & 4.3.1-4.

Figure 4.3.1-3 Net Weight Cumulative SRD with & without Cumulative LOEs



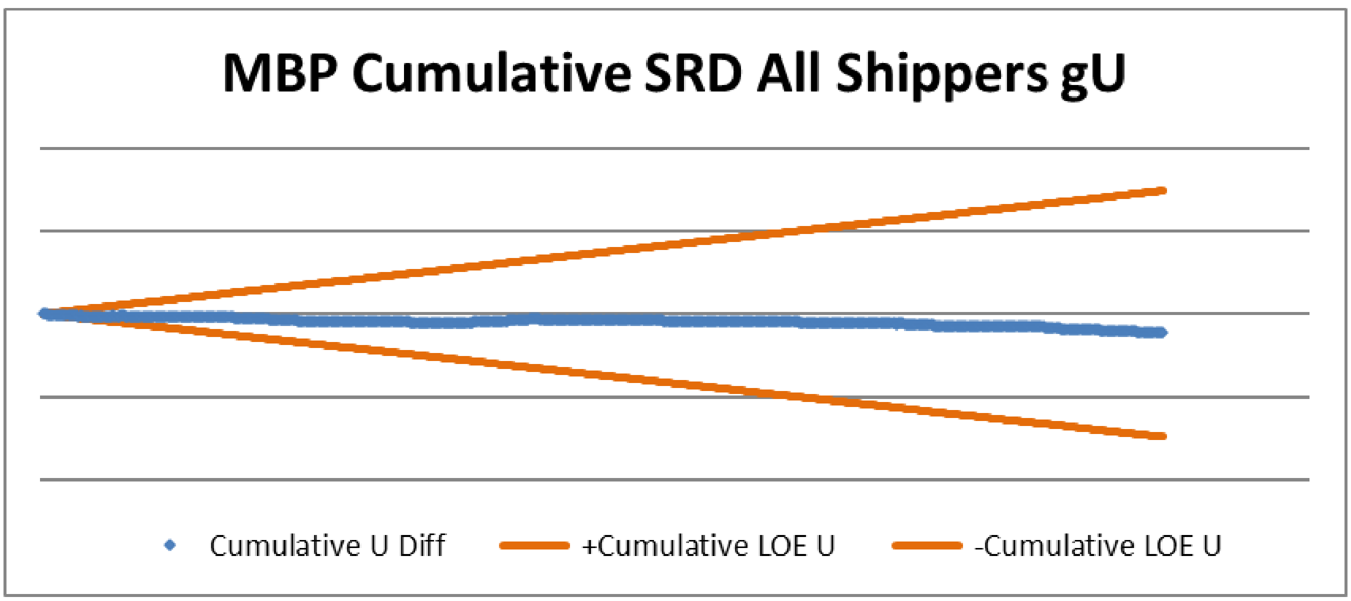
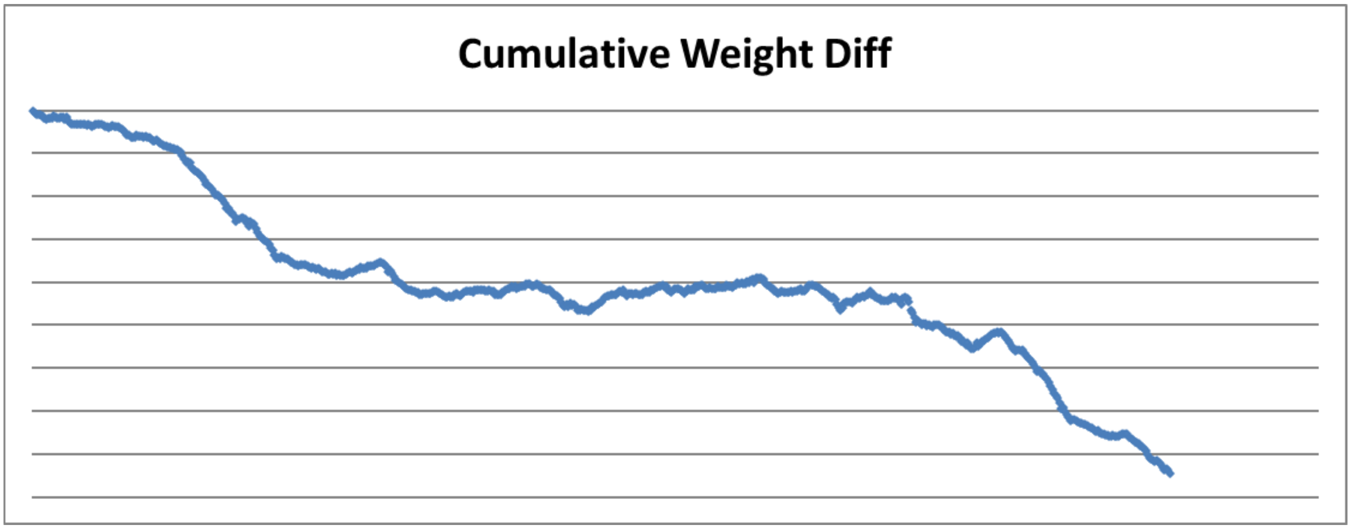
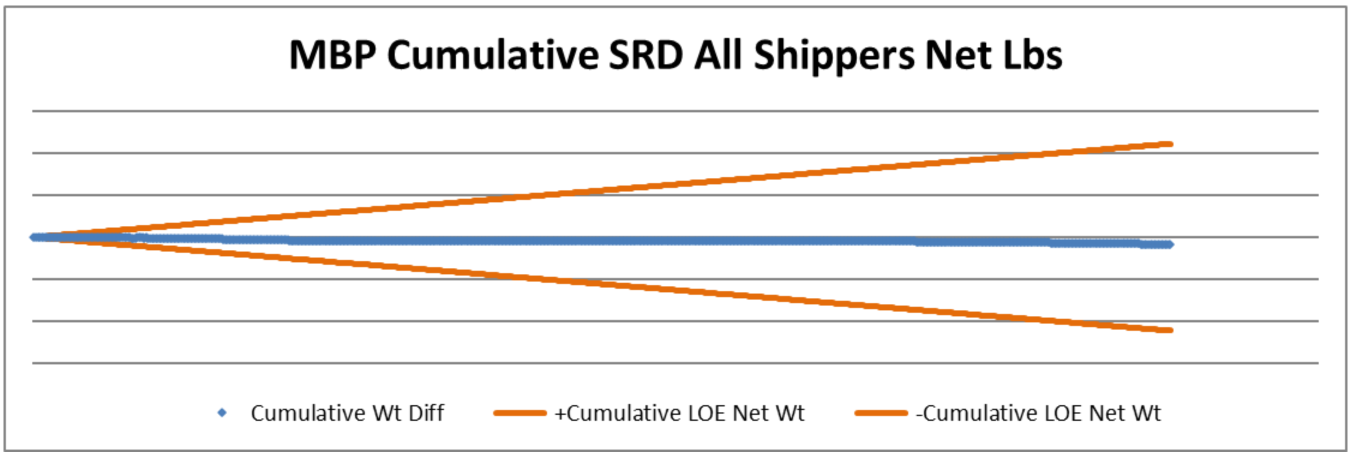


Figure 4.3.1-3 Net Weight Cumulative SRD with & without Cumulative LOEs





Finally, in each of these cumulative analyses, the final cumulative SRD can be divided by the square root of the variance to obtain a standardized cumulative SRD. If the normal distribution or central limit theorem can be reasonably assumed to apply to the Shipper Receiver Difference data, then a probability under the normal curve can be assigned to that cumulative difference, which is interpreted as "We are X% confident that we have at least one facility-to-facility bias." If the scope of the chart is net weights, U weights, or isotopic weights, one shipper or all shippers, this probability under the normal curve and nature of the bias can be isolated more narrowly.

4.3.2 Shipper Score Card

Another method that can be used is a score card or ranking system based on parameters important to the facility, whether in terms of security or financial responsibilities or both. The reference facility for this document has developed a scoring system based on cumulative weight agreement, cumulative uranium purity, and cumulative isotopic assay differences. The net weight differences are standardized by the cumulative weighing variances—the same used to create cumulative LOE bars for net weights in Figure 4.3.1-3. The uranium purity is simply the receiver's measured percent uranium (cumulative grams U divided by cumulative net grams) divided by the stoichiometric percent uranium for the receiver's cumulative assay (cumulative grams ^{235}U ÷ cumulative grams U). The cumulative assay difference is simply the weighted average shipper assay minus the weighted average receiver assay (again, cumulative grams ^{235}U ÷ cumulative grams U). Each shipper's score is defined by

$$\textbf{Score} = |\textbf{Assay Difference}| \cdot (\mathbf{1} - \textbf{Avg Purity}) \cdot |\textbf{Standardized Net Weight Difference}|$$

The smaller the score, the higher the rank. The resultant table is not shown here since the necessary redactions would make it difficult to interpret and not informative. This scoring system is arbitrary based on factors that tend to contribute to excessive nuclear material accountancy and or financial issues.

5.0 CLOSING THOUGHTS

While this document does not provide detailed statistical formulations or an example SRD, the intended audience is management or regulators who are considering the implementation of SRD LOE modeling to evaluate the possibilities, the costs, and the benefits of SRD evaluations and trending.

There are ample opportunities to create decision rules that help quantify the overall health of a nuclear material accountancy system. There are a few potential areas of concern if implemented incorrectly, namely failure to account for measurement and sampling variances correctly can lead to poor decision rules. Overestimated variances and LOEs can cause loss of sensitivity where facilities eventually find SNM they didn't know they lost. Underestimated variances and LOEs can cause loss of specificity where facilities to look for material they never had in the first place.

The question becomes how much risk is tolerable? The rule of thumb used by the author of this document is that an MUF contribution (potential bias on the accounting record, be it internally or between facilities) less than or equal to 10 grams ^{235}U or a ^{235}U σ-MUF contribution less than or equal to 100 grams may be considered *de minimis*. Potential biases or MUF impacts that exceed 500g ^{235}U and what can be explained by measurement variances are generally considered of safeguards significance. Between 10 and 500 grams ^{235}U, discretion should be used for statistically significant anomalies to minimize the aggregate impacts of small issues while balancing the cost-benefit of a graded approach.

6.0 REFERENCES

[1] NUREG/CR-4604 — Statistical Methods in Nuclear Material Accounting

[2] 10 CFR 74.31 — US Title 10, Code of Federal Regulations, Part 74Material Control and Accounting for Special Nuclear Material of Low Strategic Significance