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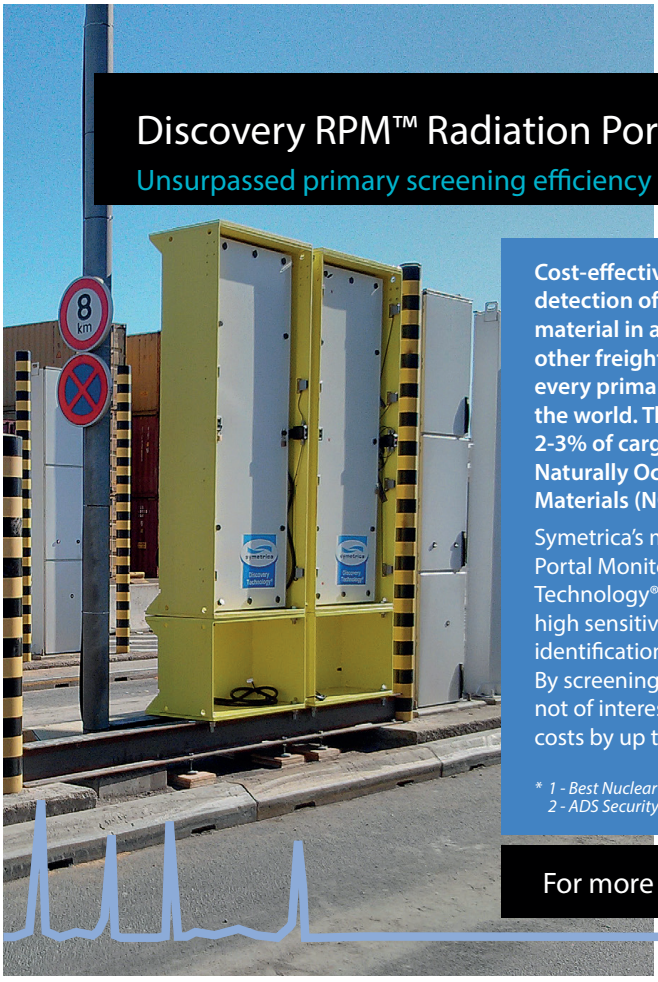

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The Institute of Nuclear Materials Management is dedicated to the safe, secure and effective stewardship of nuclear materials and related technologies through the advancement of scientific knowledge, technical skills, policy dialogue, professional capabilities, and best practices.

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INMM INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Recognizing the Good

By Corey Hinderstein
INMM President

Gift Gugu Mona, a South African born author and poet, said, "Sometimes you will do good and not get an acknowledgement for it. Don't let that dishearten you, the world is a better place with your good deeds." Too often, though, we miss the opportunity to recognize the good that is being done every day by the dedicated professionals in the nuclear materials management field. When I was INMM vice president, my favorite part of chairing the Annual Meeting was presenting awards. To focus attention, even briefly, on the work of individual members of the INMM community was a privilege. It is a task that current Vice President Cary Crawford may have to wrestle from me this summer in Indian Wells at the 58th Annual Meeting. It may not have the profile of last month's Oscars©, and nobody asks who I am wearing, but I always look forward to seeing who will be honored.

The only way we can acknowledge the great work of our colleagues is if they are nominated. I urge each of you to consider someone who has made, or is making, a difference in your world. There are INMM awards for those who have contributed to the Institute or the broader profession, for one outstanding accomplishment or a lifetime of dedication, those in the beginning of their careers or those with a long track record. We all have mentors, collaborators, and talented protégés. Think about what it would mean to see one of them applauded this year, and what it would mean to you to be part of it. We know the world is a better place, as Ms. Mona said, but that should not keep us from acknowledging it.

In that vein, I want to take this opportunity to recognize the hard work and great success of Jeff England who led the team from the Packaging, Transportation, and Disposition Technical Division, which, in partnership with the U.S. Nuclear Infrastructure Council, hosted the 32nd Annual Spent Fuel Seminar in January. This annual INMM workshop, again focused the attention of the community on the technical and international political landscape of spent fuel management issues. This seminar, which attracted approximately 120 people from eight countries, is a tent pole event for the nuclear materials management profession. The event even made news this year for the remarks made by some of the key speakers.

Workshops and seminars, like the annual Spent Fuel Seminar, are central to meeting the mission of INMM. We are dedicated to the safe, secure, and effective stewardship of nuclear materials and related technologies through the advancement of scientific knowledge, technical skills, policy dialogue, professional capabilities, and best practices. This advancement takes place not just through the *Journal of Nuclear Materials Management* and the INMM Annual Meeting, two of our most visible activities, but through the events that connect members in a specific geographic area or who work on a specific issue.

We are realistic. In a world of limited resources — both time and money — and a membership stretched across thirty countries, the Institute needs to find more and more ways to engage members who can't always travel to the Annual Meeting or apply the peer-reviewed *Journal* articles to their specific field of work. Topical and regional workshops are ways to do this, but we are interested in others, too. Is there something we could be doing better to meet your interests as a current or potential INMM member? Please, let us know by emailing inmm@inmm.org. I promise we will consider your suggestions seriously.

Work In Progress

Markku Koskelo
JNMM Technical Editor

In 2016, the INMM adopted a new strategic plan. One of the initiatives of this strategic plan is to elevate the status of the *JNMM*, particularly its "impact factor." The impact factor of an academic journal is generally used as a proxy for the relative importance of a journal within its field. That is, journals with higher impact factors are often deemed to be more important than those with lower ones. Presently, the *JNMM* is viewed to have a relatively low impact factor. To improve the situation, the INMM and the *Journal* editorial staff have agreed to a number of steps. Presently, the *Journal* is available online only for INMM members and for some institutional subscribers. Unfortunately, this means that researchers looking for references related to their work will not always see the *Journal* articles. We are investigating how to make the *Journal* and its articles more accessible. The *Journal* editorial team also continues to refine the peer review process and additional guidance to both authors and reviewers with this goal in mind.

The three papers included in this issue offer interesting insights into different within the broad topic of nuclear materials management. The first paper by Stephen Walsh, et al., explores the issues encountered when trying reconcile whether the measurements made by International Atomic Energy Agency inspectors and the measurements made by the facility operators are the same. In the nuclear materials management field all measurements have uncertainty. The paper explores the guidance offered by various standards on how to properly assign this uncertainty to each measurement, and how to then use the uncertainties to verify whether two numerically different results are in fact in agreement with each other.

While a large portion of the management of nuclear materials involves keeping track of the materials in the facilities where they are created or used, detecting materials that have been misplaced or stolen for other purposes remains an important nuclear security issue. Portal monitors continue to be part of the deterrence for illicit transportation of nuclear materials. The paper by A. Maltezos et al. describes the recent experience of operating portal monitors in Greece for the purpose of deterring, detecting, and responding to criminal and other unauthorized acts of transporting nuclear and other radioactive materials.

The third paper by J.M. Oka et al. is the 2016 J. D. Williams Student Paper Award — First Place paper from the INMM Annual Meeting. It discusses testing a pipe overpack container for its thermal steady-state. Such testing is crucial to ensure critical components for specific containers do not fail under an internal heat payload.

Book Review Editor Mark Maiello provides us a review of an interesting new book on nuclear forensics. As Maiello explains, this work combines the technology and history of nuclear forensics into a very readable framework for those new in the field as well as senior subject matter experts in nuclear forensics.

In his column, Taking the Long View in a Time of Great Uncertainty — "That Will Never Happen" — the Power of Scenario Planning, Jack Jekowski, Industry News Editor and chair of the INMM Strategic Planning Committee, gives us a brief summary of the possible consequences of the rather improbable events that have happened in the last twelve months and what actions could be taken to influence those possible consequences. This is a column that is always well worth reading.

Should you have any comments or questions, feel free to contact me.

JNMM *Technical Editor Markku Koskelo can be reached at mkoskelo@aquilagroup.com*

Discussion of the IAEA Error Approach to Producing Variance Estimates for Use in Material Balance Evaluation and the International Target Values, and Comparison to Metrological Definitions of Precision

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Abstract

Representatives from the nuclear safeguards evaluator and analytical communities are engaged in discussions on approaches to uncertainty quantification (UQ) concerning measurements taken for safeguards purposes. Their objective is to bring together an understanding of the approaches applied in each domain and to clarify the intended purpose of each. UQ in nuclear safeguards evaluation is primarily concerned with monitoring uncertainty of measurement systems at facilities under comprehensive safeguards agreements so that a material balance evaluation (MBE) can be conducted and the material unaccounted for (MUF) can be assessed for significance against that quantified uncertainty. A second objective of nuclear safeguards evaluators is the decennial publishing of the International Target Values (ITVs). To accomplish each of these, in many cases (and in the case we consider), analysis of variance (ANOVA) methods are applied to paired operator-inspector verification measurements in order to estimate variance components, assuming the simplest defensible measurement error model. The analytical chemistry community, which includes members of the network of analytical laboratories (who provide sample analysis results to safeguards evaluators for verification and MBE purposes) as well as producers of reference materials, is also concerned with UQ as it pertains to an analytical method. Following modern best practices, they typically appeal to the GUM (bottom-up) principles and/or reproducibility studies (top-down) to estimate the error variances of an analytical method. Guidance on top-down and bottom-up approaches to UQ of analytical methods is provided in multiple international standards, which include, but are not limited to: JCGM 100, JCGM 200, ISO 5725, and ISO 21748. In support of this current effort to reconcile UQ paradigms, this paper discusses the statistical underpinnings of each approach.

Introduction

The International Atomic Energy Agency (IAEA) nuclear safeguards evaluators apply an empirical (a type of top-down) approach to uncertainty quantification (UQ). This approach relies fundamentally on a one-way ANOVA (analysis of variance) model with two variance components, which are typically referred to as random and short-term systematic error variances. ANOVA is applied to paired operator-inspector measurement data in order to estimate the variance components, which in turn are used for uncertainty propagation in MBE.[1, 2, 3, 4, 5]

Analytical laboratories providing measurements of samples used for safeguards purposes will, following modern best practices, produce a measurement result and an uncertainty based on bottom-up UQ. The uncertainty may be produced following JCGM 100:2008 *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement* (the GUM) and/or via appropriate uncertainty assessments conducted under reproducibility conditions.[6] The uncertainty produced by the laboratory reflects what is known about the uncertainty of the *analytical method*.

This paper discusses the statistical underpinnings of each approach. In particular, with respect to the IAEA nuclear safeguards evaluators approach, we discuss an application of Grubb's estimation of random error variance combined with an ANOVA applied to paired operator-inspector data.[7, 8, 3] Grubb's method is one statistical approach among an ensemble employed to estimate the international target values (ITVs)[5] and for producing variance estimates appropriate for use in MBE. With respect to the UQ approach commonly implemented by analytical laboratories, we discuss briefly the structure of GUM. Additionally, we discuss definitions from JCGM 200:2012 *International Vocabulary of Metrology – Basic and General Concepts*

and Associated Terms (the VIM) wherein strict definitions on conditions of collected data and the uncertainty sources the data comprise are given.[6, 9, 10] Further, we describe the experimental design typically applied in a reproducibility study (a one-way ANOVA) where the aim is to benchmark the uncertainty of a measurement method by establishing estimates of the repeatability and reproducibility standard deviation as defined in ISO 5725.[11, 12] Measurement reproducibility standard deviation is widely recognized as the expedient estimate of the "true" uncertainty of a measurement method.

We strive to interpret the IAEA nuclear safeguards evaluator approach to UQ through the scope of the international standards and metrology definitions. It can be argued that Grubb's method, given the appropriate input data, provides a random error variance estimate that can be nearly interpreted as an estimate of method repeatability as defined in JCGM 200:2012. Systematic error variances can then be estimated using the same operator-inspector paired data and the Grubb's-based estimate of random error variance. Further, we discuss random and short-term systematic error variances in the ANOVA context and describe why estimates of these quantities are needed for MBE.

Precision Conditions and the UQ Hierarchy

International Vocabulary of Metrology (VIM)

The JCGM 100:2008 *Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement* (the GUM) is probably the most well-known metrological standard; however, the primary standard is JCGM 200:2012 *International Vocabulary of Metrology — Basic and General Concepts and Associated Terms* (the VIM). In its own words, VIM "is a terminological dictionary which…pertains to metrology, the 'science of measurement and its application.'" The vocabulary of the VIM "assumes no fundamental difference between basic principles of measurement in physics, chemistry, laboratory medicine, biology, or engineering."

The VIM, in part, arose after a paradigmatic shift in the metrology community from an "error approach" (use of specified statistical model and estimation of variance components) to an "uncertainty approach," the former being concerned with quantifying deviations from an assumed true value via random and systematic errors while the latter attempts to assign to the measurand a range of highly plausible values while taking into account all known sources of uncertainty. Therefore, the latter is not concerned with producing separate estimates of random and systematic error variances (which are needed in MBE and in any application for which UQ for the sum of two or more measurements is needed).[6,10] However, the latter also requires separation of errors into random and systematic in cases where inputs to the measurand equation (Equation 1) are correlated.

Precision Conditions

UQ is typically accomplished by establishing measures of (im)precision, and these are usually quantified by variance or standard deviation. A fundamental tenet of metrology is that a precision estimate must be accompanied by the conditions under which it is observed to ensure clear interpretation of the estimate. This is described in the VIM's definition of precision:

> [JCGM 200:2012] **2.15 measurement precision:** closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.

Typical specified conditions are repeatability, intermediate, and reproducibility, which are defined by which factors of measurement are changing under replication. Typical factors of variation are reflected in the definitions:

> [JCGM 200:2012] **2.20 repeatability condition of measurement:** condition of measurement, out of a set of conditions, that includes the same measurement procedure, same operators, same measuring system, same operating conditions, and same location, and replicate measurements on the same or similar objects over a short period of time.

> [JCGM 200:2012] **2.22 intermediate precision conditions of measurement:** condition of measurement, out of a set of conditions that includes the same measurement procedure, same location, and replicate measurements on the same or similar objects over an extended period of time, but may include other conditions involving changes. NOTE 1: The changes can include new calibrations, calibrators, operators, and measuring systems.

> [JCGM 200:2012] **2.24 reproducibility condition of measurement:** condition of measurement, out of a set of conditions that includes different locations, operators,

measuring systems, and replicate measurements on the same or similar objects. NOTE 1: The different measuring systems may use different **measurement procedures**. NOTE 2: A specification should give the conditions changed and unchanged, to the extent practical.

Experimental designs and corresponding estimation methods commonly used to estimate repeatability and reproducibility error variances under these conditions are given in ISO 5725. Many of the estimation approaches are well-known applications of ANOVA.[12]

Modeling Approach: 'Bottom-up' UQ Following GUM Principles

The GUM (JCGM 100:2008) describes a methodology for bottom-up UQ. The GUM and it supplements are lengthy, but briefly, for bottom-up uncertainty quantification, GUM applies the delta method[13] to the measurand equation,

$$Y = f(X_1, X_2, \ldots, X_N), \quad (1)$$

which relates input quantities $X_1, X_2, \ldots, X_N$ to the measurand Y. The input quantities can include, for example, measured count rates, estimates of calibration parameters or other measurands, such as measured values in the steps of an assay method. The delta-method assumes that $f(\cdot)$ in Equation 1 can be well approximated by a first-order Taylor series expansion around the mean values of each X_i, and then the linear approximation to $f(\cdot)$ can be used to estimate the standard deviation in Y (denoted in the GUM as $u(Y)$ for uncertainty of Y) given estimates of standard deviations for each X_i (denoted in the GUM as $u(X_i)$ for uncertainty of X_i). Correlation between the X_i can be accommodated; therefore, the GUM recognizes the distinction between random and systematic errors. The $u(X_i)$ can be estimated from data under an appropriate model following appropriate precision conditions — this is Type A evaluation, and in this case GUM uses the common statistical notation (σ for population standard deviation and $\hat{\sigma}$ or s for data driven estimates). Alternatively, $u(X_i)$ can be elicited from experts or taken from other sources, such as a certificate for a single point calibration (e.g., bias correction) input — this is Type B evaluation. If the first-term Taylor approximation is not adequate, the GUM supplement 1 (2008)[6, 9] suggests that simulation be used to estimate $u(Y)$). Regarding notation, we use capital letters to denote random quantities; for example, X_i and Y in Equation 1 are random variables. Also, instead of the $u(\cdot)$ symbol used in the GUM, we use σ for absolute standard deviation and δ for relative standard deviation. JCGM 100 did not attempt to be completely comprehensive; so supplements have been written that describe more intricate UQ problems, for example, propagation of uncertainty in complex calibration problems via generalized least squares.

Empirical Approach: 'Top-down' UQ

Despite wide application of the GUM, the error approach to UQ remains relevant and serves an important role. A top-down approach to UQ is commonly thought of as a complement to, and sometimes incorrectly viewed as a competitor to, the GUM bottom-up approach. The relationship between the two has been studied in detail, both theoretically and experimentally.

The relationship of GUM and a top-down approach is described in ISO 21748(2010): *Guidance for the Use of Repeatability, Reproducibility, and Trueness Estimates in Measurement Uncertainty Estimation.*[11] In ISO 21748, the top-down approach to UQ is defined as a collaborative trial involving many participants producing replicate measurements under repeatability conditions. The trial itself is data collection under reproducibility conditions — different locations, operators, measuring systems, and replicate measurements on the same or similar objects. A common design and corresponding additive error model for such a collaborative trial is

$$Y_{ij} = \mu + L_i + R_{ij} \quad (2)$$

where Y_{ij} is the measurand, i indexes the participant labs, j indexes the method replications of participant i, μ is the expectation of Y_{ij}, L_i is the systematic error of lab i (i.e., their bias under repeatability conditions) and R_{ij} is the random error under repeatability conditions. It is usually assumed that $L_i \sim N(0, \sigma_L^2)$ and $Rij \sim N(0, \sigma_r^2)$. The model assumptions imply (with or without the normality assumption) that

$$Var(Y_{ij}) = \sqrt{\sigma_L^2 + \sigma_r^2} \quad (3)$$

Equation 3 is the definition of the reproducibility standard deviation $\sigma_R = \sqrt{\sigma_L^2 + \sigma_r^2}$) as stated in ISO 5725. Given data,

σ_r^2 and σ_L^2 are estimated (sometimes denoted S_r^2 and S_L^2) according to one-way ANOVA as described in ISO 5725.[12]

The remainder of ISO 21748(2010) provides an argument that a laboratory employing a comprehensive GUM UQ, will produce uncertainty estimates consistent with estimates from a collaborative trial (the estimate is sometimes denoted). This concept was studied empirically; see for example *Dark Uncertainty,*[14, 15] which presents a meta-analysis of a number of collaborative trials and compares standard uncertainties reported by participant labs obtained by the GUM approach to estimates of the reproducibility standard deviation. A strong tendency for the reproducibility standard deviation to be *greater* than the uncertainty estimates based on the GUM approach is observed (often by a factor of 1.5 to 2), thereby indicating that important uncertainty components are not yet identified in the lab's GUM-based uncertainty budgets. These experimental observations provide a "reality check" that is compounded further by the fact that the reproducibility standard deviation is already suspected to underestimate the true uncertainty due to its inability to account for method bias.

For this paper, we adopt the VIM definition of reproducibility precision and the corresponding estimate of the collaborative trial approach to UQ, including estimating the reproducibility standard deviation of ISO 5725 shown in Equation 3, as the definition of 'top-down' uncertainty.

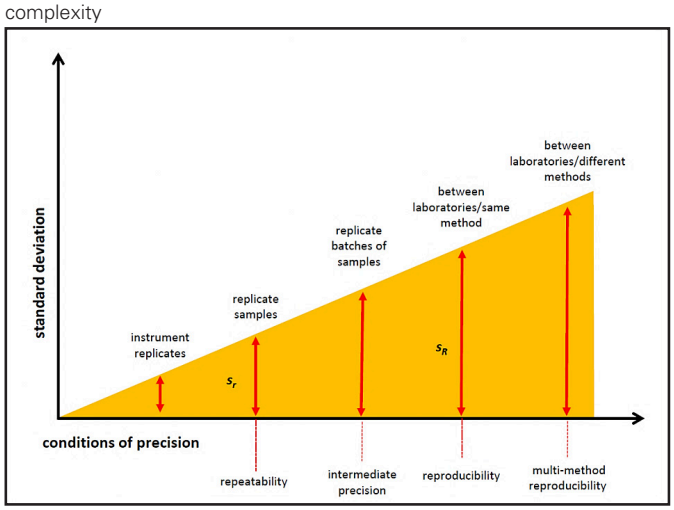
Empirical Approaches: The UQ Hierarchy

The VIM, and observations drawn in ISO 5725 and ISO 21748, describe a UQ hierarchy, which encapsulates a simple premise: the more factors that vary under replication of a method/measurement, the (potentially) larger the uncertainty. More specifically, the definitions of precision conditions in the VIM imply the relationship:

measurement repeatability ≤ intermediate measurement precision ≤ measurement reproducibility. We represent this hierarchy with a notional graphic presented in Figure 1.

The reproducibility standard deviation has largely been adopted as the best expedient estimate of a large (probably the dominant) component of the total true uncertainty in measurement. Therefore, the efficacy of any UQ methodology can be assessed by comparing to estimates of the reproducibility standard deviation when available.

Figure 1. Notional graphic illustrating the hierarchy of precision estimated (as standard deviation) derived precision conditions of increasing complexity



IAEA UQ – An Empirical Approach

The measurement error model used in IAEA statistical methodologies for UQ accounts for variation within and between "groups." In this context a group is typically defined as an inspection period (typically a one-week interval during which verification measurements are taken, and inspections are repeated approximately once per year, or in large facilities, once per month). Between inspection periods (at a fixed inspection location), there can be a number of changes in metrological conditions including: instrument calibration, change of inspectors, and/or change of background radiation or other effects that could impact the inspector's measurements (and/or the operator's measurements) — these are a description of intermediate precision conditions. A typical additive measurement error model for the measured value of item i during inspection j, I_{ij}, by the inspector is,

$$I_{ij} = \mu_i + S_{Ij} + R_{Iij} \quad (4)$$

where μ_i is the unknown true value of item i, $i \in \{1,\ldots,n\}$ where n is the number of items verified during inspection j, $S_{Ij} \sim N(0, \sigma_{SI}^2)$ is a short-term systematic error, representing changes to the environmental conditions and note that S_{Ij} remains constant within the jth inspection period but changes between inspection periods, and $j \in \{1,\ldots,g\}$ where g is the number of inspection periods (groups) for which we have data.[1] The random error $R_{Iij} \sim N(0,\sigma_{RI}^2)$ has a unique value in each measurement. Neither R_{Iij} nor S_{Ij} are observable; however, by modeling

assumption, each group of measurements has the same value of S_{Ij}, so σ_{RI}^2 and σ_{SI}^2 can be estimated, although often with large relative uncertainty in safeguards applications. Note that a similar model is assumed for the operators measurements, denoted O_{ij}, and corresponding error terms S_{Oj} and R_{Oij} with respective variances σ_{SO}^2 and σ_{RO}^2. The variance of I_{ij} is given by $V\text{ar}(I_{ij})=\sigma_{\mu}^2+\sigma_{SI}^2+\sigma_{RI}^2$, where the item variability σ_{μ}^2 is the variance of the μ_i (the true item values). Although the i items are generated from the same process with the same target content, the variance as σ_{μ}^2 accounts for variability of the process and hence the items are not true sample replicates. Because the *n* measured items are not true replicates, that is, they may contain variability in matrix components and interferences that could in principle affect variability in measurement of similar samples, the random error R_{Iij} includes any "item-specific" bias that might be present. Therefore, R_{Iij} often has larger standard deviation than purely random error, so σ_{RI}^2 is comprised of method repeatability plus any variance attributable to item-specific factors. Item-specific bias arises whenever physical effects in items differ from those in calibration items.[16] As an aside, if the errors tend to scale with the true value, then a typical model for multiplicative errors for the inspector is $I_{ij}=\mu_i(1+S_{Ij}+R_{Iij})$, where $S_{Ij}\sim N(0,\sigma_{SI}^2)$ and $R_{Iij}\sim N(0,\sigma_{RI}^2)$ where σ^2 now represents the variances of the respective error terms relative to μ_i. If there is non-negligible variation in the true values μ_i, then multiplicative error models behave differently than additive error models. For brevity, here we consider only additive error models such as Equation 4.

The GUM endorses the notion of random and systematic errors in a measurement error model such as Equation 4 in top-down UQ such as in Equation 2 and in bottom-up UQ for variance components models on the input quantities X_1 in Equation 1. We draw the reader's attention to the structural similarity of the models in Equations 2 and 4.

Grubbs Estimator of σ_{RO}^2 and σ_{RI}^2 for Paired (Operator, Inspector) Data

The IAEA safeguards evaluators compare operator to inspector measurements on a given item. Such paired (operator, inspector) data is analyzed for two reasons. One reason is to check for falsification of operator data that could mask nuclear material diversion. A second reason is to check for a diversion into MUF. Such assessments depend on the assumed measurement error model and associated random and systematic error variances, so it is important to maintain up-to-date information regarding these variance components. The estimated random and systematic error variances from prior inspection periods are used to evaluate paired data for possible falsification by the operator in the current inspection period. This allows for removal of possible outliers, and then the same paired (operator, inspector) data can be used for UQ via variance component estimation. A pooled Grubb's approach is used to estimate the random error variances of operator and inspectors.[7] Then, an ANOVA can be used to estimate the operator and inspector systematic error variances.

Before introducing the Grubb's estimator, we temporarily assume that the operator measurement on item *i*, O_i, is perfect, made with negligible measurement error. Under this assumption we use Equation 4 to write $d_i=I_i-O_i=S_I+R_{Ii}$ (group index j is omitted). This is now the model of a one-way random effects ANOVA,[4] for which there are several reasonable options to estimate σ_{RI}^2 and σ_{SI}^2. Under standard one-way ANOVA, the within-group mean sum-of-squares MSW= $\hat{\sigma}_{RI}^2$.[13] The between-groups mean sum-of-squares is used to estimate σ_{SI}^2 as $\hat{\sigma}_{SI}^2=\frac{MSB-\hat{\sigma}_{RI}^2}{n}$. The estimates $\hat{\sigma}_{RI}^2$ and $\hat{\sigma}_{SI}^2$ are based on complete, minimal sufficient statistics, so they are the uniformly minimum variance unbiased estimators (UMVUEs).[13] It turns out that there are biased estimators with smaller mean squared error (MSE) than the UMVUEs. Nevertheless, the UMVUEs are reasonable estimators, although $\hat{\sigma}_{SI}^2$ can be negative, a problem because the true parameter value $\sigma_{SI}^2>0$. Constrained maximum likelihood methods are available (and Bayesian methods are being developed) for standard ANOVA that enforce such constraints.

Next, suppose instead that the inspector made *n* repeat measurements of a standard, then recalibrated and made another set of *n* repeat measurements, and repeated the recalibration *g* times. There would be *g* calibration groups, each with *n* measurements of a standard. Then, the random-effects one-way ANOVA model would be the same as that just described, and, this is the typical scenario for estimating repeatability and intermediate precision as described in Reference 12. However, the term σ_{RI}^2 (and probably also its corresponding estimate, σ_{RI}^2) would probably be smaller than the random error variance if instead the inspector measured multiple test items, because item specific bias could in some cases be a contributor to differences between test and calibration items and among test items.[17] Recall that item-specific biases behave like random error across items.[16] Therefore, it is fortuitous that the IAEA has access to paired (operator, inspector) measurements on

the same item, because product variability and item specific biases, which may change from inspection to inspection could be a contributor to the total uncertainty and therefore should be included in the term σ_{RI}^2. Thus, the IAEAs approach using the paired operator-inspector difference data d_i ensures that the effective random error includes the effects of pure random error and of item-specific biases.

The basis of a Grubbs-based estimator (as applied, for example, to Equation 4 for both the inspector and operator) to estimate σ_{RI}^2 and σ_{RO}^2 is that the covariance between operator and inspector equals σ_{μ}^2, while the variance Var(I_{ij} | j) conditioned on a particular group j equals $\sigma_{\mu}^2 + \sigma_{RI}^2$.[8] Note that previously we wrote the unconditional variance Var(I_{ij})= $\sigma_{\mu}^2 + \sigma_{SI}^2 + \sigma_{RI}^2$. Therefore, the sample covariance between operator and inspector measurements (the second term in Equation 5 below) can be subtracted from the sample variance of the inspector measurements (the first term in Equation 5) to estimate σ_{RI}^2 (and similarly for estimating σ_{RO}^2). That is, within a single group j (inspection period),

$$\hat{\sigma}_{RI,j}^2 = \frac{1}{n-1}\left\{\sum_{i=1}^{n}\left(I_{ij} - \bar{I}_{.j}\right)^2 - \sum_{i=1}^{n}\left(O_{ij} - \bar{O}_{.j}\right)\left(I_{ij} - \bar{I}_{.j}\right)\right. \quad (5)$$

for the inspector, and similarly for the operator (O). The estimates from Equation 5 are pooled across groups to arrive at the final estimate:

$$\hat{\sigma}_{RI}^2 = \frac{1}{g}\sum_{j=1}^{g}\hat{\sigma}_{RI,j}^2 \quad (6)$$

The estimateσ_{RI}^2 in Equation 6 can be interpreted as an estimate of the repeatability precision according to JCGM 200:2012 2.2.0 when

1. The samples measured (from which the input data were produced) are all true replicates, and
2. The samples were measured at 'the same measurement procedure, same operators, same measuring system, same operating conditions, and same location,

But in typical inspections, the data is generated from samples under the following conditions:

1. The samples may contain variability in factors that interfere with measurement (leading to item-specific bias).
2. The measurements are usually made from the same analytical system but are not made on the same day and usually may be made over the course of the one-week inspection, so they may be subject to variations from changes to some environmental factors in that time window.

Therefore, the estimate σ_{RI}^2 comprises: method repeatability precision plus item-specific bias plus any aggregate effects of intermediate precision in the short one-week period over which the samples are measured.

In such paired data, there is often large uncertainty in the estimates of σ_{RI}^2 and σ_{RO}^2, in part due to small sample sizes but also largely because σ_{μ}^2 tends to be relatively large compared to measurement error variances, and therefore any estimate of σ_{μ}^2 tends to have large uncertainty, as defined by its standard deviation.[18] Therefore, the performance of the Grubbs estimators and constrained versions are currently under investigation in safeguards contexts.

Martin and Böckenhoff Estimators of σ_{SO}^2 and $\hat{\sigma}_{SI}^2$ for Paired (Operator, Inspector) Data

The previous section showed how the Grubb's estimator (Equation 5) applied to operator-inspector difference data d_{ij}=I_{ij}-O_{ij} for each inspection j can be pooled across inspections to Equation 5 yield estimates of σ_{RO}^2 and σ_{RI}^2, and this improves the uncertainty of the estimate. Pooling across groups is always done in one-way ANOVA. The error model for the differences is constructed from the model of Equation 4 as

$$\begin{aligned} d_{ij} &= I_{ij} - O_{ij} \\ &= \mu_i + S_{Ij} + R_{Iij} - \left(\mu_i + S_{Oj} + R_{Oij}\right) \\ &= \left(S_{Ij} - S_{Oj}\right) + \left(R_{Iij} - R_{Oij}\right) \\ &= S_j + R_{ij} \end{aligned} \quad (7)$$

where S_j=S_{Ij}-S_{Oj} with distribution S_j~N(0,$\sigma_{S_d}^2 = \sigma_{SI}^2$+) and R_{ij}=R_{Iij}-R_{Oij} with distribution R_{ij}~N(0,$\sigma_{R_d}^2$=σ_{RI}^2+σ_{RO}^2). The model in Equation 7 now has the structure of a one-way ANOVA. Martin and Böckenhoff appeal to this fact and investigated ANOVA estimation of the variance components $\sigma_{S_d}^2$ and $\sigma_{R_d}^2$ as well as their respective operator and inspector variance components.

We present the typical ANOVA table and expected mean squares for the paired operator inspector difference data in Table 1. The table shows how the paired difference data get processed under Grubb's ANOVA.

Following the data reduction procedure shown in Table 1, the mean square terms can be used to estimate σ_R^2 and σ_s^2. The formulae for these estimates are:[19]

Table 1. Standard one-way (one grouping variable) ANOVA-table for balanced data in groups, with measurements per group and The systematic errors for operator and inspector and change between groups (inspection periods). If the groups do not have the same number of observations then slightly more complicated expressions are needed.

Source of Variance	Sum-of-Squares	df	Mean Squares	Expected Mean Squares
Between inspections	$n\sum_{j=1}^{g}\left(\bar{d}_{.j}-\bar{d}_{..}\right)^2$	$g-1$	$MSB=\frac{n\sum_{j=1}^{g}\left(\bar{d}_{.j}-\bar{d}_{..}\right)^2}{g-1}$	$\sigma_{R_d}^2+n\sigma_{S_d}^2$
Within inspections	$\sum_{j=1}^{g}\sum_{i=1}^{n}\left(d_{ij}-\bar{d}_{.j}\right)^2$	$g(n-1)$	$MSW=\frac{\sum_{j=1}^{g}\sum_{i=1}^{n}\left(d_{ij}-\bar{d}_{.j}\right)^2}{g(n-1)}$	$\sigma_{R_d}^2$
Total	$\sum_{j=1}^{g}\sum_{i=1}^{n}\left(d_{ij}-\bar{d}_{..}\right)^2$	$gn-1$	$MST=\frac{\sum_{j=1}^{g}\sum_{i=1}^{n}\left(d_{ij}-\bar{d}_{..}\right)^2}{gn-1}$	$\sigma_{R_d}^2+\frac{n(g-1)}{gn-1}\sigma_{S_d}^2$

$$\hat{\sigma}_{R_d}^2 = MSW \tag{8}$$

and

$$\hat{\sigma}_{S_d}^2 = \frac{MSB-\hat{\sigma}_{R_d}^2}{n} \tag{9}$$

Noting that $\hat{\sigma}_{S_d}^2$ estimates the sum $\sigma_{SI}^2+\sigma_{SO}^2$, Martin and Böckenhoff[18] replace $\hat{\sigma}_{R_d}^2$=MSW with its representation by Grubbs-type estimators of σ_{RI}^2 and σ_{RO}^2 from Equation 6. They argue that (based on their experience) in practice the short-term systematic error variances of a measurement system are equal to or less than random error variances. Therefore, they assume that an upper bound on the systematic error variance is the random error variance, and so they force the corresponding estimates to obey the corresponding constraints, $\sigma_{SI}^2 \le \sigma_{RI}^2$, $\sigma_{SO}^2 \le \sigma_{RO}^2$. Based on Equation 9 and the two inequalities, they compute a defensible (but biased) estimate of $\hat{\sigma}_{S_d}^2$.[18] Estimating $\hat{\sigma}_{S_d}^2$ directly (with or without the assumption that short-term systematic error variances of a measurement system are equal to or less than random error variances) is appealing because this quantity can be estimated with smaller standard error than the operator or inspector systematic variances (σ_{SO}^2 and σ_{SI}^2) because the difference data are not subject to the item variance σ_{μ}^2. Next, they use the Grubb's estimates σ_{RO}^2 and σ_{RI}^2 in the expressions $(\sigma_{RO}^2)/(\hat{\sigma}_{R_d}^2)$ and $(\sigma_{RI}^2)/(\hat{\sigma}_{R_d}^2)$ and set the decomposition of $\hat{\sigma}_{S_d}^2$ into σ_{SI}^2 and σ_{SO}^2 according to the same proportions; that is, σ_{SO}^2 and σ_{SI}^2 are estimated using $\sigma_{SO}^2 = (\sigma_{RO}^2)/(\hat{\sigma}_{R_d}^2)\ \hat{\sigma}_{S_d}^2$ and $\sigma_{SI}^2 = (\sigma_{RI}^2)/(\hat{\sigma}_{R_d}^2)\ \hat{\sigma}_{S_d}^2$, respectively. This implies that σ_{SO}^2 and σ_{SI}^2 are dependent. A similar methodology is used by Jaech in his Constraint Expected Likelihood Estimators of precision.[3,20] The assumption that the systematic error variances decompose proportionally to the random error variances for the operator and inspector is justified in the sense that (under some assumptions) this yields estimates for σ_{SO}^2 and σ_{SI}^2 with small bias.[18] However, the IAEA does not consider the resulting estimates σ_{SI}^2 and σ_{SO}^2 under this procedure[18] to be estimates of precision components as defined in JCGM 200:2012. But, the IAEA is currently investigating an approach to estimate σ_{SI}^2 using inspector data and to estimate σ_{SO}^2 using operator data that can be considered similar to intermediate precision (JCGM 200:2012 2.22). And we note here that σ_{SO}^2 and σ_{SI}^2 are also dependent if this alternate approach that uses the O and I data separately to estimate σ_{SI}^2, σ_{SO}^2 is used. As is often the case, "errors that are random in one context can be systematic in another context" and so the IAEA uses estimates of between-inspection variance components σ_{SI}^2 and σ_{SO}^2 in MBE and makes specific assumptions regarding their mode of propagation to the variance of MUF.

Numerical Example for a Stratum "UO_2 Drums"

To illustrate how the Grubb's estimators with ANOVA on the paired operator inspector difference data are used to arrive at estimates σ_{RI}^2, σ_{RO}^2, σ_{SI}^2 and σ_{SO}^2 we provide a numerical example of a hypothetical inspection with the following structure:

1. Data are collected from inspectors over three years.
2. Operator measurements are produced by DA and inspector measurements by NDA.

Our intent is to show how the statistical calculations as illustrated in the previous sub-sections in order summarize paired operator-inspector data using estimated variance components.

Many paired comparisons used in the IAEA statistical evaluations involve a less precise inspector measurement (usually nondestructive assay involving neutron-based or gamma-based assay) and a more precise operator measurement (usually destructive chemical assay, but sometimes nondestructive assay), and are analyzed empirically using Grubbs-type estimators.[8, 20]

Table 2 lists hypothetical historical data for a stratum of UO_2 drums. There are n = 4 paired operator, inspector measurements from each of three inspection periods.

Table 2. Stratum of UO_2 drums: Measurement results for ^{235}U mass in g

Year of inspection	Group	Method 1 (Operator)	Method 2 (Inspector)	Difference	
		DA	NDA	Absolute in g	In %
2010	1	423.800	436.300	-12.500	-2.95%
	1	421.800	430.100	-8.300	-1.97%
	1	423.200	413.778	9.422	2.23%
	1	422.700	439.108	-16.408	-3.88%
2011	2	422.900	429.863	-6.963	-1.65%
	2	422.900	433.547	-10.647	-2.52%
	2	426.400	439.605	-13.205	-3.10%
	2	422.700	429.506	-6.806	-1.61%
2012	3	423.500	428.108	-4.608	-1.09%
	3	422.900	422.212	0.688	0.16%
	3	420.900	426.816	-5.916	-1.41%
	3	424.500	415.613	8.887	2.09%

We present the ANOVA decomposition results in Table 3 (computed as described in Table 1).

Table 3. ANOVA based on operator, inspector differences

Source	SS (Sum of squares)	d.f.	MSS=SS/df (Mean sum of squares)
Between groups	180.149	2	90.074
Within groups	554.282	9	61.587
Total	734.430	11	66.766

Based on the Table 3, the estimate for the variance of the random measurement errors for the difference is ($\hat{\sigma}^2_{R_d}$ = *MSW* = 61.587. The unbiased Grubbs estimators are given in Table 4. The formulae for the Grubbs estimators and the standard errors of the estimators denoted by $\sqrt{\mathrm{var}(\hat{\sigma}^2)}$ are given in Reference 18.

Based on the results in Table 4, the unbiased estimate for the variance of the short-term systematic measurement errors for the difference $\hat{\sigma}^2_{S_d} = \frac{MSB - \hat{\sigma}^2_{R_d}}{n} = \frac{90.074 - 61.587}{4} = 7.122$. In

Table 4. Grubbs unbiased estimators for the variance of the random measurement errors

	Variance Component Estimate	$\sqrt{\mathrm{var}(\hat{\sigma}^2)}$
Method 1 $\hat{\sigma}^2_{RO}$	1.42	2.92
Method 2 $\hat{\sigma}^2_{RI}$	60.16	28.5
Method 3 $\hat{\sigma}^2_{R_d}$	61.59	26.3

practice, $\hat{\sigma}^2_{S_d}$ can be negative. In fact, if we analyzed the I and O data separately in this example to get unbiased estimates for σ^2_{SI} and σ^2_{SO}, then we obtain a negative value for σ^2_{SO}. Therefore, we applied the biased but always positive estimators of Martin and Böckenhoff[18] and the results are presented in Table 5.

Table 5. Estimators for the variance of the short-term systematic measurement errors

	Variance Component Estimate	$\sqrt{\mathrm{var}(\hat{\sigma}^2)}$
Method 1 $\hat{\sigma}^2_{SO}$	0.17	3.85
Method 2 $\hat{\sigma}^2_{SI}$	6.96	14.07
Method 3 $\hat{\sigma}^2_{S_d}$	7.12	17.22

The standard errors of the above estimators are large because the number of historical data is small.

On the basis of Tables 4 and 5, we obtain Table 6, the estimated four standard deviations comprise UQ of the stratum "UO2 drums" for both the operator and inspector and can be used in material balance evaluation. Specifically, we have reduced the inspection data into these estimates: $\hat{\sigma}_{RO}$=0.28% , $\hat{\sigma}_{SO}$=0.10%, $\hat{\sigma}_{RI}$ =1.81%, and $\hat{\sigma}_{SI}$ =0.62%. Such a result as in Table 6 is then incorporated into a database of RSDs which is used to help inform the ITVs (often from an aggregate analysis of RSD tables for different facilities of the same type).

Table 6. Final results for the Martin and Böckenhoff approach to uncertainty quantification for a stratum of nuclear material using data from a number of past inspections. These uncertainty estimates are used in MBE, where RSD means Relative Standard Deviation.

Error Component from IAEA Measurement Error Model	Difference: $\hat{\sigma}_{R_d}$ (RSD $\hat{\delta}_{R_d}$)	Method 1: Operator $\hat{\sigma}_{RO}$ (RSD $\hat{\delta}_{RO}$)	Method 2: Inspector $\hat{\sigma}_{RI}$ (RSD $\hat{\delta}_{RI}$)
Random Error (Repetition within Inspection)	7.85 (1.84%)	1.19 (0.28%)	7.76 (1.81%)
	$\hat{\sigma}_{S_d}$ (RSD $\hat{\delta}_{S_d}$)	$\hat{\sigma}_{SO}$ (RSD $\hat{\delta}_{SO}$)	$\hat{\sigma}_{SI}$ (RSD $\hat{\delta}_{SI}$)
Systematic Error (Between Inspection Variation)	2.67 (0.63%)	0.41 (0.10%)	2.64 (0.62%)

Putting the Estimates σ_{RI}^2, σ_{RO}^2, σ_{SI}^2, and σ_{SO}^2 to Use in Error Propagation

Grubb's estimation and the ANOVA on the operator-inspector difference data focused on producing four parameter estimates σ_{RI}^2, σ_{RO}^2, σ_{SI}^2 and σ_{SO}^2. The four estimates are required separately for the purpose of conducting a material balanced evaluation (MBE):

1. If an MBE on the difference were required, then $\sigma_{R_d}^2$ and $\sigma_{S_d}^2$ are the only parameters required for MBE on the D-statistic.[3]
2. Because an MBE is conducted separately for the operator, the operator variances are required; we use the entire population of data reported by the operator for a material balance period.
3. An MBE conducted separately for the inspector is based on a verified random sample and the inspector's optimal MUF-D test, and thus $\sigma_{R_d}^2$, $\sigma_{S_d}^2$ and the operator variances are required; bearing in mind that it is more complex to maintain a database for $\sigma_{R_d}^2$, $\sigma_{S_d}^2$ and the operator variances, a database, which contains σ_{RI}^2, σ_{RO}^2, σ_{SI}^2 and σ_{SO}^2 is preferred because it always allows for computing $\sigma_{R_d}^2$ $\sigma_{RI}^2 + \sigma_{RO}^2$ and $\sigma_{S_d}^2 = \sigma_{SI}^2 + \sigma_{SO}^2$. The variances may be derived using paired differences as well as distinct operator/inspector measurements.
4. Due to an assumption made by MBE regarding how the random and systematic error variances propagate in the calculations, the random and systematic error components must each be known separately for conducting MBE.[21]

The law of error propagation is discussed in the GUM, and, for example, in Reference 22, and is partially repeated here. The original law of error propagation of Gauss was designed for random errors only. Gauss realized after his publication that this was not always adequate. Therefore, it was modified to allow for measurement values to be correlated. The mode of error propagation for correlated values is a minor extension from purely independent (random) values. Specifically, formula (E.3) of JCGM 100:2008 illustrates error propagation applied to the measurand equation $Y=f(X_1, X_2, \ldots, X_N)$ using the approximate result (based on a linear Taylor series approximation)

$$\sigma_Y^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 \sigma_i^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} \frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}\sigma_i\sigma_j\rho_{i,j} \quad (10)$$

σ_i^2 is the variance of X_i, $\rho_{ij}=v(X_i,X_j)/\sigma_i\,\sigma_{ij}$ is the correlation coefficient of X_i and X_j, and $v(X_i,X_j)$ is the covariance of X_i and X_j. The first term on the right side of Equation 10 is the original law of Gauss for independent errors. The second term allows for correlated errors.

To illustrate how the MBE assumptions implement propagation of variance, we show Equation 11, which gives the variance of the total nuclear material mass Y in a 'safeguards stratum' (e.g., UO_2 drums). Total material mass, say, declared by the operator is simply $Y=X_1+X_2+\ldots+X_N$ where X_i is the mass of item i. Assuming this model, then the variance of Y denoted by σ_Y^2 is given by applying Equation 10 and accounting for the fact that the random and systematic error estimates propagate differently. Note that $\frac{\partial f}{\partial x_i}$ =1 for this simple additive model, and also note that the variance of an individual item is assumed to be the same for all items, that is $\sigma_i^2 = \sigma_X^2$ for all i, and the correlations ρ_{ij} are also assumed constant for each $_{i,j}$.

$$\sigma_Y^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 \sigma_i^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} \frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}\sigma_i\sigma_j\rho_{i,j}$$

$$= N(\sigma_S^2 + \sigma_R^2) + N(N-1)\sigma_S^2$$

$$= N^2\left(\sigma_S^2 + \frac{\sigma_R^2}{N}\right) \quad (11)$$

since in safeguards the total error variance for measurement of one item is assumed as in Equation 4 to be $\sigma^2 = \sigma_R^2 + \sigma_S^2$ from (i.e., each measured item is subject to the same uncertainty with contributions due to the item, the random error of measurement, and the random shift due to changing environmental factors between inspections) and $\sigma_S^2 = \text{cov}(X_i, X_j) = \rho\sigma^2$ is the variance of the short-term systematic measurement errors. Note that the last line in Equation 11 highlights a well-known statistical result: random error variance is reduced by making more measurements, while systematic error variances are not.

The expression in Equation 11 can also be constructed directly by appealing to the IAEA's measurement error model in Equation 4 and assuming negligible product variability (i.e., μ_i is constant). Specifically $Y = \sum_{i=1}^{N}(\mu_i + S + R_i) = \sum_{i=1}^{N}\mu_i + NS + \sum_{i=1}^{N}R_i$, which has variance given exactly by $N^2\left(\sigma_S^2 + \frac{\sigma_R^2}{N}\right)$.

Equation 11 is used to estimate, for example, the variance of the operator's estimated mass Y in a particular stratum using $\sigma_Y^2 = N^2\left(\sigma_S^2 + \frac{\sigma_R^2}{N}\right)$. The variance of the operator material balance and of the inspector's material balance based on verification measurements, and the difference statistic can all be constructed using expressions similar to Equation 11 and substituting $\hat{\sigma}_{RI}^2$, $\hat{\sigma}_{RO}^2$, $\hat{\sigma}_{SI}^2$ and $\hat{\sigma}_{SO}^2$ for their respective parameters.

Conclusions

We presented a short exposition of the information required by metrological standards for communicating the meaning of standard deviations as precision estimates; these are:

1. State the conditions of precision under which the replicate samples have been measured, and
2. State the corresponding statistical model and estimation routine.

Those two pieces of information together are sufficient to completely communicate how standard deviations may be interpreted as uncertainty estimates.

With that information and context, we explored Grubb's estimators followed by ANOVA on the operator inspector difference data, which is one method among an ensemble, employed by the IAEA for estimating the ITVs. In this context, under certain conditions on the replicate samples, it is possible to interpret the resulting random error variances as a type of repeatability error variance estimates. However, it is recognized that estimates of the random error variances will often be larger than true method repeatability precision because sampled items are not true replicates and are subject to item-specific bias. Under the Grubb's with ANOVA approach, it is not possible to interpret the estimates of the systematic error variances vs. a precision estimate as defined in JCGM 200:2012 due to an ad hoc assumption in Grubb's ANOVA required to separate the systematic error variance of the O-I difference.[2] These estimates, however, are used in material balance evaluation due to assumptions on how the two components propagate in MBE, so alternative methods of estimating the systematic error variances of the operator and inspector can be employed. Some of these are discussed briefly in Reference 2.

The SG evaluator and analytical communities continue to engage each other at international technical meetings (e.g., at IAEA and ESARDA) to discuss approaches to UQ. Each side is earning a mutual understanding of the purpose of UQ in the other's field, specifically how each's UQ approach is fit for its intended purpose. These communities are close to finalizing a paper discussing this multi-year effort in communication, identification of differences, and discussion of the complementarity of approaches and intend to submit it for peer review publication in 2016-2017.

Keywords: uncertainty quantification, variance components, ANOVA, Grubb's estimation, repeatability precision, intermediate precision, material balance evaluation, reproducibility precision, error analysis, GUM

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Nuclear Security Systems at Points of Entry in Greece

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Abstract

A nuclear security framework has been established in the country to deter, detect, and respond to criminal and other intentional unauthorized acts involving nuclear and other radioactive materials. Nuclear security is an integral part of the national general security plan. The various elements of the nuclear security architecture were developed based on the national threat assessment, taking into account increasing security concerns internationally and significant changes in the global threat environment. Cooperation between the International Atomic Energy Agency, the U.S. Department of Energy, and Greek authorities has been initiated for the development and implementation of a comprehensive program adopting a multi-area coverage approach to nuclear security. As part of this program, a comprehensive nuclear security architecture was put in place, including installation and operation of state-of-the-art systems at the points of entry and exit to detect criminal and other intentional unauthorized acts involving nuclear and other radioactive materials.[1-10]

Introduction

An integrated approach to nuclear terrorism has been adopted by the international community after the resolution of IAEA General Conference in September 2002. Accordingly, illicit trafficking of nuclear and other radioactive material was identified as a global concern. The availability of significant quantities of various nuclear and other radioactive materials, used in health, agriculture, research, industry, etc., increases the potential that such material could be diverted for criminal or intentional unauthorized acts. Therefore, strengthening the nuclear security regime, including the development of capabilities for the detection of and response to such acts involving nuclear and other radioactive material out of regulatory control, is of paramount importance.[1-10]

Global nuclear security is a state, but also a shared, responsibility. Terrorist events internationally showed that there is no limit on the actions that terrorists and other criminals may pursue to achieve their goals. As the Athens 2004 Olympic Games was the first major athletic event after September 11, 2001, the International Atomic Energy Agency (IAEA), the Greek Atomic Energy Commission (EEAE), and the U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) launched an unprecedented joint project to enhance the security of the Olympic Games.[11]

In this context, a program of the DOE Second Line of Defence (SLD), using state-of-the-art technology was implemented at Greek borders to detect illicit trafficking of nuclear and other radioactive materials. In addition to detection equipment, procedures were developed, training was provided to cover the nuclear security of the Olympic venues, and the EEAE internal emergency plan and nuclear security response to radiation incidents were upgraded. IAEA had a very important role in the development and in facilitating the implementation of the nuclear security project through the evaluation of national nuclear security framework, assessment of needs, advice on how to improve capabilities, testing and validation of the detection equipment, and in-situ technical support. Greek customs, police officers, and first responders were provided with training materials and hands-on practical training on the use of detection instruments and detection methodologies and techniques. Before and during the Games, the Agency's Illicit Trafficking Database (ITDB) supplied Greece with information and assessments of incidents, patterns, trends and threats of illicit trafficking in nuclear and other radioactive materials, which were of relevance to the assessment of the overall terrorist threat to the Games.

Since that time, Greece is assuring the sustainability of the detection systems operation. An extensive program of maintenance and repair has been established and implemented by EEAE and customs, for the most effective performance of the installed radiation portal monitors (RPM) and the distributed handheld equipment. After a certain time of operation, conditions changed, and specific upgrades of relevant systems were implemented. Some RPMs ceased their operation, some

others were removed and placed to new location and additional ones must be installed. Additionally, major upgrades were performed for the more efficient operation of security issues, and precise implementation of the customs procedures related with those.

In the following sections, description of the system, the procedures used, the performance, and lessons learned are presented, regarding the security area of illicit trafficking detection of radioactive materials at borders.

The Role of the Greek Atomic Energy Commission (EEAE)

The Greek Atomic Energy Commission (EEAE) is the national competent authority for the control, regulation, and supervision in the fields of nuclear energy, nuclear technology, radiological, nuclear safety, and radiation protection. It is operating as a legal person of public law enjoying full administrative and financial independence in relation to its duties. Its mission is the protection of the public, workers, and the environment from ionizing radiation and artificially produced non-ionizing radiation.

Its main responsibilities are the legislative and regulatory work, inspections, and licensing of facilities, individual monitoring of occupationally exposed workers, calibration of ionizing radiation instruments, environmental radioactivity monitoring, emergency preparedness and response, combating illicit trafficking of nuclear and other radioactive materials, education and training, research and development, international relations, and public information. EEAE has extensive collaboration with other competent authorities in Greece and in particular with those involved in nuclear security, such as customs, national police, intelligence agency, the General Secretariat for Civil Protection, etc.

Detection Systems at Borders

Fixed RPMs for the detection of illicit trafficking of nuclear and other radioactive materials were initially installed at three main land borders with Albania (Kakavia), the Former Yugoslav Republic of Macedonia — FYROM (Evzoni), and Bulgaria (Promachon), at the Athens International Airport (AIA), and the Piraeus seaport. In 2007, when Bulgaria joined the European Union, the RPMs installed in Promachon were removed. Portable radiation detection equipment were provided to Customs for the purpose of secondary inspection, and to twenty-seven additional entry/exit points in Greece, for performing primary inspections. Details are given in the Table 1.

Table 1. Total number of RPMs installed in Greece in 2015

Site	Vehicles	Pedestrians
AIA	4	7
Seaport of Piraeus: Cargo	9	0
Evzoni	12	0
Kakavia	7	2
Seaport of Piraeus: Passenger terminal	2	4
Total	34	13

Border monitoring is a three-step process:

- **Detect —** the radiation portal monitor detects the presence of radiation
- **Locate —** the handheld search instrument locates the source of the radiation
- **Identify —** the Radioactive Isotope Identifier Device ("RIID") identifies the source of the radiation.

Figure 1. Radiation detection equipment at Piraeus Seaport (top) and at the extra-Schengen Passengers Terminal of the International Airport of Athens (bottom)

Major upgrades that were performed to accommodate current needs and ensure more efficient operation of nuclear security measures by customs can be summarized as following:

- Upgrade in the cargo area of the Athens International Airport. Two portal systems, inbound and outbound, were moved further down, about 300 meters inside secured area, according to security improvements, relevant to international security regulations in the airport.
- Upgrade in the entrance of the cargo area of the seaport of Piraeus. After the activation of second operator (Piraeus Container Terminal-PCT), the official entrance to cargo area that was operated previously by the Piraeus Port Authority (PPA), was split to two entrances, one for PPA and another for PCT. For that, out of the five portal systems that were functioning in the initial phase, nine portals were installed, five for PPA entrance and four for PCT entrance.

In both cases, private companies were involved in designing, constructing and reinstalling the portals. In both cases projects were finished successfully in time.

Radiation Portal Monitor Characteristics

RPMs are designed to detect the presence of radioactive or other nuclear materials carried by pedestrians or transported in vehicles. Differentiation has been made between pedestrian and vehicle monitors. The advantage of an RPM system is that it can passively scan a large number of vehicles or passengers per hour with minimal impact on traffic. Under normal conditions, if no radioactive material is passing through the RPM, no actions are required. Only when an alarm occurs, secondary inspection measures are required to investigate. If the alarm is confirmed as real, the occurrence of a nuclear security event is declared, and appropriate nuclear security response actions are triggered. In some cases, the situation will necessitate parallel commissioning of emergency response activities.

The RPMs are continuously measuring the gamma and neutron background. Based on the average background, the gamma and neutron alarm levels are calculated and set according to specific algorithms. Their operation is based on the following principle: a pedestrian or a vehicle passing through the portals triggers the occupancy sensor, while the radiation alarm threshold is fixed at the value just prior to that occupancy. While the RPM is occupied by the pedestrian or the vehicle, radiation measurements continue. The RPM detects nuclear or other radioactive material by comparing the occupied gamma-ray and neutron count rates to the background radiation level that was registered when the RPM was unoccupied.

An alarm occurs if the detector is occupied and the actual radiation level exceeds the alarm threshold which is higher than the background. This is described by the following condition: radiation level > alarm level > background.

A typical RPM system has two pillars, each one having the following components and characteristics:

1. Two gamma detectors (plastic scintillators);
2. Two twin-neutron detectors located behind a white polyethylene panel;
3. An occupancy sensor, informing the detector system that the portal is occupied;
4. Power supplies, signal amplifiers, and communication equipment;
5. Various electronic equipment that evaluate input from the detectors and other sensors that activate an alarm: neutron, gamma, tamper, high/low background, or internal fault. The alarm can be local at the portal, or at a remote location;
6. A backup battery allowing the system to continue functioning during brief electrical power outages. Depending on battery capacity, this could be from a few hours to as much as a day.

The gamma detectors consist of blocks constructed by scintillation plastic material, which are attached to photomultiplier tubes (PMT). When gamma radiation hits such a block, it emits light. The light within the ultraviolet spectrum is converted to visible light, then it is reflected down the foil-covered block until it enters a PMT placed at the end of the block. The PMT converts the light into electrons, which are then amplified. This amplified pulse produces a count in the system.

To reduce background radiation as much as possible, lead shielding is used behind the detector block.

The scintillation plastic material is covered with black foil to prevent the external daylight to be accounted as radiation.

Neutron detectors are metal tubes filled with He-3 gas under pressure. When He-3 nuclei absorb a neutron, a charged particle (proton) and a tritium nucleus are produced. The charged particle ionizes the gas and an electrical signal is produced, which is subsequently recorded by the circuitry as "a count." The tubes are surrounded by polyethylene. The hydrogen atoms in the polyethylene slow down the neutrons and increase the probability that an interaction occurs.

The dimensions of an RPM are:

- For pedestrians' checks, vertical dimension: up to 2m in height, horizontal dimension: 1–1.5 m wide for a single pillar and max 3m wide for a double pillar system.
- For vehicle checks, vertical dimension: up to 4m in height, horizontal dimension: 3m wide for a single pillar and max 6m wide for a double pillar system.

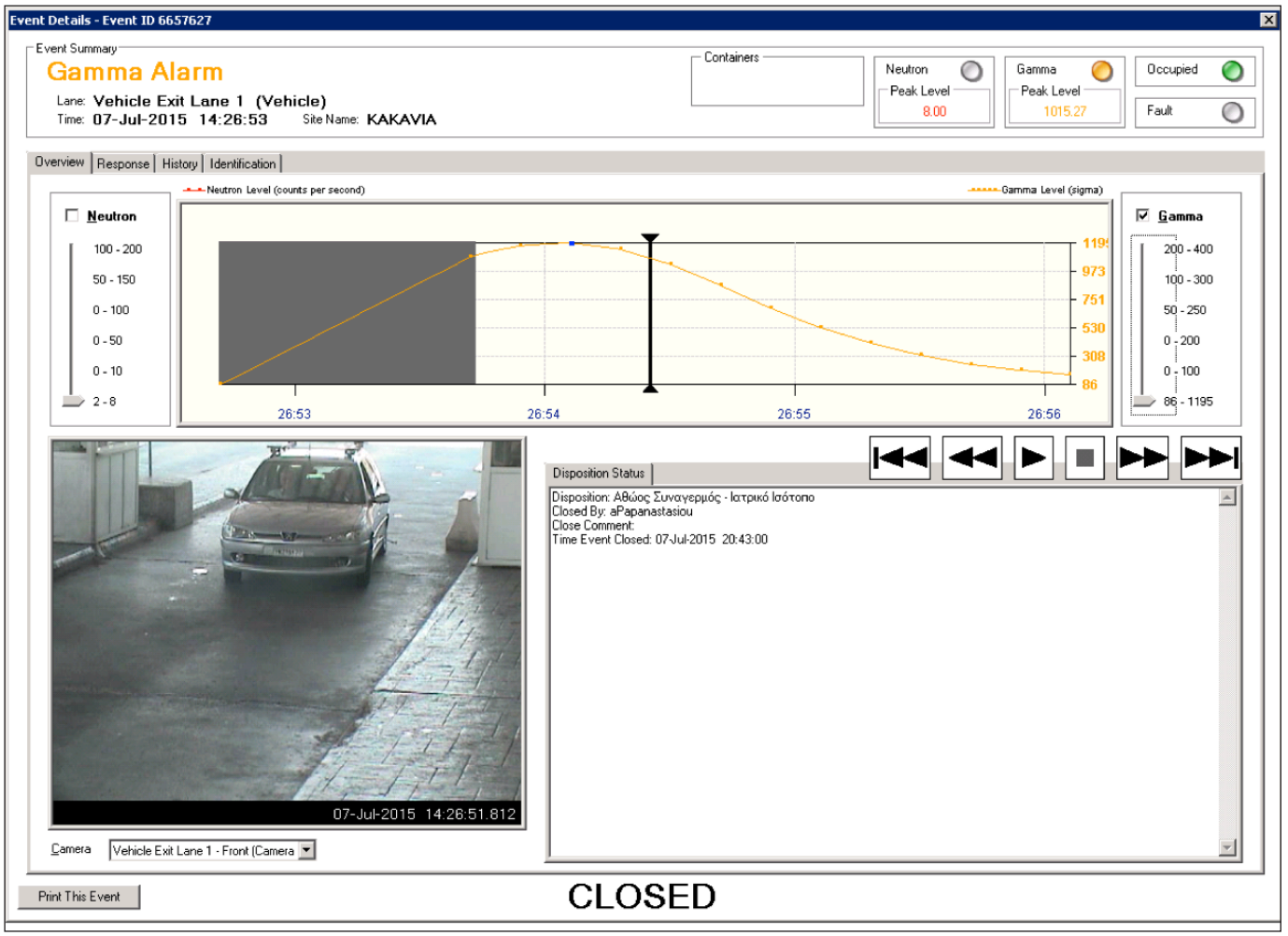
RPMs are usually equipped with several cameras arranged at different viewing angles to enable identification of the vehicle or person generating the radiation alarm. The camera images are associated with an alarm and can be stored in the RPM system computer server. Many cameras have associated lighting or infrared illuminators to help with visibility at night.

A computer, usually located in the vicinity of each site central office serves as alarm notification mechanism and also enables gate area personnel to send and receive messages to the CAS (Central Alarm System) regarding detaining, releasing or dispatching alarming vehicles or pedestrians/passengers. The server also serves as a communication tool. For all sites, the CAS handles alarms from more than one RPM. This is also the physical unit where the alarm closeout process is completed. The CAS can access information from previous alarms, and view other information that can help resolve them. The drawing in Figure 2 depicts a CAS, the alarm notification and an alarm closeout screen.

A server acts as the central communication hub and the computer processor for the entire radiation detection system. It also serves as the data storage device, where the alarm data, images, disposition of alarms, etc., are stored, serving to record the alarms in order to be available in a database with past alarm information, which can be used in closing the new ones.

Radiation detection systems indicate three types of alarms: neutron alarms, gamma alarms, and false alarms. These alarms

Figure 2. Closed Gamma Alarm at the (Greek-Albanian) Kakavia border checkpoint



may be indicated by lights located on or near the RPM accompanied by an audio signal.

Natural neutron background radiation will only generate 0 to 2 neutron counts per second, per tube. If a significantly higher number of neutrons are counted, a neutron alarm will occur. Neutron alarms are important and require special attention because there are very few innocent neutron sources. While it might be possible to have a neutron alarm due to a higher background or cosmic event, there is high likelihood that the alarm is real. The case of a neutron alarm could mean passage of special nuclear material, such as plutonium, or the legal or inadvertent transit of a neutron source. Finally, the threshold is set to 6.3 sigma, according to manufacturer recommendation.

Normally, an RPM has to be placed in areas where "person flux" is very high, e.g., in airports or borders, or in places where people enter or leave a controlled zone. Each RPM includes a gamma detector (plastic scintillators), lead shielding covering the back of detection system in order to reduce background, a neutron detector (He-3 tubes inside Polyethylene) – a set of a couple, occupancy sensor, control and communication unit, video monitoring, alarm (sound and light) classified as neutron, gamma, tamper, high/low background, internal fault, and an uninterruptible power supply (UPS) battery backup.

Secondary Inspection with Portable Radiation Detectors

The following portable detectors are used by customs, (a) for secondary inspections where RPMs are installed, or (b) for primary detection in all other cases where no RPMs have been installed:

- Pagers (indicate the presence of a radiation field, their primary purpose is the protection and safety of the inspector; 300 pagers were distributed to customs throughout Greece).
- Survey meters (TSA PRM-470 survey instruments used for secondary inspection and determine radioactive source location and intensity; ninety-eight survey meters were distributed).
- RIID – Identifiers (to locate and identify specific radioactive isotopes; fifty-eight identifiers were distributed).

Operating Procedures

A minimum number of customs officers are necessary to work closely to portal detectors, while additional customs officers are needed in the Central Alarm Station.

According to the procedures and manufacturer recommendations, all vehicles have to pass through portal detectors at constant low velocity (~8 km/h). In addition, it is prohibited for anybody to stop between portal detectors. Portal monitors measure continuously the natural background, since there is no indication from occupation detectors. When a vehicle or a pedestrian stops in between portal detectors, it changes the radiation background giving consequently low-background measurements. In this case the system recalculates the alarm level accordingly to the new background. When the vehicle or the pedestrian moves again, an apparent sudden increase in radiation occurs, giving a false alarm.

In order to simplify operating procedures by minimizing secondary inspections, the following categorization has been applied:

- **False Alarm:** Alarm set-off without the presence of radiation.
- **Innocent Alarm:** Actual increase in radiation level but not due to inadvertent movement or illicit trafficking of radioactive materials. Medical isotopes or naturally occurring radioactive material (NORM) can be reasons for setting off such an alarm
- **Real Alarm (nuclear security event):** Actual increase in radiation level due to inadvertent movement or illicit trafficking of radioactive materials.

The Figure 3 flow chart is an example of operating procedures that customs officers have to follow in case of an alarm. This particular flow chart is from the cargo area of the seaport of Piraeus.

Personnel Training

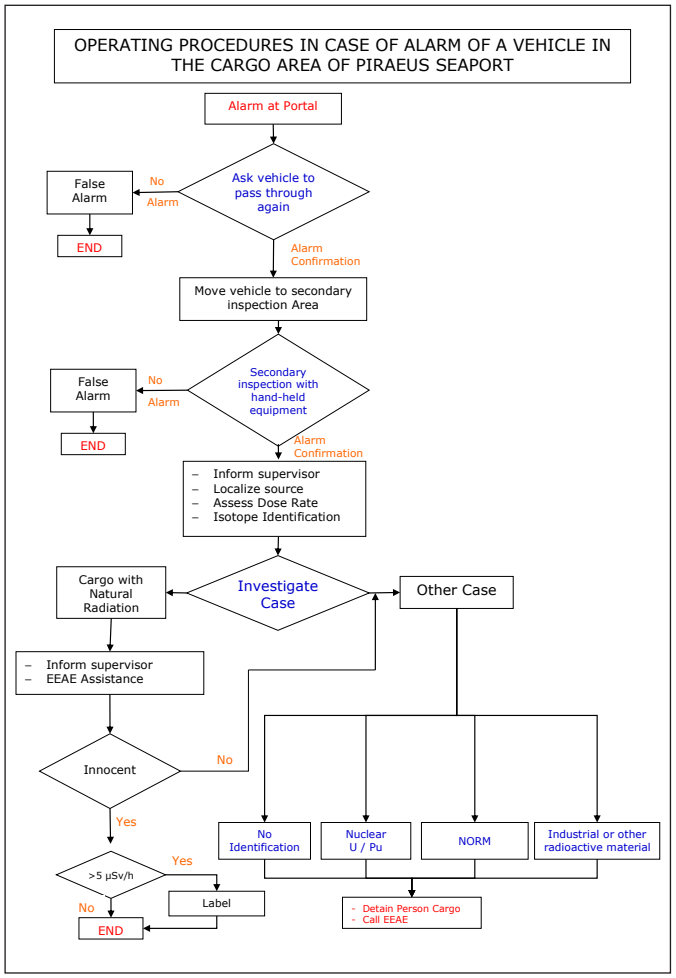
An extensive training program for the customs personnel has been put in place since the very initial phase of the project of combating illicit trafficking of nuclear and other radioactive materials.

The training program can be divided in two major periods:

- Initial phase: training performed mainly by NNSA, in collaboration with EEAE.
- Later phase: EEAE provided the whole customs training program.

The training program covers the needs of customs where the customs are equipped with both RPMs and handheld detectors for secondary inspections, as well as with handheld detectors only used for primary and secondary inspections.

Figure 3. Operating procedures flow chart



In both cases, the training program covers five major fields:

- General training — combating illicit trafficking of nuclear and other radioactive materials
- Basics about radiation and radioprotection
- Radiation portal detectors — construction and operation
- Handheld detectors used for secondary inspections
- Procedures followed by customs officers
- National response plan
- Integration with emergency response procedures

The two different audiences are handled according to this scheme. Operators of RPMs are trained individually. The training of the custom officers using handheld detectors, which in practice corresponds to the majority of employers, follows the scheme of "train the trainers." Training is planned for trainers from all sites, with the obligation of the directors in each one individual customs directorate to organize its own training course within a certain time frame. The same training cycle is repeated regularly.

Detectors Performance

The present analysis is based on the daily files stored by the system and proves the good performance of RPMs. These daily files incorporate the operational history of all RPMs since the start date of their operation when they were installed. The continuous availability of the systems can be derived from the following plot (Figure 4), which includes all occupancies for the first five months in 2015. Additionally, it may be noted that in the same plot is presented, the individual performance of four gamma and four neutron detectors installed, providing the fraction of alarms related with occupancies.

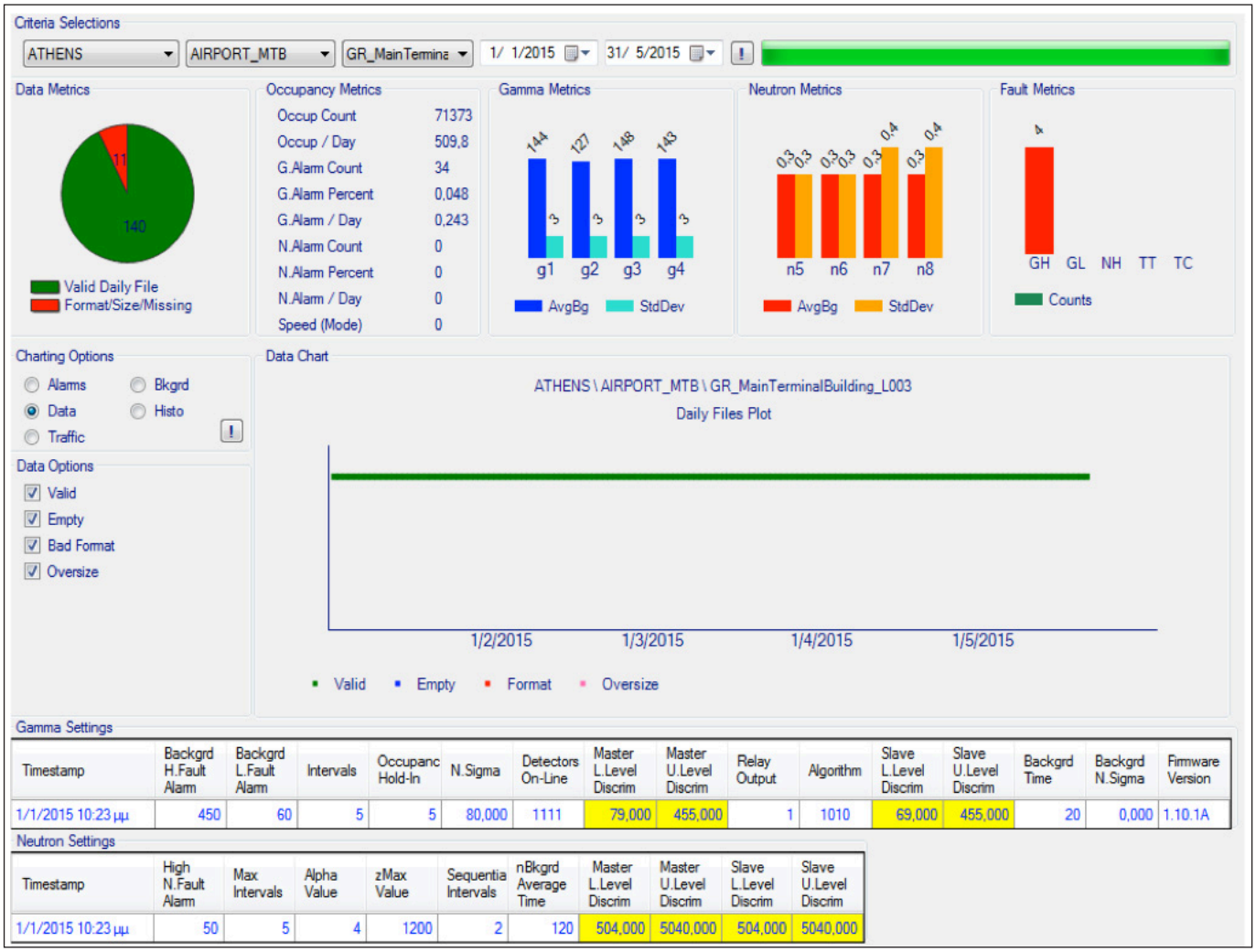
Also, daily alarms can be identified relative to occupancies as well within the day in a particular RPM, in the Main Terminal Building (MTB) at Athens International Airport, related to the time of occurrence within that day (see Figure 4). As can be observed in the graph, the alarms occur during the working hours of the airport.

Background measurements are presented in Figure 6 for a RPM in the Main Terminal Building at Athens International Airport. Usually, the background measurement on an RPM is performed while there is no occupation signal from the position detector attached to the system. According to that measurement, the alarm threshold is calculated at the time that an occupation is identified, and the system is starting, comparing the actual gamma signal with that threshold, to set-off an alarm event if the value of the above ratio is exceeded.

The ratio of all occupancies versus alarms in both flows (outbound and inbound) in the cargo area at Athens International Airport is presented. The important point is that this customs area is the only place in Greece where shipments of radioactive materials are performed routinely. According to specific procedures, customs officers are inspecting the four companies in the cargo area from where imports, exports, and transshipments are taking place.

The diagrams represent the outbound and inbound of the cargo area in Athens International Airport (AIA). The AIA, is the official entrance of almost every radioactive material transported to Greece. The diagrams indicate the radioactive materials imported to the country within the specific time period.

Figure 4. Daily file plot for the first five months of 2015



Typical Events Encountered

Event	Custom	Date		Material	Isotope
1	Evzoni	31-Oct-04	Vehicle	Coal dust	NORM
2	[illegible]	26-Jun-05	Pedestrian	Compass	Ra-226
3	Kakavia	2005	Pedestrian	Radiopharmaceutical	-
4	Piraeus Pedestrian	2005	Garbage truck	Lost Radioactive Source	Ra-226
5	Evzoni	8-Nov-07	Vehicle	Utilities	NORM
6	Evzoni	22-May-08	Vehicle	Scrap	Eu-152
7	Evzoni	6-Jul-10	Vehicle	Rolled iron bars	Co-60
8	Evzoni	July 2012	Vehicle	Coal	NORM
9	Evzoni	7-Sep-12	Vehicle	Coal	NORM
10	Kakavia	7-Nov-12	Vehicle	Industrial Radioactive Source	Am/Be & Cs
11	Piraeus Cargo	3-Jun-13	Vehicle	Rust	Ra-226
12	Kakavia	11-Jun-15	3 Vehicles	Wastes	NORM
13	Evzoni	6-Sep-15	Vehicle	Paper (Raw Material)	I-131
14	[illegible]	2-Oct-15	Pedestrian	Compass	Ra-226
15	AIA	17-Dec-15	Mail	Compass	Ra-226

Table 2. Selected examples of events from detection systems installed in customs locations in Greece

In Table 2, events from detection systems installed in customs in Greece are presented. This is not the complete list but rather an indicative sample of some important events.

Figure 5. Daily alarms

Timestamp	Backgrd H.Fault Alarm	Backgrd L.Fault Alarm	Intervals	Occupanc Hold-In	N.Sigma	Detectors On-Line	Master L.Level Discrim	Master U.Level Discrim	Relay Output	Algorithm	Slave L.Level Discrim	Slave U.Level Discrim	Backgrd Time	Backgrd N.Sigma	Firmware Version
1/1/2015 10:23 μμ	450	60	5	5	80,000	1111	79,000	455,000	1	1010	69,000	455,000	20	0,000	1.10.1A

Timestamp	High N.Fault Alarm	Max Intervals	Alpha Value	zMax Value	Sequentia Intervals	nBkgrd Average Time	Master L.Level Discrim	Master U.Level Discrim	Slave L.Level Discrim	Slave U.Level Discrim
1/1/2015 10:23 μμ	50	5	4	1200	2	120	504,000	5040,000	504,000	5040,000

Lessons Learned

The lessons learned from the development and operation of this comprehensive nuclear security program, include:[11]

- Strong leadership from a lead agency in the country is necessary to move the project forward. Good interagency cooperation is of utmost importance.
- Well-defined continuous program with determined roles for the organization involved in maintenance and repair of all installed RPMs, and all handheld equipment distributed to detect nuclear and radioactive materials.
- A calibration program is necessary for the best performance of all RPMs and handheld equipment.
- Networking of the detection systems is of great importance for supporting customs officers on their duties detecting and for maintenance and repair purposes.
- Training is crucial. Equipment means nothing unless it is used in an efficient and effective manner. Initial training and also on-going refresher training is necessary to ensure sustainability of the system.
- Effective training of customs personnel must ensure that all personnel understand what the equipment does and resolve any safety concerns; train small groups of people to use the equipment and to carry out the secondary inspections; identify a core leadership group that will interact with the competent authority in the country designated to provide expert support on radiation issues.
- Rearrangements or new installations are always necessary since the needs of the inspecting land borders, airports, or seaports are often changing. Knowhow is of great importance for private companies that are involved in this process.
- A disadvantage is the custom staff mobility within its organization.

Figure 6. Background measurements for the first five months of 2015

- Problems with the aging of the detection systems after some years of operation. A suitable program has to be established early enough to prevent any effect on inspection procedures due to the non-operating parts of the detection network.
- Best practice is a three-month reporting system. The report includes the operating status of the infrastructure, malfunctions, procedure weak points, and findings.

Conclusions

The lessons learned from the successful implementation of a comprehensive nuclear security framework in Greece are becoming available to assist other countries in their efforts to develop and implement a nuclear security infrastructure. Sustainability measures were shown to be effective in enabling the nuclear security systems and measures in place to ensure long-term protection of the country against potential criminal or intentional unauthorized acts involving nuclear and other radioactive materials out of regulatory control. The cooperation among competent authorities in the area of nuclear security can provide a model for future similar arrangements aimed at strengthening nuclear security at major public events. In this regard, Greece will continue to work with the IAEA and other international organizations sharing the technical expertise gained through this experience, leveraging the EEAE's expertise, as well as its state-of-the-art laboratory and training facilities.

Acknowledgments

The authors wish to thank the following organizations for their support and cooperation: International Atomic Energy Agency, U.S. Department of Energy, Ministry of Economy and Finances, and in particular the Office of Customs and Excise, Athens International Airport, Piraeus Port Authority.

Figure 7. Alarms versus occupancies in the outbound of AIA cargo area

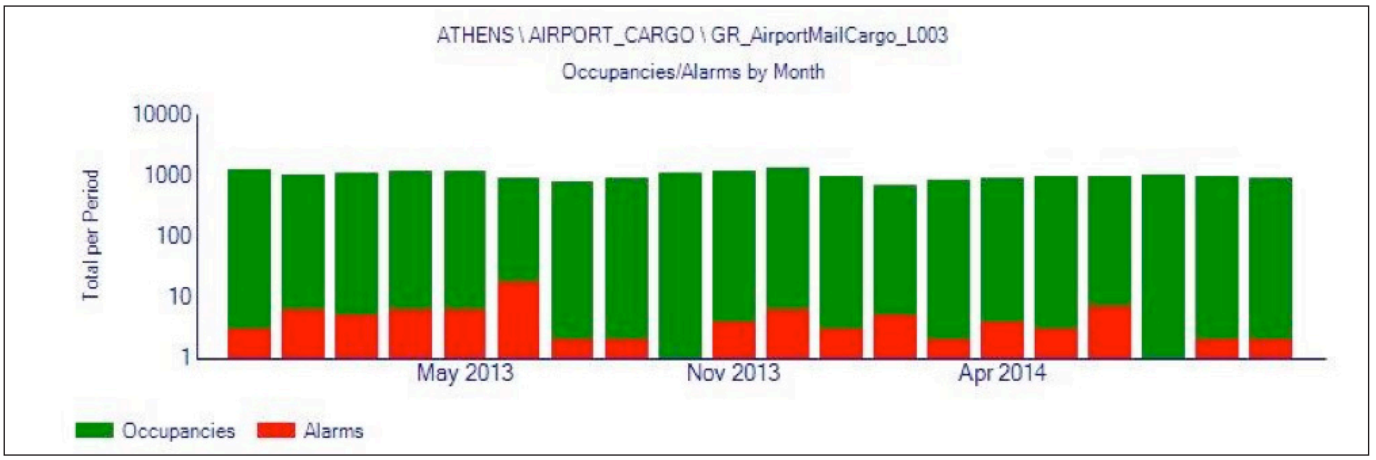
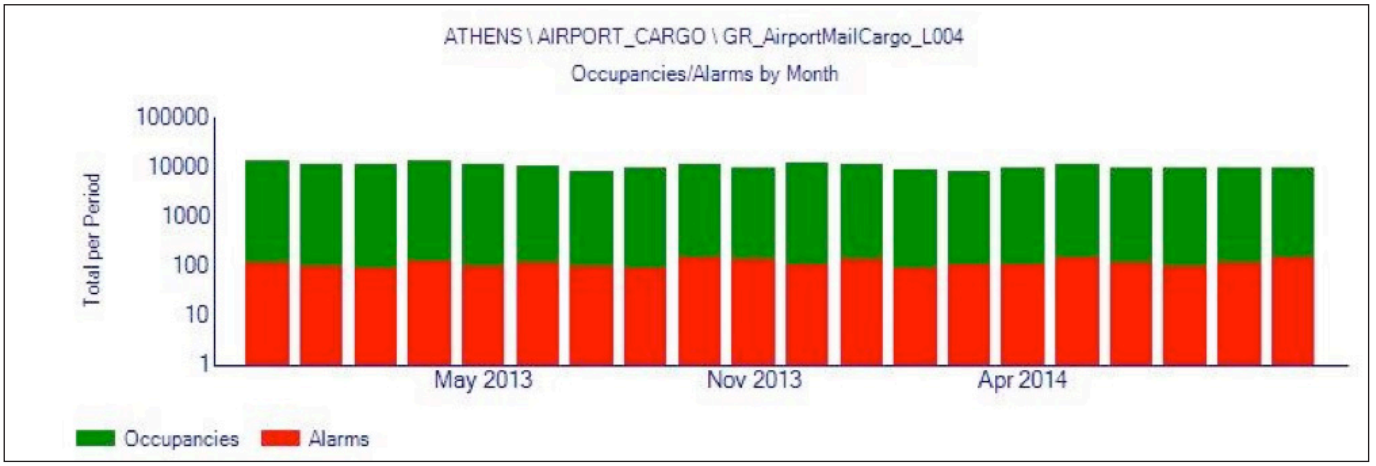


Figure 8. Alarms versus occupancies in the inbound of AIA cargo area



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Steady-State Thermal Analysis of the Pipe Overpack Container for Transuranic Waste at Los Alamos National Laboratory

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Abstract

Los Alamos National Laboratory (LANL) Technical Area 55 (TA 55) utilizes several different container types to store and transfer special nuclear material and waste for numerous programs. The Nuclear Process Infrastructure — Infrastructure Operations Group (NPI-2) analyzes and certifies containers to meet the specifications for distinct processes and storage. Engineering analyses performed on these containers include but are not limited to: leak testing, filter efficiency testing, pressure drop test, drop testing, water penetration testing, polymer (O-ring) hardness testing, and thermal steady-state testing. Of all of these tests, thermal steady-state testing is most crucial to ensure critical components for specific containers do not fail under an internal heat payload. This testing provides data for setting heat payload limits for different containers. TA 55 has been tasked to manage and store all of its Transuranic (TRU) waste for the foreseeable future. Being able to place more material into a single container conserves the physical storage space available at TA 55. The Pipe Overpack Container (POC) is a vented carbon steel container with a removable lid designed for storing or transferring nuclear waste. The POC Handling and Operations Manual requires each user to ensure that the maximum temperature of each component is not exceeded. Conducting a thermal steady-state test on the POC can benefit stakeholders in increasing the material limits of the container. The POC was loaded with sealed Plutonium (Pu-238) heat sources in a controlled laboratory environment. Thermistors attached were used to measure temperature behavior. The results of these measurements will establish new wattage limits to meet LANL's transportation requirements. The current LANL Transportation Safety Document (TSD) limits the amount of heat source plutonium to 10 grams per POC, corresponding to approximately 5 watts of heat. The result of this test was provided to the Packaging and Transportation (OS-PT) group to evaluate new wattage limits that can satisfy the needs of TA 55, while maintaining a safe packaging configuration.

Table 1. POC Component thermal limitations

PO Component	Material	Temperature Range (ºC)
55-gallon Drum	Carbon steel	-40 to 1,510
Rigid drum liner	High-density polyethylene	-40 to 121.1
Fiberboard dunnage	Celotex® fiberboard	-40 to 121.1
Plywood dunnage	Plywood	-40 to 100
Pipe container	Stainless steel	-40 to 1,426.67
Neutron shielding	High-density polyethylene	-40 to 121.1
Gamma shielding	Lead	-40 to 326.67
Cap screws	Stainless steel	-40 to 1,426.67
Filter vent	Stainless steel	-40 to 70
O-ring Seal	Elastomeric rubber	-40 to 121.1

Introduction

The Pipe Overpack Container (POC) is designed as a payload container within TRUPACT-II and HalfPACT packages. The pipe component is surrounded by softwood-based fiberboard dunnage and plywood dunnage within a vented fifty-five gallon drum with a rigid high density polyethylene (HDPE) liner.[1] Inner packaging within the pipe component consists of either a Hagan container, SAVY 4000 container or a bag out bag. The POCs are designed to be a Type-A package for non-fissile or fissile exempt radioactive materials of normal form.[1] Material thermal limitations are defined by Table 1. Table 1 can be found in the POC handling and operations manual.[1] As mentioned in the handling and operations manual, it is the responsibility of the shipper to identify the thermal load resulting from decay heat and to ensure that the decay heat does not exceed the maximum operating temperature limits of the packaging materials.[1] Currently there is a need for an in-depth thermal steady-state study to investigate POC component behavior under extreme thermal loading.

Background

The need for this testing derives from two primary sources: the Pipe Overpack Handling and Operations Manual (POC-MAN-0001) [1] and the LANL Transportation Safety Document (TSD, P&T-SA-002).[2] LANL desires to pack more heat source plutonium into POCs than it has historically.[6] Testing would aid waste generators by limiting the number of times a waste item would need to be split and by limiting the number of operations required to manage waste.[6] This would reduce costs and reduce worker exposure to radiation. Currently TA 55 has been managing and storing all of its TRU waste on site and inside its facilities.[6] More material needs to be stored in a single container to conserve on physical space. To pack more material into POCs the wattage limit in the TSD has to be raised. To assist in raising the TSD limits tests are required to study the thermal effects at different content wattages. The objective of the testing is to determine the maximum component temperatures after the system has reached steady-state. Results have assisted in presenting a new wattage limit to the Packaging and Transportation (OS-PT) group and the LANL Nuclear Materials Storage and Disposition Board (NMSB).

Testing Setup

The POC was subject to testing using Thermistors and sealed heat sources. The testing was set up in a temperature controlled laboratory to mimic the POC's current storage environment. Therefore, transient heat from insolation effects or other environmental effects were not considered in the testing. Baseline testing was also conducted without sealed sources to verify equipment performance and perform tolerance checks. Thermistors locations include, but are not limited to: pipe component steel sintered filter, pipe component O-ring, various location on pipe component body, fifty-five gallon drum liner, various locations on fiberboard and plywood dunnage, external wall of the fifty-five gallon drum and within the POC for ambient air recordings. The heat sources inside the POC were observed at various temperatures throughout a test cycle and the Thermistors recorded the temperature variations throughout each test. The recorded data is plotted in the form of graphs and listed in tables depicting maximum temperatures at steady-state for each test. Therefore, for each applied heat load, the duration of the test will be such that the package reached steady-state and remained there for a specified period of time. Three tests were observed at powers of 2.2 watts, 6.3 watts and 9.3 watts.

Figure 1. Certified Pu-238 sealed sources

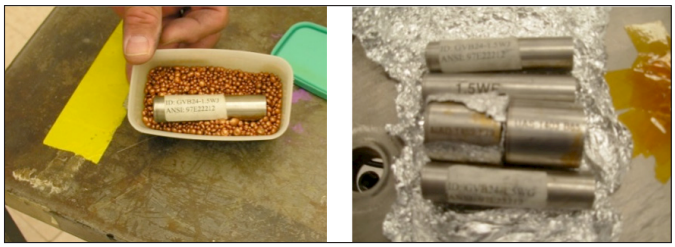
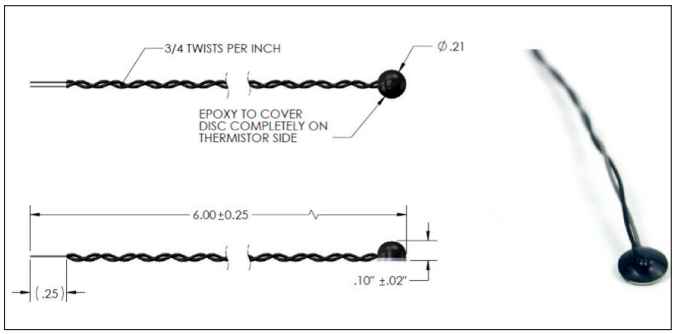


Figure 2. QT06022 Thermistors



The heat payloads in the testing consisted of sealed Pu-238 heat sources as seen in Figure 1. The sources are American National Standard Institute (ANSI) certified and are traceable to National Institute of Standards and Technology (NIST).[7] According to the certification of each source, they hold powers of 1.1 watts, 1.0 watts, 3.0 watts, and 3.1 watts. Various combinations of the sealed sources provided the three test powers.

The testing used QT06022 Thermistors from Qti Solutions. A Thermistor is a solid state, electronic device which detect thermal environmental changes for use in temperature measurement, control and compensation circuitry. The QT06022 series have a resistance of 10K ohm @ 25°C, wire size #24 and a tolerance of ±5 percent with respect to resistance measurements.[3] Figure 2 shows the Thermistors used in the testing. The Steinhart-Hart equation, Equation 1, is used for interpolating the negative temperature coefficient (NTC) Thermistor resistance/temperature curve characteristic.[4] The Steinhart-Hart equation is a third order polynomial that provides excellent curve fitting for specific temperature spans within the temperature range of -80°C to 260°C.[4]

The Steinhart-Hart equation is expressed as:

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3 \qquad (1)$$

Where:

T= temperature (Kelvin)

R=resistance (ohms)

Table 2. Manufacture recommended Steinhart-Hart coefficients

Coefficients
A=0.001026033423396
B=0.000239630543563
C=0.000000154875335

Table 3. Baseline results

Thermistors Baseline (°C) for 72 hours							
T1	T2	T3	T4	T5	T6	T7	T8
23.74	23.81	23.50	23.43	23.23	23.16	23.55	23.58

A= resistance/temperature coefficient

B= resistance/temperature coefficient

C= resistance/temperature coefficient

Table 2 shows the coefficients received from the manufacture to implement into the program used to calculate a temperature at a given resistance.[4] In addition, baseline testing was conducted to ensure the Thermistors were operating with respect to their specifications. A total of twenty Thermistors were purchased from Qti and samples of eight Thermistors were baseline tested. A piece of aluminum plate was set in the laboratory for twenty-four hours to reach room temperature. After twenty-four hours, the eight Thermistors were connected to the surface of the block as seen in Figure 3.

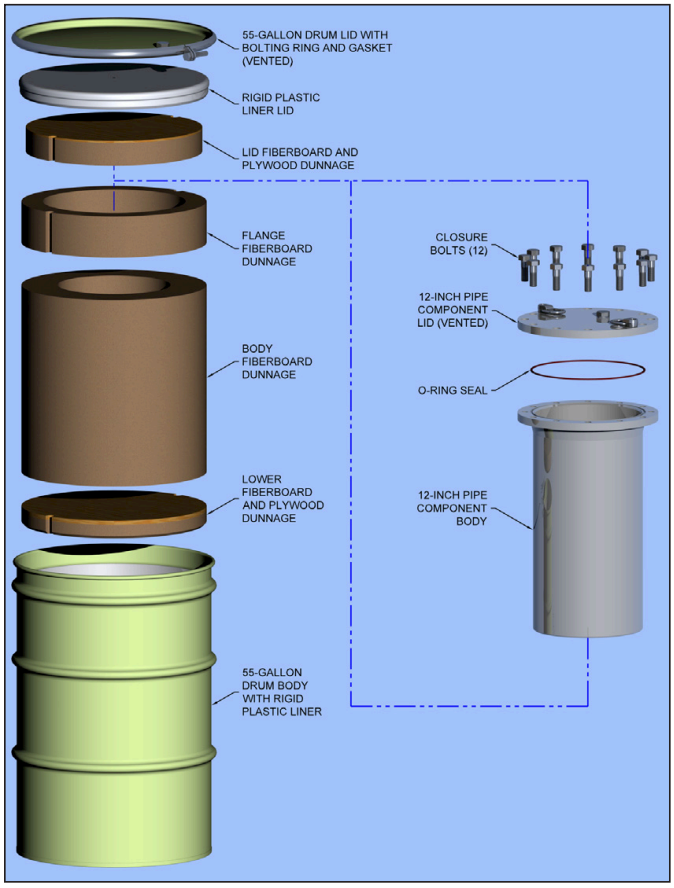
The Thermistors recorded the aluminum block temperature for a total of seventy-two hours; the average recorded temperature for each Thermistor is reported in Table 3. The objective of the baseline testing was to observe the behavior of the Thermistors with respect to each other. If any Thermistors were reporting a deviant temperature the coefficients to the Stienhart-Hart equation could be adjusted to compensate for the error. As seen in the Table 3 the difference between the highest and the lowest recorded temperatures is 0.65°C. With the small difference in measurement after seventy-two hours of baseline testing the Thermistors are determined to be operating within the manufacture's recommended coefficients.

Figure 4 shows the POC assembly depicting all the components that make up the container.[1]

For a complete thermal analysis of the POC, ten locations were chosen for temperature recording. The locations encompass critical parts that include the O-ring component, stainless steel sintered filter, body of the fifty-five gallon drum, various areas on the POC, fifty-five gallon drum rigid liner, surrounding plywood dunnage, and within the POC for ambient air recordings. Figure 5 shows the various Thermistor locations on the

Figure 3. Baseline testing of Thermistors

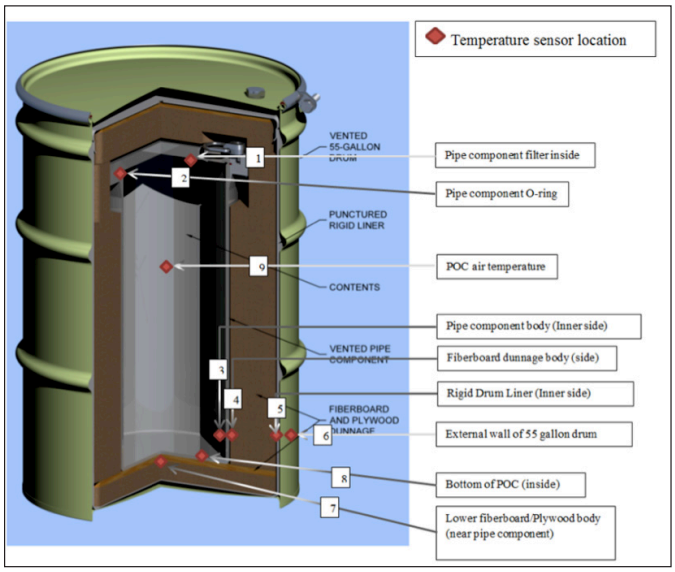
Figure 4. POC assembly diagram



POC. Temperature sensor 10 corresponds to the sensor outside the fifty-five gallon drum recording the temperature of the laboratory.

Volt meters were wired to each Thermistor for interpreting each resistance value and to the laptop computer for computation as seen in Figure 6. The output from each volt meter was interpolated using the program MulitCal 4.0. The MultiCal software package provides a robust multi-tasking operating sys-

Figure 5. Thermistor locations for testing



tem capable of operating multiple calorimeters from a single computer system.[5] Although MultiCal has been primarily used for calorimetry measurements, the inputs can also be used for NTC Thermistors and probes as well.[5] MultiCal allows the user to make simultaneous measurements with multiple power/temperature devices. Associated with each device on the system is a special window, and its popup menu provides access to information about that device. The Thermistor curves given by the manufacture along with the coefficients as mentioned above were applied to the MultiCal program for temperature profiling. The data collected during a run can be displayed as

Figure 6. Testing setup, POC wired up (left) and volt meters along with MultiCal program (right)

either a graph or a status display. The time period displayed by the graph can be adjusted from one minute to one week. Data was exported into Microsoft Excel 2010 for analysis.

Results and Analysis

The first test evaluated a payload of two sealed sources with a combined power of 2.2 watts. The POC temperatures were observed for approximately twenty-three hours. Figure 7 shows the temperature profiles.

The second test evaluated a payload of four sealed sources with a combined power of 6.3 watts. The POC temperatures were observed for approximately 72 hours. Figure 8 shows the temperature profiles.

The third test evaluated a payload of five sealed sources with a combined power of 9.3 watts. The POC temperatures were observed for approximately 85 hours. Figure 9 shows the temperature profiles.

Figure 7. Temperature profiles for the 2.2 watt test

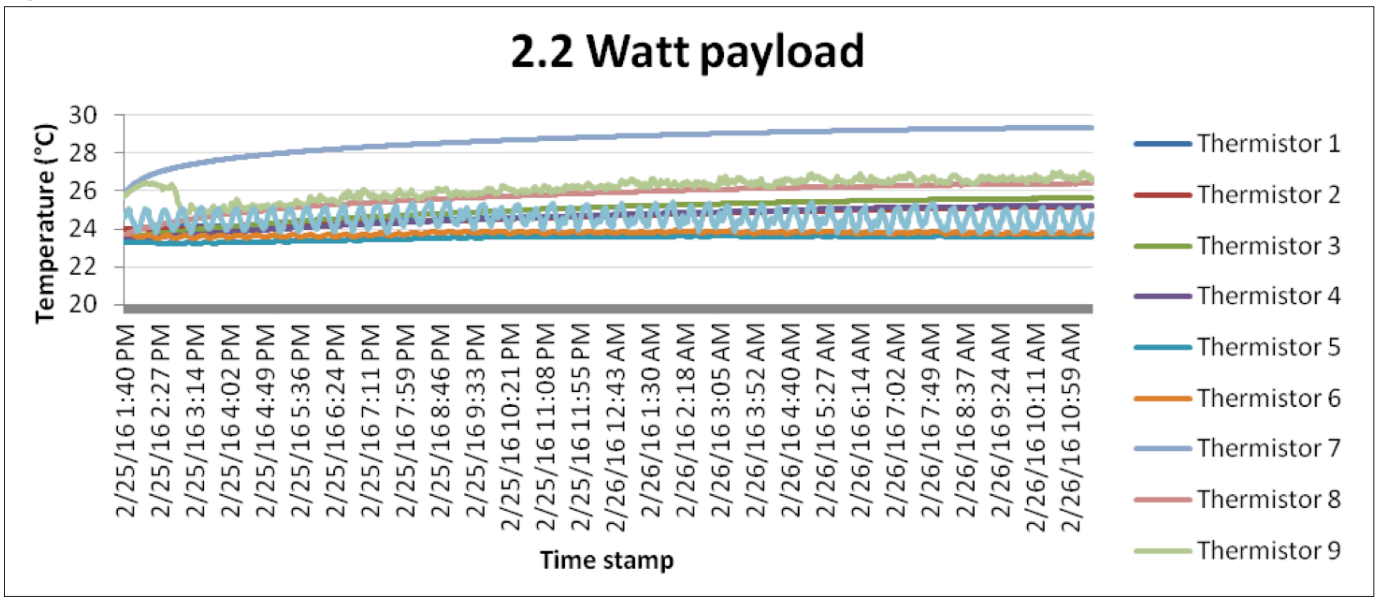


Figure 8. Temperature profiles for the 6.3 watt test

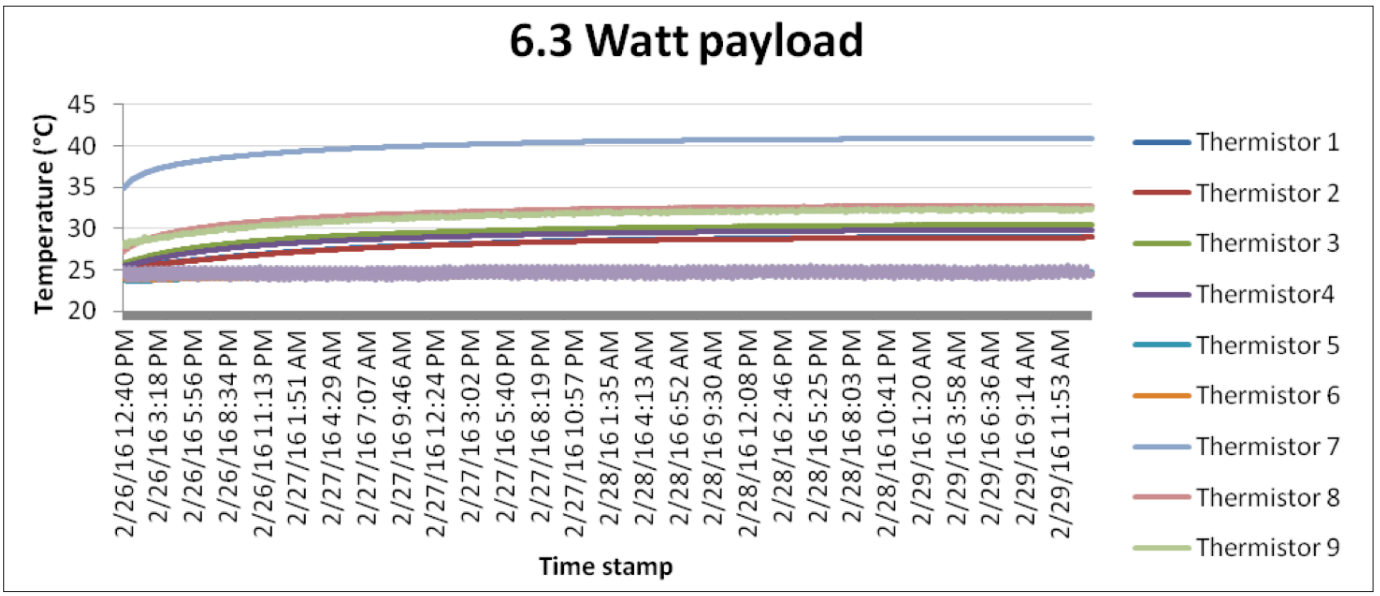
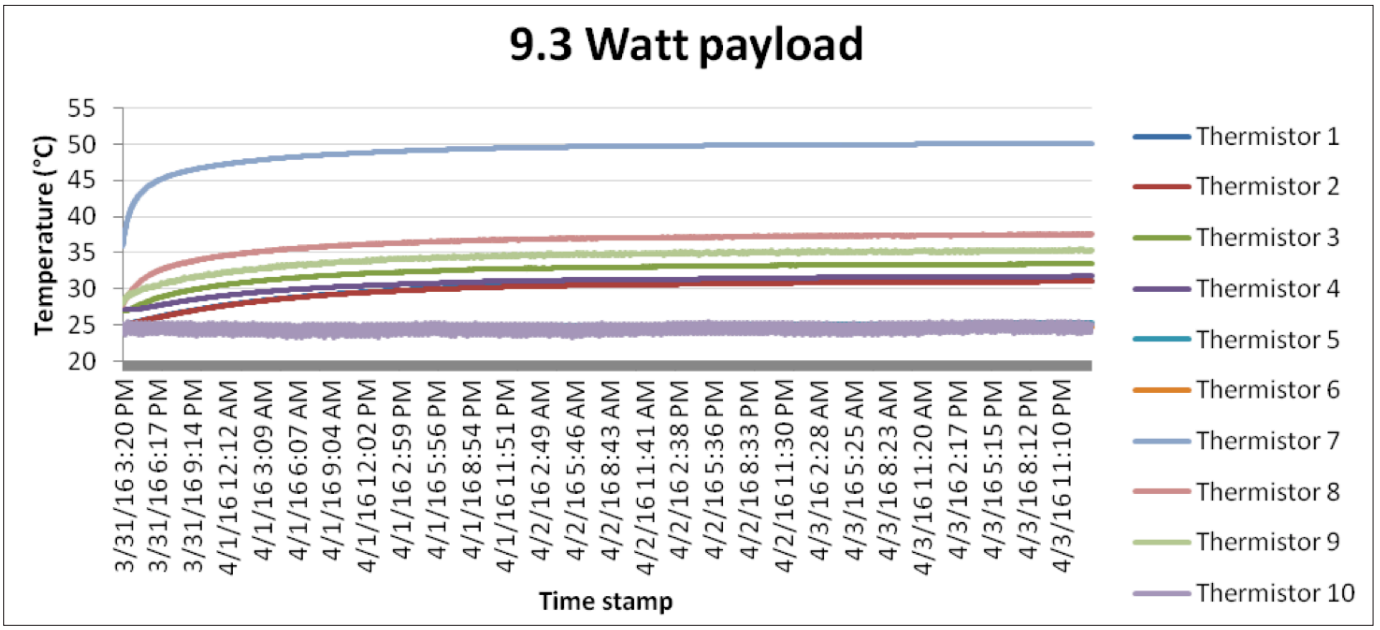


Figure 9. Temperature profiles for the 9.3 watt test



Method for Determining Maximum Temperature at Steady-state

The MulitCal 4.0 algorithm utilizes the slope of each curve as well as the standard deviation.[5] The slope indicates a change in temperature with respect to time. When the slope reaches a value close to zero, the system is said to reach equilibrium or steady-state. The standard deviation shows the spread of the data and is used as an estimate of uncertainty. The algorithm is implemented by calculating the slope for each curve then calculating the standard deviation at twenty-minute sliding intervals.[5] Figure 10 shows the diagram of implementing the algorithm. Once the slope and standard deviation have fallen below the user defined threshold, the system has reached steady-state. The threshold limits are set by the user based on engineering judgment of the data. After both conditions are met, the maximum value is then returned and represents a temperature limit that a certain location has reached after steady-state.

Figure 10. Algorithm used in analysis

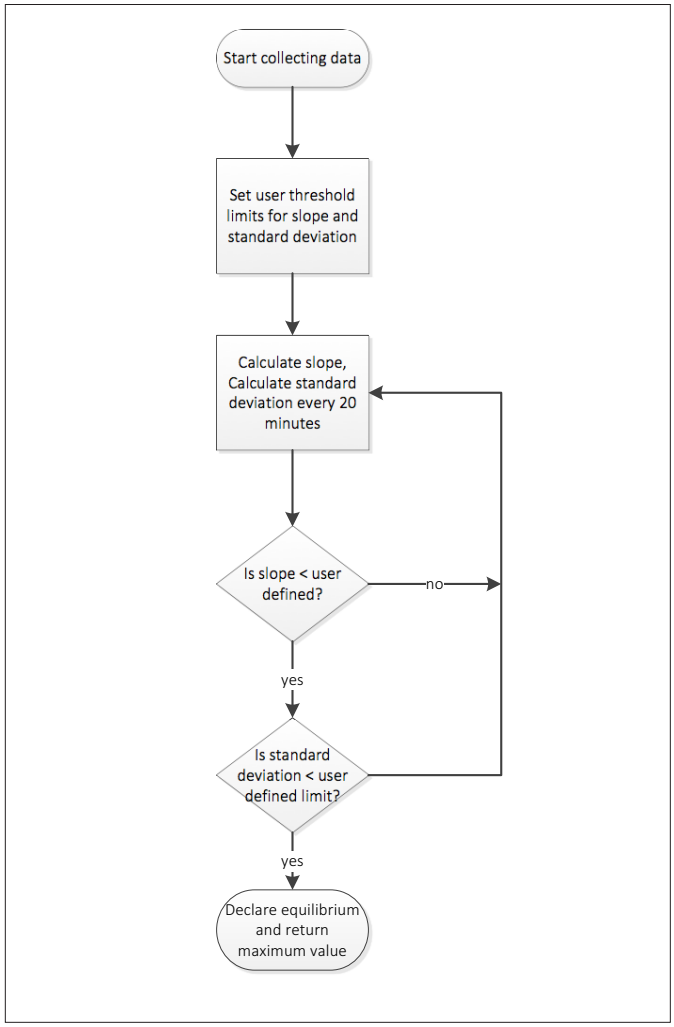


Table 4. Analysis results for all three tests

2.2 Watt Payload		
Thermistor	**Time to Reach Steady-state (hours)**	**Maximum Temperature After Steady-state (°C)**
Thermistor 1	21.5	25.24
Thermistor 2	16.6	25.18
Thermistor 3	21.7	25.63
Thermistor 4	13.3	25.23
Thermistor 5	21.7	23.57
Thermistor 6	N/A	23.83
Thermistor 7	19.7	29.35
Thermistor 8	21.7	26.98
Thermistor 9	N/A	26.71
Thermistor 10	N/A	24.77

6.3 Watt Payload		
Thermistor	**Time to Reach Steady-state (hours)**	**Maximum Temperature After Steady-state (°C)**
Thermistor 1	26.9	29.01
Thermistor 2	28.0	28.92
Thermistor 3	70.0	30.43
Thermistor 4	34.5	29.83
Thermistor 5	70.0	24.74
Thermistor 6	N/A	24.48
Thermistor 7	70.9	40.9
Thermistor 8	70.0	32.78
Thermistor 9	N/A	32.43
Thermistor 10	N/A	24.61

9.3 Watt Payload		
Thermistor	**Time to Reach Steady-state (hours)**	**Maximum Temperature After Steady-state (°C)**
Thermistor 1	38.8	31.14
Thermistor 2	38.9	31.04
Thermistor 3	81.8	33.49
Thermistor 4	42.1	31.76
Thermistor 5	81.8	25.30
Thermistor 6	N/A	24.78
Thermistor 7	71.8	50.15
Thermistor 8	81.8	37.59
Thermistor 9	N/A	35.43
Thermistor 10	N/A	25.07

Table 4 shows the results using the algorithm for finding the maximum temperature for each payload at steady-state. The user threshold for the slope was selected to be between -0.001 and 0.001 and the standard variation should be equal to or less than 0.01 for the data. The slope threshold was selected to be approximately zero to indicate the Thermistor location has reached steady-state. The data is affected by room temperature variations of a few degrees so the slope from each Thermistor will never be exactly zero. The selected threshold is based on the plotted data and the slope approaching zero. The standard deviation was set to be less than or equal to 0.01 to show the data distribution is getting closer to the actual mean value of steady-state.

Thermistor 7 is the location closest to the heat source making the plywood (Thermistor 7) the constraining POC component with respect to temperature. The filter (Thermistor 1) and the O-ring (Thermistor 2) are also constraining due to their relative low operating temperatures. These three locations are observed to ensure the thermal limits are not exceeded. The 9.3 watt test produced the highest temperatures at these locations. The maximum temperatures observed at Thermistor 7 (plywood), Thermistor 1 (filter) and Thermistor 2 (O-ring) are 50.15°C, 31.14°C and 31.04°C, respectfully. According to Table 1, the heat payload is still within the thermal limitations of each component.

Table 4 reports some "Not Available" (N/A) values recorded for the time to reach steady-state. Based off the user threshold values for slope and standard deviation, Thermistor 6

and Thermistor 10 did not reach steady-state due to the variations in room temperature. The ventilation in the room causes small but constant changes in temperature which does not allow the component temperatures to reach steady-state within the user threshold. Thermistor 9 is located inside the POC and does not have a surface contact, resulting in the Thermistor also experiencing small variations in air temperature.

Conclusion

Raising the TSD limits will help conserve on storage space, the number of operations for splitting material/bag out operations and reducing worker exposure. The testing captured maximum temperatures after the system reached steady-state. The 9.3 watt test showed the highest temperatures observed throughout testing. The plywood (Thermistor 7) experienced the highest temperatures recorded due to its close proximity to the heat sources and is the limiting location because of this heat load. The filter and O-ring (Thermistors 1 and 2) were also monitored due to their relatively low operating thermal limits. Observing the results from the 9.3 watt test, each component is still well below their operating thermal limits. Currently, the TSD has limited each POC to 10 grams of Pu-238, which equates to approximately 5 watts of power.[2] With the current testing completed, the POC can withstand 9.3 watts of power. Based on the completed testing, the POC can still be evaluated at higher powers. In addition, thermal modeling is also considered and is currently being implemented to supplement the thermal limitations of the POC.

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Book Review

By Mark L. Maiello, PhD
Book Review Editor

The New Nuclear Forensics

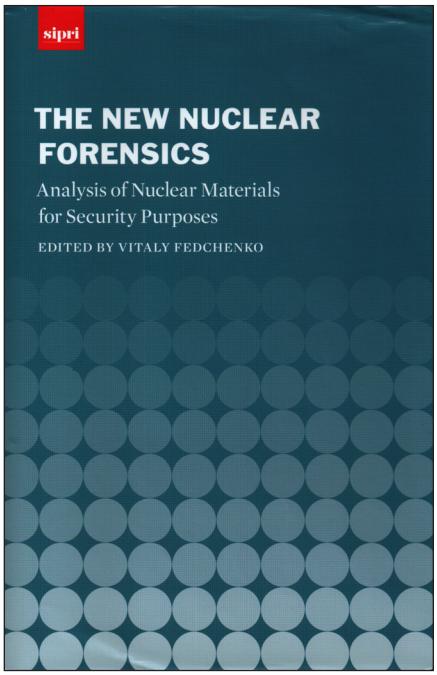
Edited by Vitaly Fedchenko

Hardcover, 290 pages
ISBN 978-0-19-873664-6
Oxford University Press, Oxford, UK, 2015

Here we have a text that fulfills its purpose well. It serves well as an introduction to nuclear forensics for those with a minimum of analytical and engineering background. If readers have some analytical chemistry or nuclear analysis capability under their belts so much the better, but in large measure, the book can be read with minimal knowledge in these areas. As a bonus, this text also provides a historical perspective of the field. Another unique contribution is the discussion of real-world applications of forensic techniques using recent events such as the North Korean nuclear tests.

This is an ensemble production with contributors hailing from across Europe and the United States. Swedish, Russian, Finnish, Hungarian, German, and American specialists have all contributed to a concise, well-constructed guide to the field. One can actually treat this text as a good read rather than a reference to be pulled down from the shelf when needed.

In the introduction, the editor Vitaly Fedchenko makes it clear that nuclear forensics has come of age. This term probably originated with the rise of nuclear smuggling in the 1990s as investigations sought techniques for evidentiary purposes in the prosecution of criminal cases. Attribution or the identification of a source of nuclear or radioactive materials and the route of transit of the materials are key components of nuclear forensics. He adopts the term "nuclear forensic analysis" because it more broadly encompasses the multiple techniques that in past years were used in isolation but now can be employed collectively for arms control, nonproliferation and intelligence work involving radioactive or nuclear materials.



The main elements of the field are explained in a very methodical way, allowing the novice to ease into the subject matter. Chapters 1 and 2 explain the field, carefully laying out such elements as its terminology and application. The "process" of nuclear forensics — essentially how it is conducted — is reviewed by explaining sample collection and characterization whereby the material is measured for physical size and subjected to elemental analysis. This is quite logically, followed up with the real meat of the process: the interpretation of analytical results.

Of the non-nuclear analyses utilized to achieve the goals of forensics, mass spectrometry in its many forms, is a key weapon in the arsenal. Though there is a brief explanation of the principals, the editor and his contributors do not waste much space explaining how the myriad mass-spec techniques work—one must look elsewhere for that. A diagram of the general principles is not to be found (probably considered too basic for the text), but this reviewer would have found it useful especially when the several mass spectrometry practices are discussed. Enough of these variants of mass spectroscopy are mentioned to warrant a fuller explanation of the overall method. A mass-spec technique comparison table somewhat along the lines of Table 3.1, which includes all forensic techniques, would have helped to elucidate and summarize application of this method. Of all the chapters in the book, Chapter 3 is perhaps the most difficult to follow. However, a lucid explanation of the *application* of mass-spec is made that will enlighten the reader as to the large role it plays in forensics.

The book flies higher afterwards. Chapters 4, 5, and 6 are where the radiological analyses hold the spotlight. Gamma-spectroscopy, nuclear signatures (uranium and plutonium), and radionuclide signatures provide the basic

foundation of nuclear forensics. Perhaps because of this, the principals of gamma spec are provided in a bit more abundance than was done for mass-spec. Detector types are discussed along with their capabilities and limitations. Competent discussions of the basic issues of gamma spectroscopy follow in turn: resolution of nuclide peaks, peak width, measurement time, and background radiation. A few brief words about airborne and underwater measurements are provided. They prove to be important in the later chapter on real-life attribution cases.

In Chapter 5, the processes that generate, transform, or modify nuclear material are discussed in the context of determining the history of the materials. The chapter is supplemented by twenty-one figures including electron microscopic images of uranium ore concentrates and fuel pellets. A good amount of effort was applied here to describe metallic uranium and plutonium because of its military use. Fuel pellets, which can be distinguished macroscopically and microscopically by the methods used to produce them, are also given their due.

A section is devoted to non-fissile materials commonly accompanying uranium, plutonium, and thorium. These elements may arise from processing of uranium oxide compounds or may accompany the feed material into the process. Rare earths and uranium oxide compounds follow a pattern unaffected by processing that allow the uranium to be traced back to a mine or geological location. Excellent figures accompany Chapter 5 that illustrate the dimensions, markings, and grain morphology of uranium fuel pellets from which manufacturers can be ascertained. Another parameter that can provide forensic evidence for attribution is the age of the nuclear material since it was chemically separated. Using both uranium and plutonium, it is explained how chemical separation during the manufacturing process removes the isotopes of decay and how new ingrowth can be utilized to determine the age of the uranium or plutonium. Even the age of uranium deposits can be estimated by using neodymium, lead or strontium isotope ratios.

We reach the post-explosion environment in Chapter 6. Despite the loss of most physical and chemical signatures by the explosion, the resulting radioactive materials in debris and fallout can be subjected to collection, characterization, and forensic interpretation that elucidate the history of the material. The chapter begins with the selection of "relevant radionuclides" used to calculate post-explosion doses to humans and to verify compliance with the Comprehensive Test Ban Treaty (CTBT) from the 2,391 known radioisotopes. The third section of this chapter is divided into ten categories that help determine the relevant radionuclides. It is an education on nuclear weapon debris. The categories include, of course, fission products and activation products, but also non-fission reaction products, residues, and tracers.

Clarity and insight mark this chapter. Tables 6.1 and 6.2 highlight a discussion of the twenty-one most important radionuclides utilized for estimating global average effective dose commitments from nuclear testing (Table 6.1) and the thirty-six deemed important for underground testing inventories in connection with France's Pacific testing from 1975 to 1996 (Table 6.2). This leads up to a discussion of the fallout particles needed to perform verification of nuclear detonations under the CTBT – the so-called "CTBT-relevant" nuclides. A simple but effective chart (Figure 6.1) illustrates a logical decision-making scheme utilizing the CTBT-relevant nuclides to determine treaty violations. The aforementioned ten categories define radionuclides associated with nuclear detonations, underground tests, underwater and atmospheric tests, and others defined by the manner in which the radionuclides are produced. The result is Table 6.3 — the forty-two particulate fission products relevant to international monitoring under the CTBT. A table of forty-two non-fission products compliments this (Table 6.4). This material is concisely and simply delivered to the reader in a manner that a novice to the field can benefit from immediately without confusion or the need for further research.

Chapters 7, 8, and 9 are excellent reads — truly interesting and extremely helpful in that they frame the historical background of nuclear forensics and then discuss real-world applications of its principles. The applied examples include discerning characteristics of Chinese nuclear weapons development and analyses of nuclear activities in Iran, Iraq, and North Vietnam. In Chapter 7, one finds a fascinating discussion of early environmental testing for German atomic bomb development including Nobel Prize winner Luis Alvarez' creation of a xenon-detection system and the collection of Rhine river water samples in 1944 by Manhattan Project foreign intelligence. As interesting are the revelations concerning the origins of soil testing to determine bomb yield credited to Herbert Anderson and Nathan Sugarman of the project's Metallurgical Laboratory. Through these efforts, Anderson discovered the glass created in the heat of atomic explosions from desert sand

(trinitite). The idea for airborne collection of bomb debris by a B-29 airplane, also the brainchild of Metallurgical Laboratory personnel and tested in 1945, is also discussed in these pages. The authors are not one-sided: a section is devoted to the development of debris analysis in the Soviet Union including Soviet investigations of U.S. tests.

The rubber really hits the road in Chapter 8. Here, Lars-Erik De Geer discusses the forensic efforts of the Swedish National Defense Research Establishment. Remote sensing (air sampling, both fixed and airborne), the principles of radionuclide fractionation, and studies of hot particles dominate the opening discussion of the chapter. De Geer then describes Sweden's rather impressive role in developing verification systems for the CTBT including its noble gas detection system. An interesting section applying Swedish-based forensics to "non-nuclear explosions" rounds out the chapter. These are events such as the 1983 nuclear-powered Cosmos satellite re-entry and the 1986 Chernobyl accident.

Appendix 8A is the "fun part" of the book. Swedish analyses of various nuclear tests are reviewed illustrating how and what forensics revealed about the past nuclear weapons tests of China. All told, the forensics of more than twenty tests are concisely reviewed.

With the basis of Chapter 8, the next logical effort is to describe recent forensic applications. This was taken on by Vitaly Fedchenko and Robert Kelley in Chapter 9, which includes the forensic analyses of North Korean enrichment and nuclear test efforts. A healthy amount of text is also devoted to the forensic efforts expended to investigate the 1990s era nuclear program of Iraq. This is all quite fascinating material some of which reads like a detective novel. There is an even a section titled quite mysteriously as "The Purple Sweater."

The New Nuclear Forensics is supplemented by a lengthy but welcome list of acronyms, a list of relevant measurement units, the chemical elements by atomic number, and a six-page glossary. There is an index and the references have been placed in footnotes. The book is more than adequately illustrated with high-quality black and white photographs.

A lean 290 pages, this work combines the technology and history of nuclear forensics into a very readable framework for those new and senior to the subject matter. There is also no question that the book will make a fine classroom companion or primary textbook, despite the lack of problems or questions to assign to future practitioners of this applied science. Its writing style and the breath of its coverage assure motivated student use. This is a sound, well-thought-out, and well-written addition to the nonproliferation literature.

Taking the Long View in a Time of Great Uncertainty

"That Will Never Happen" — The Power of Scenario Planning

By Jack Jekowski
Industry News Editor and Chair of the Strategic Planning Committee

Since the first column of Taking the Long View in late 2010,[1] I have discussed the power of scenario planning to help leaders visualize improbable future worlds, rehearse the events that might lead up to those worlds, and postulate what actions might be taken to either influence the path to those future worlds, or at least to better prepare for them.

In those discussions I have employed some common terms used in scenario planning to capture the imagination of readers, such as "what ifs,"[2]; "critical uncertainties,"[3] "wild cards,"[4] "strategic inflection points,"[5] "discontinuities,"[6] "event timelines,"[7] "bumps in the road,"[8] and "nightmare scenarios."[9] These terms have helped to create the strategic engagement necessary for organizations, including the INMM, to look "outside the box" as events unfold, such as the nuclear tests by North Korea; the Fukushima nuclear accident; the Arab Spring; the military action by Russia in the Crimea; the Iranian "nuclear deal" — the Joint Comprehensive Plan of Action (JCPOA); and the continuing struggles against terrorism in the Middle East. All of these events have had an impact on the Institute, its mission and its membership.

Brexit vote hits financial markets, UK unity

From **PAGE A1**

ish voters who wanted to remain — and for the 2 million EU nationals who live and work in Britain, but could not vote — there was sadness, anger and even panic.

At a London train station, commuter Olivia Sangster-Bullers said, "Good luck to all of us, I say, especially those trying to build a future with our children."

The decision launches a yearslong process to renegotiate trade, business and political links between the U.K. and what will become a 27-nation bloc, an unprecedented divorce that could take a decade or

born from the ashes of World War II as European leaders sought to build links and avert future hostility. With no precedent, the impact on the single market of 500 million people — the world's largest economy — is unclear.

The result triggers a new series of negotiations expected to last two years or more as Britain and the EU search for a way to separate economies that have become intertwined since the U.K. joined the bloc on Jan. 1, 1973. Until those talks are completed, Britain will remain a member of the EU.

Leaders from across the EU voiced regret inflected with anger at the

ELECTION 2016

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TRUMP STUNS AMERICA

Ultimate political outsider wins White House

GLOBAL AFTERSHOCKS

BY JILL LAWLESS AND DANICA KIRKA
ASSOCIATED PRESS

LONDON — Britain has jumped. Now it is wildly searching for the parachute.

The U.K.'s unprecedented decision to leave the European Union sent shockwaves through the country and around the world Friday, rocking financial markets, toppling Prime Minister David Cameron and even threatening the ties that bind the United Kingdom.

Britons absorbed the overwhelming realization that their anti-establishment vote has pushed the British economy into treacherous and uncertain territory, and sparked a profound crisis for a bloc founded to unify Europe after the devastation of World War II.

"Leave" campaigners hailed the result as a victory for British democracy against the bureaucratic behemoth of the EU.

Conservative former London Mayor Boris Johnson said "the British people have spoken up for democracy in Britain and across Europe," while Nigel Farage, leader of the hard-right U.K. Independence Party, said "the dawn is breaking on an independent United Kingdom."

But for the 48 percent of Brit-

Reaction in the U.S.

Trump sees the decision as vindication; Clinton says uncertainty shows need for proven leader **A6**

See **BREXIT** >> **A2**

Such was the setting when the results of the U.S. Presidential election greeted the world in the early morning hours of November 9, 2016. Although the "conventional wisdom" had predicted a win for Secretary Hillary Clinton, and many people openly avowed that a Trump victory "would never happen," nonetheless, headlines, like the one shown here from the *Albuquerque Journal* that Wednesday morning, were common across the world.

Many drew the analogy to similar occurrence only four months earlier with the "Brexit" vote in Great Britain to withdraw from the European Union

This column is intended to serve as a forum to present and discuss current strategic issues impacting the Institute of Nuclear Materials Management in the furtherance of its mission. The views expressed by the author are not necessarily endorsed by the Institute, but are intended to stimulate and encourage JNMM *readers to actively participate in strategic discussions. Please provide your thoughts and ideas to the Institute's leadership on these and other issues of importance. With your feedback we hope to create an environment of open dialogue, addressing the critical uncertainties that lie ahead for the world, and identify the possible paths to the future based on those uncertainties that can be influenced by the Institute. Jack Jekowski can be contacted at jpjekowski@aol.com.*

(EU) — reflecting a changing political view of both countries' electorate. However, even with the Brexit vote so recent in people's memories, the concept of "that will never happen" with respect to a possible Trump victory seemed to prevail.[10]

These two events have driven "soul-searching" by many to try to understand the societal and geopolitical dynamism of today's global environment. Most notably, is a recently published letter by Dr. Stephen Hawking titled, "*This is the most dangerous time for our planet,*"[11] that examines these two remarkable events from the perspective of the "elites." Other post-election analyses spoke of the "Winds of Change," depicting the one significant characteristic of these events as "uncertainty."[12]

I had listed the outcome of the U.S. Presidential election as a ***critical uncertainty*** in previous columns,[13] particularly in light of the dichotomy of positions taken by the two major candidates in areas of interest to the INMM, including positions on the nuclear stockpile modernization programs, relationships with Russia, and perspectives on nonproliferation and nuclear technologies. As the ensuing weeks since the election have unfolded, the positions of President-elect Trump in the nuclear arena have taken on heightened interest as the many uncertainties in the world today must now be viewed from a very different perspective.

"That Will Never Happen" — The Power of Scenario Planning

Since my first experience facilitating a large scenario planning activity twenty years ago for senior leadership at a major M&O contractor in the U.S. Nuclear Security Enterprise, I have been struck by how hard it is for individuals who are "integrated" into the system to "go outside the box" and speculate on improbable (but not impossible) futures. It is a difficult thing to do when you are responsible for multi-million dollar programs with high national security consequence and tight schedules, where daily "fires" must be put out: to suspend your belief system and speculate on "what might be." Since those early years of scenario planning, the statement "that will never happen" has become a bellwether in virtually every major scenario planning activity I have facilitated, creating an opportunity to open rich and challenging discussions with leadership teams to stretch their imagination and build robust strategies that would better prepare the organization for an uncertain future, particularly one which seemed improbable at first.

As an example, in late 1997 and early 1998, the research we were conducting demonstrated a possible path to the future that would have India testing a nuclear weapon, with a posited follow-on of a Pakistani test, mirroring the early days of the Cold War between the U.S. and the Soviet Union. When that future path was first presented to leadership, one senior leader scoffed, and said quite sternly "Well, that will never happen, we don't need to waste our time even talking about it." We did rehearse that future path, however, in our strategic discussions. When India tested multiple devices in May 1998, followed shortly after by Pakistan, although some shock initially rippled through the leadership team, the discussion was "What did we say that we would do if this were to happen?" and the team, comforted somewhat by having had those discussions, addressed the implications of that scenario with respect to its organizational and business strategies.

Other examples include discussions with an Agency prior to the start of the Iraq War and the formation of a new Federal Department focused on national security — both of which prompted leadership to be better prepared for when those events occurred, despite initially being characterized as "never happening."

Fast Forward to 2016

In February 2016, I was huddled in a group of high-level federal staff, think-tank strategists, lawyers, and scientists at an evening meeting in the heart of Washington, DC. The discussion was focused very seriously on the most likely event of another Continuing Resolution (CR) for FY2017 in light of the Presidential election, with an impasse between Congress and the White House until a new Administration and Congress were in place. No one dared to mention either candidate by name, so as the conversations wound down with a more-or-less comforting agreement that we have all gone through CRs in the past, I interjected — "imagine how all of that will change when Trump becomes President." After a long and painful moment of silence, a powerful DC lawyer looked at me from across the circle and said, "We will never let that happen." Thus began my research at that moment in time that this *could be* a future path with which to challenge leadership outside of the box, and to monitor as events unfolded.

The New U.S. Administration — Facing a Multitude of "That Will Never Happen" Scenarios

As this column goes to press, President-elect Trump is in the process of choosing cabinet and other high-ranking officials for his administration, as well as formulating policies that, although aligned with

campaign rhetoric, are appearing to be influenced by input from subject matter experts. It will be some time before we can piece together the implications of this new world on the INMM and the work of its membership. However, we can speculate, using published early policy documents[14] and the previous lists published in this column of critical uncertainties, of what "might be" under this new leadership. Here is a short list of "that will never happen" futures that should be stimulating our discussions:

- The dissolution of the Iran Deal — the Joint Comprehensive Plan of Action.
- Fundamental changes to the U.S. Nuclear Deterrence Policies including moving from a Triad to a Diad, and moving civilian control of nuclear weapons (DOE/NNSA) to the U.S. Department of Defense.
- The potential for proliferation of nuclear-weapon possessing states in Asia,[15] the Middle East,[16] and even within the European community.[17]
- Weakening of NATO and the rise of Russia as a global power.
- A new Cold War with China amid territorial claims in the East and South China Seas as Asian-Pacific alliances change.

In reviewing these perspectives, it is important to set aside your own biases and beliefs, and if you find yourself saying, "well, that will never happen," jot it down and later ask yourself, "what would it mean to our work (or the work of the Institute) if it really did happen." Rehearsing improbable future events in this context can raise confidence in addressing uncertainties, and may, in fact, lay the groundwork for actions that could be taken to influence that future in a more positive direction.

In keeping with the spirit of agreements reached back in 2013 at the 54th Annual Meeting,[18] discussions of these issues should be framed in the context of what the Institute can do to positively impact the future through its technical and policy expertise:

- **Joint Comprehensive Plan of Action (JCPOA) and the Iranian nuclear program.** Since the very beginning of his campaign, President-elect Trump has said that he would "dismantle" the JCPOA as "one of the worst deals" this country had ever negotiated. However, in recent reports it appears that many individuals have weighed in on the significance of this once-in-a-lifetime, multi-lateral, diplomatic accomplishment, and may be swaying the new administration's perspective.[19] Most significantly, 28 European leaders on November 14, 2016, issued a statement confirming their "resolute commitment" to the deal.[20] Nonetheless, the current speculation is that the new Administration will re-examine the construct of the agreement, which will continue to strain relationships not only with Iran, but potentially with other parties to the agreement. It is interesting to note that in President-elect Trump's "100-Day Plan" there is no mention of the JCPOA or Iran.[21] Another wild card in this scenario is the emerging economic benefits that may accrue to the U.S. as a result of eliminating sanctions, not the least of which is the granting of licenses by the U.S. Treasury to allow the sale of U.S. commercial aircraft to Iran, although recent actions by the U.S. House of Representatives to block the licenses passed on party lines as this article went to press.
- **Global nuclear stockpile modernization programs and U.S. nuclear deterrence posture.** President-elect Trump has indicated he will support the rebuilding of the U.S. military capability, including committing to the nuclear Triad modernization program.[22] However, budget realities may result in some tempering of the investment, and the recent selection of General James Mattis as Secretary of Defense-designate leaves the door open for the possibility of exploring changes to the fundamental concepts of the U.S. nuclear deterrent.[23] The incoming administration has asked Congress for a Continuing Resolution through March 2017 to provide adequate time for it to assess the investment strategy, although that approach, in and of itself, may jeopardize some aspects of the planned modernization program.[24]
- **Proliferation of nuclear weapons.** In campaign interviews, Trump acknowledged the significant problem with nuclear weapons, but also said that he would not take their use "off the table" if they were needed.[25] On the subject of proliferation, the president-elect has indicated that it is almost inevitable that other nations will acquire them, as he indicated in a response to Anderson Cooper back in March 2016:

COOPER: So if you said, Japan, yes, it's fine, you get nuclear weapons, South Korea, you as well, and Saudi Arabia says we want them, too?

TRUMP: Can I be honest with you? It's going to happen, anyway. It's going to happen anyway. It's only

a question of time. They're going to start having them or we have to get rid of them entirely. But you have so many countries already, China, Pakistan, you have so many countries, Russia, you have so many countries right now that have them.

- **Weakening of NATO and the rise of Russia as a global power.** During the run-up to the election, Trump has raised questions of whether NATO allies are fulfilling their financial obligations, and if they are not, then they need to consider defending themselves. These statements have created tensions within the alliance and concerns about further aggression by Russia if the U.S. were to take such a line.[26] Most importantly are the questions that arise with respect to NATO's nuclear posture[27] and also the complication of the U.S. nuclear weapons that are forward-deployed at Incirlik, Turkey, amid rumors that some are being moved as a consequence of the unsuccessful coup attempt earlier this year,[28] to Romania.[29]
- **A new Cold War with China amid territorial claims in the East and South China Seas and as Asian-Pacific alliances change.** Breaking with the long-standing "one China" policy, President-elect Trump spoke directly with Taiwan's President Tsai Ing-wen, creating objections by China.[30] Earlier calls with leaders in Pakistan, Kazakhstan, and the Philippines created similar concern among administration diplomats. How will these initial actions influence the current tense situation in the East and South China Seas, and the balance of power in this new global hotspot?

The use of the scenario process, where paths to the future are mapped out, during times of great uncertainty, can enhance traditional strategic planning initiatives, often stretching the mindset of management, allowing discussions of otherwise unthinkable future worlds. By pursuing discussions of events that prompt a "that will never happen" response, the actions needed today to change the future path can be rehearsed by leaders so that they can be better prepared for any eventuality.

Endnotes

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7. See "Taking the Long View in a Time of Great Uncertainty, *Looking Back at a Decade of Tumult – and Looking Forward to an Uncertain Future*," 2012 Volume 40, No. 3, pp. 99-101
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11. See https://www.theguardian.com/commentisfree/2016/dec/01/stephen-hawking-dangerous-time-planet-inequality
12. See "Winds of Change" and "Now What", *Aviation Week* & *Space Technology*, November 21-December 4, 2016, p. 22 and pp. 20-21 respectively.
13. Multiple examples exist over the past two years. As an example, see Taking the Long View in a Time of Great Uncertainty, *A World Full of Critical Uncertainties*," 2015 Volume 44, No. 1, pp. 37-39
14. See, for example, https://www.greatagain.gov/policy/defense-national-security.html and https://assets.donaldjtrump.com/_landings/contract/O-TRU-102316-Contract-tv02.pdf
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17. See "The Sudden German Nuke Flirtation," http://carnegieendowment.org/2016/12/06/sudden-german-nuke-flirtation-pub-66366, which describes a fringe element in the German political system that has opened this unpopular topic for public discussion.
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19. See "President Trump and the Art of the Iran Nuclear Deal", https://www.crisisgroup.org/middle-east-north-africa/gulf-and-arabian-peninsula/iran/president-trump-and-art-iran-nuclear-deal
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