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The *Journal* at 45 — It's déjà vu all over again

By Corey Hinderstein
INMM President

Long-time members of INMM may have rubbed their eyes after reviewing the table of contents for this issue of the *Journal of Nuclear Materials Management (JNMM).* If you recognized the names and article titles, you are not imagining things.

INMM is now in its 60th year and it is the 45th anniversary of the *Journal. JNMM* remains committed to offering a high level of technical content, providing professional development opportunities for members (and non-members) to publish peer-reviewed articles, and reflecting the state of the debate on topics related to nuclear materials management.

For this issue, in celebration of its 45th year, we wanted to highlight these enduring characteristics and shine a light on the profound impact of the *Journal* and the authors who contribute to it. John Jaech and James D. Williams are former INMM presidents. All the authors are respected leaders, some might say legends, in their fields. And anyone reading a newspaper knows that nuclear security and international safeguards remain as vital and relevant today as they were when these articles were first published.

We are not resting on our laurels. The INMM Executive Committee, *JNMM* Technical Editor Markku Koskelo and INMM's headquarters staff are actively seeking ways to improve the impact of *JNMM* and widen its accessibility and audience. We welcome your suggestions and commit to make progress on these goals, as they are reflected in our strategic plan and implementation efforts.

While we stand on the shoulders of these giants, taking time to recognize their immense contributions, it is important to look forward. I urge each of you to think about contributing and article to *JNMM*. In particular, I am looking forward to capturing diverse voices and perspective in these pages. I hope more women, non-U.S. members, students, and policy experts, among others, will offer articles to *JNMM*. This is a great opportunity to publish, share your work, and perhaps be remembered in our next retrospective issue!

Standing on the Shoulders of Our Predecessors

Markku Koskelo
JNMM *Technical Editor*

In honor of the *JNMM's* 45th anniversary, we proudly publish a commemorative issue that highlights some important papers from our past.

The work we all do endures and continues to be relevant in our field. At the same time, many of the issues that we work with are not new. As an experimentalist myself, I like to say that unless I have a credible estimate of the uncertainty and bias of my measurement result, I really do not have a measurement result. There are fields that seem to get away without estimates of uncertainty and bias. Our field is not one of them. There have been many papers that have been written on this subject. And, how to best apply the generally accepted uncertainty analysis standards to the nuclear materials management continues to be a topic of discussion and debate even today. To illustrate the fact that our predecessors already wrestled with this topic, we are republishing a paper by John A. Jaech dating back to 1975.

Nuclear materials management also deals with making sure that the materials stay where they are supposed to stay. That means worrying about insider threats, intrusions systems, and physical security of the materials and the personnel that is allowed to work with the materials. Sandia National Laboratories and James D. Williams (known to many as J. D. Williams) and the many scientists he worked with did a lot of the early work on this topic. In honor of that work, we are republishing a paper by J. D. Williams from 1981.

The early uranium enrichment plants used gaseous diffusion technology. The present generation of such plants uses gas centrifuges. Performing safeguards measurements at gas centrifuge plants has been a requirement since the introduction of the technology, especially since most of them are commercial facilities. As these facilities become larger and larger and more and more common, we are faced with a number of measurement problems to provide safeguards measurements for these facilities. Yet, some of the basics still apply. To remind us of the fact that our work is building on concepts that were pioneered more than thirty years ago, we are republishing a paper edited by Joerg Menzel from 1984.

The first nuclear materials measurements were made with gamma detectors. The simplest gamma detectors were made more than 100 years ago and were well-known and understood when it first became apparent that we need to keep track of the nuclear materials. Unfortunately, gamma radiation can be significantly attenuated by the very materials we are trying to measure. Over the last forty years, Los Alamos National Laboratory, and Howard Menlove and the many scientists who have worked with him, have developed a number of measurement methods to measure neutrons instead of gammas to overcome this problem. In honor of that work, we are republishing a paper by Howard Menlove from 1987.

I can also recommend the book review by Mark Maiello and the Taking the Long View column by Jack Jekowski. They discuss the recent significant political changes in the UK and the United States, respectively, and their potential impact in our field.

Recently one of our long-term associate editors has announced his retirement from his role with *JNMM*. Gotthard Stein has been an important part of the development of this *Journal,* our peer-review process, and many other changes in *JNMM* over the last two decades. The entire *JNMM* staff thanks Gotthard for his many contributions and years of service.

The *JNMM* continues to receive manuscripts for publication. We encourage anyone who is interested in having their work published to consider submitting their articles to the *JNMM* and our rigorous peer-review process. Naturally, the number of such submissions varies considerably from year to year and month to month. We have several manuscripts that are in the process of being reviewed and edits for publication.

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

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

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SOME THOUGHTS ON RANDOM ERRORS, SYSTEMATIC ERRORS, AND BIASES

By John L. Jaech, Staff Consultant
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Introduction

An error of measurement may be defined as the "magnitude and the sign of the difference between the measured value and the 'true' value" [1]. The subject of measurement errors is of great importance in the area of special nuclear materials (SNM) accountability. Key quantities that measure the level of SNM accountability performance, material unaccounted for (MUF) and shipper-receiver difference (S/RD), are influenced by measurement errors, and much effort is expended in evaluating the sizes of reported MUF's and S/RD's relative to the combined effect of errors of measurement. In these applications, individual measurement errors may be quite large, and their effects cannot be ignored. Further, there are many sources of error that contribute to an overall index of performance such as MUF, and the problem of how to combine their effects is a very important one.

In this field of application, the ultimate aim of taking all the measurements needed in SNM accountability is to arrive at the "true" value of some index, i.e., one not influenced by measurement errors. In attempting to arrive at "the truth," careful distinction must be made among the various kinds of errors that can be committed. In particular, the terms random error, systematic error, and bias are frequently used in this connection. One statement that the readers of this paper can universally agree on is that there has been and continues to be considerable confusion and some disagreement on the definitions of the various measurement errors just cited, and how to treat their effects statistically. The purpose of this paper is to try to clear up the confusion such that a more distinct picture of the various viewpoints will develop.

In a sense, this paper might be regarded as a defense of the terminology and methods of error propagation used by the author in a recently published TID publication [2]. The contrary opinions that have surfaced as a result of this book is one factor that has convinced me of the need for this paper. Further, various ANSI standards under preparation seem to offer conflicting viewpoints on this general subject. Finally, I am aware of different positions put forward in the international safeguards arena on this subject and I think it is time an attempt is made to begin clearing the air by trying to create a better understanding of the various viewpoints.

It is my hope that this paper will prompt others to communicate on this subject through the avenues available to members of the INMM. I will also welcome personal correspondence on the subject.

The reader will note a paucity of references. It is a hopeless task to perform a comprehensive literature search on the subject of random and systematic errors, and biases. Every author of a statistics application book must touch on this subject, and there are many such books available. Further, the number of journal articles and unpublished papers that discuss this subject is very large.

Rather than attempt to perform even a nominal literature search, therefore, I believe it more instructive to make this paper largely self-contained, with references to other literature held to a minimum. Nevertheless, there are two general references that I should like to cite because of their importance relative to this topic. These are Mandel's book relating to the analysis of experimental data [3], and especially Chapter 6 of this book, and an NBS publication on measurement and calibration comprised of a number of papers on this subject [4].

Scope of Paper

My original intent was to discuss mathematical models, estimation of the parameters, and propagation of errors. After considerable thought, however, I have decided to concentrate on modeling and error propagation in this paper, and avoid problems of estimation for the present.

There are a number of reasons behind this decision. First, it is my opinion that even in the very simple measurement situation in which repeated measurements are made on the same standard, the problem of when to make bias corrections, for example, has not been studied in sufficient depth from an applications viewpoint, and since this is basic to the estimation problem, I would rather avoid the subject for the moment. Secondly, discussions on estimation of biases are generally limited to the simple situation just discussed, i.e., when making repeated measurements on the same standard. This tends to create the impression that biases or systematic errors that may affect a statistical index such as MUF are rather simple in origin and can be evaluated rather easily. This is far from true (see, for example, the discussion in Section 3.2 of Reference 2). Thus, discussing error parameter estimation for the case of known standards only scratches the surface of a very complex subject, one of which cannot be explained in depth is a paper of this scope. Finally, I do not wish to detract from the main point of this paper which deals with error propagation.

In avoiding the subject of estimating error parameters, I do not imply that the subject is unimportant. On the contrary, the topic is of utmost importance. I would suggest that application papers on this subject would be of great use to the nuclear industry.

Historical Comments on Terminology

Before proceeding further, some comments on terminology are appropriate. Most practitioners in the field of SNM accountability with whom I have been in contact over the past several years have used the term systematic error variance in the sense in which I have used it in [2], and will use it in this paper. At least this has been my understanding of their usage. Although other terminology might be preferred by some readers, I believe it preferable to stick with common usage unless the term itself creats confusion. In my opinion, systematic error variance is properly descriptive of the idea I wish to convey, and I see no reason for discarding it in my communications on this subject.

Mathematical Models

Mathematical models of increasing complexity are discussed. In each case, x_i is the observed value of some random variable for the i-th item. For simplicity in presentation, additive models are assumed.

Model I

$$x_i = \mu + \varepsilon_i \tag{1}$$

The parameter μ is some constant. Assume that ε_i is a random variable with mean 0 and variance σ_ε^2 for all i, written $E(\varepsilon_i) = 0$, and $\sigma_{\varepsilon i}^2 = \sigma_\varepsilon^2$ respectively. Further assume that ε_i and ε_j are uncorrelated for all i and j, written $E(\varepsilon_i\varepsilon_j) = 0$. In this model, ε_i is called a random error and σ_ε^2 may be called the random error variance.

This model would apply, for example, if a number of measurements were made on the same item. Here, μ is the true value of the item characteristic in question, and ε_i is the error introduced by the i-th measurement on that item. The measured or observed value, x_i, is the algebraic sum of μ and ε_i. The expected value, or mean, of x_i is μ, and its variance is σ_ε^2.

Model II

$$x_i = \mu + \varepsilon_i + \eta_i \tag{2}$$

Make the same assumptions about μ and ε_i as in Model I and further assume that η_i is a second random error with $E(\eta_i) = 0$, $\sigma^2_{\eta i} = \sigma^2_\eta$, $E(\eta_i\eta_j) = 0$, and $E(\varepsilon_i\eta_j) = 0$ for all i, j.

This is a model in which there are two random errors, and in this case, the variance of x_i is the sum

$$\sigma^2_{x_i} = \sigma^2_\varepsilon + \sigma^2_\eta \quad (3)$$

Formula (3) is called an error propagation formula.

As an example of application, in determining the net weight of UO_2 powder in a container ε_i might represent the random error introduced by the gross weight determination and $-\eta_i$ the random error introduced by the tare weight determination. The observed net weight, x_i, is affected by both random errors. If σ^2_ε and σ^2_η are assigned values, the variance of x_i can be found using equation (3). This provide a measure of the uncertainty* in a reported net weight. Alternatively, it describes how a number of measured net weights of the same item will be expected to vary.

Model II can easily be extended to include m different errors; $\varepsilon_{1i}, \varepsilon_{2i}, \ldots, \varepsilon_{mi}$ in which case

$$\sigma^2_{x_i} = \sigma^2_{\varepsilon_1} + \sigma^2_{\varepsilon_2} + \ldots + \sigma^2_{\varepsilon_m} \quad (4)$$

provides the error propagation formula.

Model III

$$x_i = \mu + \theta + \varepsilon_i \quad (5)$$

For Models I and II, the results are straightforward and there is agreement on the error propagation formulas. With Model III, this is not always the case. The problem centers around θ. Since it has no subscript, θ is the same for all observations and hence, affects all observations in the same way.

Consider two situations, as follows:

Case (1)

θ is a constant whose value is not known. In this case, θ is called a measurement bias by the author.

Case (2)

θ is randomly selected from a population that has zero mean and variance denoted by σ^2_θ. In this case, θ is called a systematic error by the author, and σ^2_θ is called a systematic error variance. Note that θ differs from a random error only in the sense that the same value of θ applies to all observations in question, whereas ε_i is different for all i.

In the literature on this subject, bias and systematic error are generally regarded as being one and the same. In fact, this is indeed the case from point of view of the effect on an observation. Whether Case (1) or Case (2) applies, it is clear that the net effect is to cause all observations, x_i, to be θ units offset from the true value, μ. In addition, the ε_i component introduces a second error that is not the same for all i.

If bias and systematic error are the same with regard to their effect, what then is the distinction made by the author? This distinction is tied in with describing this effect. The two cases, with θ a bias and θ a systematic error, are discussed separately.

Case (1): θ a bias.

In this case, the expected value of x_i is $(\mu + \theta)$ and its variance is σ^2_ε. Say that the problem is to find some way of expressing the total uncertainty in x_i. The value of θ is known with high probability to be smaller in absolute value than some value θ_0. In describing the uncertainty in x_i, it is reasonable to make two separate statements of the following sort:

- The random error standard deviation is σ_ε.
- The bias is less than θ_0 in absolute value.

*This term is used as defined in [1]. In some circles, the term is gaining acceptance as the generic term to express the limits of error in measurement.

The use of two statements of this form serve the purpose of providing a good description of the total uncertainty in x_i. However, it falls short when it is necessary to make an overall statement on the uncertainty in x_i in order to help make some judgement about the size of μ given an observed x_i. The two statements must be combined somehow in a total uncertainty statement. This can be of the form:

$$\text{total uncertainty in } x_i = k\,\sigma_\varepsilon + \theta_0 \quad (6)$$

Case (2): θ a systematic error

We now turn to the case in which θ is regarded as a systematic error, sampled at random from a population with mean 0, and variance σ^2_θ. Then, the expected value of x_i is μ and its variance is $\sigma^2_\varepsilon + \sigma^2_\theta$. This expression for the variance of x_i provides the required statement of uncertainty. Of course, as with Case (1), separate statements can be made, with σ_ε the random error standard deviation as in Case (1). The systematic error standard deviation, σ_θ, is then used to describe the systematic error.

As an aside, it is pointed out that a systematic error, and also a bias, is only meaningful when applied to a given set of conditions. When the conditions change, so does the value of the systematic error. Thus, over a material balance period, say, there may be several sets of conditions applicable to a given measurement. The concept of a short-term systematic error may be applied in this instance [2].

A comment might be helpful to those readers familiar with the analysis of variance. In an analysis of variance, a distinction is made between a fixed and a random effect, even though the model is written the same in both cases. By analogy, I think of bias as being a fixed effect and a systematic error as representing a random effect. In this sense, then, the systematic error variance σ^2_θ is equivalent to a component of variance in the terminology of the analysis of variance.

Model IV

Model IV is the model of real interest in SNM accountability, with Models I, II, and III introduced to lead into this more complicated model. In SNM accountability applications, the analyst is frequently confronted with a random variable affected by many sources of error. The model may be written

$$x_i = \mu + (\theta_1 + \theta_2 + \ldots + \theta_m) + (\varepsilon_{1i} + \varepsilon_{2i} + \ldots \varepsilon_{mi}) \quad (7)$$

where the θ_j are biases or systematic errors, and the ε_{ji} are random errors. Assume in the following discussion that all the parameters identified are known, i.e., have assigned values. The emphasis is on the error propagation formulas.

For ease in exposition, first consider the case in which the θ_j are regarded as systematic errors, drawn from populations having zero means and variances $\sigma^2_{\theta_j}$. Then, the error propagation is straightforward.

$$\sigma^2_{xi} = (\sigma^2_{\theta 1} + \sigma^2_{\theta 2} + \ldots + \sigma^2_{\theta m}) + (\sigma^2_{\varepsilon 1} + \sigma^2_{\varepsilon 2} + \ldots + \sigma^2_{\varepsilon m}) \quad (8)$$

where it is assumed that the various errors are uncorrelated.

Now regard the θ_j as biases. Following the line of reasoning of Model III, these biases are characterized by θ_{jo} values such that, for each j,

$$|\theta_j| < \theta_{jo}, \text{ with high probability}$$

With this approach, how is the error in x_i to be propagated? This is where disagreements arise. There are those who advocate that the combined effects of the biases be characterized by summing the θ_{jo} values and asserting that the total bias is less in absolute value than $\sum_{j=1}^{m}\theta_{jo}$ with high probability. The random error variances are then propagated in the standard way and the total uncertainty in x_i is expressed as in Model III, Case (1) (see equation (6)) with θ_0 replaced by

$$\sum_{j=1}^{m}\theta_{jo} \quad \text{and } \sigma_\varepsilon \text{ by } \sqrt{\sum_{j=1}^{m}\sigma^2_{\varepsilon_j}}$$

In support of this approach, it is true that if any given $|\theta_j|$ is less than θ_{jo} with high probability, then $|\sum_{j=1}^{m}\theta_j|$ is also less than $\sum_{j=1}^{m}\theta_{jo}$ with high probability. My objection to this approach is not that the method of error propagation is theoretically not supportable, but rather, that it may be unrealistically conservative in given applications. This is especially true if there are several biases as is the case in many SNM accountability applications. The degree of conservatism is large because the implicit assumption is made that not only are all of the m biases in the same direction, but each tends to be close to θ_{jo} in value. No allowance is made for any cancellation of biases that have opposite sign.

What is an alternative? One is to characterize the uncertainty in each bias by some quantity denoted by $\sigma_{\theta j}$ rather than by θ_{jo}, where $\sigma_{\theta j}$ is descriptive of the interval in which a given bias will be expected to occur, just as θ_{jo} provides the limits on this interval. As an example, if the bias θ_j is judged to be equally likely to fall anywhere between $-\theta_{jo}$ and $+\theta_{jo}$, it can be regarded as having the same effect as if it were a uniformly distributed random variable with range $2\theta_{jo}$.* In this case, since the standard deviation of the uniformly distributed random variable is $2\theta_{jo}/\sqrt{12}$, $\sigma_{\theta j}$ may be equated to $2\theta_{jo}/\sqrt{12}$. As another example, if it is known or judged that θ_j will "almost surely" fall between $-\theta_{jo}$ and $+\theta_{jo}$, but will more likely be much smaller, then it is not unreasonable to regard the bias θ_j as being a normally distributed random variable with zero mean and a standard deviation, say, of $\theta_{jo}/3$ or, more conservatively, of $\theta_{jo}/2$.

In effect, then, with several biases affecting x_i, each constant bias θ_j, although not a random variable, may be regarded as one with variance $\sigma^2_{\theta j}$, i.e., θ_j may be treated as a systematic error for error-propagation purposes. If there is concern that some or all of the biases may tend to be in one direction, this can be taken into account by introducing a positive covariance between such biases, still regarding them as systematic errors.

It is the author's contention that this latter approach to error propagation is generally the realistic approach when several biases or systematic errors are involved. Although careful consideration should be given to each application, the general recommendation is that in many SNM accountability applications, and in particular, when finding the variance of MUF, biases be treated as systematic errors when propagating errors. This leads to what is commonly called the "root-mean'square" approach to propagating errors.

Limit of Error

Thus far we have restricted our attention to finding the variance of some random variable. The reader is aware, of course, that in application, and in particular when assigning the uncertainty to MUF, this variance must be translated to a limit of error (LE). This translation is very simple when the approach recommended in the previous section is followed, and when the principles for the calculation of LE given in the appropriate ANSI standard (5) are adopted. The solution is to describe the bias or systematic error in terms of $\sigma_{\theta j}$, apply equation (8) to find the variance of x_i (or MUF in a particular example), extract the square root of the result, and multiply by two.

It is pointed out that this approach can lead to a result that is identical to the quadrature approach in which systematic errors are described by setting limits on them, $|\theta_j| < L_j$, and propagating the total effects of these systematic errors by $\sqrt{\Sigma L^2}$. This is equivalent to regarding L_j as a $2\sigma_{\theta j}$ value, and finding the LE (for systematic errors only) by

$$LE = 2\sqrt{\Sigma\sigma^2_{\theta j}} = 2\sqrt{\Sigma L_j^2/4} \quad \sqrt{\Sigma L_j^2} \tag{9}$$

Concluding Remarks

It should be kept in mind that there is no "right" way to treat the combined effect of systematic errors or biases. There is a certain degree of arbitrariness involved with any approach and this is why there are disagreements. The choice then should be made on the basis of what is meaningful in a particular application. In advocating the root-mean-square approach in this application, I am influenced by the familiar central limit theorem of mathematical statistics that implies to me that the systematic errors that will affect a reported MUF, say, will tend to cancel out.

Many have argued that it is advisable to make separate statements about the effects of random and systematic errors. I have no quarrel with that viewpoint, and, in fact advise it. But to carry that idea one step further and forbid that the effects of such different errors be combined into a total uncertainty is not acceptable in this field of application. Judgements are required on the significance of reported MUF's and S/RD's. To make such judgements, it is necessary that the total uncertainty be expressed in some way.

Acknowledgements

I submitted the first draft of this paper to a number of individuals for review and comment. I was heartened by the response, not that all the reviewers are in complete agreement with me, or with each other, because this is not the case, but rather that so many reviewers obviously devoted a considerable amount of effort to the paper. It is further evidence to me that those working in this area, most of whom are members of INMM, have a real professional interest in approaching the very important problems of SNM safeguards. No one supplied me with superficial comments; all were well-reasoned and the products of extensive thought.

Although I would like to take this opportunity to acknowledge the contributions of the reviewers by name, I do not wish to imply by either the inclusion or exclusion of certain individuals that they support or are in conflict with the thoughts expressed in this paper. Therefore, I shall extend by thanks to them as a group for the attention given this important subject and leave it to them as individuals to express their thoughts on the subject.

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(1) "Statistical Terminology and Notation for Nuclear Materials Management," ANSI Standard N15.5-1974.

(2) "Statistical Methods in Nuclear Material Control," TID-26298, J. L. Jaech, USAEC Technical Information Center, 1974.

(3) "The Statistical Analysis of Experimental Data," John Mandel, Wiley and Sons, New York, 1964.

(4) "Precision Measurement and Calibration - Statistical Concepts and Procedures," NBS Publication 300, 1969.

(5) "Limit of Error Concepts and Principles of Calculation in Nuclear Materials Control," ANSI Standard N15.16-1974.

*Critics of this approach are disturbed that θ_j is treated as a random variable, and that the distribution of this random variable may be based partly on judgement as to what range of values θ_j may take on. The situation is analagous to the assignment of a prior distribution in Bayesian statistics, or to subjective probability in general.

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Factors Which Affect Sensor Selection for Intrusion Detection Systems*

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ABSTRACT

Areas which require physical protection systems are usually those in which very valuable material, potentially dangerous material, or strategic information is stored. The primary purpose of the physical protection systems for such areas is to prevent theft or sabotage of the protected items. Intrusion detection is one of the essential elements of a physical protection system. It is essential that any new or to-be-improved intrusion detection system be carefully planned and analyzed to ensure that it will reliably perform its intended function in the specified environment and that the system's strengths and weaknesses be identified and understood. Details about particular types of sensors and how they operate are given in the references listed and are not repeated here. The performance of intrusion detection sensors is influenced by a complex interrelationship of a large number of factors. Some of these factors for exterior and interior sensors to be used in intrusion detection systems are identified and discussed.

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Introduction

The selection of sensors for intrusion detection systems involves a complex interrelationship of a large number of factors. Because of this complexity, one is tempted to try to simplify the relationships by organizing the sensors into preferred order lists or tables. Such lists and tables are potentially dangerous because they can lull facility designers and operators into thinking they have performed an adequate sensor system design and/or they can provide excuses for poor system design by virtue of the fact that the system designer has chosen an item (or items) high on the preference list.

Physical protection systems for fixed facilities (usually referred to in the nuclear industry as safeguards systems) are designed to provide protection against acts of sabotage and theft of special material or other items being protected. Four elements must react in a timely manner to form an effective physical protection system: (1) detection and assessment systems must expose and verify any intrusion attempt from outside (e.g., intruders may pose as a person authorized to enter or they may try to enter at a point not normally used for entry), or any malevolent act by insiders or outsiders; (2) communications systems must bring all pertinent information to the point or points where appropriate action may be taken; (3) delay systems must impede continued efforts to penetrate into -- or exit from -- the protected area; (4) response systems (or forces) must counteract adversary activity and neutralize the threat.

These elements are of equal importance; none can be eliminated or compromised if the systems are to remain effective. Detection, which encompasses not only intrusion detection but also entry control, is basic to protection: Any delay scheme can eventually be overcome, and without detection the response force cannot be alerted. System considerations related to the selection of intrusion detection sensors is the subject of this article.

System Planning

If a sensor system is to perform reliably, with strengths as well as weaknesses clearly identified and understood, a new system -- or one that is being improved -- must be carefully planned and analyzed. Included in this planning and analysis are the development of system philosophy and site-related evaluation, followed by iterative design finalization, then cost analysis, scheduling, equipment procurement, and construction and installation.

System objectives, which also define the purposes of the detection equipment and the types of threats assumed, should include the specifications desired in three primary areas: (1) probability of detecting the intruder, P_d; (2) vulnerability to defeat of the equipment; and (3) the allowable alarm rates* and the manner in which these rates are calculated. These parameters cannot be represented by single-valued numbers, however, because they are influenced by many variables -- the physical environment, weather, threat, maintenance, regulations, installation procedures and operating personnel. Therefore, the conditions that apply to each number specified must also be listed. Additionally, no single sensor presently exists or is expected to exist that will reliably detect all intruders and still have an acceptably low alarm rate for all natural and manmade environments. Therefore, when a high P_d and a low alarm rate are required over a wide range of operating conditions, it will be necessary to use combinations of sensors. The combinations of sensors and the way in which the sensors provide overlapping detection volumes not only contribute to enhanced detection and reduced alarm rate, but also contribute to the safeguards concept known as "protection-in-depth." (Protection-in-depth means simply providing a

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*The alarm rates are the number of non-intruder generated alarms which occur in a given time period. The non-intruder generated alarms are the sum of the alarms due to system idiosyncrasies (false alarms) and the alarms due to nuisance sources (nuisance alarms). In modern solid state equipment which operates at low voltages, true system idiosyncrasies such as microphonics, shot noise, etc., are almost nonexistent, therefore the alarm rate is mostly due to nuisance sources.

number of protective measures in series such that an intruder must successfully circumvent or defeat each of the protective measures in sequence or simultaneously before access to the protected material or facility can be achieved.) Consideration of these combinations must be given at the time of sensor selection to assure that each is compatible with the site characteristics, that one complements the other in detection capabilities, and that threat defeat vulnerabilities are reduced rather than enhanced. This consideration requires detailed evaluation and becomes a function of site peculiarities rather than site similarities.

A detailed consideration of the interaction among the items mentioned is integral to the selection and location of the "best" technological types of equipment necessary to ensure the desired intrusion detection functions.

Hardware for intrusion detection comprises sensors, alarm-assessment and alarm-reporting systems -- the latter including alarm communications and information-display equipment. The performance of the first two groups is heavily influenced by the physical environment in which it must operate, as well as by installation and maintenance considerations.

Unfortunately, we lack full knowledge of the limitations imposed by the environment on sensor operation. Additional on-site evaluation will therefore be required during and after sensor installation. Moreover, facility type, regulations, procedures, and personnel impact on the system's operational effectiveness, along with the material to be safeguarded and the most probable threat anticipated, all influence final system design.

Selection of intrusion-detection systems involves identifying the components and installation methods that best meet the overall system objectives. A key system component, of course, is the sensor. Sensors may be categorized as either exterior or interior. Exterior sensors include fence-associated sensors, free-standing line sensors, buried-line sensors and point sensors. Interior sensors include boundary-penetration sensors, motion (volume) sensors, and proximity sensors.

Tables I and II have been prepared to illustrate the complexity and interaction of these components and the site characteristics. The tables should <u>not</u> be used for sensor selection without studying additional explanatory material. In Table I it is important to realize that if an intruder can pass entirely above or below the detection zone of a sensor the intruder will go undetected. Therefore elaborate tunnels or bridges will defeat all of the sensors listed. The terminology "low bridge" could be as simple as a 2x4 longer than the detection zone is wide and supported at its ends by several short sections of 2x4's. Such a structure could allow a careful intruder to cross the detection zone of a seismic sensor just a few inches above the ground without imparting enough seismic energy into the sensor to activate it. A "high bridge" also implies a simple structure, but one which would allow the intruder to pass a few feet above the ground. The inclusion or exclusion of an "X" in the tables is a general indication. Particular situations can alter these general indications. A number of sources of additional information about sensors are listed in the references.

Physical and Environmental Conditions Affecting Exterior Sensors

The physical and environmental conditions that can affect exterior detection systems include topography, vegetation, wildlife, background noise, meteorological conditions, and soil surface and volumetric properties (moisture content, conductivity, compactness, etc.). It is important to recognize that there is no "typical" site since combinations of conditions are site specific. Topographical concerns include slopes and hills, gullies and ditches, lakes, rivers and streams, swamps and temporary surface water, perimeter access points and manmade structures. Vegetation includes all plant life such as trees, weeds, grass, bushes, and crop foliage. The vibration of the root systems of this vegetation as well as aboveground motion of foliage can affect sensor performance. Wildlife of concern includes large and small animals, burrowing animals, and birds and insects. Background noise such as traffic, wind, natural and manmade (water and sewer lines, drainage culverts, buried power and communication lines, etc.) seismic sources, and electromagnetic interference all must be taken into account. The specific type of meteorological information which may prove useful in the design and operation of sensor systems includes wind, temperature, rain, snow, hail, visibility, airborne corrosives, moisture content of the soil, and electrical storms. Soil volumetric properties primarily affect buried sensors.

Physical and Environmental Conditions Affecting Interior Sensors

The environmental conditions which can affect interior sensors are electromagnetic, radioactive, acoustical, thermal, optical, seismic, and meteorological in nature. Two general physical conditions of importance are building or room construction and the various equipment or objects that occupy the area or room to be monitored. Certain physical features are unalterable, while others may be changed.

A careful review or survey of the area to be monitored, coupled with other detailed information about the area, will provide the user with guidance to choose a particular technological type of sensor or a combination of types of interior detection systems.

Equipment Identification

Considerations leading to the initial equipment identification for either exterior or interior applications include: (a) the compatibility of the sensors with the alarm signal transmission media and display equipment (signal levels, impedances, no-alarm condition of relays, etc.); (b) the compatibility of the assessment equipment (usually CCTV) with the overall system layout, lighting, and personnel procedures; (c) the assurance that the system is adequate but not unnecessarily complex, (d) the assurance that a proper balance between security and safety exists; (e) the assurance that the individual subsystems can be installed with a minimum of duplicated construction and that the signal cables and power lines for lights, cameras, sensors, etc., can be installed, to avoid interference, at a reasonable cost, (f) the assurance that procedures for operation during emergency conditions are established and that the equipment and personnel are compatible with these procedures, (g) the assurance that tamper-indicating circuitry is available on all critical assemblies, (h) the assurance that full end-to-end self-test circuitry is available on critical sensors or subsystems, (i) the assurance that the system also provides protection for intra-plant movement of critical material, (j) the assurance that adequate emergency power is provided and that it is properly protected, (k) the determination that adequate protection-in-depth has been designed into the overall system, (l) the assurance that the display and control equipment is human-engineered, and (m) discussion of the entire system with the personnel who will operate it to ensure their acceptance of the system.

In summary, a major design goal is to obtain an intrusion detection system which exhibits a low alarm rate and an acceptable P_d in the environment in which it must operate and is not susceptible to defeat. This goal can be achieved in a cost effective manner if the complex interrelationships of a very large number of variables are well understood and considered during the system design. No single sensor presently exists or is expected to exist that will reliably detect all intruders and still have an acceptably low alarm rate for all expected natural and man-made environments. To simplify the procedure with shortcut attempts is to court disaster.

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Table 1

EXTERIOR SENSORS SUITABLE FOR FIXED-SITE APPLICATIONS

Application	Operating Principle	Detection: Nonmagnetic	Detection: Walk, Run and Crawl	Detection: Shallow Tunnel	Detection: Climb Fence	Detection: Cut Fence	Common Conditions for Unreliable Detection (All sensors are adversely affected by improper installation)	Common Simple Defeat Methods	Typical Causes of Nuisance Alarms: High Wind	Heavy Rain	Heavy Snow	Heavy Fog	Birds	Small Animals	Large Animals	Seismic Activity	Thunder and Lightning	RFI (including electrical transients)	High Grass	Surface Water
Buried	Seismic-Magnetic	x	x		NA	NA	Frozen ground, deep and/or crusted snow	Bridge and carry no ferromagnetic material	x						x	x	x	x		x
	Seismic	x	x		NA	NA		Low bridge	x						x	x	x			
	Magnetic		x		NA	NA		Carry no ferromagnetic material									x	x		
	Balanced Pressure	x	x	x	NA	NA		Low bridge							x	x				
	Ported Coax	x	x	x	NA	NA	Conductive Soil	Medium bridge							x		x	x		x
Fence Disturbance	Electromechanical (Electret, Tribo-electric, geo-phone, piezo-electric, etc.)	x	NA		x	x	Flexible posts loose fabric, improper mounting positions	Ladder or short tunnel	x	x					x		x	x		
	Mechanical* (Mercury and inertia switches)	x	NA		x			Ladder or short tunnel	x	x					x					
	Taut-Wire	x	NA		x	x		Ladder or short tunnel							x					
Free-Standing	Electric-Field (can be fence-mounted)	x	x		x	x	High grass and/or deep and crusted snow	Tunnel High Bridge	x	x			x	x	x		x	x	x	x
	Microwave (Bistatic)	x	x		NA	NA	High grass, irregular terrain, deep and/or crusted snow	Tunnel High Bridge						x	x				x	x
	Infrared	x	x		NA	NA		Ladder, short tunnel, or redirect low beam			x	x		x	x				x	x
Point	Seismic or Electromagnetic	x	x		NA	NA	Same as Buried	Tunnel					x	x	x		x		x	x

NA Not Applicable

*Some of the inertia type switches will detect cutting.

Table 2

INTERIOR SENSORS SUITABLE FOR FIXED-SITE APPLICATIONS

Application	Operating Principle	Detection: Portal Opening	Detection: Breaking Through Wall/Floor/Ceiling	Detection: Radial Motion	Detection: Transverse Motion	Detection: Touching Object	Conditions for Unreliable Detection	Typical Defeat Methods	Major Causes of Nuisance Alarms: Air Humidity/Temp/ Velocity	Localized Heating	Movement Less Than 0.025 metre/sec	Movement Greater Than 0.025 metre/sec	Movement Outside Area	Fluorescent Lights	Loose Fitting Doors	Mount Vibration	Ambient Acoustic Noise	Rodents/Animals	RFI
Boundary-Penetration	Balanced Magnetic	X		NA	NA	NA									X				
	Vibration		X	NA	NA	NA	Improper Installation	Stay Behind Intruder or Entry Through Unprotected Area					X			X			
	Continuity		X	NA	NA	NA													
Motion	Sonic	X		X	X	NA	Acoustic Background	Disenable Electronics	X			X				X	X	X	
	Ultrasonic	X		X		NA	Air Movement		X			X				X	X	X	
	Microwave	X		X		NA	RFI	Cover When Sensor Is In Access				X	X	X		X		X	X
	Infrared				X	NA	Unstable Thermal Background		X	X		X				X		X	
Proximity	Capacitance	NA	NA	NA	NA	X		Disenable	X									X	
	Strain	NA	NA	NA	NA	X	Gross Changes in Relative Humidity, Temperature or Pressure											X	
	Pressure Pad	NA	NA	NA	NA	X		Electronics										X	

NA } Not Applicable

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SAFEGUARDS APPROACH FOR GAS CENTRIFUGE TYPE ENRICHMENT PLANTS

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ABSTRACT

For many years, safeguards experts have wrestled with the problem of how to get effective and credible safeguards at uranium enrichment plants while protecting sensitive information and minimizing the operator's burden. In an effort dedicated to solving this problem for gas centrifuge uranium enrichment plants subject to INFCIRC/153-type safeguards agreements, six technology holders and the inspectorates of the IAEA and Euratom created the Hexapartite Safeguards Project (HSP) in November 1980. After 2 1/2 years of intensive study it was concluded that, for commercial gas centrifuge uranium enrichment plants in NPT states, the safeguards approach involving limited-frequency unannounced access (LFUA) by IAEA inspectors to cascade areas offers the best solution. This report, based on the text produced by the HSP, provides (1) the essential details of the project, (2) the "LFUA" safeguards approach, and (3) the possible inspection activities inside and outside the cascade areas.

PART I: THE HEXAPARTITE SAFEGUARDS PROJECT (HSP)

A. Introduction

Commercial exploitation of the gas centrifuge process for uranium enrichment began in earnest in the early 1970's. From the outset, attention was given to the need to apply an effective and an efficient international safeguards approach to plants of this type. The general principles for achieving this were easily and relatively quickly established since the physical characteristics of the gas centrifuge enrichment process readily lend themselves to the maintenance of accurate material accounts.

However, the elaboration of a basic safeguards approach proved very difficult because of the sensitivity of this novel process. Throughout the 1970's there were many efforts at resolving these difficulties, notably in the IAEA Advisory Group Meeting held in Tokyo in 1977. In each case agreement could not be reached on the point as to whether or not inspectors would need access to the cascade halls of gas centrifuge enrichment plants if an effective and efficient safeguards approach was to be implemented under NPT conditions. It was argued by several technology holders that access was unacceptable because information sensitive on both commercial and non-proliferation grounds would be at risk and that an effective and efficient safeguards approach could be implemented without access to the cascade halls.

This situation was clearly unsatisfactory, and and in the late 1970's the need to come to an agreed safeguards approach was given added impetus by the expansion of existing gas centrifuge enrichment programs and the initiation of new ones. Eventually in 1980, there was a series of informal discussions between the IAEA, Euratom and technology holders of the gas centrifuge process and the outcome was a concensus to collaborate to reexamine the situation and to solve the outstanding problems.

B. Form and Purpose of the HSP

An initial ad hoc meeting was held at URENCO's offices in Marlow, England, in November 1980. The participants were the IAEA, Euratom, Australia, Japan, Troika (comprising the Federal Republic of Germany, the Netherlands and the UK) and the USA.

The participants all shared a common commitment to achieving rapid and real progress and to studying practical applications at real plants, not paper studies on model plants. The aim was to establish a sound technical basis for the development of effective and efficient safeguards strategies by the inspectorate(s), i.e., the IAEA and Euratom:

-- effective in the way that they met the objectives of the inspectorate(s);

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-- efficient in the way that they made good use of the resources applied.

With these aims in mind, the proposal for a Hexapartite Safeguards Project (HSP) was accepted and it was agreed that:

(1) The goal of the project would be to develop, within 2 years, an adequate basis of technical experience and information which could be used by the IAEA, Euratom and the State involved in their evaluation of the various safeguards approaches and the possible development of arrangements for the direct implementation of an effective and efficient safeguards approach to specific plants.

(2) The technical objective of the HSP was to facilitate the application of effective and efficient international safeguards at uranium enrichment plants of the gas centrifuge type.

This was to be achieved through the exchange of relevant information, thereby coordinating individual development efforts, and by the technical consideration of possible safeguards approaches. The case of non-access by inspectors to the cascade halls of the plants and other cases of varying degrees and frequency of access were to be treated in parallel.

The participants also agreed that they were not looking for a legal structure for the project but rather for practical and satisfactory co-operation towards a common objective.

C. Discussion and Results

To carry out the basic information exercise four working teams were set up, each to study a specific aspect of the problem, namely (1) facility characteristics; (2) containment and surveillance; (3) nuclear materials accountancy; and (4) safeguards strategies including different degrees of access to cascade areas.

The groups met as required to accomplish their work and their progress was monitored by a series of HSP Plenary Meetings.

The four teams completed their work and their reports provided the basis for the work of a further sub-group, which was set up to define, assess and evaluate the advantages of the "non-access" and "limited-frequency unannounced access" models.

After detailed consideration, the assessment sub-group concluded that a safeguards approach based upon limited-frequency unannounced access (LFUA) to cascade areas was capable of meeting safeguards objectives, in particular those for material of high strategic value. Part II of this paper describes the LFUA safeguards approach.

It was agreed by the participants in the sub-group that for the application of this approach it would be necessary that the approach be accepted by all participants and equally applied to all technology holders participating in the HSP; that the nature and scope of inspectorate(s) verification activities be clearly and unambiguously defined and described; and that security concerns with regard to the protection of sensitive information be satisfactorily met.

A number of participants considered that non-access approaches were also capable of meeting the safeguards objectives. However, the group agreed that the limited-frequency unannounced access model exhibited three main advantages as compared to the non-access alternative:

(1) Less intrusion into plant operations and lower equipment and manpower costs, both for the operator and for the inspectorate(s).

(2) Simpler implementation of the model, especially in already existing facilities or facilities already under construction.

(3) Greater availability, within the time-scale of HSP, of instrument measurement techniques associated with the access approach.

The principal disadvantage of the access model was that it implied a higher risk of revealing sensitive information.

The assessment sub-group recommended that a safeguards approach based upon limited-frequency unannounced access to cascade areas should be studied in detail for each technology to see how the above conditions could be applied.

The fifth plenary session of the HSP held in Sydney, Australia, in March 1982 endorsed the conclusions and recommendations of the assessment sub-group.

The seventh plenary meeting of the HSP took place in Luxembourg in January 1983. The paper "Inspection Activities Associated with Limited-Frequency Unannounced Access Model Applied to Gas Centrifuge Type Enrichment Plants" was finalized. The Hexapartite Safeguards Project completed its tasks on the technical level at the Luxembourg meeting, two years and three months after its establishment.

The final plenary meeting of the HSP was held in Vienna in March 1983 and, as of July 1, all other aspects directly related to the HSP were completed.

D. Conclusion

It has been agreed that, for commercial gas centrifuge uranium enrichment plants in NPT states, the safeguards approach involving limited-frequency unannounced access by IAEA inspectors to cascade areas together with inspection activities outside the cascade areas offers an effective and efficient safeguards measure capable of meeting the objectives of IAEA safeguards and also of minimizing the risk of revealing sensitive information in accordance with INFCIRC/153-type agreements. The experts participating in HSP thus arrived at a consensus that this safeguards approach would be appropriate for all commercial gas centrifuge uranium enrichment plants situated in states party to the NPT.

This safeguards approach clearly provides the clear and unambiguous definition and description of the nature and scope of the inspectorates' verification activities which was one of the requirements identified by the assessment sub-group.

As HSP was looking toward the common objective of an effective and efficient safeguards regime, it was necessary to formalize the acceptance of these findings by all participants and the assurance of their equal application to all technology holders. In order to meet related security concerns about the protection of sensitive information it will be necessary for each of the technology holders and the inspectorate(s) to make their own appropriate efforts as well as to cooperate to facilitate the implementation of the proposed safeguards approach.

PART II: THE "LFUA" SAFEGUARDS APPROACH

A. Scope

The participants in HSP consider that the safeguards approach described in this document is capable of meeting the objectives of IAEA safeguards in accordance with INFCIRC/153-type safeguards agreements and satisfies the relevant technical requirements. It should, however, be understood that nothing in this document shall be interpreted as altering rights and obligations of the parties concerned, as provided in the individual safeguards agreement.

Further, it is understood that, on acceptance of limited-frequency unannounced access, extended containment and surveillance (C/S) measures at the periphery of the cascade area will not be used.

The question of verification of gas phase nuclear material flows and inventories inside the cascades and associated piping is not considered relevant.

B. Objectives and Underlying Assumptions of Inspection Activities, Including Those Inside Cascade Halls

As with all investigations by HSP, only gas centrifuge enrichment plants subject to safeguards under an INFCIRC/153-type agreement (for non-nuclear weapon and for nuclear weapon states) and operating at a stated maximum enrichment level of 5 percent or less have been considered. Accordingly, the overall safeguards objective expressed in para. 28 of INFCIRC/153 has formed the basis for all considerations of safeguards capability in this report. As applied to centrifuge uranium enrichment plants, implementation of the objective of safeguards entails a set of safeguards measures whose application by the inspectorate(s) permits the detection, in a timely manner and with high confidence, of the diversion of a significant quantity of uranium, including the production of a significant quantity of uranium at an enrichment level higher than declared. In considering diversion strategies, special emphasis must be placed on meeting the relevant goals for strategies involving material of high strategic value.

It is assumed that in principle it is possible, but not necessarily easy, to produce higher enrichments than the declared design values by:

-- rearrangement of the enrichment equipment or by
-- modifying the operating mode, e.g., recycling of flows or parts of them by using alternative feed and take-off points.

Inspection activities may be categorized as (1) those needed to verify that the nuclear material flows and inventories are in accordance with declaration and (2) those needed to verify that material production is in the range of declared enrichment, i.e., to verify enrichment, to verify that all nuclear material is routed as described in the design information, and to verify that cascades are connected as declared.

It is assumed further that there are indications or anomalies which may be observed or detected by an inspector in the case that centrifuges are used for the production of high enriched uranium. The following indications might be associated with HEU diversion scenarios:

-- significant variations in UF_6 flow or concentration at feed and withdrawal stations (this includes significant MUF or systematic data falsification);
-- changes in declared UF_6 piping arrangement;
-- existence of additional storage, feed and withdrawal stations/facilities;
-- a radiation field indicating HEU.

The safeguards activities related to the detection of all except the first indication listed above require access of IAEA inspectors to the cascade hall.

Measures which might be used to implement the activities outside the cascade area would be the use of conventional material balance and C/S measures. Measures which might be used to implement those activities inside the cascade area may be broadly classified into direct visual observation by inspectors and technical measures, i.e., radiation monitoring and NDA measurements, sampling, and application and verification of seals. Wherever inside cascade area NDA enrichment measurement is referred to, it means quick NDA measurement (go/no go) to confirm only that the enrichment level is in the LEU range.

Possible inspection activities and associated measures are described in Part III of this paper. Appropriate combinations of such activities and measures will be adopted for each facility.

C. Comparability of Inspection Activities at Different Enrichment Facilities in NPT-States

Safeguards should be applied equally at similiar facilities under similar conditions. On the other hand, it must be recognized that there are safeguards-relevant differences in technology which need to be taken into account by the inspectorate(s) and which can result in some differences in the relative usefulness, frequency and time required for the inspection activity at the facility, including visual and instrumental inspection activities inside cascade areas. Therefore, it is assumed that for the various enrichment facilities the inspectorate(s):

-- utilize the same basic assumptions and safeguards approach;
-- derive the same benefit in meeting its safeguards objective from the deterrent value of unannounced access to cascade areas plus the random character of certain inspection activities, and from the detection value of inspection activities in regard to similar installed equipment, process configuration and plant features;
-- implement comparable frequency and duration of inspection activities at facilities of similar separative capacity, differentiating only on the basis of facility characteristics affecting the inspectorates' ability to draw requisite conclusions.

D. Frequency and Duration of Inspection Activities

1. Frequency and duration of routine inspection activities outside cascade areas

The mode of inspection would be intermittent. For facilities up to about 1,000,000 SWU/a, the average frequency of routine inspection visits for activities outside the cascade areas is expected to be in the range of 12-15 times per year. Since routine inspection activities outside the cascade halls and inspections within the cascade halls will not necessarily have to be carried out during the same visit, the total frequency of inspection visits may be higher. Additional routine inspection visits may be performed to service safeguards equipment or, as required due to plant operating conditions, in order to give the inspectorate(s) the opportunity to verify the feed, product and tails before they are fed to or shipped from the plant. An average duration for an inspection visit to perform a physical inventory verification would be 2 weeks and an average duration for an intermittent routine inspection visit would be 3 working days provided that the conditions at the plant allow the inspection activities to be carried out without delay or interruption. Usually it is IAEA practice to send at least 2 inspectors to perform the inspection activities. Under comparable conditions, it is expected that the total routine inspection effort for facilities with small separative capacities will be less than that for facilities with large separative capacities.

2. Frequency and duration of inspection access to cascade areas

Frequency of inspector access inside the cascade area will be determined, inter alia, by the separative capacity involved, the timescale and difficulty of modifying a facility for production of high enriched uranium (HEU), the time necessary for the production of 25 kg of U-235 in HEU and the time required to remove the resulting anomalies. In addition, the frequency and scope of inspection activities outside the cascade areas will influence the frequency of access. Under comparable conditions, the frequency of access should be higher for facilities with larger separative capacities than for those with smaller separative capacities. Important components of the timescale and difficulty of modification are the specific design features of the facility and cascade piping and valving arrangements. If the modifications require stopping the centrifuges, more time will be required than in situations where the modifications can be made without bringing the cascades to atomospheric pressure. The time required for the production of 25 kg of U-235 in HEU depends not only on the involved separative capacity but also on the production strategy applied and the flexibility of the cascades. The necessary number of inspections inside the cascade area will be plant specific. An average frequency for inspector access to cascade areas of 4 to 12 times per year for facilities up to about 1,000,000 SWU/a capacity would be appropriate.

As for facilities where use of visual observation is emphasized the duration of the inspections will be determined by the time required to carry out the visual observations and, if performed, sampling, NDA measurements and seal verifications. As for facilities where the use of installed instrumentation is emphasized the need for interrogation, maintenance and repair of the instrumentation will mainly determine the duration of the inspections. As for plants where the use of portable radiation instrumentation is emphasized the duration of access will be determined by the time necessary to make the required random measurements and visual observations. It is assumed that the time required to perform the inspection activities inside cascade areas would be in the range of 1 to 8 hours.

E. Protection of Information of Particular Sensitivity

It is recognized that there is certain information at centrifuge enrichment facilities which is of particular sensitivity.

Some of this information is required to be provided for the implementation of safeguards in pursuance of Article 8 of an INFCIRC/153-type agreement.

It is further recognized that the operator has the right to protect information which is not required to be provided in pursuance of Article 8 noted above.

The application of the relevant provisions of an INFCIRC/153-type agreement is expected to provide the necessary protection of information coming to the inspectors' knowledge.

F. Restrictions Suggested on Access Approaches

The following restrictions have been suggested for inspection activities in the cascade hall:

(1) The average frequency of inspection should be limited. (See Section D. In addition, it must be noted that the announcement of access inside the cascade hall will be made either on the occasion of routine inspection visits to the plant or as part of unannounced inspections provided in Article 84 of INFCIRC/153).

(2) The number of inspectors participating in each inspection should be restricted. (Usually, it is IAEA practice to send at least two inspectors for routine inspections at key facilities so as to maintain the necessary credibility to its safeguards system).

(3) The inspectors should be escorted. (The presence of at least one representative of the plant during the inspection is essential in order to clarify and explain anomalies).

(4) The inspectors may not depart from the predetermined and agreed paths. (However, the inspectors must have sufficient access in order to be able to perform the inspection activities properly).

(5) The instruments and equipment to be used and the modalities of their use by inspectors are to be limited to those agreed upon. (If the plant operator requests that the inspectors use his equipment, the inspectors must be in a position to verify that the equipment is functioning properly and that it is properly calibrated. It should be noted that if photographs are taken by the operator for the inspector during the inspection, these may be developed by the operator but only in the presence of the inspector. Photographs taken for verification purposes and kept in the custody of the operator must be under inspectors' seal).

(6) The duration of the inspection activities may be limited to an agreed maximum time. (However, the duration of the inspection must provide sufficient time to perform the planned activities. If any anomalies are detected, deviation from the agreed schedule may become necessary).

(7) Access may be delayed by up to 2 hours. (It is understood that from one to a maximum of two hours delay between the request for access to a cascade hall and the actual inspectors' access is required by the operator to protect certain information).

PART III: POSSIBLE INSPECTION ACTIVITIES

Possible inspection activities and associated measures are described below. Appropriate combinations thereof will be adopted for each facility.

A. Verification of Nuclear Material Flows and Inventories

Inspection activities to verify the nuclear material flows and inventories have been studied by the HSP. The findings are that conventional material accountancy and its verification is in principle adequate to meet low enriched uranium detection criteria for plants with separative capacities up to about 2,000,000 SWU/a. Some facilities in states having participated in the HSP presently lie well within this range. One facility would exceed this limit, if the full design capacity were to be built.

For plants with separative capacity up to about 2,000,000 SWU/a, except in exceptional circumstances, inspection activities associated with conventional material accountancy (and related C/S measures) would take place exclusively outside cascade areas. Other nuclear materials in the cascade area (e.g., in the chemical traps) might need to be verified.

Inspection activities outside cascade areas will include examination of operator's records and comparison of their records with reports submitted to the IAEA. In addition, the inspectors will make independent measurements for evaluation of the operator's measurement system and verification of flow and inventory of nuclear material, including the application of appropriate C/S measures.

Statistical techniques and random sampling will be used in the verification activities. Attribute and variable sampling plans should be applied to the whole population of UF6 cylinders to be verified. Provisions should be made to give the inspectors the opportunity to verify the feed, product and tails before they are fed to, or shipped from, the plant.

1. Routine inspection activites outside cascade areas

The inspectors may perform the following activities on the occasion of any routine inspection:

(1) Examination of records

-- examination of the book inventory using facility data (e.g., for the purpose of updating);
-- examination of records;
-- reconciliation of reports with records.

(2) Evaluation of operator's measurement system

-- verification of the functioning and calibration of instruments and other measuring and control equipment, and requestting recalibrations as necessary;
-- verification that the operator's analytical performance conforms to the latest international standards;
-- if necessary, standards of the inspectors may be submitted to the plant operator for measurement.

(3) Verification of nuclear material flow

-- identification and counting of UF6-cylinders and other items containing nuclear material;
-- verification of "empty," gross and net weights of feed-, product-, and tails-cylinders and other items containing nuclear material on the plant operator's scale or an inspectors' scale;
-- observation of taking representative samples for the inspectors from UF6-cylinders, UF6-streams or other UF6-containers;
-- attributes measurements by portable NDA equipment of U-235 enrichment of randomly selected feed-, product- and tails- cylinders and other items containing uranium;
-- attributes measurements by in-line monitors, if available, of U-235 enrichment in gaseous or liquid UF6-streams;
-- application, verification, removal and replacement of inspectors' seals on UF6-cylinders, safeguards equipment, records left at the plant between inspections including any design information kept on the premises of the state, and on agreed valves or flanges or UF6 pipings;
-- verification of the integrity of sealed containers or other sealed items;
-- use of temporary C/S techniques at the feed and withdrawal stations and at the UF6 cylinder storage as well as during LFUA inspections at the boundary of the cascade area, where agreed;
-- Quick Inventory Examination (QIE), if the required instrumentation is available and where agreed;
-- installation and servicing of safeguards equipment. (However, if such safeguards equipment interfaces directly with process operation, and is not removed, the operator will be requested by the inspector to perform such tasks in the presence of the inspector).

2. Physical inventory verification

The physical inventory of nuclear materials (LEU, natural U and depleted U) in gas centrifuge type enrichment plants will be taken simultaneously in accordance with agreed methods in all MBA's and at least once a year. This operation implies switching over the feed flows in the cascades to measured containers and simultaneous switching over of relevant product- and tails-flows to emptied desublimers or to measured containers. All nuclear material, except that in the cascades or where applicable and agreed in the cascade halls, will be itemized and a list of the inventory items will be prepared by the operator to be presented to the inspectors.

In this context the inspectors may perform the following activities, in addition to the activities listed under section 1 above, on the occasion of any physical inventory verification:

-- every item on the list of the inventory items is checked for its existence and for compatibility with the tag value where applicable;
-- the nuclear material in sealed and unsealed containers is verified as described in section 1.3. Verified unsealed containers should be sealed if appropriate;
-- temporary C/S measures may be taken during physical inventory verification, where agreed.

B. Verification of Material Production in the Range of Declared Enrichment

In order to produce HEU, the plant operator would need to:

-- provide the required separative capacity,
-- alter the operational configuration,
-- provide the required withdrawal station,
-- provide the required uranium feed,
-- perform the enrichment operation,
-- restore the operational configuration, and
-- remove or conceal the produced material.

Commercial gas centrifuge plants are composed of a number of identical cascades. A small number of these cascades could be used as building blocks from which cascades designed signed for production of HEU could be constructed. Alternatively, single cascade(s) could be used in a batch recycle mode to produce HEU. In either case, the rearrangement of the cascades could be accomplished by modification at the feed, tails or product headers, but without any or with only a few alterations of the interconnections between the many machines from which the individual cascades are constructed. In this fashion, sufficient separative capacity to produce a significant quantity of HEU could be made available in a centrifuge enrichment plant.

For their facilities, some technology holders have pointed to a degree of transparency for the separation equipment located within the cascade halls. It is claimed to be possible to survey readily and easily the repetitive design of the cascade connecting pipework with feed, product and tails headers. Each cascade has its own connection with valves to the main header pipes. For facilities of this type, it is assumed that the inspectors would rely primarily on visual observations. The use as necessary of installed or portable instrumentation would be a supplementary measure. However, demonstration of this transparency has been performed only for the Capenhurst facility. One of these technology holders further pointed out that the traceability of the UF6 pipes inside and outside the cascade area may assist in the verification that all nuclear material passes through declared Key Measurement Points (KMP). It must be emphasized that visual observation inside the cascade hall alone does not confirm the enrichment level. On the other hand, the access approach proposed for the other facilities would emphasize instrumental measures and verification of process equipment operation. In the latter case, the IAEA would be expected to rely on the use of instrumentation as the primary safeguards technique, and the use of visual observation would be a supplementary technique.

1. Visual observation inside cascade areas

Direct physical access allows inspectors visual observation of safeguards-relevant plant features. Visual observation of cascades assists the inspectors in performing inspections.

Visual observation can help in verification that the nuclear material contained in the cascade area is as declared and thus aid the establishment of the inventory. In addition, visual observation of cascades and associated pipework assists the inspectors in verifying the design information. Such verifications could fall into two categories:

-- the as-designed installation of process equipment, and
-- the as-designed operation of process equipment.

The verification of installed equipment would require inspectors to compare design drawings with, e.g., installed pipes, valves, conduits, pumps, traps, etc. (Some valves and flanges which are normally kept open or closed could be identified in the course of this verification and be agreed to be sealed.) This should also confirm the absence of any equipment or sampling points (as appropriate) other than those declared, which might be used to feed UF6 into or remove UF6 from the cascade.

Visual verification of process configuration can be performed by checking against the design drawings or photographic records supplied by the plant operator (or made in the presence of the Inspectorate(s)). This reference material could, for the sake of protection of information of particular sensitivity, be kept at the plant under inspectors' seal.

2. Technical measures inside cascade areas

Permanently installed radiation monitoring equipment, such as area monitors or pipe monitors, may be used to detect HEU. The inspector could also use portable NDA equipment on pipework, equipment and traps to verify that the nuclear material is as declared.

Other technical measures inside the cascade area would include sampling where safe operation allows and application/verification of seals if so agreed and specified in the Subsidiary Arrangements. In conditions of good traceability of piping it might be possible to perform such activities, and in addition QIEs (where relevant), outside the cascade area.

2.1 Radiation monitoring and NDA measurements

For those plants with greater "transparency" characteristics, any necessary enrichment measurements by portable NDA equipment may be made on the cascade connection to headers located inside the cascade hall. NDA measurements may also be performed on vessels or pipelines, including headers, outside the cascade hall, provided these are directly connected to and traceable from the cascade(s).

Some test results of gamma-ray monitoring with a Ge detector have been reported by the Netherlands, with regard to the Almelo plant. Their measurements indicate that if the plant were to produce uranium of enrichments of 20% or higher, this can be detected by gamma-ray measurements on "top" centrifuges or header pipes. The very preliminary results of neutron measurements with a He-3 neutron detector indicate that large amounts of UF6 (not quantified) are quite traceable by their neutron field. A method of determinng the enrichment of uranium in plant pipework has been demonstrated at Capenhurst. A full technical assessment of the technique has still to be made but it was possible to demonstrate that the measurement could be made with equal validity either inside or outside the cascade hall.

The following radiation monitoring and NDA measurement techniques have been proposed for plants with lesser "transparency" characteristics:

-- individual centrifuge and/or header gamma-ray measurements using a portable, high-purity Germanium (HP Ge) detector;
-- cascade area gamma-ray measurements using a portable HP Ge detector, for example, from the process building bridge-cranes;
-- cascade area neutron measurements using a large number of stationary neutron detectors mounted on cascade service modules;
-- collimated centrifuge gamma-ray measurements taken with an automated HP Ge detector system at the floor level by the operator.

Descriptions and state of the art of relevant monitors in various stages of development were reported to HSP. Monitors tested in the U.S. with promising results are a neutron monitor with four shielded detectors, an unshielded area neutron detector, a gamma-ray area monitor with four NaI detectors, and an intrinsic Ge gamma-ray detector for axial measurements. In all cases, near-field measurement techniques (neutron and gamma-ray) exhibited a greater sensitivity for the detection of HEU production in U.S. centrifuges than far-field measurement techniques. Near-field gamma-ray techniques proved to be more sensitive in detecting HEU production in short time intervals than neutron techniques. More detailed information should be obtained before selection of appropriate monitors can be made and measurement time/configurations can be determined.

2.2 Sampling

Samples may be taken from cascades or from groups of cascades where safe operation allows. The latter may be more acceptable to some plant operators. For the time being, the inspectors do not envisage taking samples inside cascade halls as a routine inspection measure. However, sampling might be considered for clarification of anomalies. Sampling may also be performed on vessels or pipelines outside the cascade hall, provided that these are directly connected to and traceable from the cascade(s).

2.3 Application and verification of seals

Seals would be applied and verified in the cascade area to maintain continuity of knowledge with respect to the status of valves and flanges, if so agreed and specified in the Subsidiary Arrangements. This could be specially useful during plant commissioning and decommissioning phases, e.g., when a new section of cascade piping is being added, or an old section is being retired, taking particular account of the protection of information of particular sensitivity.

Seals are also applied (and verified) to permanently installed safeguards equipment, if applicable.

POSTSCRIPT

Pursuant to Article 34 of the Agreement between the IAEA and the U.S.A. for the application of safeguards in the U.S.A., the United States has notified the IAEA of the addition, effective 1 July 1983, of the Gas Centrifuge Enrichment Plant (GCEP) to the license-exempt portion of the list provided for in Article 1(b) of the Agreement.

Pursuant to Article 2(b) of the Agreement, the IAEA has designated the Portsmouth Gas Centrifuge Enrichment Plant for the application of safeguards under the terms of the Agreement as of 1 August 1983.

The IAEA carried out the first Ad Hoc inspection at GCEP pursuant to Article 69 of the Agreement on 3 August 1983.

Since GCEP is under construction, the U.S. will provide the IAEA with the information needed for Subsidiary Arrangements by about 1 January 1984.

ACKNOWLEDGEMENT

The Hexapartite Safeguards Project (HSP) has received praise as an example of international cooperation at its best. The success of the project can be traced directly to the close working relationship of the technical and policy-making communities and their firm determination to solve collectively a problem which heretofore had escaped solution. In the U.S., the success of the HSP was principally due to the dedication and hard work of a group of people ranging from the scientists at several DOE contractors to senior officials at the Department of State, the Arms Control and Disarmament Agency and the Department of Energy. The list of names of all who contributed to the HSP is long. However, without the support and sound advice provided by Len Brenner (DOE/OSS) and Dave Thomas (DOE/OUE), and the technical writings by Dave Swindle (UCC-ND), Dave Gordon (BNL) and Mike Rosenthal (ACDA), the United States would not have been able to achieve its objective in this important area.

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Calibration and Error Reduction in Neutron Coincidence Counting

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ABSTRACT

The accuracy in measuring the plutonium content by means of neutron coincidence counting can be improved by setting up sample categories and analyzing the categories differently. Four categories of materials are defined, and calibration procedures are recommended for each of the categories. Methods are given to identify which category a sample belongs in and techniques are described to reduce the measurement errors. New data are presented to establish the validity of multiplication corrections, and the application of the correction to induced fissions in uranium as well as plutonium is investigated. Methods are outlined to solve the more general problem of plutonium assay when the (α,n) yield is unknown.

I. INTRODUCTION

Neutron coincidence counting has been used extensively for the nondestructive assay (NDA) of plutonium. Time-correlated neutrons emitted in the spontaneous fission of the even mass number plutonium isotopes are counted to measure the plutonium mass. Electronic circuitry[1] is used to count the total neutron rate (T) and the coincidence rate (R). In most applications, the value of R is related to the mass of ^{240}Pu-effective (^{240}Pu-effective = 2.52 ^{238}Pu + ^{240}Pu + 1.68 ^{242}Pu) to give a calibration curve.

For higher mass loadings of plutonium, this calibration function is nonlinear because of neutron-induced fission or multiplication in the sample. A theoretical procedure to correct for this multiplication was developed by K. Böhnel[2] and N. Ensslin.[3] This correction procedure requires information on the ratio of (α,n) neutrons/spontaneous-fission neutrons (α). For an accurate multiplication correction using R and T, it is essential that the neutron counting efficiency (ϵ) remain constant and that the deadtime corrections are accurate over the entire sample range. For most historical coincidence counter applications,[4,5] these assumptions were only partially valid, and this led to a larger error in the results than otherwise would have been the case.

Recent detector designs[6-8] and electronic improvements[9] have essentially corrected the problems of variable efficiency and erroneous deadtimes. This has resulted in more accurate multiplication corrections, but the basic problem remains that there are more unknowns (M_{240}, M, and α) than knowns (R and T), where M_{240} is the g ^{240}Pu-eff and M is the sample multiplication. The most popular method to deal with the above dilemma is to calculate α from the plutonium isotopics, ^{241}Am content, and (α,n) yields in oxides. However, this last factor requires knowledge of the sample's chemical composition.

Some calibration work[10] has been done by assuming M is known and using T to eliminate the need to know α. This approach works fairly well when the sample density and shape are matched to the calibration standards, but it fails when M is not a unique function of the mass.

Several technical approaches are being evaluated to solve the more general problem of three unknowns vs. two knowns. These approaches include counting higher neutron moments[11-13] add-a-source[14] such as ^{252}Cf, reflectivity or albedo change,[15] and using the measured mass and size to calculate M with Monte Carlo computer codes.

The purpose of this report is to recommend the technical approaches for different types of samples. Data reduction algorithms and calibration functions are recommended to reduce assay errors based on currently available hardware.

II. PLUTONIUM SAMPLE CATEGORIES

Several sample categories are required to cover the large diversity of plutonium samples found in the nuclear fuel cycle and plutonium processing.

These include the following:

Category A
Small samples of plutonium where variations in the neutron multiplication are small or negligible.

Category B
Medium-to-large samples that are free of impurities and that have a low moisture content.

Category C
Medium-to-large samples that are impure or have a large moisture content.

Category D
Medium-to-large samples that have a very high (α,n) activity so that the induced-fission rate dominates the spontaneous-fission rate.

Table I

Plutonium Sample Categories for Calibration of Neutron Coincidence Counters

Category A (Low Mass)	
MOX pellets	(≤5 pellets)
PuO_2 powders	(≤20 g plutonium)
MOX powders	(<40 g plutonium)
Metals	(<10 g plutonium)
Nitrates	(<5 g plutonium)
Category B (Pure Samples)	
Bulk Pellets	
Pure feed PuO_2 powder	
Pure feed MOX powder	
LMFBR fuel pins	
LMFBR fuel assemblies	
LWR MOX fuel pins	
LWR MOX fuel assemblies	
Pin and pellet storage trays	
Plutonium metal buttons	
Plutonium metal coupons (trays and birdcages)	
Scrap reject pellets	
Category C (Impure and Moist Samples)	
Impure or moist PuO_2 powder	
Impure or moist MOX powder	
PuO_2 with unknown ^{241}Am content	
Plutonium in low-Z matrix or alloy	
Plutonium in scrap or waste	
Category D (High α,n Activity Samples)	
PuF_4	
Plutonium salts	
High ^{241}Am activity salts and alloys	

Some examples of samples that fall into the four categories are listed in Table I.

III. SMALL SAMPLES – CATEGORY A

For sample Category A, where the multiplication is small or negligible, the purity, moisture content, shape, and density make little difference, because the neutrons escape from the sample before causing induced-fission reactions. The calibration curve is practically a straight line. The calibrations of any two detectors are related simply by the ratio of their responses for a ^{252}Cf reference source.

A recommended calibration function is

$$R = aM_{240} + bM_{240}^2$$

$$\text{where } aM_{240} >> bM_{240}^2$$

A typically small sample calibration curve for PuO_2 and MOX pellets is shown in Fig. 1.

The precision for measuring these types of small samples is generally limited by the counting statistics. Figure 2 shows the expected precision as a function of counting time for typical samples in the inventory sample counter (INVS).[16] This counter has a high efficiency (35%), and it was designed for a small sample assay. With careful packaging, the assay accuracy should be the same as the statistical precision down to a value of ~0.5%. Better accuracy than 0.5% will require a good match between standards and unknowns.

A potentially useful application of an INVS type system is to resolve discrepancies in bulk sample NDA. Errors in the neutron assay of large samples are often caused by

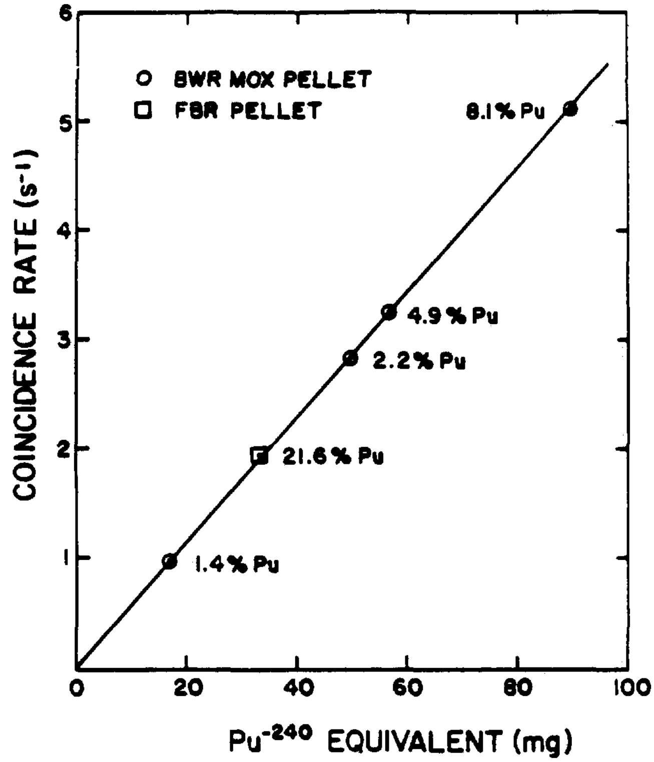

Figure 1. Linear calibration curve for Category A plutonium and MOX pellets in the INVS.

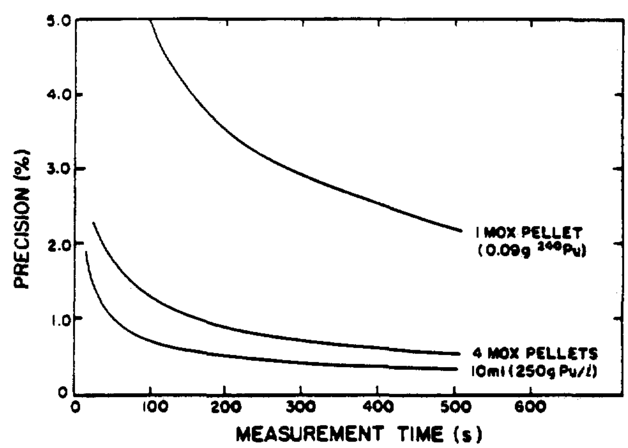

Figure 2. Assay precision as a function of measurement time for typical samples using the INVS.

$$R_{mc} = \frac{R}{CF} \quad ,$$

$$CF \equiv M \cdot r \quad ,$$

$$r \equiv \frac{\left(\frac{R}{T}\right)}{\rho_0} (1 + \alpha) \quad ,$$

$$\rho_0 = \left(\frac{R}{T}\right)_0 (1 + \alpha_0) \text{ (ρ_0 corresponds to the rates from a nonmultiplying sample)} \quad ,$$

$$M = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \quad ,$$

$$A = 2.074(1 + \alpha) \quad ,$$

$$B = -(2.074\alpha + 1.074) \quad ,$$

$$C = -r \quad ,$$

$$\alpha = \frac{134\ f_{238} + 0.381\ f_{239} + 1.41\ f_{240} + 0.013\ f_{241} + 0.02\ f_{242} + 26.9\ f_{241Am}}{10.2(2.54\ f_{238} + f_{240} + 1.69\ f_{242})} \quad , \qquad \text{Equation A}$$

impurities or moisture in the sample, giving an unexpected induced-fission component. If the large sample is subdivided into smaller samples, they can be measured in the INVS with negligible multiplication errors.

The use of R and T to make multiplication corrections should *not* be done, because T from the sample is usually smaller than T from the room background that varies with time. The large uncertainty in T translates to a large uncertainty in the multiplication-corrected reals (R_{mc}). Also, the uncertainty in actual multiplication correction is negligible.

IV. PURE SAMPLES — CATEGORY B

Category B includes the majority of cases where neutron coincidence counting has been used successfully for plutonium assay. These samples include much of the primary feed material for fuel fabrication as well as the final product in the form of pellets, pins, assemblies, and buttons. These materials are generally pure and free of moisture.

The primary requirement for accurate assay in Category B is that the *calculated* α is accurate. This is true for pure mixed oxide (MOX), where the (α,n) reaction probability is essentially the same in UO_2 as in PuO_2. Plutonium metal has the desirable feature that there are no (α,n) reactions so $\alpha = 0$.

Multiplication corrections *should always* be made for Category B samples to reduce assay errors from density, size, and shape variations. Also, induced-fission differences from varying plutonium fissile fractions and ^{235}U mixtures are accurately corrected using the new multiplication corrections given by Ensslin.[3]

This correction is: *(See Equation A at top of this page.)*

where the f_m values are the weight fractions of the plutonium isotopes with mass number m.

If the correct value of ρ_0 is used in the above equations,

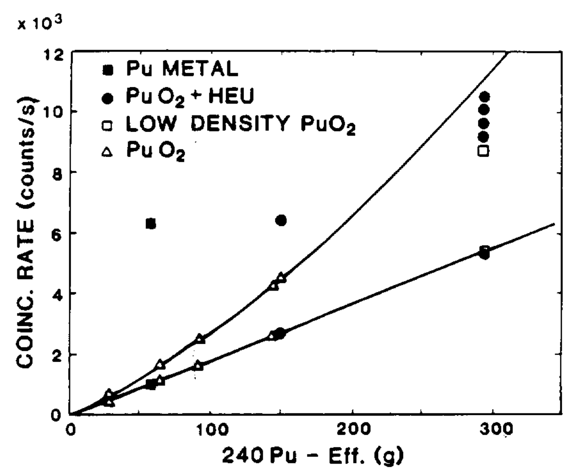

Figure 3. Coincidence rate vs M_{240} for different combinations of PuO_2, plutonium metal, and HEU measured in the HLNC-II.

M is the actual leakage multiplication that can be compared with independent Monte Carlo code computer calculations. This was recently done in Refs. 17 and 18 with good agreement.

When the value of M is measured by R and T, then agreement with the expected value of M from calibration standards and/or Monte Carlo calculations gives an effective verification of the fissile content in the sample. Thus, the passive neutron count gives not only the ^{240}Pu-effective confirmation but also the total plutonium verification by the induced-fission component. The measured value of M should always be compared with the expected value as a consistency check.

A. Multiplication Results

Some impressive examples of the accuracy of the multiplication correction are given in Table II. Several different

Table II

Neutron Coincidence Counting Results Using the HLNC-II (November 5, 1986)

Sample No.	M_{240} (g)	T (s^{-1})	R (s^{-1})	R_{mc} (s^{-1})	$\frac{R_{mc}}{240}$	M
Cf (CR-5)	—	6 539	1 264	—	—	—
Plutonium Powder						
LAO 251C10	29.32	7 717	680.2	538.7	18.37	1.050
LAO 256C10	65.18	17 376	1 698	1 185	18.18	1.079
LAO 255C10	92.2	24 872	2 503	1 669	18.09	1.090
LAO 261C10	144.50	39 623	4 264	2 637	18.25	1.109
LAO 261C11	149.27	41 165	4 510	2 725	18.26	1.115
PEO 447	81.44	25 644	2 342	1 516	18.61	1.090
261C11+261C10 (stacked)	293.77	80 864	8 995	5 329	18.14	1.120
261C11+261C10 (14 cm apart)	293.77	80 621	8 699	5 360	18.25	1.110
Plutonium Powder						
261C11+6 HEU	149.27	44 600	6 385	2 722	18.24	1.209
261C11+261C10 (0 HEU)	293.77	80 672	8 772	5 352	18.22	1.112
261C11+261C10 (1 HEU)	293.77	81 063	9 092	5 330	18.14	1.123
261C11+261C10 (2 HEU)	293.77	81 451	9 259	5 334	18.16	1.127
261C11+261C10 (3 HEU)	293.77	81 859	9 666	5 301	18.04	1.140
261C11+261C10 (4 HEU)	293.77	82 256	9 859	5 302	18.05	1.145
261C11+261C10 (5 HEU)	293.77	82 747	10 222	5 285	17.99	1.155
261C11+261C10 (6 HEU)	293.77	83 215	10 659	5 258	17.90	1.168
261C11+261C10 (7 HEU)	293.77	83 545	10 999	5 234	17.82	1.178
Plutonium Metal plus HEU						
STD 621	57.9	16 523	6 290	1 051	18.15	1.619
STD 621+(1 HEU)	57.9	17 458	7 469	1 059	18.29	1.698
STD 621+(2 HEU)	57.9	18 128	8 329	1 068	18.44	1.748
STD 621+(3 HEU)	57.9	18 572	9 076	1 067	18.43	1.793
STD 621+(4 HEU)	57.9	18.866	9 538	1 068	18.44	1.819

Table III

Plutonium Sample Specifications (Data updated to November 5, 1986

Sample ID	Pu (g)	^{240}Pu-eff (%)	^{238}Pu (%)	^{239}Pu (%)	^{240}Pu (%)	^{241}Pu (%)	^{242}Pu (%)	^{241}Am (%)	α
LAO 251C10	171.7	29.32	0.064	82.08	16.38	1.14	0.35	0.296	0.405
LAO 256C10	384.4	65.19	0.059	82.22	16.28	1.11	0.34	0.269	0.400
LAO 255C10	543.1	92.28	0.069	82.19	16.29	1.11	0.34	0.281	0.408
LAO 261C10	847.6	144.50	0.059	82.09	16.37	1.14	0.34	0.256	0.396
LAO 261C11	875.6	149.27	0.059	82.09	16.37	1.14	0.34	0.256	0.396
261C11+261C10	1 723.2	293.77	0.059	82.09	16.37	1.14	0.34	0.256	0.396
PEO 447	777.2	81.44	0.035	89.05	10.14	0.62	0.16	0.416	0.598
STD 621-000[a] (Metal Disk)[b]	999.2	57.9	(0.01)	(93.96)	5.7	(0.5)	(0.3)	—	—

[a]Isotopic fractions estimated from the ^{240}Pu fraction.
[b]The plutonium metal disk is 4.9-cm-diam by 2.31-cm-thick contained in a can that is 6.9-cm-diam by 4.6 cm high

Category B samples were measured to evaluate the correction procedure. The sample specifications are listed in Table III. The high-enrichment uranium (HEU) standards are metal disks 1-cm-thick by 6-cm-diam with a uranium mass of 500 g (93.15% enriched in ^{235}U).

For the experiments, each sample was measured in the HLNC-II in the normal way. Then the samples were modified by changing the density or high-enrichment uranium (HEU) content to significantly change the neutron multiplication. The increase in the multiplication significantly increased the measured R rate, but the change in R_{mc} was always <1%.

Figure 3 shows the results for the different sample categories in Table III. The calibration curve is a quadratic fit through the pure PuO_2 powders (LAO series). The HEU metal disks were added to the outside of the cans to increase M (the multiplication).

The following cases were evaluated:

(a) Pure PuO_2 powder,
(b) PuO_2 powder plus HEU metal,
(c) Low-density PuO_2 (stacked cans),
(d) Plutonium metal, and
(e) Plutonium metal plus HEU metal.

The R values were the greatest when the HEU metal disks were added on the bottom of the can in close proximity to the PuO_2. However, the R_{mc} values were the same regardless of whether the HEU was added to the bottom, sides, or top of the can.

1. *Plutonium Metal plus HEU Metal.* Of particular interest was the result that the R value for plutonium metal was a factor of ~5 above the PuO_2 calibration curve, but the R_{mc} value for the plutonium metal fell on the same line (0.3% mass residual) as the PuO_2 samples.

The greatest multiplication M was obtained when the 1-kg plutonium metal button was combined with 2 kg of HEU metal. In this case, the value of M was 1.82 calculated by the R to T ratio. The corrected R_{mc} value was the same (absolute mass residual of 1.0%) as for the PuO_2 powders.

2. *Low-Density PuO_2.* Low-density PuO_2 was simulated by placing two cans of PuO_2 powder on top of each other. This reduced the measured R by ~30% from the expected value for a single can containing the combined plutonium masses. This case is represented by the highest plutonium mass point in Fig. 3. The R_{mc} fits the standard calibration line with a mass residual of only 0.2%.

3. *Low-Density PuO_2 plus HEU Metal.* The two cans mentioned in the preceding section were separated with lead disk spacers (~7 cm total height) so that HEU metal could be added between the two cans in place of the lead. The separation distance between the cans remained constant by replacing the lead disks by HEU disks one at a time.

The results of this experiment are shown in Table II. For this special case of a fixed geometric coupling between the plutonium and the HEU, we can determine the amount of HEU in the composite mixture. The results are shown

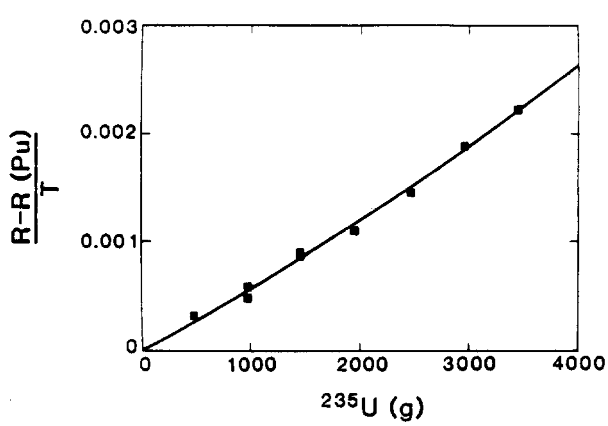

Figure 4. The induced-fission coincidence rate in ^{235}U, R(IF, ^{235}U), normalized by the totals rate vs the ^{235}U mass.

in Fig. 4, giving R(U-235,IF)/T vs g ^{235}U, where the induced-fission rate in the ^{235}U is

$$R(U\text{-}235,IF) = R - R(PuO_2)$$

This calibration curve has the same characteristics as the AWCC[19] calibration for HEU metal.

The practical significance of this result relates to the passive coincidence counting of LMFBR and LWR recycle fuel assemblies. If a series of assemblies differs only in its HEU content, then this type of analysis can verify the HEU loading in addition to the plutonium.

A more careful examination of the results for a systematic substitution of one to seven HEU disks for lead disks shows that the R_{mc} values are slowly decreasing (~0.28/disk). Thus, it is likely that the plutonium-based coefficients given in the multiplication equations (Sec. IV) are not quite right for induced fission in HEU as would be expected. On the other hand, the addition of HEU on the exterior of the PuO_2 (with no lead disk substitution) gives a slight increase in detector efficiency ϵ, which seems to compensate for the HEU/Pu coefficient mismatch.

B. Baseline Concept

The remarkable result of data shown in Fig. 3 is that a single straight line fits all of the R_{mc} cases listed in Table II, with an average mass residual of only 0.8%.

This leads to the conclusion that the most accurate calibration function for Category B materials is a straight line (or "baseline") through the origin

$$R_{mc} = aM_{240}$$

where a is the slope of the baseline. The value of a $\simeq$ 18.2 counts/s•g ^{240}Pu-eff for the HLNC-II ($\rho_0 = 0.103$). The magnitude of a is proportional to ρ_0. Thus if ρ_0 is increased to 0.108 to match the Monte Carlo calculations, the calibration coefficient a ~19.1.

The reason for introducing the baseline concept is that all legitimate data outliers after multiplication corrections will fall above the baseline. If the sample has (α,n) impurities or a high moisture content, the calculated α and/or ϵ will be too small. This results in an R_{mc} result that is above the calibration curve.

On the other hand, if the measured R_{mc} falls *below* the baseline, then the declared mass or isotopics are in error.

If the measured R_{mc} falls above the calibration line by some present error limit (for example, 2-3σ), then we must treat the sample as Category C material.

C. Calibration Results Before Multiplication Corrections

A typical calibration curve (HLNC-II) for Category B samples is shown in Fig. 5, where the PuO_2 sample masses cover the range from 60 g to 8000g.[20] The top curve corresponds to R and the bottom curve corresponds to R_{mc}.

Several different nonlinear functions were evaluated in fitting the R curve, where the primary figure of merit was the average absolute mass residual (percent) in the least-squares fit. The quality of the fit is very sensitive to the weighting on the individual data points. Typical weighting procedures are to assign equal weights to all points, or the square root of R, or the counting statistical error from the

Table IV

Calibration Functions and Fitting Errors for Category B PuO_2[a]

Calibration Form	*Function*	*Av Absolute Mass Error*[b] *(%)*
Power (zero intercept)	$R = am^b$	6.3
Quadratic (zero intercept	$R = am^2 + bm$	4.3
Quadratic (nonzero intercept)	$R = am^2 + bm + c$	3.6
Cubic (zero intercept)	$R = am^3 + bm^2 + cm$	4.3
Cubic (nonzero intercept)	$R = am^3 + bm^2 + cm + d$	3.6

[a]Data corresponds to the 39 sample set shown in Fig. 5 before multiplication corrections.

[b]The data was weighted with an equal percent error (1%) for all coincidence rates.

measurement. All of these approaches are inadequate because none of them are representative of the primary uncertainty causing the scatter in the data. The counting statistics for all data (39 samples) shown in Fig. 5 was better than 0.7%, whereas the observed scatter is 3-8%. The primary causes for the increased scatter is sample-to-sample differences in density, shape, isotopics, moisture, and ^{241}Am content. A better weighting function is to give all of the R values the same percent error (for example 1 or 2%) so long as the counting statistical error is negligible. When the mass range is large, as in the present case, this makes a considerable difference from the other weighting procedures.

Table IV lists the fitting functions used for the 39-sample data set, together with the absolute mass residuals in percent error. The best fit was obtained with a quadratic function (nonzero intercept). The quadratic would be preferred over the cubic that gave the same mass residual because there are less free parameters in the quadratic. All of the functions fit better with a nonzero intercept for a physical reason related to the mass of the samples and the under moderation in the HLNC-II. As the sample mass gets small, the efficiency of the counter decreases slightly because there is less neutron scattering in the sample. Also, the multiplication M is decreasing faster than would be the case for the change in mass alone because the sample shape is changing from a right cylinder with high multiplication

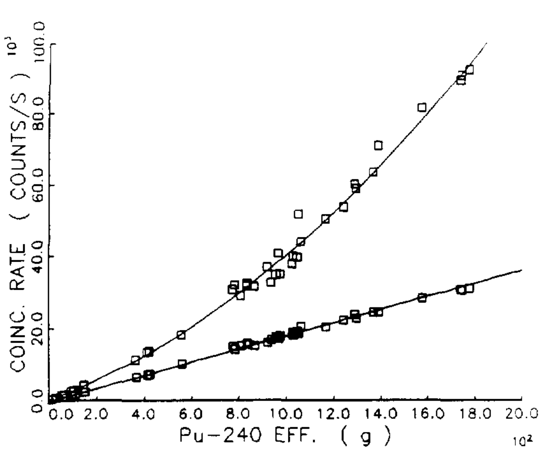

Figure 5. Calibration curves for Category B material (PuO_2) before (top curve) and after (bottom curve) multiplication corrections.

to a pancake that has a very small multiplication. These two factors result in a smaller R than would otherwise be the case for small mass values. When the calibration range is small, the calibration function will adapt to the efficiency shift and the standards and unknowns shift the same. However, for our data set covering the wide mass range, the zero offset was apparent. This zero offset for Category B and C materials does not cause problems because the sample mass cannot go to zero in these categories (low-mass samples are in Category A).

The quadratic calibration function that best fit the R data in Fig. 5 was

$$R = 0.01496\ M_{240}^2 + 25.18\ M_{240} - 52.9$$

so the nonzero offset was -52.9 counts/s on a full scale of 100 000 counts/s. For the data set in Fig. 5, the lowest M_{240} value was 10.1 g so the offset changes the calculated R by ~20% for this small sample.

V. IMPURE SAMPLES — CATEGORY C

When samples fall into Category C (see Table I), then additional information is required to obtain an accurate assay. The simple coincidence measurement gives two knowns (R and T) but there are three unknowns (M_{240}, M, α),

$$R = f(M_{240}, M, \alpha)$$

$$T = h(M_{240}, M, \alpha)$$

In the above equations, we have assumed that the deadtime corrections have been made accurately and that the efficiency ϵ is constant or that R has been corrected for any changes n ϵ. For example, the container wall thickness correction is made to keep ϵ.

In Category B samples, we were able to calculate α from the isotopic ratios and (α,n) neutron yields in oxides. For Category C samples, α is larger than would be the case for pure samples, and we must obtain additional information such as

(1) measurement of higher moments,
(2) the use of ^{252}Cf add-a-source to estimate M,
(3) the use of Monte Carlo calculations and sample parameters to calculate M, and
(4) measurement of the sample both with and without neutron reflectors to change M.

Methods (2)-(4) require an additional measurement on the sample and Method 1 requires improved electronics, data reduction, and detector characteristics. The relative accuracy and convenience of the above methods will be evaluated during the next few years. Work is in progress at Los Alamos on Methods (1)-(3). Method (4) was tried and abandoned after discouraging results.

For the present, Category C data should be fit to both the R and R_{mc} calibration curves obtained from similar standard samples. The calibration functions are the same as for Category B samples. The selection of which curve to use should be made on a case-by-case basis, depending on agreement with declared masses and experience.

A. Higher Moments Technique

In the higher moments approach, the time distribution of coincidence neutrons is evaluated for the multiplicity of the fission neutrons. When neutron multiplication takes place, the induced-fission events occur in the same time window (less than the gate length) as the birth of the original neutron that induced the fission. This multiplicity information can be used to give as many measured parameters (knowns) as unknowns.

Work in this area has been reported by M. Krick at Los Alamos using fast-neutron counting systems, by M. Zucker at Brookhaven,[12] with coincidence electronic modifications to count the third moment, and by Hage and Cifarelli[13] at Ispra, Italy.

B. Californium-252 Add-a-Source

The basis of the ^{252}Cf add-a-source approach is that the multiplication (M) in the sample can be estimated by placing a known source on the exterior of the sample and measuring the incremental multiplication of the ^{252}Cf source.[14] This requires an additional measurement with the source closely coupled to the sample can.

The procedure is to measure the sample in the normal way to obtain R and then to repeat the measurement with the ^{252}Cf source at the bottom of the can to obtain R(Cf plus sample). The totals rates also are obtained and the californium source is measured with no plutonium in the can to obtain R(Cf) from ^{252}Cf.

The parameter that can be related to the multiplication is

$$\frac{R(Cf + sample) - R(sample)}{R(Cf)} \equiv F$$

When multiplication is present, F will be in the range of 1.0-1.3 for PuO_2. In general, F will be less than the reals correction factor (CF) because the multiplication of a source positioned on the exterior of the sample will be less than the multiplication averaged over the volume of the sample.

A more sensitive way to look at F or M is to take the quantities $(F-1)\times 100\%$, and $(M-1)\times 100\%$, which give the percent change from the multiplication process. Figure 6 shows a plot of $(F-1)$ vs $(M-1)$ from a set of PuO_2 powders for masses up to 877 g of plutonium. The M values were obtained from the standard method (see Sec. IV) using R and T. The curve is almost linear until the fill height becomes greater than the diameter in which case the californium source on the bottom of the can is far removed from the added plutonium mass in the top of the can. As the fill height increases, M will increase faster than F because of geometric coupling differences.

This same type of analysis can be performed with the totals rate T rather than R. The T ratios are defined the same as for the reals ratio by

$$\frac{T(Cf + sample) - T(sample)}{T(Cf)} \equiv L$$

where L more closely corresponds to the leakage multiplication M.

The value of $(L-1)$ is about four times less than $(F-1)$ because the coincidence rates amplify the multiplication signal. In general, the T ratios have a very good counting precision, but $(L-1)$ is small and the variation in the totals room-background rates would add uncertainty in the measured L.

The relationship between F and M shown in Fig. 6 is dependent on the geometry of the sample container. Separate calibration curves for M would be required for each can diameter unless corrections are made for the changes in geometric coupling.

To get the plutonium mass, the add-a-source curve (Fig. 6) is used to obtain M, and the equations given in Sec. IV are solved for M_{240} and α.

This add-a-source method of determining M has the desirable feature that sample moisture effects on the multiplication are part of the measurement.

C. Monte Carlo Calculation of M

If the mass and size of the sample are known, Monte Carlo neutronic calculations can be used to determine M. The measured R and T values then can be used to solve for M_{240} and α to determine the total plutonium mass.

The values of M from Monte Carlo calculations[17,18] have been compared with M determined from the measured R and T rates for a large group of PuO_2 powders. A portion of these results[17] are shown in Fig. 7 for the same PuO_2 samples used in Fig. 6. The M values determined from the R and T rates depend on the value of the ρ_0 constant used in the equations in Sec. IV. The value of ρ_0 was increased from the normal value of 0.103 (HLNC-II) to 0.108 to get the agreement with Monte Carlo calculated curve shown in Fig. 7.

Normally, plutonium packages have a known size and shape so M can be calculated, but for powders, the fill height or density is uncertain, and methods are being evaluated to determine the fill height.

For many practical cases of plutonium scrap, the sample size is known but α is unknown and variable. In these cases, the relationship between M and the plutonium mass can be calculated as shown in Fig. 7.

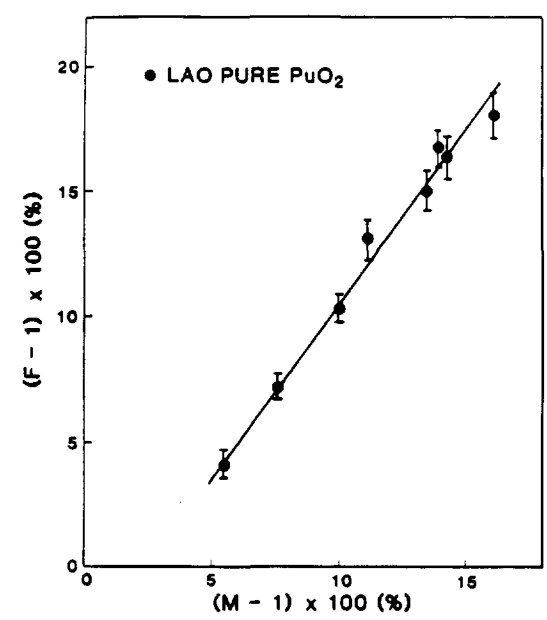

Figure 6. The percent change in the ^{252}Cf source response, (F-1)x100 vs the percent change in multiplication, (M-1)x100, for different PuO_2 masses.

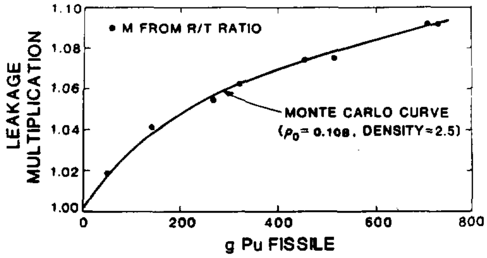

Figure 7. Calculated value of M (solid curve) using Monte Carlo code compared with M values from the R/T ratio (solid points) with $\rho_0 = 0.108$.

D. "Known" M Approach to Assay

Several methods have been outlined to determine M for assay samples. If M is taken as a known from calibration standards or supplemental measurements, then the plutonium mass can be calculated without knowing α.

The multiplication equations can be rewritten as

$$\alpha = \frac{M}{\frac{R/T}{\rho_0} - 2.074(M^2 - M)} - 1 \quad , \qquad (1)$$

and

$$M_{240} = \frac{\rho_0}{a} \frac{T}{(1+\alpha)M} \quad , \qquad (2)$$

where a is the baseline calibration constant defined in Sec. IV.B ($a/\rho_0 = 176$ for the HLNC-II).

Thus, we can treat α as a variable and M as a known for the sample size. Because M is a nonlinear function of the plutonium mass (see Fig. 7), we must assume an initial value of M to solve Eqs. (1) and (2). This gives us a new plutonium mass and M, and the equations are iteratively solved until convergence. If M is set at unity for the first iteration, then convergence was reached in approximately four iterations for several test cases of bulk PuO_2.

This method of using the "known" M to solve for the mass is very attractive for samples with low-plutonium density because M approaches unity. For example, a can containing 0-200 g of plutonium in a 1-*l* volume will have M range from only 1.00 ~1.02 and the uncertainty in M is small.

E. Reflectivity Change

The principle of this approach is to change the reflecting boundary around the sample to vary M, R, and T but to keep α fixed. Potentially there are then enough knowns to solve the problem. However, intial experiments at Los Alamos have indicated that the change in M is small and the value of ϵ changes, introducing a new variable. If thermal-neutron reflection is used, then M changes substantially, but the sample surface area becomes an additional variable. This approach has been used successfully for fixed geometry samples such as fuel assemblies.[15]

VI. HIGH-ACTIVITY SAMPLES — CATEGORY D

For samples with very high (α,n) neutron rates, the induced-fission counting rate R(IF) will normally dominate the spontaneous-fission rate R(SF). Typical samples in Category C incude PuF_4 and plutonium salts.

In this case, where essentially all of the induced fissions are from (α,n) neutrons, the measured rate can be expressed as

$$R = R(IF) + R(SF)$$

and

$$T \approx T(\alpha,n)$$

where T(α,n) is the totals rate from (α,n) neutrons.

The induced-fission rate in the sample is proportional to the neutron flux and the mass of fissionable material in the sample. The ratio of R(IF)/T is proportional to the fissionable mass in the sample.

This self-interrogation approach has been applied to bulk (1-16 kg) UF_6 samples[21] and more recently to high-activity plutonium salts.[22] For the plutonium salts, the precision is about 2-5% for a 1000-s measurement, and for UF_6 cylinders of HEU the precision is better than 1% in 300 s. This self-interrogation approach requires that the calibration standards have a geometry that is similar to the assay samples or that calculated coupling corrections to be made to the data.

VII. SUMMARY

The primary goal of this paper is to give procedures for reducing errors and extending the range of neutron coincidence assay. A key to accomplishing this error reduction is to separate the samples into Categories A-D, and to apply the standard multiplication correction for Category B. More sophisticated correction procedures are described for Categories C and D, and no multiplication corrections should be made for Category A samples.

Table V

Sample Categories and Calibration for Neutron Coincidence Counting

Fuel Category	*Characterization*	*Calibration Parameters*[a]	*Calibration Function*
A	Small Samples	R vs M_{240}	Near Linear
B	Pure and low moisture samples (variable M, calc. α)	R_{mc} vs M_{240} (primary)	Linear
		R vs M_{240} (secondary)	Quadratic
C	Impure and/or moist (variable α, calc. or measure M)	R vs M_{240} R_{mc} vs M_{240} M vs Pu	Quadratic Linear
D	High-activity salts and ^{241}Am (variable α)	R(IF)/T vs Pu fission	Nonlinear

[a]R_{mc} corresponds to the reals rate after multiplication correction.

Table V lists the materials categories and recommended calibration functions. The traditional approach of calibrating with R vs M_{240} is appropriate for Category A materials, but is inadequate for the other categories. Category B materials can give very accurate results (0.5-1.0%) after multiplication corrections. The data reduction is making use of the totals rate, so more care is required to measure T accurately. A short (~10 – s) room-background measurement is desirable before and after the sample measurement to improve the accuracy of the room-background subtraction, and for in-plant counters, exterior neutron shielding will help.

Methods to improve the accuracy of Categories C and D materials are under development and progress has been made for specific cases such as PuF_4 and samples with a predictable value of M.

For neutron coincidence counting, the challenge to reduce the biases is great because of the wide range of sample types. The sample masses range from 10^{-3} to 10^4 g of plutonium, and sizes vary from small pellets to crates and barrels. Improvements in electronics and data reduction hardware and software will expedite the transfer of the technology to the plant environment.

ACKNOWLEDGMENTS

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Howard Menlove received his Ph.D. degree in Nuclear Engineering from Stanford University in 1966. Prior to working at Los Alamos, Menlove had considerable experience in the areas of neutron and fission physics as well as gamma-ray spectroscopy. He spent a year at the Kernforschungszentrum in Karlsruhe, Germany, supported by a Fulbright Award. His recent work has been in the areas of instrumentation for international safeguards, neutron activation analysis techniques, and the application of nuclear methods to the nondestructive assay of fissionable materials. Menlove has served as the International Safeguards Group Leader at Los Alamos National Laboratory, and he is currently a Los Alamos Fellow working in the area of Nuclear Safeguards research and development.

Book Review

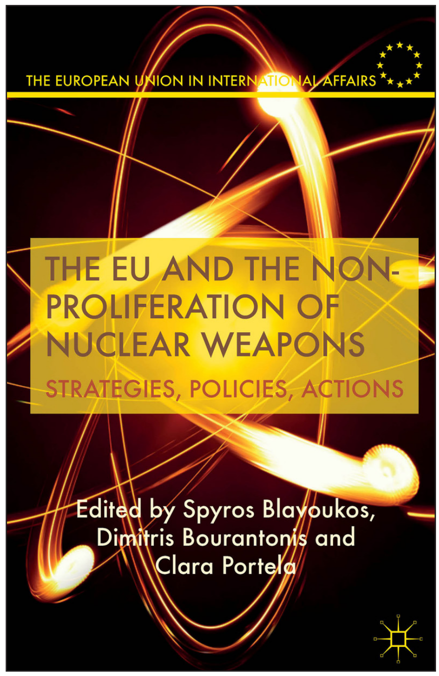
By Mark L. Maiello, PhD
Book Review Editor

The EU and the Nonproliferation of Nuclear Weapons

Edited by Spyros Blavoukos, Dimitris Bourantonis, and Clara Portela
Hardcover, 264 pages
ISBN 978-1-137-37843-9
Palgrave Macmillan, New York, USA and Houndmills, UK, 2015

The Brexit phenomenon has both heightened and potentially lowered the usefulness of this text, which is part of the publisher's series on "The European Union in International Affairs." Written prior to the UK's exit from the European Union (EU), this assessment of the effectiveness of that organization in the nonproliferation regime makes the book somewhat anachronistic if indeed the loss of UK expertise and financial backing will result in a significant detriment to that organization's efforts. No matter, as this significant effort is worthy of attention despite Brexit's unintentional potential effects.

To set the stage correctly, the EU acts as a separate entity within the nonproliferation regime although its constituent nations also sit separately at the Nonproliferation Treaty (NPT) table. The European Economic Community, later to expand into the twenty-eight nation EU, was formed by the Treaty of Rome in 1957. It was amended in 1992 by the Treaty on the European Union (the Maastricht Treaty). These agreements were further modified by the Treaty of Lisbon that entered into force on December 1, 2009. The Treaty of Lisbon abolished the



European Economic Community and the European Union "the EU," was created. The EU adopted a nonproliferation strategy in 2003. This has been backed up since then by financial resources that allow the EU to implement the strategy with a global emphasis rather than a focus say, on the dangers posed only by the former Soviet Union. The 2009 "Reform Treaty" (the aforementioned Treaty of Lisbon), modified the previous two European Union treaties (the Maastricht Treaty and the Treaty of Rome), creating an official president of the European Council and a consolidated "legal personality" for the EU (legal personality allows the EU to enter into treaties and other binding obligations). Thus, the EU became a consolidated legal entity, which allows it to be part of international treaties.

This text grades the EU's efforts in nonproliferation activities up to about the year 2013. There are a few issues for American readers that require comment. First, the very brief and cursory explanation above about the EU's history is more than one will obtain from the text. The authors assume familiarity with the EU's predecessors and structure. Without it, the discussions are still decipherable but cannot be fully appreciated. Secondly, this text is not an easy read. The syntax can be heavy, depending on the author in this ensemble effort of a dozen international contributors. Thirdly, the semi-quantitative manner in which the EU's progress is judged may leave many readers wanting. It is difficult to quantify "success." The authors use a grading system to judge EU performance based on the following criteria: output, outcome, and impact. Respectively, each refers to the policy formulation, the change in EU actions caused by the policies, and the effect the EU actions have on international activities.

What measures are used to judge the EU as a player in nonproliferation fora? The authors looked at several key issues, each author specializing on one of them in separate chapters. An obvious area was performance in the Nonproliferation Treaty review negotiations. Others include U.S.-EU interactions, EU-International Atomic Energy Agency (IAEA) collaboration, EU financial assistance to the nonproliferation regime, EU control of sensitive technologies, the EU response to the Iranian and North

Korean crises, and EU nonproliferation governance.

The essays on each are rich in detail and well organized but overall, the involved language will make this a challenging read for all but the most die-hard amongst us. One of the easier, more straight-forward, and resonant chapters is penned by Clara Portela (Singapore Management University) who assesses the EU's performance in the proliferation crises spawned by Iran and North Korea (DPRK). Her introduction concisely points out that the EU had not been a historically effective nonproliferation force. Her analysis proceeds using the book's framework, focusing on output, in this case the EU's policy formation regarding each crisis; followed by outcome or the implementation of the policies in the international arena; and finally concluding with the impact of the policies i.e., the effects the EU policies produced. As an example of the difficulties associated with the measuring of such parameters, Professor Portela points out that proving causality linked to the EU policies in the mix of policies enacted particularly by those of the U.S., which tend to dominate, is a real challenge to the analyst. To illustrate the many factors involved in evaluating performance, the author points out that Europe was much more engaged economically in Iran than in North Korea. Therefore, applying European sanctions on an already isolationist state like the DPRK has marginal effect. That said, Europe has remained engaged in North Korea by supplying humanitarian aid and agricultural assistance. The EU to its credit entered the fray in both instances and did so when U.S.-Iran and U.S.-DPRK tensions were heightened thus extending international engagement in both instances. Regarding Iran, the EU adopted U.S.-inspired sanctions that also supplemented United Nations actions. However, Portela points out that the EU's cohesive response to the Iranian crises developed under U.S. leadership and pressure and implies strongly that the U.S. influence was necessary for an EU response. As for North Korea, the EU sanctions went farther than those of the United Nations by including numerous bans on trade, banking and military technology, but with less overall effort as compared to its involvement with Iran. Portela does a rather straightforward grading analysis in this chapter. Elsewhere in this book the various discussions and analyses may require a second read.

Lina Grip's chapter on the financial assistance of the EU is perhaps the one to be most affected by Brexit. The EU is a major contributor to the IAEA and also funds the Comprehensive Nuclear Test Ban Treaty Organization. Won't those contributions be diminished with Britain's exit? To analyze the answer, one must understand the EU's output and outcomes in this area. Grip's chapter explains that the EU has taken the lead in voluntary contributions to the IAEA verification efforts. Several non-financial EU initiatives are also discussed including assistance to "third countries" and adoption of a weapons of mass destruction (WMD) nonproliferation clause. Assistance to third countries takes the form of financial, technical and economic cooperation. For example, the EU has established centers of excellence to address WMD risks and initiated efforts to counter nuclear trafficking with a budget of about 266 million Euros for the years 2007 - 2013. The adoption of a WMD clause created an EU policy to include nonproliferation agreements in broader cooperation arrangements with third countries. There have been some successes here (South Africa and South Korea), and some failures (India). This nonproliferation clause is *not* fully essential in EU agreements. It was first used in 2005 in a broad contract with developing states in Africa, the Caribbean, and Pacific island states. Grip's chapter is supported by summary tables that are helpful in grasping the EU's scope of worldwide financial involvement in curbing the spread of WMD. This is a fairly deep analysis although still readable. One supposes that a reader can more readily understand the expenditure of money than say the epistemic networks in the EU's governance (Chapter 12), although what one finds interesting and therefore more comprehensible is best left to the reader's taste.

As mentioned earlier, the text needs a chapter on the organization of the EU and how the various components interact. Unfamiliar readers will grapple with the distinct identities of the European Union, European Council, and the European Commission. As is, the reader must learn the basic function of the EU in the course of reading the chapters. This diminishes the book somewhat especially for American readers. There is a seven-page index and a useful list of acronyms. Two appendices, one on the Nuclear Test Ban Treaty and another on the EU Strategy against the Proliferation of Weapons of Mass Destruction, help to support the preceding chapters, albeit minimally. The concluding chapter summarizing the contributors' assessments of the EU is much more useful.

Will the effects Brexit may have on EU nonproliferation activities make *The EU and the Nonproliferation of Nuclear Weapons* old before its time? In the final analysis, I don't think so. There is value in knowing how impactful the EU has been until now. Brexit in fact, may have imbued this book (unknowingly to its editors) with a new mission. It is an analytical review, albeit couched in somewhat heavy wording, of the EU's historical performance as a worldwide nonproliferation player. That performance can be stated here (without revealing much of the book's insight), as not being insignificant. When considering that in order to learn from mistakes, one must study history and understand the motivations of those that make it lest that history be repeated, one realizes that this book has achieved — perhaps by events outside the efforts of its contributors — new relevance. If Brexit does indeed diminish the role of the EU in the nonproliferation regime, a means to quantify that loss will be needed. *The EU and the Nonproliferation of Nuclear Weapons* can serve as a basis for that future comparison.

Taking the Long View in a Time of Great Uncertainty

Winds of Change

By Jack Jekowski
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In my last column[1] I spoke to the concept of "that will never happen," a technique that has recently become popular in scenario planning activities to stretch the imagination of organizations and help them better prepare for the future. As we monitor current events that we have identified in our discussions of the future unfolding in real time, we can also begin to track sequences of those events that appear to be significant, and speculate on how they might lead to future worlds.

Winds of Change

"Winds of Change", the title of this issue's "Taking the Long View" article, has special significance in world history. One of the most famous references is attributed to British Prime Minister Harold Macmillan in February of 1960 while addressing the South African Parliament, acknowledging that Great Britain would have to give independence under majority rule to its colonies in South Africa:[2]

> *"Ever since the breakup of the Roman empire one of the constant facts of political life in Europe has been the emergence of independent nations. They have come into existence over the centuries in different forms, different kinds of government, but all have been inspired by a deep, keen feeling of nationalism, which has grown as the nations have grown…*
> ***The wind of change** is blowing through this continent, and whether we like it or not, this growth of national consciousness is a political fact. We must all accept it as a fact, and our national policies must take account of it."*

Fast forward to the fall of the Berlin Wall in 1990, and we see a new generation speaking to world events through the music of a hard rock/metal band, the Scorpion's. Although the roots of the ballad, "Wind of Change"[3] occurred a year before with the first hard-rock concert ever allowed in Lenin Stadium, called the Moscow Music Peace Festival, an event that itself was a harbinger of a changing world, its release after the fall of the Berlin Wall made it a worldwide smash, topping the charts in many European Countries:

> *"The world is closing in Did you ever think That we could be so close, like brothers The future's in the air I can feel it everywhere Blowing with the wind of change"*

There certainly was a glimmer of hope back then that the world had taken a major turn to a more optimistic future than what it had faced in the previous decades.

Additionally, in this column, as global events in the latter part of the first decade of the new millennium unfolded, we also explored the "winds of change" blowing through the Middle East as the Arab Spring challenged the status quo,[4] turning into what seems to be a never-ending cycle of change that has yet to stabilize.

Such is the world today – searching for a new normal, but unable to find it.

The Winds of Change Circa 2017 – Implications for the U.S. Nuclear Security Enterprise

As this column goes to print, we are five weeks into the new U.S. administration of President Donald J. Trump, and Secretary of Energy Rick Perry has just been confirmed by the Senate. Also, recently retired General James Mattis has been confirmed overwhelmingly to head the Department of Defense, with an excep-

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.*

tion made by the Senate for his recent military status; active-duty military General H.R. MacMaster, has been selected to be the President's National Security Advisor; and retired General John Kelly has been confirmed as the Secretary of Homeland Security. These and other events point to a dramatic change in U.S. posture from the Obama administration, which had set diplomacy in the U.S. National Security Strategy on an equal footing with defense.[5]

In addition to the scenarios identified in the last *JNMM* column of *Taking the Long View*, another path to the future can be identified in the early tracking of events surrounding the new appointments in the new U.S. administration that raises the specter of fundamental organization changes in the U.S. nuclear enterprise. This perspective includes the possible consolidation of the civilian-controlled nuclear stockpile (under the DOE/NNSA) into the Department of Defense.[6] This scenario had its genesis in events surrounding the DOE Abolishment Acts of late 1990s; the turmoil and public attention that continued to haunt the new National Nuclear Security Administration (NNSA) and the national labs in the first decade of the new millennium; continued targeting of the DOE as a giant bureaucracy by some political agendas based on highly critical studies, and events within the Enterprise; and, most recently, by the indicators presented with respect to the individuals named to lead critical national security agencies by the new U.S. administration:

- For three years, from 1997 through 1999, the 104th-106th Congresses created a master plan to abolish the Department of Energy, dispersing the various programs to different agencies, or eliminating them; and creating a mechanism for identifying "homes" for the seventeen DOE laboratories, from privatization, to the movement of the nuclear weapons laboratories to the Department of Defense (DoD).[7] In its final version in the 106th Congress, H.R. 1649 and the corresponding S.896, provided a detailed plan of how the DOE would be dismantled. Most significantly, the legislation directed the creation of the *Defense Nuclear Programs Administration* within the DoD to transition the current Nuclear Security Enterprise (known then as the Nuclear Weapons Complex) to the DoD. This element of the Abolishment Act defied more than five decades of fundamental policy that was decided with significant debate after the end of WWII, resulting in the creation of a "civilian-controlled" agency (the Atomic Energy Commission — now the DOE/NNSA) to separate the nuclear stockpile from the War Department (now the Department of Defense).
- To counter the growing sentiment for the Abolishment Act, Senator Domenici and others crafted the NNSA Act in 2000, which established the semi-autonomous entity that exists today.
- Despite the hope that the formation of the NNSA, along with the rebidding of the National Laboratories as for-profit models would solve the many issues being identified, problems continued to occur across the Enterprise, and even those who had staunchly held to the original concept of "civilian control" began to have doubts about the future of the Enterprise under such an environment.[8] These events were captured by the author in a graphic that depicts the major disruptions that occurred since the mid 1990s, and which continue to this day.[9]
- In past U.S. Presidential campaigns, some candidates have suggested the dissolution or change in the mission of the DOE.
- The appointment of recent and current military officers to critical national security positions, and the general tenor of the U.S. political environment toward the modernization of the nuclear triad, appear to lay the groundwork for some form of fundamental change in organizational structure, whether that be a more direct separation of the NNSA as an agency unto itself, or as described in the aforementioned Abolishment Act, and other studies, the migration of that Enterprise to the DoD.

Well, that will never happen.[10]

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. The implications for the Institute under such circumstances would be significant, and should be a part of the strategic discussions within the Executive Committee.

The use of the scenario process, where paths to the future are mapped out during times of great uncertainty, can enhance traditional strategic planning activities, 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

1. See *Journal of Nuclear Materials Management (JNMM)*, "Taking the Long View in a Time of Great Uncertainty, *That Will Never Happen – the Power of Scenario Planning*," Volume 45, No. 2
2. See http://africanhistory.about.com/od/eraindependence/a/wind_of_change1.htm for full text of this speech.
3. See http://www.rollingstone.com/music/features/scorpions-wind-of-change-the-oral-history-of-1990s-epic-power-ballad-20150902 for an interesting historical perspective, and https://www.google.com/?gws_rd=ssl#q=scorpions+wind+of+change+lyrics&* for the lyrics to the song.
4. See *JNMM* "Taking the Long View in a Time of Great Uncertainty, *Preparing for Social Chain Reactions*," Spring 2011 Volume 39, No. 3, pp. 28-29
5. See *JNMM*, "Taking the Long View in a Time of Great Uncertainty," Fall 2010 Volume 39, No. 1, pp. 39-41, for a discussion of the events during the first year of the Obama administration, which included the release of a new National Security Strategy that called for creation of a new "International Order," and raised the prominence of diplomacy to the same level as defense and military action; and *JNMM*, "Taking the Long View in a Time of Great Uncertainty, *As the World Turns Toward a More Dangerous Place…"*, Volume 41, No. 4, pp. 111-113, for a discussion on the language in the National Security Strategy equating diplomacy to defense.
6. Historically, "…control of atomic energy from military to civilian hands occurred with the passage of the McMahon/Atomic Energy Act on August 1, 1946, effective from January 1, 1947. This shift gave the first members of the AEC complete control of the plants, laboratories, equipment, and personnel assembled during the war to produce the atomic bomb." (see https://en.wikipedia.org/wiki/United_States_Atomic_Energy_Commission). The Defense establishment, however, as the final customer of the nuclear weapons developed by the Atomic Energy Commission, and subsequent entities, has always had a significant role with respect to advisement, establishing criteria, and ultimately, possession of those weapons.
7. See https://www.congress.gov/106/bills/hr1649/BILLS-106hr1649ih.pdf for the House version of the bill, a ninety-eight-page description of the dismantling plan; and https://www.congress.gov/106/bills/s896/BILLS-106s896is.pdf, a 102-page version preferred by that body. The author developed a white paper summarizing these pieces of legislation that was subsequently updated a number of times during the first decade as events surrounding the creation of the NNSA and 9/11 occurred. A copy of that document can be obtained by emailing the author.
8. In testimony to the House Armed Services Committee in the summer of 2008, Dr. Paul Robinson, former Director of Sandia National Laboratories said: "*Personally, and after many years of believing that it was important to keep the nuclear weapons design, development, and production separate from the Defense Department, I have now reached the point that I believe it is worth considering removing the weapons responsibilities from DOE and placing it as a new agency within the DoD. The presence of a uniformed military could provide a continuity that has been lacking as different administrations came and went. The nation's nuclear deterrent has only suffered from these short-term upheavals in what must be a long-term commitment."* Subsequently, in 2009, OMB asked the DoD and DOE to perform a study on moving the nuclear complex to the DoD. Although several studies in this same time frame examined such a change, nothing resulted from it.
9. See http://www.itpnm.com/whats-new-archives/inmmsw-chapter5-16-13-11x17-foldouts.pdf
10. See *JNMM*, "Taking the Long View in a Time of Great Uncertainty, *That Will Never Happen – the Power of Scenario Planning*," Volume 45, No. 2

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