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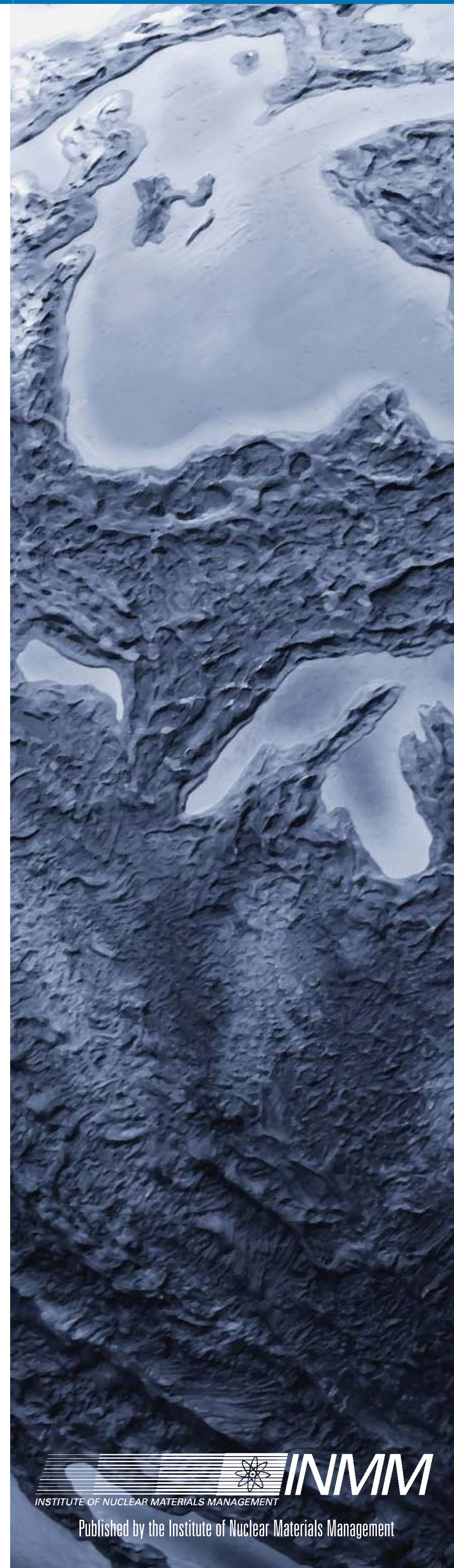

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On the Annual Meeting and the Curtis Challenge

By Cathy D. Key
INMM President

47th INMM Annual Meeting—July 10–14, 2006

We are gearing up for our 2006 INMM Annual Meeting which is scheduled to be held in Nashville, Tennessee at the Nashville Convention Center & Renaissance Hotel during the time period of July 16–20, 2006. The "Call for Papers" has been out for a period of time now with a deadline of February 1, 2006. I hope that everyone was able to meet this deadline to assure another successful meeting. I am looking forward to a very well attended meeting. The INMM Executive Committee and the INMM Technical Committee are scheduled to meet during the time period of March 7–9, 2006. During this meeting the Technical Committee will take the submitted abstracts and construct the layout of this year's meeting. I wish to thank the multitude of volunteers that work on our Technical Committee (chaired by Mr. Charles Pietri) and spend their time putting our meeting agenda together. This committee works like a "well oiled machine" and each year I marvel at how well they work.

46th Annual Meeting—2005, Charles Curtis, Opening Plenary Speaker

During the 46th Annual INMM meeting held in Phoenix, Arizona, USA, Mr. Charles Curtis, president of the Nuclear Threat Initiative (NTI) issued a challenge to the INMM as a whole to play a larger role in the world's number one security imperative—keeping nuclear weapons out of terrorist hands. Looking back at the successful cooperation between the INMM and NTI to put on a "Best Practices Workshop—Safeguards and Security" in 2004 in Prague, Mr. Curtis requested (based on the Institute's independence) that the Institute formulate best practices for safeguarding nuclear materials, to communicate them widely, and to put them into practice throughout the world. Mr. Curtis' talk prompted the Executive Committee to task the Fellows Committee in pulling together a proposal based on Mr. Curtis' speech. (You can see Mr. Curtis' complete speech by clicking on the "Annual Meeting" icon on the INMM Web site — www.inmm.org).

During our November 2005 Executive Committee meeting the Fellows presented their proposal. Basically it suggests the creation of an institutional infrastructure to put best practices in place in every nuclear materials facility in the world. This proposal addresses Mr. Curtis' second element of nuclear materials security which he discussed in his speech. The Executive Committee also allotted $50,000 for a business plan/risk analysis to be performed on the proposal so that the Executive Committee could intelligently make decisions on next moves.

Since the NTI embraced us with the challenge, we felt it appropriate to discuss our proposal with NTI. On December 20, the INMM discussed our proposal with NTI. NTI enthusiastically supports the Fellows proposal. They see it as responsive, creative, and aggressive (in a good way). We assured NTI that the INMM was not ready to move forward on any decision until an appropriate business plan/risk analysis was completed. The business plan/risk analysis would give the Executive Committee important information to move forward and make decisions on what next steps should occur.

The INMM Executive Committee is very sensitive to the fact that the proposal and ideas are very bold and risky. The proposal represents a departure from "business as usual" for the INMM and that many questions must be carefully considered before launching an initiative of this nature. This proposal will be fully communicated to our membership as well, as it will have an effect on the INMM professional organization as a whole. My promise to our members is that the Executive Committee will not move forward on any new endeavor that will not prove positive for the organization. I solicit our members' thoughts, comments and involvement on this topic.

I wish to thank Mr. Charles Curtis for his "thought provoking" speech. I wish to repeat Mr. Curtis' concluding remark to his speech as it truly "hits home" to everyone in the safeguards and security of nuclear materials profession and certainly to all of our members: *"When you took your jobs, and learned what you needed to know to do them well, you may not have envisioned the rise of global terrorism, and the emergence of terrorist groups that seek nuclear weapons. You may not have chosen your profession for the role it would give you in preventing the world's greatest threat. But here you are. Your knowledge and your position confer on you an ability to do what no one else can do as quickly or as well—help the world define and disseminate best practices so we can secure nuclear materials and keep them out of terrorist hands. Logic and professional responsibility tell us this job needs doing and that the mission is urgent. By taking on this responsibility, you can both help safeguard the world and preserve a nuclear future."*

I encourage us to keep these thoughts first and foremost in our minds. Each day we should be thoughtful of the things that we can do in our profession to assure the world is safe from terrorism. As we are involved in many symposiums, workshops, etc. we should all make a concerted effort to move in the direction that Mr. Curtis suggests. We do, like it or not, each hold a unique knowledge and capability that, if used properly, can assure the world is safe for all.

INMM President Cathy D. Key may be reached by e-mail at cathykey@key-co.com.

Developing a Policy on Publishing Annual Meeting Papers

By Dennis Mangan
Technical Editor

Occasionally we receive a paper submitted to the *Journal* where the authors asks if the paper can also be presented at our Annual Meeting. Occasionally we receive a submission of a paper that has already been presented at the Annual Meeting. Occasionally we receive a paper that has been presented at a meeting other than our own Annual Meeting (e.g., the European Safeguards Research and Development Association – ESARDA). Then there are times when I (or someone else) attend a conference and hear a paper that I (or someone else) believe would be of interest to our readers, a version of which was published (or about to be published) in another journal. And, there are articles of which I become aware that have been published in other venues that I believe would be of interest to you. For these latter papers, copyright issues need to be addressed.

We stand firm to our unwritten policy that paper published in the *Journal* should not be presented at the INMM's Annual Meeting, and likewise, papers presented at the Annual Meeting should not be published in the *Journal.* However, because preliminary results are often presented at the Annual Meeting, we encourage authors to consider publication in *JNMM* when their research is complete. At times, however, the other scenarios above are difficult to judge. For example, one of our major decision-making metrics is typically readership, i.e., was a published paper believed to be of interest to the *JNMM* readers published in a venue to which most of the INMM membership normally access?

Our Assistant Technical Editor Steve Dupree has suggested, and I agree, that a stated policy on papers appropriate for the *Journal* needs to be formulated. And I solicit your suggestions on such a policy. I envision the following steps to occur in developing such a policy that eventually would be provided on the INMM Web site in the *Journal* section. With the help of your ideas, Dupree and I will draft a policy statement by February 15, 2006. This will then be scrutinized and amended by comments from our six *JNMM* Associate Technical Editors by early March. The policy statement will then be presented at the mid-March meeting of the Executive Committee for their concurrence. So again, please provide us with any suggestions/comments regarding this publication policy.

This issue of the *Journal* contains three interesting articles, one of which definitely is not within any radar screen on my competencies. The first paper, *Bayes' Approach to System Random Inspections for Nuclear Material Control and Accounting,* by M. V. Gorbatenko, A. M. Zlobin and V. I. Yuferev of Sarov, Russia, addresses a method to facilitate the accounting of accumulated statistical information about a system during measurements of random samples conducted for the purpose of nuclear material control and accounting. William Stanbro of the University of New Mexico and a retired staff member from Los Alamos National Laboratory in the United States provides the second paper, *Seminar War Gaming in Nonproliferation Studies.* This paper definitely has potential application in the futuristic efforts envisioned by the U.S. Department of Energy in addressing proliferation concerns for new and advanced nuclear fuel cycle efforts. The final paper, *Enhanced Techniques and Improved Results in U-235 Enrichment Measurements of Large UF-6 Cylinders by Portable Germanium Spectrometer,* by J. B. Montgomery of the United States Enrichment Corporation in Paducah, Kentucky, USA, provides a pragmatic approach to improvements to the enrichment measurements to determine the U-235 content in UF-6 cylinders to what is purported to be the highest precision and lowest bias currently reported for this type of analysis.

It is with sadness that I end this note. We have received word from Takeshi (Ted) Osabe, secretary/administrative director of the INMM Japan Chapter, that their past president (1992-1998) Mr.Tohru Haginoya passed away on January 5, 2006. Mr.Haginoya played a leading role in the establishment of the IAEA's INFCIRC/153 as a representative of Japan. He also contributed to nuclear nonproliferation and international safeguards. He qualified as a senior member of INMM in 1995 and he also received the INMM's Distinguished Service Award in 1997. We were also informed by Obie Amacker, chair of the INMM's Fellows Committee, that Richard (Dick) Schneider passed away January 4, 2006. While Dick had been unable to participate actively for some time, he had been a very active INMM member, a Fellow and contributor to the profession.

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

JNMM *Technical Editor Dennis Manganmay be reached by e-mail at dennismangan@comcast.net.*

Bayes' Approach to System Random Inspections for Nuclear Material Control and Accounting

M. V. Gorbatenko, A. M. Zlobin, and V. I. Yuferev
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Abstract

A general approach, based on Bayes' theorem, to define a random sample size that would assure meeting a preset statistical criterion is presented here. The approach uses the hypergeometric probability distribution and facilitates the introduction of a function that describes the possible defect distribution in a system (the so-called binary distribution function or BDF) and accounting for *a priori* information, if any. The method will allow correct use of the statistical information about the system that was accumulated as a result of previous sampling measurements.

In the particular case of absence of the *a priori* information about the system, it is shown that both the aforementioned methodology and a typical statistical hypothesis method lead to similar results. The method is applicable to many statistical tasks in nuclear material control and accounting, in particular during inspections.

Introduction

When conducting physical inventories, random sampling, and/or inspections in nuclear material storage facilities that contain many accountable units, it is important to calculate correctly the size of a random sample that complies with a preset statistical criterion. At present, the method of estimating alternative statistical hypotheses[1-3] is widely used, which is valid provided that *a priori* information concerning the system to be inspected is absent.

Another, more general approach to the aforementioned task was proposed in references 4-6. This approach is based on Bayes' theorem, which allows the derivation of the so-called binary distribution function (BDF) for the system being considered. The BDF method facilitates defining random sample sizes whether or not *a priori* information about the system is available. In the latter case the BDF expression is simplified and transformed into a distribution function, which is referred to in reference 4 as the inverted hypergeometric distribution (IHGD).[4]

The alternative hypothesis and the BDF methods are based on different concepts: the first relies on estimating statistical hypotheses, while the second is based on Bayes' theorem and the concept of a distribution function for the probability of system states, each with a different number of deficient elements. However, both methods by their nature are intended to address one and the same task, i.e., defining a random sample size that would allow an inspector to draw a statistically meaningful conclusion regarding the maximum number of defects in the system.

If there is no *a priori* information about the system, the BDF and hypothesis estimate methods result in a similar random sample size, assuming a preset statistical criterion. If *a priori* information about the system is available, the Bayes' approach allows correct accounting for such data.

The present paper compares the results obtained using the BDF and hypothesis estimate methods. In addition it discusses possible ways to account for *a priori* information within the framework of a binary distribution. The Bayes' approach might prove to be rather useful for planning multiple random inspections of nuclear material in large storage facilities with reliable physical protection systems.

Hypothesis Estimate Method

Let us consider the following task: it is necessary to define the minimum sample size n, within which d defective elements are detected, in order to ascertain with probability P that the entire system, composed of N elements, contains less than D_0 defective elements. Sometimes the criterion value D_0 is expressed as the number αN, where α is the fraction of defective elements in the system.

Two alternative statistical hypotheses are:

Null hypothesis: the number of defective elements in the system is equal to or exceeds D_0

Alternative hypothesis: the number of defective elements in the system is less than D_0

The following inequality should be satisfied to disprove the null hypothesis:[3]

$$\sum_{m=0}^{d} w(N, D_0, n, m) \le 1 - P \ , \qquad (1)$$

where $w(N, D, n, d)$ is the hypergeometric distribution function determined by the following expression:

$$w(N,D,n,d) = \frac{\binom{D}{d}\binom{N-D}{n-d}}{\binom{N}{n}} \ , \quad \binom{N}{n} \equiv \frac{N!}{n!\,(N-n)!} \qquad (2)$$

The values N, D, n, and d should be integers and satisfy the following conditions:

$$\begin{cases} N - \text{the population size}; \\ 0 \le n \le N; \\ 0 \le D \le N; \\ 0 \le d \le D; \\ 0 \le d \le n, \quad \text{if } n \le N - D; \\ n + D - N \le d \le n, \quad \text{if } n \ge N - D. \end{cases} \quad (3)$$

In general, the inequality 1 is solved using a numerical iteration method. In a particular case, if only defect-free samplings are allowed, the inequality 1 is simplified and assumes the following form:

$$w(N, D_0, n, 0) \le 1 - P \quad (4)$$

A widely used approximate analytical expression for the required minimum random sample size is obtained from the inequality (4): [3]

$$\left(1 - \frac{n}{N}\right)^{D_0} \le 1 - P \quad \text{or} \quad n \ge \left[1 - (1 - P)^{\frac{1}{D_0}}\right] * N \quad (5)$$

It should be noted that no assumptions about the system to be checked were made with regard to the use of the hypothesis estimate method.

Bayes' Approach

Let us assume that the initial system of N elements might be in states with various defective element numbers D. Let's say that prior to the selection of a random sample of size n, in which d defective elements are recorded, we have certain statistical information about the system state. This *a priori* information may be represented in the form of the function, $p^{ap}(N,D)$, which is the *a priori* probability of the system being in state D (i.e., the probability of the system of N elements containing D defective elements).

Based on Bayes' theorem, an *a posteriori* probability distribution function can be derived based on the following postulates:[4]

- The totality of system states with the various defect numbers D forms an exhaustive group of mutually exclusive events.
- At a given defect number D, the conditional probability of an event, which deals with the detection of d defective elements in a random sample of size n, is determined by the hypergeometric distribution $w(N, D, n, d)$.

The desired *a posteriori* distribution function is:[4-6]

$$p^{post}(N, D / n, d) = \frac{p^{ap}(N,D) \cdot w(N,D,n,d)}{Z(N / n, d)} \quad \text{if} \quad D \in [d, N - n + d]$$
$$= 0 \quad \text{if} \quad D \notin [d, N - n + d] \quad (6)$$

where $Z(N / n, d)$ is a normalization constant independent of D:

$$Z(N / n, d) = \sum_{M=d}^{N-n+d} p^{ap}(N, M) \cdot w(N, M, n, d) \quad (7)$$

The value $Z(N / n, d)$ is a complete probability for the event that consists of the detection of d defective elements in a random sample of size n drawn from a system consisting of N elements.

The distribution function $p^{post}(N, D / n, d)$, defined by Equation 6, is the product of two multipliers, i.e., it possesses a binary structure. That is why it is called *the binary distribution function (BDF).* [4]

The function $p^{post}(N,D/n,d)$ presents a conditional probability that a system consisting of N elements is in the state with D defective elements provided that the random sample size n contains d defective elements.

With respect to the practical application of the *BDF*, it is useful to introduce a cumulative probability distribution function $p^{post}(N, D_0 / n, d)$ with the following form:

$$P^{post}(N, D_0 / n, d) = \sum_{M=d}^{D_0 - 1} p^{post}(N, M / n, d) \quad (8)$$

The cumulative distribution function defined by equation 8 presents the conditional probability that, in the system with N elements, the number of defective elements is less than D_0 if d defective elements are detected in a sample of size n.

The cumulative distribution function defined by equation 8 is required to compare the BDF methodology with the statistical hypothesis method and to define an adequate sample size based on the usual form of a preset statistical criterion both for single and multiple random inspections.

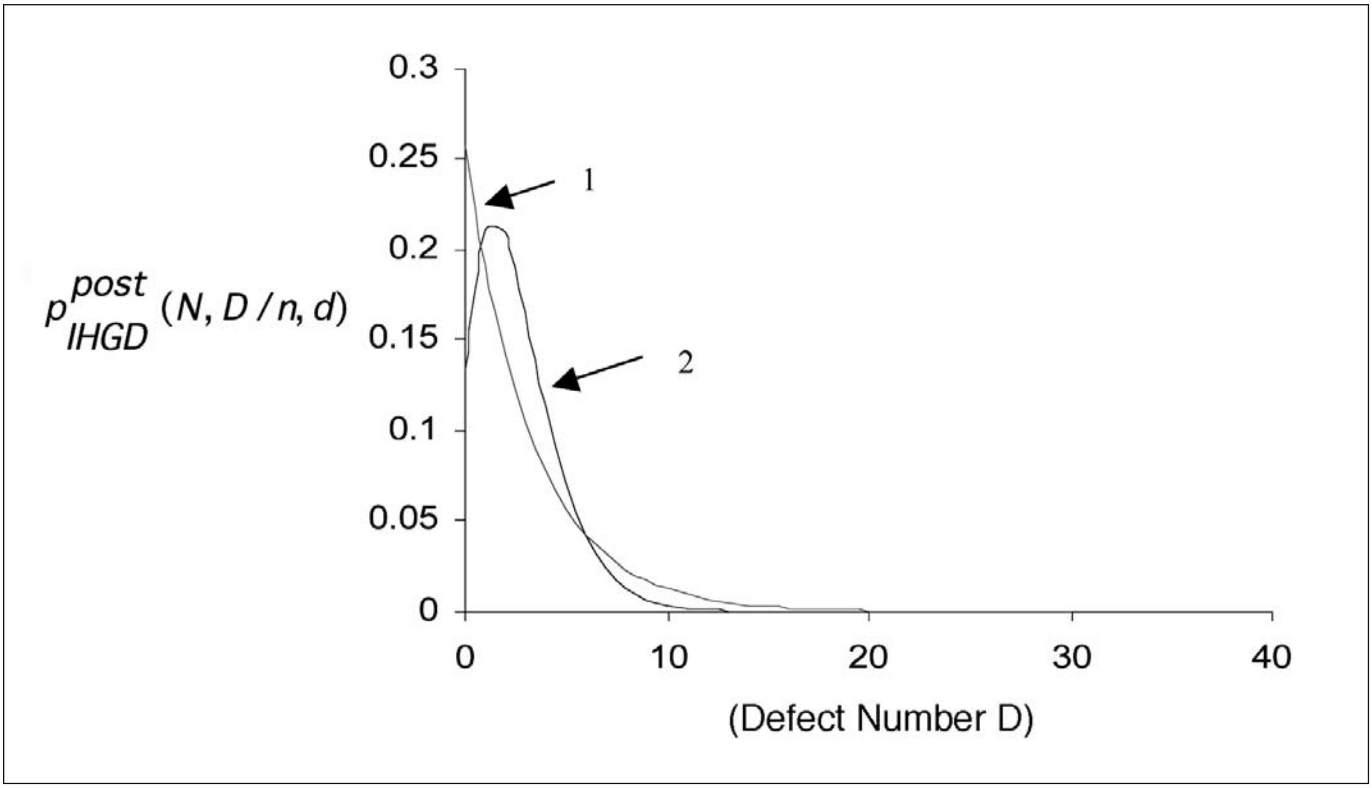
The required sample size may be found by resolving the following inequality:

$$P^{post}(N, D_0 / n, d) \ge P \quad (9)$$

Comparison of the Hypothesis Evaluation Method with the Bayes' Approach

Let us assume that there is no *a priori* information about the system. This means that, prior to conducting measurements on a sample drawn from the system, all system states, characterized by different numbers of defects, are equally probable. If the system consists of N elements, the complete number of possible states with different numbers of defects will be $N+1$, since the number of defects D in the system may assume the values 0, 1, 2,…, N.

Figure 1. *A posteriori* distribution function p^{post}_{IHGD} for the system states with various defect numbers D (N = 1,000; curve 1 has n = 257, d = 0; curve 2 has n = 605, d = 3)



Therefore, in the absence of *a priori* information about the system, the *a priori* distribution function $p^{ap}(N,D)$ is:

$$p^{ap}(N,D)=\frac{1}{N+1}. \quad (10)$$

Substituting Equation 10 into 6 and 8, we obtain the following expressions for *a posteriori* BDF:

$$p^{post}_{IHGD}(N,D/n,d)=\frac{w(N,D,n,d)}{\sum_{M=d}^{N-n+d} w(N,M,n,d)} \quad if \quad D\in[d,\, N-n+d]$$
$$= 0 \quad if \quad D\notin[d,\, N-n+d] \quad (11)$$

$$P^{post}_{IHGD}(N,D_0/n,d)=\sum_{M=d}^{D_0-1} p^{post}_{IHGD}(N,M/n,d) \quad (12)$$

In Reference 4, Equation 11 was called the inverse hypergeometric distribution (IHGD). It presents the probability that, in a system with a total number of elements N for which there is no information about the system prior to sampling, the system is in the state with a total number of defects D, provided d defects are detected in the random sample of size n.

Figure 1 shows two probability distribution functions $P^{post}_{IHGD}(N,D_0/n,d)$ resulting from calculations using Equation 11 for a system that is comprised of N = 1,000 elements. These functions correspond to two different random sampling outcomes: no defects were found in the sampling with n = 257, while d = 3 defects were found in the sampling of n = 605.

The difference between the aforementioned *a posteriori* and *a priori* distribution functions defined by Equation 10 indicates the results, obtained after random measurements, changed considerably the probabilities of the system's being in states with different defect numbers D. As was expected, should a statistical criterion be preset, the fewer defects found in the sampling the closer the maximum in the *posteriori* function is to the ordinate axis.

The random samplings considered are such that, for each, the cumulative probability defined by Equation 12 will satisfy the condition:

$$P^{post}_{IHGD}(N,10/n,d) = 0 + 95. \quad (13)$$

Thus, it is possible to ascertain with the probability of no less than P = 95 percent that in the entire system there are $D_0 < 10$ defective elements; i.e., less than 1 percent of the total number of elements in the entire system is defective.

In order to compare the hypothesis evaluation method with the Bayes' approach, it is necessary to compare the results from numerically solving the inequality given by Equation 1 to those of calculating the *a posteriori* cumulative distribution function

Table 1. Minimal sample sizes *n* required to conclude that with the probability of no less than *P* = 95 percent that the number of defective elements in the system is less than 1 percent of the total number of elements.

Total number of system elements *N*	Number of defects in a sampling							
	d=0		*d*=1		*d*=2		*d*=3	
	St. Hyp.	IHGD	St. Hyp.	IHGD	St. Hyp.	IHGD	St. Hyp.	IHGD
100	95	95	–	–	–	–	–	–
200	155	155	195	195	–	–	–	–
500	225	224	328	328	405	405	462	462
1,000	258	257	393	393	506	506	606	605
2,000	277	277	431	430	564	563	686	685
5,000	290	289	456	455	602	601	738	737

defined by Equation 12, assuming the absence of *a priori* information about the system.

Table 1 cites the computational results for sample size *n* obtained both using the statistical hypothesis method and IHGD. The computations were performed for P = 95 percent, α = 1 percent, and d = 0,1,2,3.

The Table 1 data and calculations for other systems indicate that, in the the absence of *a priori* information, the statistical hypothesis method and Bayes' approach lead in practice to similar results.

Accounting for *A Priori* System Information in Random Sampling

Binary Distribution Function with a Parameter

A priori information about the system, if any, may be accounted for in the probability distribution function. This information may be expressed as a known parameter *q*, the probability of a particular system element being defective. It should be emphasized that the value *q* should be known before conducting the random sampling. In this case the *a priori* probability distribution function $p^{ap}(N,D)$ describing the system states with different numbers of defects may be represented by the binomial distribution:[4]

$$p^{ap}(N,D) = \binom{N}{D} \cdot q^{D} \, (1-q)^{N-D} \qquad (14)$$

In this case, the task of defining the required random sample size, which would correspond to the preset statistical criterion, will be resolved using equations 6-8 and 14. According to our calculations, for the preset parameters P, N, D_0, and d, the minimum sample size *n* will be a non-linear function of the *a priori* parameter *q*.

Figure 2 shows the results of a calculation of the functional dependence of the required size of a random sample with defects on the *a priori* parameter *q*, n(q), for two probability values, P = 95 percent and P = 99 percent.

We note that for a sufficiently small *q*, there is a region of strong dependence of *n* on *q.* If the *a priori* parameter for a given system is small $(q < D_0/N)$, the random sample size required for a preset statistical criterion is small compared with the system size. If the parameter *q* is large $(q > D_0/N)$, the required random sample size becomes comparable with *N.*

Accounting for *A Priori* Information Concerning Previous Sampling

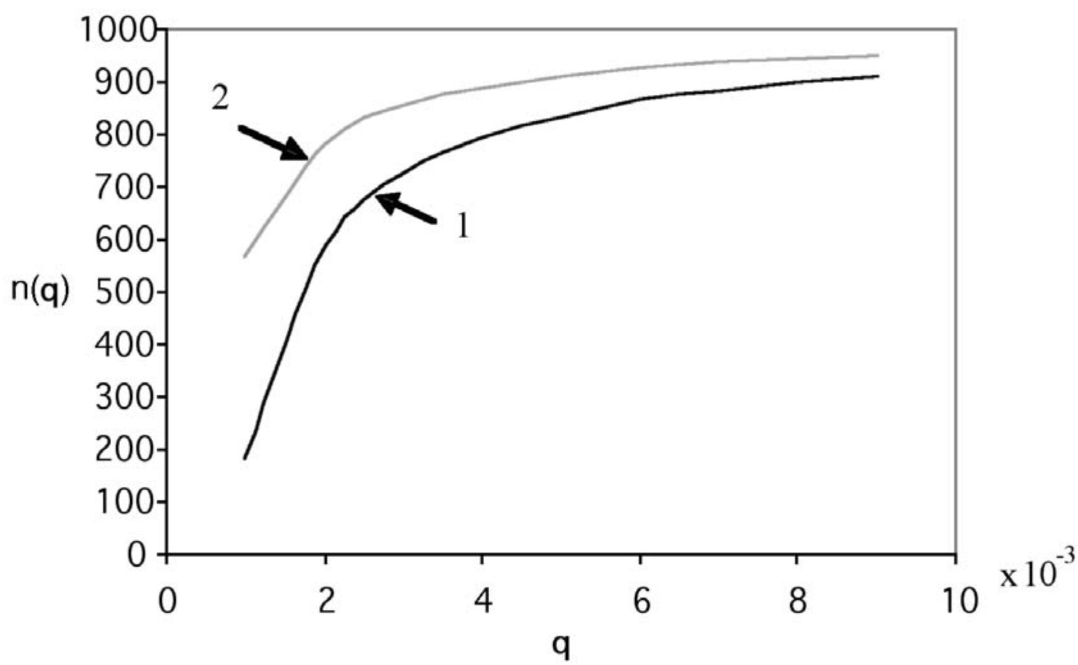
The methodology based on the Bayes' approach is suitable for statistical analysis of sampling in the case of multi-stage inspections.

Let us consider that the system with *N* elements is subject to random sampling, with sample size $n^{(1)}$ in which $d^{(1)}$ defective elements were found. We assume there is no information about the system, i.e., the *a priori* probability distribution function $p^{ap}(N,D)$ had the form of Equation 10. The random sampling outcome changed the probability distribution function for the system states with various defect numbers *D*. The expression for the *a posteriori* distribution function, taking into consideration the sampling results, is [Equation 11]:

$$p^{post}_{IHGD}(N,D/n^{(1)},d^{(1)}) = \frac{w(N,D,n^{(1)},d^{(1)})}{\sum_{M=d^{(1)}}^{N-n^{(1)}+d^{(1)}} w(N,M,n^{(1)},d^{(1)})} \quad if \quad D \in \left[d^{(1)},\, N-n^{(1)}+d^{(1)}\right]$$
$$= 0 \quad if \quad D \notin \left[d^{(1)},\, N-n^{(1)}+d^{(1)}\right] \qquad (15)$$

We assume that, prior to conducting the next sampling, a goal is set to arrive at a statistical conclusion that, with probability *P*, the number of defective elements in the system is less than D_0. Assuming that the information about the system that was obtained during the previous sampling is still valid, we may use the Equation 15 as the *a priori* distribution function to define the next required random sample size. Substituting the latter into the equations 6-8 and solving numerically the inequality given by Equation 9, we obtain the necessary random sample size.

Figure 2. Dependence of the random sampling size n on q at N=1,000, D_0=4, d=2 for two credible probability P curves: curve 1 has P=95 percent, curve 2 has P=99 percent



Such an approach allows the sample size to be defined provided the number of defects in the previous sampling is known. It is possible to account for samplings "with replacement" or "without replacement."

Table 2 illustrates the computational data for minimum sample sizes with respect to a system comprised of 1,000 elements assuming a statistical criterion that ensures, with a probability of 95 percent, that the number of defective elements is less than 1 percent of the total number of elements in the system. Both one and two sampling measurement series were assumed with no *a priori* information about the system.

The second line of Table 2 contains the minimum sample sizes $n^{(1)}$ for one set of measurements that would assure compliance with the preset criterion for different numbers of defectives detected in the sampling.

The third line cites the required sample sizes $n_r^{(2)}$ for the second measurement run in the case for which the previous sample size was $n^{(1)}$ = 50 with no defects. Notably, according to the results of the first measurement run, it was possible to state with the probability P = 40.9 percent that there were less than 1 percent defects in the system.

When calculating the sample sizes $n_r^{(2)}$ for the second run, it was assumed that the elements chosen in the first run were replaced in the system before the second measurement run was conducted (sampling "with replacement"). The values $n_r^{(2)}$ are shown for various defect numbers in the second sampling.

Table 2. Minimal required random sample size for the system consisting of 1,000 elements (P = 95 percent, D_0 = 10) for one and two random measurement runs

d	0	1	2	3	4	5
$n^{(1)}$	257	393	506	605	696	777
$n_r^{(2)}$	218	361	480	585	680	765
$n^{(2)}$	205	341	454	554	645	726

The fourth line in Table 2 differs from the third line in the sense that, after the first sampling (with the size $n^{(1)}$ = 50 without defects), the elements sampled were not returned to the system (sampling "without replacement"). Since the number of elements in the system before the second random measuring run changed, the *a posteriori* distribution function defined by Equation 15 was renormalized before computing the value $n^{(2)}$.

The computational data shown in Table 2 demonstrate the effect of incorporating the information obtained in a previous measuring run, as well as the difference between sampling with and without replacement. It should be noted that the total sample sizes for both measuring runs for the "no return" option almost coincide with the sample size for one measuring run, as required for compliance with the preset statistical criterion (see Table 1). As expected, the "with replacement" option leads to a larger total sample size.

Conclusion

Methodology was presented for determining minimum random sample sizes required to meet a preset statistical criterion based on the Bayes' theorem and on the concept of a probability distribution function that reflects the system states with different numbers of defects.[4-6] This methodology enabled us to develop a general and flexible tool in the form of the so-called BDF, which facilitates the correct accounting of accumulated statistical information about a system during measurements of random samples conducted for the purpose of nuclear material control and accounting.

The adequacy and correctness of the aforementioned approach is proven by its applicability to an important and practical case for which there is no *a priori* information about the system. This is in conformance with the assumption that, before random measurements, all system states with different numbers of defects are equally probable. In this case the BDF methodology leads to results that coincide with those obtained using the conventional statistical hypothesis evaluation technique.[1-3]

Several possible ways of accounting for *a priori* information on the system, if any, are cited. One of these is the introduction of an *a priori* parameter, which is the probability of an individual system element being defective, if such a parameter is known or could be estimated before a random sampling. The paper cites the computational dependencies of required sample sizes on such a parameter for a specific case.

As compared to the hypothesis evaluation method, the Bayes' approach provides additional possibilities for statistical analysis of samples in the case of multi-stage measurements. The Bayes' approach also enables us to consider cases with an arbitrary number of defects in the sample and to account for "with replacement" and "without replacement" sampling.

Thus, the methodology developed based on the Bayes' approach facilitates addressing a wide spectrum of statistical tasks in the area of nuclear material control and accounting, particularly in the case of multiple random inspections.

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Seminar War Gaming in Nonproliferation Studies

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Abstract
Seminar war gaming has proven to be a useful tool in the analysis of conflict situations by the military. However, this type of gaming has not found wide use in nonproliferation studies. This paper discusses the nature and advantages of seminar war games for the analysis of certain types of situations that are of interest to the nonproliferation community. When applied correctly, seminar war games can provide significant insights in a rapid and cost-effective manner.

Introduction
The goal of controlling the proliferation of weapons of mass destruction requires an understanding of technical, socioeconomic, and political systems of extraordinary complexity. While it has been repeatedly demonstrated that analyses based on the scientific method are the most reliable means of solving problems, many significant issues that must be addressed do not lend themselves to such methodologies. In these circumstances other means have been developed that rely on the knowledge and experience of acknowledged experts in a field. An earlier paper by the present author[1] addressed the use of expert elicitation for this purpose. In this paper we address the use of another tool, seminar war gaming, to analyze proliferation-related issues in situations where it is possible to identify two or more opposing points of view.

Seminar war gaming is a tool that has seen limited use in nonproliferation studies, but it is extensively used by the military. Indeed a search on Google produced 112 hits on "seminar war game" with all of them referring to use by the military. Even with the great advances in scientific study of military affairs, many situations cannot be reduced to mathematical expressions and numbers. These situations, which usually involve significant elements of human interaction, defy prescriptive rules. This paper examines seminar war gaming and suggests its application to nonproliferation-related analyses.

History
The history of war gaming is primarily the history of its use to understand and prepare for military conflict. The origins are probably lost in antiquity, but go at least back to the predecessors of the games of Go and chess in China and the Indus Valley, respectively.[2] Further developments in Prussia led to special purpose games that more accurately simulated real-life situations. The major thrust of these games, as well as most of the succeeding developments, has been to train soldiers for situations they might face on the battlefield. The 19th century saw a new use. This was the application of war games to actually develop strategy and tactics. These are referred to as analytical war games. Beginning with the Austro-Prussian war, most operations of the Prussian and German army and later navy were planned with the aid of war games. The United States Navy also took quickly to war games in the 20th century. From the 1920s until World War II the U. S. Naval War College carried out a series of games to develop tactics. Initially, the enemy was Britain, but by the 1930s it was Japan. Admiral Chester Nimitz, in a speech at the War College, credited the games played there with preparing the Navy for almost all of the tactics used by Japanese forces in the Pacific War. The exception was the suicide aircraft, the *kamikaze,* used at the end of the war. This apparently was culturally beyond the understanding of American servicemen.[3]

In the post-War period the success of war gaming led to a rapid increase in its use that continues to this day. In the United States, all of the military services make extensive use of war gaming and a number have dedicated facilities. Increasing attention has been paid to war games as a tool in developing not only strategy and tactics, but also in such areas as weapons system requirements and the capabilities of logistics systems. A major new element in this period is the addition of computer support in areas such as graphical displays, databases, and combat resolution. They have made possible truly *closed* war games (some available information is selectively withheld from opponents) in which the "fog of war" is more accurately represented than previously.[2]

Despite the new technology, the seminar war game has continued to be a mainstay of military war gaming.[2] This is due to the flexibility, cost effectiveness, and general reliability of the format.

The Seminar War Game
An operational definition of a seminar war game is one where all information is available to all sides and participants are free to discuss the possible interactions to determine the likely outcome.[2] A seminar war game is therefore an example of an *open* war game. Typically, two or more teams are formed representing groups with competing goals or interests. The heart of the game is the interaction between these teams. There will also be a control team with the responsibility of facilitating the exercise. Important roles of the control team during play include documentation and analysis

of results. A particularly important member of the control team is the game director who will actually facilitate game play.

Because much of the popularity of seminar war games stems from their great flexibility as an analytical tool, the discussion in the rest of this section should be seen as a place to start. Game designers should feel free to explore alternative approaches.

The steps involved in a seminar war game are:

- Statement of game's goals
- Definition of game scenarios and other design issues
- Selection of team members
- Preparatory meetings
- Playing the game
- After-action report
- Final report

Statement of Game's Goals—As with any analysis methodology it is important to have clear goals in mind. In the case of a seminar war game, it is important not only to put these in writing, but also to share them with all participants.

Definition of Game Scenario(s) and Other Design Issues—The next step is to define the scenarios to be gamed. At this stage, the development group (often synonymous with the control team) may specify a scenario. Another choice is to have the players on the opposing teams flesh out a scenario based on guidance from the developers. Other game design issues are usually specified at this point including the number of opposing teams, scope, number, and duration of time steps, and length of the game. Given the amount of energy expended in a gaming situation, careful attention should be paid to the length of the game to ensure that issues that arise at the end of the game are not ignored or de-emphasized due to exhaustion.

Selection of Team Members—Selection of team members is critical. One should strive to pick members who represent all relevant areas of expertise. One should seek players with good listening skills and the willingness to articulate minority views to prevent the onset of groupthink.

Preparatory Meetings—A preparatory meeting is held to introduce the game and its procedures to all participants. Individual team meetings and personal preparation by participants usually follow. These preparations are key to game success. A seminar game is not about one side or the other winning. Rather, it is about the exchange of ideas on an issue. A common practice is for opposing teams to exchange at least some information developed during the preparatory process so no one is surprised during the game. Surprises only slow game progress as a team tries to catch up by doing its homework on the fly. Another participant issue is the presence of observers at a game. This is generally a good practice, but observers should operate under ground rules that specify when and how much interaction they will have with players to avoid spending too much time on tangential issues.

Playing the Game—During the game itself considerable responsibility rests on the members of the control team. This is particularly true of the game director who is usually responsible for ensuring that all parties have ample opportunity to express their opinions, and must prevent valuable time being lost on marginal or irrelevant issues. One solution is to capture questionable issues for later study off-line. Environmental factors such as room temperature, lighting, and noise levels can be important. The facilitator should also schedule an adequate number of breaks. Providing refreshments during a game is also a good practice.

After-Action Report—Immediately after the end of a game it is appropriate to provide a first summary of what has occurred and allow participants to provide feedback on any aspect of the game. This ending session is a good place to discuss concerns about game results, or elements of the game design that did not allow important issues to be addressed.

Final Report—Unfortunately, documentation of game results and lessons learned is a critical part of war game methodology that has often been ignored. The reader is referred back to the games at the Naval War College in the inter-war years that were praised by Admiral Nimitz. Reporting and disseminating the results was a *sine qua non* of the successful outcome. Hopefully, the final report will be more than a summary of events. Thoughtful analysis of the results, particularly in the context of other information, can be extremely valuable. The report should close with recommendations for further studies or activities to resolve the inevitable questions that arise in the course of a game.

The PUREX Exercise

An example of the application of seminar war gaming to a nonproliferation problem is the PUREX Exercise conducted at the U.S. Department of Energy's (DOE) Hanford Site and at Los Alamos National Laboratory in 1994. This study was part of efforts to define verification options for a possible Fissile Material Cutoff Treaty. The particular problem being examined was determining the most cost-effective way to verify that the large military reprocessing plants in nuclear weapon states were no longer being used to produce plutonium for the production of nuclear weapons. The model facility used was the PUREX reprocessing plant at Hanford, which was at that time being prepared for dismantlement. The game ran for three days at Hanford and one day at Los Alamos.

Participants in the exercise came from the DOE nuclear weapons complex, and included former International Atomic Energy Agency (IAEA) inspectors, members of the LASCAR committee (a multinational study of international safeguards at large reprocessing plants), and experts on safeguards and arms control. The participants were divided into three teams: a facility team, an inspector team, and a control team. The facility team was generally responsible for understanding the working of PUREX under various operating conditions and discussing the effects of various inspection strategies on facility operations. The inspector team was responsible for developing a series of alternative inspection strategies that could be applied at PUREX. The control team was charged with facilitating the exercise and capturing the results.

Before the exercise, the facility team prepared a design information questionnaire (DIQ), a document required by the International Atomic Energy Agency (IAEA) when it initiates safeguards at a new facility. The DIQ provides the information necessary for the IAEA to design the inspection plan for a facility. This provided a good vehicle for the facility team to explain the facility to the participants. The DIQ was provided to the inspector team before the start of the exercise to allow it to develop its inspection plan.

The inspector team's inspection plan was also prepared before the start of the game. The baseline plan was based on "Safeguards Criteria, 1991-1995," which was written by the IAEA Department of Safeguards to cover inspections under INFCIRC/66 and INFCIRC/153. The inspector team also considered alternative inspection measures. During the exercise, the inspection plans were explained to the participants, and the facility team was allowed to comment on the feasibility and impact of the plans.

The control team was responsible for the logistic support of the exercise, the collection of results, and the preparation of the final documentation. The control team also provided questions for discussion during the exercise. This made possible the interaction between the participants on the DIQ and the inspection plan to cover a wider range of options.

The final part of the Hanford phase of the exercise consisted of a comparison of PUREX and the lessons learned there with other reprocessing plants. Facilities discussed included F and H canyons at the Savannah River Site, the Idaho Chemical Processing Plant, and selected foreign reprocessing plants.

During the Hanford phase of the exercise, an effort was made to discuss the pros and cons of each measure in isolation. During the Los Alamos phase, the participants further discussed the individual options and jointly worked on combining the alternatives to produce more effective verification schemes. All the single and combined schemes were then rated in terms of linguistic variables as to their effectiveness, intrusiveness, and cost.

The final phase of the exercise took place off-line. All of the data collected was reviewed and summarized. In addition a detailed set of results was developed. These were included in a final report on the exercise.[4]

Strengths and Weaknesses of Seminar War Games

Like all analysis tools, the seminar war game has its strengths and weaknesses. The greatest strength of a seminar game is its flexibility. In principle where it can go and what it can consider is limited only by the imagination of the participants. Thus, they are able to avoid the structural limitations of traditional closed war games. This also can be the biggest problem. In the absence of a strong, informed control team it is possible to become bogged down in tangential issues or to go off into low probability or totally unrealistic directions. On the other hand the control team must fight the urge to drive conclusions to a preferred endpoint that biases the result. As argued above, a strong, experienced game director is an important asset in avoiding either extreme.

Seminar war games are generally quite cost effective. Even at the most elaborate facilities there are few costs involved in assembling experts and initial results can be made available almost immediately. Most staff time will be taken up with initial preparation of scenarios and final analysis and reporting.

The Roles of Facilities and Computers

The essence of seminar war gaming is the interaction between the participants. That said, the experience can be significantly enhanced by the appropriate use of facilities and computer support. Adequate room size, environmental control, acoustics, the proper positioning of participants to facilitate conversation, ready access to projection equipment, and accommodation of control team members and observers are important features. The Warfare Analysis Laboratory (WAL) at the Johns Hopkins Applied Physics Laboratory is an example of a state-of-the-art facility that has developed over the years to take advantage of modern technology. In addition to the physical features mentioned above, the WAL includes videoconferencing facilities for off-site participants, three-dimensional computer graphics, and support for essentially all types of computers and operating systems currently in use.[5, 6]

Computer support is an important aspect of all types of modern war gaming. However, it is not an end unto itself. Its purpose is to aid the participants in fulfilling their roles. This may include making information available to a player on a particular topic either through dedicated databases or the Internet. It also may include models of various physical or other phenomena that may have a bearing on the participants' assessment of the likely course of an interaction. A major role is the availability of rapid access to graphics such as maps or facility photographs. Taken together these assets can provide immediate resolution of some issues that might have in the past required further analysis off-line.

Possible Applications of Seminar War Gaming in Nonproliferation Studies

Particularly in light of the current rapid evolution in nonproliferation regimes, there are numerous opportunities to implement seminar war game-based studies. These opportunities cover both traditional areas of application, methodology development, and training. Important applications fall into two broad classes: Cooperative Inspection of Sensitive Facilities and Non-Cooperative Inspections.

Nonproliferation regimes such as international safeguards and the Biological Weapons Convention are based to a large measure on a degree of cooperation between the host country and the inspectorate. However, because these inspections often occur at facilities that contain multiple activities including those of a proprietary or national defense nature, legitimate differences in priorities can arise. These situations frequently happen, for example, in Voluntary Offering and Additional Protocol inspections by the IAEA in nuclear-weapon states. Seminar war gaming can provide an ideal way to examine relevant issues in two forms. The first would involve drawing all participants from one party to an issue (either the host country or inspectorate.) This would allow that party to develop a firmer basis for concerns and possible solutions. The second type would use teams composed of members actually representing the two parties (host country members on the facility team and inspectorate representatives on the inspection team.) This second approach would appear to frame the necessary negotiations as a problem-solving exercise rather than an adversarial process.

Revelations of nuclear programs in Libya, Iraq, Iran, and the Democratic People's Republic of Korea over the last fifteen years raise significant questions as to the degree of cooperation accorded nonproliferation regime inspectors. Design of inspections and training of inspectors becomes of critical importance in these situations, as well as more formalized challenge inspections regimes such as that in the Chemical Weapons Convention. Seminar war games can provide a method of preparing for such eventualities. Here of course the members of both teams must be drawn from the inspectorate. However, this is not much different from the typical military use of seminar war games. The biggest concern will be the limited information that is often available on facilities in the host countries. However, the military typically develops a cadre of personnel who are trained to reflect the capabilities and thought processes of the adversary.

Conclusions

Properly executed, seminar war games are a valuable tool in analyzing conflict situations in proliferation related areas. They are generally quite cost effective compared to other analysis techniques and can provide answers in a timely fashion.

As with most analysis techniques involving the use of experts, the success of a seminar war game depends heavily on the individuals involved on the teams. Therefore, it should not be seen as a panacea or a substitute for careful engineering analysis where this is feasible. However, in the many situations where detailed engineering analysis based on the scientific method is impossible, seminar war gaming is an option worth considering.

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Enhanced Techniques and Improved Results in ^{235}U Enrichment Measurement of Large UF_6 Cylinders by Portable Germanium Spectrometer

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Abstract

Enrichment measurements to determine the ^{235}U content in uranium hexafluoride (UF_6) cylinders are easily performed utilizing portable gamma spectrometry via the enrichment meter method. However, previously demonstrated uncertainties associated with the method using small germanium detectors are poor, at best. In this work, control of certain analytical parameters has resulted in improvements to the measurement leading to what is believed to be the highest precision and lowest bias currently reported for this type of analysis. These parameters include:

Detector Placement

Utilization of a positioning bracket to which the detector was mounted provided stability for analysis at any point on the cylinder. This is very important because in large cylinder storage areas there are many configurations of rows and stacks of cylinders. It is expedient to be able to perform the necessary analysis in the region of the cylinder that lends itself to approach. This versatility was necessary in order to allow thickness measurements to be performed at any location on the cylinder and to avoid surface anomalies and UF_6 void areas.

More Rigorous Cylinder Wall Thickness Measurements

Multiple thickness measurements at the exact location of gamma analysis were averaged for an accurate thickness. Areas of non-reproducible thickness were avoided.

Avoidance of Cylinder Surface Anomalies

Areas of obvious corrosion, roughness, etc. were avoided. Likewise, internal areas of corrosion were avoided when detected.

Avoidance of Large Interrogation Void Areas

Regions within the cylinder void of UF_6 were avoided when detected. For example, if the UF_6 mass was known, the fill height could be determined. Also, cylinder position with respect to the sun was utilized to determine migrational characteristics of the contained UF_6.

The types of cylinders involved in the measurements were 30B, 48X, 48Y, and 48G cylinders ranging from 1/4″ to 5/8″ wall thickness. As would be expected due to a loss of signal strength in the 185.7 keV region, the uncertainty of the measurements increased with increasing cylinder wall thickness and decreasing enrichment. Even so, the results for all cylinder types and enrichment ranges measured were excellent with respect to those reported previously for other nondestructive analyses.

Introduction

In the current global environment, a strong nuclear material control and accountability (NMC&A) program is imperative to demonstrate effective control of fissile material. A significant portion of this program is the verification, or confirmatory measurement, of enriched uranium. As with measurements of all types, improving upon accuracy and precision, or decreasing uncertainty, is an elusive goal, a target that becomes smaller as gains are made. To complicate this, in the enrichment industry confirmatory measurements must be made on incoming receipts of uranium hexafluoride (UF_6) as well as randomly selected cylinders of all inventory. At the Paducah Gaseous Diffusion Plant (PGDP) in Paducah, Kentucky, thousands of large cylinders of UF_6 covering the range of ^{235}U enrichment up to the Nuclear Regulatory Commission (NRC) license maximum of 5.5 wt percent are held in various locations (yards). These cylinders not only vary in enrichment but also in the type of container, size and wall thickness. To further complicate the situation, the cylinders may be in many arrays; single cylinders, single rows, multiple rows separated by only a few feet and cylinders stacked two high in any of the row configurations.

The preferred method of analysis for ^{235}U enrichment of UF_6 is via gas mass spectrometer. However, extraction of a cylinder from a large storage yard is very time consuming and often requires the movement of many other cylinders. Couple with this the sampling of the cylinder into a laboratory friendly container, the subsequent analysis and then disposition of the sample and the analysis becomes prohibitive. The same drawbacks apply to all laboratory analyses and thus a portable field measurement is much preferred. A highly portable and long-utilized instrument for this analysis is the Shielded Neutron Assay Probe (SNAP).[1] However, the SNAP exhibits poor accuracy and precision as well as having many limitations. One of these limitations is the difficulty of shielding background neutrons. With the various arrays of adjacent cylinders, the background is far from being a constant and the measurement of a reliable background is questionable. Obviously, this affects the accuracy of any given measurement. Another limitation is that the cylinder must be full with respect to the detector view. Cylinders that are less than at least half full would yield enrichment results with a significant low bias. Gamma radiation, however, is much easier to shield and has a much smaller region of view, or interrogation volume. Hence, gamma spectrometry is the preferred method of analysis as well as the one commonly utilized by the International Atomic Energy Agency (IAEA).

The Multigroup Gamma Analysis for Uranium (MGAU) method[2,3] produces highly accurate results for ^{235}U enrichment. However, it is limited to thin walled cylinders and UF_6 that has attained equilibrium for ^{238}U and ^{234}Th (daughter of ^{238}U). In this work, the cylinders are thick walled and many must be measured prior to attaining equilibrium. Utilization of the enrichment meter method,[4-6] relying solely upon the 185.7 keV peak, with a germanium detector has proven reliability for confirmatory measurement. The IMCA (Inspection Multi-Channel Analyzer), a portable system developed by Canberra, specifically the Portable Multi-Channel Analyzer with Germanium Detector (PMCG),[7] has demonstrated improved performance in confirmatory measurement.[8] The precision of such measurements, however, has proven to be poor. Much of the uncertainty of this measurement is believed to be due to the cylinder wall thickness measurement rather than the gamma spectrometry.

More recently, small coaxial High Purity Germanium (HPGe) detectors were used with FRAM isotopic software[9,10] to supplement the enrichment meter method, allowing the ultrasonic thickness measurement of the cylinder wall to be avoided. This method is much more time consuming than the enrichment meter method making it much less desirable for use in measuring large numbers of cylinders. All of the previously reported ^{235}U enrichment measurement scenarios for thick walled cylinders suffer from poor precision and accuracy. Relative standard deviations of up to 10 percent are typical, certainly not less than 5 percent. Relative biases also range up to 10 percent. Also, data reported has been upon analysis of very few cylinders, typically <15.

In this work, the PMCG, making use of the enrichment meter method, has been utilized successfully to measure over 1,700 cylinders of UF_6 to determine the ^{235}U content. These cylinders ranged in wall thickness from 8 to 16 mm. The UF_6 ^{235}U content ranged approximately from 0.3 to 5.0 wt percent, categorized as depleted (DUF_6), normal (NUF_6) and low enrichment ($LEUF_6$). Very significant improvements to the measurement uncertainty were realized, as compared to other reported results. The improvements are due in large part to a more precise cylinder wall thickness measurement. Five thickness measurements, approximately equally spaced within a circle the size of the active surface of the detector (~1″ diameter), were averaged. These measurements were made at the exact location at which the gamma measurement was to be performed. More importantly, if the multiple measurements were not reproducible, or had outliers, another area of the cylinder was chosen for the measurement. Often, this required choosing a location on the cylinder that presented a smooth surface, absent of rust or other surface anomalies. In other cases, areas that appeared to be optimum visually did not lend themselves to reproducible results. These were assumed to contain internal corrosion due to the high reactivity of UF_6. In order to access this optimum region, a detector stand was fabricated and dubbed the Nominally Adjustable Targeting Enabler (NATE). The NATE was utilized to maintain detector stability for interrogation at any position on the cylinder. This included the top, side, end and near the bottom (especially on upper stacked cylinders). The avoidance of areas of a cylinder that contain large volumes void of UF_6 also resulted in improved results. Obviously, cylinders that are partially filled can be measured from a lower position on the cylinder. A less obvious obstacle is a cylinder that is partially shaded. Multiple rows of stacked cylinders sometimes have one end that is in direct sunlight daily while the rest of the cylinder is shaded, especially on the bottom row. This leads to migration of the UF_6 away from the end that is at higher temperature. Simply measuring the cylinder from the shaded end sometimes results in an improvement in the accuracy of the measurement. Lastly, a rigorous calibration/performance check regime was followed for the ultrasonic thickness gauges to ensure accuracy and precision.

Improved ^{235}U enrichment results based upon enhancements, as described above, to techniques commonly utilized in the confirmatory analysis of large UF_6 cylinders are demonstrated in this work. Specifically, a reduced bias (i.e. - improved accuracy) and tightened precision have been realized while maintaining high portability, speed of analysis, flexibility in the types of cylinders measured and simplicity in calculation.

Measurement System

The measurement system used in this work is the Canberra Industries IMCG (Inspection Multi-Channel Analyzer with Germanium Detector), an all-in-one system comprised of the Inspector Multi-Channel Analyzer, germanium detector and the associated software. Three of these systems were utilized, configured as follows:

Detector	Low Energy Germanium (LEGe), 500 mm^2 active area planar germanium, 25.2 mm diameter X 15 mm thickness. Systems 1 & 2 operated at a bias of – 2000 V. System 3 operated at a bias of –1,500 V.
MCA	InSpector 2000 (IN2K) portable Multi-Channel Analyzer (MCA), 4,096 channels, 185.7 keV peak centered at channel 2476.
Software	IMCA 2000 operated in the GENIE 2000 environment, communication with MCA via USB.

Figure 1. Detector system (detector, MCA, computer, NATE and absorber plate) during analysis of a U_3O_8 standard for calibration

Computers	IBM ThinkPad i Series 1400, Windows 98 (Systems 1 & 2) HP Omnibook 6100, Windows XP (System 3)	
Ultrasonic Thickness Gauges	Krautkramer Branson Krautkramer	Model DM4 DL Model DM4 E
NATE	Detector positioning bracket fabricated from 3/4″ square stainless steel tubing with a quick attachment 360° swivel hinge for multidirectional interrogation approach.	

The highly automated system included total computer control of the MCA[11] and automatic data storage and analysis through a preset region of interest containing the 185.7 keV peak. The software handled immediate calibration constants upon standard analysis or through the use of spectral files.

Calibration and Performance Limits

Calibration was performed against a set of NBS-SRM-969 U_3O_8 standards (Table 1). The U_3O_8 in these standards is infinitely thick with respect to the energy of the gamma emission at 185.7 keV. In other words, the intensity of the measured gamma rays at that energy is not subject to increase with increasing sample thickness. For all practical purposes, all standards and samples are equal in mass if at infinite thickness.

Five successive measurements of each standard were performed during the calibration with a measurement time of five minutes. All measurements were included in the generation of the calibration constants. A 1/4″ steel plate between the detector and standard was utilized to mimic the cylinder wall, partially counterbalancing the effects of the cylinder wall as an absorber. Figure 1 is a picture of the entire detector system (detector, computer, MCA, NATE positioner, and absorber plate) set up with a calibration standard in place.

Table 1. Calibration and control standards

NBS-SRM-969 standard ID	Declared enrichment (wt percent ^{235}U	Standard type
031-074	0.3166 ± 0.0002	Calibration
071-074	0.7119 ± 0.0005	Calibration
295-074	2.9492 ± 0.0021	Calibration
446-074	4.4623 ± 0.0032	Calibration
194-105	1.9420 ± 0.0014	Control

The software[12] automatically generated the calibration constant (K) for the determination of sample enrichment (E) according to the following equation:

$$E = K * R * CF_{mat} * CF_{mT} \quad (1)$$

Where: R = Net count rate @ 185.7 keV

CF_{mat} = Matrix material composition correction factor, tabulated values calculated relative to the calibration standard matrix material (internal to software)

CF_{mT} = Container wall correction coefficient = e^{mT}

m = Linear attenuation coefficient of the container wall for 185.7 keV photons

T = Container wall thickness

The IMCA 2000 software automatically applied a correction for the aluminum standard container wall thickness, matrix attenuation differences between U_3O_8 and UF_6, as well as the difference in thickness of the absorber plate and the UF_6 cylinder wall. Equation 1 is based upon standard equations for infinite-thickness[4] gamma measurement. All calculations performed by the software were verified utilizing simple spreadsheet calculations. Validation of the calibration and all calculations were performed using known U_3O_8 and UF_6 standards, utilizing absorbers of known thickness with the U_3O_8 standards.

Following calibration, a 1.942 wt percent ^{235}U standard from another NBS-SRM-969 set was utilized to set up performance limits. A series of at least 30 measurements of the performance check standard were taken. From these, the standard deviation (σ) was determined and performance limits set up with the warning at the average +/- 2 σ and control at the average +/- 3 σ. During subsequent measurement of cylinders, the performance check standard was analyzed immediately before and after each sample batch. The bias and precision of the system were calculated after measurement of at least thirty cylinders. These uncertainty values were updated as results from sample analysis were generated and tag values confirmed by the GS-MS laboratory at the Gaseous Diffusion Plant (PGDP) in Paducah, Kentucky.

Cylinder Measurements and Results

Prior to the actual analysis by gamma spectrometry, thickness measurements were performed on each cylinder wall, typically constructed of ASTM A-516 steel. The thickness was utilized by the software in correcting for the attenuation of the 185.7 keV signal. All thickness measurements were made after either calibrating the thickness gauge or verifying the accuracy thereof against a certified five-step test block, traceable to NIST. The verification was also performed after measurement of the sample batch. The requirement was for these measurements to be +/- 0.08 mm of the certified value. For cylinders, five approximately equally spaced thickness measurements were taken in a circular area the size of the active detector face (~1" diameter). These were averaged to obtain the thickness to be utilized in calculations of enrichment.

The measurements were made at the exact location at which the gamma measurement was to be performed to ensure that non-homogeneous cylinder wall thickness did not affect the quality of the measurement. More importantly, if the multiple measurements were not reproducible, or had outliers, another area of the cylinder was chosen for the measurement. Often, this required choosing a location on the cylinder that presented a smooth surface, absent of rust or other surface anomalies. In other cases, areas that appeared to be optimum visually did not lend themselves to reproducible results. These were assumed to contain internal corrosion due to the high reactivity of UF_6. Important to note is that for internal or external corrosion, even though the five successive measurements in a small region may not be precise, they may be accurate. However, the individual measurements may not be representative of the entire region covered by the active detector face.

The accuracy of the thickness measurement is crucial to the quality of the overall analysis. For example, an error of only 0.1 mm on a cylinder thickness of 13.5 mm biases a result approximately 0.05 wt percent ^{235}U on an actual enrichment of 4.4 wt percent ^{235}U (greater than 1 percent relative error). Assuming a cylinder wall thickness based upon the reported nominal wall thickness would introduce huge errors to the overall measurement. For example, cylinders with a nominal thickness of 8, 12.5 and 16 mm often measure in excess of 9, 14, and 18 mm, respectively. In earlier work,[4] the use of a thickness gauge, "essentially removing the wall thickness from consideration as a source of measurement bias", was considered accurate even without the attention to the specifics presented in this work. In part, this was due to sanding the paint off of the particular location on a cylinder for good acoustic coupling. This is not an option for current work for radiological reasons as well as for the integrity of the cylinder. The other reason that the thickness measurement bias was not considered important was because this bias was small compared with the total bias. The uncertainty due to the thickness measurement was estimated at 0.4 percent (0.002"). For 4.4 wt percent ^{235}U, this would bias the result ~0.025 wt percent, a 0.6 percent relative error. The total bias was not reported but was apparently large enough to render this thickness error unimportant. For work presented in this paper, the total bias for that particular type of cylinder will be shown to be ~1.26 percent relative, only double that quoted for the thickness measurement alone in the earlier work.

Cylinder wall curvature is one source of bias that was not taken into account in this work even though a flat absorber was utilized during calibration. The reason for this omission is the relatively small size of the active surface of the detector (1" diameter). For a 30B cylinder (the smallest diameter cylinder measured), the curvature encountered would be <4 degrees. This would increase the distance from the UF_6 to the detector a maximum of 0.02″ at the extreme edges of the detector and then only in the two locations on the detector along the lengthwise axis of the cylinder. The attenuation due to air of 185.7 keV photons is insignificant through this distance. The distance through the cylinder wall traversed by photons approaching the detector in a non-perpendicular fashion was investigated, as well. If a photon is approaching in this fashion from the outer perimeter of the detector, a maximum increase of 0.1″ thickness of steel may be added for a 45 degree approach to the detector. It should be noted that the detector is highly collimated, minimizing photon access from outside the detector radius. Also, contribution from photons approaching at 45 degrees relative to the detector is minimal, at best. This results in minimal non-perpendicular contribution of the total signal. Coupled with that is the fact that photons approaching the detector from a position perpendicular to the center region of the detector and approaching in a non-perpendicular fashion actually travel through a shorter path of the cylinder wall. This results in a partial offset to the loss from the outer perimeter. In summary, the loss in total photon signal due to curvature is expected to be relatively insignificant. Likewise, the uncertainties in the calculated loss would be relatively high. For these reasons, adjustments were not performed to account for biases due to cylinder wall curvature.

The importance of performing the thickness measurement at the exact location of the gamma analysis cannot be overstated. The thickness varies greatly at differing locations on a cylinder even if corrosion or other surface anomalies are homogeneous or do not exist. Even locations close together in the same region, such as the side of a cylinder, may exhibit relatively large differences in thickness.

Table 2. Summary of UF_6 cylinder types measured

Cylinder type	Number of cylinders measured	~ Range of enrichment (wt percent ^{235}U)	T#(mm)	Cylinder net capacity (lb UF_6)
30B	1236	3-5	12.5	5,020
48X/48Y*	71	0.3-0.7	16	21,030/ 27,560
48G	301	0.7	8	28,000
48G	45	0.3	8	28,000
Rough**	64	0.7-5.0	16	21,030/ 27,560
Smooth**	50	0.7-5.0	16	21,030/ 27,560

* 48X and 48Y cylinders are grouped due to similar enrichment and wall thickness.
** Rough and smooth describe the cylinder surface condition, and includes 48X and 48Y cylinders.
\# Nominal cylinder thickness

Another important element in the measurement system was the NATE detector stand. In order to access optimum regions of a cylinder for analysis, the NATE was utilized to maintain detector stability. These areas included the top, side, end, and near the bottom (especially on upper stacked cylinders). The avoidance of areas of a cylinder that contain large volumes void of UF_6 also resulted in improved results. Obviously, cylinders that are partially filled can be measured from a lower position on the cylinder. A less obvious obstacle is a cylinder that is partially shaded. Multiple rows of stacked cylinders sometimes have one end that is in direct sunlight daily while the rest of the cylinder is shaded, especially on the bottom row. This leads to migration of the UF_6 away from the end that is at higher temperature. Simply measuring the cylinder from the shaded end sometimes results in an improvement in the accuracy of the measurement.

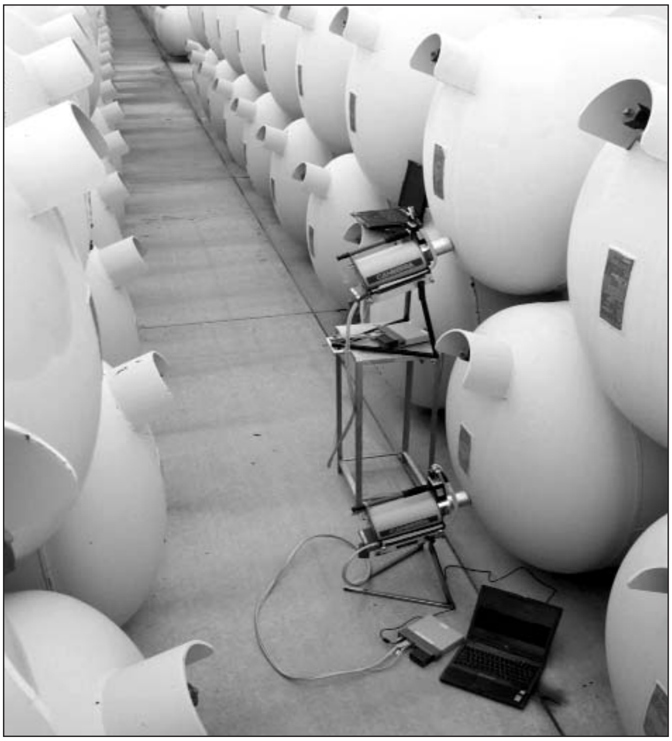
The UF_6 ^{235}U enrichment measurements were performed in the cylinder storage yards. Cylinders were routinely analyzed in batches with a defined maximum of twenty. Each cylinder was measured with a single count time of five minutes with a minimum of one duplicate analysis per batch. Between March 1, 2002, and November 5, 2003, measurements were performed on 1767 UF_6 cylinders to determine the ^{235}U enrichment utilizing the detector system described above. The cylinder types varied greatly in volume as well as nominal and measured thickness (Table 2). The entire measurement apparatus during sample analysis is shown in Figure 2. The detector was positioned with the endcap directly against the cylinder at the desired location. The cylinder weld seams were avoided due to the increased thickness as well as the inherent non-uniformity. In the figure, the detector is positioned at the side of a type 30B cylinder with the computer and MCA atop. Examples of varying interrogation positions are demonstrated for type 30B $LEUF_6$ (Figure 3) and type 48G DUF_6 (Figure 4) cylinders, as well. These, in addition to the calibration configuration shown earlier, illustrate the 360º interrogation ability provided by the NATE. In general, type 30B cylinders were measured from the top due to the ease of access and absence of cylinder stacking. Type 48X, 48Y, and 48G cylinders were typically measured from the end or side if stacked and from any of the locations if not stacked. For any given cylinder, an alternate location may have been utilized if it resulted in a preferable surface condition or access to the UF_6 if, for instance, the cylinder was partially filled.

Figure 2. Detector system set up on the side of a type 30B $LEUF_6$ cyllinder

Figure 3. Two-detector system set up at top and end locations of a type 30B $LEUF_6$ cylinder

For the purpose of calculating accurate uncertainties according to specific cylinders, the 16mm-thick cylinders with enriched UF_6 were segregated by the surface condition of the cylinder (rough and smooth). This factor affected the reproducibility and

Figure 4. Two-detector system set up at top and bottom stacked type 48G DUF_6 cylinders



accuracy of the thickness measurement due to the fact that some were aged considerably compared to others. The surface condition determination was a qualitative judgment based upon degradation of paint, surface rust and pitting. It was not necessary to specify a rough or smooth designation for the normal and lower enrichment cylinders as they typically had a very good surface condition. The ^{235}U enrichment ranged from DUF_6 (~0.3 wt percent) to $LEUF_6$ (~5.0 wt percent).

A summary of the results is presented in Table 3. Wide variations in the accuracy of the measured values existed and can be attributed to enrichment, cylinder thickness and cylinder surface condition. However, the ^{235}U enrichment measurement uncertainties (Table 4) calculated for each category (DUF_6, NUF_6, and $LEUF_6$) in all cases were lower than those listed as international target values[13] accepted by the IAEA for the PMCG method. In fact, many were significantly reduced, often approaching an order of magnitude lower for systematic uncertainty (bias).

The type 30B cylinders represented the greatest number of cylinders measured (1,236), all containing $LEUF_6$ in six distinct ^{235}U enrichment ranges. The relative biases calculated for all levels were within the range of 0.2-1.6 percent, compared to a systematic uncertainty (u_s) target of 2 percent. The relative standard deviation (RSD) range was 2.9-4.0 percent compared to a random uncertainty target (u_r) of 4 percent. The moderate cylinder thickness (12.5 mm) and higher enrichment both contributed to a strong signal at 185.7 keV. A consistently smooth cylinder surface resulted in accurate cylinder thickness measurements. The combination of these factors resulted in the excellent uncertainty values tabulated for type 30B cylinders.

The type 48G cylinders (8 mm thick) measured were of two enrichment levels, normal and depleted. The 301 NUF_6 cylinder measurements resulted in a relative bias of 3.9 percent while the 45 DUF_6 measurements exhibited only 1.9 percent. This, in comparison to a target u_s of 5 percent for NUF_6 and 10 percent for DUF_6, again demonstrates high accuracy. This is especially true for the DUF_6 for which the accuracy was ~1/5 the target limit. The RSD for measurements performed on 48G cylinders of NUF_6 and DUF_6 were 4.9 and 10.7 percent, respectively. This, compared to u_r targets of 8 percent (NUF_6) and 15 percent (DUF_6), represents a random uncertainty decrease that significantly exceeds expectations. The relative high quality of the results for 48G cylinders can be attributed to the thin cylinder wall allowing a moderately strong 185.7 keV intensity for the enrichments measured. Also, the DUF_6 cylinders were all in good condition (smooth surface), as were the bulk of the NUF_6 cylinders, resulting in reliable thickness measurements.

The type 48X and 48Y cylinders (16mm thick) measured were a potpourri of UF_6 enrichment and surface condition. The measurements of cylinders with good surface conditions containing NUF_6 yielded a relative bias (1.6 percent) and RSD (7.7 percent) that proved to be considerably lower than the target u_s (5 percent) and essentially equal to the target u_r (8 percent). The results for the cylinders containing a range of ^{235}U enrichment (~0.5-0.9 wt percent ^{235}U) yielded a bias (5.1 percent) and RSD (8.5 percent) that was essentially equal to the NUF_6 target values. It is not surprising that the uncertainties were greater for this range of enrichments even though the average enrichment was approximately NUF_6. This is because the range was from a mid-DUF_6 that is expected to yield higher uncertainty to a low $LEUF_6$ that would be expected to yield the highest uncertainty for $LEUF_6$ measurements. $LEUF_6$ (2-5 wt percent ^{235}U) measurement results for 48X and 48Y cylinders with rough surfaces yielded a relative bias of 7.1 percent and a RSD of 3.5 percent, whereas for smooth cylinders the relative bias was 1.6 percent and the RSD was 4.1 percent. These RSDs agreed well with the target u_r (4 percent) while the bias for the rough cylinders was significantly higher than the target u_s (2 percent), the increase being due to the imprecise thickness measurement as expected. Lastly, when comparing the uncertainties for the measurement of rough and smooth cylinders containing material on the low enrichment side of $LEUF_6$ (0.7-1.7 wt percent ^{235}U), little difference is realized. The biases for rough and smooth cylinders were 7.2 and 7.8 percent, respectively, while the RSD was 9.8 and 6.8 percent. The increased uncertainty is undoubtedly due in part to the difficulty in measuring the cylinder thickness. This also explains the increased random uncertainty of the rough cylinders compared to the smooth cylinders. There were only a few of this type of cylinders measured in the given range of ^{235}U enrichment resulting in poorer statistics.

Table 3. Summary of UF_6 cylinder ^{235}U enrichment measurement results

Cylinder type	Number of cylinders measured	T# (mm)	Enrichment range (wt percent ^{235}U)	Average measured enrichment (wt percent ^{235}U)	Average accepted enrichment (wt percent ^{235}U)
30B	537	12.5	4.945-5.011	4.863	4.948
30B	17	12.5	4.696-4.698	4.744	4.697
30B	233	12.5	4.390-4.497	4.349	4.404
30B	342	12.5	3.876-4.106	3.937	4.002
30B	39	12.5	3.408-3.708	3.610	3.602
30B	68	12.5	3.196-3.205	3.176	3.212
48G	301	8	0.7051-0.7267	0.7389	0.7110
48G	45	8	0.2876-0.3130	0.3084	0.3027
48X/48Y+	22	16	0.5370-0.9270	0.6996	0.7371
48X/48Y++	49	16	0.7113-0.7000	0.7113	0.7113
Rough**	46	16	2.002-4.9563	4.1711	4.4741
Rough**	18	16	0.7158-1.701	1.1597	1.2501
Smooth**	33	16	2.0015-4.9563	3.5374	3.6971
Smooth**	17	16	0.7140-1.696	2.7559	2.8942

\+ Assorted enrichment <1 wt percent U-235
++ Normal enrichment feed material
\# Nominal cylinder thickness
** Rough and smooth describe the cylinder surface condition, includes 48X and 48Y cylinders

Summary

Improved uncertainty, both random and systematic, has been demonstrated for confirmatory ^{235}U enrichment measurements of large UF_6 cylinders utilizing the PMCG method. The comprehensive results presented in this work are based upon analysis of a large number of UF_6 cylinders spanning the ^{235}U enrichment range of 0.3-5.0 wt percent. The various types of cylinders, conditions of surfaces, wall thickness, cylinder stacking, and row positioning as well as the enrichment range presented a host of problems. These problems were overcome through the use of rigorous thickness measurements, specific detector positioning as well as avoidance of anomalous surfaces when possible.

The NATE positioning device, fabricated in-house, was instrumental in improvements to the thickness measurements through allowing essentially any region of the cylinder to be analyzed. In other words, regions that were unfriendly toward thickness measurements could be avoided. Likewise, the NATE maintained the detector endcap directly against the cylinder for reproducibility. Lastly, the NATE allowed measurement in areas of minimal anomalies or UF_6 voids.

The thickness measurement consisted of five approximately equally spaced measurements taken in a circular area the size of the active detector at the exact location of the gamma analysis. These were averaged to obtain the thickness to be utilized in calculations of enrichment. If the multiple measurements were not reproducible, another area of the cylinder was chosen for the measurement.

This methodology not only produced quality levels superior to previously reported results but also yielded significantly higher quality than that prescribed by widely accepted standards. Also, the analysis required only five minutes per cylinder to perform, allowing large sample batches to be measured quickly.

Future Developments

It is expected that extended analytical run times for thicker and lower enrichment cylinders would produce lower uncertainty. However, this has not been experimentally demonstrated in this work. Also, it is not known at this time if the assumed gains in accuracy and precision would outweigh the loss in analytical speed.

Table 4. Summary of UF_6 cylinder ^{235}U enrichment measurement uncertainties

Cylinder type	T# (mm)	Enrichment range (wt percent ^{235}U)	Measurement bias (wt percent ^{235}U)	Relative bias (percent)	α (wt percent ^{235}U)	RSD (percent)
30B	12.5	4.945-5.011	-0.077	-1.56	0.144	2.91
30B	12.5	4.696-4.698	0.047	1.01	0.164	3.49
30B	12.5	4.390-4.497	-0.055	-1.26	0.135	3.05
30B	12.5	3.876-4.106	-0.065	1.63	0.137	3.42
30B	12.5	3.408-3.708	0.008	0.22	0.145	4.04
30B	12.5	3.196-3.205	-0.034	-1.05	0.123	3.84
48G	8	0.7051-0.7267	0.028	3.92	0.035	4.86
48G	8	0.2876-0.3130	0.006	1.88	0.032	10.7
48X/48Y+	16	0.5370-0.9270	-0.038	-5.08	0.063	8.54
48X/48Y++	16	0.7113-0.011	1.59	0.055	7.67	7.67
Rough**	16	2.002-4.9563	-0.260	-7.13	0.126	3.47
Rough**	16	0.7158-1.701	-0.090	-7.23	0.123	9.81
Smooth**	16	2.0015-4.9563	-0.048	-1.56	0.128	4.14
Smooth**	16	0.7140-1.696	-0.093	-7.80	0.081	6.79

+ Assorted enrichment <1 wt percent U-235
++ Normal enrichment feed material
\# Nominal cylinder thickness
** Rough and smooth describe the cylinder surface condition, includes 48X and 48Y cylinders

It is expected that significantly shorter analytical run times may yield similar results for 30B cylinders and possibly the 8mm thick normal enrichment cylinders. The software updates the averaged calculated enrichment value to the laptop screen every few seconds during analysis. It appears that the value does not change significantly after the first couple of minutes. However, this is based upon qualitative observation with no actual tabulated results from shorter times. Also, the uncertainty would be expected to suffer to some extent.

A software option should be added to compensate for a second absorber such as the aluminum container utilized in the performance check measurements. When calibrating, the options exist for both the absorber (1/4″ steel plate) and the container wall. During sample analysis (specifically the performance check), however, the software allows for only one absorber. The correction for the second must be performed manually. While this is easily accomplished in spreadsheet fashion, it adds an extra step to the overall analysis.

Calibration could be performed with an absorber having the same curvature as the cylinder wall. This would eliminate any losses due to curvature but would require a different calibration for cylinders of various sizes.

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IAEA Releases Nuclear Trafficking Statistics for 2003-04

In 2004, countries reported 121 incidents of illicit trafficking and other unauthorized activities involving nuclear and other radioactive materials, statistics released by the International Atomic Energy Agency (IAEA) Illicit Trafficking Database (ITDB) show.

The ITDB report also shows that one incident was reported since 2003 that involved fissile material — highly enriched uranium (HEU) or plutonium — that is needed to make a nuclear weapon. It occurred in June 2003 when an individual was arrested in possession of 170 grams of HEU while attempting to illegally transport it across a border.

During the two-year period of 2003-2004, the number of incidents reported by states substantially increased compared with previous years. "Improved reporting may in part account for it," the report said. "The majority of the incidents reported in 2003-2004 showed no evidence of criminal activity."

Since the database started in 1993, there have been eighteen confirmed incidents involving trafficking in HEU and plutonium according to the report. A few of these incidents involved seizures of kilogram quantities of weapons-usable nuclear material but most involved very small quantities. In some of the cases the seized material was allegedly a sample of larger quantities available for illegal sale or at risk of theft. More than two dozen incidents involved trace amounts of plutonium sources.

In the past twelve years, 220 incidents involved nuclear materials. The majority of confirmed cases with nuclear materials involved low-grade nuclear materials, mostly in the form of reactor fuel pellets, and natural uranium, depleted uranium and thorium. While the quantities of these materials have been rather small to be significant for nuclear proliferation or use in a terrorist nuclear explosive device, these cases are indicative of gaps in the control and security of nuclear material and nuclear facilities, the report said.

The majority of confirmed incidents with nuclear materials recorded during 1993-2004 involved criminal activity, such as theft, illegal possession, illegal transfer, or transaction. Where information on motives is available, it indicates that profit seeking is the principal motive behind such events.

From 1993-2004, a total of 424 incidents were reported involving other radioactive materials mostly in the form of radioactive sources. Radioactive sources are used worldwide in a host of legitimate applications while measures to protect and control their use, storage, or disposal are much less strict than those applied toward nuclear materials.

The majority of incidents involved radioisotopes and portable radioactive sources used for various industrial applications, such as gauging or radiography.

Activity levels of the majority of these sources were too low to pose serious radiological risk if used for malicious purposes. About fifty incidents involved high-risk dangerous radioactive sources that present considerable radiological danger if used in a malicious act. The overwhelming majority of incidents involving dangerous sources were reported over the last six years.

The IAEA's illicit trafficking database was set up to facilitate the exchange of authoritative information on incidents of illicit trafficking and other related unauthorized activities involving nuclear and other radioactive materials among States. Over the years its purpose has expanded to maintaining and analyzing this information to identify common trends and patterns.

DOE to Remove 200 Metric Tons of HEU from U.S. Nuclear Weapons Stockpile

The U.S. Department of Energy (DOE) announced in November 2005 that its National Nuclear Security Administration will remove up to 200 metric tons of highly enriched uranium (HEU), in the coming decades, from further use as fissile material in U.S. nuclear weapons and prepare this material for other uses.

The decision addresses future use of HEU that becomes available from nuclear weapons dismantlements and from significant reductions in the nuclear weapons stockpile. The project represents the largest amount of special nuclear material to be removed from the stockpile in the history of the nuclear weapons program.

DOE will dispose of the additional HEU in the following ways:

About 160 MT will be provided for use in naval ship power propulsion, postponing the need for construction of a new uranium high-enrichment facility for at least fifty years.

About 20 MT will be down-blended to low enriched uranium (LEU) for eventual use in civilian nuclear power reactors, research reactors or related research. Down-blending this material will eliminate its potential usefulness to terrorists.

Approximately 20 MT will be reserved for space and research reactors that currently use HEU, pending development of fuels that would enable the conversion to LEU fuel cores.

HEU is stored at NNSA's Y-12 National Security Complex in Oak Ridge, Tennessee, U.S.A. The DOE is expediting construction of a facility that will permit the consolidation of all HEU at Y-12 in a modern, highly secure building. Although DOE examined options to down-blend additional material to improve its security, it concluded that this new facility would be available before down-blending could be accomplished. Early down-blending, therefore, would add costs without improving security.

Kazakhstan and NTI Mark Success of HEU Blend-Down Project

Kazakhstan and Nuclear Threat Initiative (NTI) in October 2005 announced the success of a joint NTI-Kazatomprom project to eliminate permanently nuclear fuel containing 2,900 kilograms of highly enriched uranium (HEU). This material, if it had fallen into the wrong hands, could have been used to make nuclear bombs. Instead, the material is being blended down to safe, non-weapons usable forms of uranium for use in commercial and scientific activities.

The project to remove and eliminate the 2,900 kilograms of uranium fuel, enriched up to 26 percent, from the BN-350 fast-breeder power reactor site in Aktau, Kazakhstan, began in 2001 with discussions among NTI, nuclear industry leaders, and the governments of Kazakhstan and the United States. This project was carried out in coordination with the Ministry of Energy and Mineral Resources of Kazakhstan, U.S. Department of Energy (DOE) and the International Atomic Energy Agency (IAEA). DOE is supporting Kazakhstan in decommissioning the BN-350 reactor, which required elimination of all fissile material from the reactor site.

The project involved several steps: Nuclear workers in Aktau loaded onto rail cars fresh HEU fuel assemblies designed, but never used, for the BN-350 reactor. The fuel assemblies were transported to the Ulba Metallurgical Plant (UMP) in Ust-Kamenogorsk, where security upgrades had been installed to permit HEU storage. A blend-down line and additional security upgrades to allow HEU processing were designed, licensed, and installed at UMP to carry out the operations. Costs of the project, approximately $2 million, were shared equally between NTI and Kazatomprom. The IAEA applied safeguards during transport, commissioning, and downblending. The facilities constructed at the Ulba plant to blend down the BN-350 HEU fuel will remain operational and could be used in the future to eliminate other weapons-usable uranium.

DOE Signs Decision to Move Moab Tailings

A record of decision (ROD) clearing the way for the removal of 11.9 million tons of radioactive uranium mill tailings from the banks the Colorado River in Utah has been signed, according to the U.S. Department of Energy (DOE). Under the Moab Uranium Mill Tailings Remedial Action Project Site Record of Decision, the tailings will be moved, predominately by rail, to the proposed Crescent Junction, Utah, site more than thirty miles from the Colorado River.

In 2001 the U.S. Congress transferred responsibility for cleanup of the Moab site and vicinity properties to DOE. The Moab Project Site is a former uranium ore processing facility about three miles northwest of the city of Moab in Grand County, Utah, on the west bank of the Colorado River at the confluence with Moab Wash. The site covers roughly 400 acres and includes a 130-acre uranium mill tailings pile that occupies much of the western portion.

DOE issued its final environmental impact statement (EIS) on the Moab Project in July 2005. In reaching its final decision, DOE considered the potential environmental impacts, costs, and other implications of both on-site and off-site disposal, and DOE considered all comments it received on the final EIS.

NTI Announces $1 Million for New 'Outside Technopark' in Sarov

A $1 million grant announced in October by the Nuclear Threat Initiative (NTI) will support the infrastructure to bring civilian jobs to former nuclear weapons scientists at Sarov. The NTI funds are being matched by a $1 million investment by AFK Sistema to help build an energy efficiency center as part of Sarov's new "Outside Technopark," a business park being built outside the fence of the closed city. In January, Russian President Putin announced that the Russian government was going to establish four special economic zones for innovative economic development based on high-tech industries. These special zones will be centered around technoparks and scientific research centers in Russia. One of these zones includes Sarov and its Outside Technopark. The Energy Efficiency Center will design and develop local and regional power plants that maximize energy efficiency, use environmentally clean fuels, and supply power to the buildings at the Outside Technopark. The Energy Efficiency Center is designed to meet crucial power needs in a way that is efficient and innovative, and increases the opportunity for new companies to take advantage of a uniquely qualified scientific and technical labor pool to develop new businesses in the region.

Several major Western companies are in negotiations with the Outside Technopark and are considering establishing new facilities there. Intel Corporation, which first established a small software operation in Sarov in 1993 and has grown its business to a current level of more than 100 full-time employees, will move its operations to the new Outside Technopark and become the park's first tenant. Over the course of the next six years, the Outside Technopark projects the creation of 2,000 new jobs and the establishment of more than 100 companies. The Outside Technopark model, once proven, could be transferred to other closed cities, where development is hindered by similar restrictions on access. Over the last decade, the city of Sarov has made several attempts to establish technoparks and business incubators within the confines of the closed city. Largely, however, businesses and investors were deterred by the difficulty in accessing the closed city. That led to the decision to build a new technopark just outside the fence.

Since 2002, NTI has identified pilot projects in Russian closed nuclear cities that can be replicated elsewhere, specifically in the nuclear cities of Sarov and Snezhinsk. NTI previously made a $1 million investment in the Fund for Development of Conversion Companies (FDCC), which provides interest free loans to support new and growing businesses in Sarov.

To date, the joint NTI-FDCC project has created three new companies and many new jobs for former nuclear weapons employees. More than one-third of the funds have been repaid, freeing them up for reinvestment in additional new businesses in Sarov. Through these types of projects, NTI is strengthening nuclear security by reemploying personnel with knowledge of sophisticated weapons design and materials handling practices.

Calendar

February 27–March 3, 2006
International Conference on Effective Nuclear Regulatory Systems
Moscow, Russia
Contact:
International Atomic Energy Agency
Web site: http://www-pub.iaea.org/MTCD/Meetings/Meetings2006.asp

May 29–June 2, 2006
ESARDA Annual Meeting
Luxembourg
Sponsor:
European Safeguards Research and Development Association
Web site:
http://esarda2.jrc.it/events/esarda_meetings/luxembourg-2006/index.html

June 4–8, 2006
2006 ANS Annual Meeting
A Brilliant Future: Nexus of Public Support in Nuclear Technology
Reno Hilton
Reno, Nevada, U.S.A.
Sponsor:
American Nuclear Society
Web site: http://www.ans.org/meetings

June 19–23, 2006
International Conference on Management of Spent Fuel from Nuclear Power Reactors
Vienna, Austria
Contact:
International Atomic Energy Agency
Web site: http://www-pub.iaea.org/MTCD/Meetings/Meetings2006.asp

July 16–20, 2006
47th INMM Annual Meeting
Renaissance Nashville Hotel/Convention Center
Nashville, Tennessee, U.S.A.
Sponsor:
Institute of Nuclear Materials Management
Contact: INMM
847/480-9573
Fax: 847/480-9282
E-mail: inmm@inmm.org
Web site: http://www.inmm.org

December 11–15, 2006
International Conference on Lessons Learned from Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities
Athens, Greece
Contact:
International Atomic Energy Agency
Web site: http://www-pub.iaea.org/MTCD/Meetings/Meetings2006.asp

October 21–26, 2007
PATRAM 07
Marriott Doral
Miami, Florida U.S.A.
Host:
Institute of Nuclear Materials Management
Web site: http://www.patram.org