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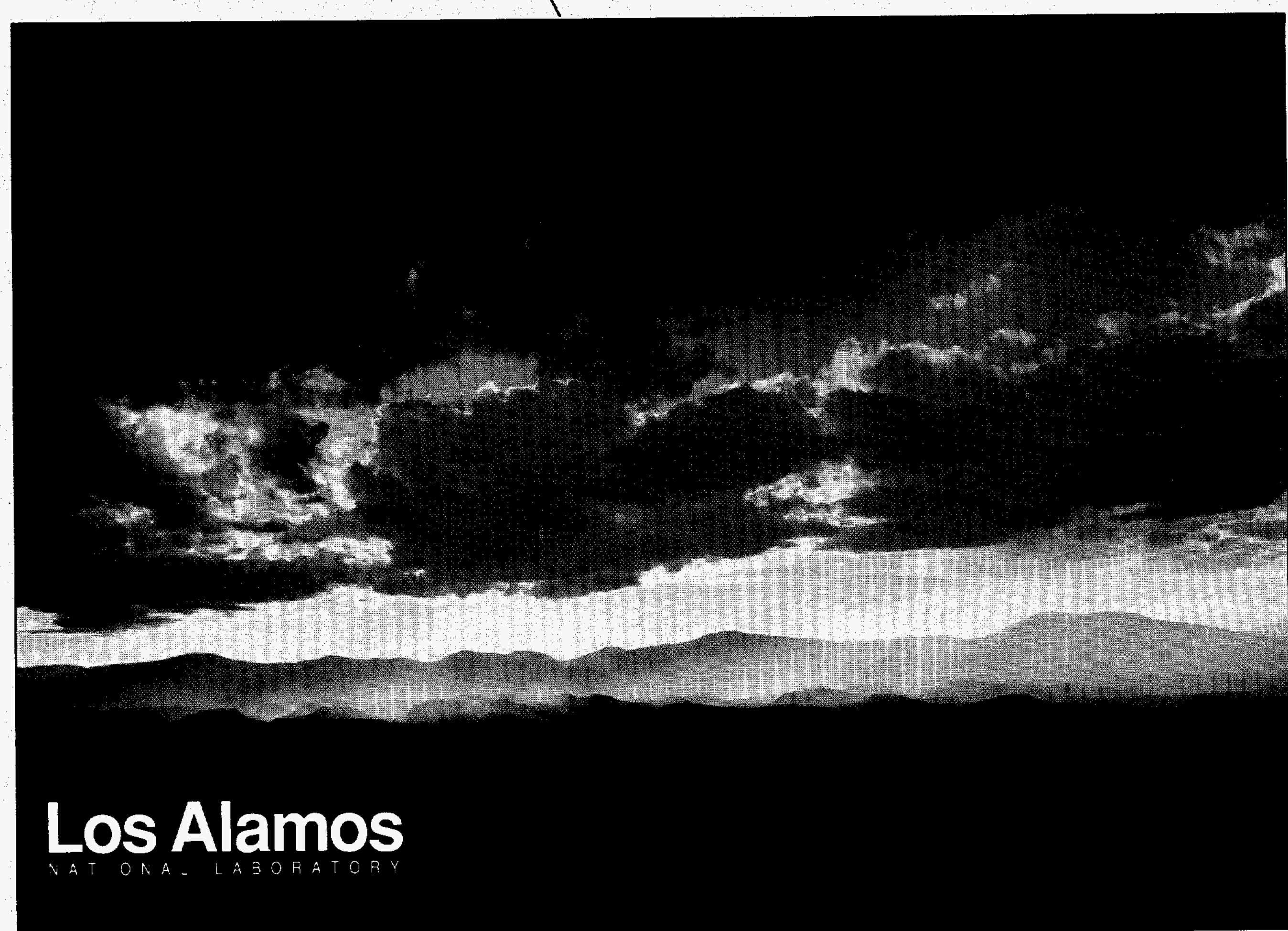

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Holdup Measurements under Realistic Conditions*

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Introduction

Quantification of holdup, the residual nuclear material remaining in process equipment, has long been a challenge to those who work with nuclear material accounting systems. Fortunately, nuclear material has spontaneous penetrating radiation emissions that can be measured. If gamma ray measurements can be made, it is easy to determine what isotope the holdup deposit contains. Unfortunately, it can be quite difficult to relate this measured signal to an estimate of the mass of the nuclear deposit. Typically, the measurement expert must work with incomplete or inadequate information to determine a quantitative result. Simplified analysis models, the distribution of the nuclear material, the intervening attenuators, background(s), and the source-to-detector distance(s) can have significant impacts on the quantitative result.

The quality of the quantitative assay result is intrinsically part of the result and must be understood and held by any system or person making use of the quantitative results. Measurement quality is often divided between two descriptors: precision and bias. Specifically, the uncertainty in the measurement results can be divided into two categories. Precision is used to describe the reproducibility or random error component, while bias is used to describe the systematic error component or the concept of "average difference from truth."

As the Department of Energy (DOE) complex undergoes decommissioning and even demolition of some of its facilities, new opportunities arise for obtaining precision and bias estimates for holdup measurements. A comparison of measurement results with cleanout values or with alternative measurement techniques provides information about bias of, while replicate measurements provide information about the precision of holdup measurements. Unlike other nondestructive assay measurements (NDA), counting statistics are typically not the primary source of measurement error, consequently propagation of error calculations based on counting statistics generally underestimate the

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uncertainty in holdup measurement results. This paper reviews the documentation of the precision and bias of holdup measurements[1-23] and presents previously unreported results.

This compilation of experience from the last two decades for special nuclear material (SNM) processing facilities demonstrates the quality of measurements of SNM process holdup. This compilation may be useful in future decisions regarding allocation of measurement resources.

Brief Statement of the Measurement Issues

First we review the differences between holdup measurements and other measurements used for the accountability of SNM. For other accountability measurements, an important objective is to control parameters which can impact the quality of the measurement results. Generally this is accomplished to a level such that precision rather than bias dominates the measurement uncertainty. However for holdup measurements, the measurement expert is presented with a black box and limited tools and time with which to examine it. The unknown characteristics of the measurement situation are:

- the chemical form of the SNM,
- the location of the SNM,
- the distribution (extent and thickness) of the SNM is unknown,
- the SNM-to-detector distance,
- the type and thickness of intervening attenuators, and
- the location of background sources.

Typically, the holdup measurement expert is expected to generate a result without spending adequate resources to clarify the measurement situation. Consequently, unlike most other measurement situations, bias effects tend to dominate the uncertainty for holdup measurements. The measurement expert will gather as much information as possible, but typically must estimate some parameters.

The Best Possible Results

The best precision and bias one might expect for holdup measurements performed by a variety of personnel are found in measurements of simulated holdup such as those performed in the following training situations:

1. The SNM loading is well known, the simulated holdup is actually well characterized reference materials placed inside uncontaminated pipes, ducts, and equipment.
2. The students have more time and resources than in actual facility measurements. They have ready access to suitable reference materials, accessories to help make the measurements, instructors to ask questions of, and high-quality stable measurement equipment.
3. The instructors assist and mentor the students. Specifically, the instructors know the correct result. They encourage the students to stay with a specific measurement until the students consider most of the concepts that are expected to be important.
4. The students work in pairs, with one instructor for every 2–3 pairs of students.
5. The seminar presents a simplified approach to calibration and assay of unknowns, the "generalized geometry holdup" measurement approach.[10]

The following tables were generated from 4 years of seminars, with about 24 attendees per year — this implies almost 45 pairs of students making measurements. The measurements are made with shielded, collimated NaI(Tl) detectors, using portable electronics. The analysis uses two regions-of-interest (ROIs) to determine the net count rate within an energy region. For most measurements counting statistics of 5% or better, often better than 1%, are achieved despite using count times of the order of 10 s. The measurement teams perform the calculations manually. The tables list results for holdup assays of items containing highly enriched uranium (HEU), plutonium, and low enriched uranium (LEU). The reference value is the result the students are attempting to achieve, the actual value is the true SNM loading, number refers to the number of measurement teams who measured that specific item.

Some observations about these simulated holdup measurement results include the following:

1. the relative standard deviation ranges from 10% to 50%,
2. the average result divided by the reference value ranges from 50% low to 50% high, with a slight clustering around unity, and
3. longer counting times with better counting statistics will not improve the measurement uncertainty.

Table I. Results from Holdup Training Seminar: (HEU)

ID	Annular Tank	Pipe Array	V-blender	Al Pipe	Steel Pipe	Rectangular Duct
Reference g ^{235}U	109	17.63	9.76	16.83	45.44	26
Number	34	27	41	39	39	27
Average	149.6	15.0	10.5	18.5	44.1	34.4
Std dev	62.4	5.2	5.8	4.2	4.7	17.1
Avg/ref.	1.37	0.85	1.08	1.10	0.97	1.32
Rel. std dev.	0.42	0.35	0.55	0.23	0.11	0.50

Table II. Results from Holdup Training Seminar: (Pu)

ID	Large Duct	Large Duct	Large Duct	Large Duct	Small Duct	Small Duct	Single Pipe	Pipe Pair	Pipe Array	Valve	V-blender
Reference	286	126.1	158	177.1	84.3	65	16.8	25.3	70.5	13.3	16.7
Actual g ^{239}Pu	337	144.4	182.9	208.4		143	46.7	70.1	94.1	15.0	19.7
Number	5	7	2	9	5	20	20	19	34	7	12
Average	243.2	104.4	130.7	193.1	78.6	72.5	21.3	28.2	58.6	14.6	16.1
Std dev.	44.1	11.0	10.4	100.2	5.3	23.2	4.8	5.6	22.6	11.6	3.3
Average /ref.	0.85	0.83	0.83	1.09	0.93	1.12	1.27	1.11	0.83	1.10	0.96
Rel. std dev.	0.18	0.11	0.08	0.52	0.07	0.32	0.22	0.20	0.39	0.80	0.21

Table III. Results form Holdup Training Seminar: (LEU)

ID	Steel Pipe	Al Pipe	Rect Duct	Large Annular Tank	Pipe Array	Slab Tank	HEPA Filter	UF6 Cylinder
Ref. kg ^{238}U	4.44	1.86	5.33	7.1	2.89	4.44	2.2	12
Number	4	3	6	7	1	4	6	3
Average	4.73	1.24	2.41	17.31	0.72	4.51	2.66	9.21
Std dev.	1.62	0.31	0.67	1.60		2.00	0.86	0.33
Avg./ref.	1.07	0.67	0.45	2.44	0.25	1.02	1.21	0.77
Rel. std dev.	0.34	0.25	0.28	0.09		0.44	0.32	0.04

Considering that the attendees were presented with

- measurement items that were well isolated in a low-background environment;
- high quality reference materials for both calibration and periodic verification of the calibration;
- lectures followed by assistance in determining suitable measurement geometries, measurement directions, and source-to-detector distances;
- plenty of time to evaluate, discuss, and perform the measurement; and
- continual assistance from instructors who know the true answer;

it is difficult to believe the attendees could perform measurements as well at their own facilities. In addition, many of these school exercises take into account the SNM self-absorption, something that is difficult to detect or correct for in actual facility measurements. This explains the differences between the reference mass and the actual mass in the tables above. In short, holdup measurement uncertainties should not ever be expected to be better than 10%–50%.

Improving Results with Automation

In addition to the manual mode discussed above, data have been collected during some training exercises using an automated system. Holdup Measurement System version 2 (HMSII) is a database developed for use at the ORNL Y-12 Plant.[24] In demonstrations for the training seminars, the database was configured, including specification of measurement locations and geometries, a uniform source-to-detector distance was selected, and seminar attendees observed or used the system to perform measurements.

Table IV lists the results obtained by two operators in the HEU holdup training seminar, each of whom performed five measurements of each item with the automated HMSII system. Typical count times were 10 seconds per data acquisition; one item included 8 distinct data acquisitions.

Table IV. Replicate Measurement Results, Using Automation, by Two Operators

Operator	Pipe Array	V-Blender	Al Pipe	Steel Pipe	Floor Spot	Rectangular Duct
JKSJ	0.97 ± 0.08	1.45 ± 0.08	1.12 ± 0.07	1.10 ± 0.10	1.00 ± 0.08	1.07 ± 0.10
SES	0.93 ± 0.05	1.41 ± 0.10	1.12 ± 0.10	1.07 ± 0.09	0.91 ± 0.02	1.08 ± 0.08

The major difference between these automated results and the previous manual results is that the standard deviations are much smaller for the automated measurements. We would expect the standard deviations to be smaller for replicate measurements because there should be less variation in the source-to-detector positioning and in the selection of the measurement geometry.

Table V lists the HEU measurement results obtained with automation when each measurement is performed by different operators, such as seminar attendees. The number of measurements per item in each year varied from 2 to 17, except for the case of single measurements (where no uncertainty is given).

Table VI lists measurement results, using automation, for simulated plutonium holdup.

All of the results listed above, both manual and automated, assume that the self-shielding of the holdup deposits have been taken into account. This is an optimistic assumption. In general, it is very difficult to detect or even estimate self-shielding of the SNM deposits when making low-resolution holdup measurements in the facility. Therefore, facility holdup measurement results could well be worse than these results, biased low due to self-absorption of the measured gamma-rays in the SNM. These results do support the general opinion that holdup measurements can have measurement biases no better than the order of 10%–50% under ideal conditions. In addition, it seems that measurement precision can be reduced to 15% or better with the help of automation.

Table V. Measurement Results with Automation Compared to Reference Value

Class Year	Pipe Array	V-Blender	Al Pipe	Steel Pipe	Floor Spot	Rectangular Duct
1992	0.92 ± 0.06	1.49 ± 0.18	1.13 ± 0.06	1.02 ± 0.10	0.92 ± 0.09	1.14 ± 0.14
1993	0.98 ± 0.04	1.05	1.11 ± 0.04	1.04 ± 0.04	1.03 ± 0.02	0.99 ± 0.06
1994	0.87 ± 0.15	1.05 ± 0.18	0.97 ± 0.07	0.92 ± 0.06		1.05 ± 0.06
1995	0.87 ± 0.06	1.19 ± 0.12	0.85 ± 0.11	0.91 ± 0.05	0.99 ± 0.01	0.83 ± 0.07

Table VI. Measurement Results, Using Automation, by One Team of Operators

Note: 20-s Count Times

Item- Source-to-Detector Distance	Reference Mass (g)	Average	Std Dev.	Average/ Ref.	Rel. Std Dev.	Number of Measurements
HEPA filter - 25 cm	75.2	50.44	± 3.6	0.67	0.071	27
HEPA filter - 40 cm	75.2	77.41	± 5.2	1.03	0.067	25
Al Pipe - 40 cm	125.8	94.48	± 6.6	0.75	0.070	27
V Blenders - 250 cm	18.8	12.76	± 3.4	0.68	0.26	27
Slab Tank - 25 cm	82.1	51.44	± 6.8	0.63	0.13	27
Pump - 75 cm	54.0	45.51	± 5.2	0.84	0.11	27

Results Obtained in Actual Facility Measurements

Several sets of holdup measurement results have been reported by facilities. Many more examples exist, but they have not been documented in the public domain. In the author's experience, these values for measurement uncertainties are consistent with the quality one expects to find in facility holdup measurements.

It is generally accepted that the best way to certify holdup measurement quality is to perform cleanout and recovery of the SNM in the equipment.[25] A few examples have been reported. In most cases it is assumed that the cleanout value has the smaller measurement uncertainty, but sometimes no information is offered to substantiate that assumption. Sometimes the measurement method used to determine the recovery value is not specified, the relevant measurement uncertainty almost never is. There are several documented cases where the cleanout included more or less SNM (or equipment) than covered in the holdup measurement. In short, it can be difficult to draw rigorous conclusions from comparisons with cleanout and recovery values. Appropriate planning and care in the cleanout execution, with attention to the objective of certifying the holdup measurement quality, helps to prevent mistakes that reduce the usefulness of the result.

It is the author's opinion that holdup measurements require more technical oversight and understanding of the measurement principles than other measurement methods. Both destructive and nondestructive measurements in an analytical laboratory or in a count room are more consistent, require less operator expertise, and are more tolerant of operator mistakes. By their very nature, other measurement methods include sample preparation, limit their application to suitable samples, and attempt control over parameters that influence the quality of the result. Holdup measurements often have little or no sample preparation, little or no limits on their applicability, nor control of parameters that can cause bias.

Reported experience with plutonium measurements in facilities varies from situations with measurement errors similar to those obtained in the training seminars to factor of 10 differences between the measurement and the best estimate of the true value. Results have been reported that are both much higher and much lower than the best estimate. Table VII summarizes some holdup measurement experience in plutonium processing facilities.

The recommendations (lessons learned) include:

1. clean out as much as possible before measurements, short of disassembly (this assumes cost of disassembly exceeds cost of measurements);
2. minimize intervening attenuators (partial disassembly is often worth the cost);
3. maximize choices for distance selection and viewing angles by removing shrouds;
4. move or shield other sources (reduce background);
5. cleanup the immediate area, such as floor sweepings or viewing ports for the detector, change out glove box gloves if the detector views through them, especially if detector-glove distance is small (reduce background);
6. allow access to quality calibration materials (and transmission sources);
7. measure background carefully and frequently, distinguish between signal from item being measured and other sources;
8. avoid measuring a small signal in the presence of large background. Biases of an order of magnitude have been reported, credited with this justification;
9. note many of the reported results indicate biases < 20%;
10. understand the limits of the detector shield and collimator;
11. verify assumptions about geometry or intervening attenuators if possible, especially when relying on simple geometric models;
12. scan to evaluate assumptions of uniformity;
13. talk with process operators before, after, and during measurements to gain useful information;
14. spend more time on the largest deposits (often but not always the "hot spots"); and
15. evaluate operator input. While process operators are valuable sources of information; they may not believe high holdup values. This situation requires tact and diplomacy.

It is generally believed that it is easier to measure plutonium holdup rather than uranium because the energy of the gamma rays is higher and plutonium is typically handled in smaller batches. Unfortunately, the higher radiation emission rates from plutonium often require additional shielding and containment. Consequently, the precision and bias for plutonium holdup measurements in many instances is not very different from that observed in measurements of HEU.

Table VII. A Comparison Between Holdup Measurements and Reference Values for Plutonium Processing Plants		
Measure Value	Reference	Assav/Reference
373	389	0.96
582	759	0.77
719	596	1.21
948	922	1.03
1093	1462	0.75
1210	1375	0.88
1175	1111	1.06
1814	1170	1.55
2576	1968	1.31
2735	3126	0.87
2090	4175	0.50
926	1105	0.84
851	920	0.93
41	36	1.14
790	724	1.09
54	58	0.93
307	302	1.02
150	124	1.21
76	76	1.00
124	122	1.02
2147	1743	1.23
473	343	1.38
1723	1317	1.31
3376	2579	1.31
824	719	1.15
na	na	0.50
na	na	0.47
na	na	0.26
na	na	0.73
na	na	1.30
na	na	0.90
na	na	1.24
na	na	1.57
na	na	1.46
na	na	1.56
na	na	1.05
na	na	0.74
na	na	0.10
na	na	1.00
1354	2183	0.62
	Average =	1.00
	Std. Dev. =	0.34

Reported experience with measurements of HEU in facilities varies from situations with measurement errors similar to those obtained in the training seminars to factor of 7 between the measurement and the NDA measurement of the true value. Results have been reported that are both much higher and much lower than the best estimate. Table VIII summarizes some holdup measurement experience in HEU processing facilities.

Table VIII. A Comparison Between Holdup Measurements and Reference Values For HEU Processing Plants

Measured Value	Reference	Assay/Reference
266	225	1.18
511	645	0.79
79	463	0.17
23	23	1.00
286	303	0.94
na	na	0.14
	Average =	0.70
	Std. Dev. =	0.44

Recommendations (lessons learned) include concepts similar to those stated above for plutonium measurements and the following:

1. consider effects of attenuation. Since the uranium gamma ray used most often has a lower energy, it is attenuated more severely than the plutonium signal for the same intervening materials;
2. consider self-attenuation by the uranium in the deposit, especially if there is a possibility for metallic chemical forms;
3. clean out as much as possible, short of disassembly (this assumes cost of disassembly exceeds cost of measurements);
4. minimize intervening attenuators (partial disassembly is often worth the cost);
5. perform more measurements (higher sampling rate) with shorter counting times than a few measurements with long counting times;
6. holdup is rarely the dominant term in the ID or sigma(ID) expression for operating facilities;
7. the wide analysis region (161-211 keV) used in low-resolution measurements makes attenuation corrections susceptible to errors from gamma-ray buildup;
8. low resolution measurements can be biased if the presence of other radioisotopes is not properly accounted for; and
9. we noted many reported results indicated bias < 20%. On the other hand, when large bias was reported, it was generally discovered by accident.

There has been less experience with holdup measurements for LEU facilities because of the lower value (strategic and monetary) of the SNM. Experience with measurements of LEU in facilities varies from situations with measurement errors similar to those obtained in the training seminars to factor of 3 between the measurement and the best estimate of the true value. Results have been reported that are both much higher and much lower than the NDA measurement. Holdup measurements in LEU facilities have had even fewer resources, been made under much tighter time constraints, and must contend with larger equipment. Larger quantities of ^{238}U suggest the possibility of using the 1001 keV from the ^{234}Pa daughter. But the lower emission rate per gram of uranium offsets the improved penetrability of the higher gamma-ray energy. Table IX summarizes some holdup measurement experience in LEU processing facilities.

Table IX. A Comparison Between Holdup Measurements and Reference Values for LEU Processing Plants		
Measured Value	**Reference**	**Assay/Reference**
181	183	0.99
227	235	0.97
28.4	27.9	1.02
25.2	27.6	0.91
8.7	8.7	1.00
15.9	14.3	1.11
540	562	0.96
560	617	0.91
633	641	0.99
630	601	1.05
365	407	0.90
16.7	17.1	0.98
13.7	14.8	0.93
542	546	0.99
538	512	1.05
544	512	1.06
674	669	1.01
481	441	1.09
100	64	1.56
	Average =	1.02
	Std. Dev. =	0.14

Recommendations (lessons learned) include:

1. verify the material is in secular equilibrium if using a gamma ray emitted from the daughter;
2. LEU measurements are often made in units of kg, with results similar to HEU measurements in units of g (1000 times less sensitive);
3. at 1001 keV, the density of gamma-ray absorbers is more important than the atomic number (The mass attenuation coefficient varies by perhaps a factor of 3 for all materials rather than orders of magnitude as at 186 keV.);
4. the practice of shifting negative numbers to zero (before or after summation or calculation of mass) causes a positive bias in the results;
5. incorrect background assessment can bias results high or low; and
6. calibration for LEU can be more challenging than for HEU or plutonium, because of the low emissivity of 1001 keV gamma rays, causing self-absorption effects during calibration with large pieces of LEU.

Experience with the need to measure the enrichment (^{235}U abundance) in enrichment plants has also led to unexpected results. Relative measurement uncertainties ranged from 0.2% to 40% in one report. Recommendations (lessons learned) include:

1. if the measurement technique requires secular equilibrium, be sure it exists and
2. the problem of insufficient uranium causes inadequate counting statistics, raising the sensitivity to background effects or other sources of error.

The authors believe that the experiences reported above apply to all isotopes. If more experience was documented, the lessons learned from the different isotopes would eventually list identical factors, except for issues like secular equilibrium. The authors also suspect that the measurement uncertainties would be similiar for all istotopes. No experience with automation in facility holdup measurements has yet been reported.

Another Approach to Actual Facility Measurements

In the interest of saving time and money, one facility embarked on a campaign that attempted to minimize bias in holdup measurements. The initial resource estimate for the holdup measurement campaign using subject matter experts to perform the field work was at least an order of magnitude higher than the facility operators felt was appropriate. Management made a decision to accept upper limits for the holdup in several buildings from a less skilled measurement team operating under the supervision of subject matter experts. Management decided that positive bias (overstating the SNM value) was acceptable as long as there was high confidence that there was no negative bias (understating quantities or not measuring some of the holdup locations). This approach relied heavily on sampling, scanning for hot spots, and was supported with a significant cleanout (D&D) effort. It is possible that the cost of the cleanout and recovery effort ended up exceeding the original cost estimate for the holdup measurement campaign. Two levels of measurements were performed. Phase I was predominately scanning measurements made at contact using portable health physics hardware that searched for the hot spots and provided relative values. Phase II was a mixed effort to quantify the amounts of holdup which included some quantitative measurements for selected locations (that relied on generalized geometry models) and a large number of relative measurements. The following breakdown of uncertainty estimates was reported.

Table of Phase I and Phase II Estimated Uncertainties, 1 rel. std. dev.

		Uncertainty	
Phase	**Source**	**Systematic (%)**	**Random (%)**
Phase I	Counting Statistics	<1	1
	Repeatability	2	6
	Geometry/Model	80	<1
Phase II	Counting Statistics	<1	5
	Repeatability	<1	1.4
	Geometry/Model		
	Distance	8	8
	Width	<1	18
	Nonlinearity	<1	<1
	Calibration	3.8	<1

Several lessons learned were documented in the report of this activity:

1. the bias (ratio) between the semiquantitative and the quantitative measurement results was discovered to vary widely, from 1.37:1 to 1:6.2. The largest problem reported was that some

measurements were made with the health physics unit discriminator set to count above a threshold instead of in an energy window;

2. it was assumed that the equipment attenuation corrections were always small, therefore making a negligible contribution to the overall error;
3. the overall uncertainties were estimated to be 36% or greater;
4. despite indications that some systematic errors canceled each other, the analysis assumed systematic errors were additive; and
5. the value of a brief initial survey based on count rates to assess the problem followed up by careful planning before the quantitative campaign was demonstrated.

Summary

In general, the random error component of holdup measurements is less than the systematic error component. Contrary to other NDA methods, counting statistics are generally a less interesting or even an insignificant source of error. The factor that is a more likely candidate for causing measurement error is the making of incorrect assumptions about the measurement; such as assumptions about background, measurement geometry, or the attenuators of the measured signal. Measurement precision on the order of 10% can be achieved, but not without some difficulty. Automation, as it becomes available, should make better precision easier to maintain for periodic remeasurement programs. While perhaps most of the holdup measurements made have biases in the 10%–50% range, some results are biased as much as an order of magnitude.

When large biases are discovered, efforts are made to diagnose the causes, to identify similar situations that might also be susceptible to bias, and to avoid similar situations in the future. But the limited resources typically applied to holdup measurements suggest that some level of bias is acceptable. Input from the facility operator, training, modification of procedures, and technical peer review help reduce the incidence rate of large biases. Building a cooperative collaboration between the facility operators, the holdup subject matter experts, and the measurement teams seems to provide extensive benefits by reducing measurement bias and resource needs. When additional effort is expended performing holdup measurements, if it consists merely of additional data collection, the quality of the results might actually degrade. If the additional effort includes technical review and analysis by subject matter experts, the quality of the results might improve. After an initial substantial effort by subject matter experts, it is the opinion of the authors that application of additional resources towards performing holdup measurements should generally be expected to follow the law of diminishing returns. At some point, additional effort generates very little additional improvement. This point can be reached much earlier for holdup measurements than for other analytical methods.

In most, if not all instances, the bias of poor quality holdup measurements can be improved. However, there is reluctance to allocate resources to reduce measurement bias, especially since there is rarely an indication which measurements have a significant bias. This is easily understood if one considers that not many industries spend large amounts of resources measuring their waste, discards, or holdup. The nuclear industry may be unique in this particular allocation of resources. Many holdup measurements are made on small quantities of nuclear material. Poor precision or large bias in these results is of little consequence and therefore acceptable. If the holdup measurements are used to demonstrate that the facility holdup inventory is static, then bias is of little consequence as long as it is consistent. Perhaps half of the measurement results have a small or acceptable level of bias. Therefore the more important issue might be to identify which measurements might be biased. Indiscriminate selection of measurement locations for further activity may well be a fruitless expenditure of resources. In most cases for operating facilities, even if holdup measurements are biased by a factor of 3, the quantity of material is too small to have a significant impact on either the inventory difference, its sigma, or safety (criticality, radiation, or environmental). While for static facilities, or decommissioning, even if the holdup component of the inventory is biased, the ID or change in inventory is not susceptible to such a bias. Consequently, since a return on the investment is in no way guaranteed, it is difficult to justify the allocation of more resources to the problem of holdup measurements.

References

1. M. Righetti, A. Bonino, J. Fernandez, N. Fruttero, E. Grassi, and E. Ponce, "A Methodology for the Calibration and Measurement of the Inventory of Nuclear Material in a Gaseous Uranium Enrichment Plant by NDA techniques," report from the National Board of Nuclear Regulation, Republica Argentina, private communication (1996).

2. R. L. Mayer, B. R. McGinnis, J. N. Cooley, J. M. Whittaker, and T. D. Reilly, "Nondestructive Assay," Measurements in Support of the Cooperative Effort Between the United States and Argentina, Portsmouth report POEF-TS-03 (November 1995).

3. "Safeguards and Security Research and Development progress report, October 1993–September 1994," Los Alamos National Laboratory report LA-12953-PR (August 1995).

4. T. R. Wenz, P. A. Russo, M. C. Miller, H. O. Menlove, S. Takahashi, Y. Yamamoto, and I. Aoki, "Portable Gamma-Holdup Attributes Measurements of High- and Variable-Burnup Plutonium," in *Proc. Fourth International Conference on Facility Operations-Safeguards Interface* (American Nuclear Society, La Grange Park, IL., 1992), pp. 226-236.

5. P. A. Russo, R. Siebelist, J. A. Painter, and J. E. Gilmer, "Evaluation of High-Resolution Gamma-Ray Methods for Determination of Solid Plutonium Holdup in High-Throughput Bulk-Processing Equipment," Los Alamos National Laboratory report LA-11729-MS (January 1990).

6. P. A. Russo, J. K Sprinkle, Jr., and T. H. Elmont, "Holdup Measurements of the Rocky Flats Plant 371 Precipitator Canyons," Los Alamos National Laboratory report LA-10967-MS (April 1987).

7. K. E. Thomas, S. P. Pederson, N. R. Zack, S. A. Jones, and B. R. McGinnis, "Holdup Data Analysis for Portsmouth Building X705," *Nucl. Mater. Manage.* **XX** (Proc. Issue), 79-82 (1991).

8. R. S. Marshall, "SNM Holdup Assessment of Los Alamos Exhaust Ducts," Los Alamos National Laboratory report, LA-12700 (February 1994).

9. "Safeguards and Security Research and Development Progress Report , October 1994 - September 1995," Los Alamos National Laboratory report LA-13250-PR, (March 1997).

10. P. A. Russo, H. A. Smith, J. K. Sprinkle, Jr., C. W. Bjork, G. A. Sheppard, and S. E .Smith, "Evaluation of an Integrated Holdup Measurement System using the GGH Formalism with the M^3CA," 5^{th} International Conference on Facility Operations-Safeguards Interface, Jackson Hole, Wyoming, Los Alamos National Laboratory document LA-UR-95-3321, (September 1995).

11. S. Smith, Lockheed Martin Energy Technologies Y12 Plant, private communication (April 1997).

12. W. D. Reed, Jr., J. P. Andrews, and H. C. Keller "A Method for Surveying for Uranium-235 with Limit of Error Analysis," Gulf General Atomic Report Gulf-GA-A12641 (Fall 1973).

13. T. H. Elmont, and V. Maurello-Scott, "Quantitative Estimate of Holdup in a Plutonium Processing Facility," Rockwell International Report, RFP-4012 (November 1986).

14. T. H. Elmont, and V. Maurello-Scott , "Building 371 Holdup Determination," Rockwell International RFP Internal Report, private communication (November 1984).

15. A. Sheppard, P. A. Russo, T. R. Wenz, M. C. Miller, E. C. Piquette, J. K. Haas, L. C. Glick, and Garrett, "Models for Gamma-Ray Holdup Measurements at Duct Contact," *Nucl. Mater. Manage.* **XX** (Proc. Issue), 68-73 (1991).

16. R. C. Hagenauer, "Nondestructive Uranium Enrichment Determination in Process Holdup Deposits," *Nucl. Mater. Manage.* **XX** (Proc. Issue), 74-78 (1991).

17. H. L. Frederick, "Final report on Process Holdup in the Enriched Refinery Denitration Area," Westinghouse Material Company, Fernald, Ohio, memorandum.

18. D. J. Dreher and F. W. Lamb, "NDA Fissile Material in Gloveboxes and Equipment at RF Envir. Tech Site," to be presented at the 38th INMM Annual Meeting (1997).

19. F. Lamb, Rocky Flats Environmental. Technology Site, private communication (April 1997).

20. "Safeguards Measurements, Duct Holdup Measurement Program," Task 1: Final Report Addendum, SMDA-92.105, EG & RF report (Dec. 21, 1992).

21. C. H. Kindle, "In Situ Measurement of Residual Plutonium," Atlantic Richfield Hanford Company, ARH-SA-248 (June 30, 1976).

22. G. A. Westsik, "Field Nondestructive Assay Measurements as Applied to Process Inventories," Westinghouse Hanford Company, RHO-SA-96 (August 1979).

23. G. A. Westsik, "Resolution of USQ Regarding Source Term in the 232-Z Waste Incinerator Building," 5th International Conference of Facility Operations-Safeguards Interface, Jackson Hole, Wyoming, (September 24-29, 1995).

24. S. E. Smith, "Holdup Measurement System II (HMSII)," Version 2.1, User's Guide and Software Documentation, LMES Oak Ridge Report Y/MA-37-7210/R2 (May 1995).

25. NRC Regulatory Guide 5.23, "In Site Assay of Plutonium Residual Holdup" (February 1984).