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DISCLAIMER

^{235}U HOLDUP MEASUREMENT PROGRAM IN SUPPORT OF FACILITY SHUTDOWN (U)

by

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A paper proposed for publication in the proceedings of the
4th International Conference on Facility Operations - Safeguards Interface
Albuquerque, New Mexico
~~November 11, 1991~~
Sept.-Oct, 1991

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ABSTRACT

In 1989, the Department of Energy directed shutdown of an enriched uranium processing facility at Savannah River Site. As part of the shutdown requirements, deinventory and cleanout of process equipment and nondestructive measurement of the remaining ^{235}U holdup were required. The holdup measurements had safeguards, accountability, and nuclear criticality safety significance; therefore, a technically defensible and well-documented holdup measurement program was needed. Appropriate standards were fabricated, measurement techniques were selected, and an aggressive schedule was followed. Early in the program, offsite experts reviewed the measurement program, and their recommendations were adopted. Contact and far-field methods were used for most measurements, but some process equipment required special attention. All holdup measurements were documented, and each report was subjected to internal peer review. Some measured values were checked against values obtained by other methods; agreement was generally good.

INTRODUCTION

In September 1989, the Department of Energy directed the shutdown and placement in cold standby of an enriched uranium processing facility at the Savannah River Site (SRS). As part of the shutdown requirements, deinventory and cleanout of process enclosures and equipment, and nondestructive measurement of the remaining ^{235}U holdup were required. Because the measured ^{235}U holdup values had safeguards, accountability, and nuclear criticality safety significance, a program to obtain technically defensible and well-documented holdup measurements for the entire facility was needed. A suitable program to support an aggressive shutdown schedule was developed, implemented, and completed on schedule.

DISCUSSION

Brief Description of Measurement Program

Initial efforts involved identification of appropriate techniques, fabrication of standards, and development of the measurement program.[1,2,3] The facility had processed highly enriched uranium for about three years before the shutdown. Inside the facility, gamma ray spectra taken with an NaI detector and a multichannel analyzer (MCA) showed a very clean ^{235}U spectrum, with ^{235}U the only detectable radioisotope. Therefore, measurements inside the facility were made using very simple equipment: NaI detectors with Eberline ESP-2 count rate instruments operated in the gross counting mode (counting all pulses over threshold). Outside the facility, in the process waste water treatment area, the very low ^{235}U concentration and natural radiation background made it necessary to reduce the background by using a MCA with the NaI detector. The combination of low ^{235}U concentration and high background caused the 186 keV ^{235}U peak to be indistinct but still usable. A few readings were taken using a portable high purity germanium (HPGe) detector and an MCA. These readings were primarily for spectrum checks and for a transmission measurement of a large outside reboiler.

Because process tanks and equipment were closely spaced and available personnel lacked experience with far-field measurements, initial measurements were made with a shielded but uncollimated NaI detector in contact with the item assayed. Later in the program, the far-field technique was used wherever possible because it is faster and does not require opening enclosures. However, contact measurements were useful throughout the program to assay long pipe runs and some specialized equipment as well as to verify that "clean" equipment and lines (e.g., steam, segregated water), in fact, did not contain detectable holdup. Some equipment items with thick metal walls required disassembly and visual estimation or mathematical modeling to estimate the holdup.

The measurement program required appropriate, well-characterized standards and adequate measurement control.[2] Some standards used for calibrating nondestructive assay (NDA) instruments were already on hand at shutdown. Other standards (to model holdup in small pipes) were fabricated. Assay values from the different standards and arrangements of standards were found to be mutually consistent, adding confidence in the accuracy of the assigned values. To ensure accurate calibrations, a bias check of the assay instrument was performed before and after each assay session. Also, in several instances, field-measured values of holdup material were compared with values obtained by assay of the material in a Cf shuffler or segmented gamma scanner after removal. The in situ measurements were generally within ±15% of the assay values.

Extensive documentation was a feature of the SRS measurement program. Each original data sheet was signed and dated by the person making the measurement, and all data sheets were retained as backup documentation. Computer spreadsheets were used for all but the simplest computations, and all spreadsheets were retained. A one-page report was issued for each of the 73 areas assayed stating the ^{235}U content by smallest logical entity (e.g., tank, sump, cabinet), measurement techniques used, unusual circumstances encountered, and the estimated measurement uncertainties (generally +100%/-50% of the measured value). Each report was subjected to internal peer review before it was issued. In addition to the individual area reports, a comprehensive report was issued documenting the measurement program, equipment, standards, techniques, and cases of special measurement difficulty. Early in the measurement program, personnel from the Los Alamos National Laboratory (LANL) Safeguards Assay Group (SAG) visited the SRS facility and reviewed the measurement program. The group concurred with the program and made several recommendations. The recommendations were adopted.

The measurement program was conducted by four Ph.D. nuclear scientists (two of whom worked on the program part time) and four specially trained NDA specialists. All NDA personnel were assigned to an organization separate from the production organization to ensure their independence and objectivity. Teamwork and cooperation among production, technical, health protection, and NDA personnel were key elements in the successful accomplishment of the program. The program required eight months to complete. NDA manpower was 58 man months and included significant overtime. Cost of NDA manpower and equipment for the measurement program exceeded $300,000.

Holdup Measurement Methods

Initial efforts to measure the ^{235}U held up in process equipment used the contact method exclusively. A set of calibration standards and a technique that appeared to work well and to be technically supportable was developed. But the contact method required the assay person to enter a cabinet in a plastic suit and take readings at many points in the cabinet. This method was time-consuming in both the acquisition of the data and in its analysis. And it was subject to errors from the frequently non-uniform distribution of ^{235}U in process equipment.

Later measurements were made using the far-field method. A review and measurement exercise with LANL SAG personnel further illustrated the value of this (far-field) technique, and it provided us with additional experience. The far-field technique, with advantages in efficiency and versatility, then became the primary measurement method. But we continued to use the contact method for such items as pipes outside of cabinets and process ducts that were difficult to access.

One other drawback to the contact method is that standards must be developed to approximate the geometry and absorption of the types of process components to be measured. On the other hand, a far-field detector can be calibrated using a single ^{235}U source. The difficulty (or art) of the far-field method is estimating the distribution, self-shielding, and attenuation effects of the held up material and the equipment containing it.

All measurements and calibration constants were determined in English System units because all drawings and measuring tapes were in those units, and measurement personnel were most familiar with the English System. Using feet and inches directly, without converting to SI units, minimized the probability of measurement and conversion errors. In this paper, values in SI units are given in parentheses following English System values.

Holdup Measurement Equipment

A contact measurement system consisted of a shielded 1/2x1/2-in. (1.3x1.3 cm) NaI detector connected by a single coaxial cable to an Eberline ESP-2 readout device. A 32-mil (0.81 mm) Cd filter covered the detector face, and 3/16-in.-thick (0.48 cm) lead surrounded the detector. The lead extended about 5 in. (12.7 cm) along the body of the detector-photomultiplier assembly. A wrapping of black electrical tape held the shielding and Cd filter in place. Three detectors were configured to be nearly identical. A cross-section of a detector assembly is shown in Figure 1.

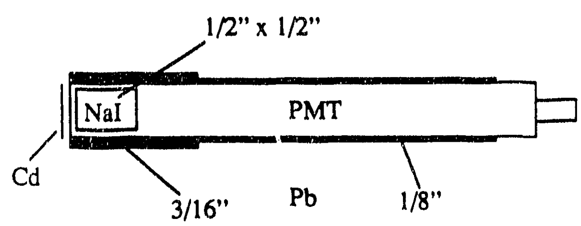

Figure 1. Cross section of a shielded detector used or contact measurements

For measurement of holdup in some process equipment, the shielding of one detector was changed so that the face of the detector was shielded and one "side" of the detector was unshielded - the detector "view" was to one side. These particular applications required a small detector assembly to fit into limited spaces. The detectors were specially calibrated for these applications.

The ESP-2 readout device is compact and battery-powered. It uses a single cable to supply high voltage to the photomultiplier and to return signal pulses to the unit. The unit displays the detector count rate on a two-line liquid crystal readout. Two of the available display modes were used: a numerical display of the average count rate after a preset counting period, or an analog-meter-like display of the relative count rate updated at 0.5-sec intervals. The former was useful for recording data; a 10-sec counting time was generally used. The latter was useful fo: "scanning" a cat ~et to locate the areas with the highest count rates.

A useful feature of the ESP-2 unit is that it provides for scaling of the displayed count rate. By adjustment of the scaling factor, the responses of the several contact measurement systems were made equivalent to the response of the first-calibrated contact measurement system. This made it unnecessary to correct the readings by a system-dependent scale factor - all contact readings could be treated as coming from the same detector system.

Two collimated, far-field measurement systems were set up. The first (Det #1) consisted of a Ludlum 2x2-in. (5.1x5.1 cm) NaI detector-photomultiplier assembly with two ~6 in.-long (~15 cm), 3/16-in.-thick (0.48 cm) commercial lead collimator/shields installed from the two ends of the detector assembly. 0.125-in. (0.318 cm) lead sheet was used to shield the gap between the two lead shields. The front collimator/shield overhung the detector face by 3.5 in. (8.9 cm).

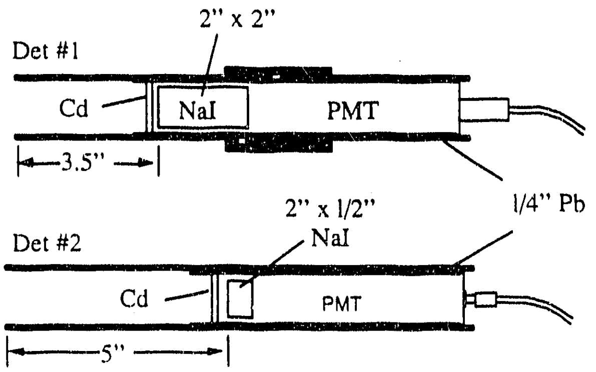

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Figure 2. Cross section of collimated detectors used for far–field measurements

The second far-field detector (Det #2) consisted of a 2x1/2-in. (5.08x1.3 cm) NaI detector-photomultiplier assembly with a collimator/shield fabricated from 0.125-in. (0.318) lead sheet and CPVC pipe. The shield thickness was 0.25 in. (0.64 cm), and the collimator overhang was 5 in. (12.7 cm). Cross sections of the two far-field detector assemblies are shown in Figure 2.

The longer collimator overhang of Det #2 means that it is more tightly collimated than Det #1. This situation was a benefit because the person doing the assay could choose the detector assembly that would give him the degree of collimation he needed for a particular application.

Each of the far-field units was connected to an ESP-2 unit. No effort was made to scale the readout of one of the units so it would agree with the other because the difference in collimation meant that the sets of calibration factors for the two detector assemblies had to be different. The off-axis position response curves for the two far-field detectors are shown in Figure 3. The two detectors were calibrated for point, line, and area sources.[1,3]

Two other assay systems were used. For holdup measurements outdoors in the waste water area, it was necessary to use an MCA to reduce the natural background because of the very low ^{235}U content in that area. Far-field Det #2 was used with a Canberra Series 10 MCA for that application. The other assay system was a portable HPGe detector (Ortec GEM gamma gage) and Canberra Series 35 Plus MCA. It was used for verifying that the gamma spectrum in the indoor process areas showed only ^{235}U peaks, for determining the gamma spectrum in outdoor process areas, and (with a ^{169}Yb source) for measuring the transmission through a waste water reboiler.

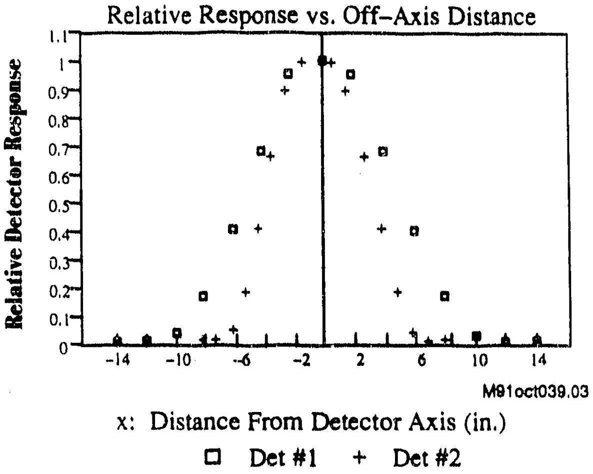

Figure 3. Detector response as a function of off--axis source position for far–field detectors #1 and #2. The source–detector distance at x=0 is 18 in. (45.7 cm).

Calibration

1. Contact Measurements. Calibration of the contact detectors was time consuming and difficult. Ideally, standards were needed in the form of all types of items to be measured: pipes, valves, tanks, flanges, and so on. From a practical standpoint, this was an impossible task, and so effort was concentrated on developing calibration coefficients for pipes (and therefore tanks and circular ducts) and surfaces (cabinet sumps and walls, large tank walls). Extrapolated values were used when justified. (See Table 3.) A list of 28 calibration coefficients for the contact detectors was developed. The same set of coefficients applied to each of the contact detectors since the ESP-2 units were set up to scale the readings to agree with the first detector that was set up.

The calibration factor, ki, for contact measurements has units of counts/sec per ^{235}U quantity, where the ^{235}U quantity is g, g/ft, or g/ft^2. Attenuation corrections are not needed with these factors because attenuation effects are accounted for in the calibration factors themselves. The following equations are used for contact measurements:

Surface:

$$^{235}U\ [g] = \frac{\text{count rate [c/s]} \cdot \text{area [ft}^2]}{k_s\ [(c/s)/(g/ft^2)]}$$

Cylinder/Pipe:

$$^{235}U\ [g] = \frac{\text{count rate [c/s]} \cdot \text{length [ft]}}{k_c\ [(c/s)/(g/ft)]}$$

Valve:

$$^{235}U\ [g] = \frac{\text{count rate [c/s]}}{k_v\ [(c/s)/(g)]}$$

The area and length specified here are the dimensions of the region to which a single measurement (count rate) applies. Typically, contact readings were taken at intervals along a cylindrical tank or run of pipe, and the total ^{235}U was obtained by summing the quantities inferred from the different readings.

2. Far-Field Measurements. Calibration of the far-field detectors was done by the method recommended by LANL.[1,3] Only two standards were used. A high content point source was used to map each detector response profile (Figure 3). These data were used to calculate the effective length and area "viewed" by the detector at an 18-in (45.7 cm) distance. A well-characterized and lower density point source was then used to determine the calibration factor for a point source, and the calibration factors for line and area sources were derived from that value and the effective length and area values mentioned.

The calibration factor, Ki, for far-field measurements has units of grams per foot squared – counts per second. The following equations are used for far-field measurements:

Area Source:

$$^{235}U\ [g] = k_a\ [g/(ft^2 \cdot c/s)] \cdot \text{count rate [c/s]} \cdot \text{area [ft}^2] \cdot \text{attn corr}$$

Line Source:

$$^{235}U\ [g] = k_l\ [g/(ft^2 \cdot c/s)] \cdot \text{count rate [c/s]} \cdot \text{distant [ft]} \cdot \text{length [ft]} \cdot \text{attn corr}$$

Point Source:

$$^{235}U\ [g] = k_p\ [g/(ft^2 \cdot c/s)] \cdot \text{count rate [c/s]} \cdot \text{distant-squared [ft}^2] \cdot \text{attn corr}$$

Distance here is the source-to-detector distance, and area and length specify the size of the region to which the particular measurement (count rate) applies.

A factor "attn corr" had to be applied to each calculation. This factor was needed to correct for attentuation by equipment structure and cabinet panels of the gamma flux from the held-up material. Selection of each correction factor made use of a list of measured attenuation correction factors, and required a knowledgeable judgement on the part of the person doing the calculation. Considerations included: The fraction of ^{235}U inside the process equipment vs. the fraction on the surface, the wall thickness and composition of the equipment, and the distribution of the holdup in (and on) the equipment. No correction was made for self-shielding in the ^{235}U because final holdup quantities were so low that self-shielding was insignificant.

Instrument Setup

The ESP-2 readout units allow setting up parameters for three different detector - data display either counts per second averaged over a 10-sec interval, or to give an analog-meter-like indication of count rate magnitude. The former was used to take quantative readings, and the latter, to scan an area for hot spots.

Standards and Calibration Factors

Our initial attempt at calibration of the contact detector systems made use of a 1/2-in. (1.3 cm) CPVC pipe and two 1/2-in. (1.3 cm) CPVC valves cut from process equipment. The ^{235}U content of the items was determined by measurement in a segmented gamma scanner (SGS). This method was not very successful because of the uncertainty in the SGS results for items so unlike the SGS calibration standards and problems with the held-up residue flaking off. The method yielded a ball-park calibration for 1/2-in. (1.3 cm) CPVC pipe, and a set of crude calibration coefficients for assay of CPVC valves.

The standards actually used in calibrating the holdup measurement systems are listed in Table 1. All standards except the sheet standard are traceable to national standards. The stainless steel vial is less a standard than a point source. This item was useful for determining the off-axis response profile of far-field detectors.

Standard		^{235}U Content
Uniform Sheet, ~1 ft² (0.093m²)		0.68 g/ft² (7.3 g/m²)
Stainless Vial, ~2.5x0.75 in. dia (~6.35x1.9 cm, point source)		87.5 g
Pipe Standard, CPVC	- 1/2 in. (1.3 cm)	0.58 g
(8 in. long)	- 3/4 in. (1.9 cm)	0.75 g
(20.3 cm)	- 1 in. (2.5 cm)	0.80 g
	- 1/2 in. (1.3 cm)	3.76 g
Pipe Standard, SS	- 1/2 in. (1.3 cm)	0.70 g
(8 in. long)	- 3/4 in. (1.9 cm)	0.89 g
(20.3 cm)	- 1 in. (2.5 cm)	0.73 g
	- 1/2 in. (1.3 cm)	3.39 g
Pillow Standards (10 ea)		1. g
Pillow Standards (20 ea)		5. g

Table 1. Facility calibration standards for holdup measurement equipment.

To determine calibration factors, standards were used by themselves, in arrangements with large pipes and ducts, and to mock up larger or more complicated geometries.

1. Pipe Standards. The primary set of standards for calibrating the contact detector systems was the set of CPVC and stainless steel pipes. The 8-in.-long (20.3 cm) pipes were split longitudinally and manually coated on the inner surface with ^{235}U-containing material. Spray adhesive was used as the binder. After coating, the pipes were glued together and end caps were glued in place.

Some difficulty was encountered in accurately measuring the ^{235}U deposited in the pipes because of evaporation of the spray adhesive. Three standards were re-made due to suspected problems with adhesive weights. The final set of pipe standards was checked by comparing the calibration factors determined from them: counts/second per gram ^{235}U/foot [(c/s)/(g/ft)]. The count rate was determined with the contact probe touching the center of each pipe standard, and the ^{235}U linear density was calculated from the standard content.

The pipe calibration factors are shown in Figure 4. The graph shows that for both the CPVC and stainless pipes of similar ^{235}U content, the calibration factor varies linearly with pipe size. Standards with higher content (P4 and S3) give smaller values, consistent with self-shielding effects. Factors for the two high content CPVC standards (P4 and P4') are in good agreement; the second was one of the re-made standards. Overall, the figure shows that the set of pipe standards is self-consistent.

__2. Sheet Standard.__ A sheet standard had been fabricated before shutdown for calibration of assay devices for waste water tanks. ^{235}U content data (documentation) from its fabrication were not available, but checks of this standard showed it to be consistent with other well-characterized standards.

The sheet standard was used to determine the calibration factors for 4- and 6-in. -diameter (10.2 and 15.2 cm) CPVC pipes. The standard was curled inside the 4-in. (10.2 cm) pipe and contact readings were taken to obtain the calibration factor 53 (c/s)/(g/ft) [16.2 (c/s)/(g/m)]. The standard covered only about two-thirds of the circumference of the 6-in. (15.2 cm) pipe, so the calibration factor was determined in a two-step process: separate contact readings were taken on the near and the far inner pipe surfaces, and the results were added to obtain the effective reading for a uniform surface deposit. The resulting calibration factor for 6-in. (15.2 cm) CPVC is 35 (c/s)/(g/ft) [10.7 (c/s)/(g/m)].

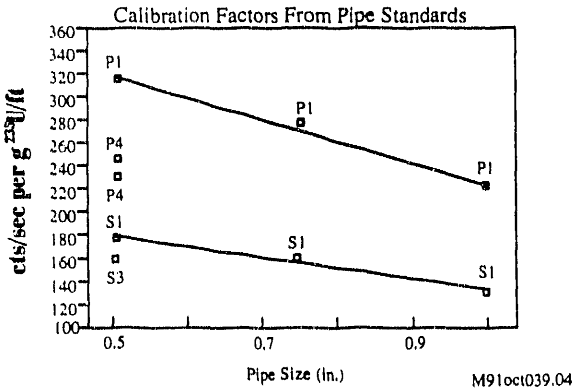

Figure 4. Calibration factors for ^{235}U pipe standards. (The labels Pn and Sn denote CPVC and stainless steel, respectively, and the numbers n indicate the approximate grams ^{235}U content.)

__3. Extension to Other Pipe Sizes.__ It was not feasible to fabricate or mock up standards for every size and type of pipe or duct. So a method of extending the calibration factors determined by standards to other pipe and duct sizes was developed.

For large diameter pipes, a contact reading should be approximately proportional to the surface density of ^{235}U (ignoring attenuation and self-shielding effects). For a given ^{235}U linear density, the surface density is inversely proportional to the pipe inner diameter (ID). We found it reasonable to use a 1/(Pipe ID) factor to extend the measured calibration coefficients to other pipe sizes. Results for schedule 40 CPVC pipe are shown in Table 2.

The extrapolation appears to work well. The factors are normalized for 6-in. (15.2 cm) pipe, but extrapolated values agree well with the measured factors for 3/4- and 1-in. (1.9 and 2.5 cm) pipe. The calculation breaks down for 1/2-in. (1.3 cm) pipe, as might be expected, because the pipe ID is about the same size as the detector. Extrapolated calibration factors were used when measured coefficients were not available.

SCHEDULE 40 CPVC PIPE CALIBRATION FACTORS

Pipe Size (in.)	Actual Inner Diameter (in.)	Calibration Factor (counts/Sec per g/ft) Calc (1/d)	Meas with Std
1/2	0.525	375	317
3/4	0.715	275	283
1	0.921	214	228
1-1/2	1.440	137	
2	1.871	105	
3	2.829	70	
4		50	53
5		41	
6	5.625	35	35 <- Norm Point
6	6.0	33	
8	8.0	25	
10	10.0	20	
12	12.0	16	

Table 2. Data for extrapolation of measured calibration factors to intermediate and larger pipe and duct sizes. The calculated and measured data are normalized for 6-in. pipe.

__4. Pillow Standards.__ Pillow standards are absorbant wipes with ^{235}U in solution deposited uniformly on them. The solution was allowed to dry, and the wipes sealed in plastic bags. These standards were fabricated before shutdown for use in calibration of a far-field gamma waste assay instrument. The pillow standards were used to mock up unusual geometries such as furnace channels and rectangular ducts.

__5. Final Set of Calibration Factors.__ Representative values from the final set of calibration factors determined from the standards are listed in Table 3. They include factors used for both contact and far-field instruments. Calculations were generally performed using a computer spreadsheet and calibration factor symbols were used rather than the values themselves. These measures reduced the chance of error and allowed efficient revision of the results if data or calibration factors were revised.

CALIBRATION FACTORS FOR FACILITY HOLDUP MEASUREMENTS

Category	Symbol	Factor	Units	Description
–CONTACT–				
Surfaces	A_1.5	240 e	r/(g/ft²)	1.5 in. angle iron (g/ft)
	S_0	30	r/(g/ft²)	At contact(g/ft²)
	S_3	30	r/g/ft	3 in. from surface(g/ft²)
Cylinders	G_5	41 e	r/(g/ft)	5 in. glass pipe (g/ft)
	G_6	34	r/(g/ft)	6 in glass pipe
	I_0.5	179	r/(g/ft)	1/2 in. CPVC pipe (g/ft)
	I_4	34	r/(g/ft)	4 in SS pipe
	P_0.5	317	r/(g/ft)	1/2 in. CPVC pipe (g/ft)
	P_0.75	283	r/(g/ft)	3/4 in. CPVC pipe
	P_3	70 e	r/(g/ft)	3 in CPVC pipe
	P_4	53	r/(g/ft)	4 in. CPVC pipe
	P_5	41 e	r/(g/ft)	5 in CPVC pipe
	P_6	35	r/(g/ft)	6 in CPVC pipe
Valves	VB_0.75	320	r/g	3/4 in ball valve (g)
	VM_0.75	320	r/g	3/4 in. valve, back
Misc	D_WD	7 e	r/(g/ft)	Duct in WD cabinet (g/ft)
–FAR-FIELD–				
Det #1	FFA1	0.0390	g/(ft²or)	FF area calib
	FFL1	0.0224	g/(ft²or)	FF line calib
	FFP1	0.0137	g/(ft²or)	FF point calib
Det #2	FFA2	0.0961	g/(ft²or)	FF area calib
	FFL2	0.0352	g/(ft²or)	FF line calib
	FFP2	0.0144	g/(ft²or)	FF point calib

Table 3. Representative calibration factors used in facility holdup measurements. Factors marked with "e" were extrapolated. Units for the factors depend on the method and geometry. The letter "r" denotes the count rate (per second.)

6. Attenuation Correction Factors. Attenuation correction factors for the 186 keV ^{235}U gamma were important components of the assay calibration data. Some factors were taken from Reference 3. Other factors were determined by transmission measurements. The factors used are listed in Table 4. Correction factors (CF) for thickness t can be obtained from values in the table (thickness T) by the formula

$$\text{CF at thickness } t = (\text{CF at thickness } T)^{t/T}.$$

ATTENUATION CORRECTION FACTORS

Material	Thickness (in.)	Thickness (cm)	Attn Corr Factor
Stainless steel	0.25	0.64	2.08
Aluminum	0.25	0.64	1.24
CPVC	0.25	0.64	1.09
Plexiglass	0.375	0.95	1.12
Glovebox glass	0.500	1.27	1.22
Glass tank cylinder	- -	- -	1.1
Pipe insulation	1.0	2.54	1.07
Rubber glove	1 layer	1 layer	1.05

Table 4. Attenuation correction factors for 186 keV gamma rays. The values listed were scaled as needed by the formula given in the text.

Assay Procedure and Techniques

1. Preparation. Before making measurements in an area, NDA personnel made use of available resources to become familiar with the process equipment, likely locations of holdup, pipe and tank composition and wall thickness, and connecting lines to other subunits of the process. One of the most useful sources of information was operations personnel who had worked in the area, but other important sources were process schematics and layout drawings. To expedite data recording, personnel often made sketches in advance on which to record assay readings.

If the measurements required entry into a contaminated area, the detector, cable, and ESP-2 units were sealed in two layers of plastic. Items of equipment found useful during assays include:

- Bag to hold supplies
- 1/8-in. (0.32 cm) lead shielding (sealed in plastic)
- 2-in. (5.1 cm) electrical tape
- Clipboard
- Scissors
- Blank sheets of paper
- Prepared data sheets
- Pens (spares)
- Tape measure
- Broom handle for extending reach with contact detectors
- Plastic sleeves for sealing data sheets for photocopying

Assays were generally done by two-person teams. One person performed the measurements; the other recorded the readings. Before beginning an assay session, the team assayed the check standard (3.76 g ^{235}U CPVC pipe standard) and recorded the reading. The team also performed this check at the end of the assay session. These measures ensured that the instrument was in calibration during all measurements.

2. Contact Method. The number of readings taken with a contact detector depended on the count rates of assays taken in the area. When readings were comparable to background, an initial scan was made to locate any hot spots, areas of higher holdup than their surroundings. When all readings were low and no significant hot spots were located, a few representative readings were recorded. When, on the other hand, readings indicating significant quantities of ^{235}U were found, enough readings were taken to determine the count rate distribution with reasonable accuracy.

Complete information about the vessel or surface at each point measured and the measurement conditions were recorded for the subsequent analysis. The recorded information included such items as use of lead shielding, pipe length, size, and schedule, locations of installed components (valves, elbows, or flanges), and locations of measurement points. The contact method was very time consuming for both data collection and analysis.

However, the contact method was useful in checking long runs of pipe between areas or cabinets. These pipes generally contained very low quantities of ^{235}U, and far-field was a less sensitive method of measurement.

Use of a contact detector also expedited some ductwork assays. The headers for most of the cabinet/glovebox exhaust systems were installed just above a double-wide electrical cable tray. With the "view" of the headers substantially obscured, it was almost impossible to take far-field readings without constructing scaffolding along the length of each header. To circumvent this problem, a contact detector assembly was recessed into the end of an approximately 1-in. (2.5 cm) CPVC pipe. The inner surface of the pipe was machined so that the detector fit snugly into the pipe, and the pipe projected 3 in. (7.6 cm) beyond the detector. The 3-in. (7.6 cm) projection was cut at an angle so it formed a wedge, and could be pushed through the cable mass, against the duct surface, and the reading taken.

3. Far-Field Method. The far-field method was generally more efficient than the contact method for most gloveboxes and cabinets. Most far-field measurements required minimal protective clothing: a lab coat, shoe covers, and gloves. Cabinets and gloveboxes were assayed as if they represented uniform area sources. The front cabinet panel was divided into roughly 2x2 to 3x3-ft (0.6x0.6 to 0.9x0.9m) sections, and each section was assayed at a distance to cover the required area - generally about 1 to 3 ft (0.3 to 0.9 m) from the panel. Sumps and cabinet sides were assayed through the front panel with the detector at an angle of about 30° to the normal to the surface assayed. The measured contributions from all sections (front to back view, side panels, and sump) were summed to obtain the cabinet total.

Results of the two measurement techniques are somewhat difficult to compare. But an early joint measurement exercise with LANL personnel produced good agreement between measurement values obtained previously with the contact method and far-field measurements taken by the LANL team. The contact readings were also shown to be reproducible. In one case, measurement of the lower 9 ft (2.7 m) of a cabinet by far-field gave a result of 140 g ^{235}U, while the contact method yielded 170 g for the entire system cabinet (21 feet or 6.4 m high).

4. Background Measurement. For both measurement methods, efforts were made to minimize and measure the backgrounds. Two types of background measurements were generally made:

A shielded background was taken by making a measurement with the detector positioned to assay an item or region, but with the collimator opening covered with a 0.25-in. (0.64 cm) lead plug. This type of background measurement counted gammas penetrating the collimator or reaching the detector from the open back end of the collimator, but did not include gammas from behind the item measured and passing through it. It provided a low-side estimate of the background.

An offset background was taken by maintaining roughly the same direction as for an assay, but offsetting the detector so it was not directly viewing the item being assayed. This type of background is sometimes difficult to measure, and the measurements were generally used to provide an upper limit of the background.

So that our measurements would be conservative (report at least as much as is in the cabinet/item), we generally used the shielded background values.

5. Special Cases.

- **Thick-Wall Steel Pipe.** At several points in the process, held up material was located in thick-wall pipes. In these cases, a correction factor was calculated under the assumption of a uniform coating of ^{235}U on the inner surface of the pipe. The calculation included the effect of the pipe wall attenuation and the response profile of the detector. Correction factors ranged from 1.58 for 1/2-in. (1.3 cm) schedule 40 steel pipe to 6.14 for 6-in. (15.2 cm) schedule 80 steel pipe. The correction factor due to geometry effects alone in the case of the 6-in. (15.2 cm) steel pipe (wall thickness 0.432 in. or 1.1 cm) was 1.73.
- **Heat Exchangers.** Some heat exchangers in the process were made of tantalum. They could not be assayed by gamma techniques. The content of these units was calculated from the holdup material volume and expected material density. The material volume was obtained by disassembly of the heat exchanger and visual estimation of the deposit thickness.
- **Outside Reboiler.** The waste water tanks, reboiler, and piping had very low ^{235}U content, and required measurement in the presence of a natural radioactivity background. A MCA was used with an NaI far-field detector (Det #2) to make these measurements. Most equipment was of fiberglass or thin steel construction, and attenuation correction factors could be estimated. The reboiler, however, was 16 in. (40.6 cm) in outer diameter, had a 0.375-in. (0.95 cm) wall, and was full of thin-wall, stainless steel tubes. Thus, assay measurements were of no use without a transmission measurement. The reboiler was drained and an HPGe detector was used with a ^{169}Yb source to measure the transmission (≈1/400) and correct for self-attenuation.

Comparisons of Holdup Measurements with Other Methods

Several cases for which holdup measurement values were compared to assay values from other methods are given here. These cases comprise most of the available comparison data, and are representative of the generally good agreement obtained between methods.

Assay of a CPVC seal pot by the contact method gave a result of 195 g ^{235}U. Subsequent complete cleanout of the sealpot and assay of the removed material in a SGS gave a result of 210 g. The holdup measurement relative error was -7.1%.

Assay of a 3-ft (0.92 m) section of 4-in. (10.2 cm) stainless steel pipe to a scrubber by the contact method gave a result of 175 g ^{235}U. The pipe section was removed and assayed in a Cf shuffler. The shuffler result was 155 g. The holdup measurement relative error was +13%.

Assay of a 6-ft (1.8 m) section of 3-in. (7.6 cm) stainless steel pipe by the far-field method gave a result 14% less than the assay value of the removed material in a SGS. In this case, a self-attenuation correction would have reduced the error.

Documentation

Results of calibration checks and assays were recorded on data sheets and signed and dated by the persons doing the assay. All data sheets and spreadsheets used to determine the holdup value for an area were attached to the holdup report for the area, and all these reports and supporting documents were assembled into a four-volume internal SRS document.

CONCLUSIONS

Our experience with the Holdup Measurement Program at SRS suggests the following guidelines to keep from repeating past mistakes:

- Make provision for holdup measurement a design requirement for new facilities. Many of the shortcomings and difficulties in our measurements would have been eliminated had this guideline been observed.
- Develop a holdup measurement program before it is needed.
- Subject the program to external review. This will enhance program credibility and help avoid oversights.
- Beware of complacency; question your results. It's easy to fall into a routine and overlook an effect that strongly affects your results.

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ACKNOWLEDGEMENT

The information contained in this article was developed during the course of work under Contract No. DE-AC09-89SR18035 with the U. S. Department of Energy.

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