A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR -83-3381

LA-UR--83-3381

DE84 [illegible]

CONF-831106 6

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best available copy to permit the broadest possible availability.

TITLE: MEASUREMENTS OF URANIUM HOLDUP IN AN OPERATING GASEOUS DIFFUSION ENRICHMENT PLANT

AUTHOR(S): R. H. Augustson, R. B. Walton, R. Harris, W. Harbarger, J. Hicks, G. Timmons, D. Shissler, R. Taylor, S. Jones and L. Fields

SUBMITTED TO: ANS/INMM Conference on Safeguards Technology
The Process-Safeguards Interface
Hilton Head Island, South Carolina
November 28-December 2, 1983

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy

MASTER

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MEASUREMENTS OF URANIUM HOLDUP IN AN OPERATING GASEOUS DIFFUSION ENRICHMENT PLANT[a]

R. H. Augustson and R. B. Walton
Los Alamos National Laboratory
Los Alamos, NM 87545
(505) 667-5332

R. Harris
U.S. Department of Energy
Oak Ridge Operations
Oak Ridge, TN 37830

W. Harbarger, J. Hicks, G. Timmons,
D. Shissler, R. Tayloe, and S. Jones
Goodyear Atomic Corporation
Piketon, OH 45661

L. Fields
Union Carbide Corporation
Nuclear Division
Bldg. K-1001, MS-189
Oak Ridge, TN 37830

ABSTRACT

Holdup of nuclear material in process equipment is one of the major sources of uncertainty in materials balances, particularly for high-throughput facilities with large equipment and extensive piping, such as gaseous diffusion uranium-enrichment plants. Locating and measuring the holdup while the plant is operating is a challenging problem because of background from the process material and the neighboring equipment. This paper reports NDA measurements performed at the Goodyear Atomic Gaseous Diffusion Plant, Portsmouth, Ohio, on enrichment equipment at the higher enrichment end (>10% ^{235}U isotopic abundance) of the cascade. Both neutron and gamma-ray measurements were made to locate anomalously large deposits in converters and compressors and, within the limitations of the techniques, to quantify the amount of the deposit.

I. FACILITY DESCRIPTION

All the measurements were made in the 326 building at the high-enrichment end of the cascade. In this building, the two sizes of equipment are designated Type 27 (lower enrichments) and Type 25 (higher enrichments). The cascade is organized by individual stages with 12 stages per cell, 20 cells per unit, and 9 units in the 326 building. A cell is identified by an equipment size number (25 or 27), a unit number, and then the individual cell, for example, 27-3-5.

Each cell, ~6 m wide and 30 m long, is enclosed by walls and roofing made of thin metal and thermal insulation. Each enrichment stage contains a converter, cooler, compressor, and connecting piping. The nondestructive assay (NDA) measurements were made from the roof of the cell housing.

Within a cell, the stages are numbers 1-12; number 1 is the input side and number 12 is the output. The unit structure is shown in Fig. 1. A stage comprises piping, a converter containing the barrier material, a cooler, and a compressor. The stages are interconnected in a complicated cluster arrangement with three stages per cluster. Figure 2 is a drawing of two typical interconnected cells. It is important to understand the details of the equipment layout because it strongly influences the choice of measurement location and data interpretation. For example, note how the converters are displaced from the center line, alternating from one stage to the next. The choice of measurement location must take this into account.

II. GAMMA-RAY MEASUREMENTS

A. Uranium-235 Detection with 1.27-cm-Thick, 5-cm-Diam NaI Detectors

Most of the gamma-ray survey data were collected with two portable 1.27-cm-thick, 5-cm-diam NaI detectors coupled to Eberline SAM-II (two-channel) electronics packages. This thickness of NaI is nearly optimum for the detection of ^{235}U 186-keV gamma rays in the presence of higher energy background gamma rays from the daughters of ^{238}U. Each NaI detector is housed in a 0.64-cm-thick lead collimator with a handle and an additional 0.95-cm-thick lead shield over the region containing the NaI crystal. The collimator diameter is 6 cm, and the distance from the front of the collimator to the front of the detector was set at 5 cm, corresponding to a distance to the "effective" detection position of 6 cm. The single-channel analyzers were set at energy windows of 161-211 keV and 230-287 keV to measure simultaneously 186-keV gamma rays from ^{235}U and a count above this energy for background subtraction.

---

[a] Work supported by the US Department of Energy, Office of Safeguards and Security.

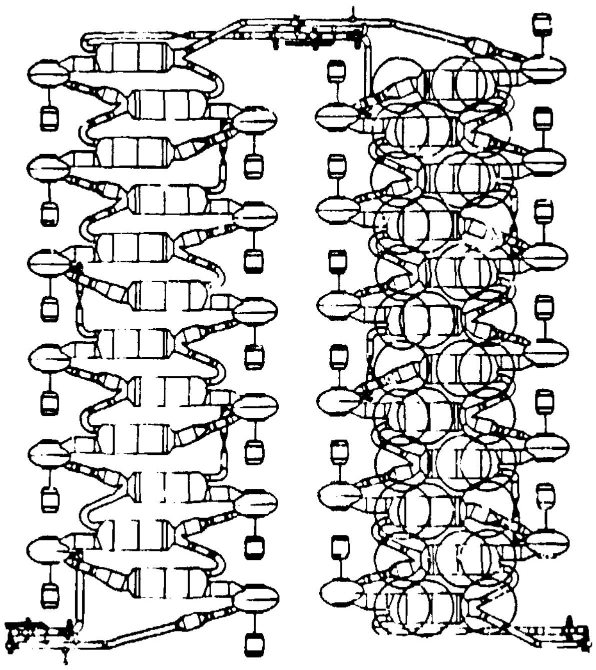


Fig. 2. Locations of stage components in two cells.

This technique and the cell overhead geometry used for this exercise are very similar to those used several years ago by Los Alamos to evaluate holdup in the high-enrichment portion of the shutdown cascade at K-25 Oak Ridge Gaseous Diffusion Plant.[1] Except for the collimator, the NaI thickness, the background subtraction capability, and the temperature stabilization of the SAM-II, the method is also similar to the RASCAL survey instrument recently developed and implemented by Goodyear Atomic Corporation. The advantages of detector collimation are higher detection sensitivity and the capability of measuring holdup in individual components of an enrichment stage. The principal disadvantage of the collimator and shield assemblies used in the present work is their weight. They are too heavy for routine surveys that are performed manually by production personnel.

The overhead surveys were performed with the detectors placed on the cell rooftops looking downward at selected components. Given the distance of 213 cm from the rooftop to the median plane of the converters and most of the UF_6 gas transfer components, the detector views a 175-cm-diam circle in the median plane and, in the case of a line source, a 155-cm effective length. The effective source dimensions were derived from the measured angular response of the detectors.

Figure 3 shows a plan view of the areas and components viewed by the 1.27- by 5-cm collimated NaI detectors in the overhead cell surveys. For each stage, measurements were performed at three positions centered above the circles and normal to the converter axis. The measured response was from the materials located within the circles superimposed on the cell layout drawings. Note that signals from adjacent stages are blocked by the collimator.

These two detectors were calibrated by two independent methods. The first method, point-source calibration, was made by first measuring the counting rate with a thin ^{235}U foil standard (0.395 g ^{235}U) at 36.5 cm from the effective detection position in the NaI. This calibration was then scaled to the distance used in

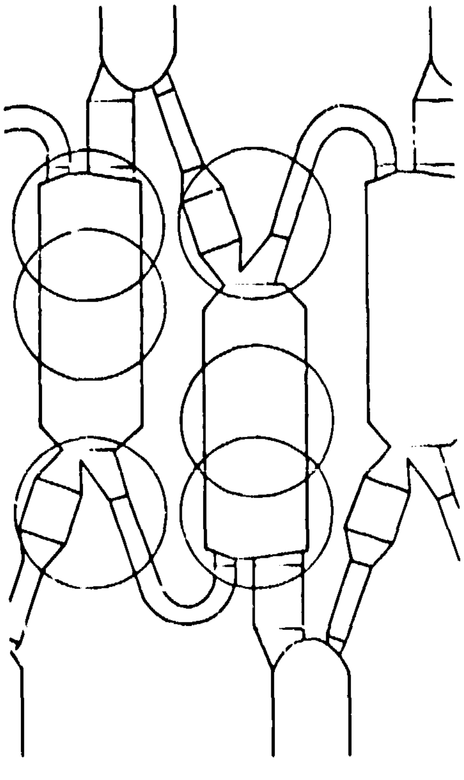


Fig. 3. Gamma-ray detector viewing areas of a stage.

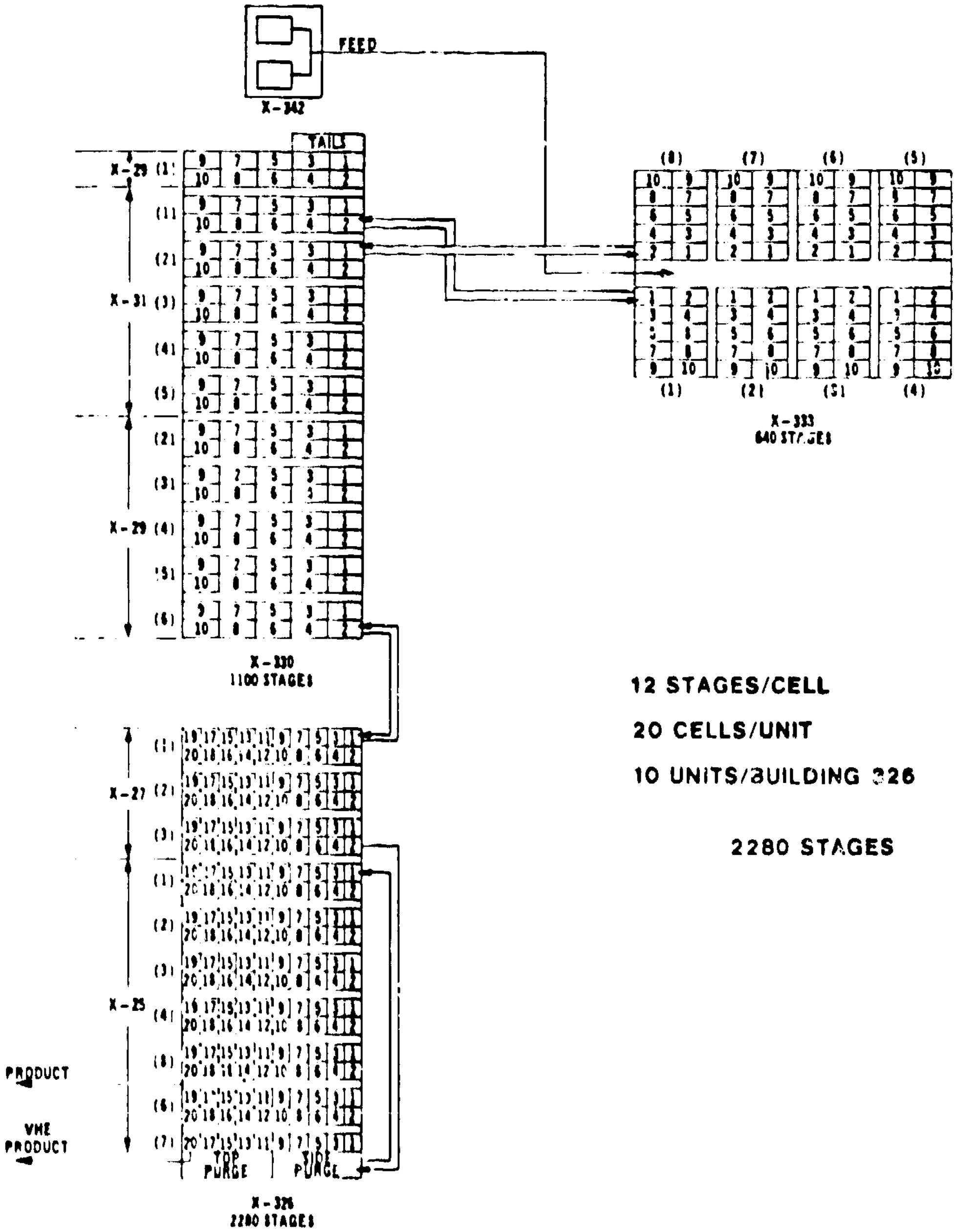


Fig. 1. Layout of the enrichment cascade at the Goodyear Atomic Gaseous Diffusion Plant.

TABLE I

^{235}U HOLDUP IN CALIBRATION CELL
(grams)

Stage	Converter[a]
1	116
2	22
3	26
4	15
5	20
6	47
7	45
8	35
9	77
10	139
11	117
12	255

---

[a] Quantities derived using calibration constant and assuming uniform distribution of material in converter.

example of direct holdup measurement results, in this case for the evacuated calibration cell. The quantities shown for stages 1-9 can be attributed essentially all to solid deposits, whereas those for the higher stages also comprise significant amounts of residual gas-phase ^{235}U. Based on stages 1-9 data, the average holdup in a single entire converter is 45 g ^{235}U and the average for an inlet region is 4 g ^{235}U. The minimum detectable amounts of the ^{235}U in an entire converter and in an inlet region, that is, the detection sensitivities for counting times of 30 s are 10 and 3 g, respectively.

Figure 4 shows an example of the peak stripping procedure applied to the converter data measured with a collimated 1.27- by 5-cm NaI detector over a cell that was operating at the time of the measurement. Significant deposits are evident in converters of stages 4 and 11. A variance parameter, σ, was used to identify anomalously large ^{235}U quantities above the baseline composite of gas-phase ^{235}U and smaller amounts of uniform holdup. Sigma is defined as the square root of the sum of the squares of the per cent variance of the UF$_6$ gas phase in the converters in the calibration cell, (7.7%), and the standard deviation (%) of a 30-s count of a cell converter that showed no significant anomaly. The detection limit of 2σ permits us to identify anomalies that lie outside the stage-to-stage UF$_6$ gas-phase variations in a normally operating cell.

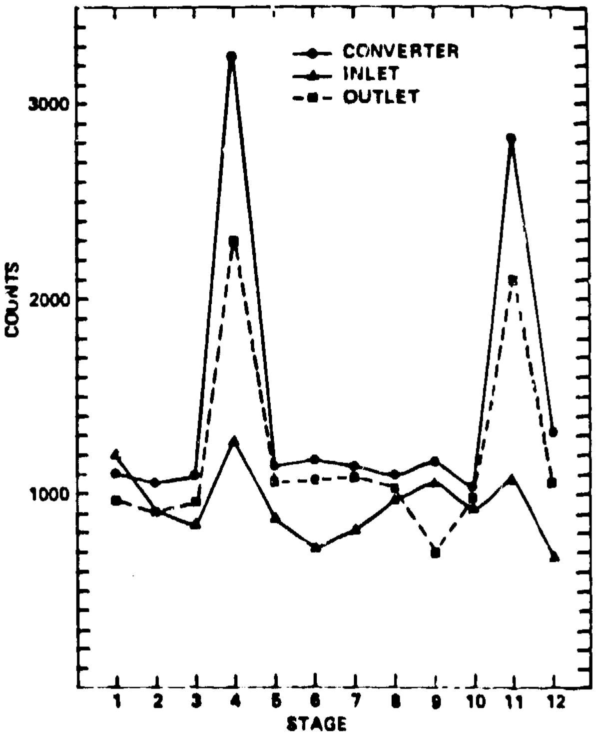


Fig. 4. Grams ^{235}U (from gamma-ray measurements) vs stage for three viewing areas.

Table II shows the difference between the baseline count and the counts for stages 1, 2, 8, and 10 of another cell, together with the conversion to g ^{235}U. The first-pass results for ^{235}U were so large that an iteration to account for the self-attenuation of these deposits was needed. The numbers in the last column were obtained assuming that the uranium was uniformly deposited within each converter and using data taken over the center of the converter. The largest attenuation correction was 1.09.

Without independent information about the operating parameters of the cell, it is not possible to subtract the gas-phase ^{235}U to obtain the smaller, more uniformly distributed the survey measurements, 219 cm, by the appropriate $1/r^2$ ratio. Next, the angular response of the detector was measured so that the effective area of the component viewed by the collimated detector could be determined for two-dimensional analysis, or for one-dimensional analysis, the effective length of the source could be determined. The angular or lateral response was determined by measuring the counting rate of a large-mass ^{235}U sample as a function of the perpendicular distance from the collimator line of sight at a point 169 cm from the detector. The attenuation of the cell roof cover hatch relative to that at zero lateral displacement was included in the final lateral response function used to reduce the overhead survey data.

The next step in applying the point-source calibration was calculating the attenuation of the 186-keV gamma rays by the components being viewed. For the purpose of calculating attenuation corrections, most UF_6 gas transfer components, except for the converter, the central (heat exchanger) region of the cooler, and the compressor, can be considered as simple pipes with 0.95-cm walls. A detailed point-source calibration was applied only to the overhead measurement of converters, a case that is amenable for quantitative assay based on 186-keV gamma-ray detection and important because converters frequently collect significant deposits of uranium solids.

The second calibration method used was the gas-phase technique, which is based on measuring the components of stages in a cell operating normally with UF_6 and repeating measurements with the UF_6 displaced from the cell. Figure 3 shows the viewing circles and enclosed components in the median horizontal plane of a generic stage. The centers of the circles correspond to the three gamma-ray measurement position on the cell roof. The difference between the observed counts with and without UF_6 can be attributed directly to the amount of ^{235}U in the detector viewing area, providing that the gamma-ray attenuations of the various components in the field of view are the same. This condition is met in the case of the measurements made directly above the converter centers. At the other extreme, the heat exchanger regions of the coolers are very dense and transmit essentially no gamma rays to the detector. Thus, the cooler region is omitted entirely as a component in the measurement calibration of the converter input region. Finally, the gas-phase calibration requires that UF_6 masses be obtained from stage temperature and pressure measurements and purity and isotopic analyses of samples. The ^{235}U masses in the components encompassed in the three measurement viewing areas used in the surveys were provided by Goodyear Atomic Corporation.

The point-source and gas-phase calibration methods agreed within 17%. The gas-phase value was used in the subsequent analyses.

B. Overhead Measurements with the 1.27-cm-Thick Detectors

These surveys were conducted with the SAM-II set for automatic background subtraction in the 186-keV window from Compton tails of the high-energy gamma rays from ^{238}U daughters, cosmic rays, and the environment. Separate channel counts were taken at least once during the survey of a cell to obtain a background count for estimation of statistical precision. A typical net count and a background count over a converter in an operating cell in Unit 27-3 were 2400 and 100 counts/min, respectively. The counting time was 30 s for each measurement point. The stability of each instrument was checked at least once during a cell survey by counting a ^{235}U foil in fixed geometry. The measurement point above the converter was 2.4 m from the cell housing wall on the side of the compressor for that stage, and the measurement points for the converter inlet and outlet regions were 1.5 m from one side or the other of the cell walls, depending on the stage and cell number. Because of this topography, measurement points were designated as left, center, and right, relative to the direction of increasing stage number; the correspondence with the actual component regions was made as a part of the data analysis.

The calibration constants obtained from the UF_6 gas-phase measurements performed on the calibration cell can be used to convert observed counting rates to g ^{235}U. If the quantity of gas-phase ^{235}U in the stage components is obtained from pressure and temperature measurements and analyses of gas samples, this portion of the measured ^{235}U can be subtracted to yield ^{235}U holdup. Alternatively, the baseline in a plot of the measured amount of ^{235}U in a particular equipment zone as a function of cell stage can be subtracted to find the amounts of large, localized deposits, which correspond to peaks in the data. Of course, the latter method, referred to as "peak stripping" or baseline subtraction, will not give the amount of ^{235}U that has built up uniformly in a cell. This uniform holdup combined with the in-process UF_6 is the source of the baseline counts.

For shutdown cells, the collimated NaI detector provides a direct measurement of the holdup in its viewing field. Table I gives an

TABLE II

PEAK-STRIPPING EVALUATION OF ANOMALOUS ^{235}U DEPOSITS IN CONVERTERS OF OPERATING CELL

Stage (Converter)	Counts (Baseline per 30 s)	Net Counts/min	First-Pass g ^{235}U	Attenuation Corrected g ^{235}U
1	2375	4750	1185	1292
2	528	1056	263	268
8	2176	4352	1085	1172
10	417	834	208	212
			Total	2944

baseline holdup in the cell converters. For this example of peak stripping, the minimum amount of ^{235}U that can be detected in a single operating converter, that is, the detection sensitivity, is 90 g. These numbers also correspond to the uncertainties that we assign to the measurements, neglecting, of course, errors from nonuniform converter distributions.

As an example of data reduction using the gas-phase inventory and enrichment obtained from Goodyear Atomic Corporation operations and analytical chemistry laboratory, we show in Table III results for measurements of converters in cell C. This cell had no anomalies. Clearly, there is a negative bias of at least 14 g per stage in the unlikely event that the converters in this cell have no holdup. A more reasonable assumption is that this cell has a baseline average uranium holdup about the same as that of the calibration cell, which is ~20 g ^{235}U per converter.

Possible sources of the negative bias of ~34 g ^{235}U (20 g + 14 g) per converter are (1) changes in cell gas-phase inventory and enrichment in the time interval between the temperature, pressure, and enrichment measurements and the NDA measurements; (2) a 5% error in the gas-phase calibration; and (3) instrument drift. The last of these is ruled out because of the stability of the SAM-II unit and the record of the measurement control data with the standard ^{235}U foil. On the other hand, the enrichment of the calibration cell changed by 25% in 1 day during the measurement campaign. Even larger negative numbers for converters, except one with a large deposit, were obtained when the gas-phase subtraction method was applied to data for cell E. Clearly, taking the difference between two large numbers can yield meaningful results only if the accuracies of these numbers are very good, that is, a few per cent uncertainty.

TABLE III

HOLDUP IN CELL C CONVERTERS DERIVED FROM OVERHEAD MEASUREMENTS AND KNOWN GAS-PHASE INVENTORY AND ENRICHMENT

Stage	Measured Total ^{235}U (g)	Stage Average ^{235}U (g) in Converter	Net ^{235}U Holdup
1	473	447	25
2	407	447	- 40
3	415	447	- 32
4	367	447	- 80
5	415	447	- 33
6	438	447	- 9
7	470	447	23
8	424	447	- 23
9	472	447	25
10	413	447	- 42
11	427	447	- 20
12	484	447	37
	Mean = 433	Total =	-169
	σ = 35		

As a consistency check, we used the UF_6 gas subtraction method to evaluate the holdup in the calibration cell. These results, together with the results of the direct measurement with the UF_6 displaced, are given in Table IV. Although the differences between the by-difference holdup values and those measured directly for individual stages fluctuate considerably as expected, the totals are in excellent agreement. This may be a consequence of measuring the process parameters and enrichment simultaneously with the NDA measurements.

C. Conclusions and Recommendations for Gamma-Ray Measurements of Holdup

(1) The most valuable and probably the only overhead measurement needed for early detection of localized holdup was that made with the collimated 1.27- by 5-cm NaI 186-keV detector positioned on the cell roof directly over the converter center. Results of this study support the assumption that converters function as efficient filters for collection of solids. No new information was gained from measurements with this detector over the converter inlet and outlet components, and the amount of holdup in these components was consistently much less than that in the converter (except in cell A where the sudden multiple leaks occurred).

TABLE IV

^{235}U HOLDUP IN CELL G DERIVED
FROM OVERHEAD MEASUREMENTS AND
KNOWN GAS-PHASE INVENTORY AND ENRICHMENT

Stage	By-Difference Holdup ^{235}U (g)	Directly Measured Holdup ^{235}U (g)
1	163	116
2	43	22
3	16	26
4	40	15
5	6	20
6	66	47
7	34	45
8	4	35
9	27	77
Totals	402	403

(2) The contents of cooler heat exchangers could not be determined by gamma-ray measurements because they are opaque to the gamma rays used in this study.

(3) The collimated 186-keV gamma-ray detector calibrated by the gas-phase technique can measure absolute holdup to an accuracy usually better than ±20%. It also sharply isolates the ^{235}U signal from individual stage components. Figures 5 and 6 compare gamma-ray measurements with and without collimation. The minimum amount of ^{235}U that can be detected in a single operating converter in a counting time

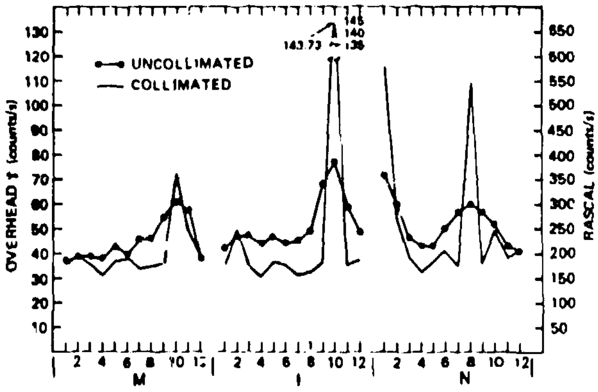


Fig. 5. Gamma-ray counts vs stage comparing collimated and uncollimated detectors.

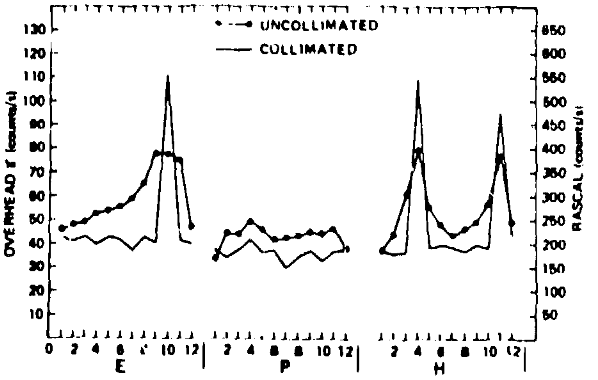


Fig. 6. Gamma-ray counts vs stage comparing collimated and uncollimated detectors.

of 12 s is ~100 g if the data for a cell are analyzed by peak stripping. This sensitivity for detection of anomalies is limited by variations in UF_6 gas-phase loadings of the converters within a cell. For a shutdown cell, the sensitivity for detecting ^{235}U in a converter is 10 g in 12 s.

(4) Converter holdup in an operating cell can also be derived from gamma-ray measurements by subtracting the signal from the UF_6 gas phase, providing the gas-phase ^{235}U is determined from careful and simultaneous measurements of stage process parameters and the cell enrichment.

(5) On the basis of gamma-ray measurements of shutdown cells, converter holdup can be classified as normal if less than 100 g ^{235}U and anomalous if greater. Data for 46 shutdown converters having less than 100 g ^{235}U indicate that the nominal holdup in a size 27 converter is on the average of 100 g uranium.

(6) Inasmuch as the average anomalous deposit in a converter was approximately 1000 g ^{235}U for the cells measured, the collimated 186-keV gamma-ray detector can be used for detection of holdup from new leaks long before they reach this level.

(7) The collimated 186-keV detector showed promise for detection of holdup in compressors either from the floor or several feet above the compressor.

Fig. 7. Large neutron area monitor used for holdup measurements.

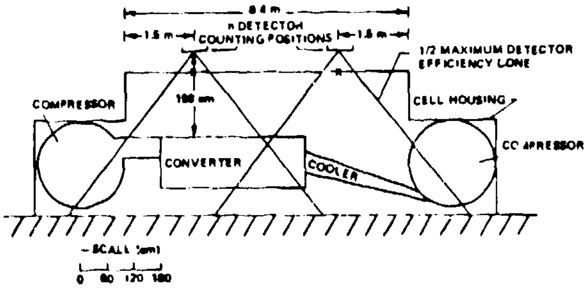
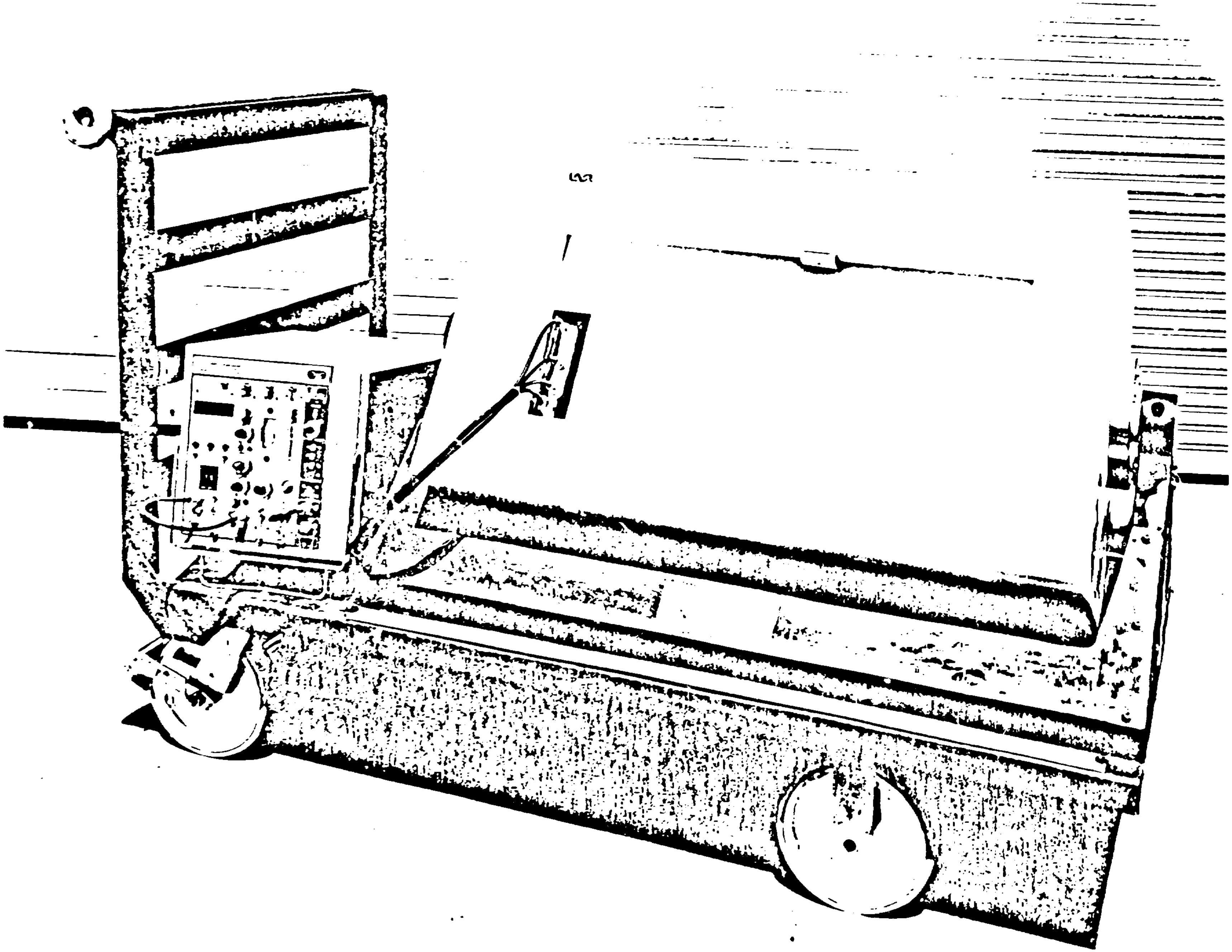


Fig. 8. Counting geometry (1/2 maximum cone) for neutron measurements of converter-cooler components.

III. NEUTRON MEASUREMENTS

A. Description of the Neutron Measurements

The neutron emission from UF_6 comes primarily from the $F^{19}(\alpha,n)$ reaction driven by alpha particles from ^{234}U. Thus, if the ^{234}U isotopic percentage is known, it is possible to calibrate a detector geometry for measuring the uranium in the cascade. The detector-geometry arrangement chosen to measure holdup in the Goodyear Atomic Corporation equipment was a large neutron area monitor, suspended over a cell with the active detector area looking down on a stage. Figure 7 shows the detector with polyethlene moderator and ^3He gas tubes. The viewing angle of such a detector is quite wide, particularly when compared with the collimated gamma detectors. By making two measurements, positioned as shown in Fig. 8, along the axis of a converter, an almost equal weighting is given to uranium neutrons emitted by material in a stage, except for that in the compressor. A third measurement was made to determine the quantity in the compressor (Fig. 9). The side viewing angle also includes neutrons emitted from adjacent stages. Therefore, to measure the quantity in a single stage, the data must be unfolded, subtracting the neutron rate from other stages. Such an unfolding procedure has been developed and applied to the data. The calibration of this detector geometry was performed by measuring each stage of a specific cell with and without UF_6 gas present, just as for the gamma detectors. Knowing the amount of UF_6 gas from plant data, the calibration constant, neutron count rate per kilogram of ^{234}U was calculated. Because the emphasis of



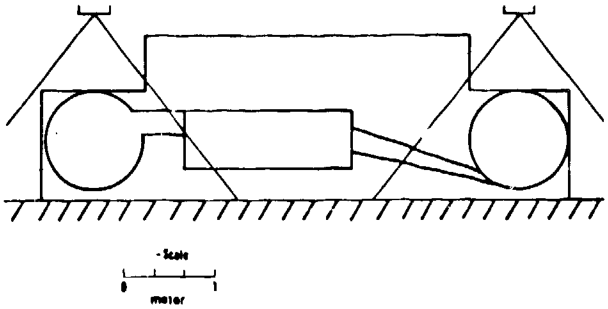


Fig. 9. Counting geometry (1/2 maximum cone) for neutron measurements of compressor-cooler components.

the present measurements is on material held up in cascade equipment, the calibration constant must be corrected for the different neutron emission rates of UF_6 and UO_2F_2. The chemical form of holdup material, UO_2F_2, has an emission that is only 0.44 times that of UF_6. To determine the amount of uranium holdup in an operating stage, one first subtracts the neutron rate for the known gas-phase inventory and applies the corrected UO_2F_2 calibration constant. This procedure assumes that the amount and isotopic composition of the stage gas-phase inventory and the isotopic composition of the holdup material are known. Holdup isotopic composition is subject to large uncertainties because it is not known when the deposits were formed.

The neutron detector geometry was calibrated as described. A cell was measured with UF_6, then shut down and pumped out. By subtracting the neutron counts with and without gas present, the counts due to only the gas can be determined. These data were then unfolded. Table V summarizes the data to this point. For this cell, the gas-phase inventory was calculated from process information and a sample taken for isotopic analysis.

The neutron data, while involving a series of analysis steps, hold promise of giving a quantitative estimate of large holdup deposits located by the gamma survey measurement. The following steps summarize the data analysis.

1. Add right and left measurements.
   - Measurement positions allow approximately equal weighting to be given to the various locations in the stage except for the compressor. Compressor measurements are analyzed separately.

TABLE V

COUNT DATA FOR CALIBRATION OF CONVERTER PLUS COOLER
Count/100 s = Left + Right − Background

Stage	Gas + Holdup	Holdup	Gas (Calculated) Inventory		Unfolded Gas
1	445	94	351		211
2	607	87	520		290
3	682	72	610		359
4	638	67	571		249
5	716	82	634		353
6	702	68	634		358
7	651	81	570		262
8	671	89	582		295
9	704	87	617		373
10	640	121	519		217
11	633	120	513		326
12	481	144	337		198
		1112	5824	Total	3491

Note: $(Gas)_{Calc} = (Gas + holdup)_{Meas} - (Holdup)_{Meas}$

2. Subtract background.
   - Background, measured by looking down at the end of a unit with only one cell on one side and doubling it, was consistently 100 counts/100 s ± 30 counts/100 s.
3. Unfold resultant stage net count rates next to give the contribution from a single stage.
   - This requires solving a set of 12 coupled but linear equations.

     C_i is the measured quantity and S_i is the desired neutron source:

     $$C_i = S_i + \alpha(S_{(i+1)} + S_{(i-1)}) + \beta[S_{(i+2)} + S_{(i-2)} + \cdots]$$

   - α, β need to be determined. From the detector angular distribution and the stage geometry, the values used in this analysis are $\alpha = 0.36$, $\beta = 0.10$.
4. Separate the single-stage count rates into a component from gas-phase inventory and a second component from uranium holdup.
   - Gas-phase inventory is estimated from process parameters and assay values. Then using the calibration

constant counts/time/kg ^{234}U, the counts from gas-phase inventory are calculated and subtracted from the total.

- The uranium holdup is determined from the counts remaining but using the calibration factor for UO_2F_2.
- The assay (isotopic composition) of the holdup material will probably be different from the gas phase and not known This will contribute to the uncertainty in the holdup determination.

B. Results

1. Holdup Determinations for Converter-Cooler Combination. Figures 10-12 show the stage-by-stage unfolded neutron counts for eight cells. These results correlate exactly with the gamma measurements. The deposits in coolers also contributed to the neutron count, whereas for the gamma count they did not. Thus, neutron detection samples more of the stage components. As for the gamma method, it is only possible to calculate a total holdup number for those cells not on-line or if the gas-phase inventory is known.

Cell A

This cell had ruptures in three expansion joints and was off-line when measured. After measuring each stage, converter 5 was removed from the cell, and the cell was remeasured. Converter 5 was also measured in a location isolated from the cascade equipment.

Cell A--Before and after converter 5 was removed

Stage	Measured Kilograms of Uranium Before	After
1	1.5	1.6
2	7.1	7.1
3	6.6	6.4
4	12.9	13.3
5	27.1	25.2
6	33.5	25.8
7	10.5	13.2
8	2.7	2.6
9	5.9	5.6
10	1.1	1.2
11	0.6	0.6
12	3.0	2.9
	112.5	105.5

Δ = 7 kg U

These measurements indicate a total cell holdup of 105.5 kg U after removal of converter 5 and that converter 5 contained 7 kg U.

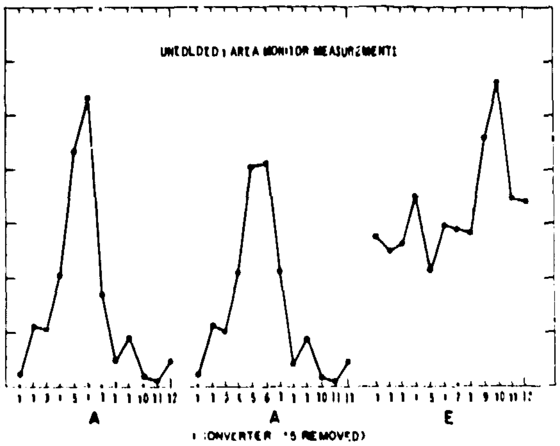


Fig. 10. Neutron counts vs stage.

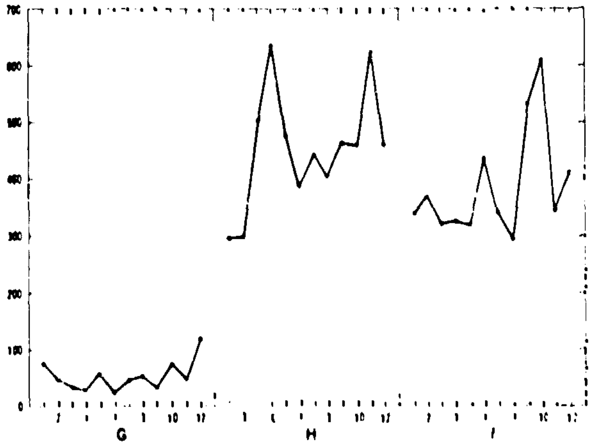


Fig. 11. Neutron counts vs stage.

Converter 5

Unfolding was not required because these measurements were made after the converter was removed and isolated from the cell. The counts were 147/100 s corresponding to 9.2 kg U.

This is compared with 7 kg from the previous difference value. The isolated measurement should be more accurate than the difference measurement made on the cell with and without converter 5.

Cell B

Off-line--drawing a negative pressure, that is, no UF_6 gas. Holdup was 19 kg U.

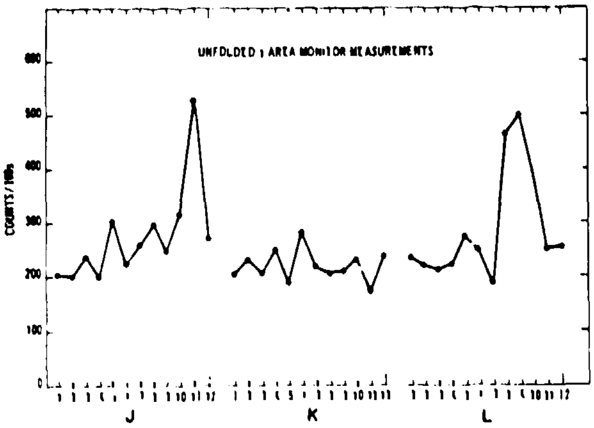


Fig. 12. Neutron counts vs stage.

Cell C

Operating cell--so an estimated count rate from the gas-phase must be subtracted.

Stage	Total Counts	Estimated Gas-Phase Counts	Difference (Holdup)
1	209	163	46
2	219	163	56
3	281	163	118
4	180	163	27
5	206	163	43
6	252	163	89
7	223	163	60
8	255	163	82
9	186	163	23
10	223	163	60
11	306	163	6
12	306	163	143
			753

Equivalent to 39 kg U

NOTE: If the background had been 30 counts/100 s higher, then the holdup would be reduced to 20.2 kg U, showing that the difference approach can be very sensitive to the background value.

2. Analysis of Compressor Data. The neutron data analysis procedure for the overhead compressor measurements is similar to that for the converter portion of the stage. The unfolding procedure is simpler because the compressors are farther apart. To the first approximation, the present analysis used α = 0.15 and β = 0. Figure 9 shows that the detector viewed the compressor, some piping, and most of the next upstream stage cooler within the half-maximum efficiency cone. This overlap makes interpretation of the data difficult because it is not possible to separate the compressor and cooler contributions.

Table VI summarizes the data and indicates an average holdup per compressor-cooler of 1.4 kg U for the cell measured. For cell G the stage-by-stage holdup is as follows:

Stage	Compressor Holdup U (kg)
1	1.5
2	1.7
3	1.5
4	1.4
5	0.4
6	0.8
7	0.8
8	0.9
9	1.6
10	1.3
11	1.7
12	1.7
Total	15.3

3. Summary of Neutron Measurements. Table VII compares the results of the neutron measurements with amounts of uranium recovered for three cells and one converter. Adding the converter and compressor values gives higher values than the amounts recovered. This is

TABLE VI

COMPRESSOR-COOLER HOLDUP

Cell	Total Counts	Gas-Phase Inventory	Δ	Uranium (kg)
A	988	--	988	71
B	410	--	410	10
C	1418	960	458	27.4
		(1080)[a]	(338)	(20.3)
E	1932	1572	360	10.8
		(1769)[a]	(163)	(4.9)
F	2063	1464	599	20.2
		(1647)[a]	(416)	(14)
G	625	--	625	15.4

Av/stage (excluding A) = 1.4 kg

---

[a] Attempt to include cooler in gas-phase counts.

TABLE VII

COMPARISON OF NEUTRON MEASUREMENTS VS RECOVERY

Cell	Neutron Measurements (kg U)			Recovery (kg U)
	Converter	Compressor	Total[a]	
A	105	71	176	120
B	19	10	29	25
C	39	27	66	--
E	18	11	39	--
F	12	20	32	28
G	7-15	15	22-30	--
Stage 5 converter			9.2	6.9

[a] "Total" counts the cooler twice; therefore, total values should be high; how high depends on the amount of material in the cooler.

expected because some components, for example, coolers, are weighted too much by the simple addition of results. As more experience is gained, a more suitable data analysis can be applied.

C. Conclusions and Recommendations for Neutron Measurements

The purpose of NDA holdup measurements is to identify cells with problems by detecting deposits, and in some cases, observing the growth of deposits from one month to the next. Ideally, the measurements should localize the deposit within a cell to a given stage and within the stage to a specific component, for example, converter, cooler, or compressor. In addition to locating the deposit, the measurement should quantify the amount within a known uncertainty.

Using the present neutron measurements, the deposit can only be localized to within one or two stages because of the relatively wide detector viewing angle. The detector looks at all components in a stage but cannot effectively indicate whether the material is in the converter, compressor, or upstream cooler. The quantitative comparisons of neutron results for a cell with Goodyear Atomic Corporation results (Table VII) are in reasonable agreement (±50%) but at present are based on only four cases. The factors affecting the measurement uncertainty are understood but more information is needed to determine the range of these factors.

To interpret the data, the UF_6 gas-phase inventory and isotopic assay must be known. The detector background, holdup isotopic assay, and holdup chemical composition directly affect the quantitative results. Therefore, effort should be made to improve the knowledge of these factors.

The principal disadvantages to routine use of the neutron measurements are the time and effort required to collect the data and the uncertainties in certain key information. The advantage to the neutrons is that they "see" the entire stage with approximately equal weighting, which is particularly important for criticality safety measurements.

REFERENCE

1. R. B. Walton, "The Feasibility of Nondestructive Assay Measurements in Uranium Enrichment Plants," Los Alamos Scientific Laboratory report LA-7212-MS (April 1978).