**CATALOGUE
OF
NUCLEAR MATERIAL SAFEGUARDS INSTRUMENTS**

**by
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MASTER

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Introduction

This catalog of data sheets on nuclear materials assay instrumentation has been prepared in order to provide a concise review of assay instrumentation presently in operation throughout the nuclear industry. It is not intended as a historical review, so that instrumentation which has been significantly improved or considered out of date has not been included. The information presented here has been taken from presentations at professional meetings and the published technical literature, and the authors of the original material have been contacted and asked to correct, update, and revise the data contained on these sheets. Some small changes have also been made by the editors with the aim of providing a uniform presentation of results without introducing errors of omission or changing meanings intended by the original authors.

It should be noted that no attempt has been made to consistently define the terminology used relating to accuracy, precision, assay time per sample, etc., but the information available was incorporated into the data sheets. Care must be taken when attempting close comparisons of one technique with another since the quantities presented here may be defined somewhat differently by individual authors. In these cases, it is recommended that the user contact the original developers directly for more precise information.

It is hoped that this catalog will provide a useful reference for technical professionals, managers, and administrators in government and private industry who are concerned with the non-destructive assay of nuclear materials.

NOTICE

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MASTER

**CATALOG OF
NUCLEAR MATERIAL SAFEGUARDS
ASSAY INSTRUMENTATION**

This catalog has been divided into three sections, each section designated by a broadly defined class of assay sample types (see below). Instrumentation designed for assay of a given class of samples are included in the respective section of this catalog. Where more than one class of sample can be assayed by a single instrument, cross references are included.

A list of contributors, a list of abbreviations used, and further information on obtaining reference documents are included after Section C.

<u>SAMPLE TYPE</u>	<u>SECTION</u>
PELLETS, PINS, RODS, PLATES	A
PACKAGES, CANS, BOTTLES, CONTAINERS (< 5 GALLONS)	B
DRUMS, BOXES, CONTAINERS (> 5 GALLONS)	C

SECTION A - PELLETS, PINS, RODS, PLATES

- A1 Fuel Pellet Enrichment Meter
- A2 Ge(Li) Fuel Plate Assay Unit
- A3 Automated Fuel Scanner
- A4 Sodium Iodide Fuel Scanner
- A5 Low Enrichment Rod Scanner
- A6 Isotopic Neutron Source Assay Unit (Rods)
- A7 Active Coincidence Unit - Rods - NNC - 1A3
- A8 Reactor Activation Analysis
- A9 Fuel Pin Calorimeter

Also see sheets:

B1, B9, B11, B13, B14

A1

1. Assay Instrument - Fuel Pellet Enrichment Meter.
2. Developer - Division Nuclear Materials Safeguards (District 1) and Brookhaven National Laboratory. ⁽¹⁾
3. Principle of Measurement. The detector views the sample through an appropriate "mask" or collimator and the 185 KeV activity is measured with a NaI crystal to obtain the ²³⁵U enrichment of pellets and rods. The use of the mask and a simple method for proper subtraction of the Compton continuum allows one to measure a signal which is truly proportional to the ²³⁵U enrichment. The net counts in the 185 KeV peak are proportional to the percent enrichment of the sample.
4. Design and Operation
 - a. Physical Layout

A 2 in. x 2 in. NaI crystal is enclosed in a lead shield. It views a portion of the sample through a 1/4 in. x 1/2 in. rectangular hole in a lead "masking plate" held rigidly in place with respect to the detector.
 - b. Electronics

The NaI crystal was used with standard electronics including a multichannel analyzer (MCA) with the capacity to integrate. Two single channel analyzers could readily be substituted in place of the multichannel analyzer.
 - c. Data Readout

The Compton continuum below the ²³⁵U 185 KeV peak is subtracted off using a method which is amenable to two single channel analyzers or multichannel analyzers with an integrating capability. The printout could be made available directly in enrichment, given a reasonably sophisticated small computer.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
²³⁵ U	Low enriched fuel pellets and rods.	(A) Enrichment 0.17% (2σ) (Absolute).		300 sec.	DNMS District 1 van.	1

6. References

1. Gunderson, Cohen, Zucker, Proc. 13th Annual INMM Meeting (1972) in press.

1. Assay Instrument - Ge(Li) Fuel Plate Assay Unit.
2. Developer - Nuclear Materials and Equipment Corp. (1)
3. Principle of Measurement - The plutonium gamma rays in the "385 KeV complex" (taken in this case from 371 to 468 KeV) and the 208 KeV gamma rays from ^{239}Pu (^{241}Pu) were measured with a Ge(Li) gamma ray detector. The measured activities were used to determine the ^{239}Pu and ^{241}Pu content of the fuel plate. No correction was made for contribution to the 208 KeV peak from ^{241}Am gamma rays since all the material under assay had the same processing history.
4. Design and Operation
 - a. Physical Layout
A shielded 55 cm³ Ge(Li) detector was placed 12 in. from a fuel plate holder and a 36 mil Hf absorber was placed between the detector and the holder. Fuel plates were reproducibly clamped onto the holder and were assayed in a fixed position (not scanned).
 - b. Electronics
Standard Ge(Li) detector electronics were used. The low level discriminator was set at 180 KeV to minimize dead time in the analyzer ADC. A pulse generator was used to routinely check the calibration of the system.
 - c. Data Readout
Data was printed out, corrected for Compton and ambient backgrounds and converted to material content by hand. The spectrum was displayed on an oscilloscope and checked visually for unknown contaminants before the data was printed out.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	Fuel plates, mostly 2 x 4 x 1/16 in. (99% Pu, 92% 239 + 241).	(A) 0.3 to 0.6% (1σ) compared to chem- ical assay of a melt. (Results for a total of 378 plates dif- fered from chemical assay by 0.1%).		6 min. (total)	NUMEC	1

6. References

1. J. W. Kormuth, J. F. Gettings, D. B. James, Proc. 11th Annual INMM Meeting (1970), p. 266.

1. Assay Instrument - Automated Fuel Scanner.
2. Developer - Argonne National Laboratory. ⁽¹⁾
3. Principle of Measurement. A Ge(Li) detector is used to measure the intensity of the 414 KeV gamma rays from ^{239}Pu , the 185 KeV gamma rays from ^{235}U , and gamma rays from other heavy isotopes. An automated table is used to spacially scan the samples to increase the efficiency for measuring a large throughput of the same type of sample. Data handling is also computerized, requiring a minimal amount of operator attention. The measured Pu 414 KeV gamma activity is used to determine the amount of ^{239}Pu in the sample; other isotopes from Pu can also be assayed by measuring their respective gamma activities (for example, the ^{241}Pu , ^{241}Am and ^{238}U contents of samples have been routinely measured).
4. Design and Operation
 - a. Physical Layout
A 20 cm³ Ge(Li) detector is collimated with lead to a 1 in. x 2.5 in. aperture. Samples are placed on a computer controlled scanning table which can routinely assay a batch of samples consisting of (for example) 8 rows of 6 plates each (2 in. x 4 in. plates). The system can scan 480 of these plates in a 40 hour work week.
 - b. Electronics
Standard Ge(Li) counting electronics are used. In addition, a system is in use for making a dead time correction by introducing pulses from a pulse generator into the detector preamp and comparing the number recovered by the ADC to the number generated. Effects due to gain shifts are minimized by notifying the computer of the 414 KeV peak position before the assay of each batch of samples.
 - c. Data Readout
Data is accumulated and processed by a PDP-8 computer. Data is presented in terms of ^{239}Pu content of the assayed samples; other isotopes can be measured as well. Confidence limits for the assay values are calculated on-line.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	U/Pu metal alloy fuel plates	(P) $\pm 3\%$ (2 σ)		2-3 min./ plate	ANL	1, 2, 4
Pu	U/Pu mixed oxide ZPR fuel pins	(P) $\pm 2\%$ (2 σ)		4-5 min./ pin	ANL	3, 4
U	UC ₂ ZPR fuel pins	(P) $\pm 2\%$ (2 σ)				

6. References
 1. R. B. Perry, R. W. Brandenburg and N. S. Beyer; Proceedings - 9th Annual INMM Meeting (1968) p. 205.
 2. N. S. Beyer, R. B. Perry, R. W. Brandenburg and L. K. Hurst; Proceedings - 10th Annual INMM Meeting (1969) p. 143.
 3. N. S. Beyer, R. B. Perry, R. W. Brandenburg and R. N. Lewis; ANL-7907 (1972).
 4. R. B. Perry, N. S. Beyer and R. W. Brandenburg; Proceedings - 11th Annual INMM Meeting (1970) p. 363.

1. Assay Instrument - Sodium Iodide Fuel Rod Scanner.
2. Developer - General Electric - Pleasanton. ⁽¹⁾
3. Principle of Measurement - A NaI gamma ray detector is used to measure the gamma ray activity from a fuel rod in the following four spectral regions or energy channels: 0.20 to 0.30 MeV; major contributors ^{239}Pu , ^{237}U , ^{241}Am , ^{238}U (daughter). 0.30 to 0.50 MeV; major contributors ^{239}Pu , ^{237}U , ^{241}Am , ^{238}U (daughter). 0.50 to 0.75 MeV; major contributors ^{241}Am , ^{238}U (daughter). 0.75 to 1.20 MeV; major contributors ^{241}Am , ^{238}U (daughter). Since there are four major contributors to the activity as measured in four separate energy channels, the individual activities of each of the isotopes can be determined from the solution of four simultaneous equations which relate contributions from individual isotopes to the measured activity in each channel. Calibration of the system is accomplished using known standards. The ^{239}Pu , ^{241}Pu , ^{241}Am , and ^{238}U contents of the fuel rod are determined from the measured gamma ray activities.
4. Design and Operation
 - a. Physical Layout
A 2 in. x 2 in. NaI crystal views the fuel rod as it passes through a lead shielded collet-slit assembly at approximately 1 in. per minute. The system is calibrated by placing a ^{22}Na source in a fixed position in the collet assembly. Rods are scanned singly.
 - b. Electronics
Standard NaI electronics are used. The data is collected in four separate single channel analyzers (1 in./min.) set to cover the energy ranges specified above or in a multichannel analyzer. (The multichannel analyzer has proven to be the best method for reasons of stability).
 - c. Data Readout
Fuel rod and background data from the SCA's are analyzed by computer and the output including error analysis, is printed out in terms of fissile material content per rod.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	Mixed oxide fuel rods (2 to 25 w/o Pu).	Average deviation from chemical analytical value. (A) 1.7% (^{239}Pu) (A) 2.2% (^{241}Pu) (A) 13.3% (^{241}Am) (A) 14.1% (^{238}U) (A) 22.4% (^{235}U)		1000 sec.	GE	1, 2, 3

6. References
 1. D. M. Bishop, E. A. Aitken, Quarterly Report - Plant Instrumentation Program. GEAP - 12114-3 (1970).
 2. D. M. Bishop, E. A. Aitken, Quarterly Report, Plant Instrumentation Program GEAP - 12114-5 (1970).
 3. D. C. Wadekämper, D. M. Bishop and L. T. Hagie, Quarterly Report - Integrated Safeguards Experiment, GEAP - 12114 - 7, (1971).

1. Assay Instrument - Low Enrichment Rod Scanner.2. Developer - LASL. (1)

3. Principle of Measurement. A mechanized rod handling device passes fuel rods through an irradiation-counting chamber. A moderated spectrum of fission neutrons from a ^{252}Cf source irradiates the sample fuel rod in the chamber. The moderated source neutrons produce fissions primarily in the fissile material contained in the sample. The fission neutrons are detected by ^4He gas recoil counters which are biased above the median energy of the moderated source neutrons. The measured background of source neutrons which reach the detector with energies above the bias level is used in a feedback loop to stabilize the system response. The measured count rate of fission neutrons from the sample is used to determine the fissile material content of the sample. This assay apparatus is designed for rapidly measuring a large throughput of low enrichment fuel rods of the same size and basic design.

4. Design and Operationa. Physical Layout

The instrument is comprised of a rod handling mechanism which can accommodate fuel rods 13 feet in length and an irradiation-detection unit which is capable of making simultaneous measurements on up to four power reactor fuel rods. The irradiation-detection cylinder is about 2 feet long and 2 feet in diameter. It contains a $100\text{ }\mu\text{g}$ ^{252}Cf source in the center and is shielded for personnel safety. Four separate rod irradiation channels are located near the periphery, each containing a set of ^4He gas recoil counters.

b. Electronics

Modular electronics are used; a single NIM bin holds the amplifier and scalars for four separate data channels. Output from the channels is fed directly to a programmable calculator.

c. Data Readout

A programmable calculator accumulates the data from each of the separate data channels, reduces the data to grams ^{235}U , * and prints the results.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{235}U	Low enrichment fuel rods (1-3% ^{235}U).	(P) $\pm 1.2\%$ (1 σ) (A) For large numbers of rods, the measurement accuracy should be limited by the calibration accuracy.		Approx. 4 rods every 70 sec. (total).	LASL at GE Wilmington.	2

*Laboratory assays have been run on mixed oxide rods for ^{239}Pu + ^{235}U content with favorable results.

6. References

1. H. O. Menlove, R. A. Forster, D. B. Smith, Nuclear Safeguards R&D, LA-4705-MS (1971) p. 6.
2. H. O. Menlove, R. A. Forster, D. B. Smith, H. Forehand, Nuclear Safeguards R&D, LA-4794-MS (1971) p. 8.

1. Assay Instrument - Isotopic Neutron Source Assay Unit - (Rods) - NNC-1A2
2. Developer - National Nuclear Corp. ⁽¹⁾
3. Principle of Measurement. A portion of a fuel rod is irradiated with neutrons from an isotopic source with an average energy below that of the neutron fission thresholds of ^{238}U and ^{232}Th . These source neutrons fission the fissile material in the rod and the stimulated fission neutrons are detected. The detector system discriminates between fission and source neutrons. Fuel rods can be scanned to provide pellet-to-pellet information as well as total fissile content for each rod. The detector count rate is related to the fissile material content of the sample. The unit can also be operated in a passive mode without the isotopic source and spontaneous fission neutrons from the rod can be measured and related to the material content.
4. Design and Operation
 - a. Physical Layout
The rod is placed on an automated rod scanner which transports it through the source-detector assembly at speeds which can be varied from 1 in./min. to 12 ft./min.
 - b. Electronics
NNC fabricated circuits and assembly.
 - c. Data Readout
Analogue data is recorded on a strip chart recorder and the integrated count for each rod is printed out on paper tape. The analogue information can be used to locate pellets with above or below average enrichments. An alarm sounds if high or low level preset limits for integrated count are exceeded.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{235}U	Fuel rods, 3% enrichment.	Average error in rod enrichment - 0.4 to 2.1% (relative) @ 12 ft./min.	Locates single pellets with enrichment 30% different from spec @ 1 in. to 1 ft./min.		NNC	1
^{239}Pu - ^{235}U	Mixed oxide fuel rods (1-10% enrichment).	Average error in rod enrichment 2 to 3% (relative).			NNC	1

6. References

1. H. Miller, T. Shea, Results of Typical Non-destructive Measurements of Fissionable Material in Various Forms Using NNC Machines, Proc. 12th Annual INMM Meeting (1971) Vol. II, p. 402.

1. Assay Instrument - Active Coincidence Unit - Rods - NNC - 1A3
2. Developer - National Nuclear Corporation^(1,2)
3. Principle of Measurement. A low energy Pu neutron source or a moderated ^{252}Cf source is used to irradiate the fuel rod (the source used depends on the scan speeds required). Detectors count the emissions of induced fission gamma rays and neutrons from neutron induced fission primarily occurring in the fissile material in the rod. The detectors use nanosecond coincidence logic to sort out fission events (multiple emissions of gamma rays and neutrons) from background radiation. The coincidence count rate is directly related to the amount of fissile material within the rod. Only a short segment of the rod (approximately 1 inch) contributes to the observed coincidence count rate as the rod passes through the detector providing spacial information on the fissile material distribution.
4. Design and Operation
 - a. Physical Layout

Fifty or more rods are placed on a rack; the machine automatically loads one rod at a time and feeds it through the detector at speeds which are controlled by a crystal timer and can be varied from 1 inch/minute to 12 feet/minute. Where pellet-to-pellet information is required, a low energy Pu source can be used to run 10 to 20 rods per day or a ^{252}Cf source for throughput rates of 40 to 100 rods per day. If it is sufficient to measure integrated ^{235}U content, without detecting localized variations, then either source can be used to handle several hundred rods per day.
 - b. Electronics

Stabilized NNC coincidence circuits, amplifiers, etc. are contained in a unit which is integrated in the rod drive main frame. Two out of 4 and 3 out of 4 coincidences are both measured.
 - c. Data Readout

Analogue data is recorded on a strip chart recorder and the integrated count for each rod is printed out on paper tape. The analogue information can be used to locate pellets with above or below average enrichments. An alarm sounds if high or low level present limits for integrated count are exceeded. Data output is compatible for use with teletype or a computer.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay Time per sample	User	Ref.
^{235}U	LWR Fuel Rods	(A) $\pm 1/2\%$ using standard rod		3 min./rod	NNC	1
		(A) $\pm 1\%$		1 min./rod		
^{239}Pu	LWR Mixed Oxide Rods	(A) $\pm 1\%$		1 min./rod	NNC	1

6. References

1. H. Miller, LWR Fuel Rod Non-Destructive Assay Measurement Using NNC Production and Portable Systems, Proc. 13th Annual INMM Meeting (1972) in press.
2. U. S. Patent No. 3,018,374.

1. Assay Instrument - Reactor Activation Analysis.2. Developer - Gulf Radiation Technology. (1)

3. Principle of Measurement - Samples are irradiated by a thermal neutron flux from a reactor. They are then transferred from the irradiation position to a moderated neutron proportional counter where the yield of delayed fission neutrons is measured for a specified period of time following the irradiation. Where larger sample sizes introduce differences in the system response (cts/g) due to attenuation effects, a calibration curve of response versus sample size is developed using NBS precision standards. The fissile content of the sample is determined from the measured delayed neutron yield. The thorium content of samples has also been determined after the same irradiation by measuring the residual 312 KeV gamma activity from ^{233}Pa with a Ge(Li) or NaI spectrometer (the ^{233}Pa is a daughter of ^{233}Th which is produced during the irradiation in the $^{232}\text{Th} (n, \gamma) ^{233}\text{Th}$ reaction). A similar measurement can be made of ^{239}Np gamma rays (from the reaction $^{238}\text{U} (n, \gamma) ^{239}\text{U}$; ^{239}U is the daughter of ^{239}Pu) to determine the amount of ^{238}U present in the samples, although radiochemical separation may be required when the ^{235}U or ^{239}Pu enrichment is high.

4. Design and Operationa. Physical Layout

The samples are irradiated in the outer fuel ring of a TRIGA Mark I reactor. Reactor power is adjusted for each particular sample type to produce less than 10^{10} fissions/sample in order to avoid sample heating problems. The sample chamber has a maximum volume of 7 cm^3 . A pneumatic sample transfer system moves the sample from the irradiation position to the neutron counting position. The neutron counter consists of 6-high pressure, 2 in. dia., 12 in. long moderated BF_3 tubes with centerlines located 2.5 in. from the centerline of the sample. The counter efficiency is 7 percent. A 36 cm^3 Ge(Li) detector or a 3 in. x 3 in. NaI detector is used to perform ^{232}Th assays.

b. Electronics

Standard proportional counting electronics are used with the neutron counter. A photosensor and electronic timer provide accurate timing and gating for measurement of the time dependent decay of delayed neutrons. Standard Ge(Li) and NaI counting electronics are used for Th assays.

c. Data Readout

The delayed neutron counts are displayed on a scaler and Ge(Li) and NaI data are obtained from a multichannel analyzer readout.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{235}U	U/Th fuel sticks (0.11g ^{235}U , 3.5g ^{232}Th).	(P) $\pm 0.1-0.2\%$ (^{235}U). (A) $\sim 0.5\%$ relative to standards. (P) 1% (Th).	$2 \times 10^{-10} \text{ g } ^{235}\text{U}$ (steady-state irradiation) $\sim 1 \times 10^{-11} \text{ g } ^{235}\text{U}$ (pulsed irradiation).	^{235}U -2 min. Th-10 min. to 1 hr. after 1-3 day cooling period.	Rad. Tech.	1

6. References

- H. R. Lukens, D. M. Fleishman, R. L. Bramblett, "Applications of Neutron Activation Analysis to Assay Small Samples of U, Pu, and Th," Gulf-RT-A10818, 1971.
- H. R. Lukens, D. M. Fleishman, R. L. Bramblett, Proceedings - International Meeting on Nondestructive Measurement and Identification Techniques in Nuclear Safeguards, Italy, 1971, unpublished.

1. Assay Instrument - Fuel Pin Calorimeter.
2. Developer - Argonne National Laboratory. (1)
3. Principle of Measurement. The calorimeter measures the amount of heat generated by the natural radioactive decay of nuclear materials. For example, ^{239}Pu nuclei decay by alpha particle emission, with each decay producing about 5.5 MeV of energy in the form of kinetic energy of the emitted alpha particle plus associated gamma radiation. Most of this energy is absorbed in the sample itself and converted into heat (for ^{239}Pu , the natural rate of heat production is about 2 milliwatts per gram of material). This calorimeter measures the amount of additional electrical heating power required to maintain a fuel rod at a specific temperature which is higher than that which could be maintained by the heat produced in radioactive decay of nuclear materials within the rod. If the isotopic composition of the rod is known, the nuclear material content of the sample can be determined from the difference in electrical heating power required to maintain a fuel rod at the same temperature as a dummy rod which does not contain fuel.
4. Design and Operation
 - a. Physical Layout
The instrument is contained in a single package measuring 21 in. wide by 12-1/2 in. high by 9-3/4 in. deep. The fuel rod is inserted in the center of three concentric cylinders, each of which is maintained separately at a selected temperature. The instrument includes a programmer and a measurement cycle which consists of pre-heating, stabilizing, measuring, and print-out. Except for inserting the fuel rod, the measurement cycle is automatic.
 - b. Electronics
The calorimeter consists of three concentric cylinders each maintained at a selected temperature by solid state feed-back temperature control systems. The electrical power required for maintaining the temperature of the innermost cylinder at a constant value is reduced when a heat-yielding sample is inserted.
 - c. Data Readout
Data is presented on a 5-digit voltmeter and printed on a paper tape by a digital printer.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	U/Pu mixed oxide ZPR fuel pins. (6 in. length)	(P) $\pm 0.8\%$		20 min./ pin.	ANL	1

6. References
 1. N. S. Beyer, R. N. Lewis and R. B. Perry; Proc. 13th Annual INMM Meeting (1972) in press.

SECTION B - PACKAGES, CANS, BOTTLES,
CONTAINERS (less than 5 gallons)

- B1 Enrichment Meter (NaI Configuration)
- B2 Enrichment Meter (Ge(Li) Configuration)
- B3 Gamma Counter (Helix)
- B4 Gamma Counter (Can II)
- B5 L-10 Bottle Assay Unit
- B6 Isotopic Source Assay System (ISAS) - Passive Mode
- B7 Ge(Li) Segmented Gamma Scanner
- B8 Ge(Li) Low Level Package Assay Unit
- B9 Neutron Coincidence Counter
- B10 Neutron Coincidence Can Counter
- B11 Random Source Interrogation System
- B12 Isotopic Source Assay System (ISAS) - Active Mode
- B13 Isotopic Neutron Source Assay Unit (Containers) - NNC-1A1-5
- B14 Isothermal Trans-bridge Calorimeter

Also see sheets:

C6

1. Assay Instrument - Enrichment Meter (NaI Configuration)
2. Developer - LASL. ⁽¹⁾
3. Principle of Measurement. It can be shown that for samples of uranium bearing materials which are opaque to the 185 keV gamma rays, the measured 185 keV activity per unit is proportional to the ^{235}U enrichment. The measurement is approximately independent of matrix material ($Z \leq 30$) and relative densities of sample components ($\rho_{\text{U}}/\rho_{\text{matrix}} \geq 1$).¹ Corrections can usually be made (when necessary) for effects of cladding thickness and the relative densities of uranium and matrix. Any appropriate gamma ray detector may be used, i.e., Ge(Li) or NaI as described here.

4. Design and Operation

a. Physical Layout

Usually a 1/2 in. thick, 2 in. diam. NaI crystal with Pb or W shielding and collimation appropriate to shield detector and to define the desired area on the sample.

b. Electronics

The Ludlum 22A and the Eberline SAM-1 portable assay units have been used.

c. Data Readout

Single channel analyzer counts in the signal window (~160 to ~210 keV) and in the background window (~220 to ~280 keV).

5. Operating History

SNM	Sample Description	P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
235U*	Reactor fuel rods (1-10% enrichment).	(A) 4.5% (1 σ) (relative)		5 min.	LASL at Nat'l Lead	2
235U*	UF ₆ product in shipping container.	(A) typically 3 to 6%; $\pm 10\%$ possible due to variations in cylinder wall thickness. (absolute)			LASL at Portsmouth Diffusion Plant.	3

* Enrichment only.

6. References

1. T. D. Reilly, R. B. Walton, J. L. Parker, Nuclear Safeguards R&D, LA-4605-MS (1970) p. 19.
2. T. D. Reilly, R. B. Walton, J. L. Parker, Nuclear Safeguards R&D, LA-4605-MS (1970) p. 37.
3. T. D. Reilly, R. B. Walton, Nuclear Safeguards R&D, LA-4705-MS (1971) p. 18.

1. Assay Instrument - Enrichment Meter (Ge(Li)) Configuration.
2. Developer - LASL. (1)
3. Principle of Measurement. It can be shown that for samples or uranium bearing materials which are opaque to the 185 keV gamma rays the measured 185 keV activity per unit area is proportional to the ^{235}U enrichment. The measurement is approximately independent of matrix material ($Z \leq 30$) and relative densities of sample components ($\rho_{\text{U}}/\rho_{\text{matrix}} \geq 1$).⁽¹⁾ Corrections can usually be made (when necessary) for effects of cladding thickness and the relative densities of uranium and matrix. Any appropriate gamma ray detector may be used, i.e., NaI or Ge(Li) as described here.

4. Design and Operation

a. Physical Layout

Ge(Li) detector with shielding and collimation appropriate to shield detector and to define the desired area on the sample.

b. Electronics

Usually amplifier, pulse height analyzer, and interfaced calculator or computer. Versions not requiring a pulse height analyzer are feasible.

c. Data Readout

When using interfaced calculator or computer readout is automatic. In simpler versions required data are presented on two scalars.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
$^{235}\text{U}^*$	Mostly incinerator oxides in 6 in. diam. cans, ~80% U.	(P) 1% (A) 5% (relative)		5 min.	LASL	1
$^{235}\text{U}^*$	UO ₂ fuel pellets in 2 gal. container.	(P) 1% (1σ) (A) 2% (relative)		5 min.	LASL at Nat'l Lead	2

* Enrichment only

6. References

1. T. D. Reilly, R. B. Walton, J. L. Parker, Nuclear Safeguards R&D, LA-4605-MS (1970) p. 19.
2. T. D. Reilly, R. B. Walton, J. L. Parker, Nuclear Safeguards R&D, LA-4605-MS (1970) p. 37.

1. Assay Instrument - Gamma Counter (Helix)
2. Developer - Dow Chemical Co., Rocky Flats Division (1, 2, 3, 4)
3. Principle of Measurement - Gamma rays in the 385 KeV complex from Pu are counted by a NaI scintillation detector. The window of a single-channel analyzer is centered about the complex. Transmission measurements are made in order to correct for sample attenuation. The counter is used only for Pu homogeneously distributed in materials such as incinerator ash or graphite in amounts up to ~ 700 Pu per one-gallon plastic container. The plutonium content of the cans is determined from the measured gamma activity.

4. Design and Operation

a. Physical Layout

The sample container is placed on a turntable that both rotates and translates it past a 2" x 2" NaI scintillation detector. An external 200 g PuO₂ source is located on the opposite side of the container. The helical motion of the sample allows the transmission of the container to be measured along its entire length. Two 100-sec scans are made, one with the external source, and one without it. The counter is contained within a shielded enclosure on a movable cart.

b. Electronics

NIM standard electronics are used including preamplifier, amplifier, single-channel analyzer, scaler-timer, and HV supply.

c. Data Readout

Data is read out via a computer teletype which is interfaced to a small digital computer. The computer makes instantaneous decisions for sample disposition. Permanent records are derived from punched paper tape generated by the computer.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time Per Sample	User	Ref.
Pu ²³⁹	10-700 g Pu homogeneously distributed in ash or graphite matrix	(A) $\pm 14\%$	0.2 f	200 sec	Dow Chem. Co. USA, Rocky Flats Div.	3, 4

6. References

1. Chemistry Research and Development Quarterly Progress Report, April, May, and June, 1968, RFP-1215, July 31, 1968.
2. Research and Development Quarterly Progress Report, Chemistry Division, January, February, and March, 1970, RFP-1519-A, April 30, 1970.
3. Research and Development Quarterly Progress Report, Chemistry Division, April, May, and June, 1970, RFP-1579-A, September 16, 1970.
4. Trans. Am. Nucl. Soc. 13, 748 (November, 1970).

1. Assay Instrument - Gamma Counter (Can II)
2. Developer - Dow Chemical U.S.A., Rocky Flats Division^(1,2)
3. Principle of Measurement - The gamma rays in the 385 KeV complex of Pu are detected by an NaI scintillation counter. Neutrons from spontaneous fission and (α, n) reactions are counted by BF₃ detectors for diagnostic purposes only, quantitative assay is based on the gamma count rates. Two windows established by single-channel analyzers, one wide and one narrow, are centered on the 385 KeV complex. The wide window provides the information for subtraction of the Compton continuum. Selective absorption by means of lead, tin, and copper shielding is used to suppress the low energy portion of the spectrum. Corrections for attenuation of the Pu gamma rays by the matrix are based on the weight of the sample. Samples are segregated according to matrix and the instrument is calibrated for each matrix type. It is currently calibrated for graphite, insulation, sand and crucibles, ash, laboratory glass and slag.
4. Design and Operation
 - a. Physical Layout
A 3" x 3" NaI detector is located 40 cm from the axis of the sample. Six BF₃ neutron detectors are positioned in a linear array on one side of the sample. The can rests on a rotating turntable. The entire counter assembly weighs 1000 lbs. and is mounted on a movable cart. Ambient background is equivalent to 2 g of plutonium.
 - b. Electronics
Standard NIM-bin compatible instrumentation is used. The gamma-ray and neutron portions each use an HV power supply, preamplifier, amplifier, single channel analyzer, (2 SCA's for gamma-rays) and a scaler for each SCA. One timer controls the scalers.
 - c. Data Readout
The data is presently manually recorded from the visual scaler display. By November, 1972, the system will be interfaced to a small digital computer, which will read the scalers, compute the answer, and print out by teletype or line printer.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy ^(a)	Sensitivity	Assay Time Per Sample	User	Ref.
Pu ²³⁹	Scrap and waste cans (matrices listed above)	(A) $\pm 15\%$ ^(b)	0.75 g ^(a)	100 sec.	Dow Chem. USA Rocky Flats Div.	3

(a) 95% confidence

(b) Average accuracy for all matrices, accuracy varies slightly with different matrices.

6. References

1. Research and Development Quarterly Progress Report, Chemistry, July, August, and September, 1971, RFP-1790-A, October 29, 1971
2. Research and Ecology Annual Report, Chemistry Research and Development, RFP-1837-A, April 14, 1972.
3. Private communication.

1. Assay Instrument - L-10 Bottle Gamma Assay Unit.
2. Developer - Aerojet Nuclear Co. (1)
3. Principle of Measurement. A high resolution Ge(Li) detector is used to measure the intensity of the 129, 149, 152, 160, and 414 KeV gamma rays from 10 liter bottles of plutonium nitrate solution. The ratio of the measured intensities of the 129 and 414 KeV gamma ray lines is used to correct for attenuation in the sample. The measured activities are used to determine the total Pu content of the sample and the ^{240}Pu , ^{241}Pu , and ^{238}Pu contents relative to ^{239}Pu .
4. Design and Operation
 - a. Physical Layout
An uncollimated Ge(Li) detector with good energy resolution (~1 KeV FWHM at 129 KeV) is located about 2 meters from the 10 liter bottle centerline. Better than average energy resolution is required to resolve the ^{238}Pu gamma rays at 152 KeV from those of other Pu isotopes.
 - b. Electronics
Standard Ge(Li) counting electronics are used with special attention paid to those parameters which affect the system's energy resolution and counting-rate characteristics.
 - c. Data Readout
Multichannel, analyzed by hand or in computer.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	10 l. bottles of Pu nitrate (100-300g Pu/f.)	(A) 4-5% (Pu) (A) ~10% ($^{240}/^{239}$) (A) ~ 5% ($^{241}/^{239}$) (P) ~ 2% (238) (P) ~ 5% (238)		30 min. (total)	ANC	1, 3
Pu	10 l. bottles of Pu nitrate (100-230g Pu/f.).	(A) 4% (Pu)		1000 sec.	Numeo	2*
Pu	One hundred 10 l. bottles of Pu nitrate.	(A) 6% (Pu)** (P) 4% (Pu) (P) 4% (238) (P) 5% ($^{238}/^{239}$) (P) 10% ($^{240}/^{239}$) (P) 4% ($^{241}/^{239}$)		400 sec	ANC at ARHCO plant	4

*A slightly different system than the one described was used for these measurements.

**In some bottles, ^{241}Am was assayed to determine the date of the last chemical separation.

6. References

1. J. E. Cline, E. B. Nieschmidt, A. L. Connelly, E. L. Murri, A Technique for Assay of L-10 Bottles of Plutonium Nitrate, IN-1433, (1970).
2. J. E. Lovett, D. B. James, Plant Instrumentation Program - Quarterly Report, BH 0-69-3 (1970).
3. J. E. Cline, A Non-destructive Technique for Assay of Load-out Bottles of Plutonium Nitrate Solution. International Meeting on Non-destructive Measurements and Identification Techniques in Nuclear Safeguards - sponsored by Euratom Ispra, Italy - Sept. 1971 (unpublished).
4. J. E. Cline - Private Communication.

1. Assay Instrument - Isotopic Source Assay System (ISAS) - Passive Mode.
2. Developer - Gulf Radiation Technology. (1)
3. Principle of Measurement. An array of fast response, plastic scintillation radiation detectors detect radiation emitted from spontaneous fission events in the sample (e.g. ^{240}Pu). The fission events are distinguished from other spontaneous reactions which emit radiation by utilizing the high multiplicity of emitted radiation associated with a single fission event (2 to 3 neutrons and about 7 gamma rays are emitted for each fission) as compared to the low multiplicities associated with other types of reactions. A coincidence circuit requires that two or more of the detectors register a count within nanoseconds of one another in order to register a coincidence event. The coincidence events will be primarily due to spontaneous fissions occurring within the sample, so that the measured coincidence rates can be related to the amount of spontaneously fissioning material in the sample. If the relative isotopic content of the material is known, the total amount of fissionable material in the sample can be calculated. An external ^{252}Cf source can also be placed adjacent to the sample and a second measurement made to determine a multiplication-absorption correction to the basic data.

4. Design and Operation

a. Physical Layout

The sample chamber can accommodate samples up to 8 in. diameter, 50 in high containers. Four separate plastic scintillation detectors are located in the walls of the sample cavity. The sample is rotated during the assay and scanned vertically. This setup is identical to the ISAS unit (active mode), but without the source container and collimator.

b. Electronics

Fast anode pulses from the scintillator photomultiplier tubes are routed to a coincidence circuit with a time gate of ~40 nsec. Linear dynode pulses are summed, passed through a linear gate which is enabled by the output of the coincidence circuit (provided the selected coincidence requirement is met), amplified, and passed through a single-channel analyzer to select the pulse height range of interest. The output of the single channel analyzer is recorded on a scaler. Three out of four coincidences have proved to be the most commonly used mode of operation.

c. Data Readout

The contents of five scalars are printed on a teletype. These data are (1) time of scan (2) number of four-detector coincidences, (3) number of three-detector coincidences, (4) number of two-detector coincidences between two selected detectors, (5) number of two-detector coincidences between the remaining two detectors.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	Waste material in 1 gal. containers.	(A) 5% (bias of 2%)	0.25 to 0.5g Pu	400 sec.	Rad. Tech. at Rocky Flats.	1

6. References

1. R. L. Bramblett, et. al., Application of Photoinduced Reactions to Nuclear Material Safeguards Problems, Gulf-RT-A10826 (1971).

1. Assay Instrument - Ge(Li) Segmented Gamma Scanner.
2. Developer - LASL. (1, 4)
3. Principle of Measurement. The 414 KeV ^{239}Pu gamma activity, the 765 KeV ^{238}Pu gamma activity, or the 185 KeV U gamma activity is measured with a collimated Ge(Li) gamma ray detector. The detector scans the sample in the vertical direction, collimated so as to view about a 1/2 inch slice of the sample at any one time. The data is corrected for self absorption by measuring the transmission of an external source through the sample (for ^{235}U - ^{169}Yb , $t_{1/2} = 32$ days, $E_\gamma = 177.6$ and 198.0 KeV; for ^{239}Pu - ^{75}Se , $t_{1/2} = 120$ days, $E = 400.6$ KeV; for ^{238}Pu - ^{137}Cs , $t_{1/2} = 30$ years, $E_\gamma = 661.6$ KeV). The data is collected and the absorption correction applied as a function of vertical height of the sample to minimize errors due to sample inhomogeneities. The measured activities are used to determine the amount of fissile material present in the sample.
4. Design and Operation
 - a. Physical Layout
The Ge(Li) detector and appropriate transmission source are placed on opposite sides of the sample. The detector is collimated with lead to a 1/2 in. vertical aperture. The sample rests on a variable speed turntable which has a 20 in. vertical travel at variable speed.
 - b. Electronics
The Ge(Li) detector amplifier drives an analog to digital converter, the output of which is fed in parallel to four digital stabilizers. These stabilizers act as single channel analyzers (SCA) and also as spectrum stabilizers. The SCA outputs and live time pulses are multiscaled on a time base using a 1024 channel multichannel analyzer capable of simultaneously scaling 8 inputs. Twenty time bins for each input have proved adequate for assays of 2 liter bottles.
 - c. Data Readout
The data from the multichannel analyzer is fed into a programmable calculator. The calculator relates the measured count rates to fissile material content, computes the absorption correction, and prints out the results relative to vertical height along the sample and also the total assay value for the sample. The data reduction process takes about 1 minute after the scanning is completed.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{235}U	2 l. bottles of high enriched U scrap.		1g ^{235}U	10 minutes (total)	LASL at NUMEC Apollo, Penn.	1
^{239}Pu	1 gal. cans of molten salt residues (high ^{241}Am content).	(A) $\pm 10\%$ ($\pm 5\%$ estimated using better standards).	0.3 to 1.0g Pu depending on ^{241}Am activity.	5 minutes (total)	LASL (Rocky Flats Samples).	2
^{235}U	Uranium low density waste in 30 gal. drums.	(A) $\pm 10\%$ (estimated)			LASL	3*
^{239}Pu	Filter media, incinerator ash, broken crucibles in 4 in. D x 8 in. H sealed can.	(A) $\pm 5\%$ compared with chemical recovery.	0.2 g Pu	5 minutes	LASL (samples from Rocky Flats and Hanford)	5
^{235}U	Leached residues of highly enriched U scrap in 9 in. D x 14 in. H cream cans.	(A) $\pm 5\%$ compared with active neutron assay.		10 minutes	LASL at Y-12 Oak Ridge, Tenn.	6
^{235}U	Incinerator ash in 6 in. D x 15 in. H sealed cans.	(A) $\pm 6\%$ compared with sampling/analytic assay.		10 minutes	LASL at K-25 Oak Ridge, Tenn.	6
^{238}U	"	(A) $\pm 4\%$ compared with sampling/analytic assay.	(25 g ^{238}U)	5 minutes	"	6**

*A "barrel version" of the scanner described herein was used for these measurements.

** ^{238}U measurements were made with a 5 in. x 5 in. NaI detector for increased sensitivity.

6. References

1. J. L. Parker, T. D. Reilly, R. B. Walton, D. B. Smith, L. V. East, Nuclear Safeguards R&D, LA-4705-MS (1971) p. 12.
2. T. D. Reilly, J. L. Parker, Nuclear Safeguards R&D, LA-4794-MS, p. 13.
3. J. L. Parker, T. D. Reilly, J. S. Hendricks, Nuclear Safeguards R&D, LA-4794-MS, p. 14.
4. J. L. Parker et al, "Passive Assay - Innovations and Applications," Proceedings of the 12th Annual Meeting of the INMM, Vol. II, pp. 519-524, or LASL preprint LA-DC-12295, pp. 5-10.
5. Unpublished data.
6. T. D. Reilly, "Assay Experience with Monal at Oak Ridge," LA-DC-72-604; Proc. 13th Annual INMM Meeting (1972) in press.

1. Assay Instrument - Ge(Li) Low Level Package Assay Unit.
2. Developer - Nuclear Materials and Equipment Corp. ⁽¹⁾
3. Principle of Measurement. A Ge(Li) detector is used to measure the gamma rays from ^{239}Pu in the "384" KeV complex (an 85 KeV interval including the strong lines at 375, 383, and 414 KeV and several other weaker lines), and those from ^{237}U (in secular equilibrium with ^{241}Pu) at 208 KeV. The transmission of gamma rays through the sample from an external Pu source is measured to make an absorption correction to the data. The ^{239}Pu content of the samples is determined from the measured gamma ray activity in the "384 KeV complex" and the ^{241}Pu content is determined from the measured activity in the 208 KeV peak.

4. Design and Operation

a. Physical Layout

A 55 cm³ Ge(Li) detector is collimated to view the entire package which is located about 1 foot from the detector. An 18 mil Hf absorber is placed between the sample and detector to selectively absorb the low energy Pu gamma rays. The sample is assayed on a rotating platform (2 rpm).

b. Electronics

Standard Ge(Li) detector electronics are used. Signal and background runs are stored in two halves of a 1024 channel memory.

c. Data Readout

Data is collected and stored in 512 channels of the multichannel analyzer. After visual inspection, background stored in the second 512 channels is subtracted and the integrate feature of the analyzer is used to sum the total counts from 371 to 455 KeV as well as the number of counts in the first 10 channels above the 384 KeV complex (Compton background correction). The results are printed out on a typewriter. An attenuation correction and a horizontal Compton background subtraction are applied to the data by hand calculation. A similar procedure is followed for determining the 208 KeV activity.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	Solid glove box waste materials in 1.5 gal cardboard packages (.05 to several g Pu/package).	(P) - 3% (60 mg Pu) (P) - 1% (1g Pu) (A) - 10% (2σ)		~ 30 min. (total)	Numec	1, 2

6. References

1. R. A. Deal, J. F. Gettings, D. B. James, Proc. - 10th Annual INMM Meeting (1969) p. 62.
2. Plant Instrumentation Progress Report, BHO-69-1 (1970).

1. Assay Instrument - Neutron Coincidence Counter.
2. Developer - Brookhaven National Laboratory⁽¹⁾ and Naval Research Laboratory^(2, 3, 4)
3. Principle of Measurement. Neutrons emitted spontaneously from samples of fissionable material are detected by moderated BF₃ neutron detectors. The detector coincidence logic, designed to distinguish between fission neutrons and (α , n) neutrons, operates on the principle that each fission event produces 2 to 3 neutrons on the average, while an (α , n) event only produces a single neutron. The fission neutrons detected from a single fission event are correlated in time; on the average they will be detected within a time which is roughly equivalent to the neutron lifetime in the detector moderator. The number of coincidence events (a coincidence event is one in which a pair of neutrons are detected within a specified time interval) is therefore related to the amount of spontaneously fissioning material in the sample. A correction is measured for the accidental coincidences which occur due to the detection of two (α , n) neutrons or two neutrons from different fissions within the coincidence time interval. Other methods have also been proposed to correct for this effect (see Refs. 9, 10). A known isotopic content allows the total amount of fissionable material in the sample to be determined from the measured neutron coincidence count rate.

4. Design and Operation

a. Physical Layout

The walls of the sample chamber are of polyethylene containing 24 - 2 in. dia., 1 atm. BF₃ detectors. The sample chamber, which is lined with Cd sheet, can accommodate samples up to 8 in. dia. and about 10 in. high. The entire unit is about 22 in. high and 20 in. in diameter. A layer of neutron shielding outside the counter is usually desirable.

Operating Parameters

<u>Condition</u>	<u>Total Efficiency</u>	<u>Decay Time</u>	<u>Gate Counting Width</u>
As described above.	18.5%	84 μ sec	32, 64 or 128 μ sec (selectable)
Detectors partially covered with Cd. sleeves.	~8.2%	42 μ sec	Same as above

b. Electronics

The signal from the neutron detector bank is fed to a common preamplifier and amplifier. After a fixed time delay, during which pulse shape and pulse height discrimination occurs, gates corresponding to true + accidental coincidence counts and (after a longer delay) accidental counts are opened enabling the appropriate scaler to record subsequent neutron signals from the detectors. A detailed explanation of the electronics, complete with circuit diagrams, is contained in Ref. 1.

c. Data Readout

Gross counts, coincidence + accidental counts, accidental counts, and counting time (in newer models) are displayed on scalars. (See Ref. 1.) The conversion from coincidence counts to grams of Pu, including dead-time corrections is made by hand.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	Clean $\text{PuO}_2\text{-UO}_2$ (3.5 w/o Pu) scrap in 1-gal cans; $\text{Pu}^{240}/\text{Pu} \sim 0.10$.	(P) 1.2% relative (1 σ) for sample containing 1g Pu^{240} ; $A/T^* \sim 0.67$. (A) 3% relative (2 σ).	1400 counts/min per gram of Pu^{240} for gate width of 128 μsec .	10 min.	G. E (Vallecitos)	5, 6
Pu	PuO_2 feed material in 1-kg. cans; $\text{Pu}^{240}/\text{Pu} \sim 0.18$.	(P) 3.5% relative (1 σ) for sample containing $\sim 150\text{g}$ Pu^{240} ; $A/T^* \leq 100$. (P) $\sim 0.6\%$ average deviation for 2 cans using 3rd as standard.	~ 70 counts/min per gram of Pu^{240} (poisoned detector, gate width 64 μsec).	6 min. 60 min.	G. E. (Vallecitos) G. E. (Vallecitos)	5, 6
Pu	PuO_2 or $\text{Pu}(\text{NO}_3)_4$ waste in matrix of moist rags and paper, in PVC bags (6 in. dia., π 6 in. high); $\text{Pu}^{240}/\text{Pu} \sim 0.14$.	(P) 7% relative (1 σ) for sample containing 0.25g Pu^{240} ; $A/T^* \leq 2$. (A) 5-15% relative (2 σ) for range of samples studied (0.1-0.2g Pu^{240}).	~ 700 counts/min per gram of Pu^{240} (gate width 64 μsec).	5 min.	Westing-house (Cheswick)	7
Pu	Ashed scrap (80% PuO_2 , 10% UO_2 , 10% C) in 1-pint stainless steel cans; $\text{Pu}^{240}/\text{Pu} \sim 0.14$.	(P) 5% relative (1 σ) for sample containing 4g Pu^{240} ; $A/T^* \leq 11$. (A) 5-10% relative (2 σ) for range of samples studied (2-6g Pu^{240}).	~ 700 counts/min per gram of Pu^{240} (gate width 64 μsec).	5 min.	Westing-house (Cheswick)	7
Pu	PuO_2 and PuO_2 (25%) -UO_2 (75%) in 1-quart containers; $\text{Pu}^{240}/\text{Pu} \sim 0.09$.	(P) 3.5% relative (1 σ) for sample containing 8g Pu^{240} .	1400 counts/min per gram of Pu^{240} (gate width 128 μsec).	1 min.	Nuclac	8

*A/T = Ratio of accidental to true coincidences.

6. References

1. R. Sher, Operating Characteristics of Neutron Well Coincidence Counters, BNL-50332 (January 1972)
2. R. J. Omohundro, A Prototype Coincidence Neutron Counter for Safeguards and Arms Control Applications, NRL Memorandum Report 2005 (June 1969).
3. C. V. Strain, Potential and Limitations of Several Neutron Coincidence Equipments, NRL Memorandum Report 2127 (May 1970).
4. C. V. Strain and R. J. Omohundro, Coincidence Neutron Equipment, NRL Memorandum Report 2107 (March 1970).
5. D. M. Bishop and E. A. Aitken, Plant Instrumentation Program, Third Quarterly Report, Oct. - Dec. 1970, GEAP-12114-5.
6. D. C. Wadekamper, D. M. Bishop, and L. T. Hagie, Integrated Safeguards Experiment, Fourth Quarterly Report, April-June 1971, GEAP-12114-7.
7. J. C. Limpert, Plant Instrumentation Program, Final Quarterly Progress Report, WCAP-7562-4 (May 1971).
8. J. E. Lovett and D. B. James, Plant Instrumentation Program, Third Quarterly Report, BHO-69-3 (April 1971).
9. J. Jacquesson, J. Phys. 24 (1963) p. 112.
10. G. Birkhoff, L. Bondár, and N. Coppo, "Variable Dead Time Neutron Counter for Tamper-Resistant Measurements of Spontaneous Fission Neutrons", Paper presented at the International Meeting on Non-Destructive Measurement and Identification Techniques in Nuclear Safeguards, Ispra, Italy, Sept. 1971

1. Assay Instrument - Neutron Coincidence Can Counter.

2. Developer - LASL. (1, 2)

3. Principle of Measurement. Neutrons emitted spontaneously from fissionable material samples are detected by moderated ^3He neutron detectors. Detector coincidence logic, designed to distinguish between fission neutrons and (α, n) neutrons, operates on the principle that each fission event produces 2 to 3 neutrons while an (α, n) event only produces a single neutron. The fission neutrons detected from a single fission event are correlated in time; on the average they will be detected within a time which is roughly equivalent to the neutron lifetime in the detector moderator. The number of coincidence events (a coincidence event is one in which a pair of neutrons are detected within a specified time interval) is therefore related to the amount of spontaneously fissioning material in the sample. A correction is measured for the accidental coincidences which occur due to the detection of two (α, n) neutrons within the coincidence time interval. Additional measurements made with an external fission source placed adjacent to the sample can be used to correct for changes in the effective counter efficiency due to the moderating effects of different sample matrices. A known isotopic content allows the total amount of fissionable material in the sample to be determined from the measured neutron coincidence count rate.

4. Design and Operation

a. Physical Layout

A cylindrical counting well is surrounded by a bank of 28 moderated, 4 atm ^3He neutron detectors. The counting well can accommodate up to 8 in. dia. cans, (1 gal. scrap cans). Cadmium sheets for shortening decay times are removable.

Operating Parameters

<u>Condition</u>	<u>Total Efficiency</u>	<u>Decay Time</u>	<u>Gate Width</u>
Cadmium removed, all detectors in place	~40%	23 μsec	
Cadmium in, inner ring of detectors removed	~ 9%	11 μsec	25 μsec

b. Electronics

A single NIM bin contains all the electronics required for detector operation. All electronic components are commercially available with the exception of the variable gate width coincidence circuit. (4)

c. Data Readout

The data (gross counts, true coincident counts + accidental, and accidental counts) are displayed on 3 scalars located in the NIM bin.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
PuO ₂	Ash residue spiked with PuO ₂ in cans packed in 6 in. dia. x 12 in. high containers.	(A) 2% (average deviation)			LASL	2
PuO ₂	Contaminated and crucible material in 1 gal. cans.	(P) 5 to 15% for A/T*~20 (A) 5 to 15% (estimated)			LASL	2
²³⁸ Pu	Metal or metal oxides.	(P) 1 to 3% for A/T* of .01 to .6 (A) 5 to 10% for A/T* of 2 to 5 (estimated)			LASL	2
Pu	LMFBR mixed fuel capsules. (UO ₂ , PuO ₂)C pellets 0.25 in. dia., 0.25 in. length.	(A) 2% (absolute) (A) 1% (relative to a standard)		17 min.	LASL	3
²³⁸ U	Incinerator ash samples containing 10 ² to 10 ⁴ gU.	(P) 5% (1σ) for 10 kg sample (A) ~3% compared to chemical sampling		3 min.	LASL	4
²³⁸ U	Recovery cans containing enriched (1-5%) uranium.	(A) < 10%	200 g	200-1000 sec	LASL at Nat'l Lead	5

*A/T - ratio of accidental counts to true counts.

6. References

1. L. V. East, M. M. Stephens, J. E. Swanson, Nuclear Safeguards R&D, LA-4368-MS (1969) p. 16.
2. H. O. Menlove, R. B. Walton, Nuclear Safeguards R&D, LA-4457-MS (1970) p. 26.
3. L. V. East, J. O. Barner, Nuclear Safeguards R&D, LA-4523-MS (1970) p. 16.
4. J. E. Foley, Nuclear Safeguards R&D, LA-4605-MS (1970) p. 18.
5. J. E. Foley, Nuclear Safeguards R&D, LA-4605-MS (1970) p. 34.

1. Assay Instrument - Random Source Interrogation System.
2. Developer - LASL. (1, 2)
3. Principle of Measurement. Uranium sample containers are placed inside a fast plastic scintillation counter. An AmLi (α, n) random neutron source ($E_n \sim 0.6$ MeV) scans the outer surface of the sample container. The average energy of the AmLi neutrons is below the fission thresholds of the fertile material, consequently they primarily fission the fissile materials in the container. The neutrons from these induced fission events and the source neutrons are both detected by the fast scintillation counter (the counter is shielded with Pb to reduce gamma ray sensitivity). However, the fission neutrons are distinguished from the (α, n) source neutrons by their multiplicity (i.e., 2-3 neutrons per fission event compared to 1 neutron per (α, n) event). The fission neutrons detected from a single fission event are correlated in time; on the average they will be detected within a time which is roughly equivalent to the neutron lifetime in the counter (approximately 40 nsec). A correction is measured for accidental coincidences which occur due to the detection of two (α, n) source neutrons within the coincidence time interval. An additional correction is made by a neutron flux counter that corrects for thermalization of the interrogation neutrons within the sample. The fissionable material content of the sample is directly related to the corrected coincidence count rate.

4. Design and Operation

a. Physical Layout

Two fast plastic scintillation detectors (2" x 10" x 24") shielded with 2 in. of Pb, are located on each side of the sample to be assayed. An AmLi source ($\sim 5 \times 10^5$ n/sec) provides the interrogating neutrons. Scanning is accomplished by rotating the sample and oscillating the source vertically alongside the sample container.

Operating Parameters

<u>Total Efficiency</u>	<u>Coincidence Efficiency</u>	<u>Decay Time</u>
$\sim 10\%$	$\sim 1\%$	~ 40 nsec

b. Electronics

All components are commercially available from EG&G (MIOO fast electronic counting equipment).

c. Data Readout

The data (time coincidence counts + accidentals, accidentals only, and flux counter) are displayed on 3 scalars located in a NIM bin.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
235U	Lab samples	A (10%)	5 g/600 sec	200 sec	LASL	3

6. References

1. J. E. Foley, M. M. Thorpe, Nuclear Safeguards R&D, LA-4705-MS (1971) p. 9.
2. J. E. Foley, Nuclear Analysis R&D, LA-4883-PR (1971) p. 9.
3. Ibid, p. 10-11.

1. Assay Instrument - Isotopic Source Assay System (ISAS) - Active Mode.
2. Developer - Gulf Radiation Technology. ⁽¹⁾
3. Principle of Measurement. A collimated beam of neutrons from an external source is used to stimulate fissions in the assay sample. When a fission event occurs in the sample, 2 to 3 neutrons and about 7 gamma rays are emitted simultaneously. An array of fast response, plastic scintillation radiation detectors are used to detect two or more of the emitted fission neutrons and gamma rays in coincidence. The coincidence requirement is used to discriminate against other reactions occurring within the sample which produce fewer particles per event as well as direct interactions of the source neutrons with the detectors. The coincident count rate (2, 3 or 4 detectors registering detection events simultaneously) is related to the amount of fissionable material in the sample.
4. Design and Operation
 - a. Physical Layout
A 24 μg ^{252}Cf source ($\sim 6 \times 10^7$ n/sec) is located in a 2 ft. diameter, 2 ft. long cylinder containing both gamma and neutron personnel shielding. A collimator extends from the source position to a sample cavity which can accommodate up to 8 in. diameter, 50 in. high sample containers. Four separate plastic scintillation detectors are located in the walls of the sample cavity. The sample is rotated during assay and scanned vertically.
 - b. Electronics
Fast anode pulses from the scintillator photomultiplier (PM) tubes are routed to a coincidence circuit with a time gate of ~ 40 nsec. Linear PM dynode pulses are summed, passed through a linear gate which is enabled by the output of the coincidence circuit (provided the selected coincidence requirement is met), amplified, and passed through a single-channel analyzer to select the pulse height range of interest. The output of the single channel analyzer is recorded on a scaler. Three out of four coincidences have proved to be the most commonly used mode of operation.
 - c. Data Readout
The contents of five scalers are printed on a teletype. These data are (1) time of scan (2) number of four-detector coincidences, (3) number of three detector coincidences, (4) number of two-detector coincidences between two selected detectors, (5) number of two-detector coincidences between the remaining two detectors.

6. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{239}Pu	Waste material in 1 gal. containers.	(A) 6.6% (1 σ) bias of 1%	3.28g to 0.68g Pu.	400 sec.	Rad. Tech. at Rocky Flats	1
^{235}U	Pot hydride, item product scrap, fluid bed reactor clean- out, bomb slag, in small containers.	(A) 5.8% (1 σ) bias of 2% (com- pared to gamma ray assay).			Rad. Tech. at UNC Hematite	1
^{235}U	HTGR scrap (C, TH, U (92.5% enriched).	(A) $\pm 10\%$ (estimated)			Rad. Tech. at Gulf General Atomic	1
^{235}U	High enrichment (>80%) oxides in 5 in. dia., 6-3/4 in. high cans.	(A) 1.6% (standard enrich- ment within 5% of samples). (A) 4.3% (stand- ard enrichment within 16% of samples).	$\sim 5g$ ^{235}U	25 min. (total)	UNC	2
^{235}U	UO ₂ Powder 18% enriched.	(A) $\pm 1.47\%$ (1 σ) $\pm 0.4\%$ bias.		4 min.	Rad. Tech. at NRTS	3
	PBF fuel pellets	(A) $\pm 3.2\%$ (1 σ) $\pm 0.0\%$ bias.		4 min.		
	PBF fuel rods	(A) $\pm 2.2\%$ (1 σ) $\pm 0.4\%$ bias.		2.5 min.		
	SPERT	(A) $\pm 2.9\%$ (1 σ) $\pm 0.8\%$ bias.		2.5 min.		
	ATR fuel plates	(A) $\pm 1.5\%$ (1 σ) $\pm 0.1\%$ bias.		2.5 min.		
	ROVER fuel rods	(A) $\pm 3.5\%$ (1 σ) $\pm 0.6\%$ bias.		2.5 min.		

6. References

1. R. L. Bramblett, et. al., Application of Photoinduced Reactions to Nuclear Material Safeguards Problems, Gulf-RT-A10826 (1971).
2. W. J. Gailagher, Evaluation of ISAS Under Commercial Operating Conditions, BH0-67-4 (1971).
3. R. L. Bramblett et. al., Applications of Photoinduced Reactions to Nuclear Materials Safeguards Problems, Gulf-RT-A 10914 (Dec. 1971).

1. Assay Instrument - Isotopic Neutron Source Assay Unit - (Containers). - NNC-1A1-5
2. Developer - National Nuclear Corp. (1)
3. Principle of Measurement. The sample is irradiated with neutrons from an isotopic source with an average energy below that of the neutron fission thresholds of ^{238}U and ^{232}Th . These source neutrons fission the fissile material within the sample and the stimulated fission neutrons are detected. The detection system discriminates between fission neutrons and source neutrons. The detector count rate is related to the fissile material content of the sample. The unit can also be operated in a passive mode without the isotopic source and the spontaneous fission neutrons from a sample can be measured and related to the material content.
4. Design and Operation
 - a. Physical Layout
A unit which will handle up to 5 gallon cans is completely self-contained including neutron source, detectors, and electronics. A turntable rotates the sample during the assay. The unit is mounted on wheels.
 - b. Electronics
NNC fabricated circuits and assembly.
 - c. Data Readout
The total neutron counts per assay are displayed on a scaler.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{235}U	UO_2 powder various enrichments, 1 qt. cans.	Agreement with known values to about 1%.			NNC	1
^{235}U	Virgin UO_2 powder in 3 and 5 gal. cans.	(A) $\pm 5\%$ relative to calibrated standards.			NNC	1
^{239}Pu	Mixed oxide scrap. (0-100g per container).	Average error of 1 to 2g fissile.			NNC	1
^{239}Pu	Pu ash in tin cans contained inside iron pipes, (0-12g Pu/sample).	Mean deviation for fissile Pu-0.03g.			NNC	1

6. References

1. H. Miller, T. Shea, Results of Typical Non-destructive Measurements of Fissionable Material in Various Forms Using NNC Machines, Proc. 12th Annual INMM Meeting (1971) Vol II, p. 402.

1. Assay Instrument - Isothermal Twin-bridge Calorimeter.2. Developers - Mound Laboratory. (1, 2)

3. Principle of Measurement. The calorimeter measures the amount of heat generated by the natural radioactive decay of nuclear materials. For example, ^{239}Pu nuclei decays by alpha particle emission with each decay producing about 5.5 MeV of energy in the form of kinetic energy of the emitted alpha particle plus associated gamma radiation. Most of this energy is absorbed in the sample itself and converted into heat (for ^{239}Pu , the natural rate of heat production is about 2 milliwatts per gram of material). This calorimeter measures the difference in heat output between a standard or electric heater of known output and the output from the unknown sample. There are several different techniques used to carry out this measurement, all of which employ a measurement of the temperature difference between the sample chamber and the chamber containing the known sample or reference heater. This temperature difference is measured with thermoresistive elements placed inside each chamber and connected in a Wheatstone bridge configuration. If the isotopic content of the sample is known, the quantity of nuclear material in the sample can be determined from the measured heat output from the reference chamber and the Wheatstone bridge measurement of the temperature difference between the chambers.

4. Design and Operationa. Physical Layout

The calorimeter consists of two identical thermal elements (thermals) which can accommodate samples up to 4-3/4 in. dia. and 8-3/4 in. height. Two nickel resistance thermometers are wound over the entire length of each thermal and each sample chamber has a calibration heater wound around it. The calorimeter is operated in an environmental bath whose temperature is kept constant to within a millidegree.

b. Electronics

The nickel resistance thermometers are connected as a transposed - arm Wheatstone bridge supplied with constant current. The bridge reading is made with a potentiometer or high impedance digital voltmeter. A highly regulated DC power supply is connected to the heaters. The heater voltage (minus the voltage drops in the leads) is measured with a voltage divider and the current determined by measuring the voltage across a standard resistor in the heater circuit.

c. Data Readout

Data is read out at a control panel containing the potentiometer or digital voltmeter, heat controls and heater voltage/current measuring circuitry. A recorder can be used to record the potentiometer reading as a function of time.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	Pu oxide feed material (fast reactor feed and (WR recycle) in 4 in. dia. x 5 in. cans (~1 Kg/can).	(P) $\pm .02\%$		5 hr.	Mound	1
Pu	PNC fuel plates up to 2 in. x 4 in. x .04 in. (7-65g Pu).	(P) 0.3 to .03% depending on sample size (2 σ) (A) -1.9 to +0.9% compared to destructive analysis.			Mound	1

6. References

1. F. A. O'Hara, J. D. Nutter, W. W. Rodenburg, Calorimetric Determinations of Plutonium in Bulk Reactor Materials, Proc. 12th Annual INMM Meeting (1971) p. 424.
2. F. A. O'Hara, J. D. Nutter, W. W. Rodenburg, M. L. Dinsmore, Calorimetry for Safeguards Purposes, MLM-1798 (1972).

SECTION C - DRUMS, BOXES, CONTAINERS
(Greater than 5 gallons)

- C1 ^{238}Pu Scrap Recovery Monitor
- C2 Low Level Waste Gamma Scanner
- C3 Gamma Counter I - 55 Gallon Drums (2 versions)
- C4 Gamma Counter II - 55 Gallon Drums
- C5 Eight Channel Drum Scanner - Large Waste Drums (20-55 gal)
- C6 Ge(Li) IV ^{239}Pu Package Counter
- C7 Ge(Li) Waste Assay System
- C8 NaI Barrel Scanner
- C9 4π Neutron Coincidence Counter - Up to 55 gallon drums
- C10 Electron Linear Accelerator - Gulf Atomic Materials Assay System (GAMAS)
- C11 14 MeV Neutron Generator - Mobile Assay Laboratory (MONAL)

Also see sheet:

B7

1. Assay Instrument - ^{238}Pu Scrap Recovery Monitor.
2. Developer - Mound Laboratory - Monsanto Research Corp. ⁽¹⁾
3. Principle of Measurement. The 766 KeV gamma ray from ^{238}Pu is detected using a NaI detector. An absorption correction is determined by measuring the transmission of an external ^{238}Pu source through the sample. The ^{238}Pu content of the sample is inferred from the measured 766 KeV gamma ray activity.
4. Design and Operation
 - a. Physical Layout
A single fixed 3 in. x 3 in. NaI detector is located 2 or 4 meters from the center line of the drum (the distance used depends on the amount of ^{238}Pu in the sample). The drum is rotated during the assay.
 - b. Electronics
The NaI detector is used with standard counting electronics.
 - c. Data Readout
Data is read out on a multichannel analyzer and the Compton background is subtracted.
5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{238}Pu	Scrap and waste material in 30 gal. drums contained inside 55 gal. drums.	(A) $\pm 20\%$ (2 σ)	-	30 min.	Mound Lab. Monsanto Research Corp.	1, 2, 3

6. References

1. W. W. Strohm, Gamma-Ray Assay of the ^{238}Pu Content of Cans, 55 Gallon Drums and Coated Glove Boxes, Proceedings - AEC Symposium on Passive Gamma Ray Assay, Germantown, (1970) WASH - 1177.
2. W. W. Strohm, Gamma-Ray Assay of ^{238}Pu in Waste Drums, Nucl. Appl., 5:3 (1968) 183.
3. W. W. Strohm, A.B. Combs, J. Y. Jarvis, Gamma-Ray Assay of ^{238}Pu Waste Cans, MLM-1585 (1969).

1. Assay Instrument - Low Level Waste Gamma Scanner.
2. Developer - Westinghouse Nuclear Energy System. (1, 2)
3. Principle of Measurement - The Pu gamma rays in the "385 complex" or in the 414 KeV ^{239}Pu peak are detected using either a NaI or Ge(Li) detector respectively. The high efficiency, low resolution NaI detector is useful for minimizing assay time for wastes which are free from fission products and where the ^{237}U is in secular equilibrium with ^{241}Pu ; the use of the lower efficiency, high resolution Ge(Li) detector is required for chemical processing and reprocessing wastes where fluctuating backgrounds from higher energy gamma lines originating from fission products and thorium contamination tend to mask the plutonium peaks in the lower resolution NaI system. The ^{239}Pu content of the drums is determined from the measured gamma activity. Waste categorization with respect to the area of its origin and waste segregation (using hand meters to locate high activity packages) are necessary prerequisites to effective waste assay with this system.

4. Design and Operation

a. Physical Layout

A Ge(Li) detector is collimated with 2 in. of lead so as to view a 55 gal. drum whose centerline is located about 4 feet from the detector. A 22 mil hafnium sheet is placed between the sample and detector to selectively cut down the intensity of low energy photons from the sample. The drums are rotated at 8 rpm during assay on a platform with a 1,000 lb. capacity.

b. Electronics

Conventional Ge(Li) detector electronics were used.

c. Data Record

All data are accumulated in a multichannel analyzer with an integration capability. The integrated peak area is corrected for background and the net counts are related to Pu concentration via a calibration curve prepared daily from equivalent standards.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time Per Sample	User	Ref.
Pu	Low level recycle Pu wastes in 55-gallon drums (to 10g). Waste containing no separated Pu.	(A) $\pm 21\%$ (1 σ) (NaI)	0.5 g	400 sec.	<u>W</u> *	2, 3
Pu	Low level recycle Pu wastes in 55-gallon drums (to 10g). Waste suspected of containing recently separated Pu.	(A) $\pm 21\%$ (1 σ) (Ge(Li))	0.5 g	1000 sec.	<u>W</u>	2, 3
Pu	Low level recycle Pu wastes in packages. No separated Pu. (Up to 5 packages per 5-gallon drum).	(A) $\pm 6\%$ (1 m) (NaI)	0.2 g	400 sec.	<u>W</u>	3
Pu	Low level recycle Pu wastes in packages. Containing separated Pu. (Up to 5 packages per 5-gallon drum.)	(A) $\pm 5\%$ (1 σ) (Ge(Li))	0.2 g	400 sec.	<u>W</u>	3

*W - Westinghouse

6. References

1. J. C. Limpert, Plant Instrumentation Progress Report, WCAP-7562-1 (1970).
2. As above, WCAP-7562-3 (1970).
3. As above, WCAP-7562-4 (1970).

1. Assay Instrument - Gamma Counter I - 55 Gallon drums (2 versions)
2. Developer - Dow Chemical Co., Rocky Flats Division (1, 2, 3)
3. Principle of Measurement - Gamma rays in the 385 KeV complex from the α decay of Pu are counted by NaI scintillation detectors. A window set above this complex is used for subtraction of the Compton continuum. Neutrons emitted by spontaneous fission or in (α, n) reactions are counted by BF₃ detectors. The ratio of neutron counts to gamma counts is used for diagnostic purposes only, the gamma counts are used for quantitative assay. Attenuation corrections are based on net weight of the drums. Since transmission measurements are not made, it is essential that drums be segregated according to matrix. The instrument has been calibrated for a number of matrices, including combustibles, washables, resin, graphite, lead gloves, Raschig rings, CWS filters, and insulation. The system is calibrated up to 350 g of Pu.
4. Design and Operation
 - a. Physical Layout
Four 2" x 2" NaI detectors are located at a distance of 24" from the axis of the drums which are rotated during the measurement. The detectors are mounted in pairs in a vertical array on opposite sides of the drum. Sixteen BF₃ counters moderated by polyethylene are arranged around the periphery of the drum. Background is equivalent to ~ 5 g Pu for the version of this counter that is above ground. Shielding in this case is provided by polyethylene and cadmium. In the below-ground version, shielded by concrete and a water jacket, background is equivalent to 3.7 g of Pu.
 - b. Electronics
Standard nuclear instrumentation is used.
 - c. Data Readout
Data is recorded manually from the visual scaler count.

5. <u>Operating History</u>		(P) Precision	(a)	(c)	Assay Time	User	Ref.
SNM	Sample Description	(A) Accuracy		Sensitivity	Per Sample		
Pu ²³⁹	Waste and Scrap as follows:						
	CWS Filters	(A) $\pm 25\%$ (b)		0.6 g	100 sec.	Dow Chemical USA,	4
	Lead Gloves	(A) $\pm 30\%$ (b)		1.2 g	100 sec.	Rocky Flats Div.	4
	All other categories	(A) $\pm 10\%$ (b)		0.6 g	100 sec.		4
	(a)	at 100 g Pu					
	(b)	95% confidence limits on standards.					
	(c)	95% confidence evaluated from long-term background data.					

6. References

1. Research and Development Quarterly Progress Report, Chemistry, April, May, and June, 1971, RFP-1748-A. July 30, 1971.
2. Research and Development Quarterly Progress Report, Chemistry, July, August, and September, 1971, RFP-1790-A, October 29, 1971.
3. Research and Ecology Annual Report, Chemistry Research and Development, RFP-1837-A, April 14, 1972.
4. R. N. Chanda, private communication.

1. Assay Instrument - Gamma Counter II - 55 gallon drums
2. Developer - Dow Chemical Co., Rocky Flats Division (1, 2, 3)
3. Principle of Measurement - Gamma rays in the 385 KeV complex from the α decay of Pu are counted by NaI scintillation detectors. Neutrons emitted by spontaneous fission to in (α , n) reactions are counted by BF₃ detectors. The ratio of neutron counts to gamma counts is used for diagnostic purposes only, the gamma counts are used for quantitative assay. Two windows established by single-channel analyzers, one wide and one narrow, are centered on the 385 KeV complex. The wide window provides the information for subtraction of the Compton continuum. Corrections for attenuation of the Pu gamma rays by the matrix are based upon the matrix weight. Provision exists for making transmission measurements. The instrument has been calibrated for a number of matrices, including combustibles, resin, graphite, lead gloves, Raschig rings, CWS filters and insulation. The system will be calibrated up to $\approx$ 350 g.
4. Design and Operation
 - a. Physical Layout
Three 1" x 2" NaI detectors in a vertical array view the drum from a distance of about three drum diameters. Surrounding the drum is a ring of 16 polyethylene moderated BF₃ detectors for neutron counting. The instrument is in an underground shielded cavity.
 - b. Electronics
Standard NIM nuclear instrumentation is used.
 - c. Data Readout
Data is recorded manually from the visual scaler display. Future plans call for interfacing a small digital computer which will read the scalers, compute the answer, and print out via teletype or line printer.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy(a) (at 100 g Pu)	Sensitivity	Assay Time Per Sample	User	Ref.
Pu ²³⁹	Waste and scrap as follows:					
	CWS filters	(A) $\pm$ 25%(a)		100 sec.	Dow Chemical, USA	4
	Lead Gloves	(A) $\pm$ 30%			Rocky Flats Div.	4
	All other categories	(A) $\pm$ 10%				4

(a) Expected accuracies based on other systems. Calibrations in progress at present.

6. References

1. Research and Development Quarterly Progress Report, Chemistry, April, May, and June, 1971, RFP-1748-A, July 30, 1971.
2. Research and Development Quarterly Progress Report, Chemistry, July, August, and September, 1971, RFP-1970-A, October 29, 1971.
3. Research and Ecology Annual Report, Chemistry Research and Development, RFP-1837-A, April 14, 1972.
4. R. N. Chanda, private communication.

1. Assay Instrument - Eight Channel Drum Scanner - Large Waste Drums (20 - 55 gal)
2. Developer - LASL. (1, 2, 4)
3. Principle of Measurement. A vertical array of collimated NaI gamma ray detectors views the rotating sample. The detectors measure the sample activity in the 385 keV complex from ^{239}Pu , the 766 or 153 keV gamma rays from ^{238}Pu , or the 185 keV gamma from ^{239}U . Vertical and horizontal collimation are provided for each detector; this can be adjusted to flatten the variation in response with respect to material location. An absorption correction is applied based on a measurement of the transmission of an external source (^{22}Na (511 keV) or ^{137}Cs (662 keV)) through the sample. The corrected gamma activity is related to the sample content of the isotope being measured.

4. Design and Operation

a. Physical Layout

Up to eight collimated 2 in. x 2 in. NaI crystals are mounted in a vertical plane 4 - 6 in. apart about 5 in. from the drum surface. Vertical and horizontal collimation is adjustable. Individual 100 μCi sources are opposite each detector in a vertical array. These sources can be completely shielded from the detector when required. The drum is placed between the sources and detector on a rotating platform. The background for the system in a well shielded location is about 16 cps or 0.6 g ^{239}Pu .

b. Electronics

Each detector has an independent preamp-amplifier and single channel analyzer. Special multiple circuit modules were constructed for this system;⁽⁴⁾ standard NIM electronics can be used. The SCA outputs are multiscaled in a 1024 channel analyzer capable of simultaneously scaling eight inputs. The multiscale is synchronized with the rotating platform and provides a picture of the radial distribution of material in the sample. The SCA outputs can also be scaled in a standard Timer - Scaler string.

c. Data Readout

The data from the multichannel analyzer is fed into a programmable calculator which is capable of handling the analysis required.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{239}Pu	Pu scrap and waste in 55 gal. drums.	(A) 11% (1 σ)		10 minutes total (in- cluding absorption correction).	LASL at Dow Rocky Flats.	2
^{238}Pu	^{238}Pu residues in 30 gal. drums.	(A) agrees to within $\pm 12\%$ (1 σ) with Ge(Li) measurements on subdivided samples.	0.16g ^{238}Pu (767 KeV line) 0.01g ^{238}Pu (153 KeV line).		LASL	3

6. References

1. J. L. Parker, R. B. Walton, T. D. Reilly, *Nuclear Safeguards R&D*, LA-4457-MS (1970) p. 19.
2. J. L. Parker, T. D. Reilly, R. B. Walton, *Nuclear Safeguards R&D*, LA-4523-MS (1970) p. 29.
3. J. L. Parker, T. D. Reilly, M. M. Thorpe, R. B. Walton, *Nuclear Safeguards R&D*, LA-4605-MS (1970) p. 22.
4. L. V. East, et al, "Gamma-ray Scanning System for Barrels Containing Plutonium Waste," *IEEE Trans. Nuc. Sci.*, NS-19, No. 1, (1972) p. 211.

1. Assay Instrument - Ge(Li) IV ^{239}Pu Package Counter.
2. Developer - Atlantic Richfield Hanford Co. (1)
3. Principle of Measurement. The 414 KeV gamma ray from ^{239}Pu is detected using a vertical array of Ge(Li) gamma detectors. The transmission of gamma rays through the sample from external ^{137}Ba sources ($E\gamma = 355 \text{ KeV}$) is used to make an absorption correction to the data. The ^{239}Pu content of the sample is inferred from the measured 414 KeV activity.
4. Design and Operation

- a. Physical Layout

A vertical array, 32 cm in height, of 4 collimated -20 cc Ge(Li) detectors views the sample. The detector to sample centerline distance can be varied from 35 cm to infinity. Samples are rotated (~4 rpm) and large samples can be oscillated vertically (10 cm/min).

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{239}Pu	Waste material in container sizes ranging from pill boxes to 55 gal. drums.	(P) $\pm 30\%$ (2 σ) (70 $\mu\text{g } ^{239}\text{Pu}/1$) (P) $\pm 5\%$ (2 σ) (7 mg $^{239}\text{Pu}/1$)	-70 $\mu\text{g/liter } ^{239}\text{Pu}$ in 127 liter and 55 gal. containers.	1000 sec.	Atlantic Richfield Hanford Co.	1, 2

6. References

1. W. H. Zimmer, The Ge(Li) IV ^{239}Pu Package Counter, ARH-1993 (1971).
2. W. H. Zimmer, The Ge(Li) IV ^{239}Pu Package Counter - Operating and Servicing Procedures, ARH-2021 (1971).

1. Assay Instrument - Ge(Li) Waste Assay System.
2. Developer - Aerojet Nuclear Company. (1)
3. Principle of Measurement. A Ge(Li) detector is used to measure the activity of a group of gamma rays from Pu including those with $E_\gamma = 129, 149, 208, \text{ and } 414 \text{ KeV}$. Absorption corrections are made to the basic data by comparing the relative attenuation of two or more gamma rays of different energies emitted from the Pu sample material. The measured activity is used to infer the amount of Pu contained within the sample material. Isotopic analyses can be made for ^{241}Pu , and ^{239}Pu in certain cases.
4. Design and Operation
 - a. Physical Layout
A single shielded 50 cc (Ge(Li) detector is positioned about one container length from the center line of the container. The container is rotated at a rate of at least 1 rpm. An absorber equivalent to about 40 miles of cadmium is placed between the detector and the sample container.
 - b. Electronics
Standard counting electronics are used with the Ge(Li) detector. Recommendations concerning desirable detector, amplifier, and multichannel analyzer characteristics are given in Ref. 1.
 - c. Data Readout
Data is presented on the multichannel analyzer. It can be read out, plotted, and analyzed by hand or analyzed by computer. Background subtraction techniques are discussed in Ref. 1.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{239}Pu	Waste in 55 gal. drum.	(P) 5% for 0.5g for one hour counting period.	0.5 c/s/g ^{239}Pu (414 KeV)	15 min.	Aerojet Nuclear Co.	1

6. References

1. J. E. Cline, A Relatively Simple and Precise Technique for the Assay of Pu Waste, ANCR-1055 (1972).

1. Assay Instrument - NaI Barrel Scanner.
2. Developer - Gulf Radiation Technology. ⁽¹⁾
3. Principle of Measurement. The 185 KeV gamma ray from ^{235}U or gamma rays in the 305 KeV complex from ^{239}Pu are detected using a single NaI detector. An absorption correction is applied to the data by measuring the transmission through the sample from an external ^{137}Cs source (662 KeV). The ^{235}U or ^{239}Pu content of the sample is determined from the respective measured activities.

4. Design and Operation

a. Physical Layout

A single 3 in. x 3 in. NaI detector, collimated in the horizontal and vertical directions, is used to scan the sample barrels. The barrel is rotated while being driven vertically past the collimated detector. The barrel scanner is the same one used for LINAC assays on the GAMMAS system. ⁽¹⁾

b. Electronics

The NaI detector is equipped with standard counting electronics.

c. Data Readout

The data during a scan is collected in vertical segments. For each segment, the counts in the peak of interest are determined, a Compton background is subtracted, and the data is corrected for absorption. This is done to minimize the effect of local regions of high density. The entire gamma spectrum is collected and displayed after completion of the scan. The data analysis is performed using the Hewlett-Packard 2116B computer carried onboard GAMMAS.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
^{239}Pu	Waste materials (dry and wet combustibles, Rashig rings, resins, washables) in 55 gal. drums.	(A) 7% (1 σ) good standards (A) 14% (1 σ) poor standards		10 min.	Rad. Tech. at Dow Chemical Rocky Flats.	1, 2
^{239}Pu	Waste and heavy sludge barrels.		3 g. Pu (fast scan)	5 min. scan. 7-8 min. total (fast scan)	Rad. Tech. at National Reactor Test Sta., Idaho.	2
^{235}U	Waste materials (vermiculite, kimwipes, rubber, tin, plastic) in 55 gal. drums.	(A) $\pm 30\%$	$\sim 1\text{g. }^{235}\text{U}$	---	Rad. Tech. at Atomic International.	1
^{235}U	Dense bulk waste in 55 gal. drums.	(P) better than $\pm 6\%$	1g. ^{235}U	---	Rad. Tech. at United Nuclear Corp.	1
^{235}U	Waste material (paper, plastics, graphite).		$\sim 1\text{g. }^{235}\text{U}$	---	Rad. Tech. at Gulf General Atomic.	1

6. References

1. R. L. Bramblett, et. al., Application of Photo Induced Reactions to Nuclear Material Safeguards Problems, Gulf-RT-A 10826 (1971).
2. R. L. Bramblett, et. al.; Application of Photo Induced Reactions to Nuclear Material Safeguards Problems, Gulf-RT-A 10914 (1971).

1. Assay Instrument - 4 π Neutron Coincidence Counter - Up to 55 Gallon Drums
2. Developer - LASL. (1, 2)
3. Principle of Measurement. Neutrons emitted spontaneously from fissionable material samples are detected by moderated BF₃ neutron detectors. Detector coincidence logic, designed to distinguish between fission neutrons and (α , n) neutrons, operates on the principle that each fission event produces 2 to 3 neutrons while an (α , n) event only produces a single neutron. The fission neutrons detected from a single fission event are correlated in time; on the average they will be detected within a time which is roughly equivalent to the neutron lifetime in the detector moderator. The number of coincidence events (a coincidence event is one in which a pair of neutrons are detected within a specified time interval) is therefore related to the amount of spontaneously fissioning material in the sample. A correction is measured for the accidental coincidences which occur due to the detection of two (α , n) neutrons within the coincidence time interval. Additional measurements made with an external fission source placed adjacent to the sample can be used to correct for changes in the effective counter efficiency due to the moderating effects of different sample matrices. A known isotopic content allows the total amount of fissionable material in the sample to be determined from the measured neutron coincidence count rate.
4. Design and Operation
 - a. Physical Layout

Sample chamber is designed to accommodate samples up to the size of a 55 gal drum. The walls of the chamber contain 48 - 2 in. diam. BF₃ detectors sandwiched between 1 in. thick polyethylene slabs. The top and bottom of the chamber each contain an additional 15 BF₃ detectors. The chamber is shielded on the outside by a two foot thick water shield. A door in the side of the counter opens to admit the samples; an entrance ramp to the chamber facilitates sample handling. An earlier version of the system contained 52 BF₃ detectors.

Operating Parameters

<u>Total Efficiency</u>	<u>Coincidence Eff.</u>	<u>Decay Time</u>	<u>Gate Width</u>
~15%	> 2%	80 μ sec	64 - 128 μ sec

Measured coincidence background rates--0.6 cps at 7200 ft altitude
 Estimated coincidence background rate--0.1 cps at sea level

- b. Electronics

Similar to that used in the LASL Neutron Coincidence Can Counter.
- c. Data Readout

Similar to that used in the LASL Neutron Coincidence Can Counter.

5. Operating History

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	Ref.
Pu	Mocked up 55 gal drums containing hydrogenous and non-hydrogenous scrap and waste matrices.	(A) ~10% for non-hydrogenous matrices. (A) ~20% for hydrogenous matrices.			LASL 3
Pu (5% ^{240}Pu)	Mocked up 55 gal drums of vacuum filter sludge (40% solids, 60% H_2O).	Technique samples about 1/3 of the drum volume. Response varies drastically with Pu location.	< 10 m3 ^{240}Pu		LASL 4
Pu (5.8% ^{240}Pu)	Routine assay of material from Pu processing plant (~1000 samples counted).	(A) 10%	< 2 m3 ^{240}Pu at sea level (1000 sec)	~200 sec	LASL 5

The system has been permanently installed⁵ at the LASL plutonium processing plant (DP-site) for routine assay of Pu content in scrap containers. It has been in continuous operation since February 1972.

6. References

1. J. E. Foley, R. B. Walton, Nuclear Safeguards R&D, LA-4523-MS (1970) p. 13.
2. J. E. Foley, Nuclear Safeguards R&D, LA-4763-MS (1971) p. 20.
3. J. E. Foley, Nuclear Safeguards R&D, LA-4603-MS (1970) p. 24.
4. J. E. Foley, Nuclear Safeguards R&D, LA-4763-MS (1971) p. 18.
5. J. E. Foley, Nuclear Analysis R&D, LA-4603-EN (1971) p. 14.

1. Assay Instrument - Electron Linear Accelerator - Gulf Atomic Materials Assay System. (GAMAS)
2. Developer - Gulf Radiation Technology. (1)
3. Principle of Measurement. An electron linear accelerator (linac) is used to produce a pulsed electron beam in the energy range 5.0 to 8.0 MeV. The electron beam impinges on a tantalum converter and produces a continuous bremsstrahlung spectrum of X-rays from zero energy up to the energy of the electron beam. The X-rays are collimated to a well defined spot size at the sample irradiation position. The X-rays produce neutrons in the sample material by photofission (γ, f) and photoneutron (γ, n) reactions. These neutrons are detected by moderated banks of BF₃ neutron detectors located on either side of the sample. Prompt neutrons from (γ, f) and (γ, n) reactions are detected between about 40 and 300 μ sec after each electron beam pulse; delayed (γ, f) neutrons are detected between about 1 to 4 milliseconds after each electron beam pulse.

There are several different schemes for determining the fissionable material content of the sample, but one which is commonly used involves two separate irradiations of the sample - one at about 7.5 MeV and the other at about 5.5 MeV. Prompt neutrons measured during the 7.5 MeV irradiation are produced in (γ, f) and (γ, n) reactions within the sample; the prompt neutron yield at 5.5 MeV is due primarily to (γ, n) reaction. (The main contributors to the (γ, n) yield at 5.5 and 7.5 MeV from non fissionable materials are typically deuterium in homogeneous samples and beryllium.) The 7.5 MeV yield is therefore corrected for the non-fissionable (γ, n) contribution using the 5.5 MeV data. Both yields are normalized to the integrated X-ray dose delivered to the sample as measured with an ionization chamber. Neutron and gamma attenuation factors can be measured and applied to the data. The corrected 7.5 MeV prompt neutron yield is used to determine the fissionable material content of the sample. For a limited class of samples both the fissile and fertile contents of the sample can be determined separately by measuring the prompt to delayed neutron ratio at two different energies.

There are variations of the above technique which can be used on a variety of sample types. Larger samples (e.g. 55 gallon drums) are rotated and vertically scanned during assay. The GAMAS installation is transportable and can routinely handle samples as large as 55 gallon drums on a production basis. The total GAMAS system includes other types of assay devices - only the electron linear accelerator system is described in this review.

4. Design and Operation

a. Physical Layout

A traveling wave linac with a magnetic analysis system provides 2.0 to 10.0 MeV electron beams capable of average electron beam power of about 100 watts. The X-ray beam produced at the converter is collimated to a spot size of about 6 in. high by 12 in. wide, 5 feet from the accelerator output. A barrel scanner which can handle samples as large as 55 gallon drums rotates the samples and moves them vertically through the X-ray beam. Neutrons produced in the sample are detected in moderated banks of BF₃ detectors located on opposite sides of the sample.

b. Electronics

The electronics for the moderated neutron detectors are similar to those conventionally used for BF₃ proportional counters with the following important exception. The signals from the detector banks are gated off during the X-ray pulse to allow the system to recover from transient overloads produced by the intense radiation. Prompt neutrons, emitted during the X-ray pulse, are detected after the system recovers within several neutron lifetimes of the moderated detector assembly. Data is collected on blind scalars which are read out by computer.

c. Data Readout

The data is collected and processed by an on-line computer. The data can be recorded as a function of vertical height of the sample including attenuation corrections. The computer can be used to completely control the barrel scanning sequence. All corrections to the basic data can be carried out by computer and the output presented in terms of calculated fissionable material content for each sample.

5. Operating History*

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay, time per sample	User	Ref.
U	Waste material in 55 gal. drums (5-100g U/drums).			20 min.	Rad. Tech. at Atomics International.	1
Pu	Waste material in 55 gal. drums (20-200g Pu/drums).	(A) $\pm 15\%$ (1 σ) (poor standards; no segregation) (A) $\pm 7\%$ (1 σ) (good standards and segregation).		10 min.	Rad. Tech. at Rocky Flats.	1
U	Waste material in 55 gal. drums.	(P) $\pm 2\%$ (1 σ) (dry waste) (P) $\pm 9\%$ (1 σ) (wet waste).		10 min.	Rad. Tech. at UNC, Hermatite.	1
U	Residue samples of enriched U in 1 gal. cans (5-220g U/can).	(A) $\pm 2\%$ (1 σ)		1 min.	Rad. Tech. at UNC.	1
U	1/2 gallon bottles of enriched UO_2 and $UA1_x$.	(A) $\pm 2\%$ (2 σ)		100 sec.	Rad. Tech. at NRTS	2
U	Fuel assemblies ATR & ETR fuel assemblies.	(P) $\pm 1\%$ (1 σ)		3 min.	Rad. Tech. at NRTS	3

*This table is not complete, but is intended to be representative of the type of results obtainable using this technique.

6. References

1. R. L. Bramblett, Application of Photoinduced Reaction to Nuclear Material Safeguards Problems, Gulf-RT-A-10826 (1971).
2. R. L. Bramblett et al, Application of Photoinduced Reactions to Nuclear Materials Safeguards Problems, Gulf-RT-A 12038.
3. R. L. Bramblett et al, Application of Photoinduced Reactions to Nuclear Materials Safeguards Problems, Gulf-RT-A 10914.

1. Assay Instrument - 14 MeV Neutron Generator - Mobile Assay Laboratory (MONAL)
2. Developer - LASL. (1, 2)
3. Principle of Measurement. A 14 MeV neutron generator accelerates deuterium ions to about 200 KeV and these ions impinge on a tritium loaded target to produce 14 MeV neutrons through the $d(t,a)n$ reaction. The 14 MeV neutrons can be used to irradiate the sample directly or their energy spectrum can be shifted to one with a lower median energy by placing moderating materials between the source (tritium target) and the assay sample. The source neutrons fission material in the assay sample. 14 MeV source neutrons will fission both fertile and fissile materials; however, if a moderated spectrum is used with a median energy less than the fertile material fission threshold, the fissions will occur primarily in the fissile material. (For example, if a uranium sample is irradiated with source neutrons having a median energy less than about 1.0 MeV, fissions will occur primarily in ^{235}U with some fissions occurring in ^{238}U due to that fraction of the moderated spectrum with energies greater than 1.0 MeV.)

Following fission, some of the fission products decay with the emission of delayed neutrons ($t_{1/2}$ - 0.2 to 55 sec.). To detect these neutrons, the accelerator is repetitively pulsed using approximately equal irradiation and counting periods on the order 10^{-1} to 10^0 seconds in length. During the time the accelerator is off (a counting period), delayed neutrons from decaying fission products are detected in a bank of moderated BF_3 or HE_3 detectors. The measured yield of delayed neutrons from the assay sample is normalized to a detector which measures the neutron output from the accelerator (eg. a fission chamber). A technique has been developed to correct the data for moderating effects of the sample matrix on the source neutron spectrum. The fissile or (fertile + fissile) material content of the sample is determined from the measured delayed neutron counting rate.

There are variations of the above technique which can be used on a variety of sample types. The MONAL installation is transportable and can routinely handle samples as large as a 55 gallon drum on a production basis. The total MONAL system includes other types of assay devices - only the 14 MeV neutron system is described in this review.

4. Design and Operation

a. Physical Layout

A 14 MeV neutron generator with a maximum output of -2.5×10^{11} n/sec. is mounted adjacent to a 4 foot wide x 6 foot long x 7 foot high, shielded interrogation chamber capable of handling samples up to the size of 55 gallon drums. A pneumatic transfer system for small samples leads from the chamber to a counting position. A "slab" neutron detector consisting of a moderated bank of BF_3 detectors is located in the chamber for the detection of delayed neutrons. An automated handling system for moving 55 gallon drums (up to 1000 pounds each) into the irradiation chamber and rotating them during the assay facilitates handling of a large throughput of this type of sample.

b. Electronics

The electronic instrumentation for the proportional counters is contained in standard NIM bins. A gating system is used to enable the counter circuitry after each pulse of source neutrons has decayed to an insignificant level in the moderated detectors. The data is stored in scalars which are interfaced to a programmable calculator.

c. Data Readout

A desk top, programmable calculator takes the data from the scalars and calculates the sample's material content. Corrections for sample matrix moderation effects can be made on-line. The results are printed on an electric typewriter.

5. Operating History*

SNM	Sample Description	(P) Precision (A) Accuracy	Sensitivity	Assay time per sample	User	Ref.
Pu	Waste material in 55 gal. drums.	(A) $\pm 36\%$ (1 σ)			LASL at Rocky Flats.	3
²³⁵ U	UA f powder (93% enriched U) in cans, packaged inside steel containers in an Argon atmosphere.	(A) ± 0.5 to 1% (1 σ)		3 min.	LASL	4**
U	Inventory verification samples.	(A) $\pm 1.25\%$ (1 σ)			NUMEC samples at LASL.	5
²³⁵ U;U	Miscellaneous scrap (10 to 97% enrich- ment) in cans.	(A) $\pm 10\%$ (1 σ) (estimated)		12 min. (total)	LASL at NUMEC	6
²³⁵ U;U	K-25 dirty scrap and ash in cans 6-1/4 in. dia., 15 1/4 in. high 3 to 5% enrichment.	(A) $\pm 10\%$ (total U) (A) $\pm 12\%$ relative (²³⁵ U enrich- ment)		10 min.	LASL at National Lead.	6
U	Reject product (97% enriched) in cans.	(A) $\pm 5\%$ (estimated)		6 min.	LASL at NUMEC	7

* This list is not complete and is only intended to be representative of the type of results obtained using this assay system.

**A similar system to that described on MONAL was used for these measurements.

6. References

1. G. R. Keepin, et. al., Nuclear Safeguards R&D, LA-4162-MS (1969) p. 19.
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5. R. H. Auguston, et. al., Nuclear Safeguards R&D, LA-4705-MS (1970) p. 2.
6. G. R. Keepin, et. al., Nuclear Safeguards R&D, LA-4705-MS (1970), p. 26.
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ABBREVIATIONS

LIST OF CONTRIBUTORS

REFERENCES - ADDITIONAL INFORMATION

ABBREVIATIONS

ANCR	Aerojet Nuclear Company
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ARH	Atlantic Richfield Hanford Company
BHO	Prefix for reports produced by private contractors under the AEC's Plant Instrumentation Program (PIP)
BNL	Brookhaven National Laboratory
GEAP	General Electric Corporation
Gulf-RT	Gulf Radiation Technology
IEEE	The Institute of Electrical and Electronic Engineers, Inc.
INMM	Institute of Nuclear Material Management
IN	Idaho Nuclear Corporation (now Aerojet Nuclear Company)
LA	Los Alamos Scientific Laboratory
MLM	Monsanto Corporation - Mound Laboratory
NRL	Naval Research Laboratory
RFP	Dow Chemical Corporation - Rocky Flats Division
WCAP	Westinghouse Nuclear Energy Systems

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REFERENCES - ADDITIONAL INFORMATION

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