Integrated Waste Assay System (IWAS)

Features

- Combines multiple assay techniques
- Quantitative and isotopic gamma-ray analysis
- Passive neutron multiplicity coincidence counting
- Active neutron interrogation using Differential Die-Away Technique (DDA)
- 200 liter (55 gallon) drums and 320 liter (85 gallon) over-packs
- MDAs of less than 30 nCi/g
- Fully automated operation and analysis
- 27% Efficiency for ^{240}Pu fission neutrons
- 2.8% Active mode detection efficiency
- Multiple HRGS detectors
- 10^8 neutron/second Zetatron
- AAS based active neutron mode moderator correction
- NDA 2000 Non-Destructive Analysis Software
- Operates under Windows® NT®/2000

Introduction

IWAS, CANBERRA's Integrated Waste Assay System, is designed to quantify plutonium and uranium in 55 gallon drums and 85 gallon over-packs. The IWAS provides passive and active neutron interrogation and quantitative gamma analysis, allowing rapid characterization of TRU wastes for proper shipment and disposal.

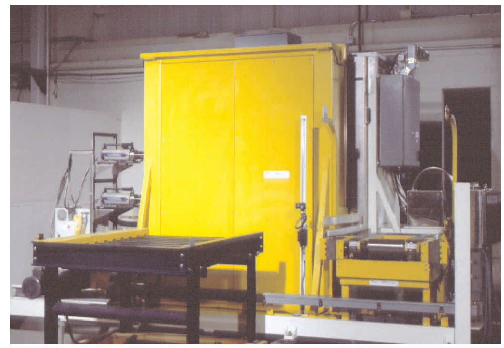

Figure 1.
Integrated Waste Assay System (IWAS)

The IWAS provides a complete NDA instrumentation suite in a single assay cavity. The system offers performance, speed and ease of use while using a fraction of the floor space of three independent systems. The IWAS is based on the CANBERRA High Efficiency Neutron Counter (HENC) design with integrated Differential Die-Away (DDA) and High Resolution Gamma-Ray Systems. Results from individual assay modes are combined automatically by the NDA 2000 software to provide the best result for the sample. Because all assays are performed by the same system in a single assay sequence, there is no confusion over item ID or modification of drum contents between assays.

The system is designed to be operated as an automated counting system which can process batches of drums, or can be incorporated in a facility process line. The following sections describe the various assay sub-systems, hardware, software and indicate typical performance characteristics.

Description

Shield Assembly

The IWAS shield assembly provides a 4π, 40 to 55 cm thick High Density Polyethylene (HDPE) moderator/shield as a measurement chamber for the drums and over-packs. The thickness of the HDPE assembly provides the needed personnel protection against the Zetatron pulsed neutron source used in the active neutron analysis mode. The neutron shield also provides an assay chamber that minimizes the effects of outside gamma radiation levels.

As configured, the neutron shielding is also effective for the gamma-ray measurements and is equivalent to a 2.5 in. thick steel shield allowing detection levels in the gamma analysis mode similar to those obtained in CANBERRA's Q^2 system.

The shutter mechanism is interlocked with the neutron generator so that inadvertent damage to the HPGe detectors is avoided. All doors and access points are interlocked with the neutron generator to minimize the risk of inadvertent personnel exposure.

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Sample Handling Mechanism
In order to provide minimum personnel exposure from the neutron source and a uniform response within the assay cavity, the shield door extends below the assay cavity floor. Sample loading and unloading is provided by a bridge conveyor. Normally the bridge conveyor will mate with the facilities material handling conveyor system. The drum is presented to the bridge conveyor, signaling the IWAS system to start the assay sequence. (Note: A stub conveyor can be provided if a facility does not use an automated material handling system.) Once the drum is positioned at the start of the bridge conveyor, the drum is weighed, the door opens and the drum moves into the assay cavity. The loading mechanism is designed for a working weight of up to 545 kg (1200 lb) and drum sizes of 200 and 320 liters (55 and 85 gallons).

Passive Neutron Assay System
The IWAS utilizes the same basic design parameters for passive neutron assay analysis as CANBERRA's High Efficiency Neutron Counter (HENC)[1]. The passive neutron counting system uses 122 ^{3}He proportional tubes arranged in a 4π counting geometry providing a total neutron detection efficiency of 27% for ^{240}Pu spontaneous fission neutrons and a coincidence sensitivity of 47 cps/gram ^{240}Pu effective. Due to its generally greater accuracy, the passive neutron analysis mode is the primary assay technique for plutonium over the range of 0.1 grams to several hundred grams. The detection level for the passive neutron analysis mode is approximately 4 mg ^{240}Pu effective in 600 seconds at sea level and decreases to 1.7 mg for a 3600 second count time. This corresponds to a detection level of 30 mg weapons grade Pu (6% ^{240}Pu) in 3600 seconds.

Add-A-Source (AAS) Matrix Correction
The Add-A-Source (AAS) technique provides a means of measuring the impact of the waste matrix on the neutrons emitted within the drum. In practice, a small ^{252}Cf source (about 100 000 n/s) is introduced into the assay cavity with no sample in the counter. The measurement is repeated after the sample is loaded and the results compared. The difference in the measured count rates can be used to correct the measured sample rate. The IWAS includes a single position AAS matrix correction module. An illustration of the AAS measurement is shown in Figure 2. The ^{252}Cf source is normally stored in a shield module located to one side of (or above) the counter. The source is automatically moved through a guide tube to the interrogation position and then retracted.

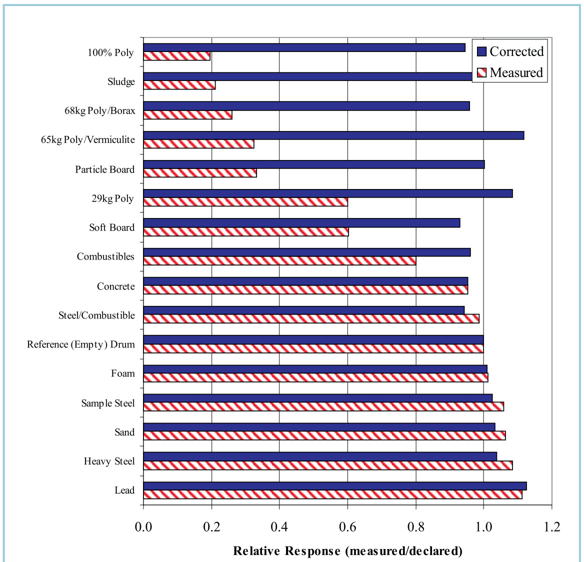

Figure 3.
Typical AAS correction results for the IWAS counter for a series of homogeneous and non-homogeneous matrix drums with a simulated uniform source distribution. The uncorrected response is reported as much as a factor of five too low while the corrected response has a standard deviation of only a few percent.

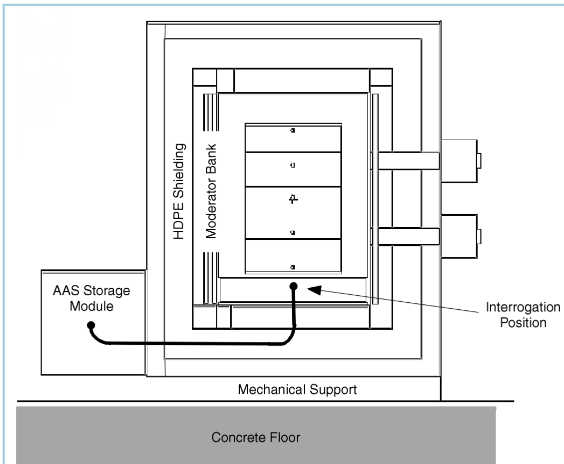

Figure 2.
Relative location of the ^{252}Cf source interrogation position for the IWAS Add-A-Source measurement.

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For homogeneous distributions of Pu in the drum, the AAS correction results in a typical error of ±2% from the expected values. Without the correction, the errors can exceed 50%. The effectiveness of the AAS correction is illustrated in Figure 3.

Passive Neutron Analysis Background Corrections

The coincidence neutron background has two primary sources: the presence of nearby fission sources and cosmic-ray-induced neutron events. The IWAS shielding is sufficient to remove most of the ambient neutron background, but cannot eliminate the neutrons generated by cosmic rays interacting with the counter's body or the contents of the sample. Drums containing lead or steel have an associated cosmic-ray-induced coincidence background (or interference) that results in a positive bias in the reported mass if not corrected. Conversely, highly moderating drums (e.g. sludges) tend to attenuate the cosmic-ray-induced coincident neutrons, potentially resulting in a negative bias. The IWAS can correct for these effects using the NDA 2000 software.

The NDA 2000 software has a suite of correction algorithms available. The Matrix Based Background Correction (patent pending) will adjust the background rates based on the moderator content of the drum determined from the AAS measurement. The cosmic-ray rejection (CCR) algorithms include the typical truncation techniques as well as a more sophisticated multiplicity analysis that can determine the high-Z material content of the drum and correct the measured coincidence rates (patent pending) for this effect and eliminate the bias.

Active Neutron Interrogation

The active neutron interrogation mode allows the IWAS to provide lower detection levels than would normally be achievable by a passive neutron assay system in a short counting time. The active neutron analysis uses an intense pulsed neutron source to induce fission in the plutonium and uranium contained within the drum. The neutrons from the induced fission events are detected in a sub-set of the ^{3}He tubes that are mounted in cadmium wrapped HDPE packages. The detection efficiency for induced fission neutrons within these Fast Neutron Detector Packages (FNDP) is 2.8%. The difference in the characteristic decay time for the source neutrons to thermalize and induce fission and the characteristic decay time for neutrons to be detected gives the technique its sensitivity and its name – Differential Die-Away (DDA). Figure 4 illustrates the relative time response for a drum with and without uranium.

The IWAS active neutron analysis mode is based on the Second Generation Differential Die-Away technique, but with enhanced matrix correction algorithms. Traditional second generation DDA systems rely on the passive neutron measurement to estimate the moderator correction factors and so cannot provide a measured correction for uranium only or for low Pu content drums. The IWAS provides both absorber and moderator correction factors for the matrix effects even when there is no fissile material within the drum. The absorber correction is based on the ratio of neutrons detected in the cavity and barrel flux monitors. The IWAS system uses the AAS measurement for the determination of the moderation correction, providing a more accurate measurement for the low fissile mass drums. The overall effectiveness of the matrix correction factors is illustrated in Figure 5.

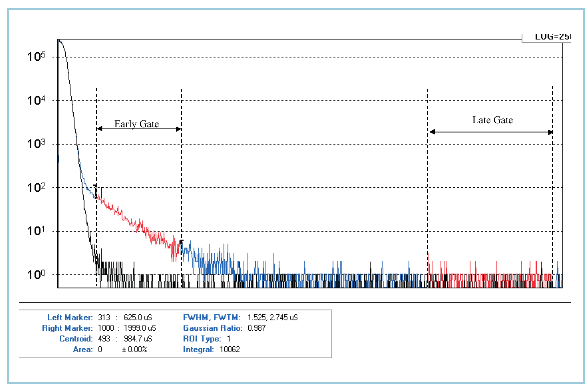

Figure 4.
Time response of the Fast Neutron Detector Packages for a zero matrix drum. The upper curve shows the response for a 1 gram ^{235}U source and the lower for a drum with no fissile material.

Gamma-Ray Assay System

The gamma-ray assay system is based on CANBERRA's Q² concept[2]. Two or more High Resolution Germanium Detectors are mounted on retractable stands that allow the detectors to be inserted into the shield assembly during the passive neutron assay. The thick HDPE shield serves as an effective gamma-ray shield, allowing detection levels of less than 10 mg ^{239}Pu in a 600 second count time using two BE2820 detectors. Additional or larger detectors can lower this detection level substantially.

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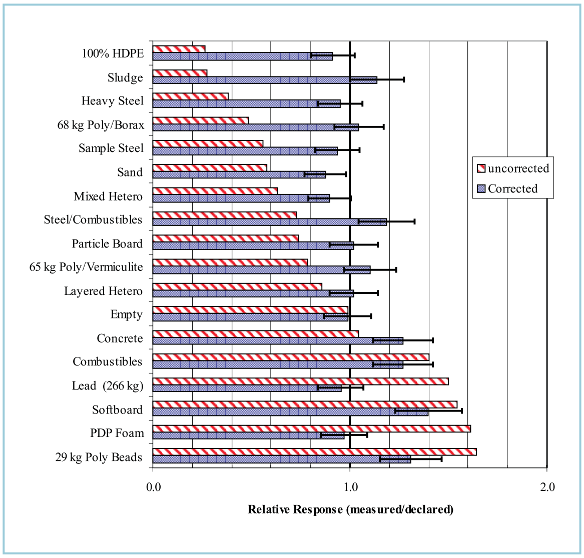

Figure 5.
DDA analysis results showing the corrected and uncorrected response from a uniformly distributed uranium source.

Gamma-Ray Transmission Matrix Correction (Option)
A transmission measurement option is available for the IWAS system to provide a measured matrix correction, rather than the density based correction approach of the Q^2 style systems. The transmission source shield and actuator mechanism houses one 5 cm long line source for each HRGS detector. The sources are located across the assay cavity at the same height as the germanium detectors. This measurement provides an accurate determination of the average density of the matrix material in the drum at multiple positions in the drum.

The sources are interconnected by a rod and exposed by being pulled vertically up into the collimator slots. This design ensures that the sources will drop into the shielded position in the event of a power failure. Sensors verify the fully open and fully closed positions of the transmission sources, and a red warning light indicates when the transmission source is exposed.

Plutonium Isotopics Measurement
The IWAS is typically provided with CANBERRA's Broad Energy Germanium (BEGe) detectors. These detectors provide the efficiency required for quantitative gamma measurements and the resolution required for the most sensitive plutonium isotopics codes, such as the Multi-Group Analysis (MGA) software, developed at Lawrence Livermore National Laboratory by Dr. Ray Gunnink. CANBERRA's MGA code has been enhanced for waste assay applications and the complications resulting from poor counting statistics. This package can provide plutonium isotopics for very small sources in waste containers. In addition to the plutonium isotopics, it will determine other actinides such as ^{235}U, ^{238}U, ^{237}Np, and ^{241}Am. (Note: other isotopics codes such as the Los Alamos FRAM code and TRIFID are available upon request).

Table 1. IWAS Gamma System Detection Levels.

Nuclide	Energy (keV)	Typical LLD (pCi/g)[a] Density (g/cc)				Worst Case LLD (pCi/g)[b] Density (g/cc)			
		0.1	0.3	0.8	1.8	0.1	0.3	0.8	1.8
^{137}Cs	662	0.72	0.32	0.20	0.16	1.04	0.52	0.60	1.76
^{134}Cs	800	0.75	0.35	0.20	0.15	1.05	0.55	0.55	1.35
^{60}Co	1173	0.65	0.26	0.17	0.13	0.86	0.39	0.39	0.69
^{58}Co	810	0.75	0.35	0.20	0.15	1.05	0.55	0.55	1.35
^{144}Ce	134	12	5.6	4.1	4.0	17	10	27	198
^{232}Th	908	2.2	1.0	0.6	0.5	2.9	1.6	1.5	3.2
^{228}Th	239	1.8	0.8	0.6	0.5	2.5	1.5	3.0	17.0
^{228}Th	583	2.1	0.9	0.6	0.5	2.9	1.5	1.9	7.7
^{238}U	1001	93	39	24	20	126	60	61	135
^{238}U	609	1.3	0.6	0.4	0.3	1.9	0.9	1.1	3.2
^{235}U	185	1.6	0.75	0.55	0.5	2.3	1.35	3.2	21.5
Pu detection levels in nCi/g									
^{239}Pu	414	19.9	9.0	8.5	5.6	30.1	16.4	25.2	124

a. Detection levels for a nominal 600 second passive assay.
b. Estimated detection levels for a non-self attenuating point source at the position of lowest sensitivity in the drum.

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Table 2. IWAS Detection Levels for U and Pu for the three analysis modes.

	Pu Detection Levels (mg total Pu)			HRGS Detection Levels[d]	
Matrix (net weight)	DDA[a]	PNCC[b]	HRGS[c]	^{235}U (mg)	^{241}Am (mCi)
Combustibles (54 kg)	10	70	10	16	1.0
Scrap Steel (220 kg)	20	80	40	61	4.5
Wet Soil (70 kg)	6	100	16	23	1.6
Sludge (150 kg)	45	250	35	50	3.5

a. The ^{235}U detection levels for the DDA mode will be 1.5 times greater than the Pu detection levels.
b. Weapons Grade Plutonium (≈6% ^{240}Pu), and the counter is installed near sea level with no additional cosmic-ray shielding.
c. Limits for two BE2820 detectors.
d. Quantitative gamma detection levels for ^{241}Am and ^{235}U not keyed to neutron measurement.

IWAS Detection Levels

The typical detection levels for the three analysis modes of the IWAS are presented in Table 2. The detection levels are stated for a typical assay duration (Passive measurement: 700 seconds, Active Neutron: 120 seconds, AAS matrix measurement: 60 seconds). Sample load/unload and QA check measurements put the total assay sequence count time at 21.5 minutes. These detection levels are equivalent to 30 nCi/g.

Dynamic Range

Detection limits are only half the story for most waste assay systems. Typical applications require that the assay system accommodate wastes containing hundreds of grams of plutonium. The integrated assay techniques allow the software to determine the optimum analysis mode whether the drum contains a few mg or 200 grams of plutonium. At the low concentrations (a few hundred mg or less), the combination of active neutron and quantitative gamma analysis generally provides the best result. However, for high concentrations, the active neutron and quantitative gamma analyses suffer from self-attenuation effects so that the combination of passive neutron coincidence and gamma-ray isotopics provides the best result. The IWAS can accurately accommodate this entire mass range in a single instrument.

Total Measurement Uncertainty

IWAS reports the final assay values based on an analysis of the data from all available analysis modes. For each assay mode, the software performs a set of analytical tests (e.g. was gamma-ray self attenuation observed?) to determine the validity of the individual mode and its associated Total Measurement Uncertainty (TMU). The best assay result is selected based on the results of the diagnostic tests, mass range, and TMU for the analysis mode.

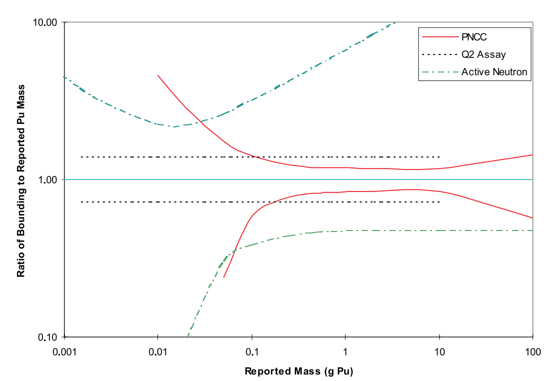

Figure 6.
Total Measurement Uncertainty estimate for a 50 kg combustibles drum (10 minute passive count time, at 1500 meters altitude) with no prior knowledge of the waste matrix. In the simple case, the assay choice selection is based predominantly on the reported Pu mass.

S529C NDA 2000 Software

The system is operated from CANBERRA's NDA 2000 software. NDA 2000 is a complete acquisition, analysis and archival package for use with all CANBERRA neutron and gamma waste assay counters.

Analysis Modes

NDA 2000 supports a variety of analysis types to provide flexibility in sample assay. With NDA 2000, it is possible to select which type or types of analysis are to be performed for a given sample. A selection of the system and analysis types supported by the IWAS operating under NDA 2000 are given in Table 3.

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Table 3. IWAS Analysis Modes Under NDA 2000.

- Quantitative Gamma-Ray Spectroscopy
  - Segmented Gamma-Scanning
  - Multi-Detector Analysis (Q^2)
  - Transmission Correction
  - Differential Peak Attenuation Correction
  - MGA/MGAU Isotopics Analysis
- Passive Neutron Counting
  - Totals Neutron Counting
  - Passive Coincidence Counting
  - Passive Multiplicity Analysis
  - Add-A-Source Matrix Correction
  - Cosmic-Ray Neutron Coincidence Correction
- Active Neutron Counting
  - Differential Die-Away
  - Add-A-Source Matrix Correction
- Simultaneous Neutron-Gamma Assay
- Total Measurement Uncertainty Analysis
- Automated Drum Handling
- Automated Waste Assay (AWA) Review

Setup

NDA 2000 offers Simplified Startup through the use of a wizard to step the user through the setup of a neutron assay system. For most standard system configurations, default counter profiles exist to facilitate initial system startup. To define a new counter, the user selects from a list of predefined systems or creates a new one. The wizard leads the user through the counter setup. To minimize setup errors, the wizard will prompt the user if a required parameter is omitted.

The setup utility provides a single location for the entry of sample and matrix parameters, assay sequence, and hardware definition. And it simplifies definition of new container and sample types as well as default isotopic and reference mass files.

Operations

Following setup, operation can be as simple as a single click of the mouse, where a full assay sequence is launched requiring little or no operator intervention.

The software accommodates neutron, gamma and integrated data acquisition systems. Integrated gamma-neutron assay sequences can acquire this data simultaneously, sequentially or independently. Following completion of the measurements, the neutron and gamma-ray assay results can be combined automatically even if the measurements were performed days apart.

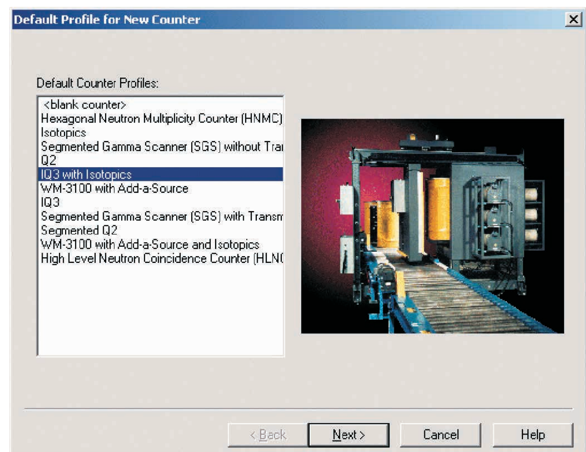

Figure 7.
NDA Setup Wizard simplifies software startup.

Physical

The overall dimensions of the passive active neutron counter are 645 cm long by 400 cm wide and 254 cm tall. This footprint includes the requirements for the door in the open position and the PLC control cabinets, plus a 150 cm long load conveyor. Overall weight of the counter is approximately 8000 kg.

References

1. "The Design of a High Efficiency Neutron Counter (HENC) for Waste Drums to Provide Optimized Sensitivity for Plutonium Assay," H.O. Menlove, et al., Proceedings of the 5th Nondestructive Assay and Nondestructive Examination Waste Characterization Conference," Salt Lake City, UT, January 14-16, (1997).
2. "Q^2 – A Very Low Level Quantitative And Qualitative Waste Assay And Release Certification," F. Bronson, Proceedings of Waste Management '90, February 25-28, 1990, University of Arizona, Tucson, Arizona.

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