AUTOMATIC AND INTERACTIVE ANALYSIS SOFTWARE FOR BETA-GAMMA COINCIDENCE SYSTEMS USED IN CTBT MONITORING

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ABSTRACT

A suite of software has been developed by Veridian Systems as part of the Prototype International Data Center (PIDC) to assist in the analysis of noble gas monitoring data for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). There are two acceptable noble gas monitoring methods for CTBT verification purposes: high-resolution gamma-ray ( ) spectrometry and beta-gamma (-) coincidence. Data from - spectrometry systems can be analyzed with the existing software at the PIDC and the International Data Center (IDC). Because commercially available software did not exist to analyze data from the - coincidence systems, this software has been developed at the PIDC for eventual deployment at the IDC.

The suite of software consists of automatic analysis software and CORIANT (COincident Radiation Interactive ANalysis Tool). The automatic analysis software automatically identifies and quantifies radionuclides present in the sample and categorizes the sample based on the type and quantity of radionuclides present. CORIANT is a graphical user interface that gives an analyst the capability to view three-dimensional β-γ coincidence data, view automatic analysis results, view temporal trends in the data, generate reports, and override the automatic analysis if needed. A general description of the automatic analysis software and CORIANT, and the implementation of this software at the PIDC are discussed in this paper.

1. OVERVIEW

Eventually 80 radionuclide monitoring stations will be deployed as part of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification. All of these stations are required to monitor the atmosphere for the presence particulate radionuclides. Half of these stations are also required to monitor the atmosphere for the presence of gaseous radionuclides. Two acceptable noble gas monitoring methods are defined in the CTBT text: high-resolution gamma-ray (γ) spectrometry and beta-gamma (β-γ) coincidence. Noble gas data from γ-spectrometry systems can be analyzed with the existing software that is currently being used to analyze particulate station data at the Prototype International Data Center (PIDC) and the International Data Center (IDC). Because commercially available software did not exist to analyze β-γ coincidence data, a suite of software has been developed and installed at the PIDC to analyze these data both automatically and interactively.

This paper begins with a general description of the β-γ coincidence data used in CTBT monitoring. This is followed with a detailed description of the developed software suite that includes an automatic analysis package and a stand-alone interactive tool. The automatic analysis software automatically identifies and quantifies radionuclides present in the sample. It also categorizes the sample based on the type and quantity of radionuclides present. A general description of the automated analysis software and the implementation of this software at the PIDC will be discussed here. A detailed description of the analysis algorithms is given in references 1 and 2. The interactive tool, CORIANT (COincident Radiation Interactive ANalysis Tool), is a graphical user interface that gives an analyst the capability to view and manipulate three-dimensional β-γ coincidence data, view automatic analysis results, view temporal data trends, and generate reports. CORIANT also provides the analyst with a tool to override the automatic analysis if needed. The capabilities of CORAINT will be demonstrated in this paper.

2. β-γ COINCIDENCE DATA

Currently only two prototype systems are available to measure three-dimensional - coincidence data useful for CTBT monitoring. These are the Automated Radioxenon Sampler Analyzer (ARSA) designed by PNNL, USA and SAUNA designed by FOA, Sweden. A detailed description of the ARSA system can be found in reference 3. A general description of data from - coincidence systems will be presented here.

The β-γ coincidence data are generated in the following manner. A large quantity of air is collected over an extended period of time (typically 8-12 hours). The four gaseous radionuclides relevant in CTBT monitoring are ^{131}Xe, ^{131m}Xe, ^{133}Xe, and ^{133m}Xe. In order to reduce background signals, predominantly

Table 1 [(a)]

ROIs in β-γ Coincidence Spectra Relevant in CTBT Monitoring

ROI	Nuclides Possible	Quantification Nuclide	Centroid γ-Energy (keV)	Centroid β-Energy (keV)
1	^{214}Pb	[(b)]	352	-
2	^{214}Pb, ^{135}Xe	^{135}Xe	250	-
3	^{214}Pb, ^{133}Xe	^{133}Xe	81	-
4	^{131m}Xe, ^{133m}Xe, ^{133}Xe, ^{135}Xe	^{133}Xe [(c)]	30	-
5	^{131m}Xe, ^{133}Xe, ^{135}Xe	^{131m}Xe	30	130
6	^{133m}Xe, ^{133}Xe, ^{135}Xe	^{133m}Xe	30	199

(a) From Ref. 1

(b) Only used for determining interference from ^{214}Pb in ROIs #2 and #3.

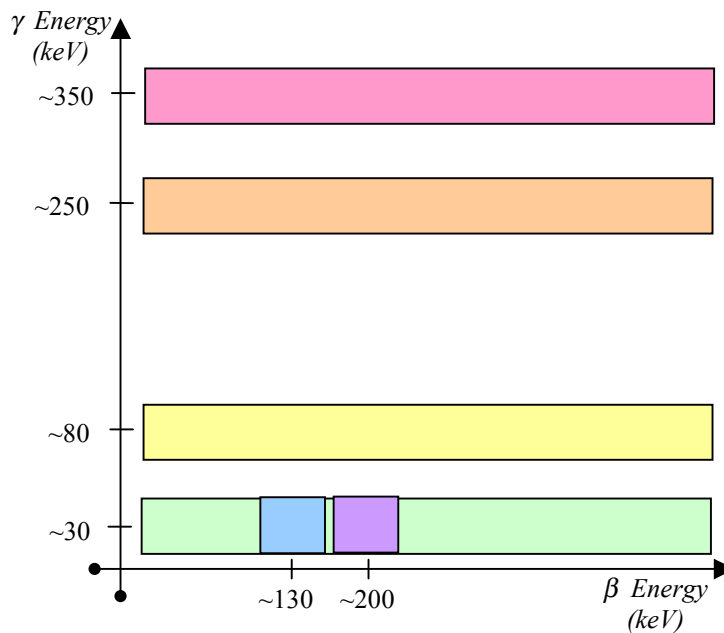(c) Not currently being used for quantification purposes.

Figure 1: Required Regions of Interest with ROI Number
(not to scale – from Ref. 1)

from naturally occurring radon and its daughters, xenon gas is separated from the sampled air. The pure xenon gas is automatically placed in a scintillation chamber that can measure the energy and arrival time of electrons and photons emitted by a nucleus. The electrons can be either beta particles or conversion electrons and will be collectively called betas in this paper. Likewise, the photons can be either x rays or gamma rays and will collectively be called gammas. A three-dimensional spectrum is created by only storing the events in which an electron and a photon are detected in coincidence. The three axes of the spectrum are beta energy, gamma energy, and number of coincidence events. Each relevant decay event produces a gamma at a discrete energy and a beta over a range of energies. By summing the number of counts within each gamma and beta energy range, it is possible to calculate the activity of the radionuclides present. The gamma and beta energy range for each radionuclide is called a region-of-interest (ROI). Table 1 summarizes the important characteristics of the relevant ROIs and Figure 1 shows a graphical depiction of the ROIs.

2. AUTOMATIC ANALYSIS

3.1 Radionuclide Monitoring System Pipeline

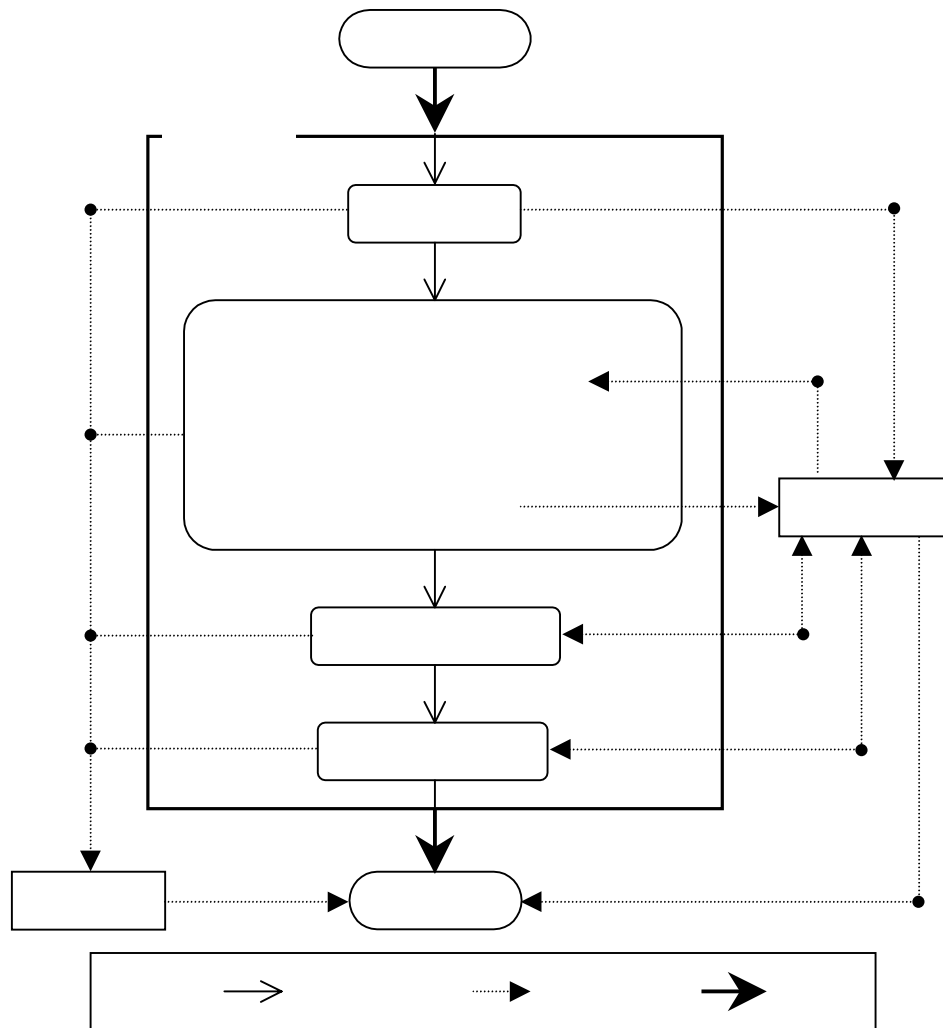Figure 2 shows the radionuclide monitoring system data pipeline. The four main components are *Input*,

Figure 2: Radionuclide Monitoring System Data Pipeline

Analyze, *Categorize*, and *Flag*. The same pipeline is used for particulate systems, γ-spectroscopy gas systems, and β-γ coincidence gas systems except that the functionality the *Analyze* component is different. Each component of the process stores its results to an Oracle database and writes errors to an error log file. The pipeline automatically begins when a pulse height data (PHD) message is emailed into the system. The PHD message is a text file that contains the spectral data along with the sample, station, and detector parameters required in data processing. The *Input* software automatically parses the PHD file and stores the appropriate data in the database. Next, the pipeline calls the *Analyze* software. The *Analyze* software identifies which radionuclides are present in the spectrum and calculates the concentration of the identified radionuclides that are relevant in CTBT verification. The *Analyze* software is described in more detail in the following section.

After successful completion of the *Analyze* software, the pipeline next calls the *Categorize* software. This software automatically categorizes the sample based on the identified radionuclides. Each sample is assigned a category level based on whether the automatic analysis identified natural and/or man-made radionuclides at normal or abnormal levels. Only man-made radionuclides or radionuclides with a statistical filter are considered. The category levels are
- Level 1 indicates no radionuclides identified or only natural radionuclides identified,
- Level 2 indicates abnormal levels of natural radionuclides identified (not used for noble gas data),
- Level 3 indicates normal levels of man-made radionuclides identified,
- Level 4 indicates abnormal levels of a single man-made radionuclide identified, and
- Level 5 indicates abnormal levels of multiple man-made radionuclides identified.

In the final step of the *Categorize* software, the categorization results are saved to the database.

The pipeline next calls the *Flag* software. The *Flag* software determines whether the sample parameters, the *Analyze* results, and the *Categorize* results are within normal specifications. The *Flag* results are saved to the database and the program control returns to the pipeline. Before termination, the pipeline sends various emails to any user subscribing to that type of data product. The content of these emails includes the results, the error messages, and the warring messages generated in the spectral data processing. A user can view the automatic analysis results by using interactive tools such as CORIANT, subscribing to the emails, viewing the log file, or by directly accessing the database.

3.2 Analyze Software

The *Analyze* software begins by extracting three-dimensional β-γ coincidence data and the associated processing and sample parameters from the database. The spectral data are stored in channels whereas the ROI boundary definitions are stored in energy units. The ROI boundaries are converted to channels by calibrating the gamma axis and the beta axis (see Figure 1) using calibration data contained in the PHD file.

The gross counts are calculated by summing the counts per channel within the ROI boundaries. Because the calculated boundary channels are real numbers, not integers, a boundary typically falls within the middle of a channel. Hence, the boundary channel counts are weighted by the percentage of the boundary channel located within the ROI. The net counts are calculated by correcting the gross counts for the affects of Compton continuum background, gas cell background (i.e., "memory effect"), detector background, and interference from other nuclides.

The Compton continuum counts are background counts that exist in the absence of the associated radionuclide of the ROI. The Compton background is only a concern along the gamma axis and not along the beta axis. Two Compton regions are defined per ROI: one at higher gamma channels (the upper region) and one at lower gamma channels (the lower region).
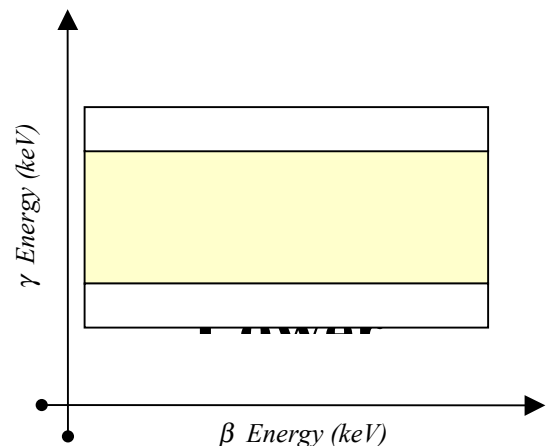

Figure 3: Compton and Gross Regions

Figure 3 shows an example of the upper and lower Compton regions. The boundaries of the upper Compton region are the ROI beta boundaries, the upper ROI gamma boundary, and the upper ROI gamma boundary plus three channels. Likewise, the boundaries of the lower Compton region are the ROI beta boundaries, the lower ROI gamma boundary, and the lower ROI gamma boundary minus three channels. Using the Compton region boundaries, the counts in each region are calculated in the same manner as the gross counts. The Compton counts are then calculated by adding the counts from the upper and lower Compton regions and multiplying the resulting sum by the ratio of the ROI area to Compton area. The ROI area is defined as the number of channels within the ROI boundaries and the Compton area is defined as the number of channels within the upper and lower Compton boundaries.

The gas cell background is any signal that would be present in a purged gas cell after a sample has been counted. It is often called the memory effect because is caused by the adsorption of radionuclides from the previous sample on the detector cell wall. The gas background counts are calculated by multiplying the net counts of the most recent prior (MRP) gas background sample by a decay factor. The decay factor accounts for differences in live time between the two samples and for the decay of the radionuclide associated with the ROI between acquisitions. A gas background sample is measured prior to every sample measurement.

The detector background is any signal that would be present in a purged gas cell with no memory effect. The detector background counts are calculated by multiplying the net counts of the MRP detector background sample by the ratio of the live time of the current sample to the live time of the MRP detector background sample. A detector background sample is measured only occasionally with relatively long acquisition times and with a new gas cell or one that has not been used in a sufficient amount of time for the memory effect to be significant.

A decaying radionuclide may produce counts in multiple ROIs (see Table 1). A ROI, by definition, can only be associated with one radionuclide. The current ROI to radionuclide association is shown in Table 1. The counts in a ROI not from its associated radionuclide are called the interference counts. The interference counts are calculated by multiplying the counts of the interfering radionuclide's associated ROI by the interference ratio. The interference ratio (from the PHD file) is equal to the ratio of counts in the current ROI to counts in the associated ROI of the interfering radionuclide. The interference ratio is a calibration parameter that is determined experimentally before the current measurement and depends on the ROI boundaries.

The critical level (Lc) is calculated for each ROI with an associated radionuclide as described in references 1 and 2. A radionuclide is declared identified if the net counts in its associated ROI are greater than its Lc value. The concentration is calculated as described in reference 1 for each radioxenon that was identified. The minimum detectable concentration (MDC) is calculated for each radioxenon, regardless of whether it was identified, as described in reference 2. All analysis results are then saved to the database.

3. INTERACTIVE ANALYSIS

CORIANT is the new interactive review tool for three-dimensional β-γ coincidence data used in CTBT monitoring. CORIANT graphically displays the β-γ coincidence data and allows an analyst to verify the automatic analysis results, add comments to samples, view temporal trends in the data, and generate reports. The main CORIANT window displays six tabbed windows, see Figure 4. The first tab is the Histogram window, which shows the sample data currently under review; the other five tab windows are called ROI tabs. Each ROI tab shows detailed information about the possible nuclides found in the sample. The five ROI tabs are ^{214}Pb, ^{135}Xe, ^{133}Xe, ^{133m}Xe, and ^{131m}Xe. In addition to the tabbed windows, there are multiple pop-up windows accessible through the pull down menu. The tabbed and pop-up windows are described separately below.

4.1 Histogram Window
The Histogram window, see Figure 4, shows a color-coded three-dimensional (third dimension in color) representation of the β-γ coincidence data. Each dot on the display represents a β-γ coincidence event
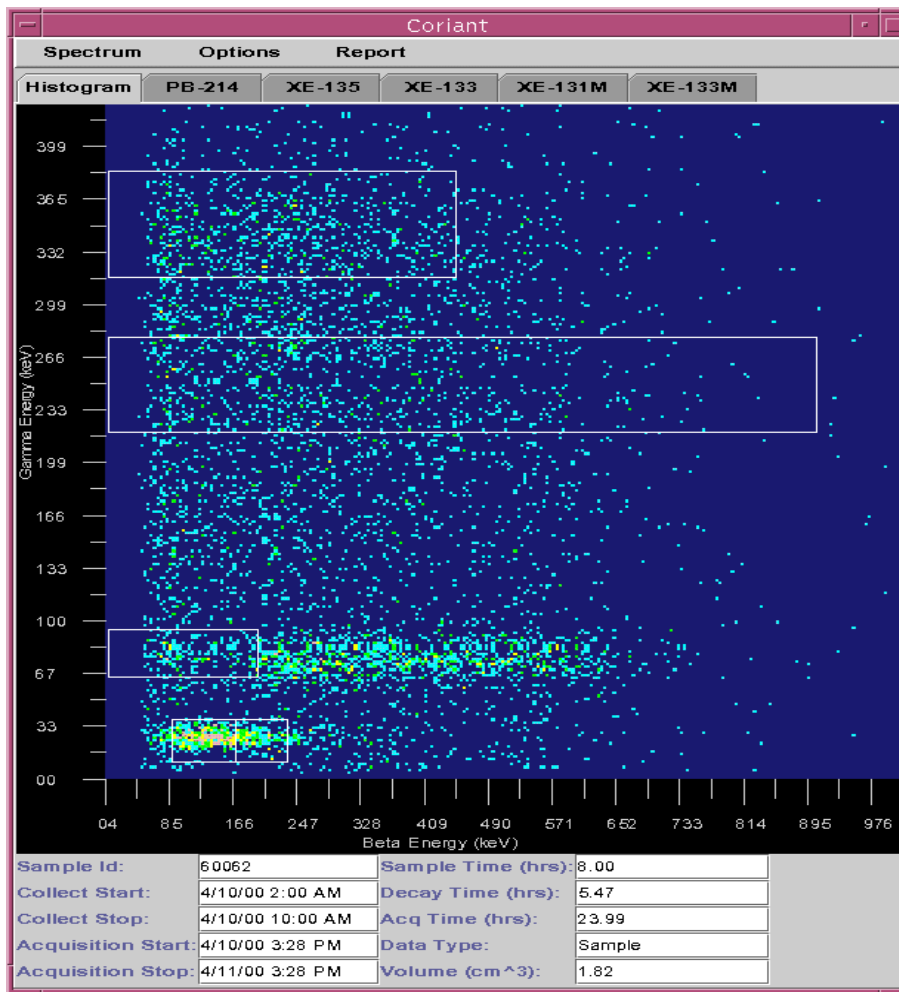
detected at that particular beta and gamma energy. The dot color indicates the number of events detected (counts) at that beta/gamma channel. ROI boxes can be overlaid on the histogram to show the exact locations of the five ROIs used for nuclide identification and quantification. The ROI overlays help an analyst determine if the energy/channel calibration equations are correct. At the bottom of the Histogram window, a text area displays important sample parameters including the sample id, decay time, collection start time, collection stop time, acquisition time, xenon gas volume.

5.2 ROI Tab Windows

Each ROI tab window represents one of the nuclides that can be found in β-γ coincidence data: ^{214}Pb, ^{135}Xe, ^{133}Xe, ^{133m}Xe, and ^{131m}Xe. Figure 5 shows the ROI tab window for ^{131m}Xe. The four sub-windows on each ROI tab window are

- Beta-Gated Gamma graph – shows a plot of the beta-gated gamma spectrum over that ROI,
- Gamma-Gated Beta graph – shows a plot of the gamma-gated beta spectrum over that ROI,
- Count summary pie chart – graphically represents how the gross counts are distributed between interference, memory (gas background), Compton, (detector) background, and net counts, and
- Information summary – displays the nuclide half-life, coincidence event abundance, coincidence event detection efficiency, gamma energy range, beta energy range, and if the nuclide was identified.

5.3 ROI Table Window

The ROI Table window, see Figure 6, is a tabular display that has one row for each of six ROIs shown in Table 1. This window is accessible through the pull-down menu. ROI 4 is not currently being used for nuclide identification or quantification; however, it may be used in future versions of the *Analyze* software.
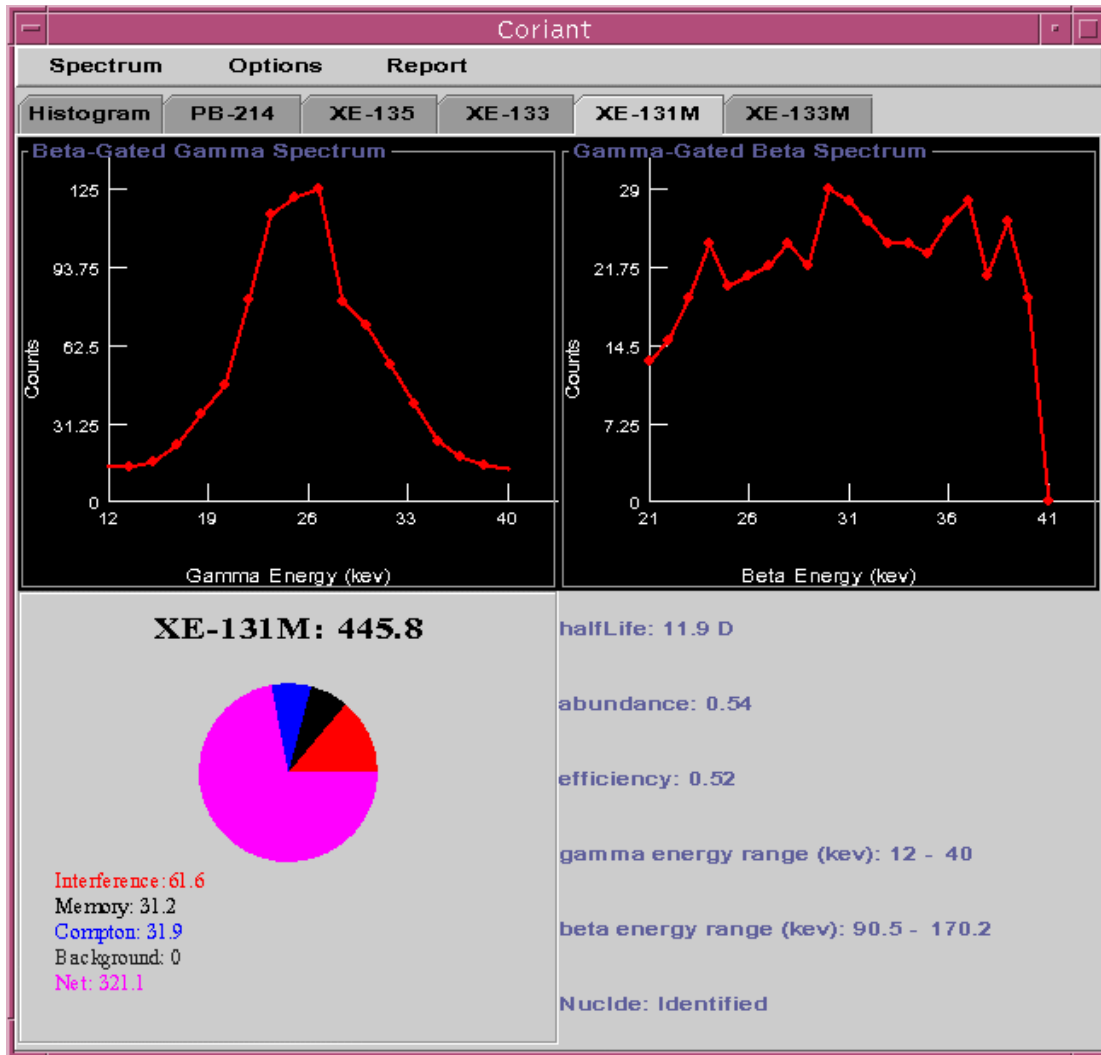
Figure 5: CORIANT Window Displaying the [131m]Xe Tab

The columns in the table include ROI number, nuclide identification flag, nuclide name, gross counts, net counts, Lc, activity, MDC, and ROI β-γ coincidence efficiency. Right-clicking the mouse on a row in the ROI window displays a pop-up menu. This menu allows an analyst to add a comment for the selected ROI, add a general comment for the sample, or plot the activity or MDC of that nuclide over the last 30 days, see Figure 7. Along the bottom row of this window are five check boxes that toggle the ROI box displays on the Histogram window.

4.4 Other Pop-up Windows

There are multiple pop-up windows accessible through the pull-down menu bar. A description of several of these windows is given below.

- *Assignment Window* is a tabular display that allows analysts to view the samples in the sample assignment queue that require review.
- *Beta Graph Window* shows a plot of the gamma-gated beta spectrum over the entire beta energy range.
- *Comment Window* displays all comments added to the current sample. These comments are

Roi	Id	Nuclide	Gross Counts	Net Counts	Lc	Activity	MDA	Effic
1	*	PB-214	687.340	152.442	104.007	0	0	0.288
2		XE-135	822.664	-49.794	108.222	0	1.677	0.355
3	*	XE-133	196.064	64.749	47.795	0.257	0.447	0.361
4		None	816.503	582.471	0	0	0	0.523
5	*	XE-131M	445.782	321.133	45.976	0.668	0.197	0.523
6	*	XE-133M	195.619	140.116	24.852	0.352	0.132	0.523

☑ Pb-214   ☑ Xe-131M   ☑ Xe-133   ☑ Xe-133M   ☑ Xe-135   Clear
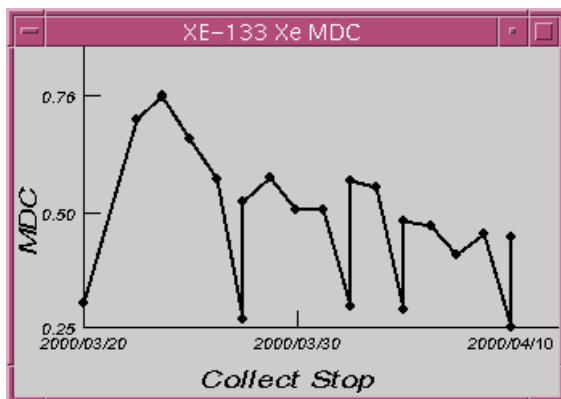

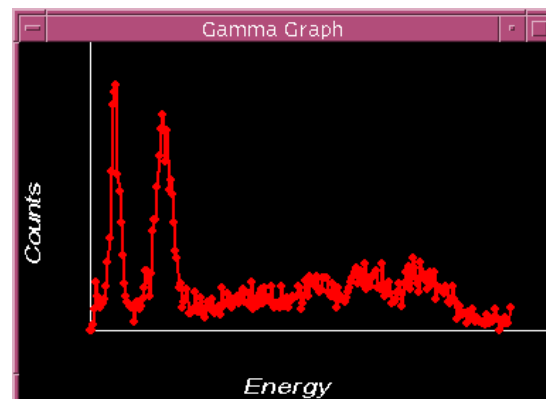**Figure 7: Historic MDC Values for ^{133}Xe**

Figure 8: CORIANT Gamma Graph Window

included in the report that is distributed when the sample is released.

- *Count Summary Window* displays the "Count summary pie chart" described in Section 5.2 for each ROI.
- *ECR Window* shows the energy to channel calibration for both the gamma and beta axes.
- *Gamma Graph Window* shows a plot of the beta-gated gamma spectrum over the entire gamma energy range, see Figure 8.
- *Library Window* is a tabular display that has one row for each of the five radionuclides of interest. The table columns are the name, coincidence event abundance, and half-life of each nuclide.
- *Release Window* allows an analyst to mark a sample "released" or "viewed." A sample marked "released" indicates that the analyst agreed with the results of final analysis. The final analysis includes the automatic analysis plus any changes made by the analyst during the interactive review. A sample marked as "viewed" indicates the analyst reviewed the sample but that in the analyst's opinion, the final analysis results were flawed.
- *Station/Detector Window* is a report that displays the name, location, station type, and detector type.

SUMMARY

A suite of software has been developed at the PIDC to assist in the analysis of noble gas monitoring data for the CTBT. There are two acceptable noble gas monitoring methods for CTBT verification purposes: high-resolution γ-spectrometry and β-γ coincidence. Data from γ-spectrometry systems can be analyzed with the existing software at the PIDC and the IDC. Data from β-γ coincidence systems can be analyzed

with this newly developed software. This software is currently installed and is used in daily operations at the PIDC and is scheduled to be installed at the IDC in fall 2000.

The software suite consists of an automatic analysis package and a stand-alone interactive tool. The automatic analysis software automatically identifies and quantifies radionuclides present in the sample. It also categorizes the sample based on the type and quantity of radionuclides present. The interactive tool, CORIANT, is a graphical user interface that gives an analyst the capability to view three-dimensional β-γ coincidence data, view automatic analysis results, view temporal trends in the data, generate reports, and override the automatic analysis if needed. A general description of the automatic analysis software and CORIANT, and the implementation of this software at the PIDC were discussed in this paper.

Key Words: beta-gamma coincidence, radionuclide monitoring, noble gas, CTBT, PIDC, IDC

REFERENCES
[1] Biegalski, K.M.F. "Automatic Analysis Algorithm for Radionuclide Pulse Height Data from Beta-Gamma Coincidence Systems." MARC V Conference. Submitted for publication in the Journal of Radioanalytical and Nuclear Chemistry, April 2000.

[2] Biegalski, K.M.F. and Biegalski, S. "Determining Minimum Detectable Concentrations for Noble Gas Detectors Utilizing Beta-Gamma Coincidence Systems." MARC V Conference. Submitted for publication in the Journal of Radioanalytical and Nuclear Chemistry, April 2000.

[3] Reeder, P.L., Bowyer, T.W., and Perkins, R.W. "Analysis of Beta-Gamma Spectra for the PNNL ARSA and Estimate of Minimum Detectable Activities for (^{131m}Xe + ^{133m}Xe), ^{133g}Xe and ^{135g}Xe." PNNL-11784