Mirion Spectroscopic Stack Monitor – System Overview, Data, and Analysis

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ABSTRACT

The Mirion spectroscopic stack monitor is an autonomous system used to quantify releases of noble gas from stacks in real time. The system utilizes an electronically cooled HPGe detector along with an automatic analysis device to achieve unattended operation. The system acquires data automatically over regular time intervals, performs analysis on the live data to determine activity concentrations and stack release rates, and stores the data permanently in a SQL database. Also, it is possible for the user to set alarm levels on the reported activity concentrations or release rates and receive notifications when alert or alarm levels are exceeded. To this point Mirion has provided three spectroscopic stack monitors to the STAX program as well as three more to national labs. These systems have been collecting continuous emissions data for nearly five years across three different continents. The results demonstrate the wide measurement range, data quality, and the uninterrupted operation possible with the system. Each of these systems have been calibrated with ISOCS™ mathematical efficiency calibrations and then verified with Xe-133 and Kr-85 gas, and the results are both consistent and accurate across all monitors. Data from multiple sites are discussed and compared to factory calibration results along with an alternate lightweight design.

SYSTEM OVERVIEW

The spectroscopic stack monitor accurately quantifies stack releases over a broad energy range (up to 3 MeV) and activity range (100 - 6x109 Bq/m3 for Xe-133). It was designed specifically for noble gas detection (e.g. Xenon, Krypton, and Argon) in an unattended mode. There are now six systems operating in the field (IRE, ANSTO, Niowave, and three at research reactors). The IRE system has been running nearly continuously for 4.5 years, providing large amounts of valuable data. The system, Figure one, consists of a modular design with a control cabinet housing power distribution, the system computer, and the signal chain electronics and a sampling skid that houses the HPGe detector in a 10 cm thick lead shield.

The signal chain, Figure 2, consists of a coaxial HPGe detector coupled to a transistor reset preamp (TRP), which feeds signals into a Lynx® MCA. The Lynx MCA is controlled by the Data Analyst which sums 1 second MCA snapshots into longer averaging intervals (many averaging intervals may be used in parallel) and automatically performs analysis on the resulting spectra. The results along with analyzed spectra are then sent to the Horizon® database (SQL database) for permanent storage and historical analysis. System health data are also recorded and tracked by Horizon software for visual trending or notification alerts.

HPGe/Transistor reset preamp

- High energy resolution
- Provides high throughput capability (500,000 cps)
- Electronically cooled Cryo-Pulse® 5 Plus (CP5)

Lynx MCA

- Receives signals, shapes them, and bins them to create spectra
- Performs live time correction for accurate reporting at high count rates

Figure 1 – The Mirion Spectroscopic Stack Monitor System with the sampling skid (left) and control cabinet (right).

Data Analyst

- Operates the MCA in MSS mode. One second acquisitions
- Sums up acquisitions and performs analysis automatically
- Uses existing Genie™ 2000 analysis algorithms
- May have multiple workflows in parallel with different analysis parameters, averaging times, libraries, etc.
- Provides a UI to view live data and historical data

Horizon software

- Relational database for permanent data storage
- Provides UI to view historical data and trend incoming data
  – Compare multiple nuclides
- QA feature for system health. Automatically trend and send notifications for:
  – FWHM – track energy resolution
  – Centroid energy – track gain drift
  – Activity – track efficiency
  – Cooler (CP5) statistics
  – Lynx and Data Analyst health
- Reporting feature – activities, system health

Custom scripts

- We provide support to customize the system for the end user/facility
  – Create log files for effluent reporting in a custom format
  – Create custom alarms and notifications
  – Automatic file conversion

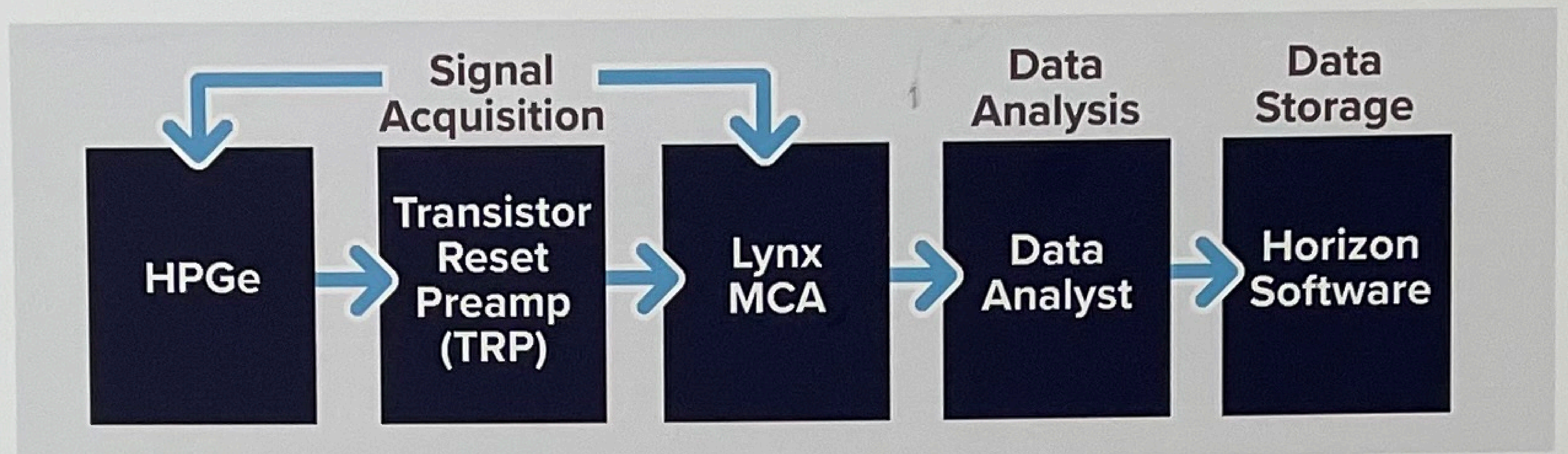

Figure 2 – Schematic of the system signal chain from radiation detection (HPGe) to data storage and visualization (Horizon platform)

SYSTEM PERFORMANCE

Each system is calibrated using the ISOCS mathematical efficiency calibration tool and verified with Xe-133 and Kr-85 gas measurements. Agreement within 3% was found between the measured and calculated efficiencies at both Xe-133 (81 keV) and Kr-85 (514 keV) energies. System backgrounds were measured and a full spectrum count rate of 2.7 cps was found to be typical. These backgrounds and the efficiency were then used to calculate the Minimum Detectable Concentration (MDC), see Table 1, of the system as a function of measurement time using the Currie formalism.

- An MDC of 100 Bq/m³ (Xe-133) is achievable with the system

MDC (Bq/m³)			
Nuclide	600 sec acquisition	3600 sec acquisition	14,400 sec acquisition
Kr-85	6.91E+04	2.50E+04	1.19E+04
Kr-85m	1.85E+02	6.77E+01	3.25E+01
I-131	2.20E+02	7.67E+01	3.61E+01
Xe-131m	7.41E+03	2.72E+03	1.31E+03
Xe-133	5.74E+02	2.10E+02	1.01E+02
Xe-133m	1.56E+03	5.66E+02	2.70E+02
Xe-135	1.87E+02	6.77E+01	3.24E+01
Xe-135m	2.46E+02	8.25E+01	3.82E+01

Table 1 – Minimum Detectable Concentration of the system for various averaging intervals

The accuracy of the system at high count rates is also an important metric as puff releases may create high count rate conditions. The dual source method was used to determine the accuracy of the live-time correction performed by the Lynx MCA. In this method one source (Cs-137) is held at a fixed location relative to the detector that produces a low deadtime count rate (800 cps or 1% deadtime). A reference peak (662 keV) is used to determine the baseline count rate in this geometry. A second source of a different nuclide (Eu-152) is then introduced at various distances to elevate the count rate incrementally. As the total spectrum count rate increases the activity of the reference peak is monitored. The result, see Figure 3, shows the accuracy of the live-time correction as a function of count rate, or deadtime, and shows that the system accurately measured activity upwards of 500,000 cps or 95% deadtime.

- A 5% systematic error is introduced at 500,000 cps, this is taken as the upper end of the measurement range
- 500,000 cps corresponds to an activity concentration of 6.4x10⁹ Bq/m³ (Xe-133)
- The system will continue to count at even higher rates

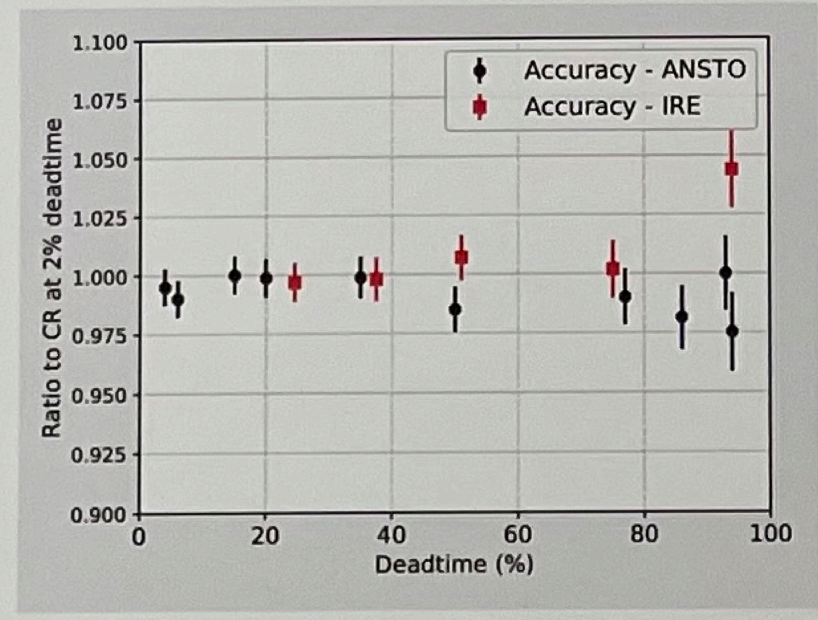

Figure 3 – Accuracy of the Lynx MCA live-time correction as a function of deadtime. At 95% deadtime (500,000 cps) the correction reproduces the known activity to within 5% for both the IRE and ANSTO systems.

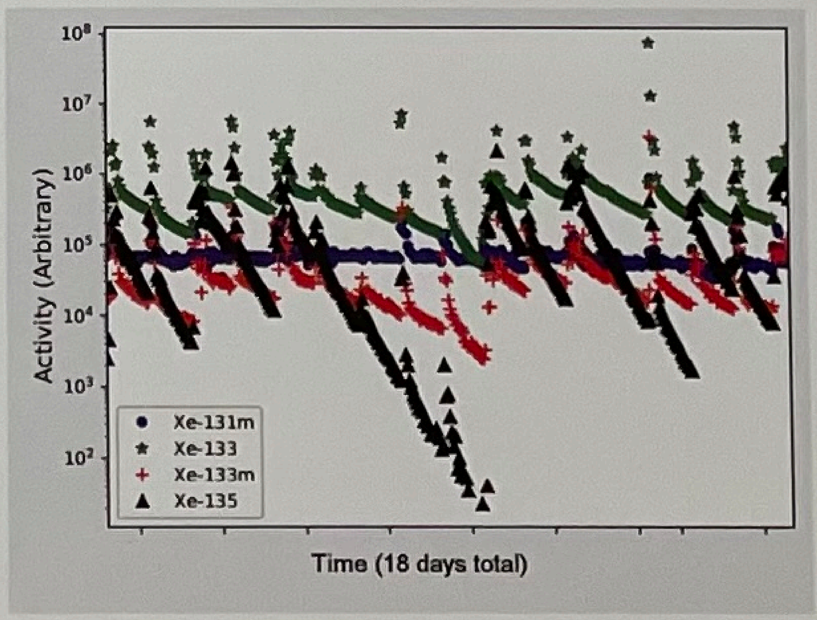

Figure 4 – Time series of activity from the IRE system. Note the plot covers nearly 7 orders of magnitude.

DATA/ANALYSIS

While historical data from several installations have been reviewed and analyzed, the results shown in this section correspond to in-field measurements of stack releases at IRE. While the data from installations at medical isotope production plants are dominated by xenon isotopes, installations at research reactors are generally dominated by Ar-41 but do produce smaller amounts of xenon and krypton.

IRE Data

- Time series plot of xenon activities shown in Figure 4
- Clear cycles of spikes in activity followed by slow decay
- Slopes of the individual traces after each spike correlate with the half-life of each radionuclide
- Likely period of reduced production (5-6 days) where the Xe-135 curve dips to the lowest point
- Much less variability in Xe-131m than the other three

IRE Spectrum

- Spectrum (Figure 5) corresponds to the highest activity point in Figure 4
- 15 minute acquisition
- Full spectrum count rate = 11,000 cps (8% deadtime)
- 0.99 keV FWHM at 81 keV
  – 0.94 keV FWHM at 81 keV measured at the factory under ideal conditions
- Xe ratios for this spectrum
  – Xe-135/Xe-133 = 0.00291
  – Xe133m/Xe131m = 3.98

IRE Data

- Repurposing the data into a 4-isotope plot (Figure 6) shows the high activity releases of the time series plot correspond to the points furthest to the right in the 4-isotope plot
- The spikes in Figure 4 correspond to a high Xe-133m/X-131m ratio
- Potentially problematic for discriminating weapons testing

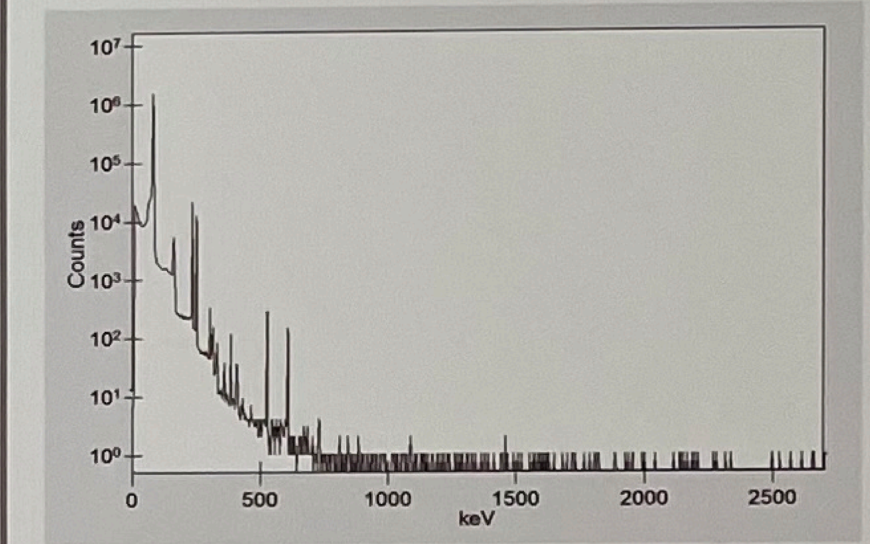

Figure 5 – Spectrum corresponding to the highest activity point in the time series plot (Figure 4)

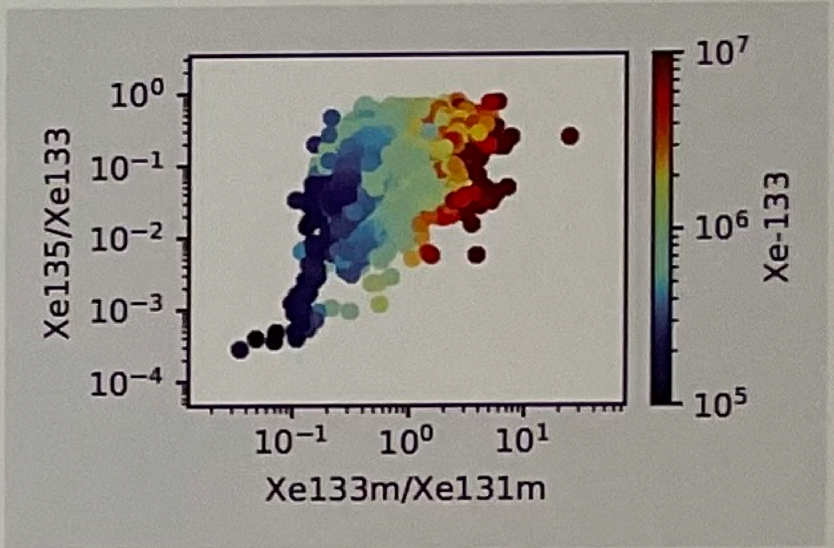

Figure 6 - Xenon 4-isotope plot of 4-hour acquisitions over 5 months of continuous operation. The color scales with Xe-133 activity.

ALTERNATE CONFIGURATIONS

While the spectroscopic stack monitor as designed accommodates a large dynamic range, it is possible that the activity concentration at some facilities is much higher than the level the system was designed for. In this case an alternate sample geometry may be implemented, see Figure 7. Here a smaller sample vessel can replace the existing large sample container. In this way the dynamic range can be adjusted by orders of magnitude. Also, if weight requirements prohibit the use of a large shield, a combination of smaller vessel and/or thinner shielding may be implemented.

Possible measurement geometry adjustments

- Small sample geometry to accommodate high activity concentrations
- Small sample geometry to decrease the inner radius of the shield, which may significantly reduce the mass of the shield
- No change to the sample geometry but thinner shield wall to reduce mass

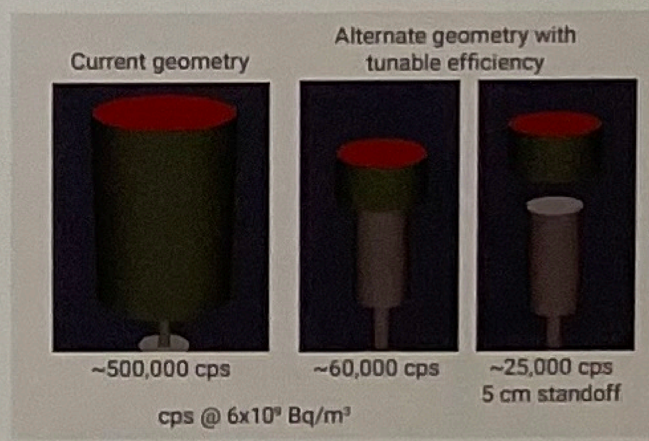

Figure 7 – Alternate measurement geometries possible to accommodate less massive shield and/or higher activity concentrations.

CONCLUSIONS

The Mirion spectroscopic stack monitor shows excellent dynamic range, accuracy, and versatility. There are currently six systems in the field at research reactors and medical isotope production plants. IRE data confirm the dynamic range is adequate for typical MIP releases and shows the importance of HPGe quality measurements for stack release characterization. For installations that require a lightweight version, adjusted dynamic range, or custom scripts and reporting, customizations are available.

MIRION TECHNOLOGIES

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