

APPLICATIONS OF TRIGGERED AND/OR CONTINUOUS AUTONOMOUS GAMMA SPECTRAL ANALYSIS

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Obligatory CYA Disclaimer

1. These are my personal comments. Apply the appropriate number of Standard Deviations and Confidence Level to them.
2. The following have NOT has said they agree with them:
 - Mirion corporate attorneys
 - Our esteemed CEO
 - My wife
3. Alternate Facts will be entertained, as long as accompanied by fine Scotch whiskey more than 20y old
 - [except if it is Laphroaig]

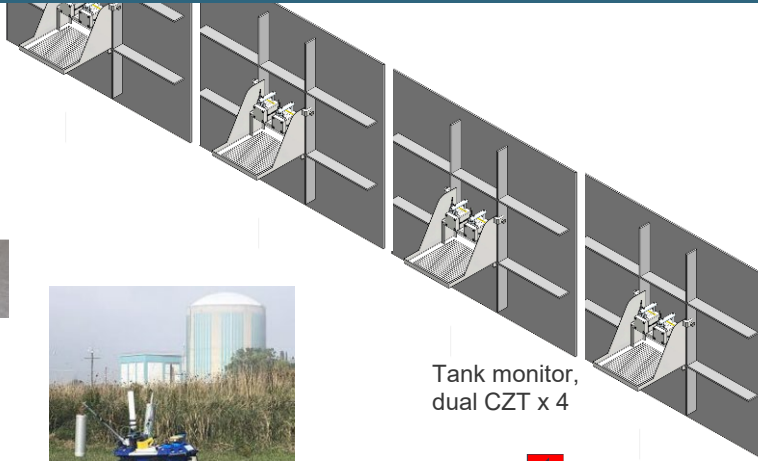
Continuous or Triggered Spectroscopy in recent Mirion projects using the Data Analyst



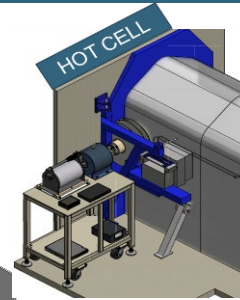
Stack Gas Monitor HPGe



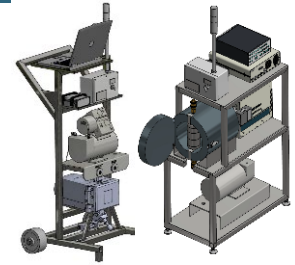
HPGe Primary Coolant Monitor



Tank monitor, dual CZT x 4



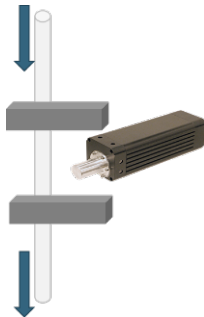
Fuel Rod Scanner HPGe



Particulate, Iodine, Gas monitor CZT [left] HPGe [right]



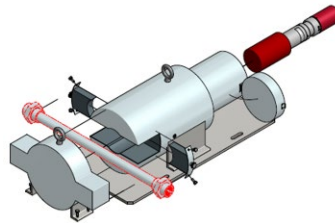
NPP in-situ CZT system



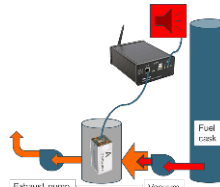
Plutonium chromatography system, uGe



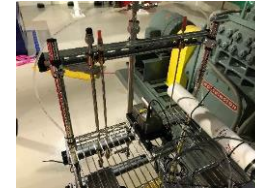
Robot ground and floor, dual



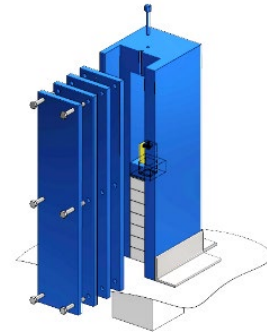
Pipe process monitor NaI



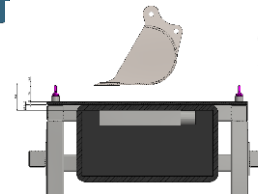
Fuel cask monitor CZT detector



BWR primary coolant monitor, CZT



Lu177 assay, CZT



Excavation bucket monitor

Common elements in all of these Applications

Building Blocks:

Detector
MCA
Data Analyst
Shielding

Support Tools:

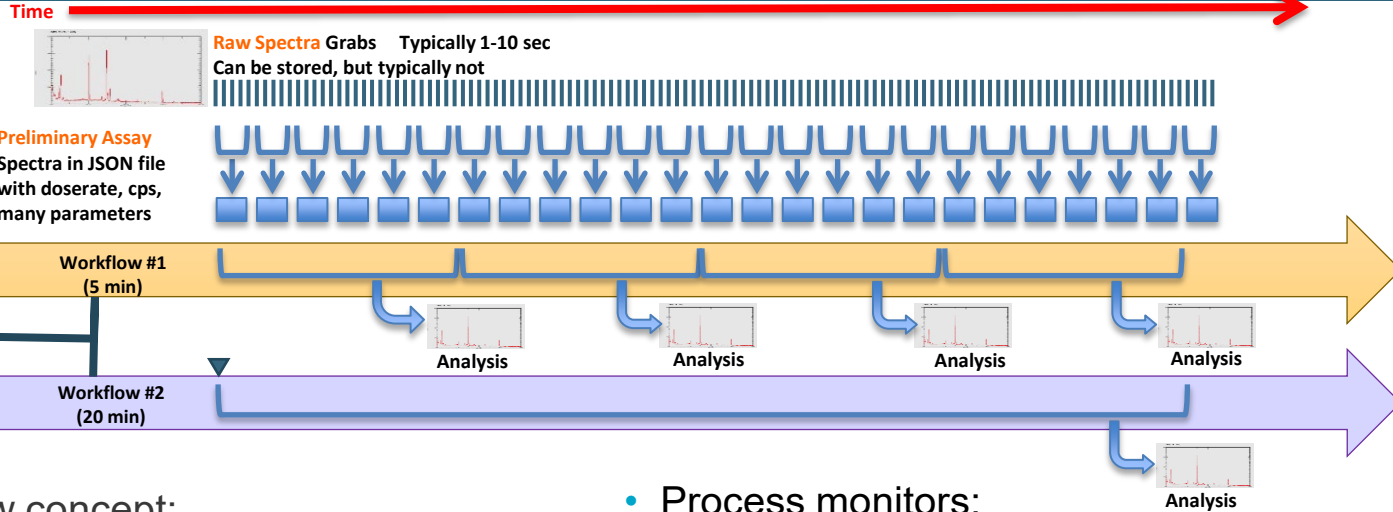
ISOCS
Genie
Display software
Viewing software
Reanalysis software



The Data Analyst provides unattended **continuous sequence** of quantitative gamma assays
OR **remotely triggered** spectral acquisition and analysis
OR both simultaneously

- ◆ Works with various detector/MCAs
 - ▶ **CZT** with internal MCA
 - ▶ **Scintillation** detectors with Osprey MCA
 - ▶ **HPGe** detectors with Lynx MCA
- ◆ Autonomous – apply power and immediately starts running; PC only for setup and data readout
- ◆ Runs standard Genie inside the box
- ◆ Wi-Fi, or Ethernet communications
- ◆ Includes GPS to correlate nuclide activity with location
- ◆ Compatible with EcoGamma for concurrent doserates
- ◆ Includes remote temperature sensor

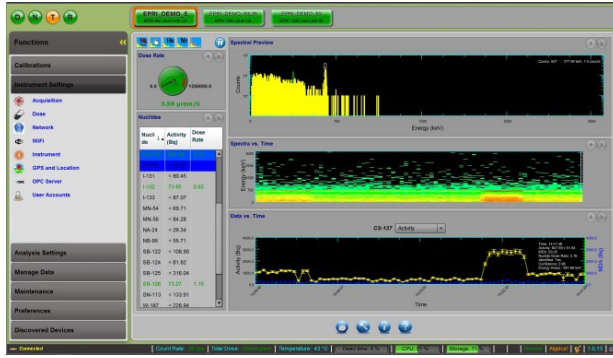
Data Analyst Key Features used in these Projects



- Workflow concept:
 - Each with own Count time, Libraries, Analysis parameters
- Multiple workflows can operate at the same time:
 - e.g. short sample, long sample, very long QC
- Continuous Spectroscopy Mode; Triggered Mode; or Both
- Alarm outputs: based upon nuclide-specific assay results
- Process monitors:
 - Generally Continuous Mode
 - Short count workflow for quick response
 - Long count workflow to detect low activity nuclides
 - Longer count time for continuous QC assay
- Sample assay systems
 - Triggered for sample type 1
 - Triggered for sample type 2
 - Triggered for sample type n
 - Continuous mode long count time for QC assay

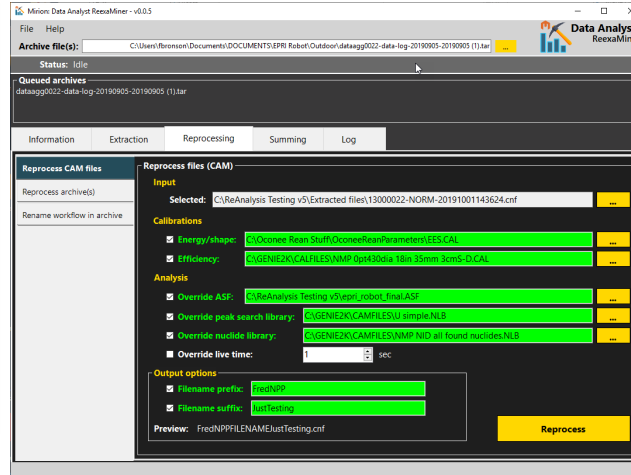
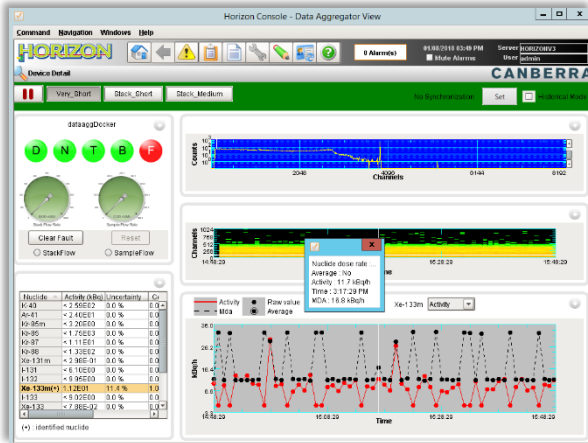
Operational and Support Tools to work with Thousands of Spectra

Main Screen of **Data Analyst** User Interface for viewing with connected PC



DA Prospector:
Grouped Nuclide viewing and live data export to remote PC

Horizon:
Relational Database and Central Supervisory display



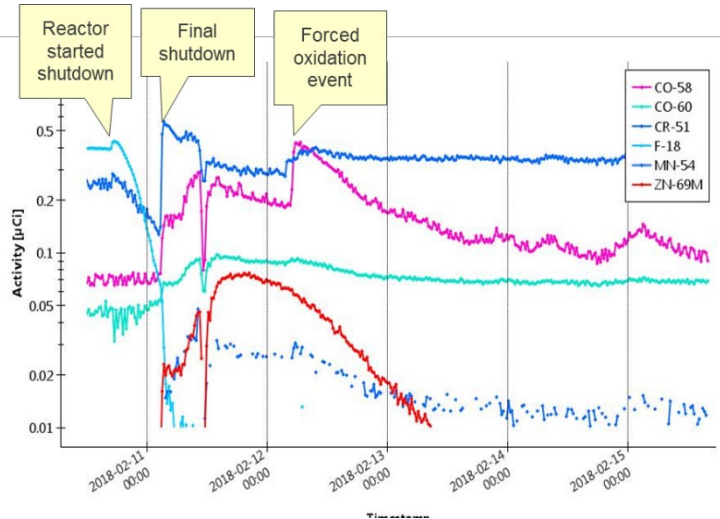
Reexaminer:
Batch reanalysis tool allowing parameter changes

EPRI - Fresh Primary Coolant in Operational NPPs

- DCPD 1: 2 week initial trial
- DCPD 2: 5 units for entire outage
- Oconee 2: 1 unit for entire outage
- Oconee 1: 1 unit for 2.5 years
- Assay Results consistent with expectations

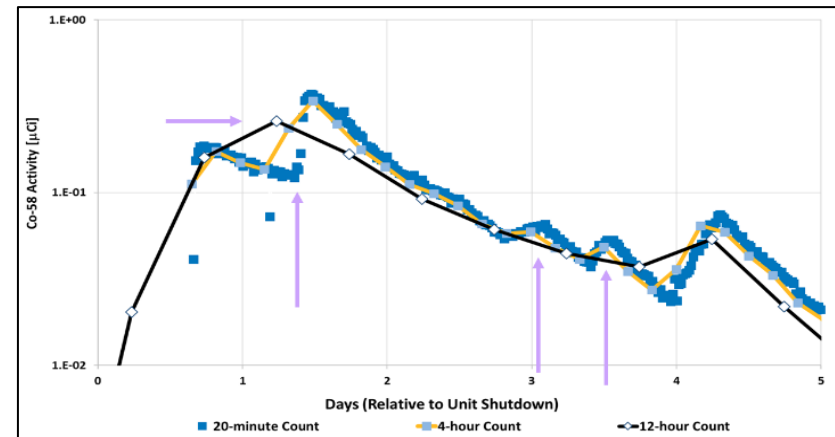
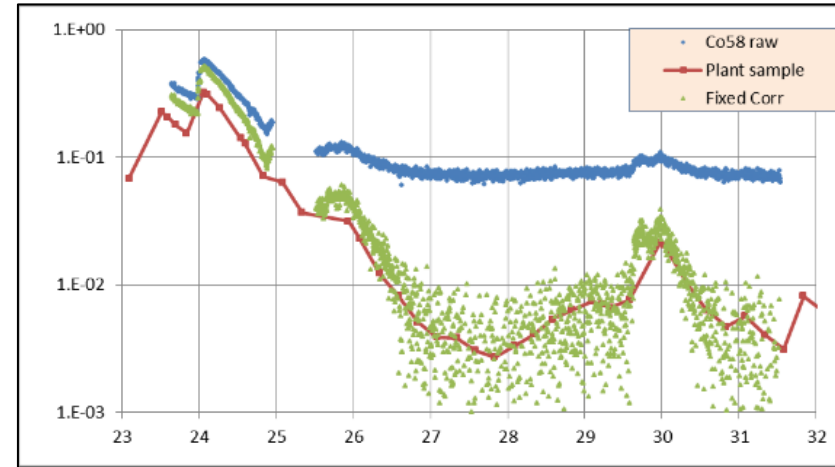


- CZT does good job for major gamma emitters
- Requires careful setup of Libraries and analysis parameters
- Weak gammas and low energy gammas would do better with HPGe system; much easier to set up
- Reliable power for temporary applications difficult to come by



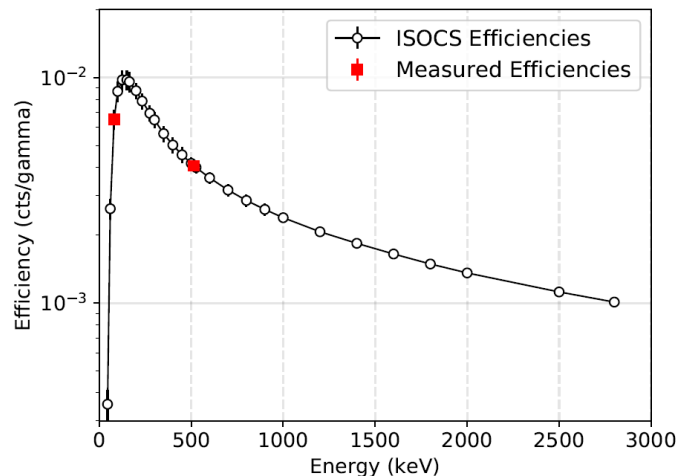
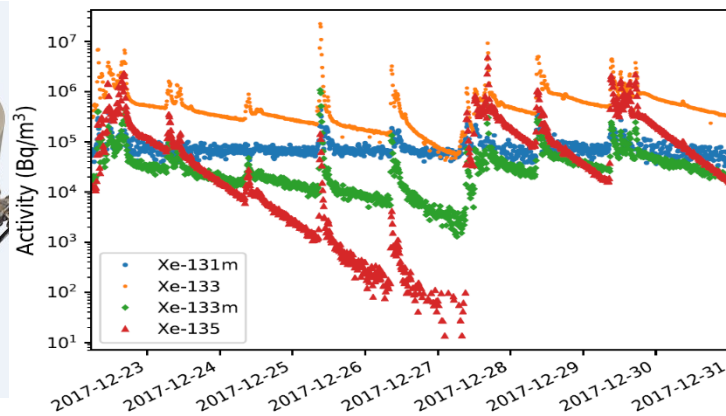
Typical Data from NPP deployments

- Easy to see Co58 from forced oxidation event
- Each spectrum is a combination of radioactivity in fluid and fixed contamination on pipe surfaces – can't tell which it is.
- Subtraction of fixed amount from total reading gives results similar to plant measurements
- That fixed amount subtracted allows calculation of fixed contamination activity
- F-18 [PWR] or N-13 [BWR] dominate countrate and doserate when Rx at power
- Multiple parallel Workflows essential to interpret data
 - Short counts show short term events and when they happened, but higher MDA and therefore miss low-level nuclides
 - Long counts better to assay minor constituents but miss transient events
- **ReexaMiner** essential for tuning the libraries
- **DAProspector** essential for these projects – 30000 spectra per year



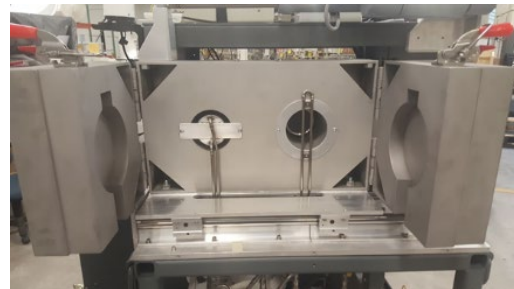
Stack Gas Monitor 4 similar units [Belgium, Australia, 2x USA]

- 2017, 2018, 2019, 2021
- Assay container 17 Liter Marinelli Beaker
 - Inside modified 747 shield
- HPGe detector [30% RE] and Lynx MCA
 - Electrically cooled with CP-5
- Lynx MCA and Data Analyst
- DA set for 3 different simultaneous count times
- Dynamic inputs to correct results for container pressure, temperature, and stack flowrate
- ISOCS gas calibration validated with gas standards accurate to within 3%
- 8 decades dynamic range
- <5% net peak area error up to 95% deadtime



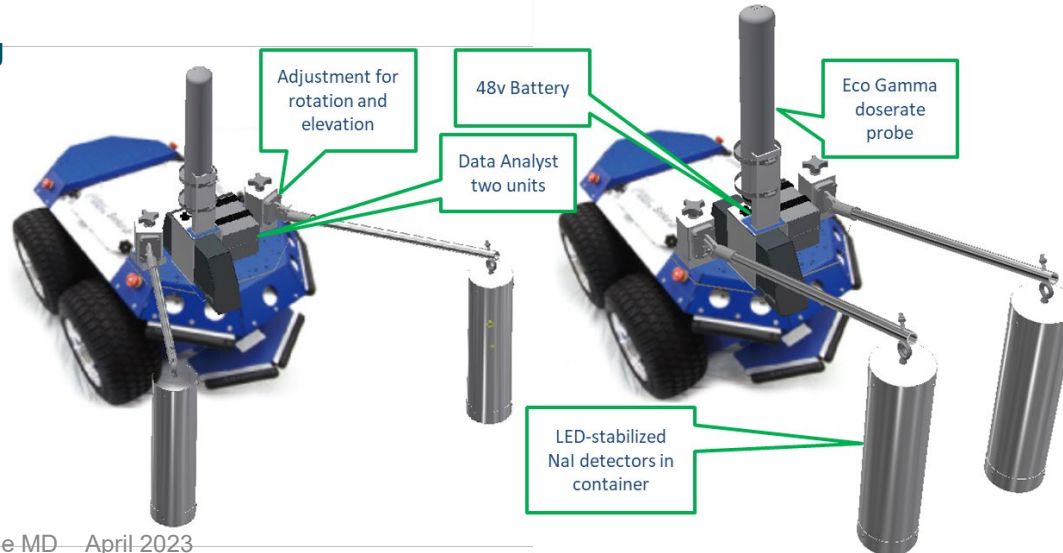
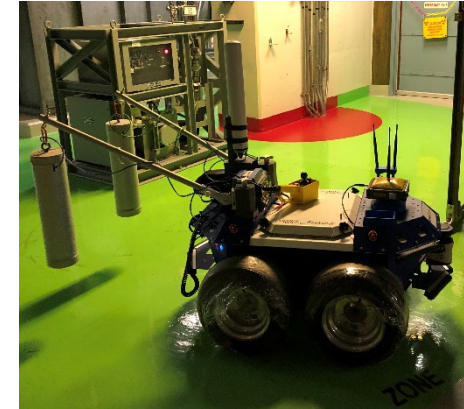
EPRI HPGe Reactor Primary Coolant Monitor

- Extracted Sample assay system with **dual counting chambers**
 - ▶ Sliding backshield exposes proper chamber to detector
- Chamber 1 for **continuous** flow measurements
 - ▶ Assays every 20m 2hr 23hr e.g.
- Chamber 2 for **sample > decay > count** measurements
 - ▶ Larger volume for better sensitivity
 - ▶ 24 hour decay e.g.
- Plumbing system at bottom
 - ▶ Controls chambers
 - ▶ Chambers can be filled with other fluid for background measurements and for cleaning
- **Embedded Thorium source for continuous QA measurements**
- Horizon for remote data viewing and historical records
 - ▶ Plant allowed us to remote in via TeamViewer to view/adjust system
- Installed at Monticello for successful 7-month run



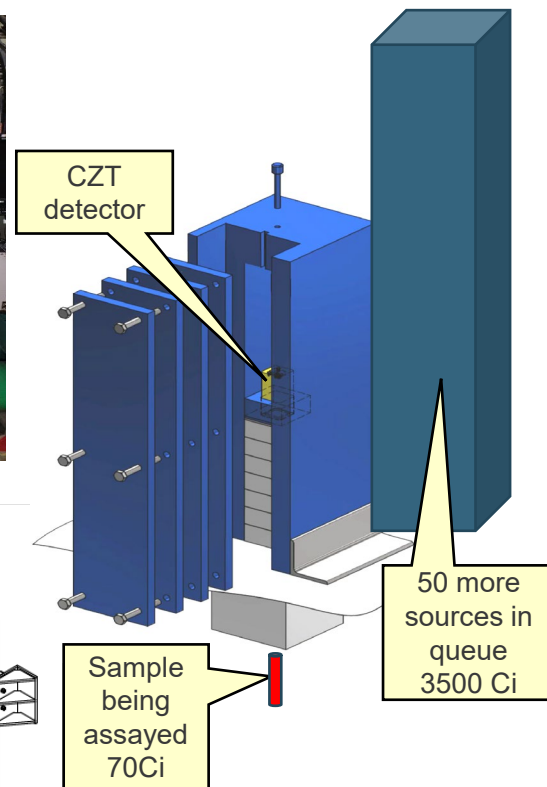
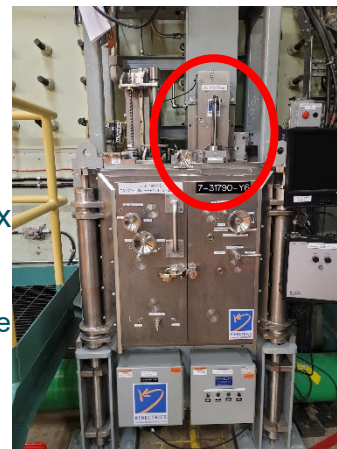
EPRI Robotic Survey demonstration

- Measurement Services contract
- EPRI supplied robot with LIDAR mapping and pre-programmed autonomous control of vehicle movement
- Dual sets of Data Analyst, LED-stabilized NaI, and Osprey MCA, plus EcoGamma doserate sensor
- Continuously analyzing both spectra 3 and 15 seconds
- Each spectrum has timestamp stored in record
- Post-processing to combine radiation data and location coordinates on map

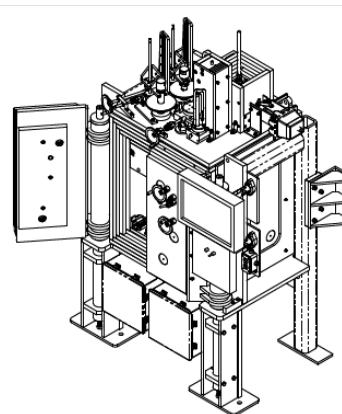


Lu-177 assay system at Bruce Power

- Targets containing enriched Yb-176 are irradiated in the Bruce Power reactors
 - Yb-177 [$T_{1/2} = 1.9\text{hr}$] produced; decays to Lu-177 [$T_{1/2} = 6.7\text{d}$]
 - Irradiated ~ 1 week; decayed ~ 24 hours before assay
- Sample assayed at 40cm away inside 15cm thick tungsten box
 - Estimated activity at time of measurement is ~ 70 Ci [$3\text{E}12$ Bq]
 - About 50 more samples of similar activity are waiting in the queue only 20 cm and away behind 15cm of Tungsten
- Heavily attenuated CZT detector will be used
 - MicroGe detector recommended, but too “complicated”
- New feature on DA allows custom dead-time for CZT which extends accurate counting range
- Operator TouchPanel software has QC module to measure check source, and Assay module to count the targets.
- Custom software will consolidate all the data, load into database, and generate shipping document

A screenshot of the Data Analyst software interface. The interface displays the shipping container number (4444), the sample count status (Idle), and a table of sample count results. The table has columns for Sequence ID, Timestamp, Type, Shipping container, and Result. The results show three samples: S1 (ALARM), S2 (WARNING), and S3 (PASS).

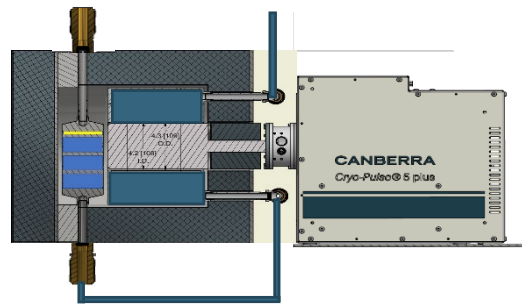
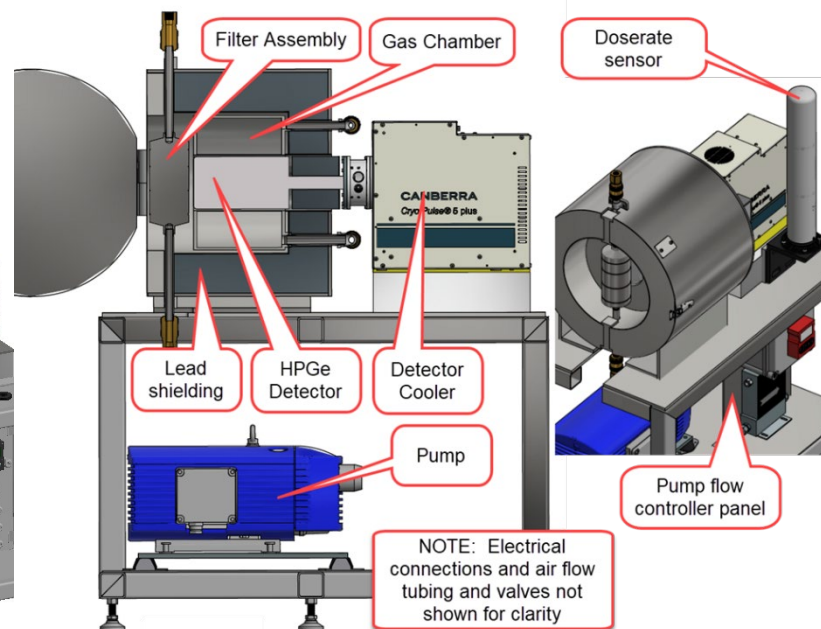
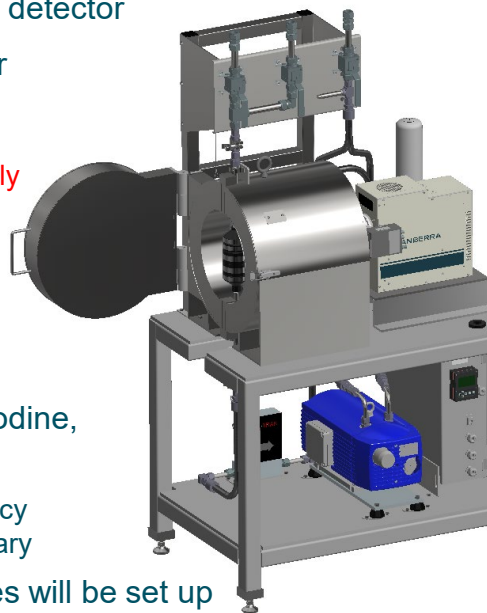
Sequence ID	Timestamp	Type	Shipping container	Result
S1	2021-08-11 23:46:18	Sample	60808008	ALARM
S2	2021-08-11 23:47:00	Sample	1777777	WARNING
S3	2021-08-11 23:47:47	Sample	4444	PASS



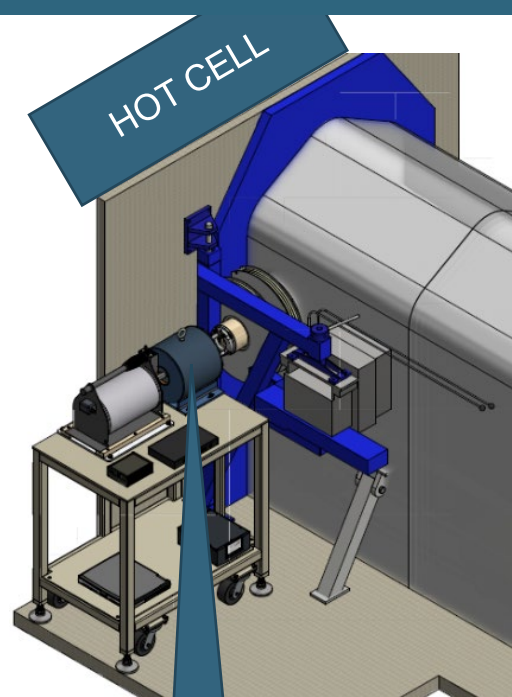
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Spectroscopy Particulate Iodine and Noble Gas Monitor

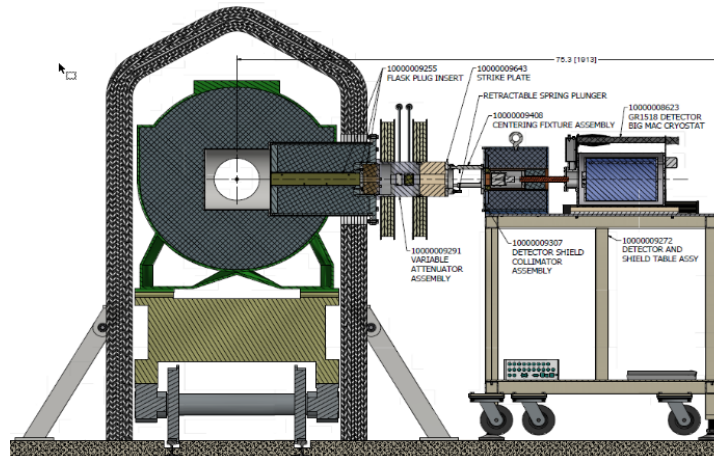
- Active project for a ORNL isotope production reactor
- Particulate and Iodine filter in front of detector
- Gas chamber around side of detector
- Can be configured for:
 - Particulate only; Iodine only; Gas only
 - Any combination of the above
- Filter exchange by replacing cartridge assembly
- Electronics in separate cabinet
- Separate workflows for Particulate, Iodine, and Noble Gas
 - Each workflow has separate efficiency calibration and separate nuclide library
- Multiple Workflows with different times will be set up
 - Short count times for early detection of higher level events
 - Long count times for lower detection limits and more precise results
- New: **Differentiation software for filter assays**
 - Results in Concentration during that assay time, instead of total activity on filter
 - Allows alarms and reports in regulatory values



Chalk River National Lab – Fuel Rod Scanner



Detector and collimator



- ▶ CNL supplied
 - Shielded fuel rod chamber
 - Mechanism to incrementally move fuel rod
- ▶ Mirion-Canberra supplied
 - HPGe detector with TRP
 - Tungsten collimator 30cm long with 0.5mm slit
 - 0.6mm FOV
 - Other shielding around the detector
 - **Data Analyst operated in Triggered single-assay mode**
- ▶ Triggered mode for stepped scanning

HPGe

Lynx MCA

Data Analyst

Trigger after advancing fuel rod

DA does 1 count and analysis cycle and waits for next trigger

“Pushbutton” Sample Assay Application

- Over the past few years had a variety of requests for a simple error-proof gamma-spec assay system for standardized operations
 - Back-shift laboratory operation without radiochemist presence
 - Ship-board 24 hr operations
 - In-situ field assays
 - Emergency response field assay laboratories
 - D&D field assay operations
- Standard Data Analyst has 2 hardware trigger inputs for 2 different automated assay operations workflows
 - Each with its own library, efficiency, assay parameters, ...
- Created a modified version with a large number of software-triggered workflows
 - Each with its own library, efficiency, assay parameters, ...

New Control Console

- Integrated unit for quick setup
 - Plug in detector cable & 12v power supply; then start counting.
- **Touch screen panel** for Operator control
- Inside the console
 - Data Analyst
 - Temperature monitor
 - GPIO to send outputs to panel LEDs
- Data Analyst pre-configured for multiple Workflows – for example:
 - QC source Iodine cartridge
 - Filter paper 60cc sample container
- Each workflow can have specific library and alarm levels
- **QC workflow will evaluate/alarm on activity, peak centroid and FWHM**
- Touch screen configurable for desired user input
 - Sample ID; Additional description
 - Count time – user input or select pre-defined choices
 - Sample collection time – to allow proper decay calculations
- Works with CZT or HPGE or Scintillation detectors



Example Operator Interaction Screens

Data Analyst Touch GUI (v1.0.10)

Data Analyst
Online

Selected workflow: **60cc_Container**
Full sample container
Last updated: 2 minutes ago

Workflows

- 60cc_Container
- Check_Source
- Filter_Cartridge_A
- Filter_Cartridge_B
- Filter_Paper
- Long_MFDT

Radionuclide	Activity [Bq/unit]	1 σ
CS-137	572.496	± 58.71
QA-1593	< 1.872	< MDA
QA-2615	< 3.581	< MDA
QA-969	< 3.092	< MDA
Thorium	< 10.367	< MDA
U-235	19.337	± 5.20
U-238	< 382.210	< MDA
U-KXray	< 21.088	< MDA
W-Xray	< 164.421	< MDA

Controls

START COUNT

ALARM

ALERT

FAULT

CLEAR ALARMS AND FAULTS

ARCHIVE

CPS: 554

2022-10-28 16:34:03

CONFIGURATION

EXIT

Data Analyst Touch GUI: Start count

Data Analyst

SAMPLE COUNT: **60cc_Container**
Full sample container

Sample ID: sample_ID_here (16 char max)

Comment: whatever you want here (64 char max)

Count time: sec [] 30 sec [] 300 sec []

COUNT PROGRESS: 60 %

BACK

ABORT COUNT

Data Analyst Touch GUI: Configuration

Data Analyst

WORKFLOW CONFIGURATION: **60cc_Container**

Parameter	Enabled	User entry	Units	Preset #1	Preset #2	Preset #3
Activity			Bq			
Count time	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	sec	30.0	60.0	300.0
Sample collection START	<input type="checkbox"/>					
Sample collection STOP	<input type="checkbox"/>					
Sample flow rate	<input type="checkbox"/>	<input type="checkbox"/>	LPM			
Sample volume	<input type="checkbox"/>	<input type="checkbox"/>	mL			
Sample mass	<input type="checkbox"/>	<input type="checkbox"/>	g			

Command triggering enabled

NUMPAD

CANCEL

SAVE

Data Analyst Touch GUI (v1.0.10)

Data Analyst
Online

Selected workflow: **Filter_Cartridge_A**
Blue cartridges used for long term sampling
Last updated: 46 seconds ago

Workflows

- 60cc_Container
- Check_Source
- Filter_Cartridge_A
- Filter_Cartridge_B
- Filter_Paper
- Long_MFDT

Radionuclide	Activity [Bq/CF]	1 σ
CS-137	9.787	± 0.99
QA-1593	< 0.016	< MDA
QA-2615	< 0.030	< MDA
QA-969	< 0.009	< MDA
Thorium	0.194	± 0.02
U-235	0.332	± 0.05
U-238	< 4.019	< MDA
U-KXray	< 0.251	< MDA
W-Xray	< 1.919	< MDA

Controls

START COUNT

ALARM

ALERT

FAULT

CLEAR ALARMS AND FAULTS

ARCHIVE

CPS: 598

2022-10-28 17:03:59

CONFIGURATION

EXIT

Data Analyst Touch GUI: Start count

Data Analyst

SAMPLE COUNT: **Filter_Cartridge_A**
Blue cartridges used for long term sampling

Sample ID: Sample_ID_here (16 char max)

Comment: whatever (64 char max)

Count time: 5 min

Sample collection START: 2022-10-28 Date @ 15:01:00 -H +H -M +M -S +S

Sample collection STOP: 2022-10-28 Date @ 16:01:00 -H +H -M +M -S +S

Sample flowrate: 5 CFM

COUNT PROGRESS: 10 %

BACK

ABORT COUNT

Data Analyst Touch GUI: Configuration

Data Analyst

WORKFLOW CONFIGURATION: **Filter_Cartridge_A**

Parameter	Enabled	User entry	Units	Preset #1	Preset #2	Preset #3
Activity			Bq			
Count time	<input checked="" type="checkbox"/>	<input type="checkbox"/>	sec	60	300	
Sample collection START	<input checked="" type="checkbox"/>					
Sample collection STOP	<input checked="" type="checkbox"/>					
Sample flow rate	<input checked="" type="checkbox"/>	<input type="checkbox"/>	LPM	28	280	
Sample volume	<input type="checkbox"/>	<input type="checkbox"/>	mL			
Sample mass	<input type="checkbox"/>	<input type="checkbox"/>	g			

Command triggering enabled

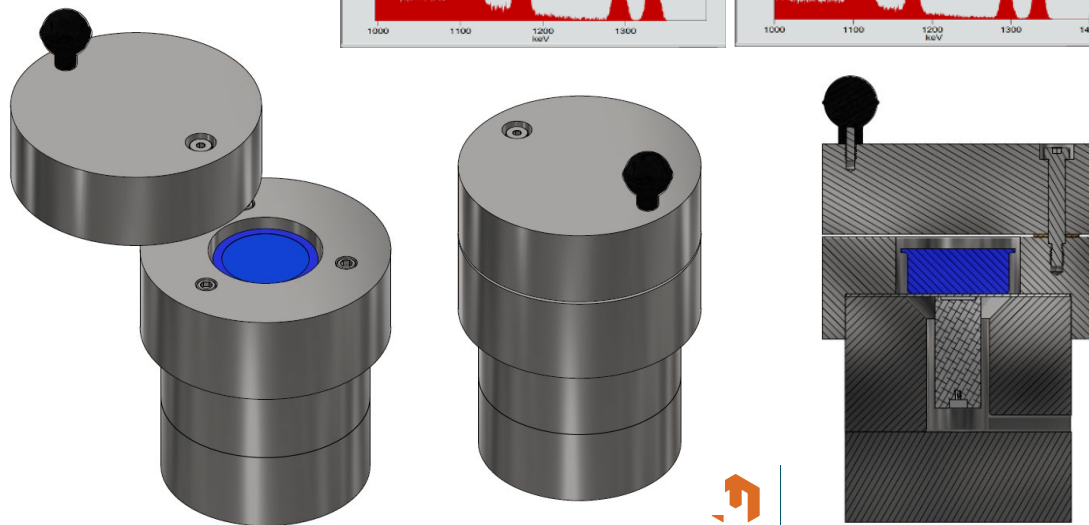
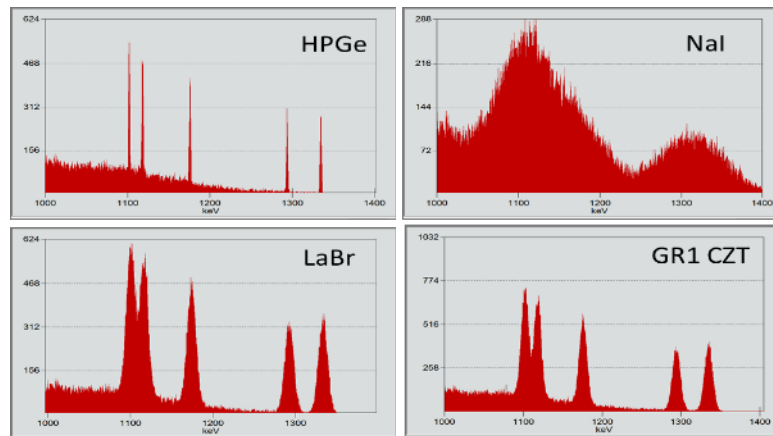
NUMPAD

CANCEL

SAVE

Filter and Small Sample counting application

- Portable system for quantitative assay of filters at work site
 - Fresh releases therefore multiple iodine isotopes, adsorbed gasses
 - Gamma spec is a requirement
- CZT detector and MCA
 - Small, therefore lightweight shield
 - 2% FWHM – good for fresh samples with many nuclides
 - USB powered – low power
 - Stable with temperature
 - 40 – 3000 keV
- Shield – 2” steel thick
 - Sample cavity for
 - Iodine filter cartridge [primary ap]
 - Particulate filter
 - 100cc sample container



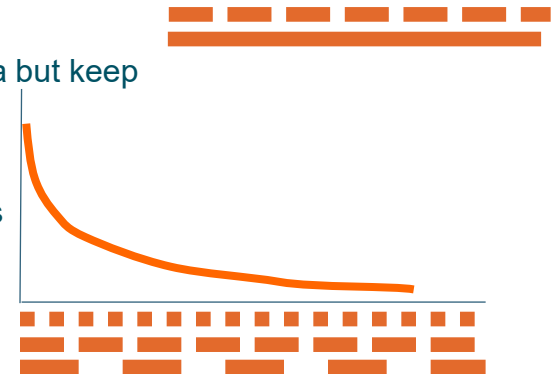
Future applications under discussion with potential clients

InSitu Assays

- ▶ Add TouchPanel to ISOCS system – small 12v battery will run all day
- ▶ No laptop needed in the field
- ▶ Pre-defined standard procedures for semi-trained operators

Gamma Counting Laboratory Applications

- ▶ Push-button Automated Sample Assay
 - For novice operators
 - For unattended assay system – worker measures own samples
 - For backshift operations; converts to standard system during day
- ▶ Low level assays with very long Counting times
 - One workflow for shorter counts, one for the Very Long count time
 - Examine short counts to assure no anomalies; reject non-statistical data but keep rest
- ▶ Neutron Activation Analysis
 - Automatic sequence with simultaneous Short, Medium, and Long counts
 - Short counts for short-lived nuclides early after irradiation
 - Long counts for long lived nuclides later in irradiation



Conclusion

- ◆ Data Analyst is a useful tool to support a wide variety of applications with no or minimal customization – just select software settings
- ◆ Deployed in dozens of applications over past 4 years
- ◆ Continuous monitoring with Spectroscopy systems provides continuous record of events, with no gaps as with “grab” samples
- ◆ Generates a lot of spectral assay results
 - ▶ Developed several good tools to help user display and evaluate this data
 - DA Prospector for evaluation
 - ReexaMiner for re-analysis with new parameters
 - Horizon for live displays of multiple systems and Data Base for long term storage
 - ▶ Good data to analyze for possible insights about past or future operations
 - ▶ Many analyses viewed as a group give user a true picture of the reliability of the data
 - Most gamma spec systems don't truly measure down to the computed LLD
 - “Interesting” things happen during variations of nuclide ratios in complex mixtures
- ◆ Helps users create automated remote systems for better data with less operator risk and labor



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