Solutions for Difficult Radiation Measurements

Interesting [to me anyway] projects with creative solutions

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Obligatory Disclaimer

1. These are my personal comments.

2. The following have NOT has said they agree with them:
   - Mirion corporate attorneys
   - Our CEO
   - My wife

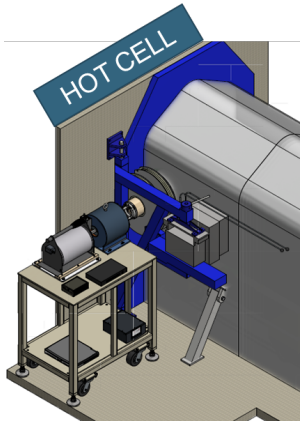
3. Alternate Facts will be entertained, as long as accompanied by fine Scotch whiskey more than 20y old
   - [except if it is Laphroaig]

Executive Summary of Presentation

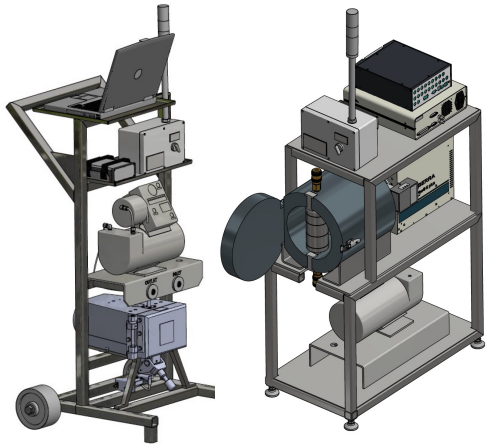
Stack Gas Monitor HPGe

HPGe Primary Coolant Monitor

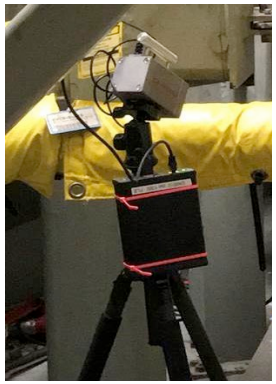
Robot ground and floor, dual NaI



Fuel Rod Scanner HPGe

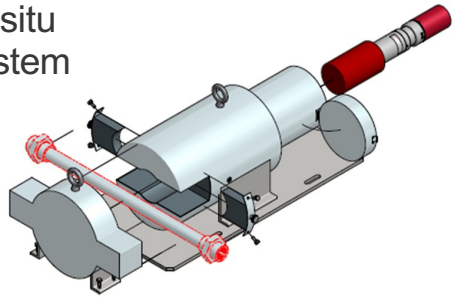


Iodine spectroscopic monitor
CZT [left] HPGe [right]

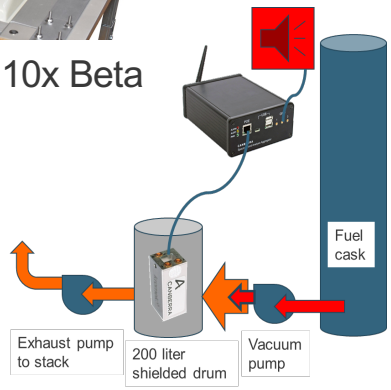


NPP in-situ CZT system

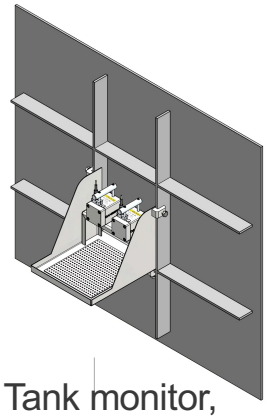
Conveyor monitor – 10x Beta



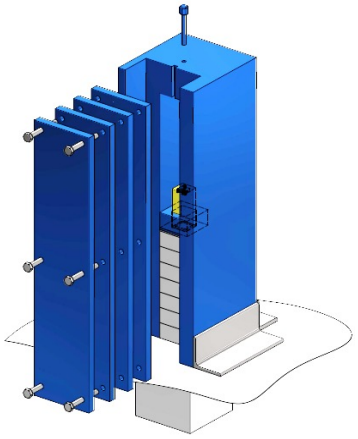
Pipe process monitor NaI



Fuel cask monitor CZT



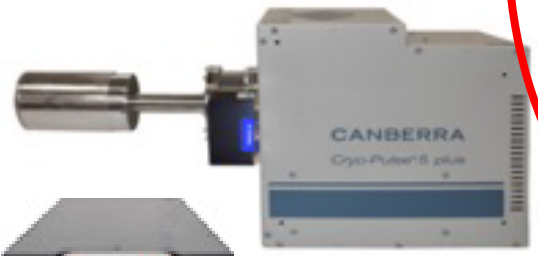
Tank monitor, 2-CZT x 4

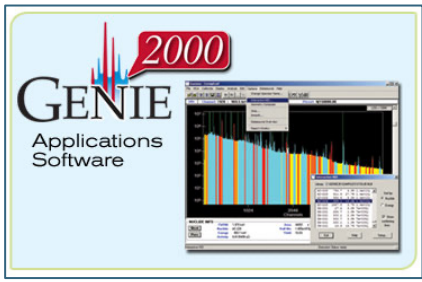


Lu177 assay, CZT

Building Blocks: Detector MCA Data Analyst Shielding
Support Tools: ISOCS Genie Display and Reanalysis software

NEW TOOL

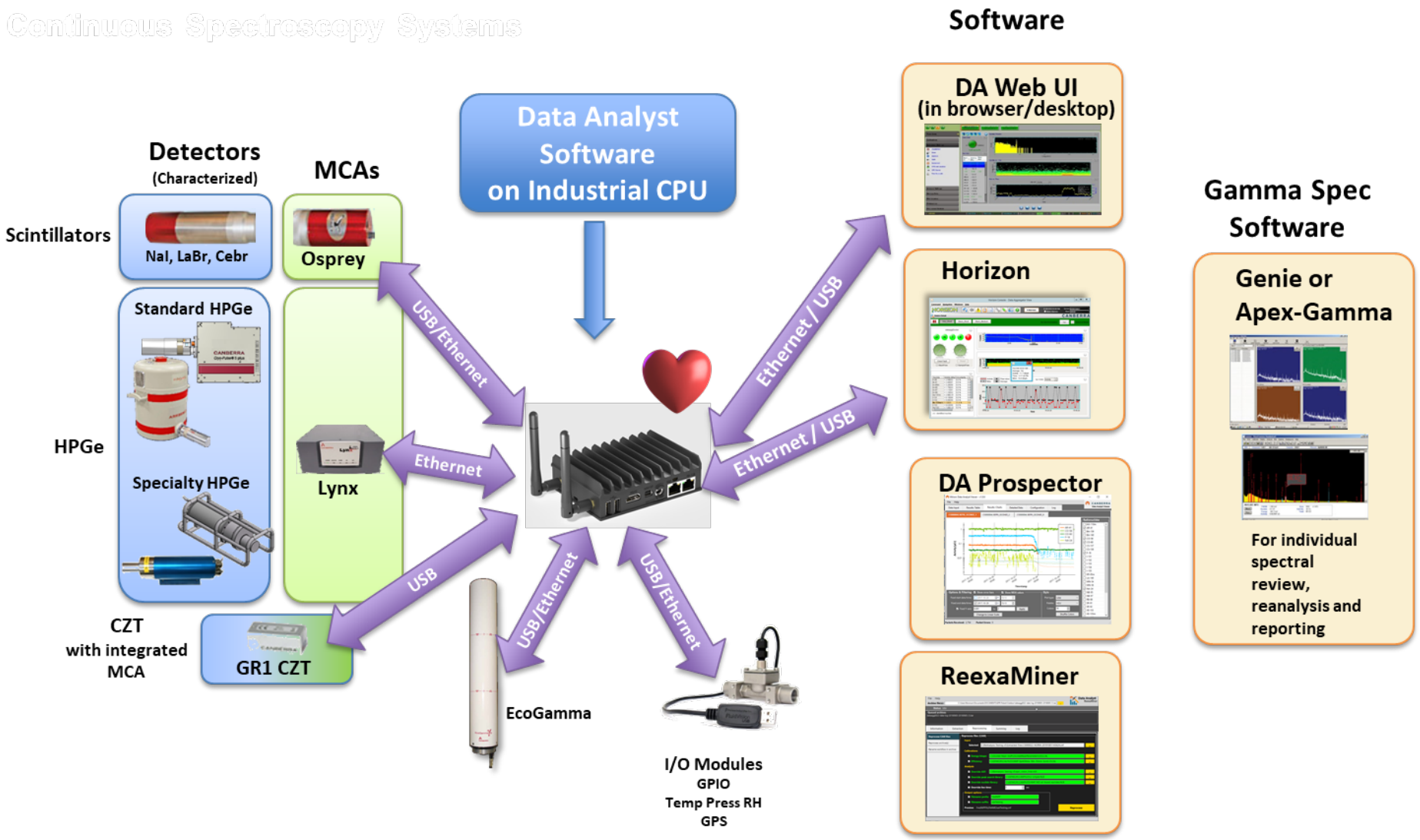




The Data Analyst provides unattended continuous sequence of quantitative gamma assays
Or remotely triggered spectral acquisition and analysis

- 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

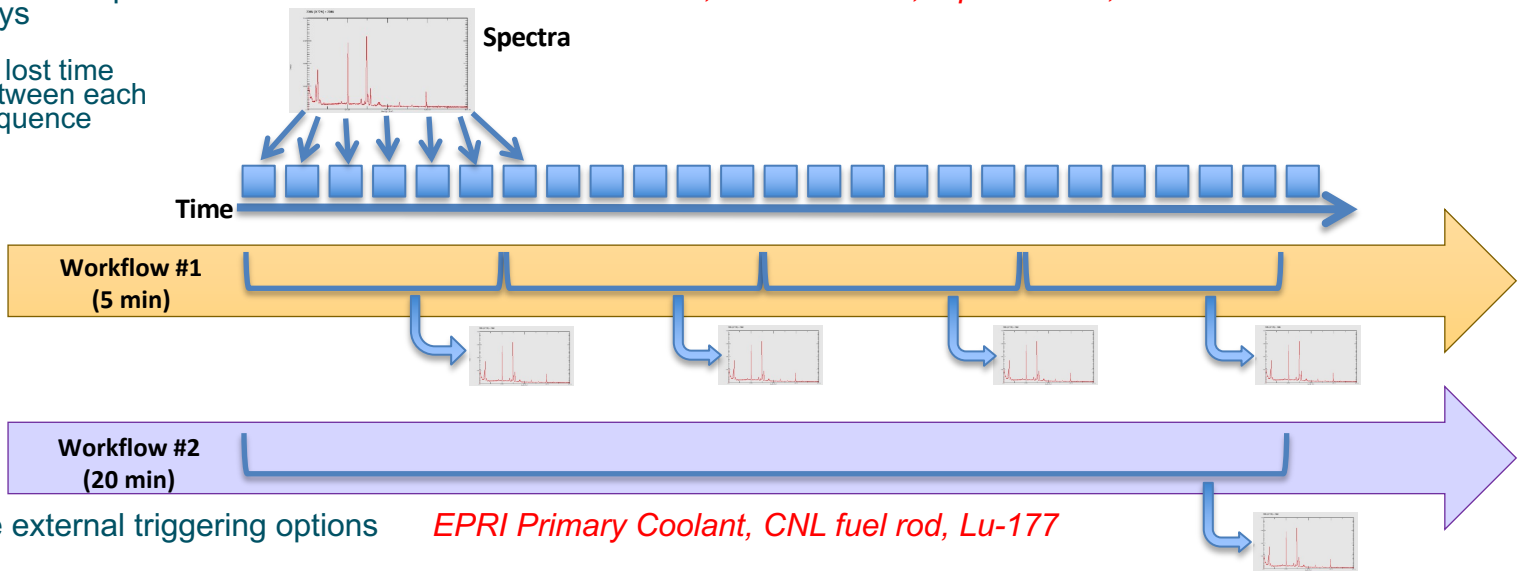
Available building blocks and application support tools



Data Analyst Key Features used in these Projects

- Workflow concept
  - Each workflow has its own Count time, Libraries, Analysis parameters [like ASFs] and more items
  - Multiple workflows can operate at the same time
- Continuous Sequence of Assays
  - no lost time between each sequence

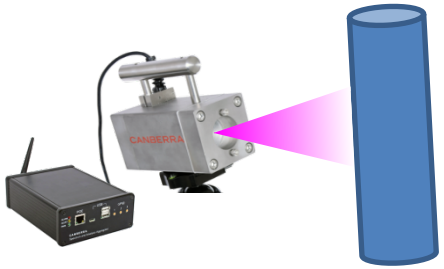
EPRI NPPs, Gas monitors, Pipe monitor, URENCO tanks

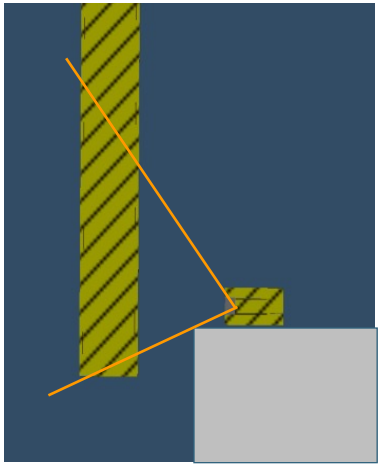


- Multiple external triggering options *EPRI Primary Coolant, CNL fuel rod, Lu-177*
- Alarm output signal - based upon nuclide-specific assay results *OPPD Fuel Drying*
- Results can be exported immediately to FTP server *EPRI NMP, EPRI Robot, EPRI Primary Coolant*
- Detector-specific deadtime factor for CZT detectors Lu-177 project
- Supports special scripts for custom applications
  - Input of external information; e.g. flow rate, pressure *Stack Gas Monitors*
  - Special calculations based upon assay results *Future Iodine and Particulate monitors*

EPRI 1 – CZT Feasibility Demonstration at Diablo Canyon

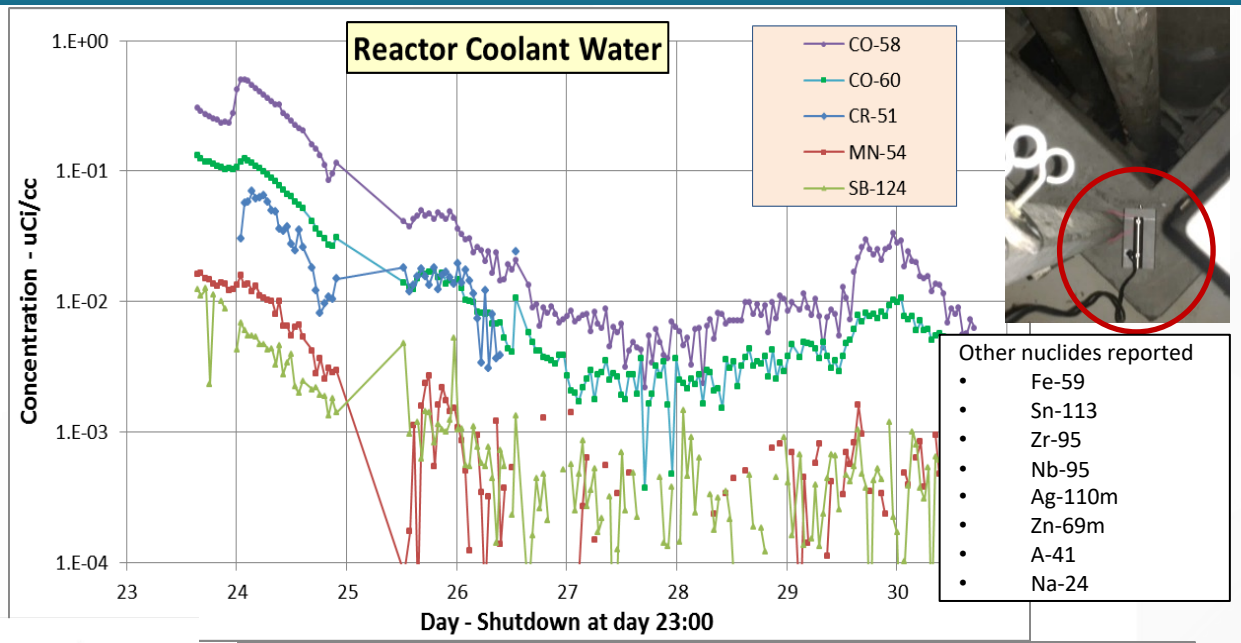
- When: Spring 2017
- What:
  - Initial trial to demonstrate that the CZT was capable of measuring fresh primary coolant
  - ~1 week deployment at initial phase of shutdown, data analysis, report, presentation
- Equipment
  - Measurement service project; GR1, Shield, DA
- Lessons
  - Setup very easy; CZT quite stable; sensitivity adequate
  - Complex gamma spectrum; marginally successful analyses after much tuning; major nuclides easy but minor nuclides difficult with CZT
  - DA doesn't like to restart after power failure; power failures frequent; fixed problem – implemented internal UPS on DA
  - Cannot separate radioactivity on surface of pipe from radioactivity in the solution inside the pipe. But after access to plant sampling data can quantify both liquid activity and pipe activity



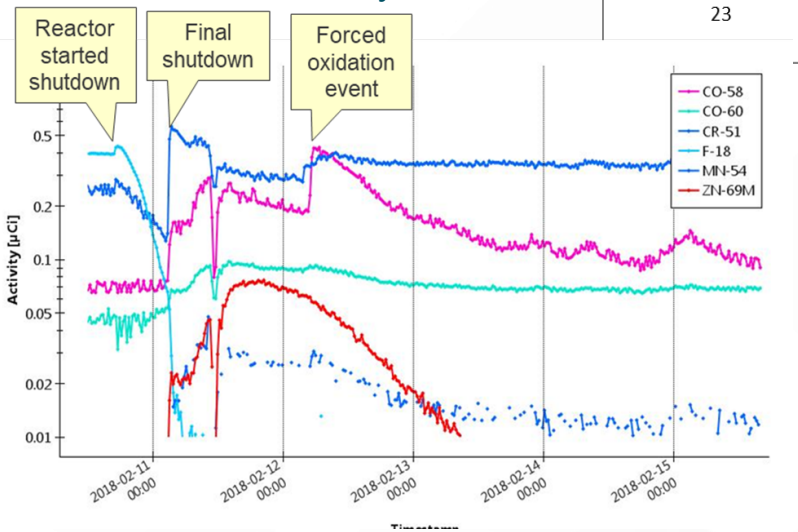


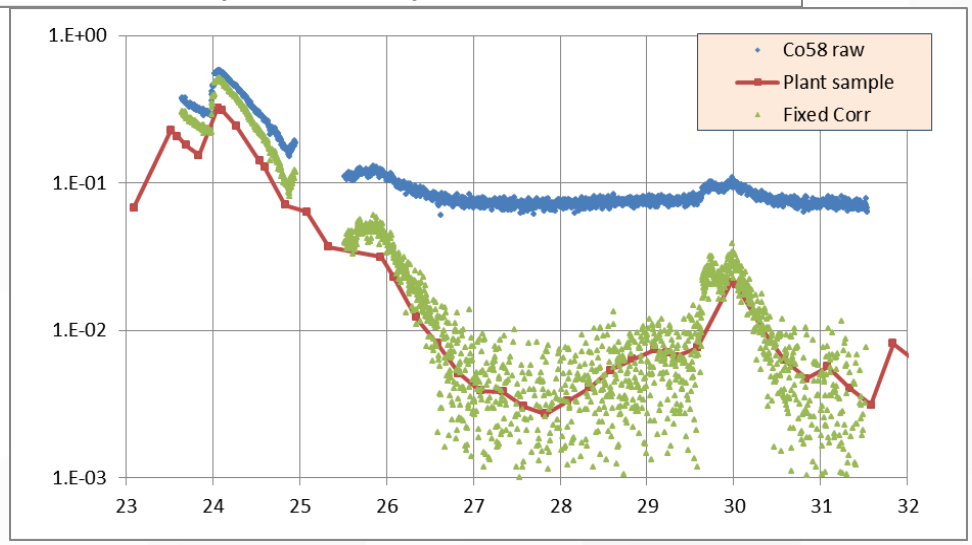
1st Deployment of Continuous Gamma Spectroscopic Measurements

- Spectra combination of radioactivity in fluid and fixed contamination on pipe surfaces
- Subtraction of fixed amount from total reading gives results similar to plant measurements
- That fixed amount subtracted allows calculation of fixed contamination activity



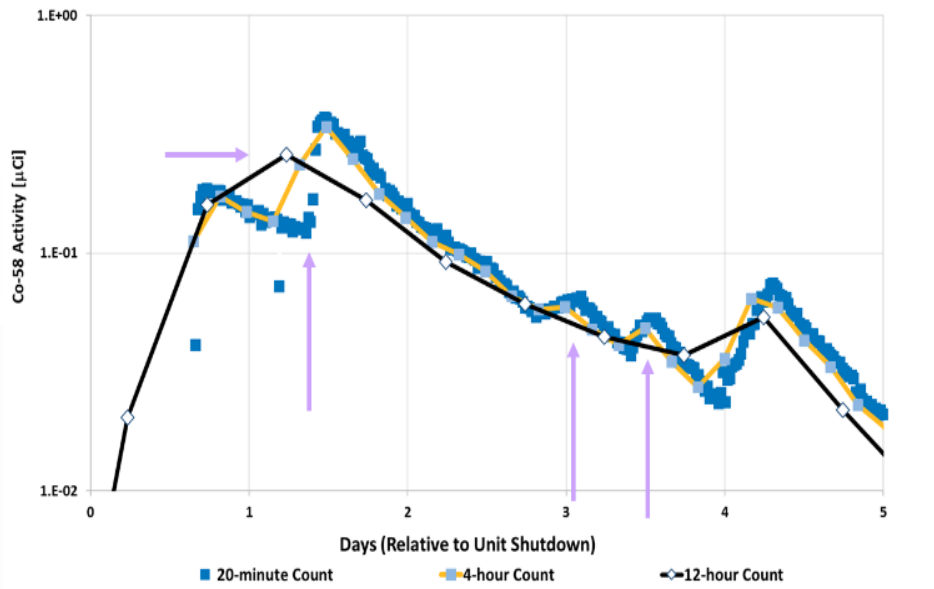
Other nuclides reported
- Fe-59
- Sn-113
- Zr-95
- Nb-95
- Ag-110m
- Zn-69m
- A-41
- Na-24

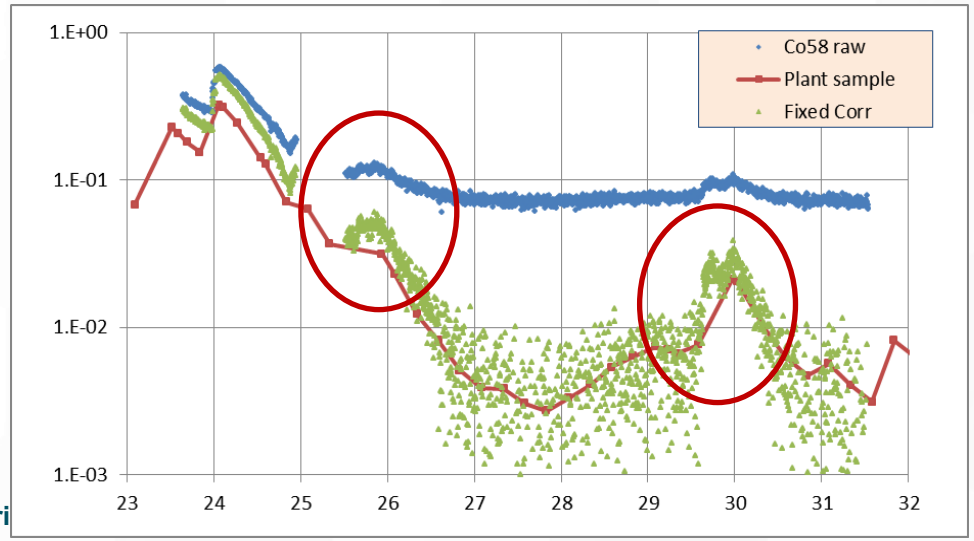




Demonstration of benefit of multiple time acquisition windows

- Top graph shows same data for Co-58 with 20min, 4hour, and 12hour acquisition time window
- Short measurements detect transients and see them quickly
- Long term measurements have better statistics and are better to measure minor nuclides
- Bottom graph compares 20min data with 4hr grab sample results
- 20min on-line results show fine structure in activity that the grab sample results miss



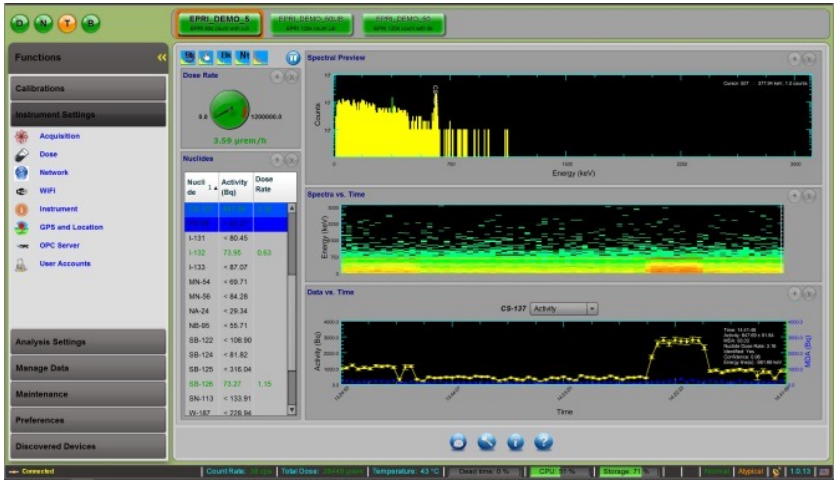


Improvements based on lessons from from 4 EPRI NPP deployments

- There is a LOT of data being gathered; ~2,500 spectra per month per detector; 30,000/yr
  - Developed tool on this project to display it – Data Prospector
    - Reads Archive files
    - Can overlay multiple nuclides on same graph
    - Can export nuclide results as CSV file so Excel can read them
    - Functions as FTP server if on-line
    - If individual result is interesting, a double-click will open Genie with that spectrum loaded ready for review
  - Created batch process to reanalyze groups of files - ReexaMiner
    - Can change libraries, calibration files, analysis parameters
    - Reanalyzes the thousands of spectra in the batch and creates new Archive file
  - Get data into real database for faster handling and data mining operations
    - Horizon Supervisory software does that automatically and is a very nice real-time display

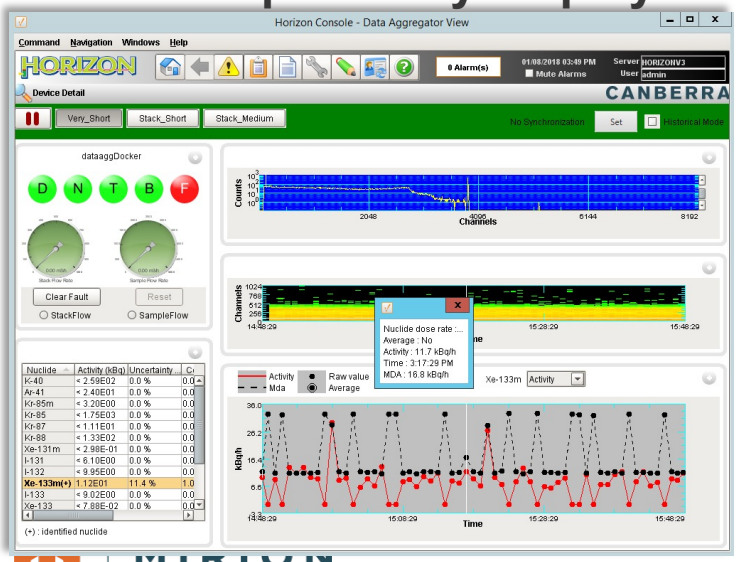
Operational and Support Tools to work with Thousands of Spectra

Main Screen of User Interface

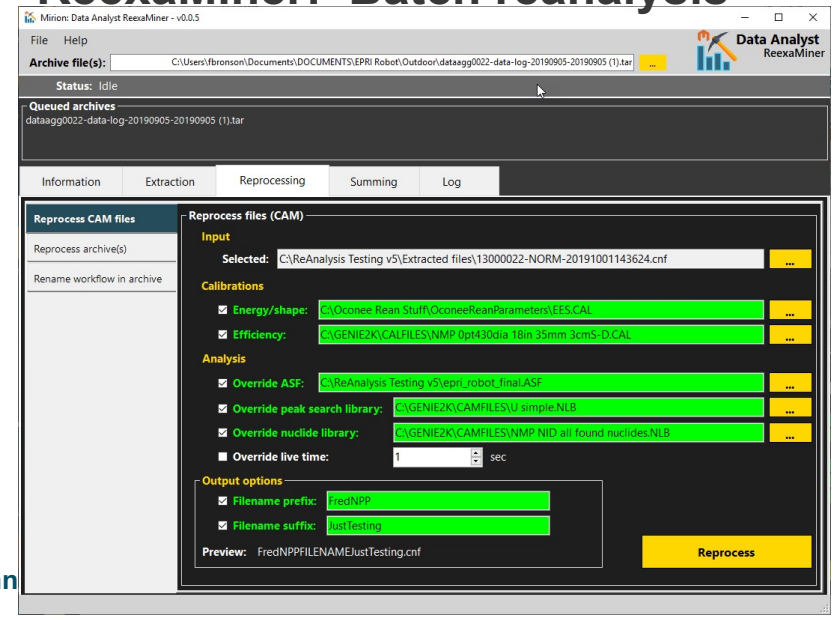


DA Prospector: Grouped Nuclide viewing and export to Excel

Horizon: Relational Database and Central Supervisory display

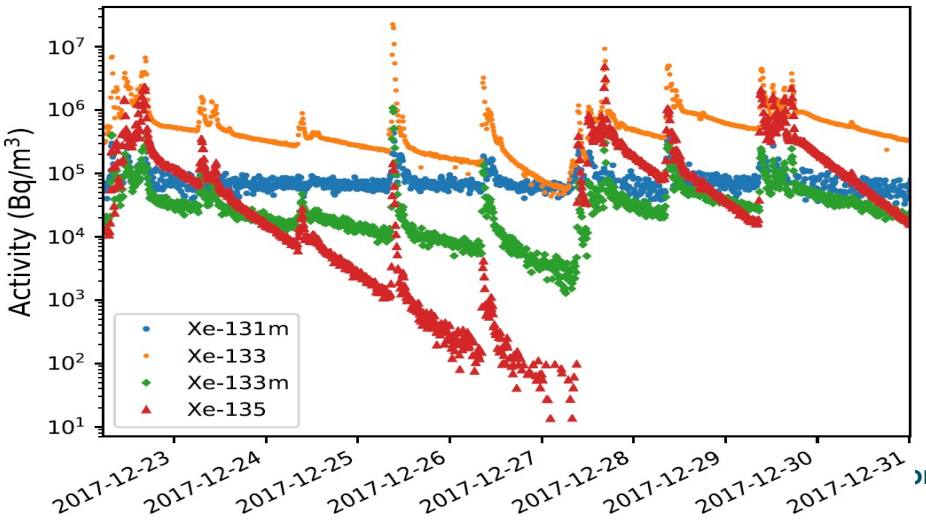


ReexaMiner: Batch reanalysis



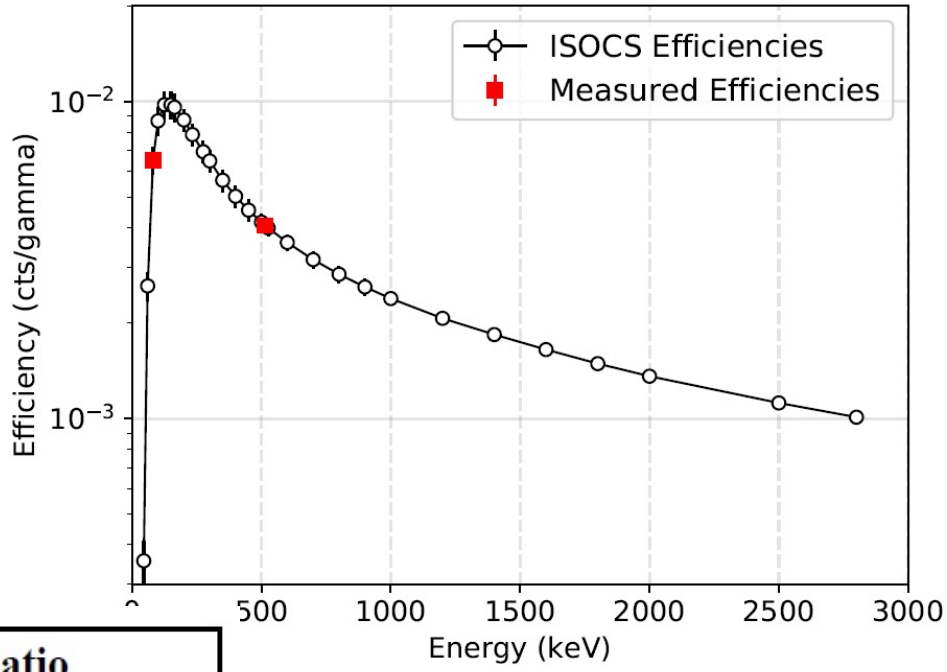
Stack Gas Monitor 3 similar units [Belgium, Australia, USA]

- 2017, 2018, 2019
- Pump pulls sample from stack
- Pre-filter to remove particulates and Iodine
  - Could be monitored separately for P-I-NG
- 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



MDC (Bq/m^3)			
Nuclide	600 sec acquisition	3600 sec acquisition	14400 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

Efficiency validation with gas standards



Belgium System

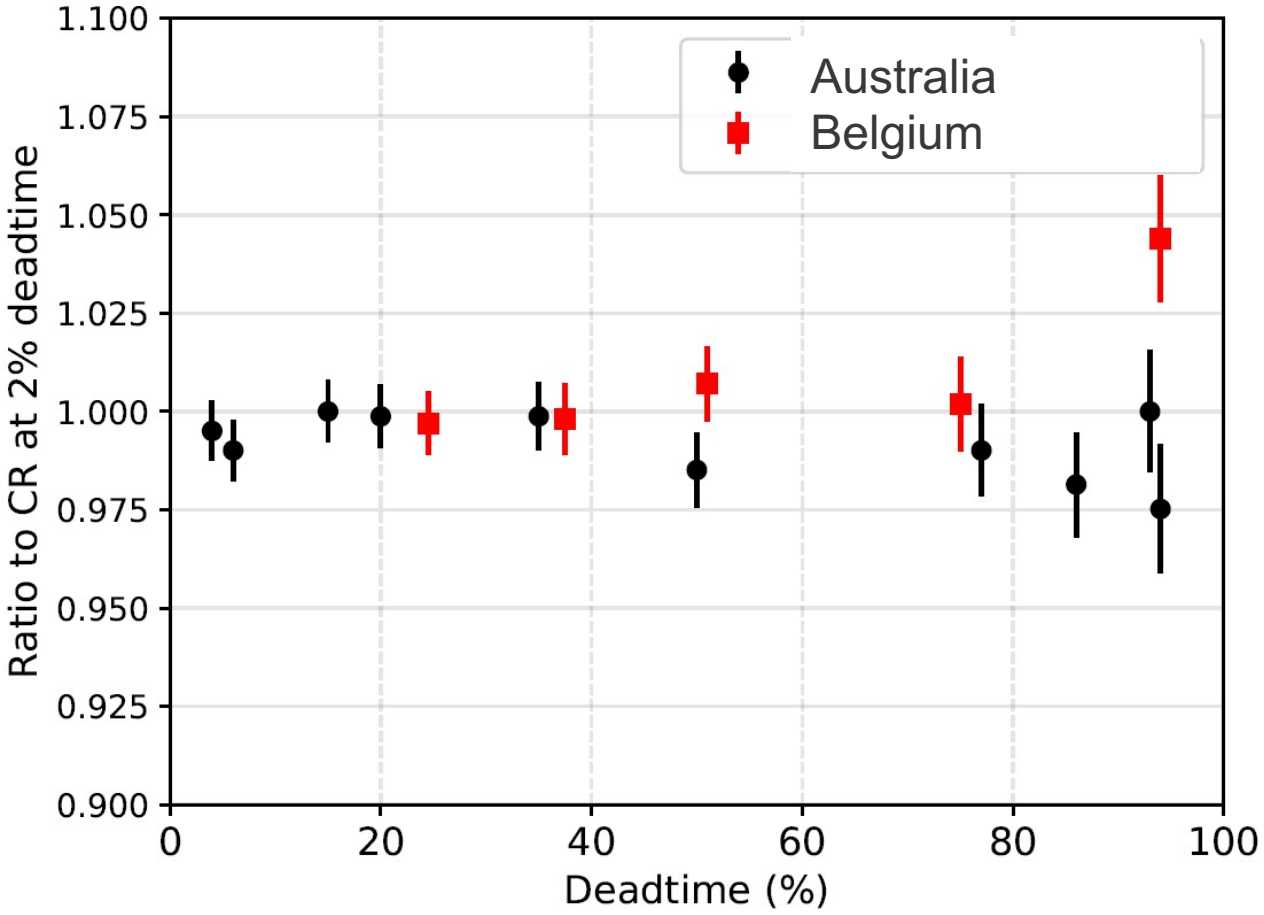
	Efficiency (cts/γ)		Ratio (ISOCS/Meas)
	ISOCS	Measured	
81 keV	6.448×10^{-3}	6.513×10^{-3}	0.990
514 keV	4.065×10^{-3}	4.167×10^{-3}	0.976

Australian System

	Efficiency (cts/γ)		Ratio (ISOCS/Meas)
	ISOCS	Measured	
81 keV	6.900×10^{-3}	6.944×10^{-3}	0.994
514 keV	4.287×10^{-3}	4.304×10^{-3}	0.996

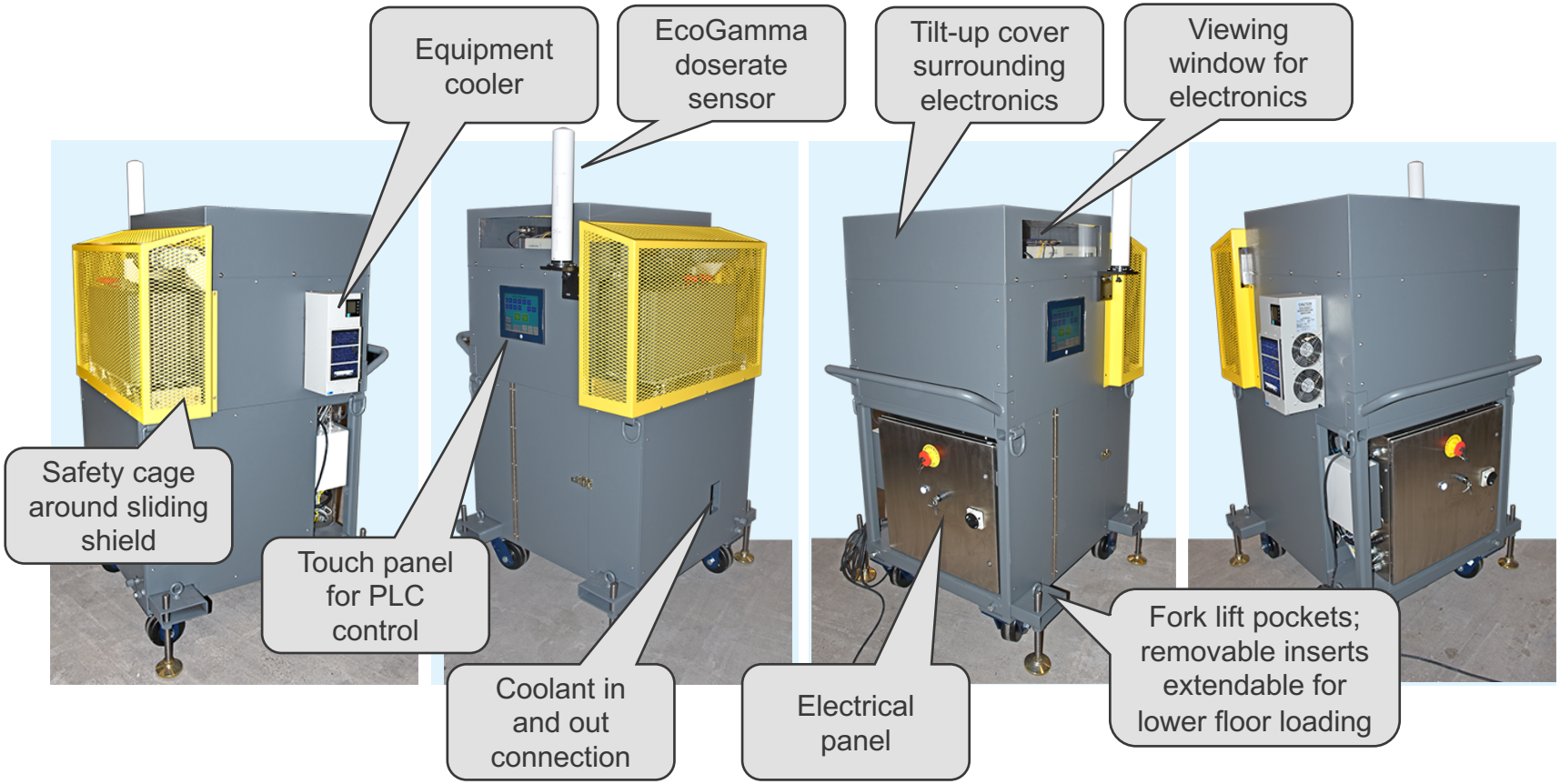
Accuracy (at 2.8 µs rise time) at various count rates

- Cs-137 source held at a fixed distance (fixed count rate)
- Eu-152 source moved to increase total count rate
- Net peak area of Cs-137 peak determined at each measurement point
- No change in net peak area up to 75% dead time
- 4.4% change in net peak area at 94% dead time (510,000 cps)
- Peak analysis settings remained constant during testing



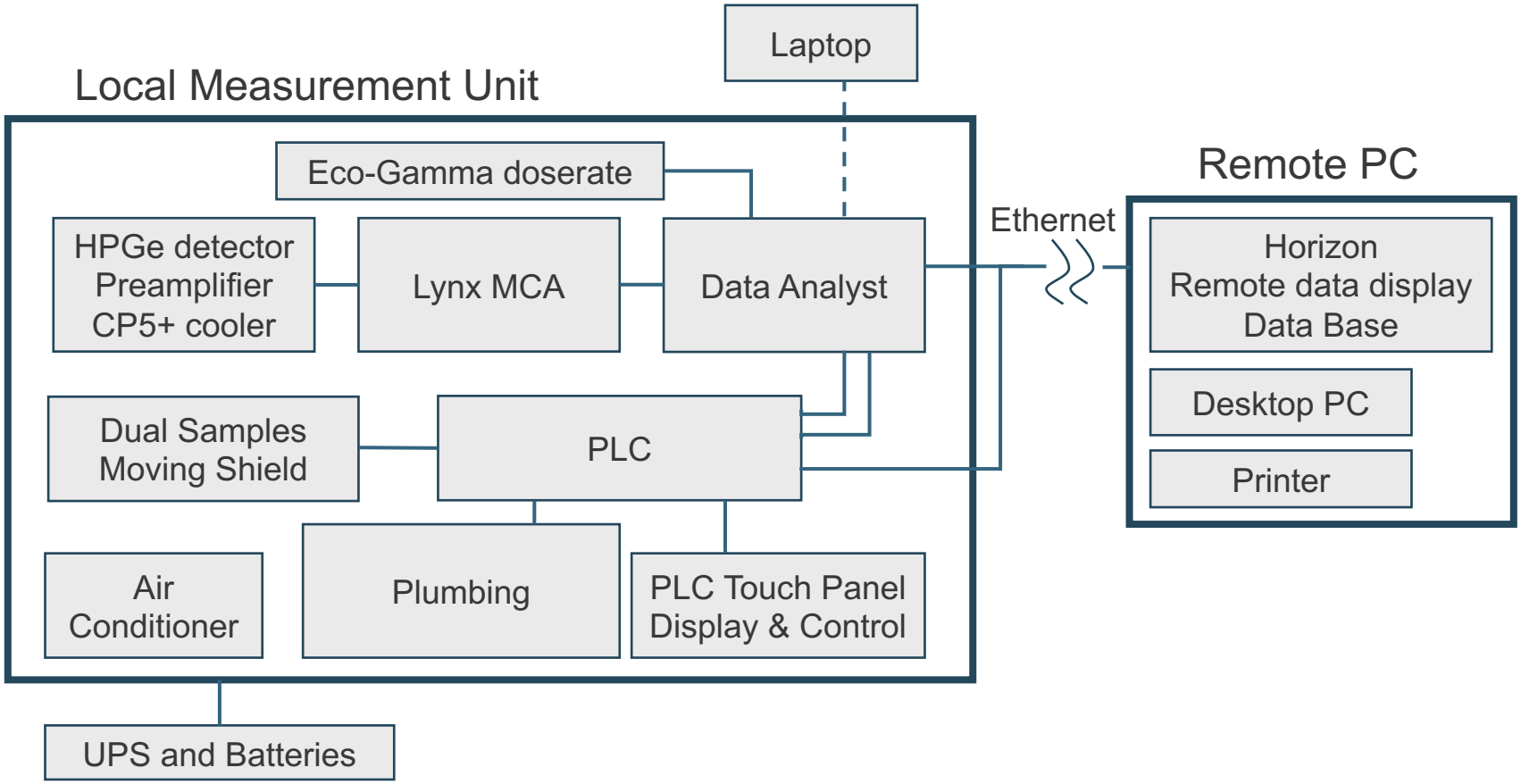
EPRI Primary Coolant System

The walk-around tour



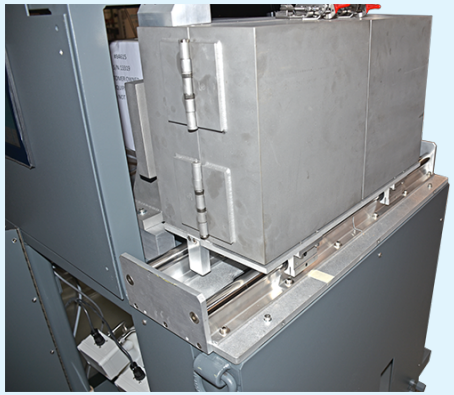
EPRI Primary Coolant System

System Electronics



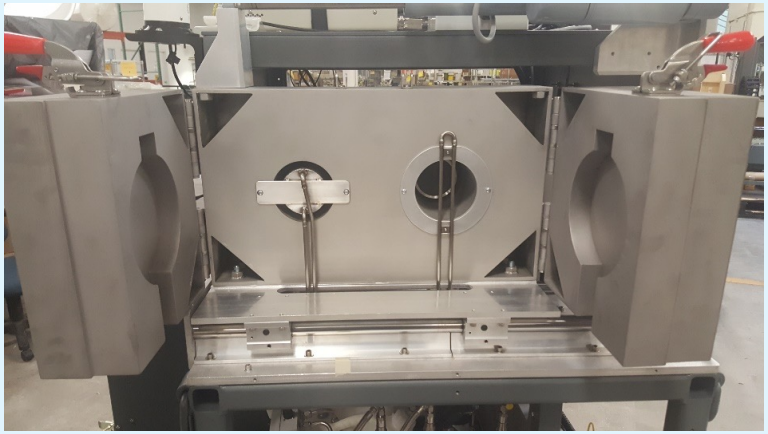
EPRI Primary Coolant System

Shield with sliding dual assay chambers



Shield moves left and right to expose appropriate sample chamber to detector

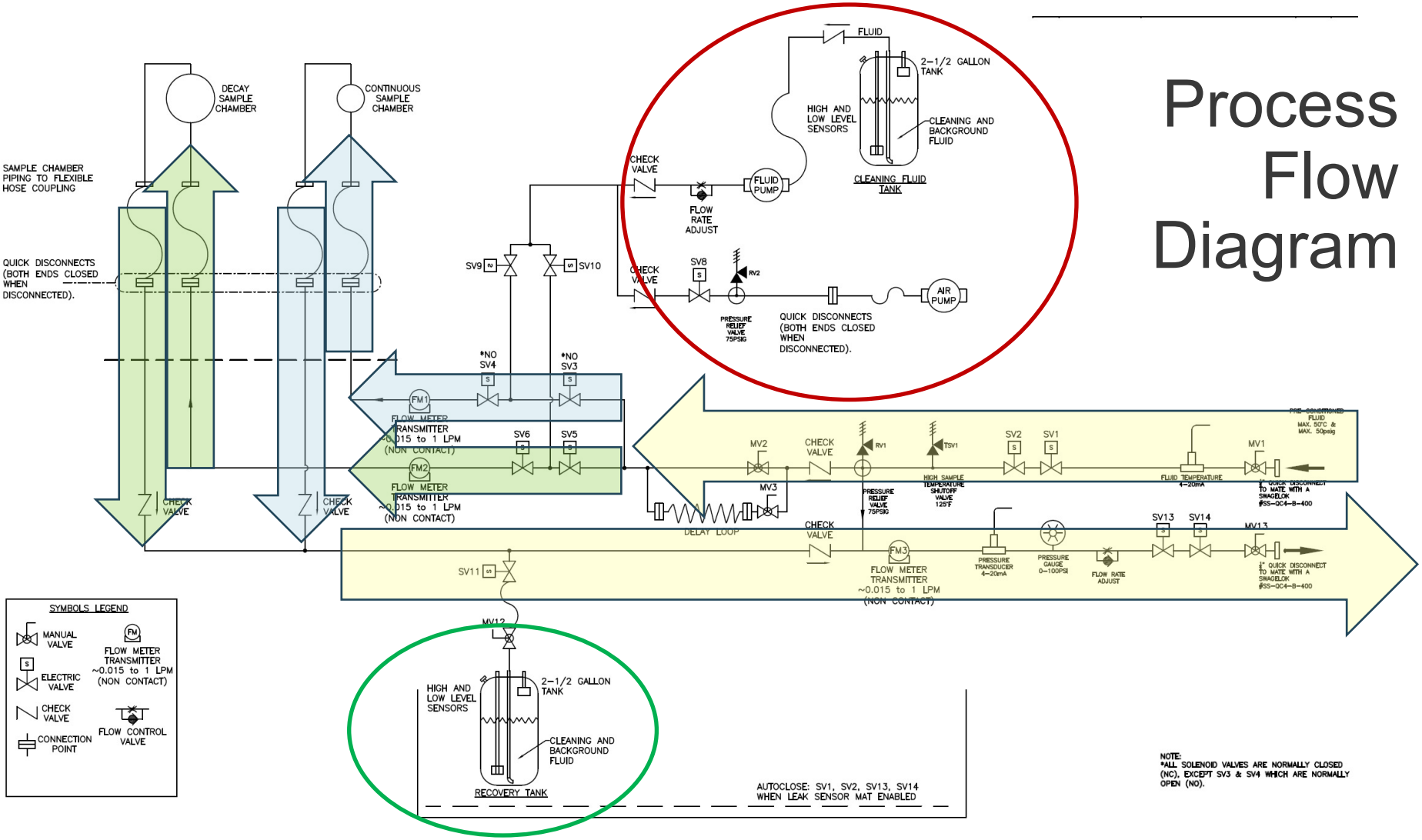
Shield with doors closed [above] and open



Sample assay chambers

- Continuous flow on right – 2 sizes
- Decayed count on left – 2 sizes
- Each with two flex tubes and Swagelok quick-disconnects with both ends closed with disconnected

Process Flow Diagram



EPRI Primary Coolant System

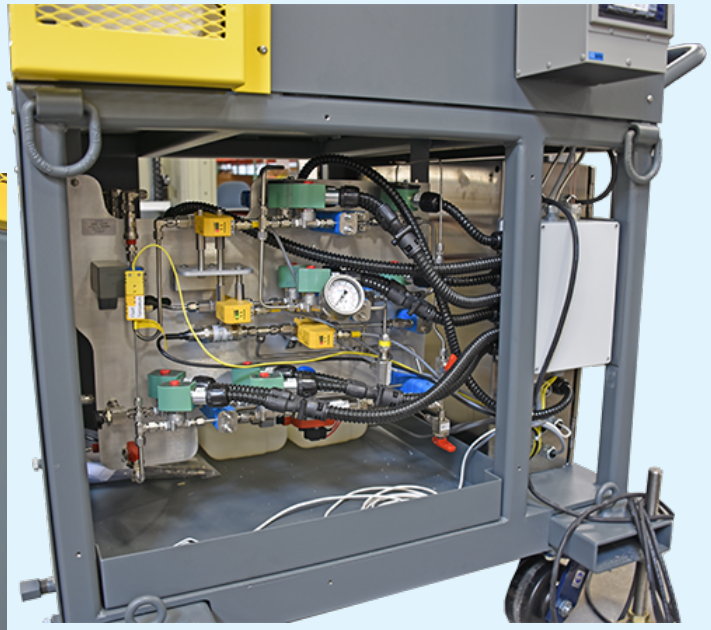
Open panel views

CP5 cooler and back of detector shield

Enclosure cooler

Back of Touch Panel PLC

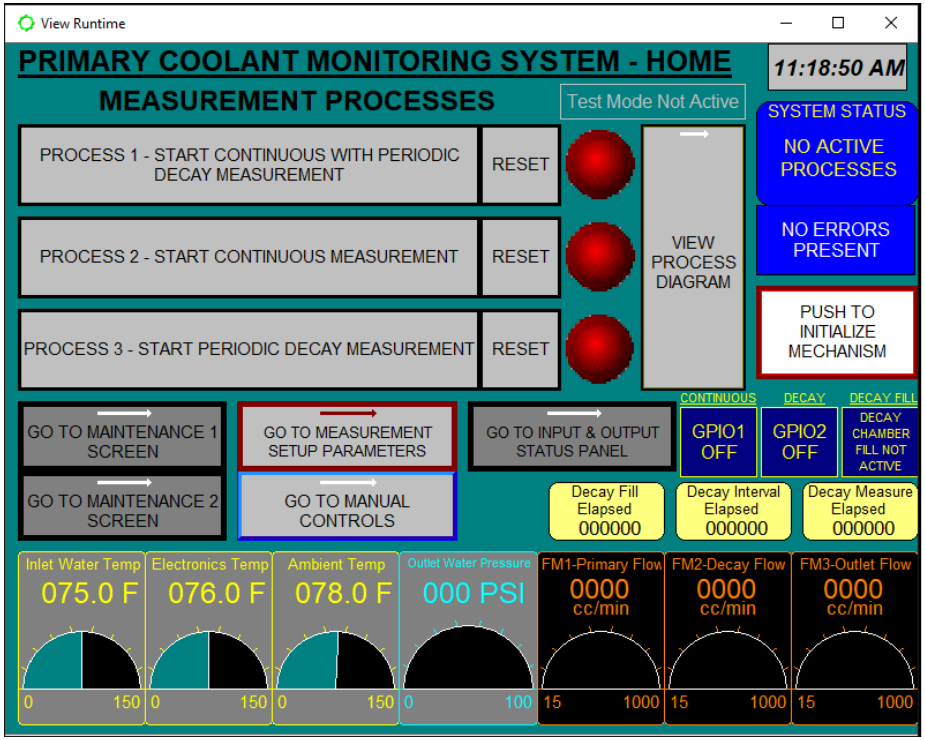
Containers for drain and water fill/cleaning liquids.

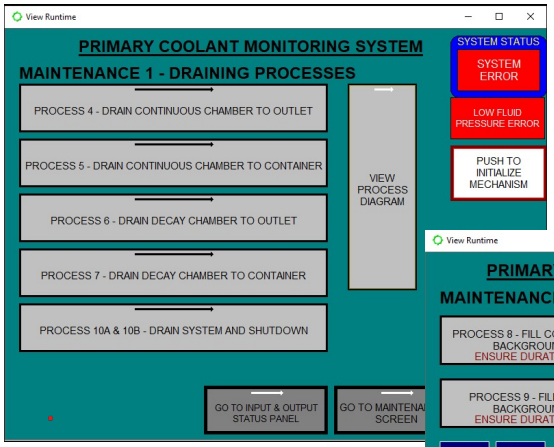


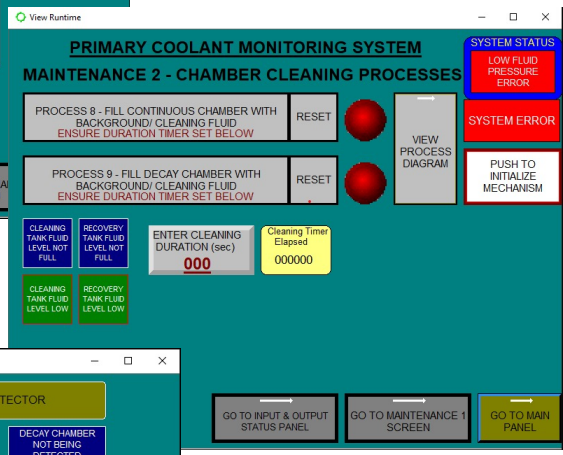
Process fluid valves, flow gauges, temperature gauges

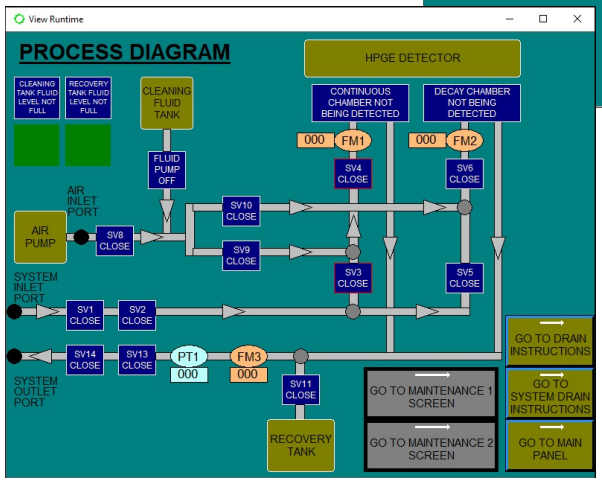
EPRI Primary Coolant System

PLC Control Touch Panel screens









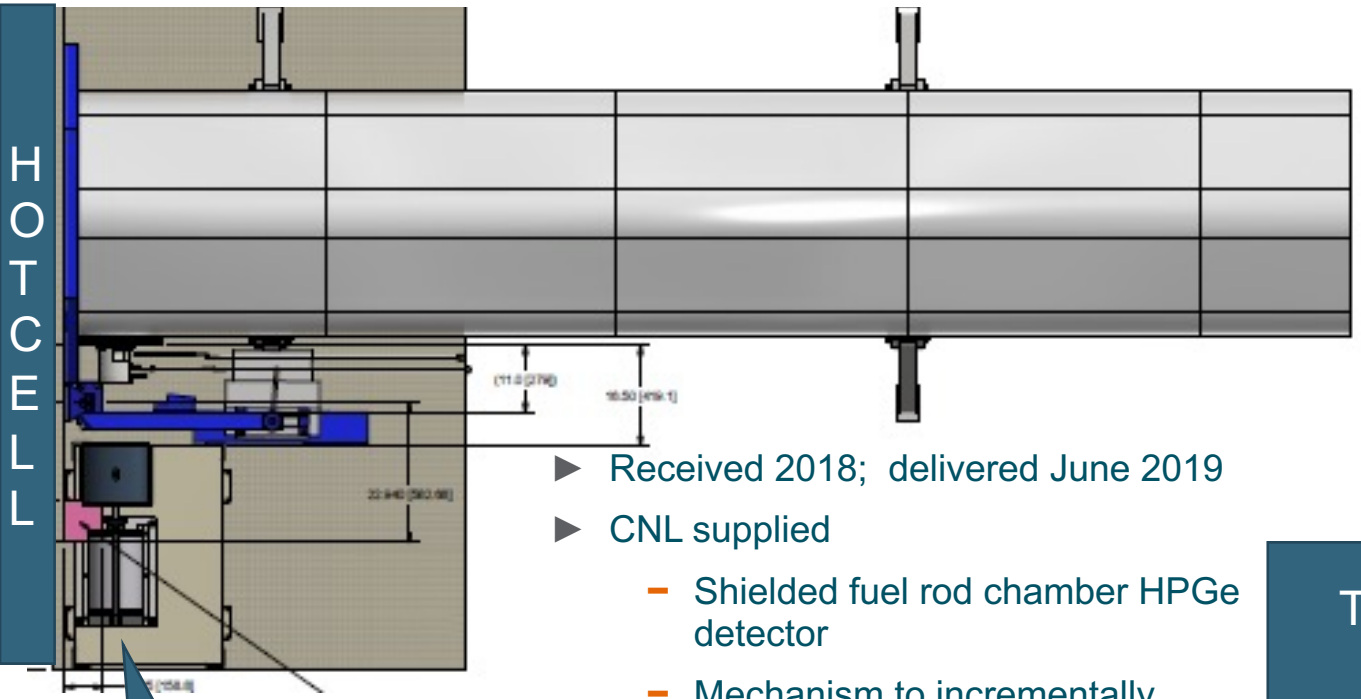
EPRI Primary Coolant System – Early Comments

- Performance – Continuous vs. Delayed and Decayed
  - Countrate dominated by positron emitters – F-18 PWR N-13 BWR
  - For nuclides > 511 keV, MDAs about the same for Long counts vs 24hr Decay count
  - For short lived nuclides, Long count better
  - ?? Is complexity of decay count worth it ??

Nuclide	comment	30m MDA	3hr MDA	23hr MDA	Decay MDA
Ag-110	Hi Energy	18	8	3	2
Sb-124	Hi Energy	9	4	1.3	1.6
Ar-41	Hi E, short T1/2	10	3	1	5
Ce-144	Lo Energy	70	28	10	4

- Reliabilty
  - Excellent. No unplanned shutdowns over ~7mo period
- Contamination – yes
  - Wall contamination on chambers – better material needed
  - Large crud burst higher than expected doserate from plumbing – better shielding needed

Chalk River National Lab – Fuel Rod Scanner



HPGe

Lynx MCA

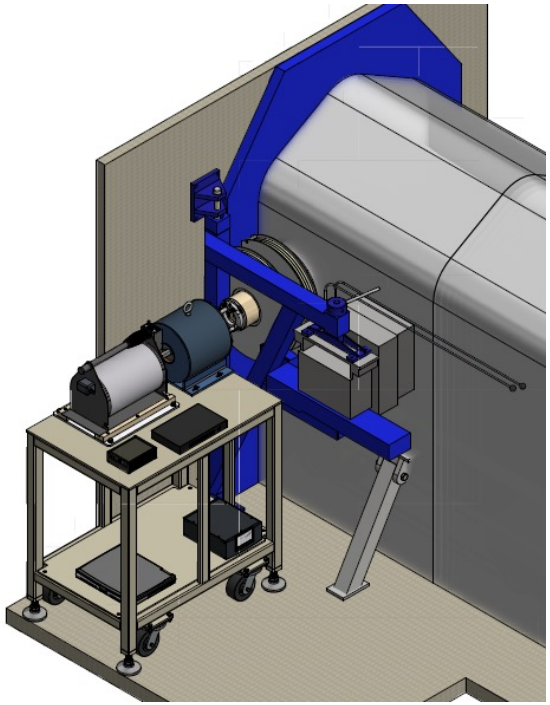
Data Analyst

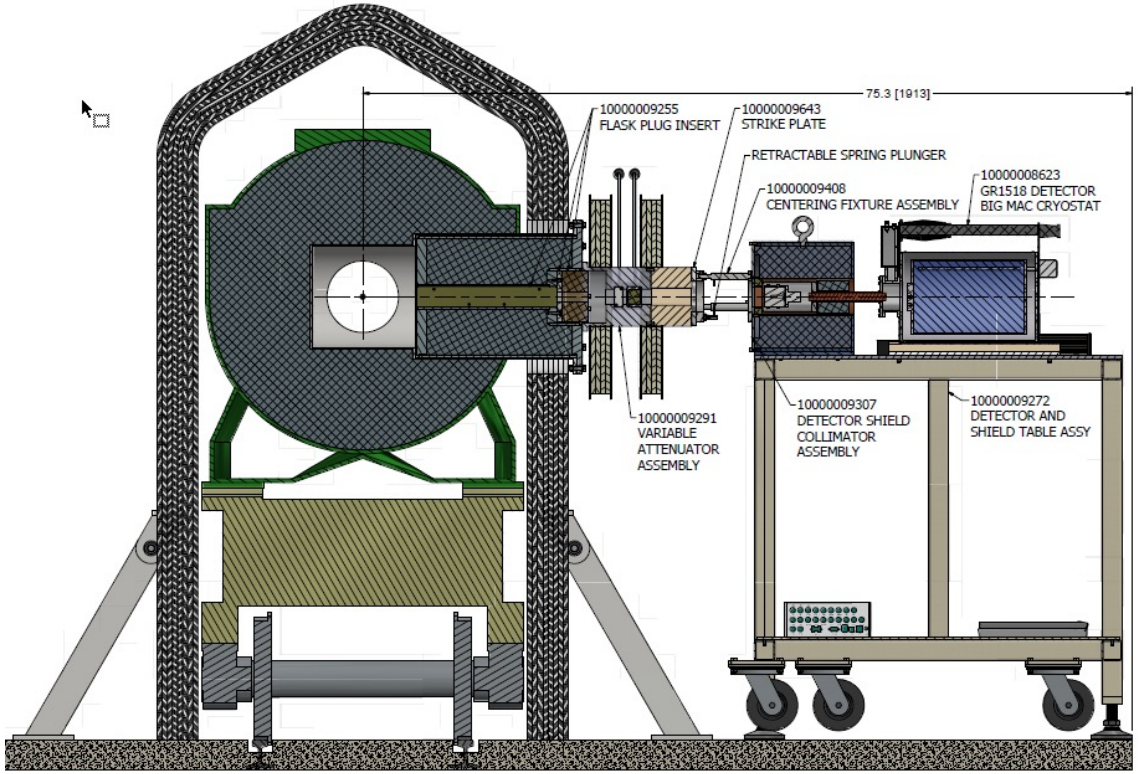
Trigger after advancing fuel rod

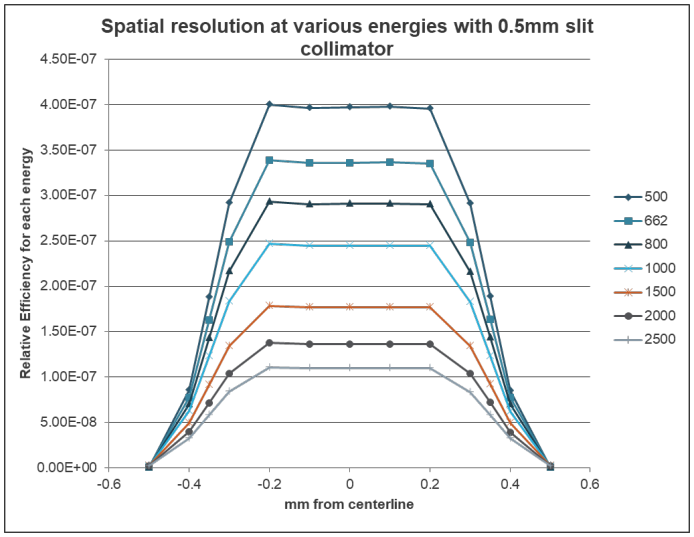
DA does 1 count and analysis cycle and waits for next trigger

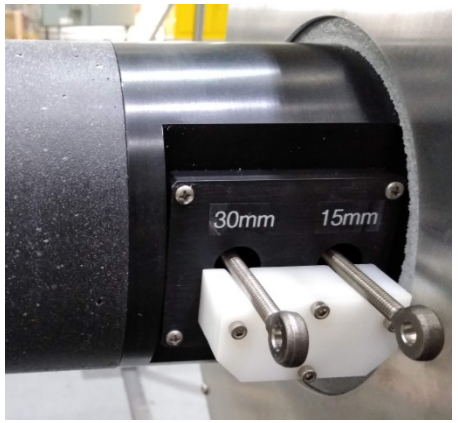
Detector and collimator

- Received 2018; delivered June 2019
- CNL supplied
  - Shielded fuel rod chamber HPGe detector
  - Mechanism to incrementally move fuel rod
- Mirion-Canberra supplied
  - HPGe detector with TRP
  - Tungsten collimator 30cm long with 0.5mm slit
  - Other shielding around the detector
  - Data Analyst to operate in Triggered single-assay mode
- 0.6mm FOV
- Triggered mode for stepped scanning



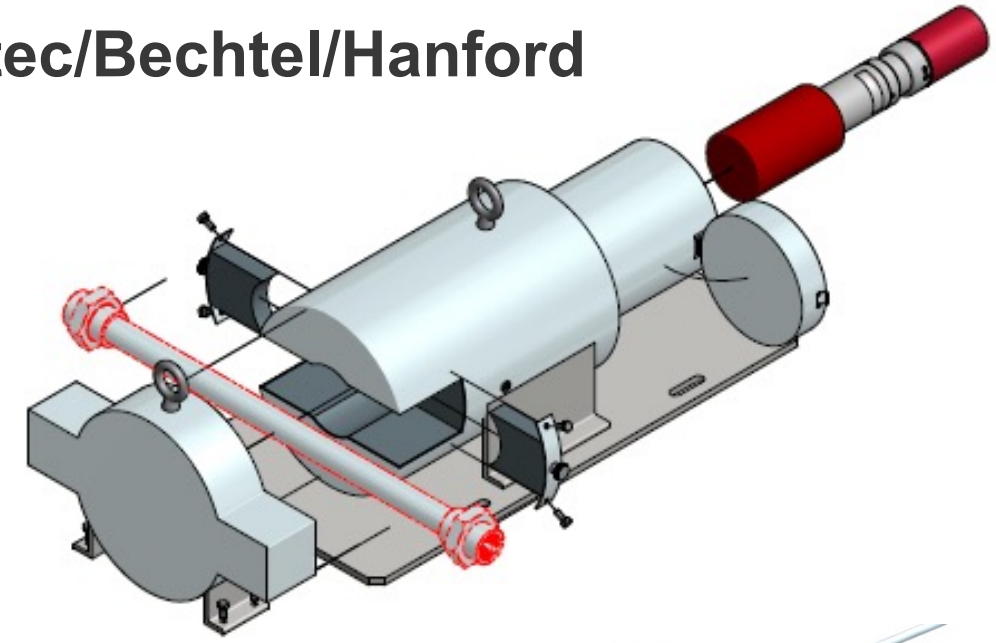

75.3 [1913]
10000009255
FLASK PLUG INSERT
10000009643
STRIKE PLATE
RETRACTABLE SPRING PLUNGER
10000009408
CENTERING FIXTURE ASSEMBLY
10000008623
GR1518 DETECTOR
BIG MAC CRYOSTAT
10000009291
VARIABLE
ATTENUATOR
ASSEMBLY
10000009307
DETECTOR SHIELD
COLLIMATOR
ASSEMBLY
10000009272
DETECTOR AND
SHIELD TABLE ASSY

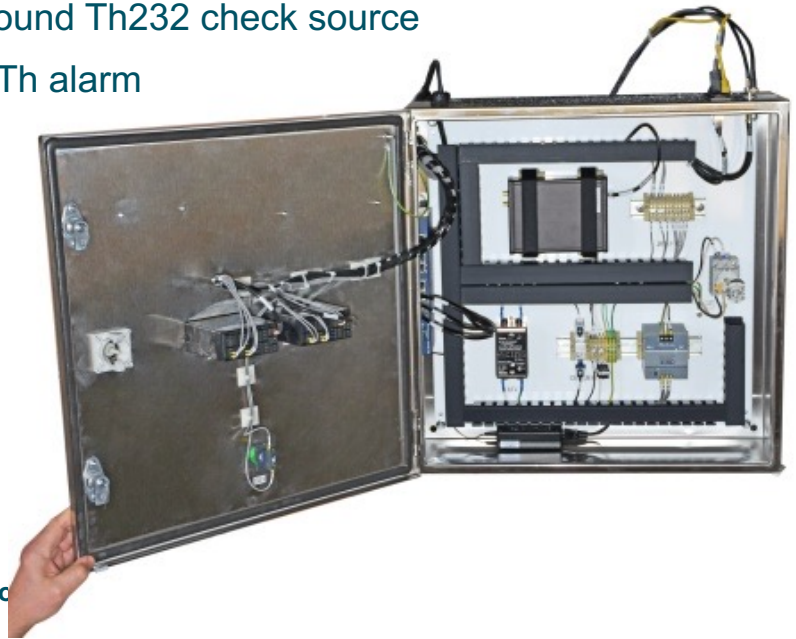

Spatial resolution at various energies with 0.5mm slit collimator
Relative Efficiency for each energy
4.50E-07
4.00E-07
3.50E-07
3.00E-07
2.50E-07
2.00E-07
1.50E-07
1.00E-07
5.00E-08
0.00E+00
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
mm from centerline
500
662
800
1000
1500
2000
2500


30mm
15mm

Pipe assay system – Avantec/Bechtel/Hanford

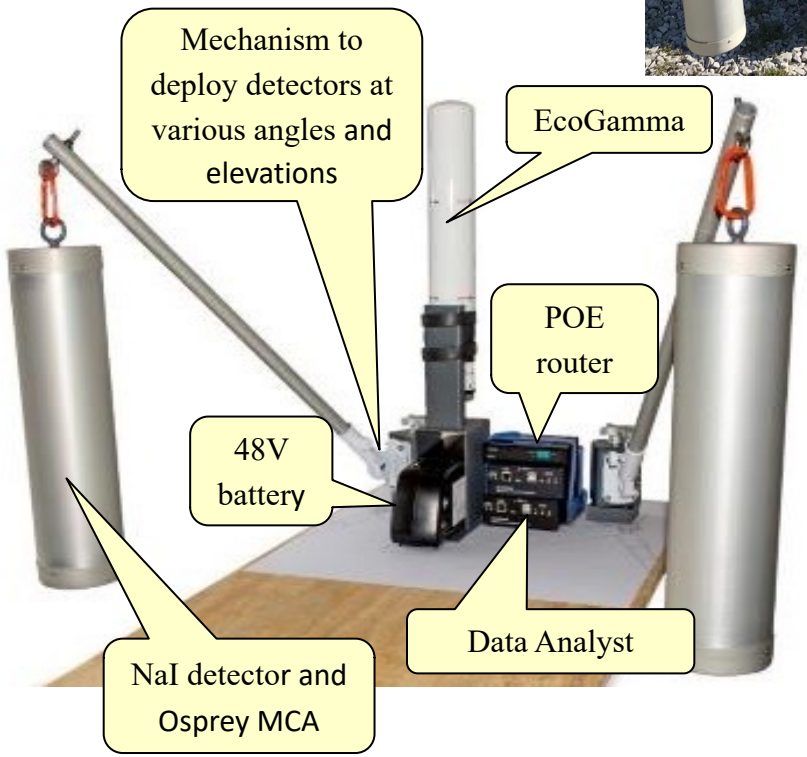
- 2018 – June 2019
- Monitors Sludge in Pipe
  - High Cs137 will divert material
  - LED-stabilized NaI detector
  - Lead shield with through cavity for customer pipe
  - Osprey MCA
  - SCA window 1 around Cs137
  - Ratemeter 1: Hi Cs alarm, 4-20ma signal to control room
  - SCA window 2 around Th232 check source
  - Ratemeter 1: Lo Th alarm
  - Data Analyst in continuous assay mode to create database of all nuclide activity





EPRI Robotic Survey Demonstration

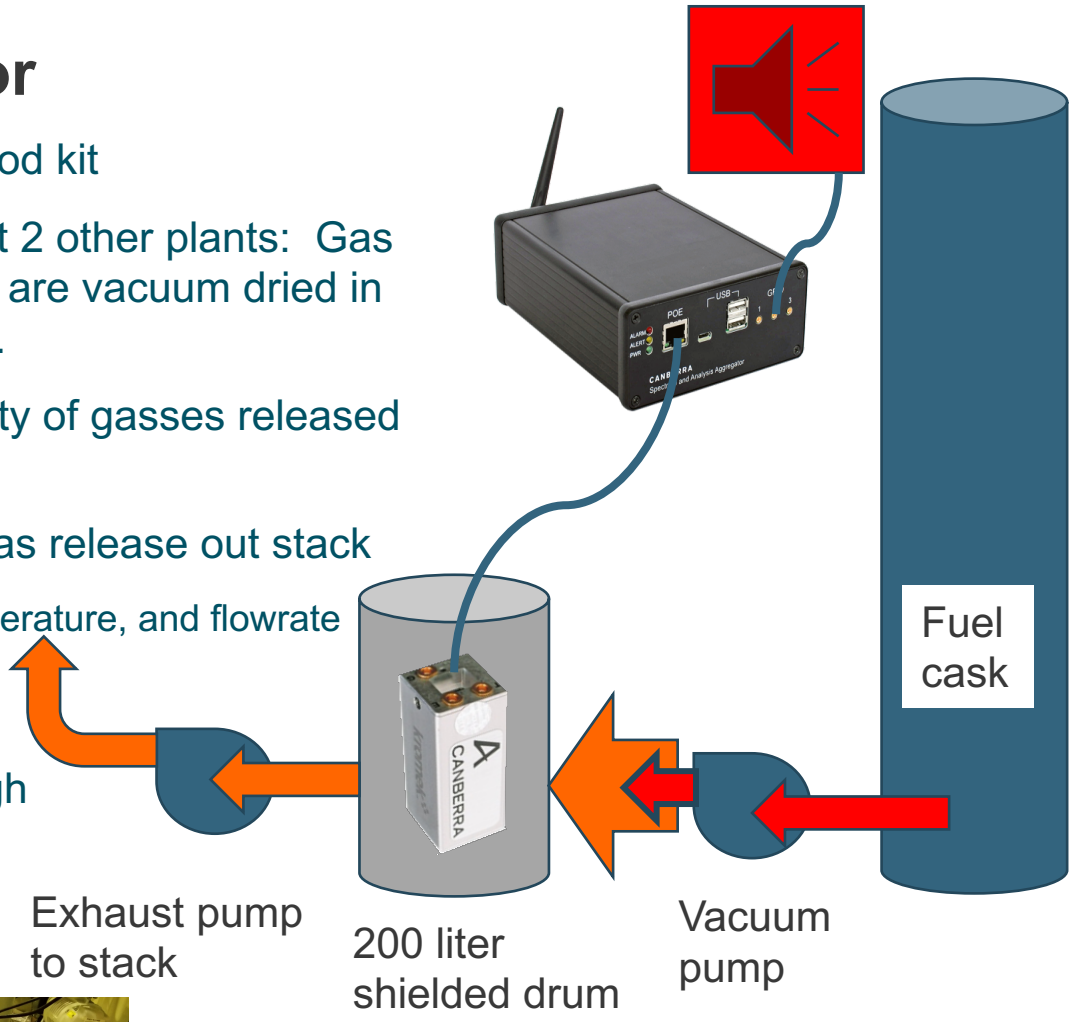
- Fall 2019
- Measurement Services contract
- Other contractor supplies robot with LIDAR mapping and pre-programmed autonomous control of vehicle movements
- Continuously recording two spectra every 3 seconds
- 1 sec spectra stored
- Timestamp stored in record
- Post-processing to combine radiation data and location coordinates on map

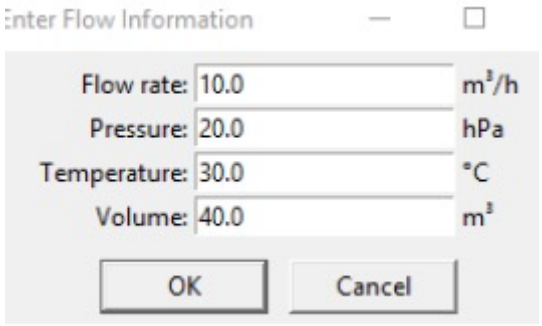


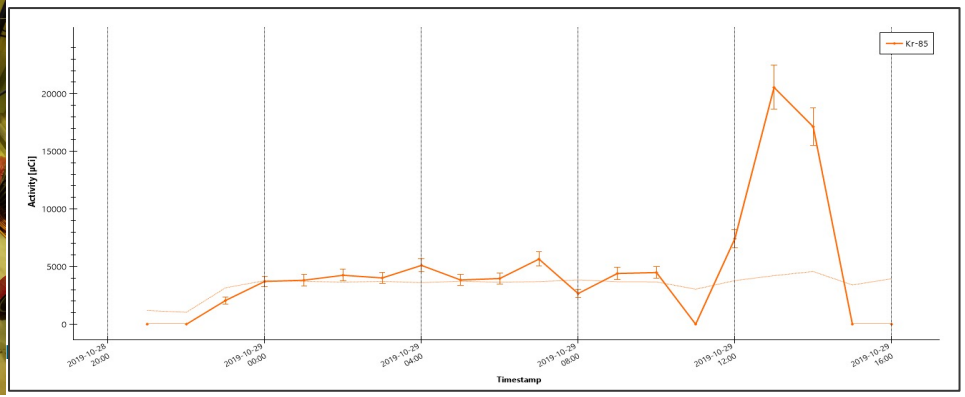
Video of EPRI Autonomous Site Characterization Demonstration

OPPD Fuel Drying Monitor

- 2018 customer bought CZT/shield/tripod kit
- NRC issued IE notice about problem at 2 other plants: Gas released unexpectedly as fuel bundles are vacuum dried in storage cask before welding cask shut.
- Want to determine nuclides and quantity of gasses released from each storage cask
- Calculation modification to compute gas release out stack
  - Corrections for chamber pressure, temperature, and flowrate
  - Results in Bq/m3 in the exhaust
- Alarm triggered if activity in gas too high

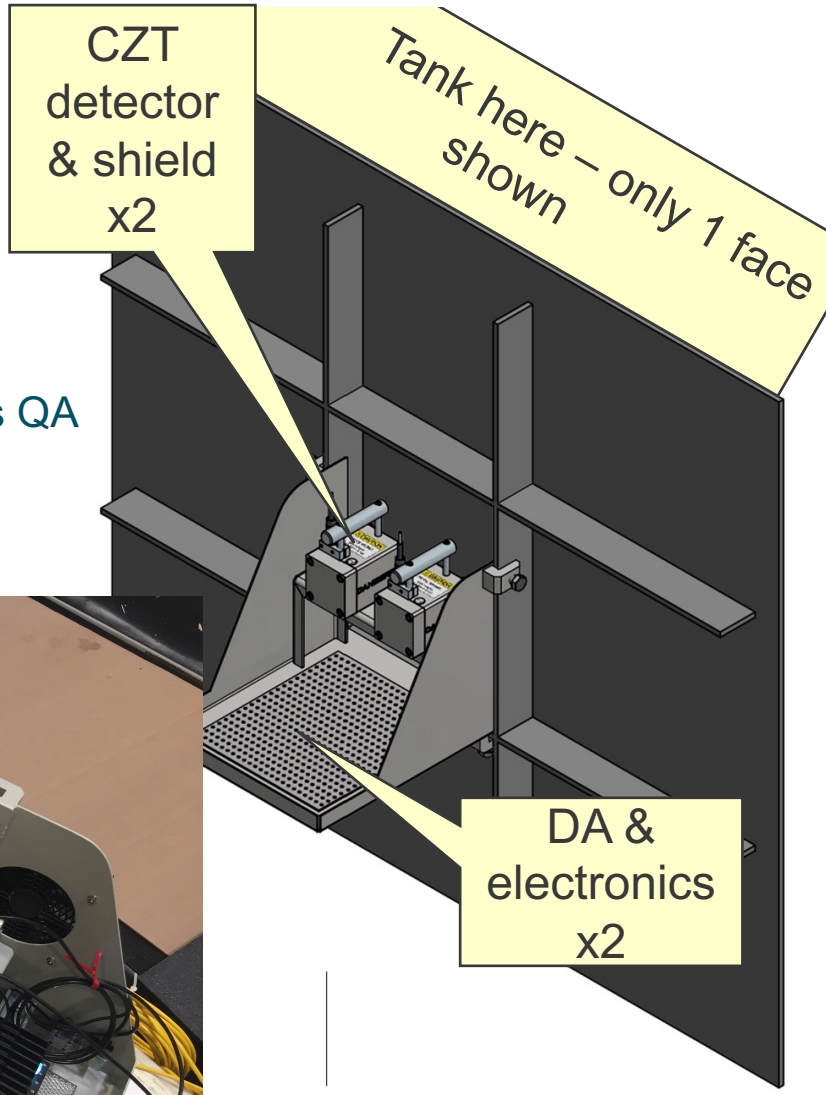


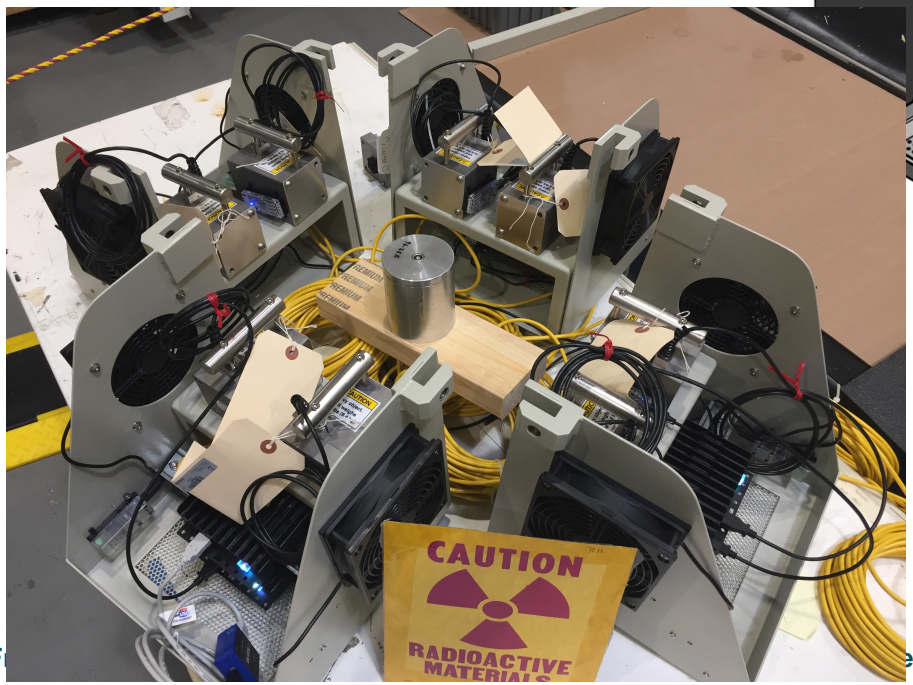




URENCO Waste Processing Tank Dual-Assay System

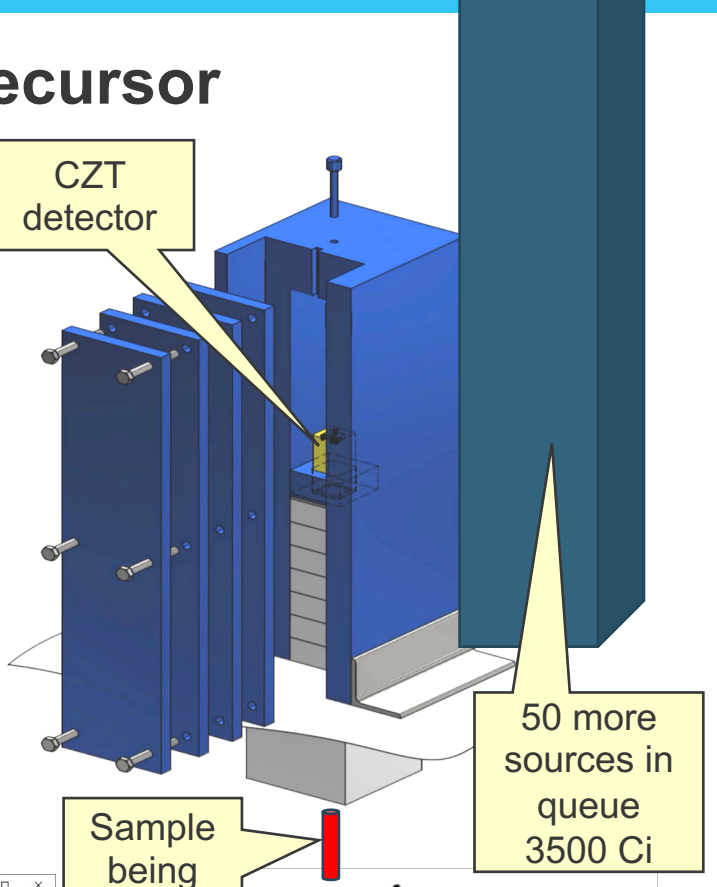
- 4 identical tanks with enriched Uranium waste ~1m3
- Require dual independent criticality assessments of tank contents before tank can be discharged
- 2 shielded CZT detectors aimed at each tank
- Data Analyst for each detector
- Shield has embedded Thorium source for continuous QA
- Horizon software continuously collects data from all systems for remote viewing and database storage
- Special report showing time history of the QA results and the tank assay for all 8 detectors

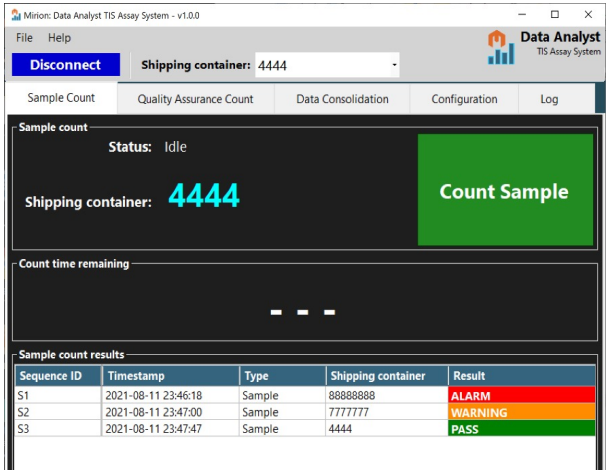


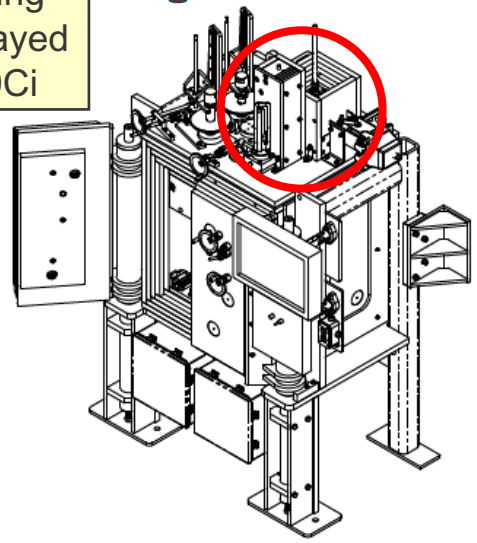


Lu-177 Assay of Reactor Activated Precursor

- Targets containing enriched Yb-176 will be irradiated in the Bruce Power reactors
  - Yb-177 [T½ = 1.9hr] produced; decays to Lu-177 [T½ = 6.7d]
  - Irradiated 2-4 weeks; decayed ~12 hours before assay
- Samples inside 15cm thick tungsten box
  - Estimated activity at time of measurement is ~70 Ci [3E12 Bq]
  - About 50 more samples of similar activity are waiting in the queue about 19cm and 15cm of Tungsten away
- Heavily shielded and 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 will view each sample report, and then if OK load and count the next one.
- Custom software will consolidate all the data, load into database, and generate shipping document

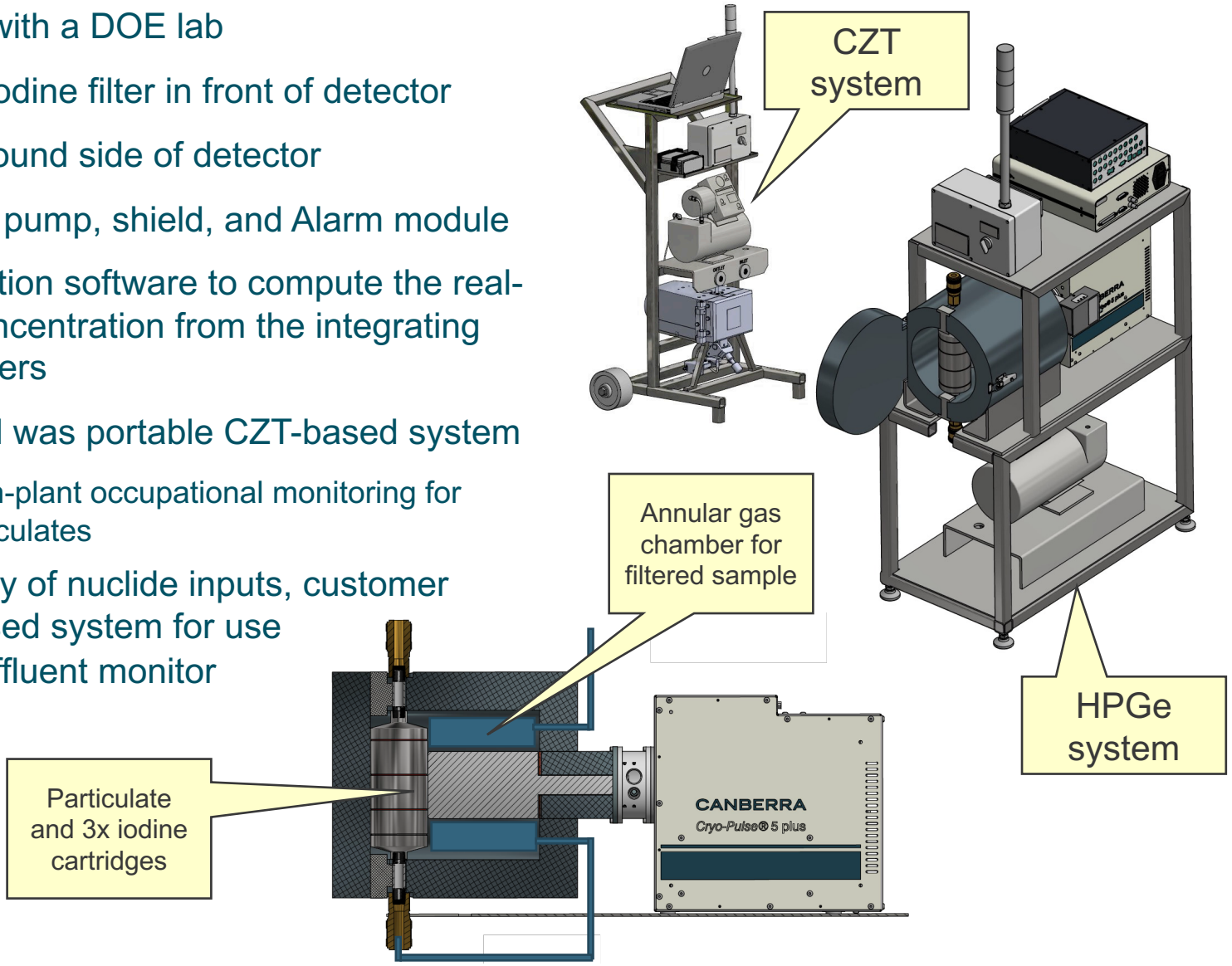






Spectroscopy Particulate Iodine and Noble Gas Monitor

- Active proposal with a DOE lab
- Particulate and Iodine filter in front of detector
- Gas chamber around side of detector
- Data Analyst, air pump, shield, and Alarm module
- New: Differentiation software to compute the real-time airborne concentration from the integrating activity on the filters
- Original proposal was portable CZT-based system
  - Adequate for in-plant occupational monitoring for I-131 and particulates
- Due to complexity of nuclide inputs, customer wants HPGe based system for use as a stack gas effluent monitor



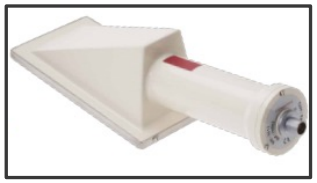
CZT vs. HPGe flavors

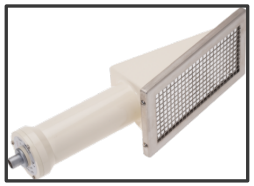
Common items
Configurable by user P, I, NG, P+I, P+I+NG
Horizon compatible for remote monitoring and database
ISOCS efficiency cals
Same DA workflows and Differential Analysis algorithm
Compatible with EcoGamma for doserate
DAProspector and ReexaMiner tools

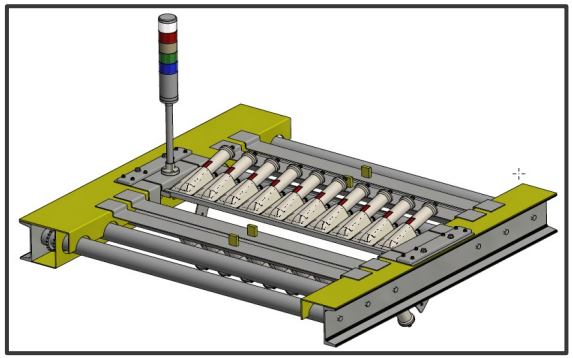
ITEM	CZT	HPGe
Shield	2” Pb	3” Pb
Detector volume	1 cc	114 cc
Detector resolution	12 keV at 662	1.5 keV at 662
Weight	250 lbs Portable	1600 lbs Fixed
LLD for I-131 at 30m	2.5 E-9	1.1 E-10 ~23x lower
Count time to detect 8 DAC-hrs of I-131	4-5 hours ~8x longer	30 minutes
Count time to detect I-131 effluent limit in air	3 hours ~8x longer	30 minutes
2nd copy price		~ 3x higher
Applications	- Field HP measurements - Simple stack effluent monitoring	- Complex nuclide matrices - High visibility situations - Best available technology

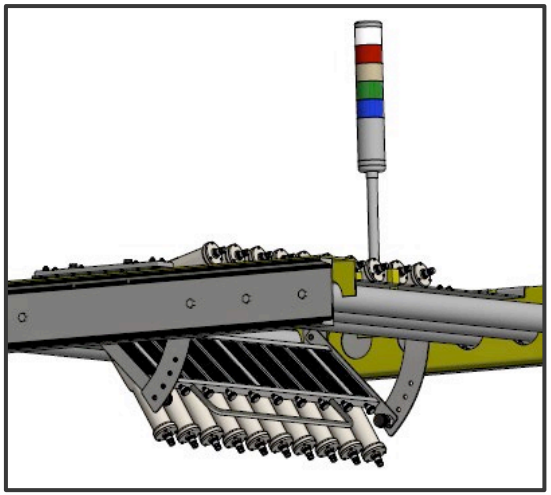
Conveyor Monitor

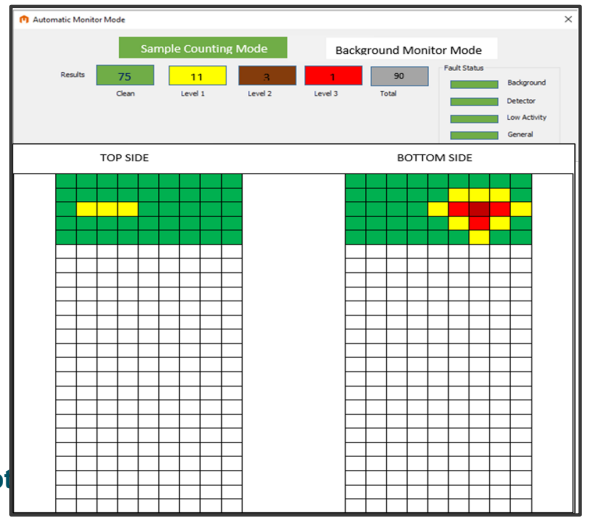
- DOE Laboratory is processing large sheets of material to remove contamination
- They requires 100% survey both top and bottom
- Automated system built to replace hand surveys
- 20 CSP 100cm2 thin-beta scintillator probes
  - 10 on top, 10 on bottom
- Custom software for continuous unattended operation, if sheet meets contamination specifications
- Graphical display of contamination location
- Background monitoring mode in-between sheets









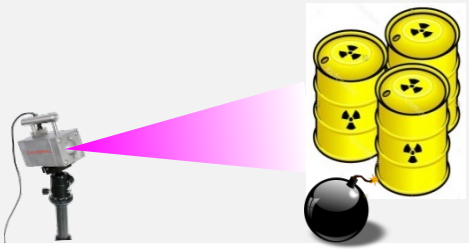


VAGAS Box Counter

Applications that are easy to set up and do using the Data Analyst

Emergency response applications

- Municipal water intakes
- Unstable situations with potential for liquid or airborne releases

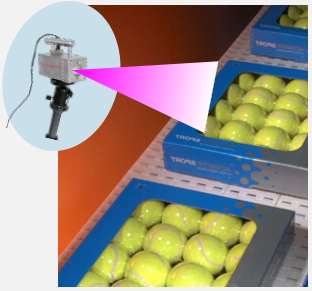


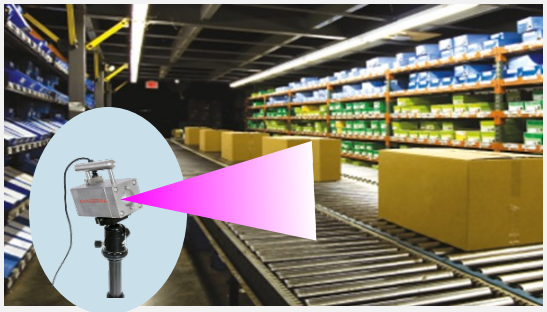
Detector on moving platform

- Radioactivity on the ground, along with GPS coordinates
- In UAV for radioactivity in plumes or on ground

Conveyor monitoring applications – nuclide-specific screening and sorting

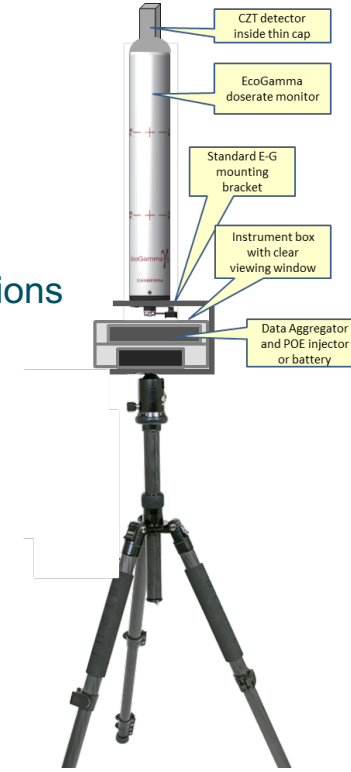
- Excavated soil
- Crushed concrete
- Containers of food
- Ad Hoc screening applications

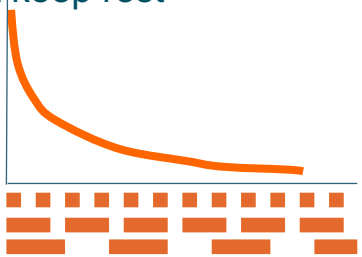




Future applications under discussion with potential clients

- **Nuclear Power Applications to monitor for Fuel Integrity**
  - Primary Coolant at PWRs and BWRs
    - Shielded CZT detector aimed at existing pipe w/Dose Equivalent Iodine calculations
  - Off-gas monitoring at BWRs
    - Shielded CZT detector aimed at continuously flowing extracted gas sample
- **Spectroscopy environmental or in-plant doserate monitor**
  - CZT top-hat on EcoGamma, with DA in weatherproof box below
- **Laboratory Applications**
  - Low level assays with very long Counting times
    - Use Data Analyst to do 10 short counts and one long count.
    - Use Data Prospector to view Peak activity and Background region under peak
    - Examine short counts to show no surprises; reject non-statistical data but keep rest
  - Neutron Activation Analysis
    - Automatic sequence with simultaneous Short, Medium, and Long counts
    - Short counts short-lived for, Long counts for long lived nuclides
  - Push-button Automated Sample Assay – for novice operators
    - Configure system to count/analyze/display upon the push of a button
    - 2 buttons available now, up to 8 is an easy modification





Conclusion

Most likely there will be no time for any conclusions

For those of you that are still awake, thank you for being so polite.

Enjoy the dinner tonight.

Have a safe trip back home – we need all of our customers to survive the journey, and to come back next year.


THANK
YOU!
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