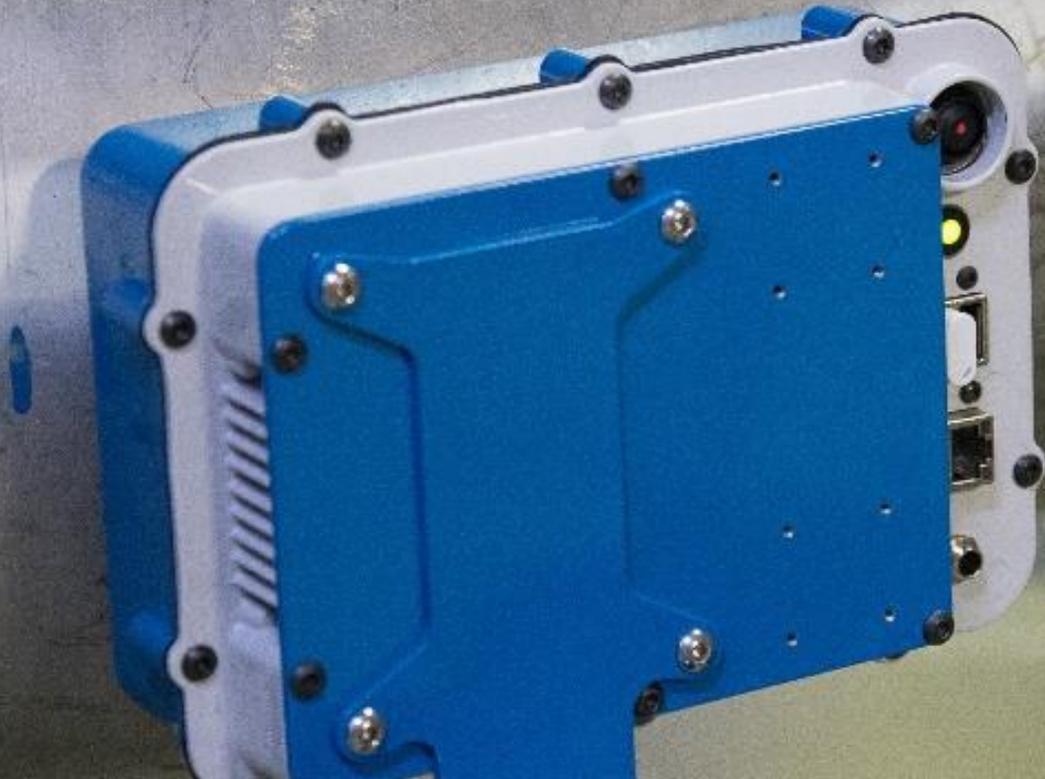


Real-Time Monitoring of PWR CRUD Bursts & Fuel Defect Using Pixelated CZT Spectra

Brian Eick, Radiation Protection/Chemistry Manager, Point Beach NPP

David R. Nestle, CHP, H3D, Inc. (former RPM at Palisades NPP)



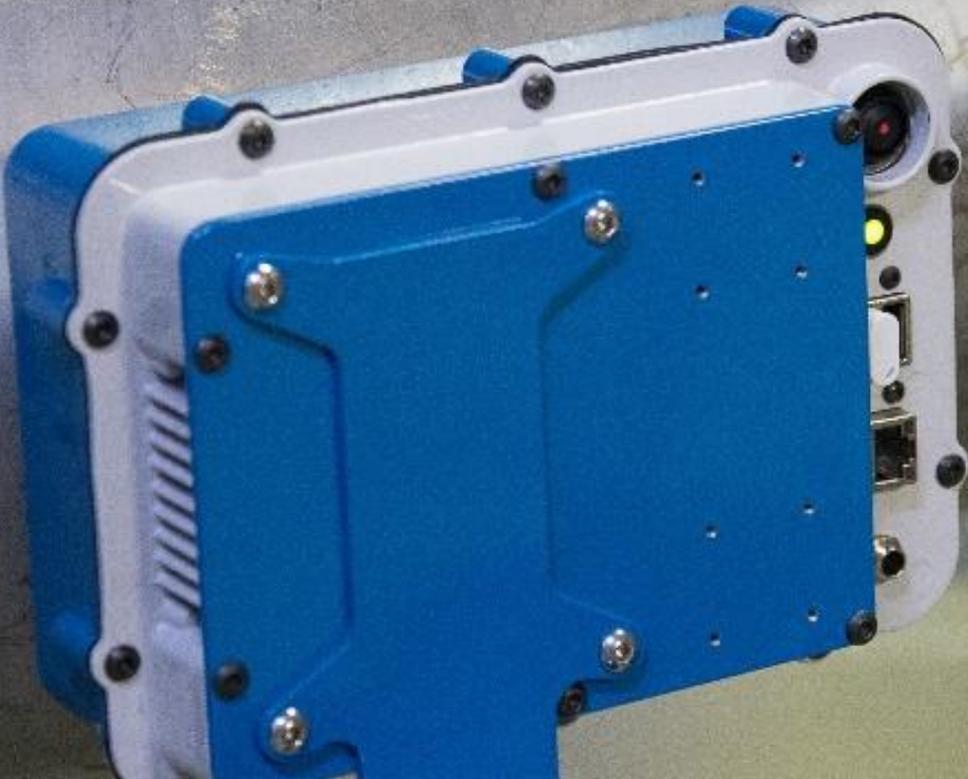
Contents:

Describe Emerging Use of Real-Time Spectrometers

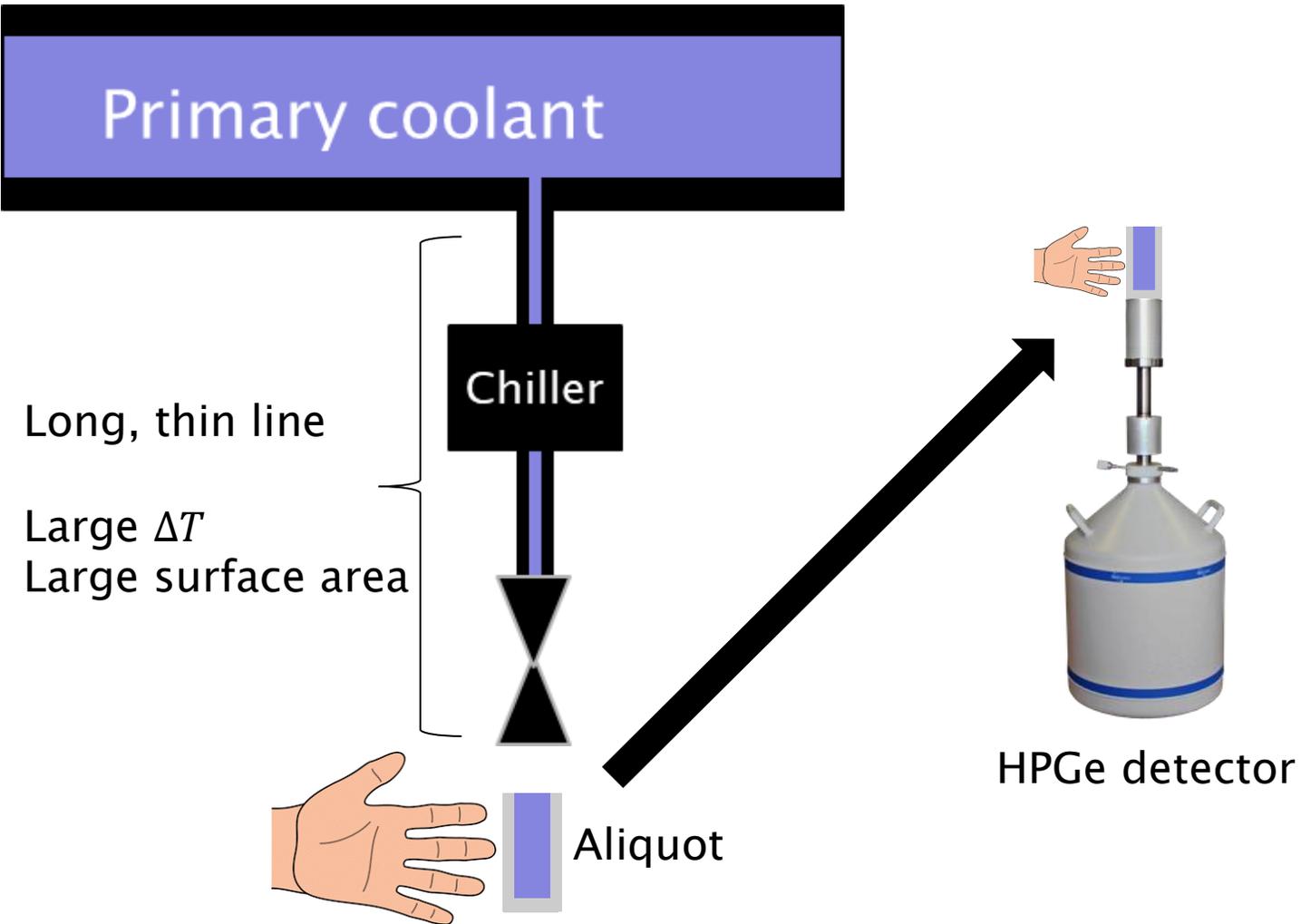
Use Cases for RP and Chemistry Organizations

Case Study: CRUD Burst

Case Study: Fuel Defect



Traditional Coolant Sampling



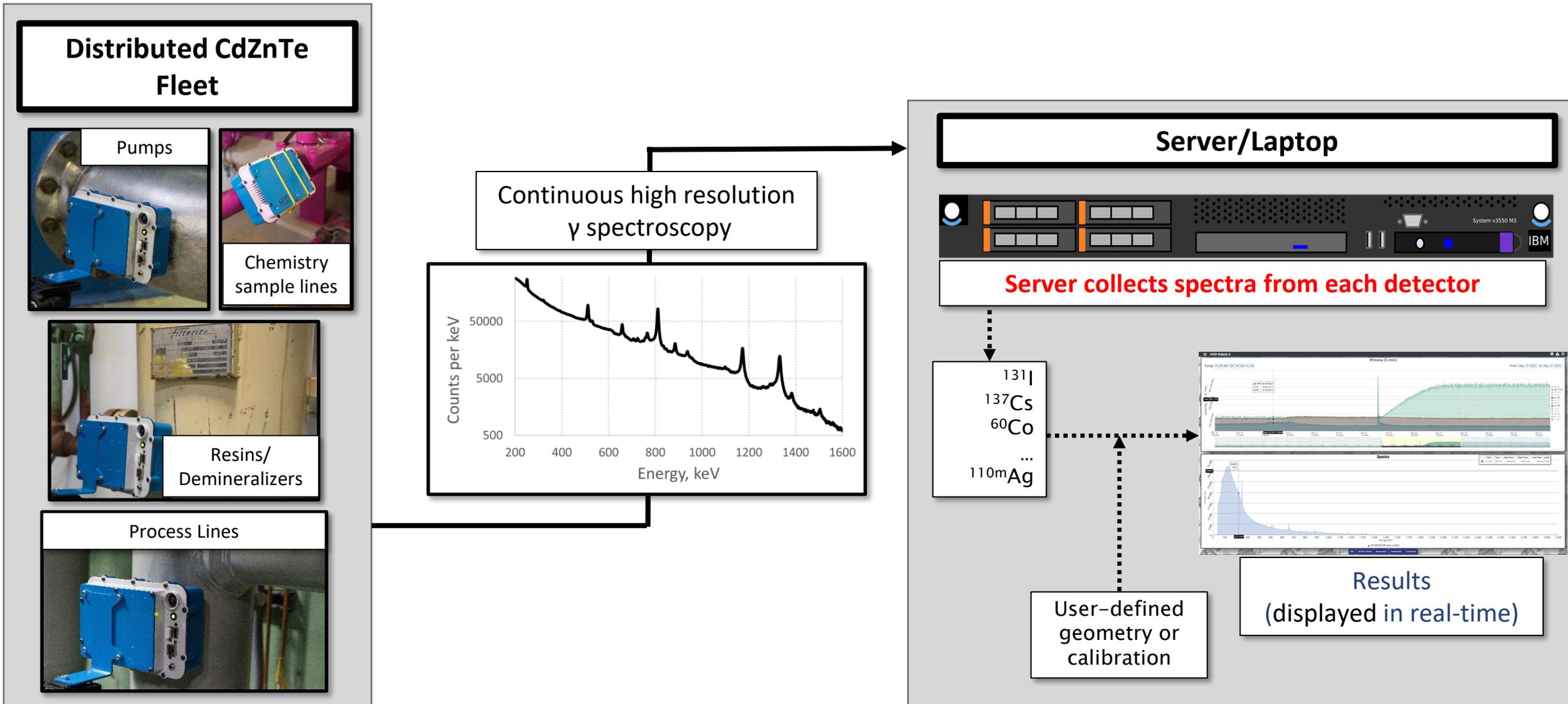
Pros:

- Tradition
- MDA (certain isotopes)
- Decayed measurements
- Soluble/Insoluble

Cons:

- Cost (labor)
- Dose (valve in RCA)
- Time between samples
- Limited sampling locations
- Insoluble particulate may not make it into the sample

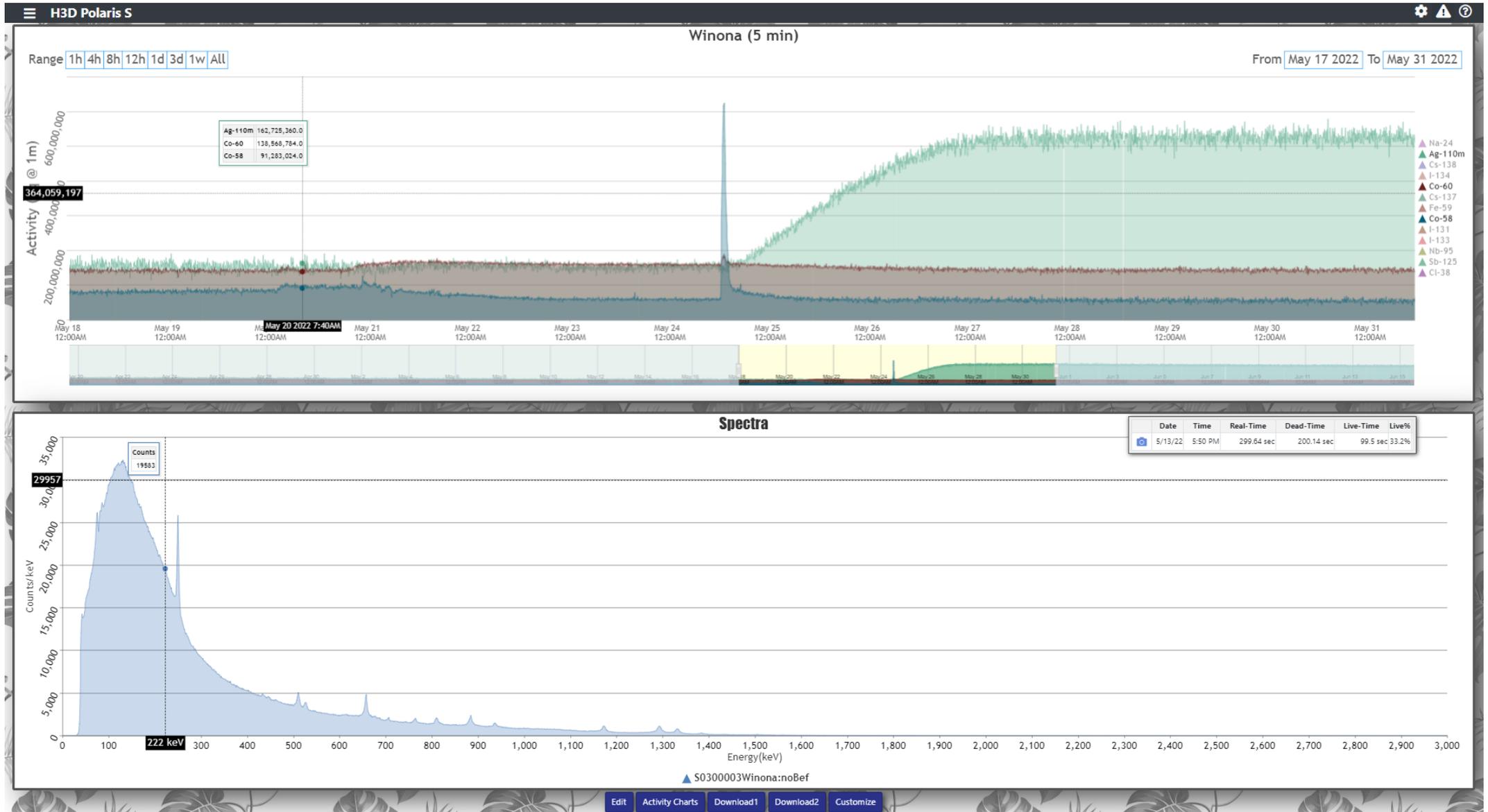
Process Monitoring/Trending



Use Cases for Real-Time Spectrometry

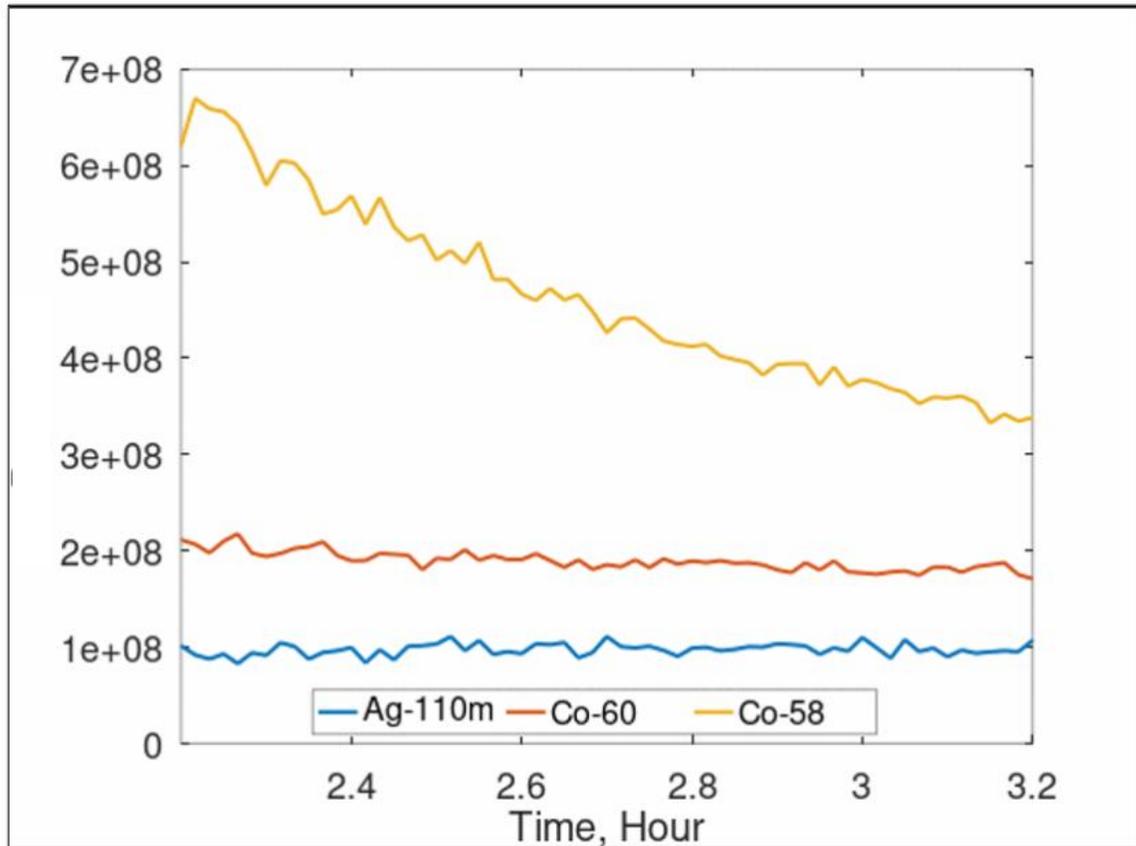
- Pressurized Water Reactor Forced Oxidation During Outages (CRUD–burst monitoring)
- Online Xenon Monitoring for Fuel Defects (PWRs and CANDUs to–date)
- Changes in Reactor Water Chemistry (Piloting KOH vs. LiOH in US PWRs)
- Inputs into Strategic Source Term Evaluations (Comparisons between Operating Cycles, Units, Sites)

Example Spectrometer Results

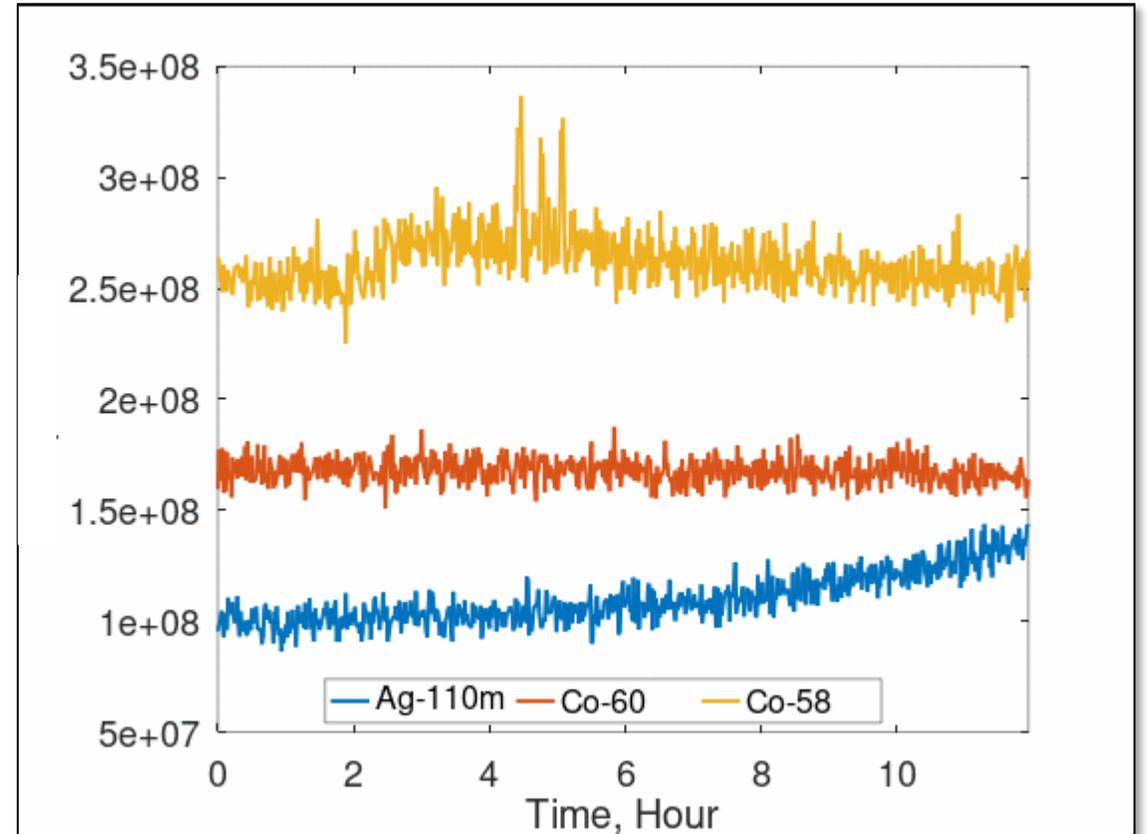


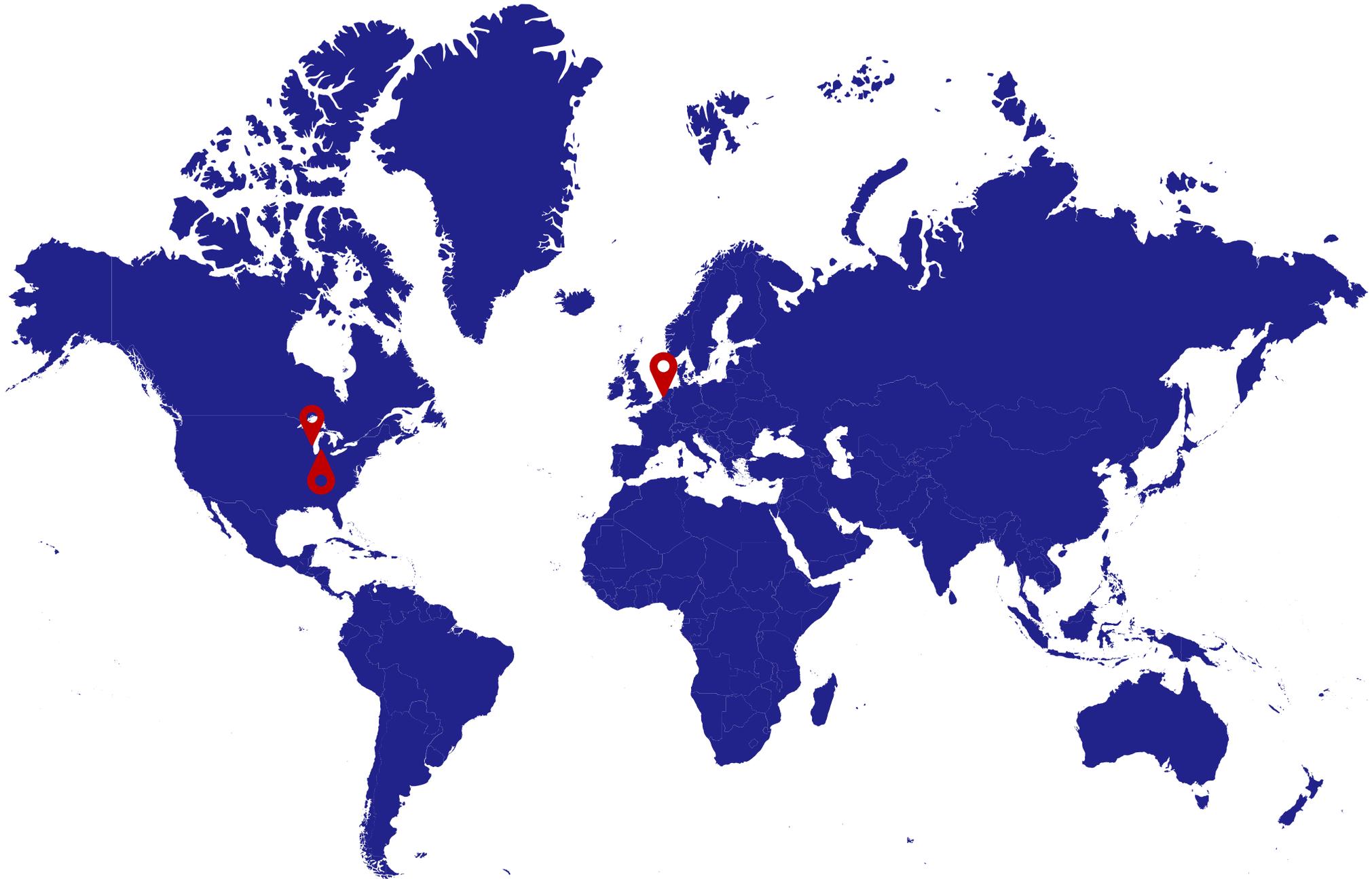
GammaTrend Use Cases

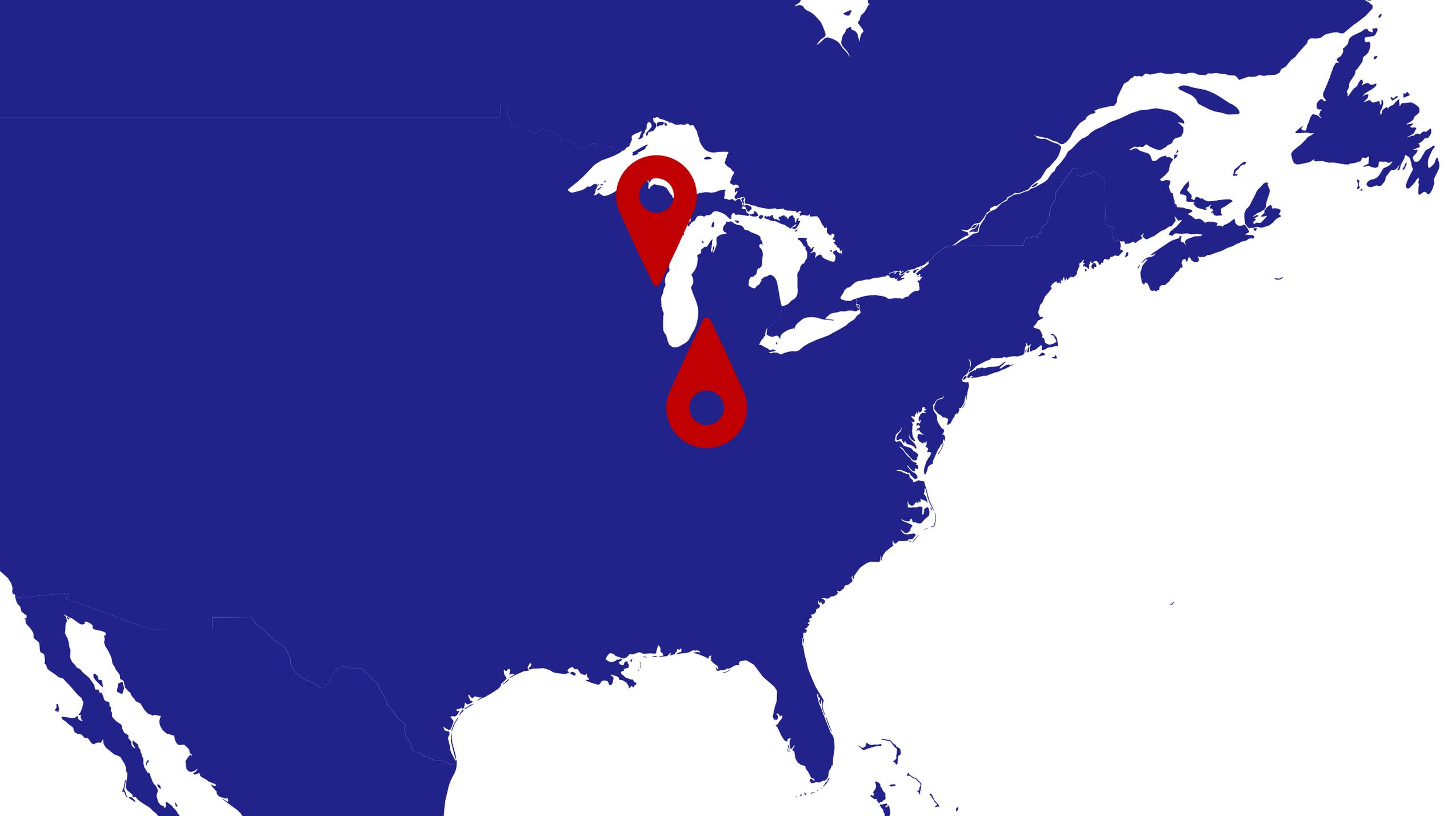
- Trend process activities/
concentrations

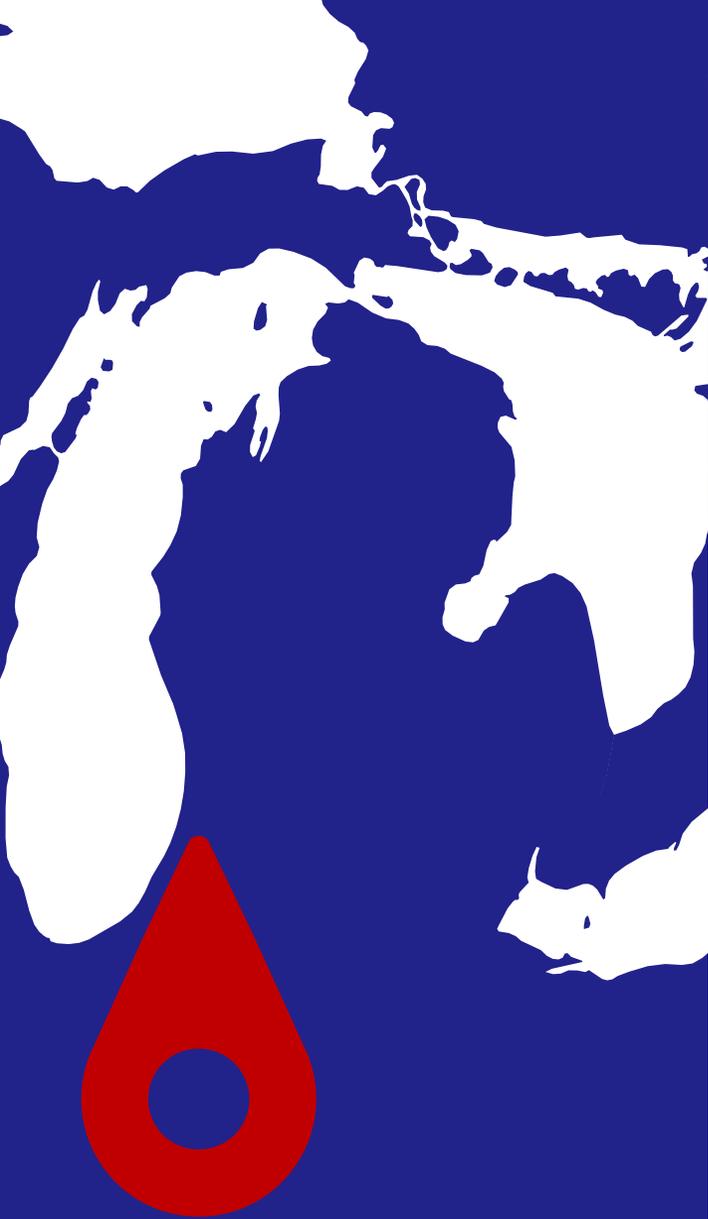


- Detect **unexpected** trends









Palisades Nuclear Power Plant

Location: Covert, Michigan, USA

Operator: Holtec Decommissioning International

License Expires: 03/24/2031

Docket Number: 05000255

Reactor Type: Pressurized Water Reactor

Licensed MWt: 2,565.4

Reactor Vendor/Type: Combustion Engineering

Containment Type: Dry, Ambient Pressure

Decommissioning Plan Began June 2022

Recent Announcement to Resume Operation late 2025

Case Study: Palisades

- Traditionally a very high source–term plant
 - Highest dose rates (and worker dose) of all Pressurized Water Reactors in the United States
- Typical Industry Recommendations Deployed
 - EPRI source–term recommendations
 - Long–term zinc injection
 - Cobalt supply chain controls
 - Macroporous and specialized resin technologies
 - Underwater resins during refueling
 - Supplemental underwater resins for spent fuel pool

Case Study: Palisades

- Installed four real-time spectrometers along the charging/letdown systems as part of R&D effort

Charging inlet



Charging outlet



Demineralizer inlet



Demineralizer outlet



Case Study: Palisades

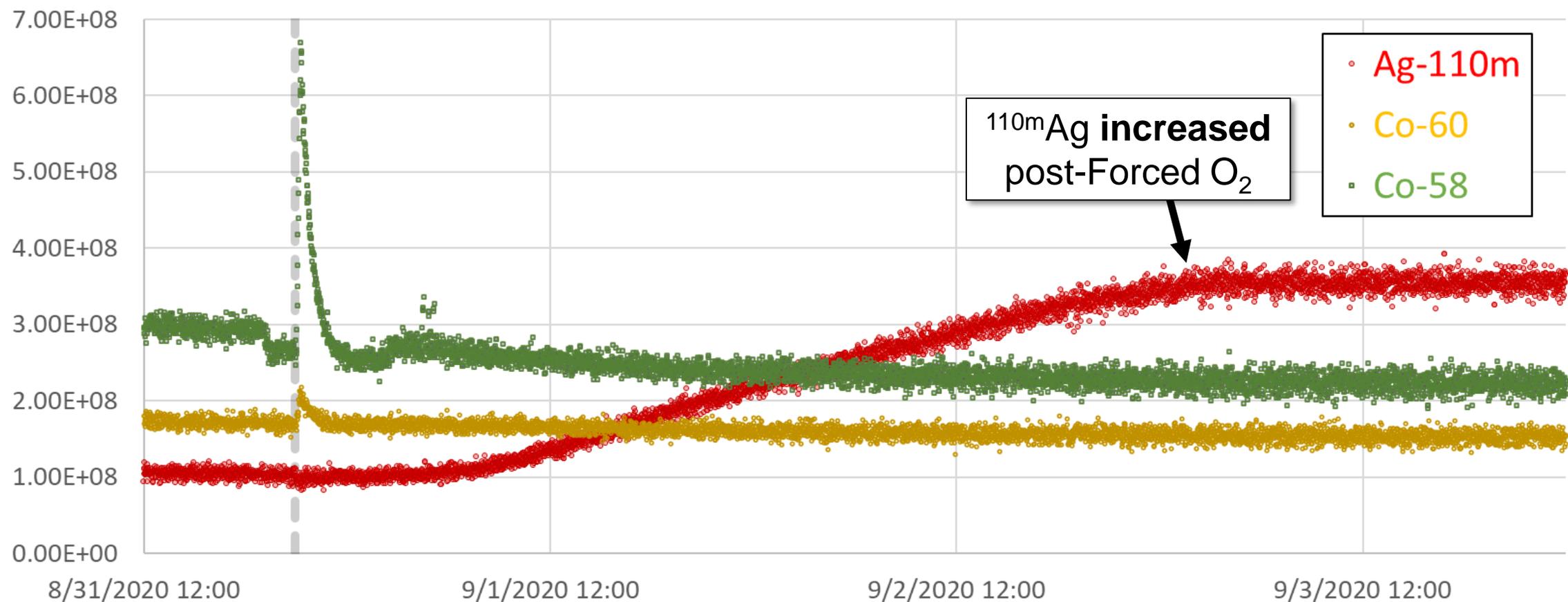
- Instrumentation remained in place during multiple operating cycles and outages
- Trends were collected throughout outages, including forced oxygenation and hydrazine addition
- Provided for direct comparison of trending results from outage-to-outage and cycle-to-cycle
- Data-driven revisions to source-term reduction strategy
- Results provided insight into success of actions taken.

Case Study: Palisades

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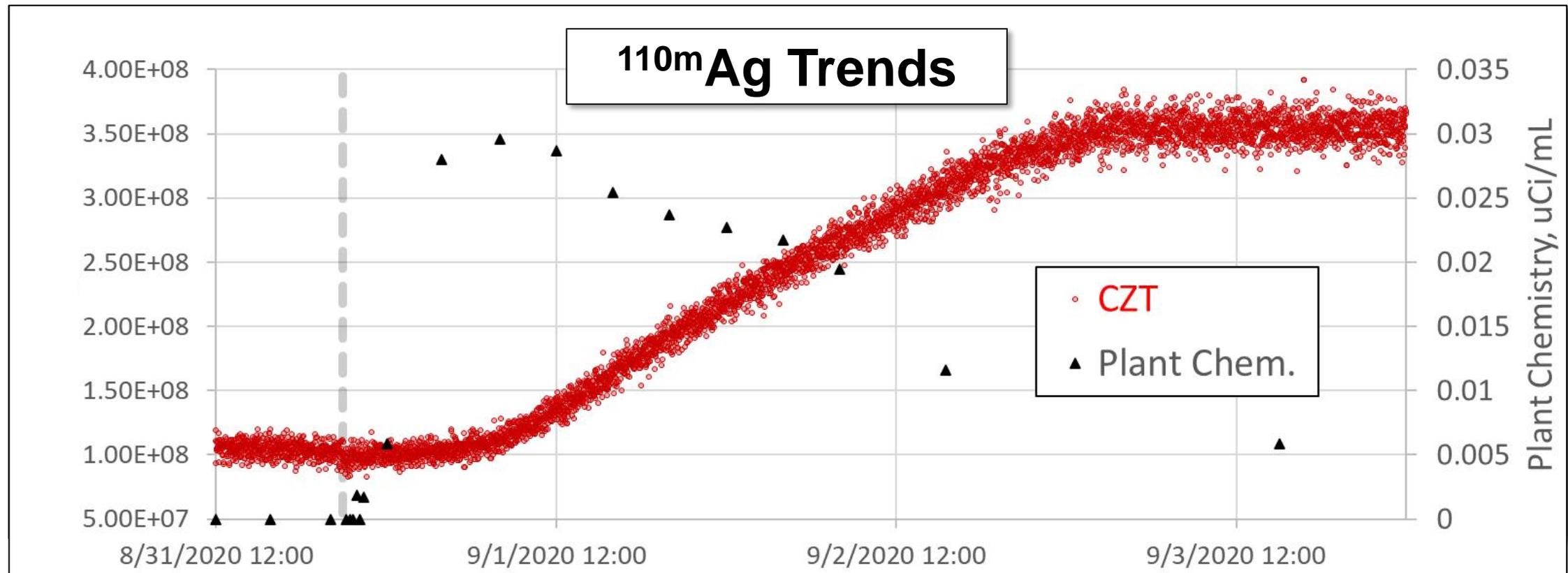
Charging Pump Inlet: Forced Oxygenation

- H_2O_2 add at 8/31/2020 20:55
 - Pre-burst: $170 \mu\text{Sv/h}$ Post-burst: **$270 \mu\text{Sv/h}$**



Charging Pump Inlet (In-situ vs RCS Sampling)

- Water sampling shows that ^{110m}Ag is **decreasing**
- Yet local dose rates (trended by CZT) increased **3.5x**



Case Study: Palisades

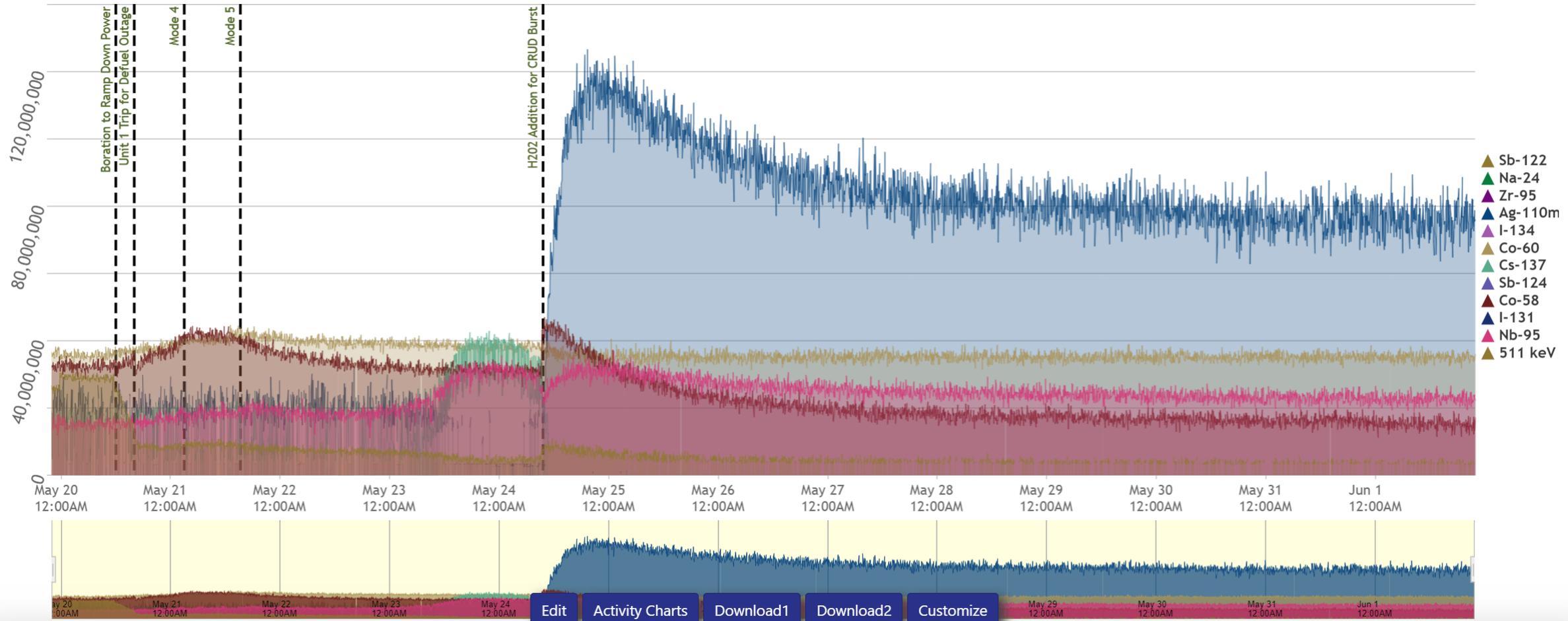
- Data provided input for a revised STR strategy:
 - Spectrometer trends and sample data from 1R27 were reviewed
 - EPRI/Industry expertise sought for silver/cobalt mitigation
 - Final cycle strategy included:
 - Increased end-of-cycle boron concentration (earlier coastdown)
 - Use of longer acid-reducing period at start of defuel outage
 - Higher concentration of hydrogen peroxide during forced oxygenation
 - Higher primary coolant temperature during forced oxygenation (to promote better cleanup and mitigate silver insolubility challenges)
 - Changes in demineralizer usage during 1R27 hydrazine add
 - Revised zinc injection strategy to remove nickel limitation

Defueling Outage Trends

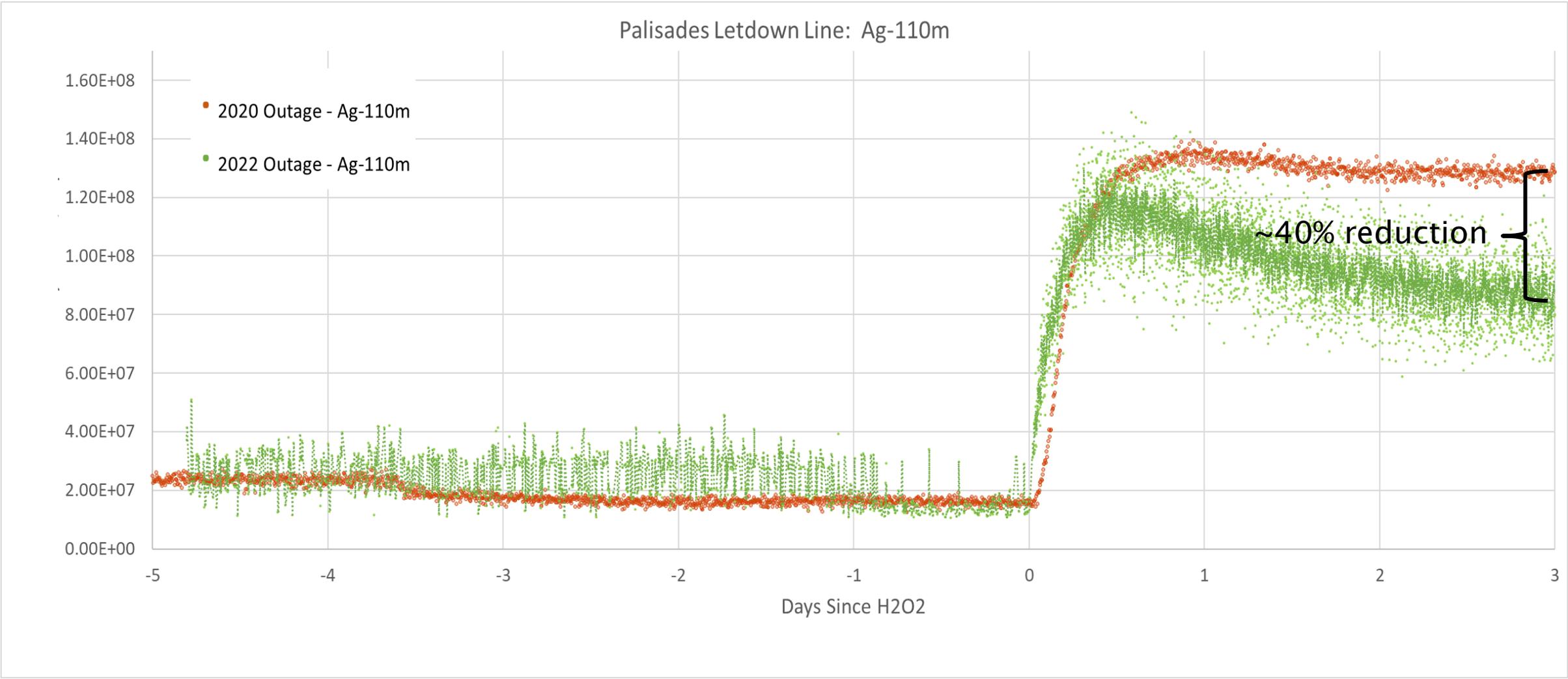
Palisades 2022 Defueling Outage (5 min interval, Activity by Nuclide)

Range

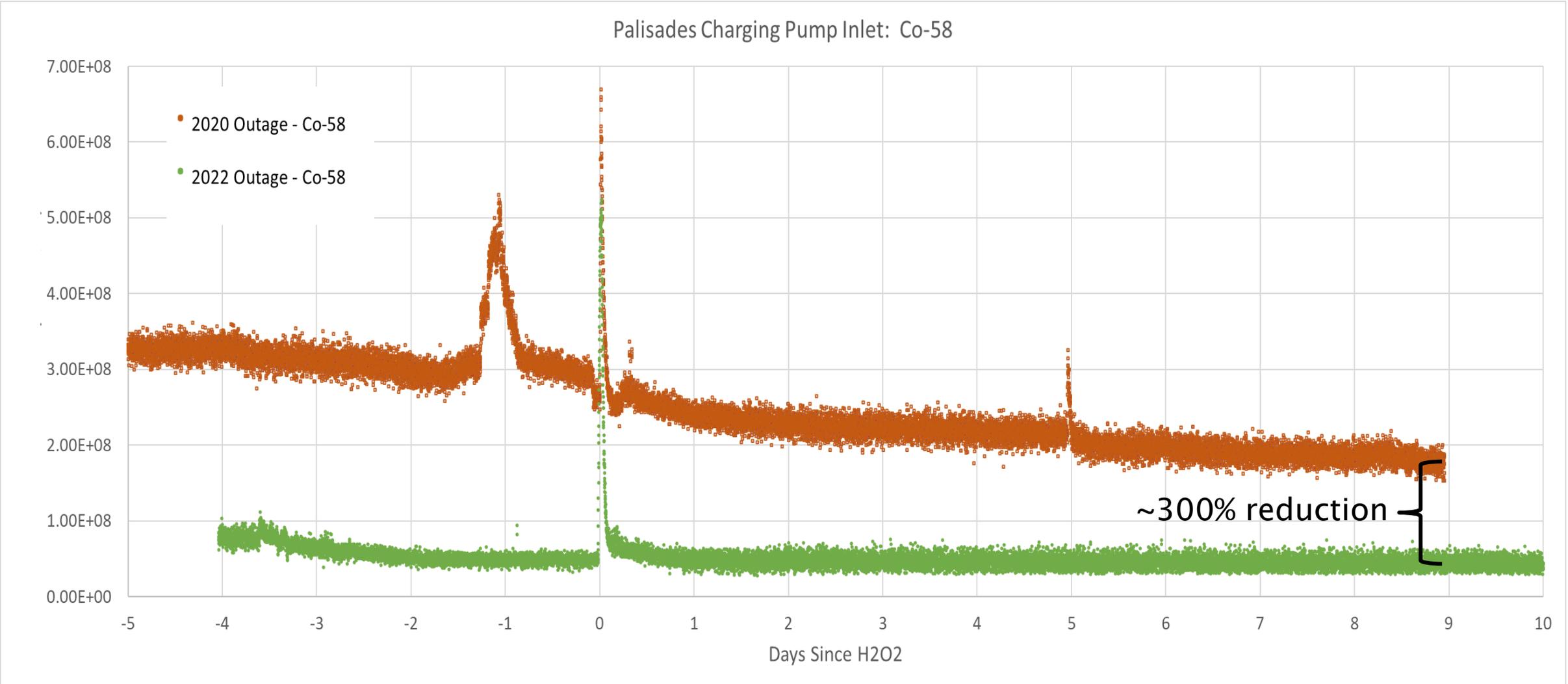
From To

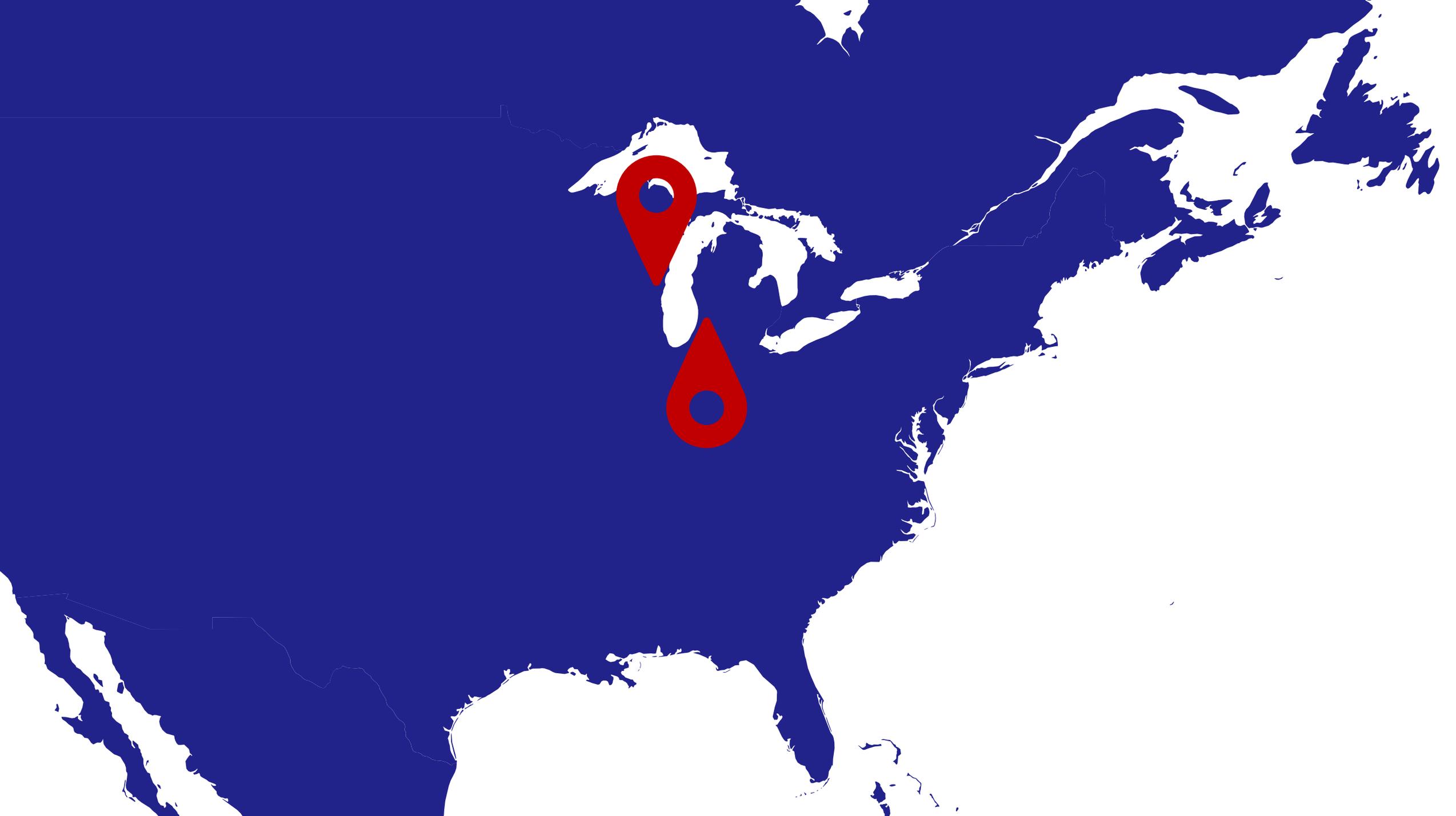


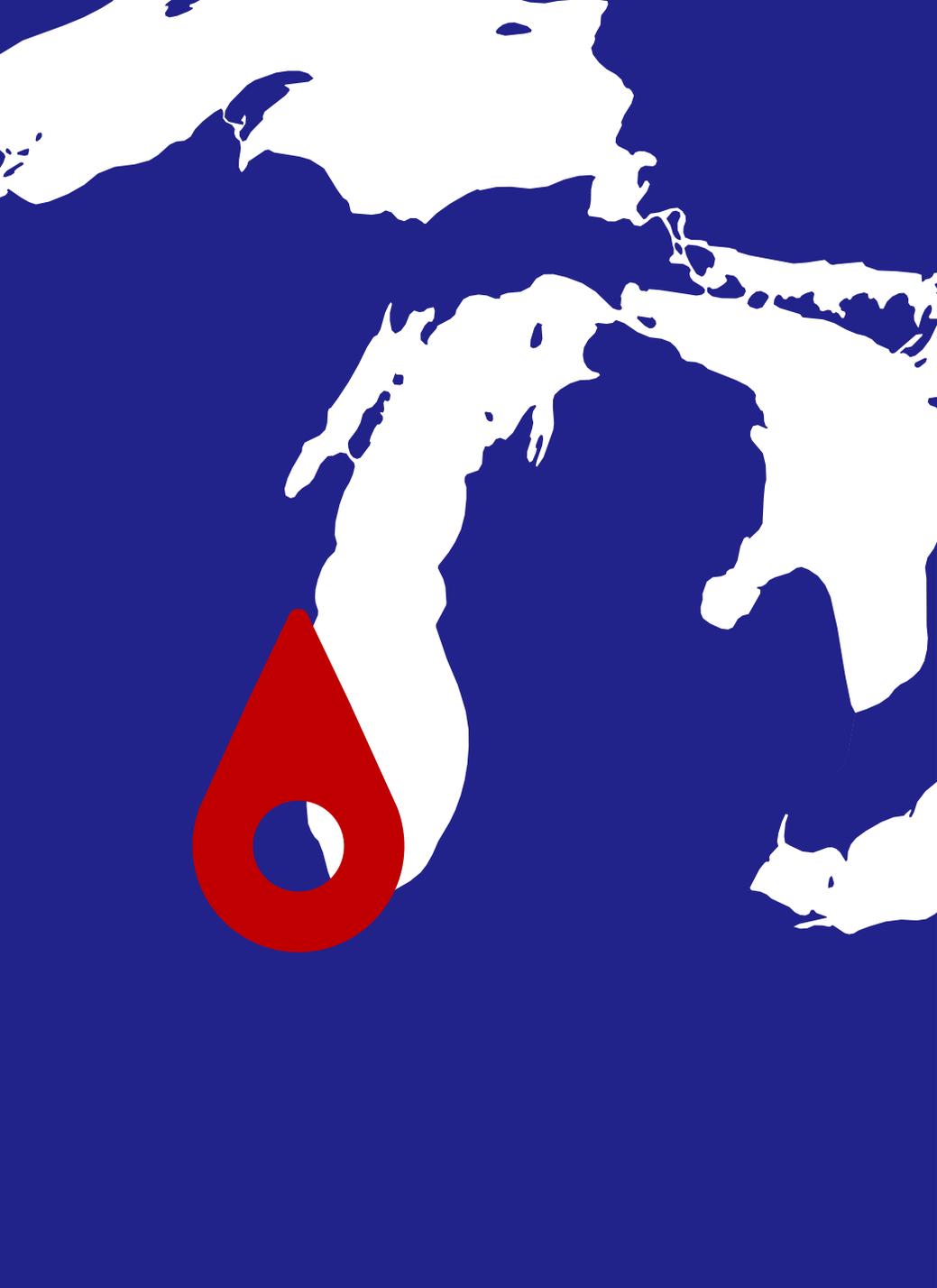
Palisades: 2022 vs 2020



Palisades: 2022 vs 2020







Point Beach Nuclear Power Plant

Location: Two Rivers, Wisconsin, USA

Operator: NextEra Energy Point Beach, LLC

Unit 1

License Expires: 10/05/2030

Reactor Type: Pressurized Water Reactor

Licensed MWt: 1,800

Reactor Vendor/Type: Westinghouse Two-Loop

Containment Type: Dry, Ambient Pressure

Unit 2

License Expires: 03/08/2033

Reactor Type: Pressurized Water Reactor

Licensed MWt: 1,800

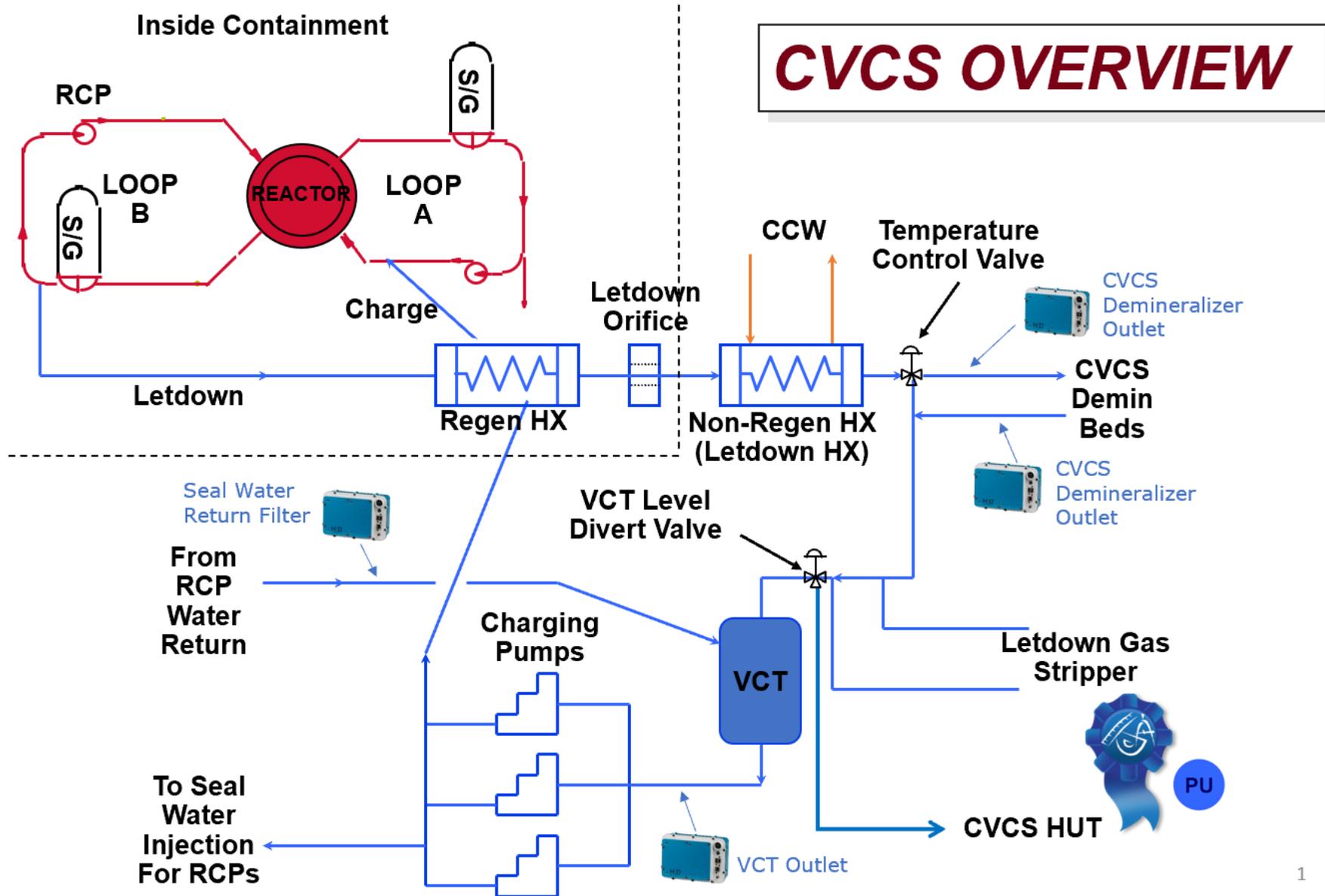
Reactor Vendor/Type: Westinghouse Two-Loop

Containment Type: Dry, Ambient Pressure

Case Study: Point Beach

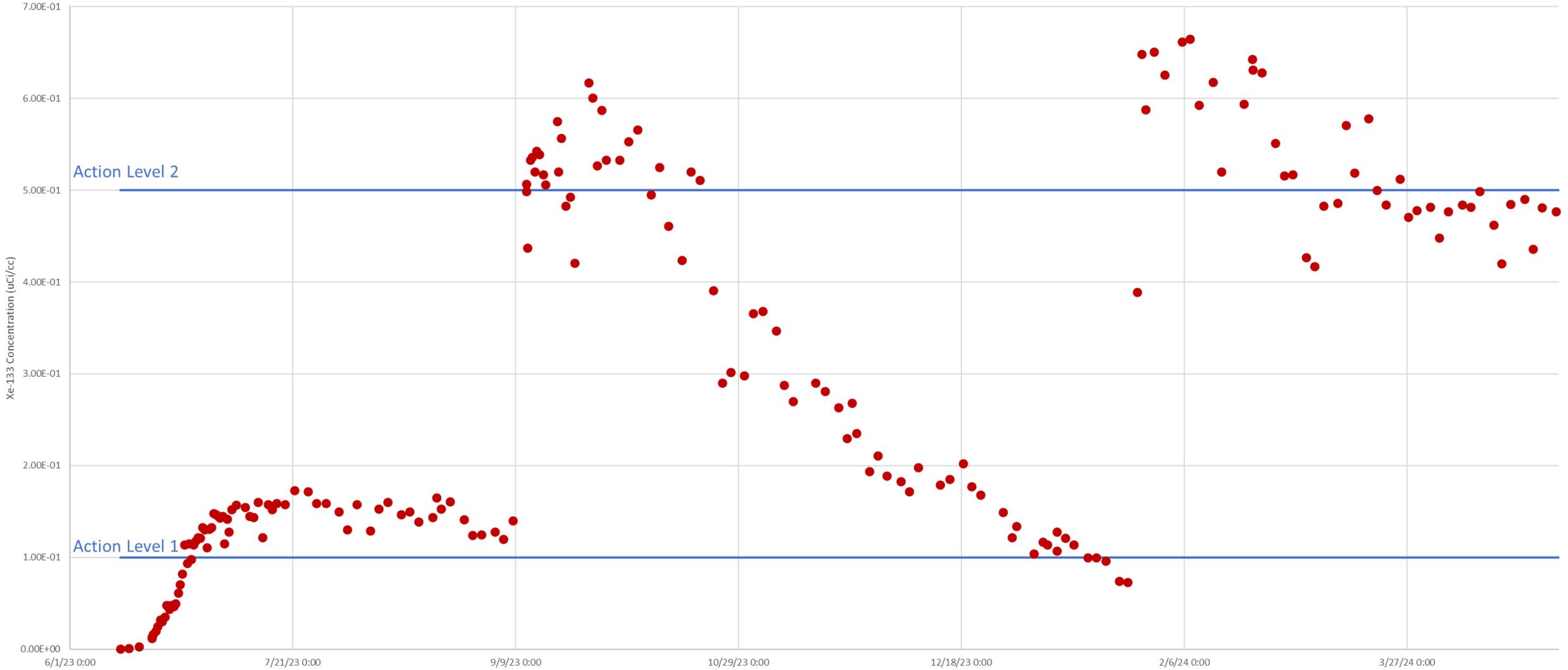
- 2023 Implementation of field spectrometers prior to Unit 2 outage
- Instrument placement at five locations on Unit 2 and, later, on Unit 1
- Monitoring performed continuously outage and during plant operation

Measurement Strategy



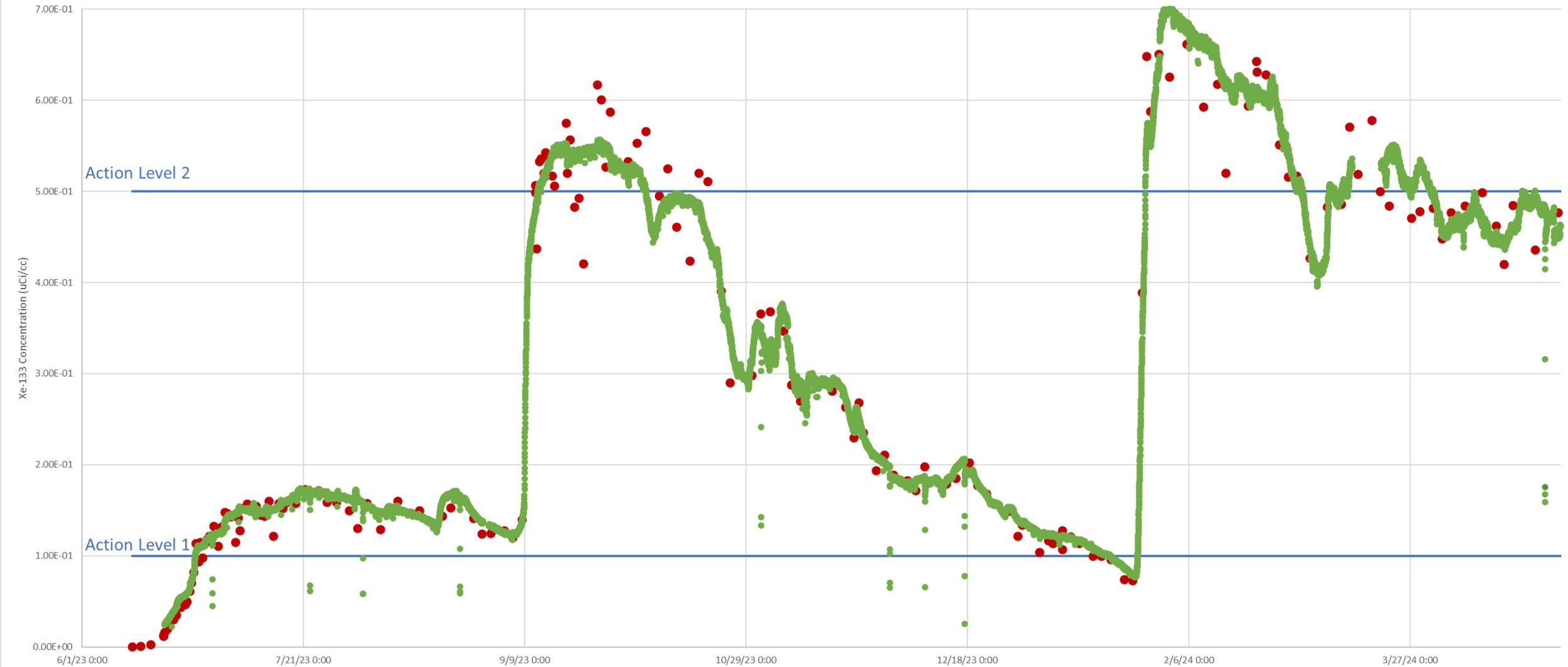
Xe-133 Trend

Xe-133 Concentrations Derived via Chemistry Sample and GammaTrend Monitoring



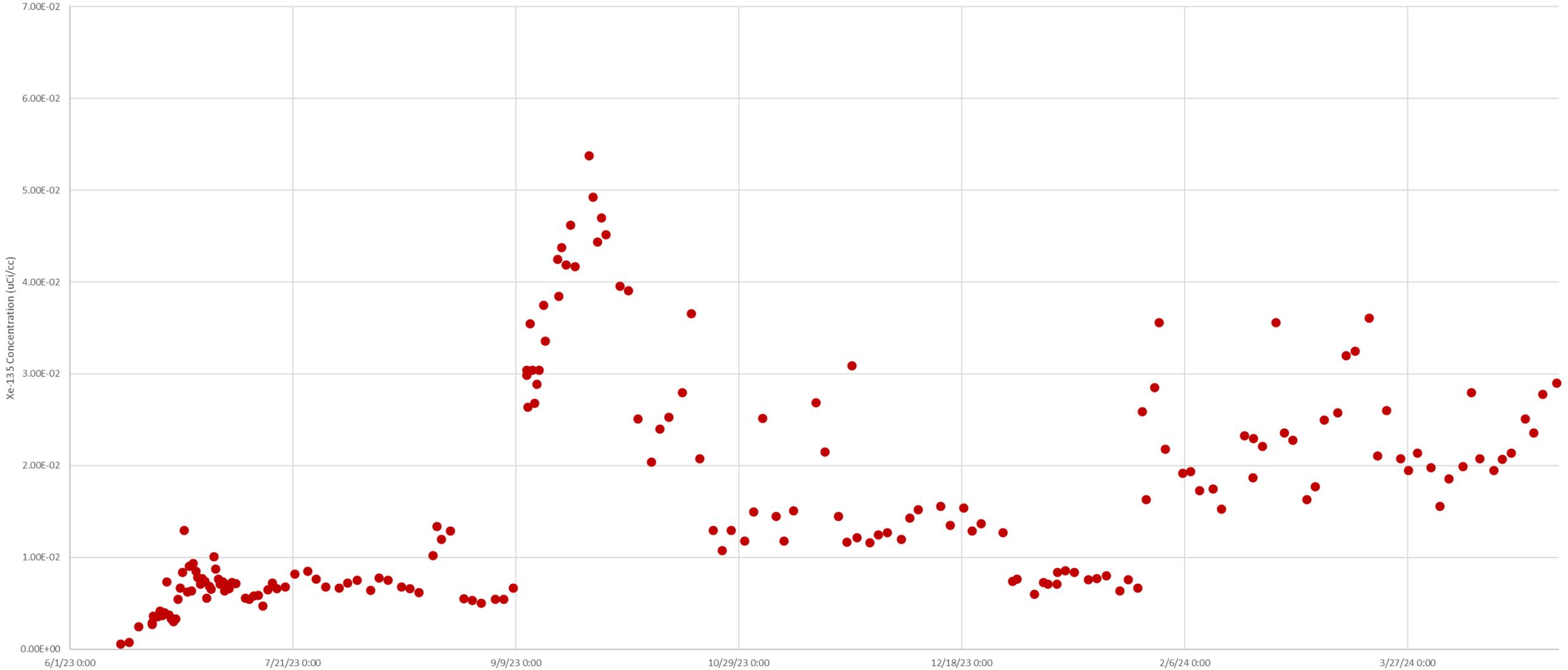
Xe-133 Trend

Xe-133 Concentrations Derived via Chemistry Sample and GammaTrend Monitoring



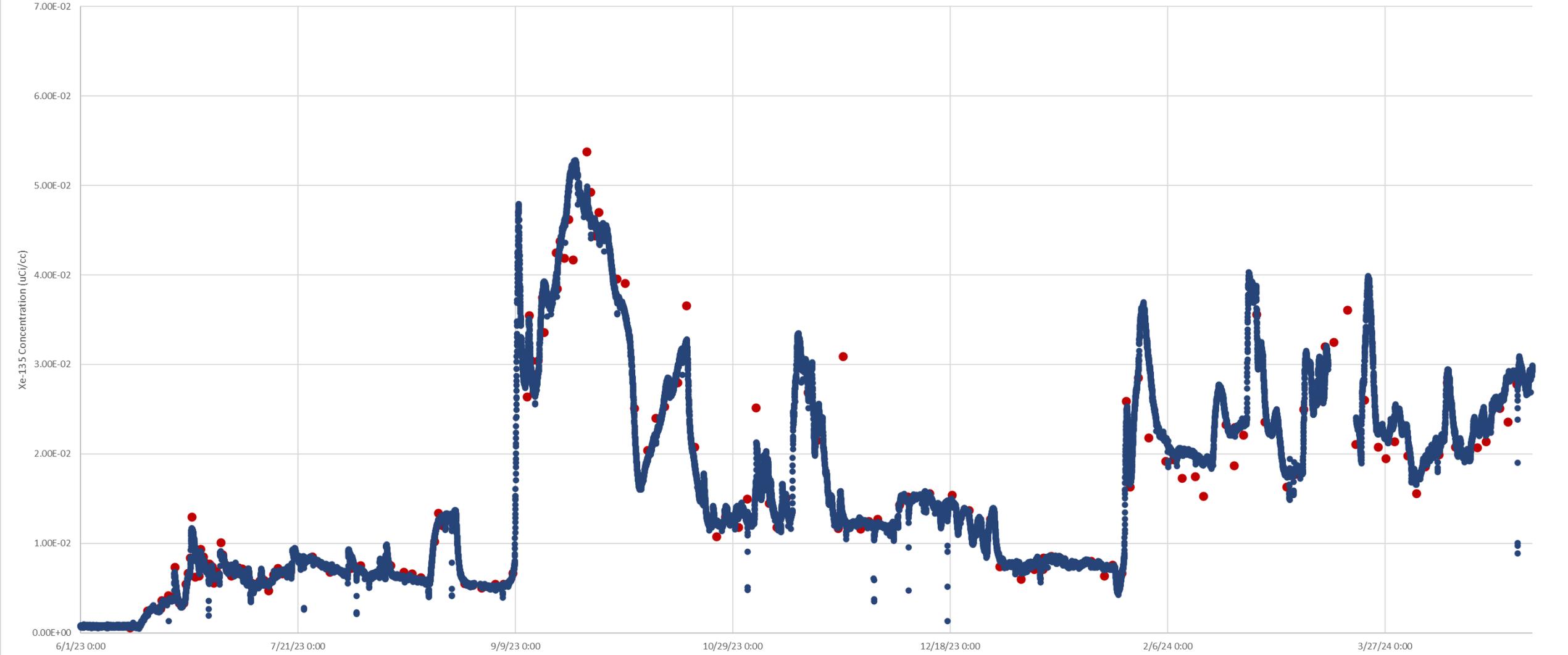
Xe-135 Trend

Xe-135 Concentrations Derived via Chemistry Sample and GammaTrend Monitoring

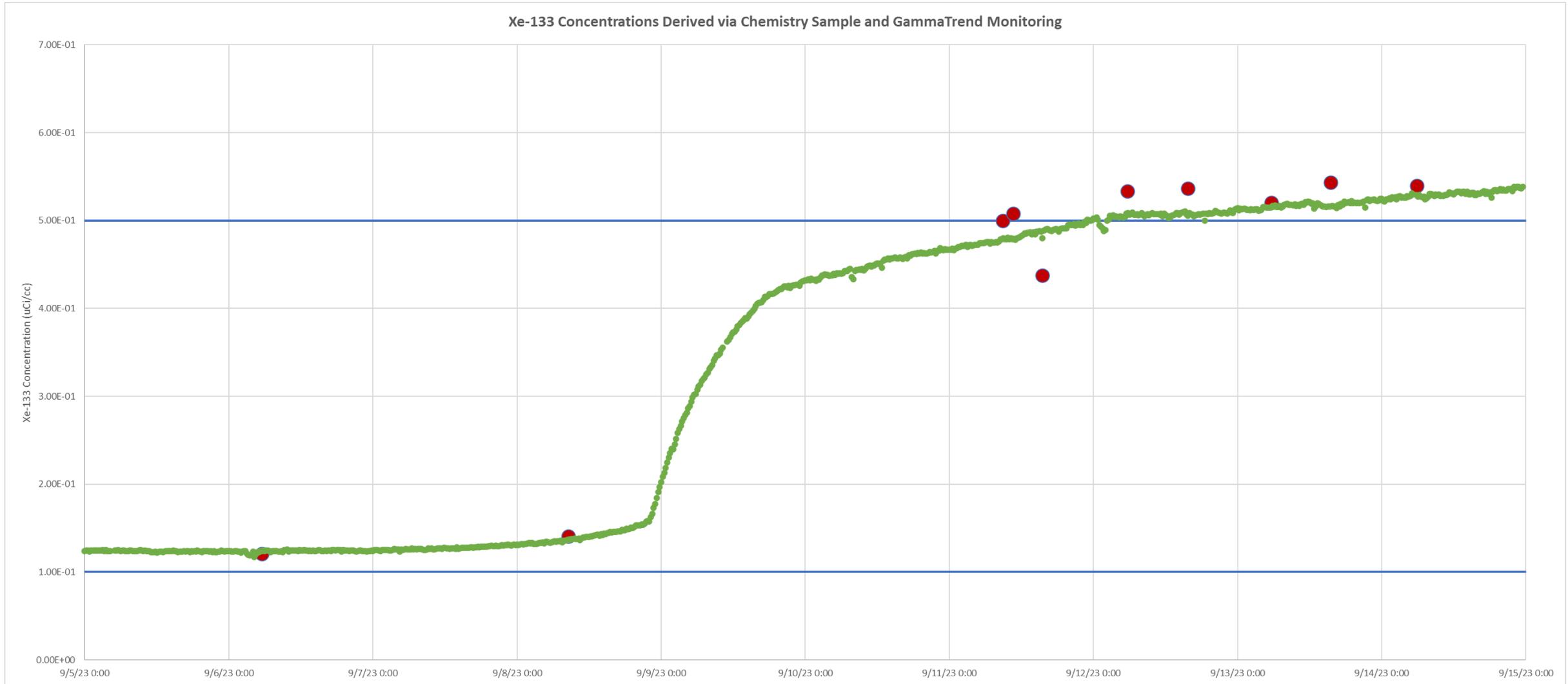


Xe-135 Trend

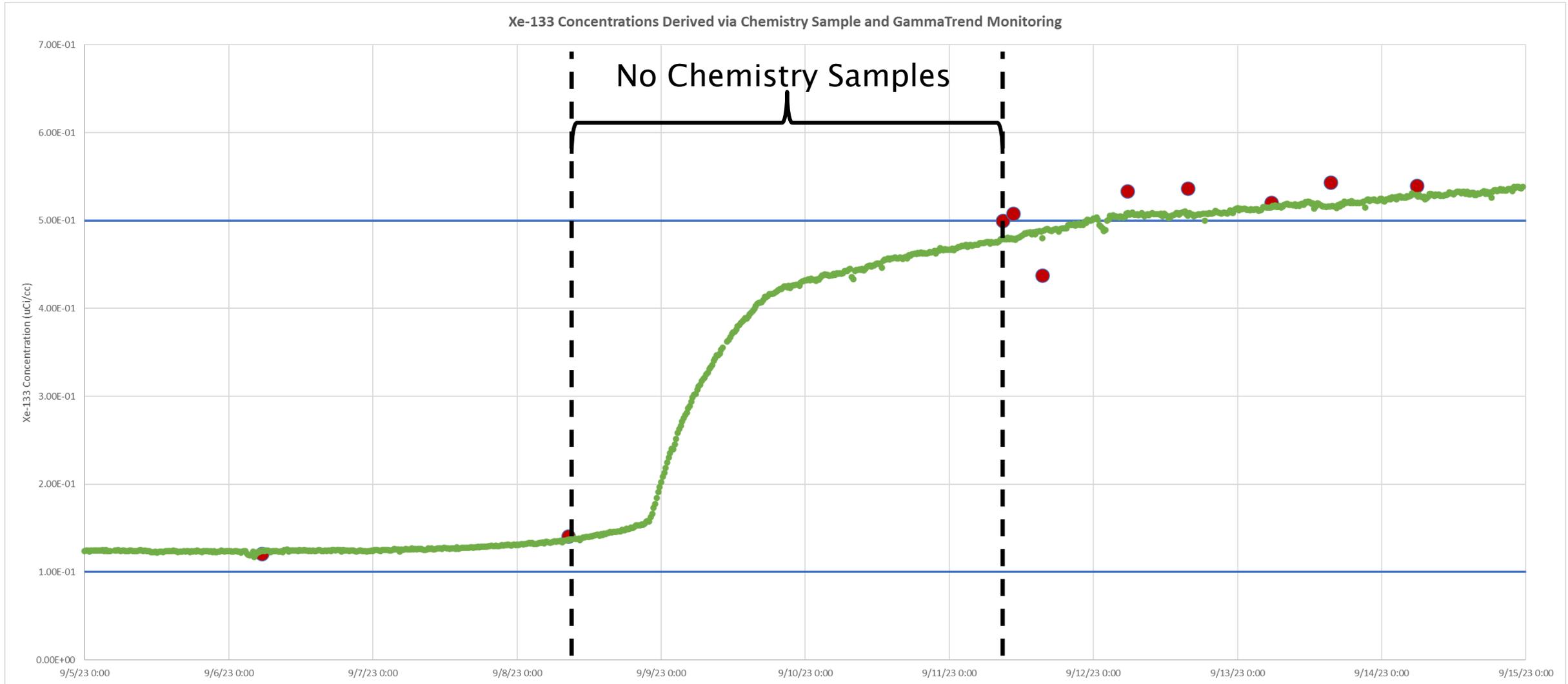
Xe-135 Concentrations Derived via Chemistry Sample and GammaTrend Monitoring



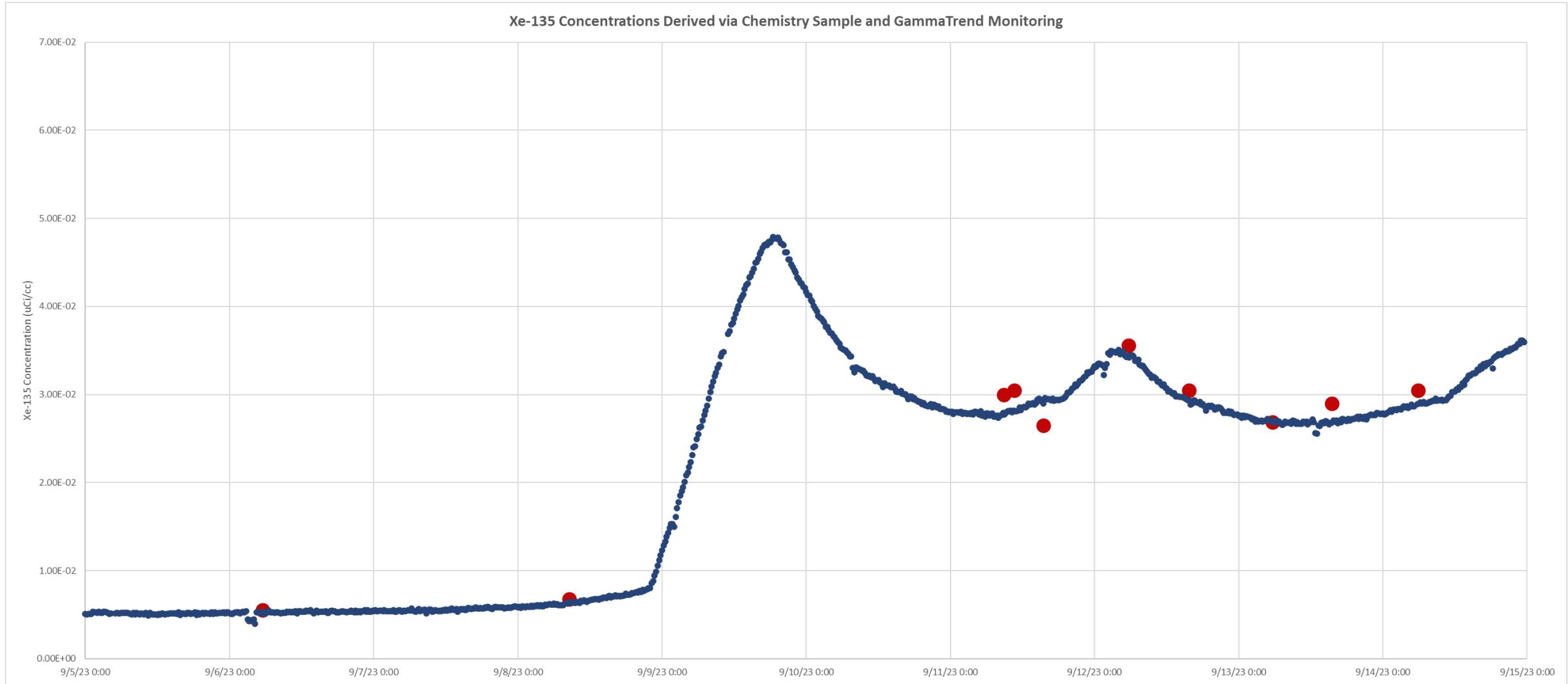
Xe-133 Trend (during Step Change to AL2)



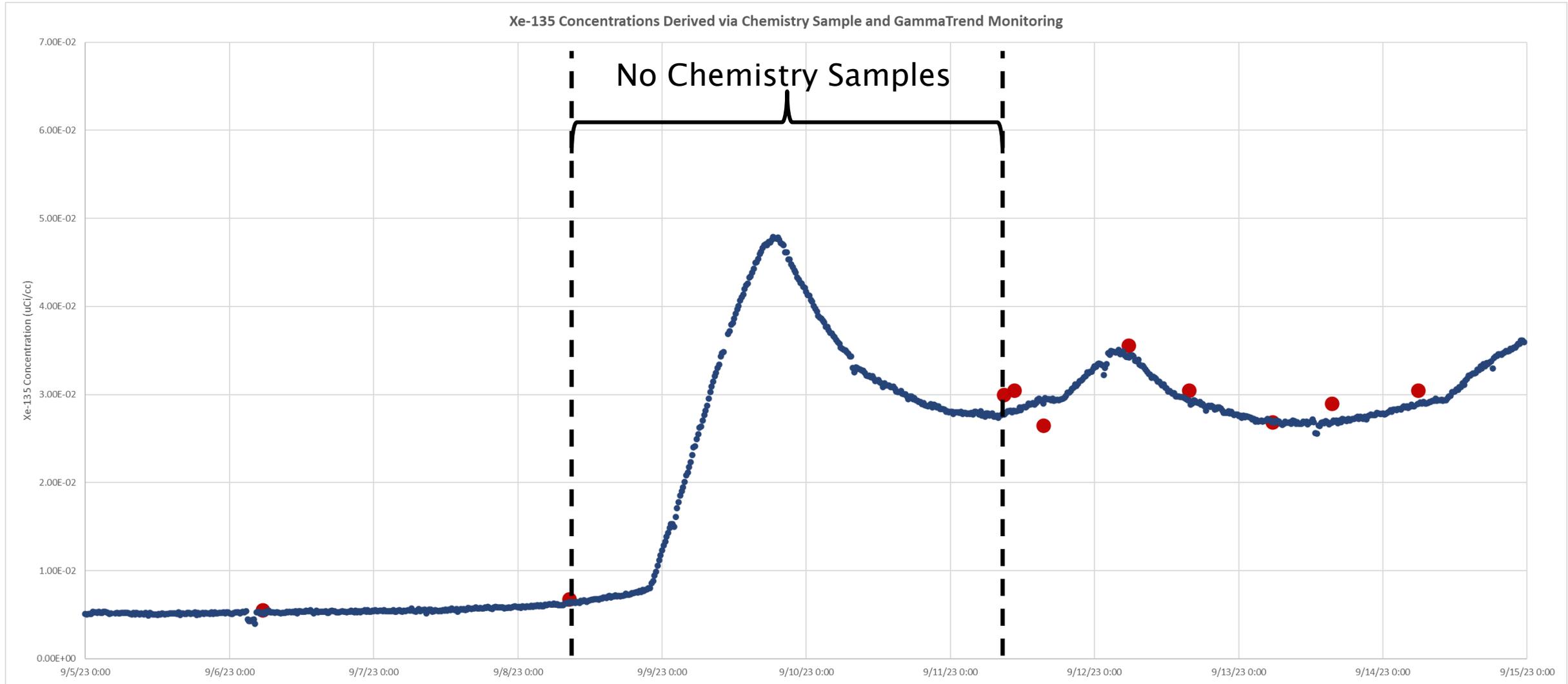
Xe-133 Trend (during Step Change to AL2)



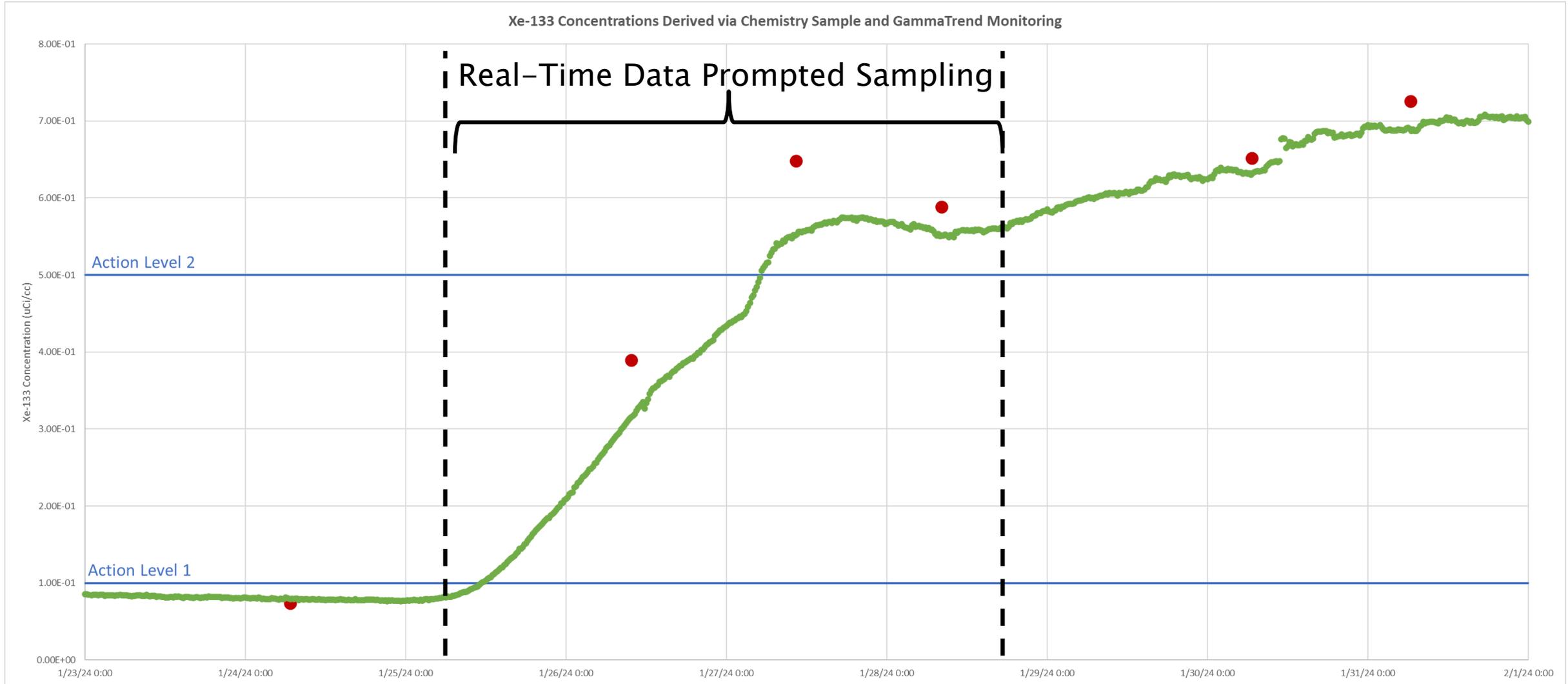
Xe-135 Trend (during Step Change to AL2)



Xe-135 Trend (during Step Change to AL2)

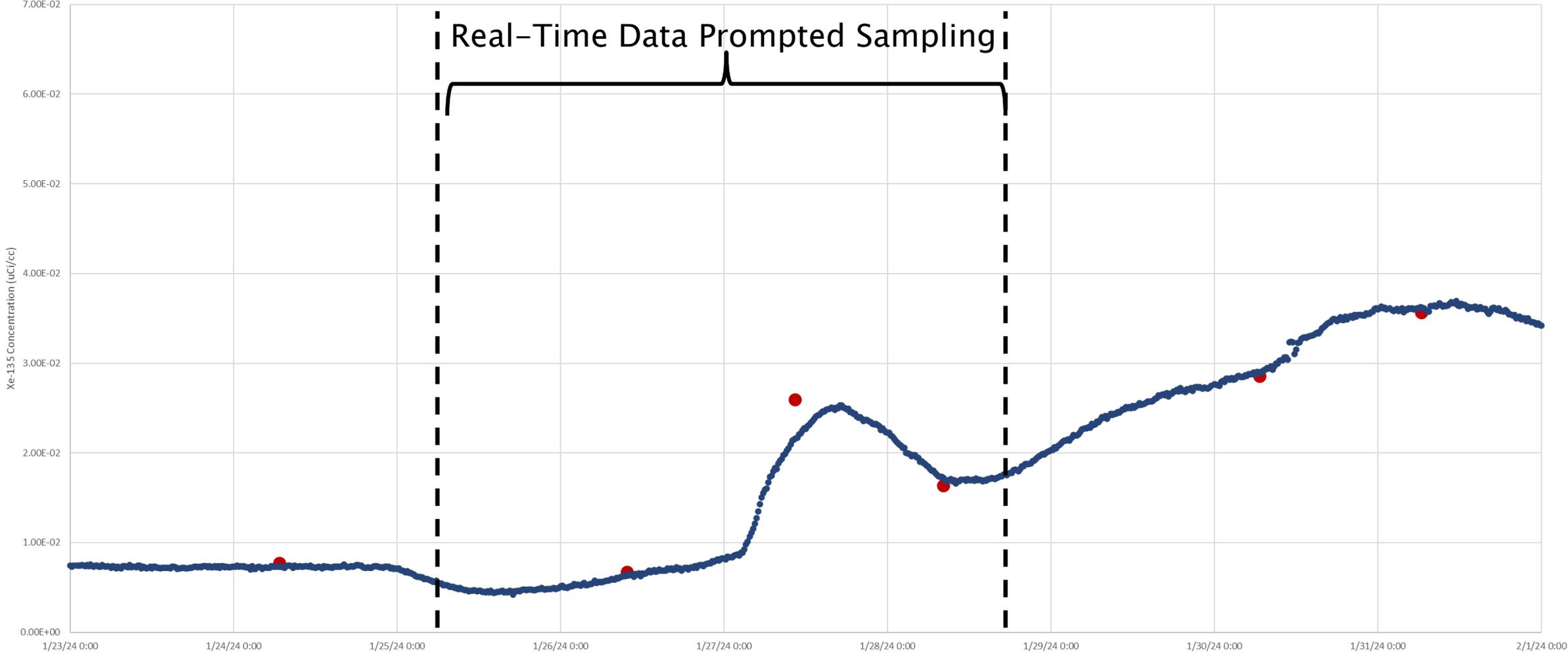


Xe-133 Trend (Next Step Change to AL2)



Xe-135 Trend (Next Step Change to AL2)

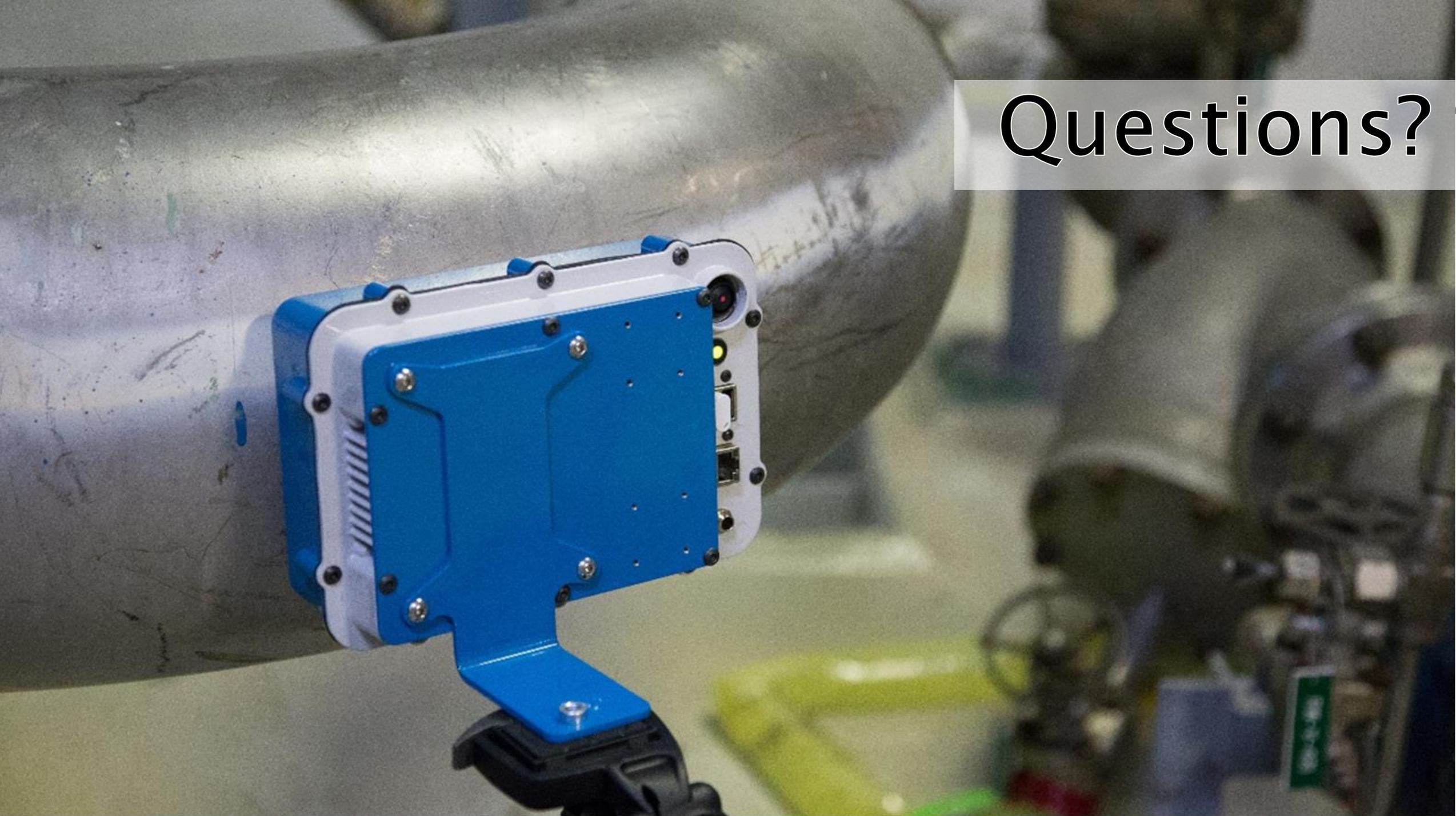
Xe-135 Concentrations Derived via Chemistry Sample and GammaTrend Monitoring



Case Study: Point Beach

- Lessons learned
 - Field spectrometers can provide:
 - Immediate indication of changes (intended or not) in the source term
 - Greater precision showing how source term changes over small periods of time between manual sampling (eg, Xe-133/Xe-135 ratios)
 - Precision of data collection allows for interrogation of plant activities for impacts to source term
 - Can provide insights as to when chemistry sampling should be performed outside of schedule.
 - Understanding of what nuclides are impacting dose rates at each location
 - **A lot of data** – Personnel development opportunity to collect/interpret data and champion program impact

Questions?

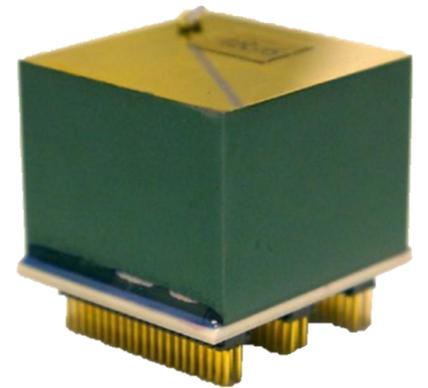
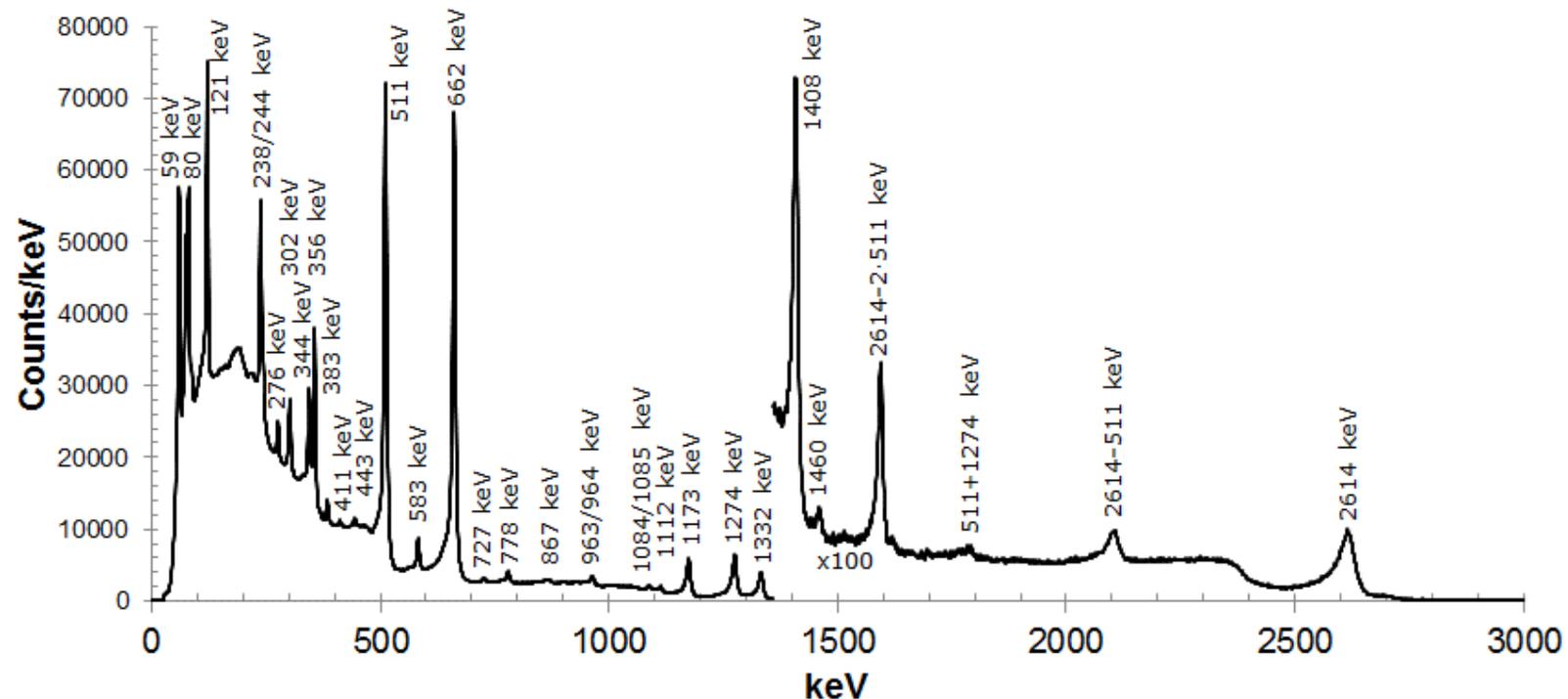


CZT Field Spectrometer Applications

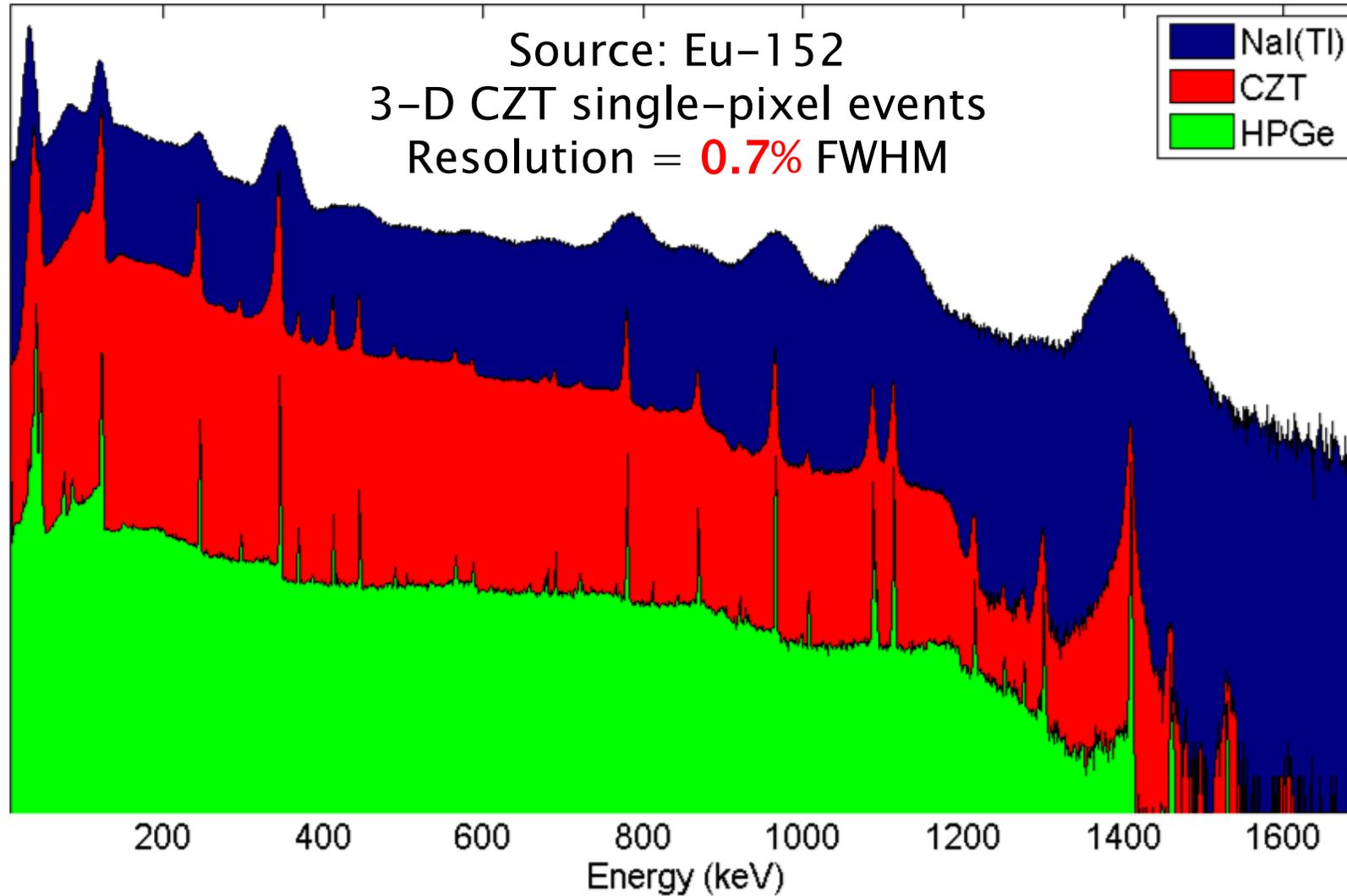
- Initial CZT offerings were gamma cameras 2014–2017
- ~2017: Request from industry to monitor nuclide-specific real-time trends of process lines.
- Initial usage: CRUD Burst monitoring
- More recently:
 - Online and Outage monitoring to support source term understanding and STR initiatives
 - KOH injection pilot (potential source term changes)
 - 2023: Multiple plants trending fuel defects

Why CZT for Real-Time Field Spectroscopy?

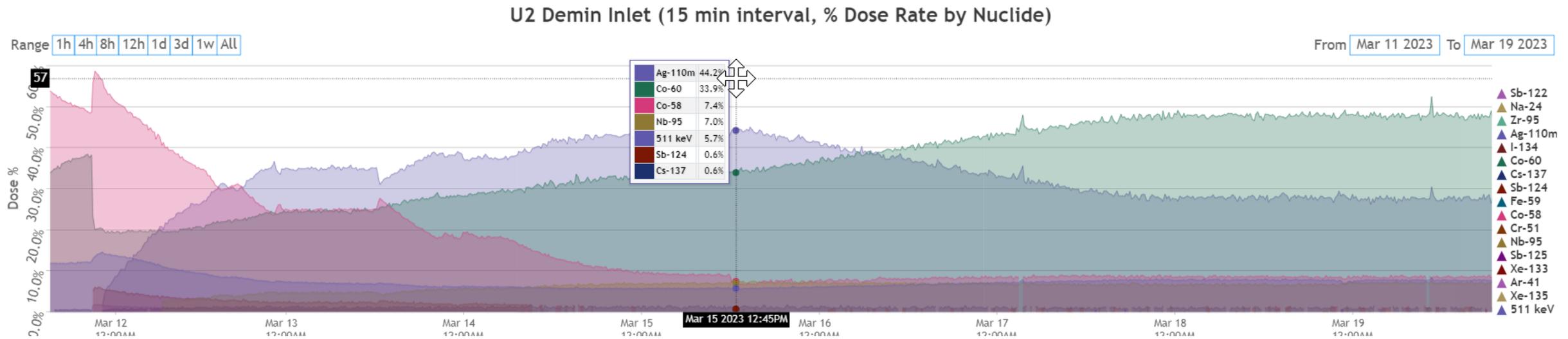
- NaI: **7% @662 keV**, room-temperature operation
- HPGGe: **0.2% @662 keV**, **-200C operation temperature**
- 3D CZT: **<0.8% @662 keV**, room temperature, up to 24 cm³
- Best of both worlds: HPGGe-like energy resolution + rugged



CZT versus HPGe and Scintillators



Dose Rate Contributors over Time



Dose Rate Contributors over Time

	CRUD Burst	CRUD Burst + 48 hours	"Normal" – Online stable
U2 Pre-Demin	59% Co-58 20% Co-60 13% 511-keV 6% Sb-124	38% Ag-110m 28% Co-60 19% Co-58 6.3% 511-keV 5% Nb-95	68% 511-keV 18% Co-60 2% Co-58/Nb-95
U2 Post-Demin	54% Co-60 26% Co-58 12% 511-keV 3% Sb-124	72% Co-60 11% 511-keV 6% Co-58 3% Cs-137	57% 511-keV 38% Ar-41 3% Xe135(before defect) 2% Xe133 (before defect)
VCT Outlet	61% Co-58 30% Co-60 9% 511-keV	95% Co-60 4% Co-58	85% Co-60 11% 511-keV 2% Co-58
U2 RHR	50% Co-58 30% Co-60 9% 511-keV 8% Sb-124	45% Co-60 25% Co-58 19% Sb-124 5% Sb-122	86% Co-60 7% Co-58 5% Sb-124