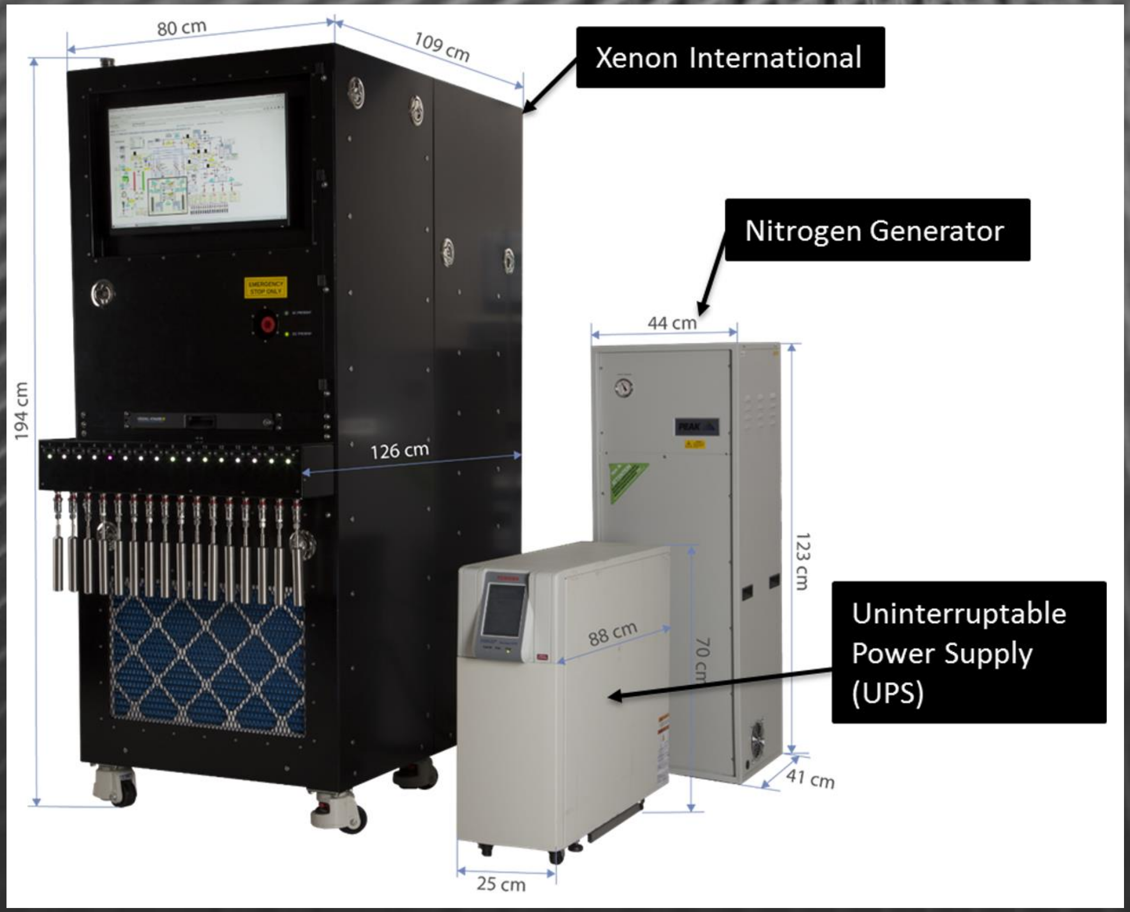
Xenon International

Jun 17, 2020

James C. Hayes

Pacific Northwest National Laboratory

WOSMIP



https://tbe.com/energy/xenon-international

Increased Sensitivity on Xenon International

- Increase (from IDC Requirement of 1 cm^3 to 2.5 cm^3) the amount of Xe (**V_{Air}**) in the detector.
- Faster collection (**T_C**) and processing time (T_P), from 12 to 6 hours.
- Increase sensitivity through improving the Minimal Detectable Concentration:

$$MDC\left(\frac{Bq}{m^3}\right) = \left(\frac{2.71 + 4.65 \cdot \sigma_{0_i}}{\varepsilon_{\gamma_i} \cdot \varepsilon_{\beta_i} \cdot BR_{\gamma_i} \cdot BR_{\beta_i}}\right)\left(\left(\frac{\lambda_i \cdot \boldsymbol{T_C}}{1 - e^{-\lambda_i \cdot \boldsymbol{T_C}}}\right)\left(\frac{1}{e^{-\lambda_i \cdot T_P}}\right)\left(\frac{\lambda_i}{1 - e^{-\lambda_i \cdot T_A}}\right)\right)\left(\frac{1}{\boldsymbol{V_{Air}}}\right)$$

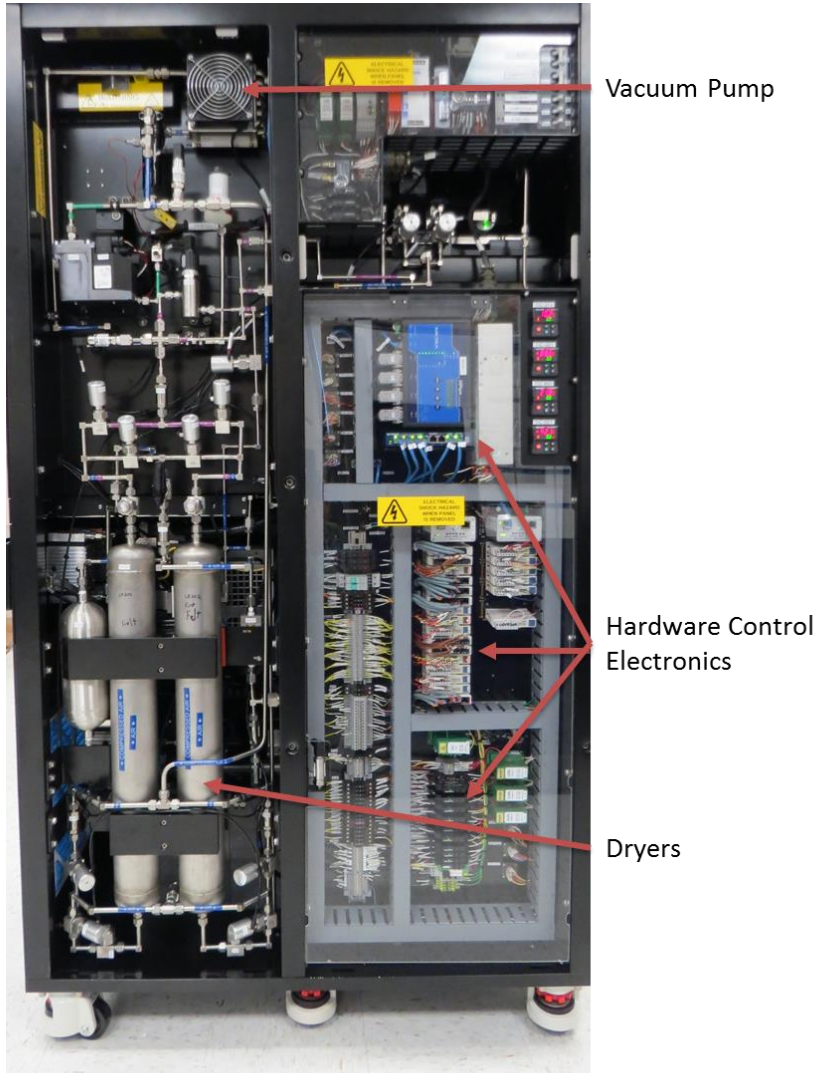
Major improvements

Xenon International Technical Goals and Specifications

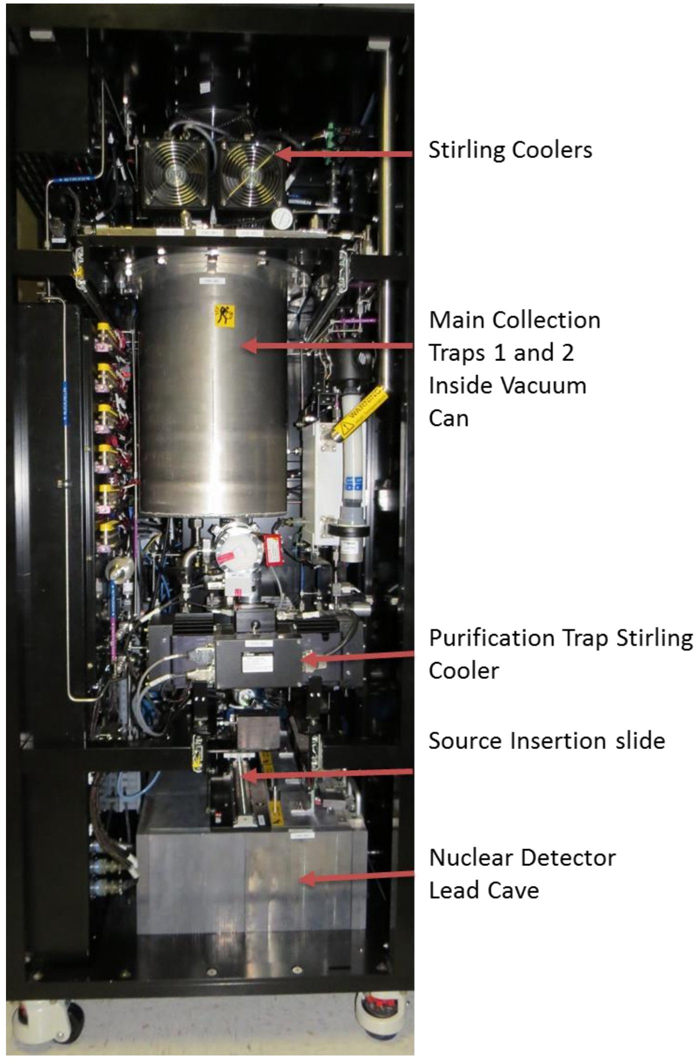
- **Increase sensitivity**
  - 6-hour collection, 4 samples per day, continuous sampling 24/7, 100% duty cycle
  - Increased flow rate 100 L/min (stp; 0°C, 760 torr)
  - MDCs: ^{133}Xe: 0.15 mBq/m^3, ^{135}Xe: 0.5 mBq/m^3, ^{131m}Xe: 0.15 mBq/m^3, ^{133m}Xe: 0.15 mBq/m^3
- **Improve reliability and uptime**
  - PNNL software and hardware control
  - Included manufacturer in design phase
  - 2-years of testing during development
    - ✓ Demonstrated combined uptime 97.8%
- **Reduce/eliminate consumables**
  - Nitrogen carrier gas (nitrogen generator on-site)
- **Reduce weight and size** of the system over currently deployed systems
  - 1240 kg, 80 cm X 109 cm X 194 cm
- **Reduce power** and heat load compared to current IMS xenon systems
  - 208 VAC (160-275 volt), 50/60 Hz, 30 amp circuit, 4kW (3.5 kW for Xenon International without nitrogen generator)

Xenon International's Integrated Functions

- Air Intake and Compression
- Air Drying
- Xenon Collection and Elution
- Separations
- Purification of Xenon
- Nuclear Detection of Radioxenon
- Xenon Quantification
- Xenon Archiving



Xenon International with right side panel removed



Xenon International with rear panel removed

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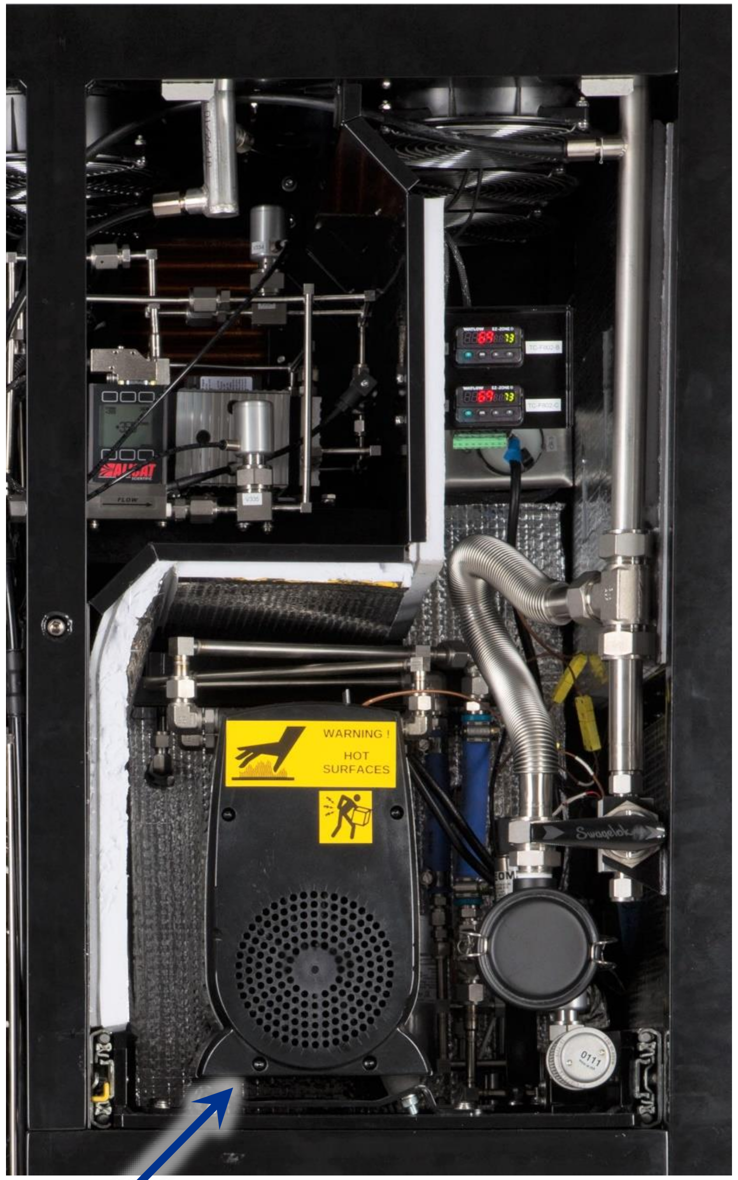
Air Intake and Compression

- Air flow is at **100 Liters per minute.**

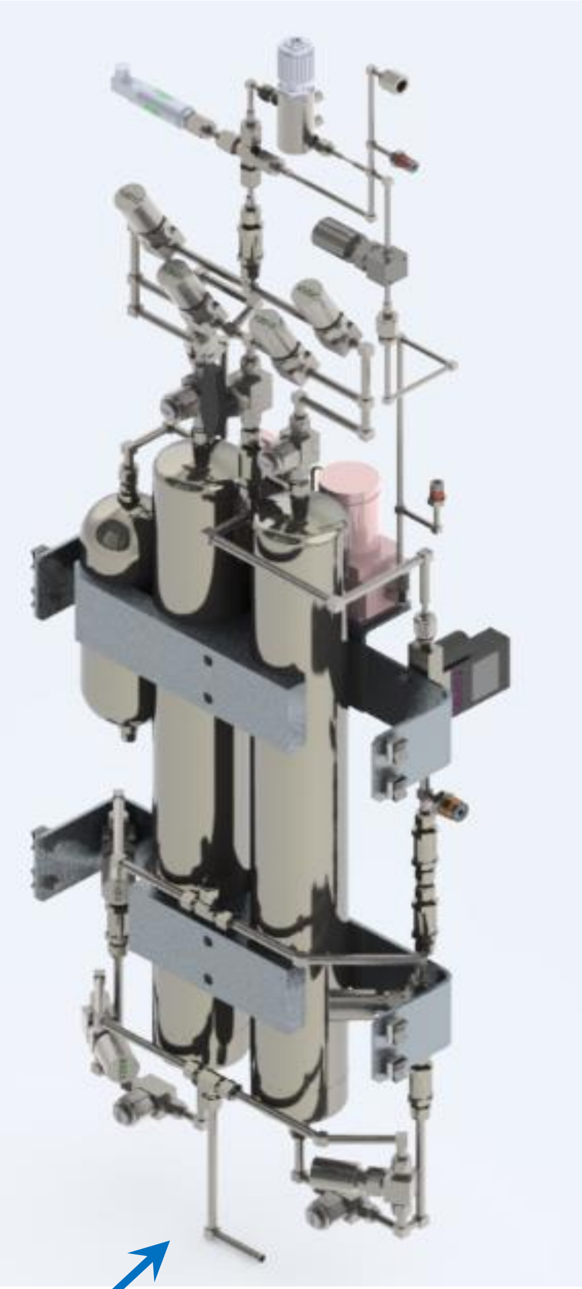
- The pressure is regulated and excess airflow is redirected to the compressor inlet, ensuring the target sample flow rate is met while allowing the compressor to operate at the target system pressure.



Compressor

Air Drying

- Two dryer columns remove CO_2 and H_2O.
- One column dries while the other regenerates.
- Regeneration of the dryers uses recirculated air that exits from the main trap.
- The dryer cycle has been optimized for minimal product loss while still sufficiently drying the air for the low temperature collection trap.



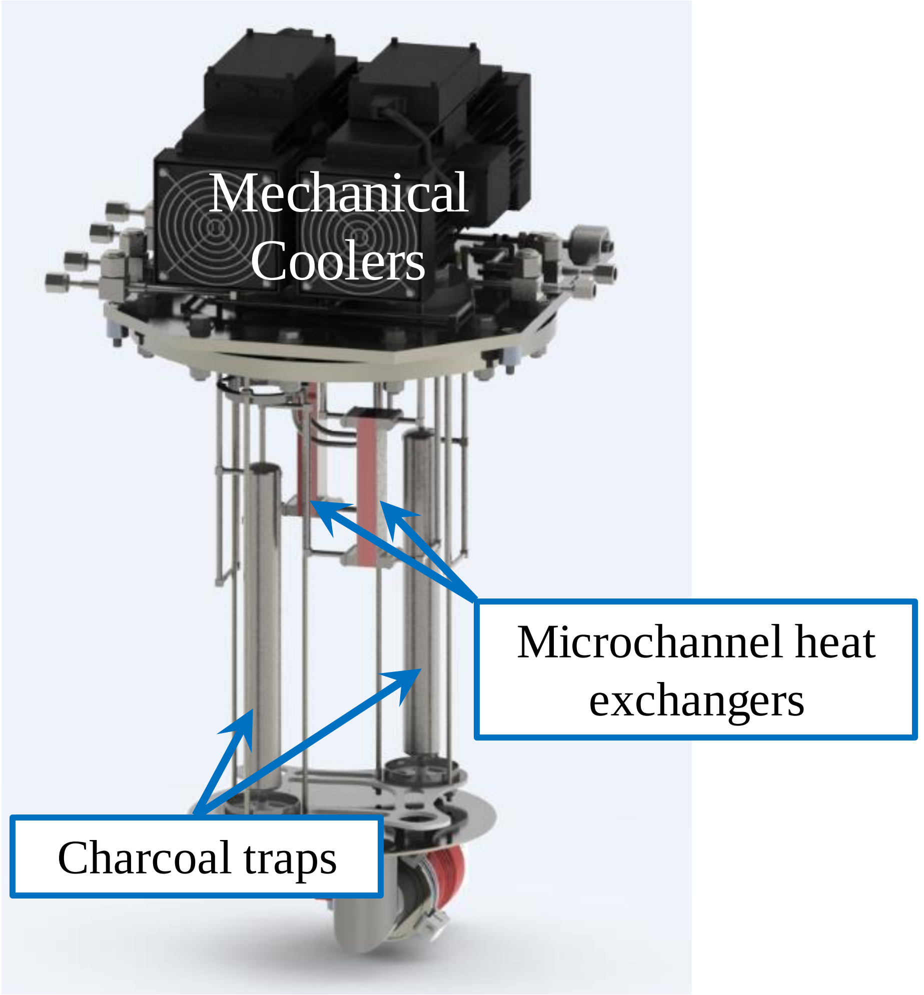
Drying Manifold Model

Dryer Columns

Xenon Collection and Elution

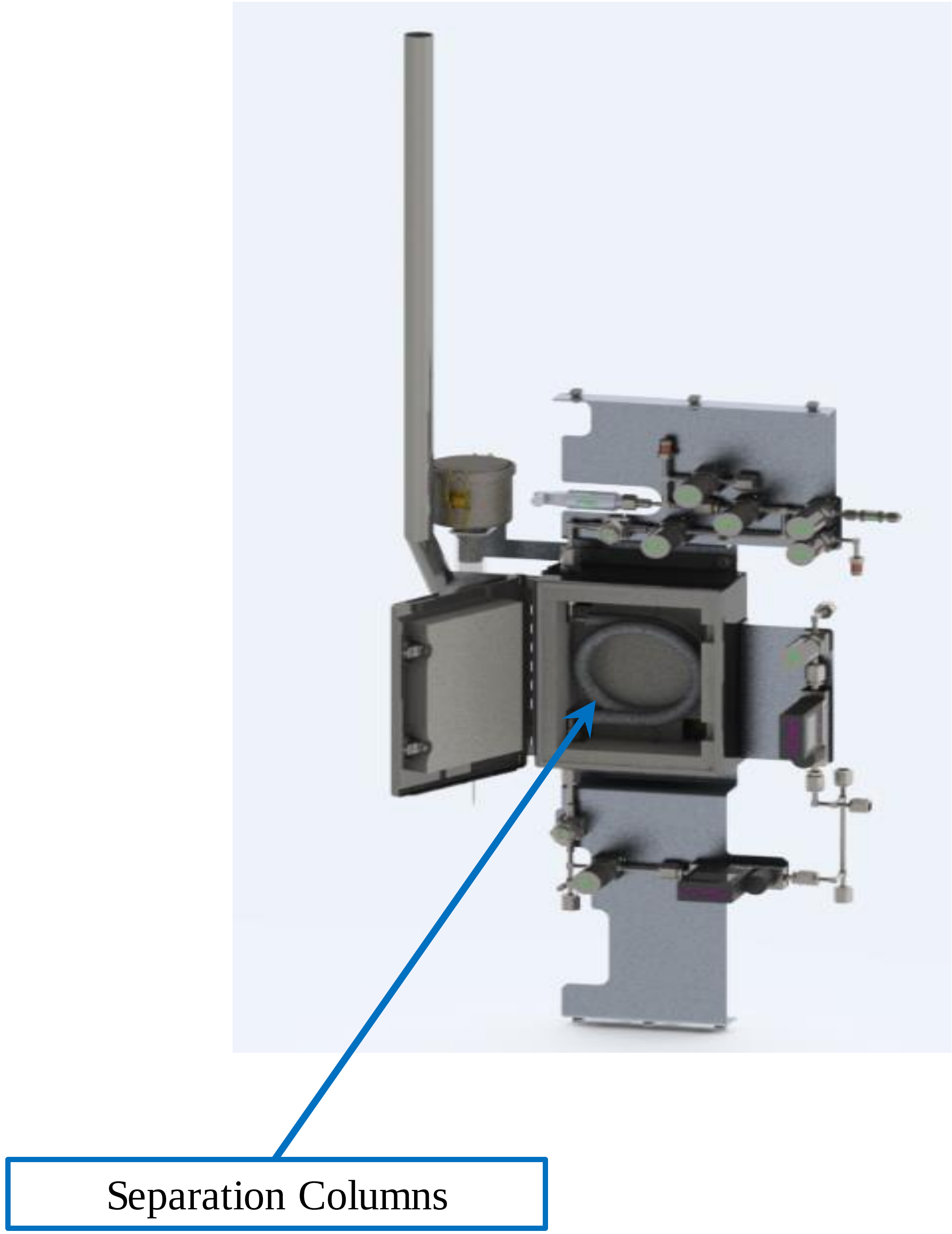
Collection and elution use:

- Two **high efficiency microchannel heat exchangers.**
  - **Recuperation of energy** through highly efficient heat exchange of incoming air and discharged cold air.
- **Two mechanical cooler units** that allow a minimal amount of activated charcoal (~200 grams per trap) to be used and still have a very efficient collection.
  - Modeling to **optimize charcoal volume.**
- Two parallel activated charcoal traps alternate between collecting and regenerating after the sample is eluted off.
  - The traps undergo oxygen removal and then are heated to the desorption temperature while sealed. The sample is pushed onto the separation column in a short time so that the sample is not diluted by an extended elution process.
- Collection and elution requires sophisticated software to monitor and regulate the temperature to efficiently process samples.



Separations

- Xenon is separated from contaminants using a molecular sieve separation column.
- Nitrogen gas from the nitrogen generator is used as a carrier to push the xenon through the separation column.
- The columns perform clean separations of xenon from carbon dioxide, radon, and other trace components.

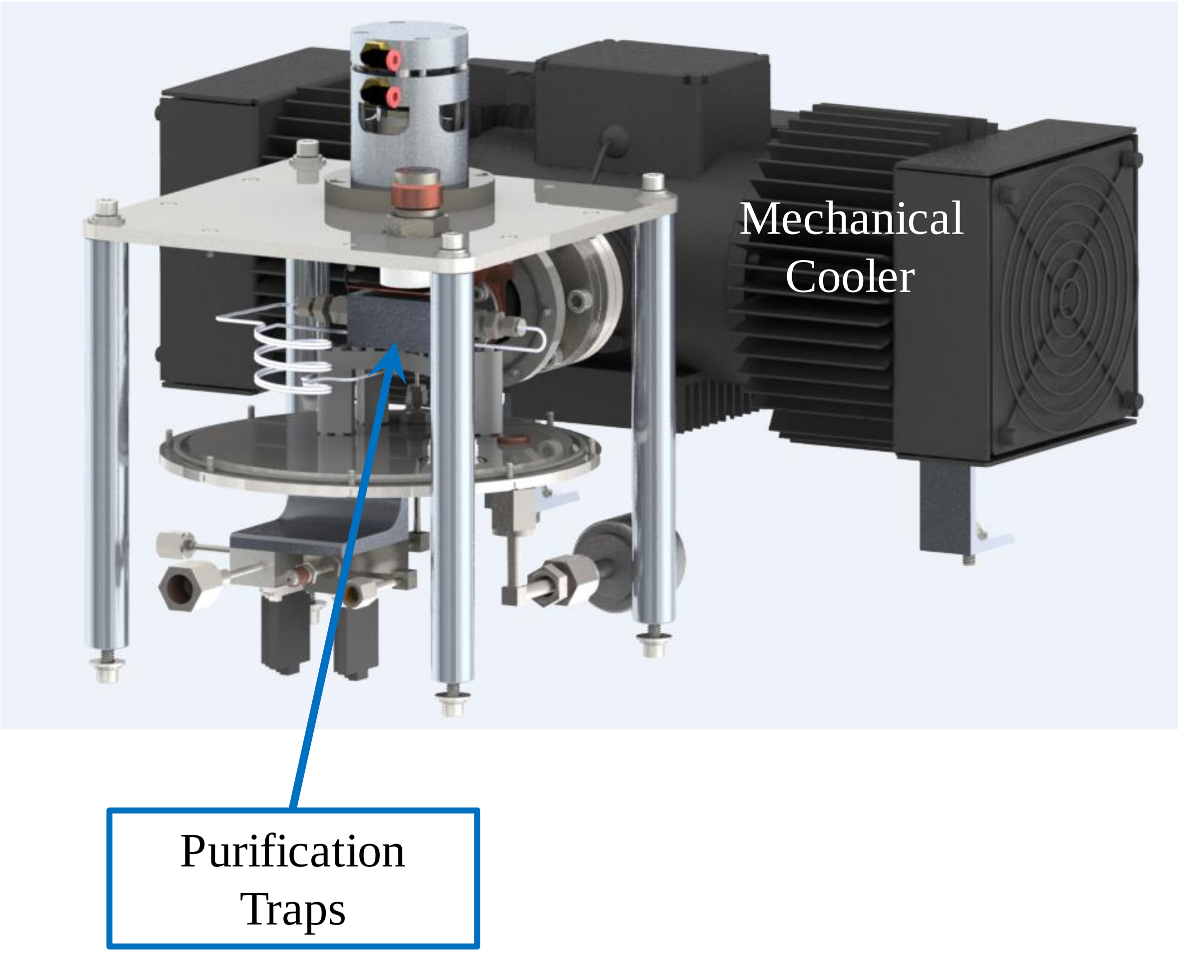


Purification of Xenon

- The purification trap is cooled to an optimal temperature to efficiently collect xenon and remove impurities.

- Due to the cold temperatures of the process, very little activated charcoal is required (~120 mg).

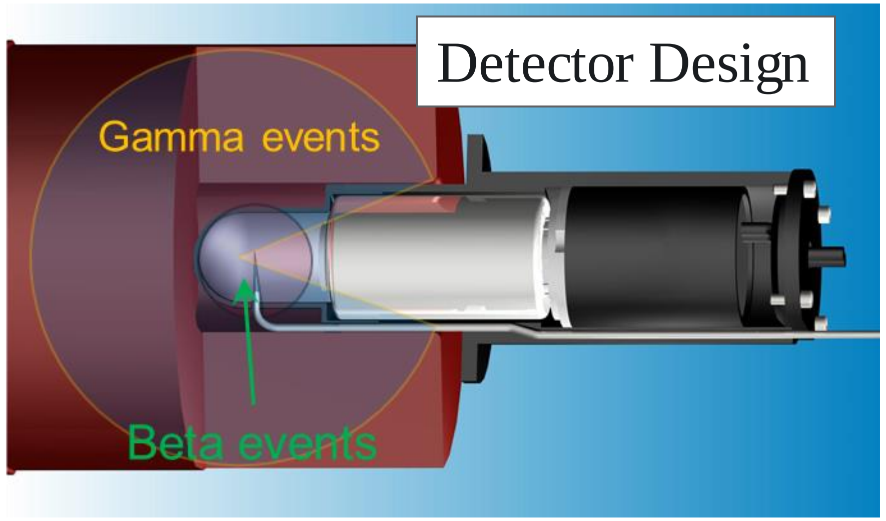
- Processing in the purification trap allows the xenon to volumetrically expand into the detector cell with high efficiency. This is followed by a nitrogen push that quantitively transfers the sample into the nuclear detector.



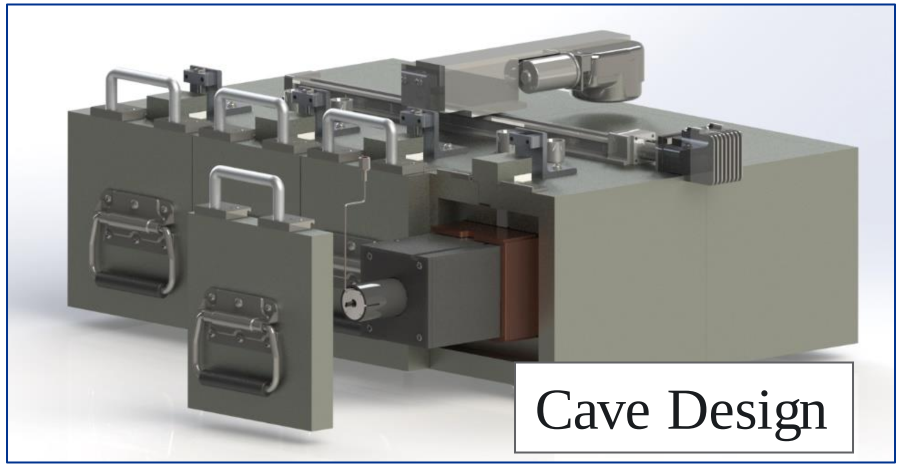
Nuclear Detection of Radioxenon

Four beta-gamma detectors allow measurement of the xenon isotopes from a continuous 6-hour collection process.

- The beta detector uses a coated plastic scintillator to reduce the memory effect and has a curved end to enable light collection by a **single PMT**.
- The gamma detector is a NaI(Tl) well detector that has high detection efficiency.
- QC uses a single ^{137}Cs source.
  - Uses an automated gain correction based on a rotated frame of reference analysis.
  - **Demonstrated to have < 2% drift over a 1-year field test**.



Detector Design


Cave Design

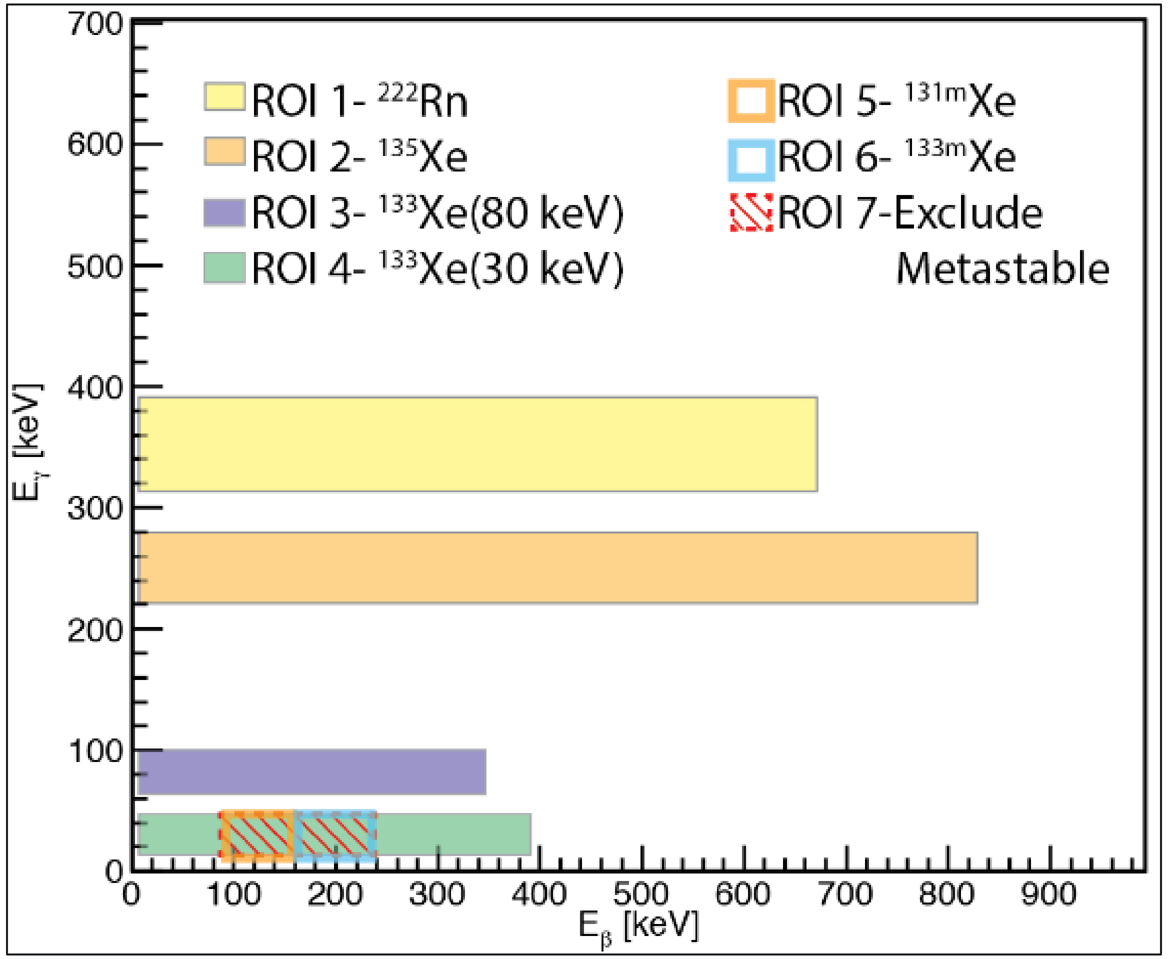

Beta Cell

Nuclear Detector: Regions-of-Interest

Xenon International uses the net count calculation (NCC) method for analysis.

- Seven regions-of-interest provide robust analysis while minimizing complexity.
- Interferences are assumed to always be present, so interference subtractions are always performed.

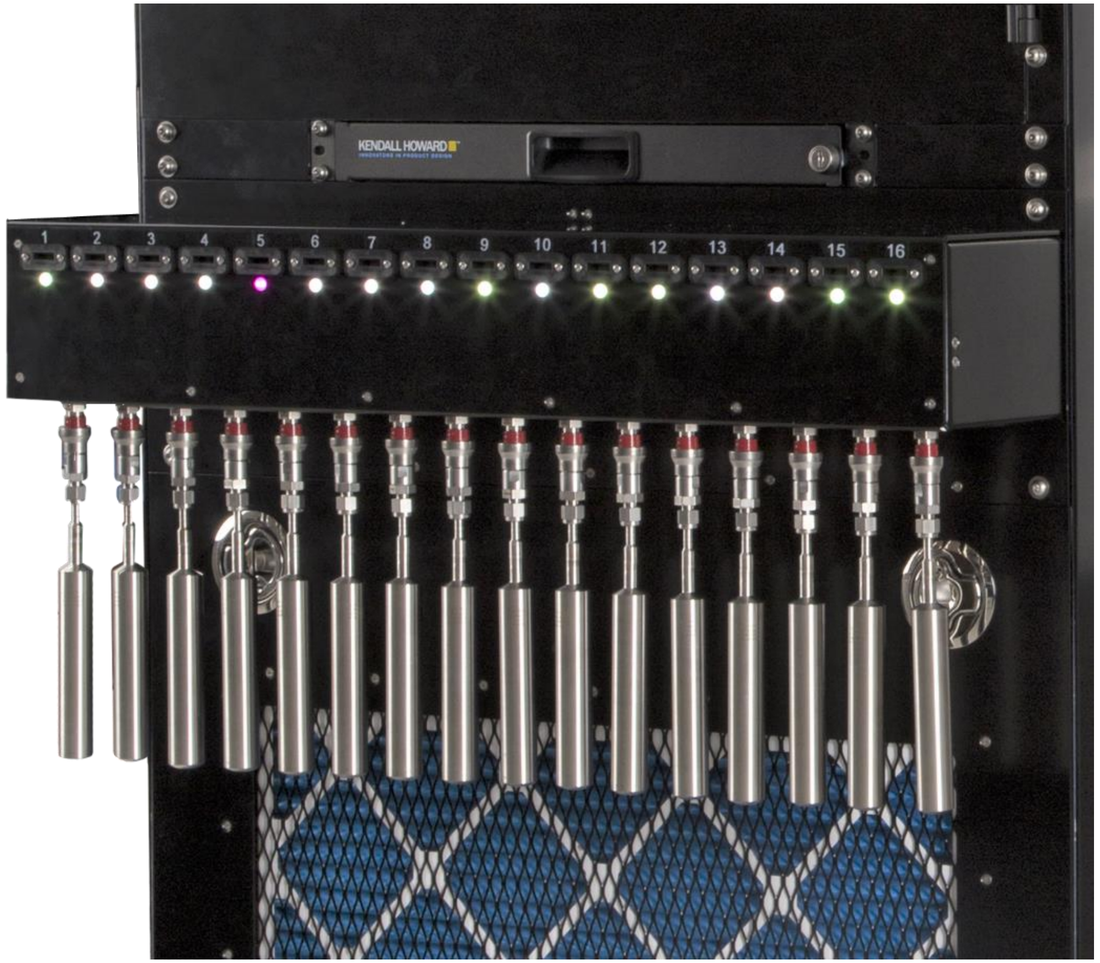
Region	Isotope of interest	7 ROI Nomencl ature	Typical Gamma range (keV)	Typical Beta range (keV)
1	^{222}Rn (352 keV of ^{214}Pb)	7R-1	313-391	4-672
2	^{135}Xe	7R-2	220-280	4-830
3	^{133}Xe (80 keV)	7R-3	63-99	4-346
4	^{133}Xe (30 keV)	7R-4	15-48	4-392
5	^{131m}Xe	7R-5	15-48	90-164
6	^{133m}Xe	7R-6	15-48	165-238
7	^{133}Xe	7R-7	15-48	87-241



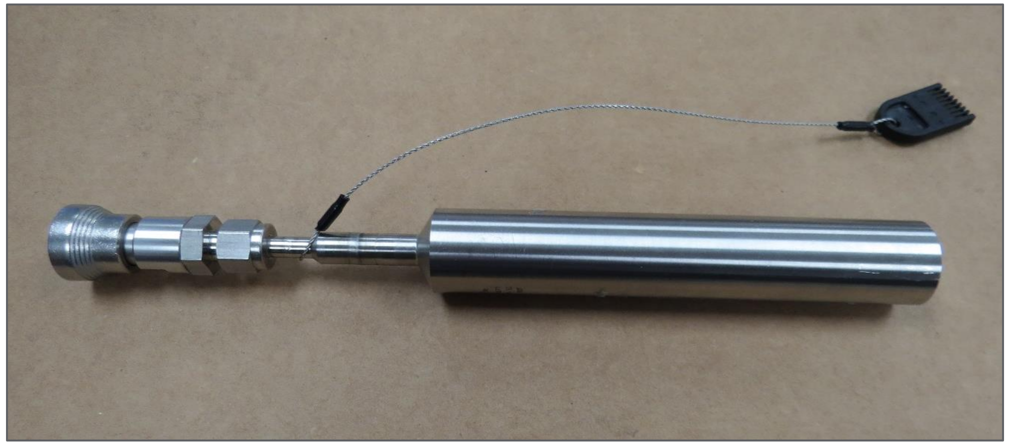
Cooper, M. W., M. Auer, T. W. Bowyer, L. A. Casey, K. Elmgren, J. H. Ely, M. P. Foxe, A. Gheddou, H. Gohla, J. C. Hayes, C. M. Johnson, M. Kalinowski, F. J. Klingberg, B. Liu, M. F. Mayer, J. I. McIntyre, R. Plenteda, V. Popov, and M. Zahringer, 2019, **Radioxenon Net Count Calculations Revisited**, *Journal of Radioanalytical and Nuclear Chemistry*, doi:10.1007/s10967-019-06565-y.

Xenon Archiving

- Xenon International has a 16-bottle archiving system.
  - Provides 4 days of archiving.
- Archive bottles allow samples to be sent to a radionuclide laboratory for confirmatory measurement.
- Bottle size, 50 cm^3, was selected to exceed xenon archive volume requirement of 0.32 cm^3.
  - Provides 1.8-2.1 cm^3 xenon archival samples.



Xenon International Archiving Manifold



Photograph of a sample archive bottle

Xenon International Operational Field Test (OFT)

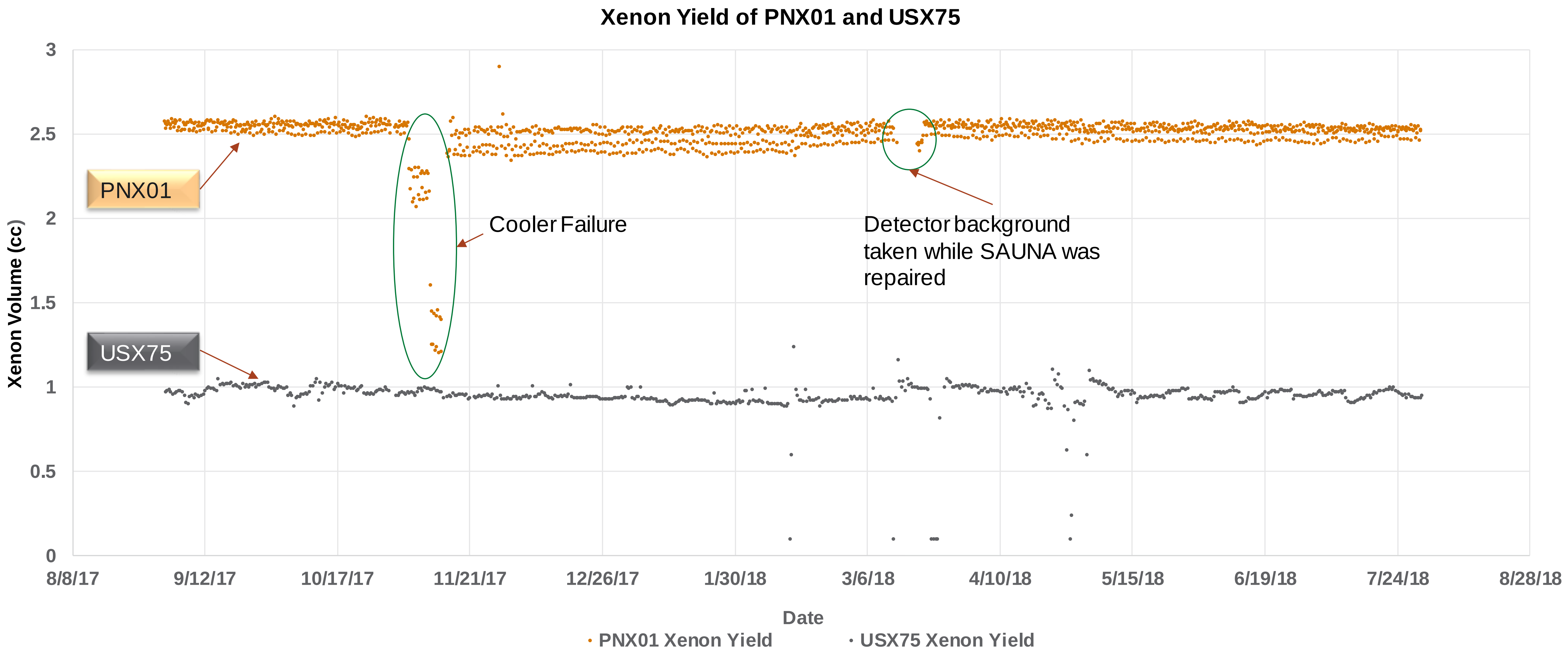
Startup:

- On July 28, 2017 the first sample collected was counted.
- On July 31, 2017 the QC source was received and installed into the system. All four detectors had QC spectra generated and the system was declared fully operational.

End of Test:

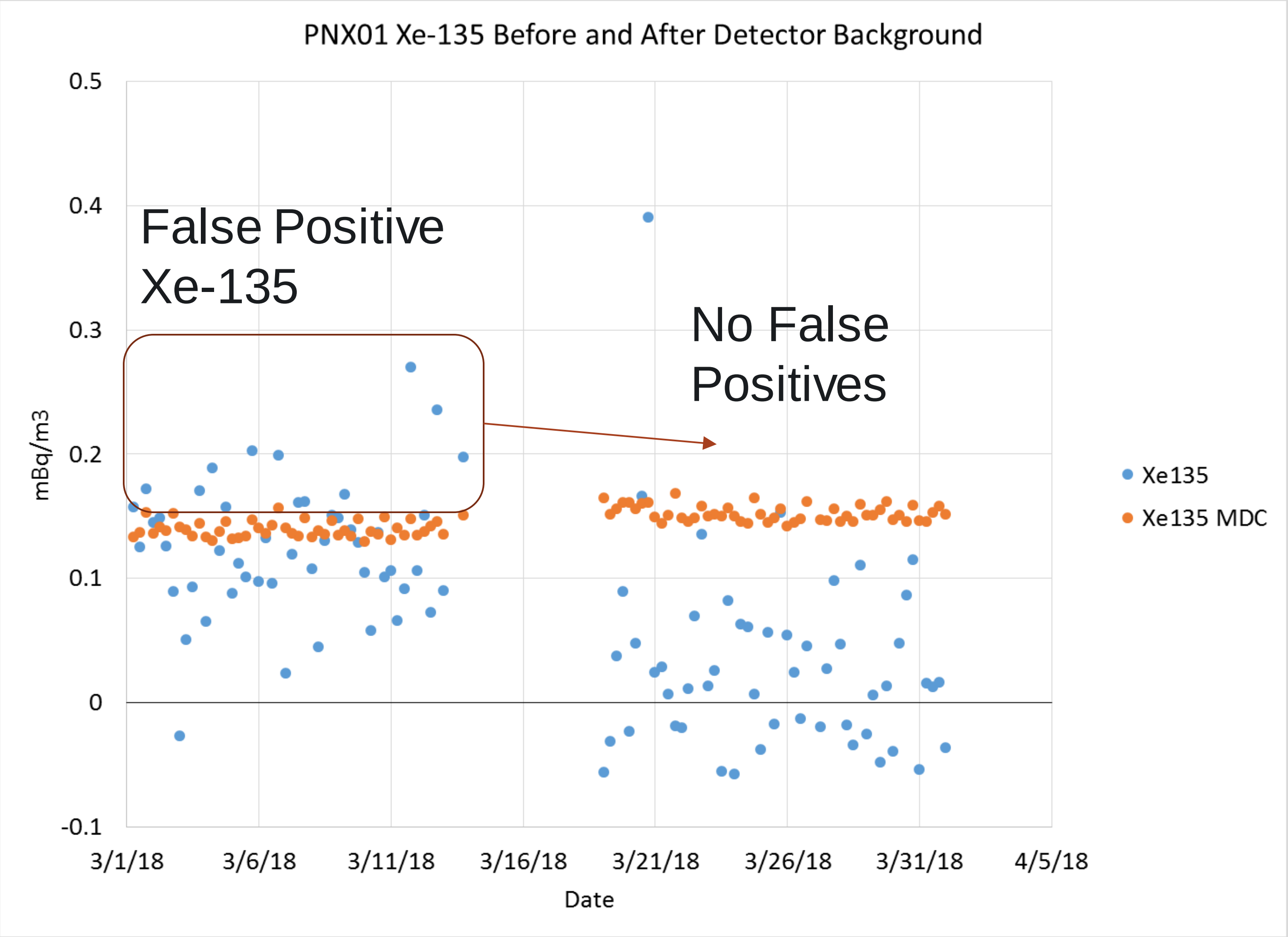
- 03:03:26 Zulu July 31, 2018 PNNL staff remotely executed a maintenance shutdown, so the system would be ready for dispositioning when personnel arrived on station.
- On July 31, 2018 staff arrived on station to inspect, shutdown, disassemble and package the system for shipment.
  - No issues were identified during the visual inspection (prior to disassembly).
  - No issues arose during the disassembly and packing.
- On August 1, 2018 FedEx Custom Critical picked up and transported the system to TBE for EMD upgrades.
- The final FTP data transfer to USNDC was August 3, 2018.

Xenon International OFT Xenon Gas Volumes

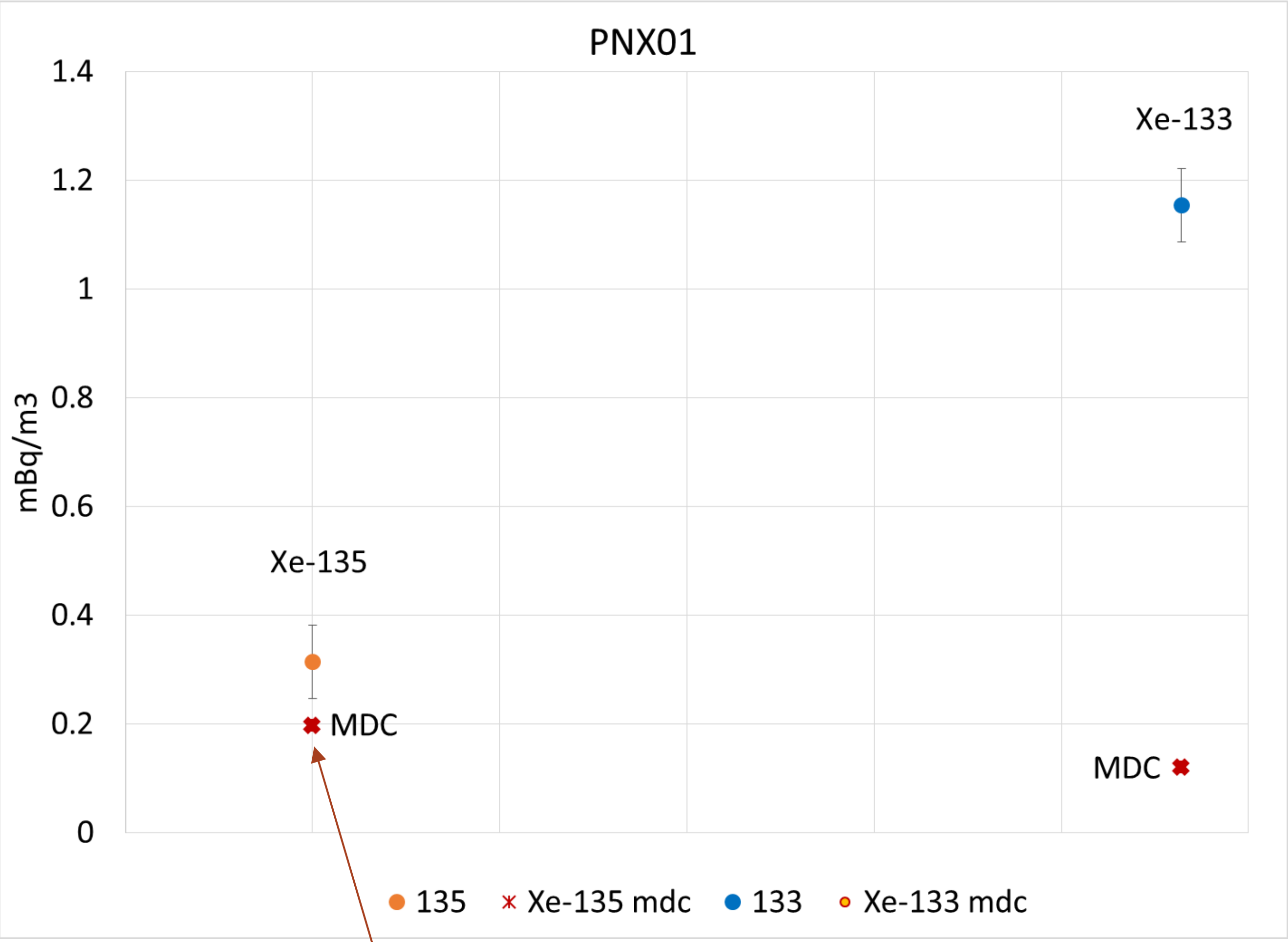


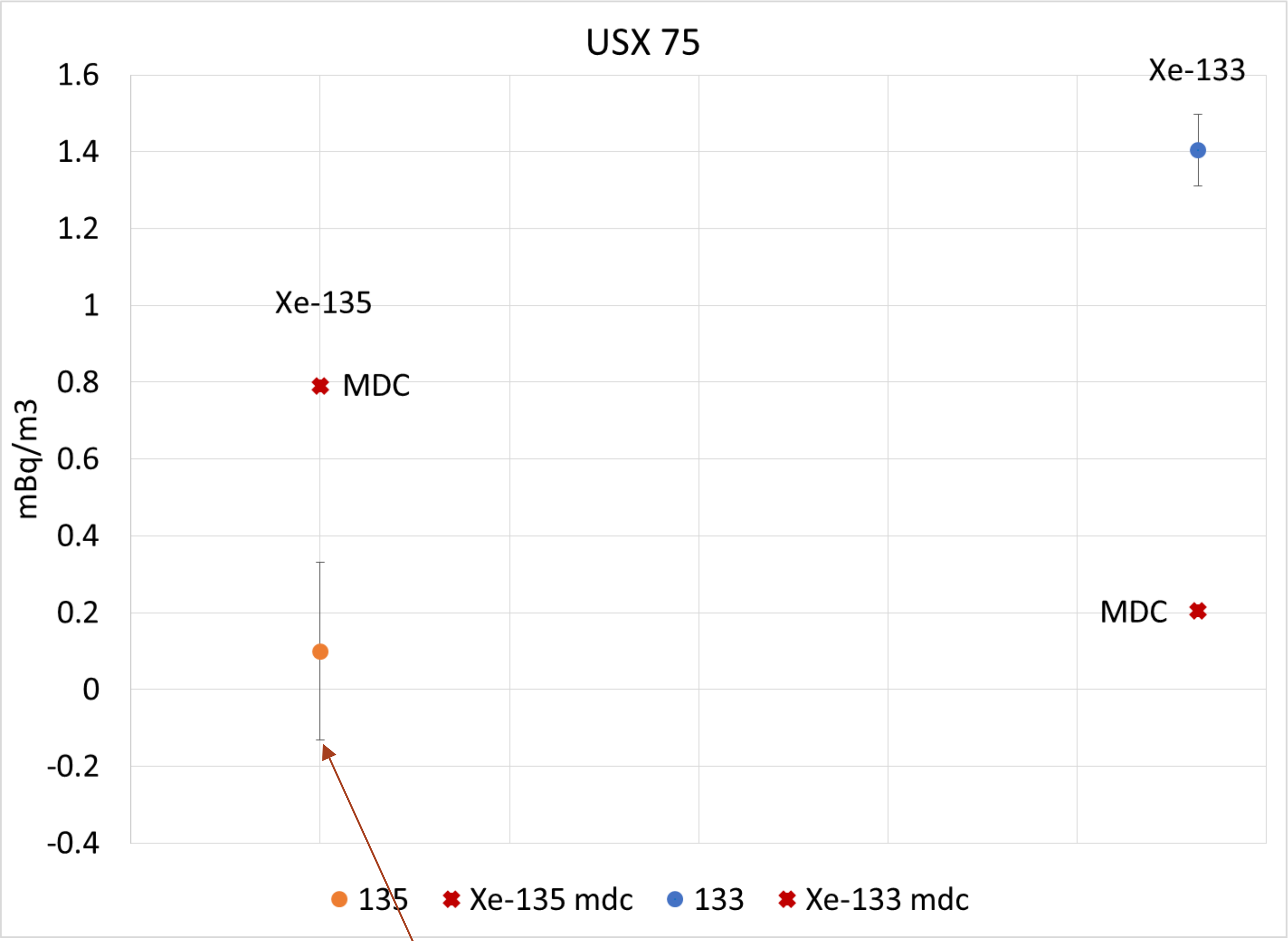
Detector Background Taken

- A detector background was taken in March, 2018.
- Normally taken at setup, however, high memory effect due to prior testing at setup
- This graph demonstrates the importance of taking background measurements for understanding the signals



Xenon International OFT First Xe-135 Hit (March 21, 2018)



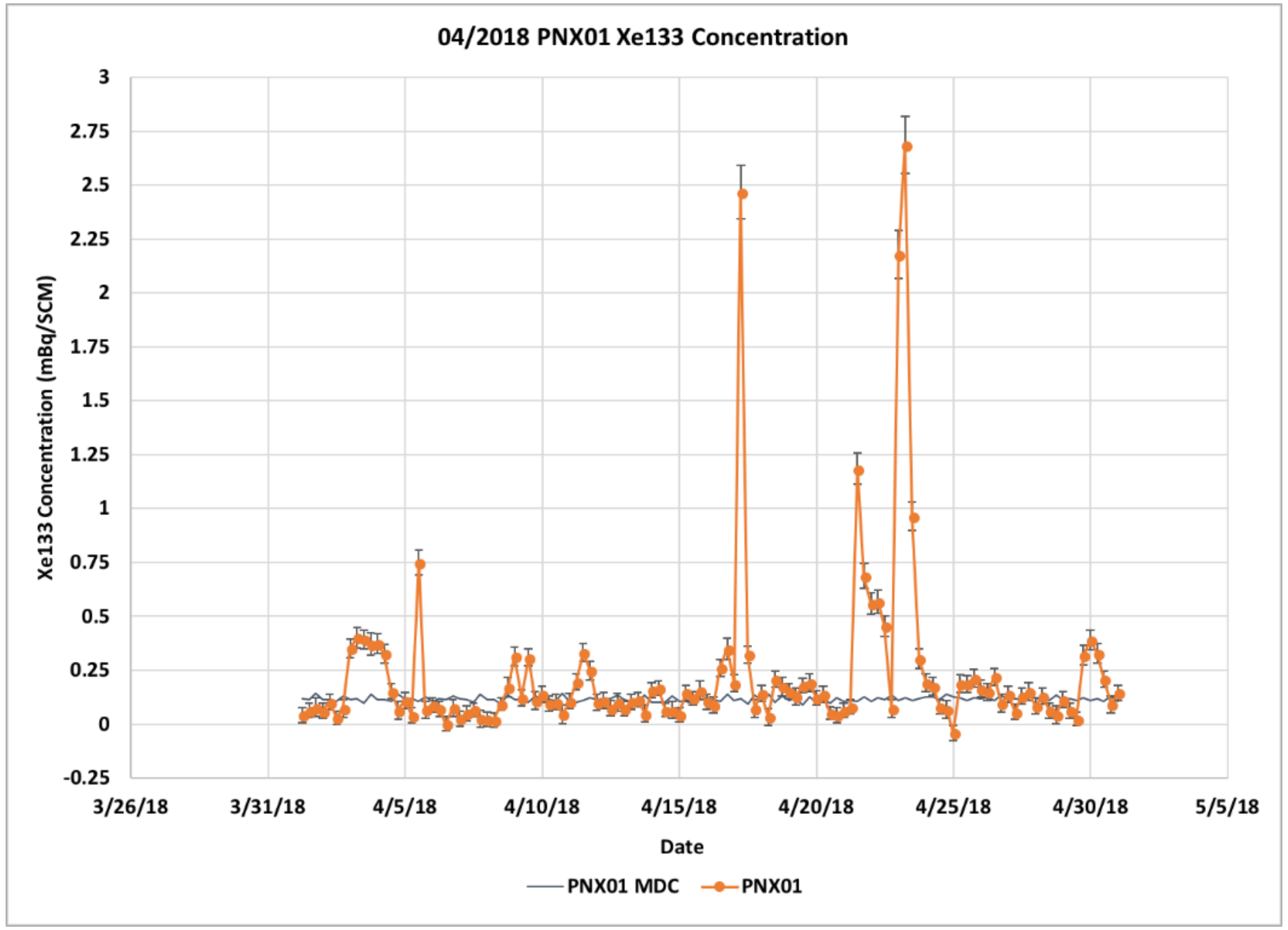


Xe-135 above MDC

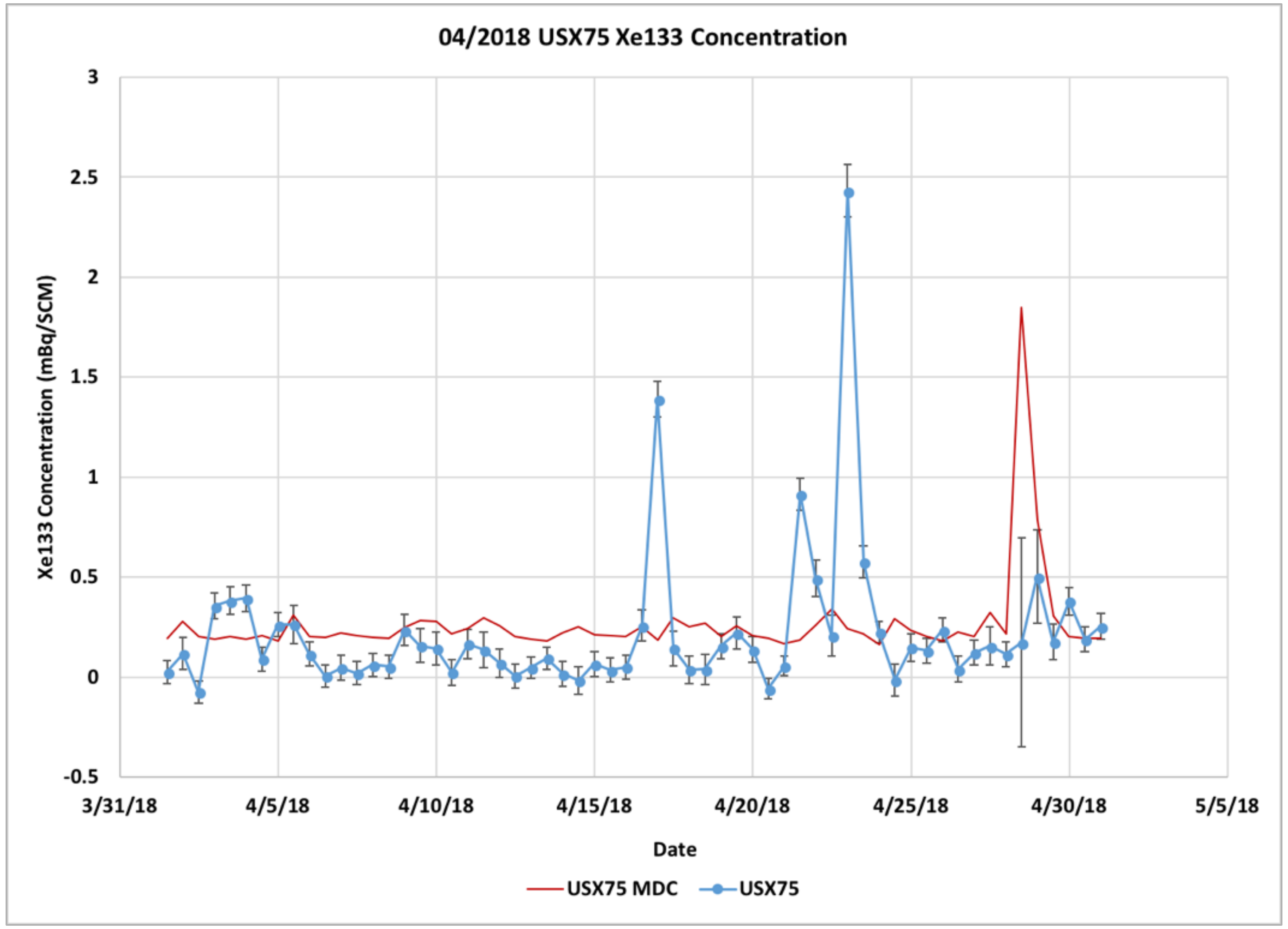
Xe-135 below MDC

Xenon International (PNX01) OFT April, 2018

- USX75 data example vs. PNX01 showing Xe-133 hits vs. minimum detection concentration (MDC).



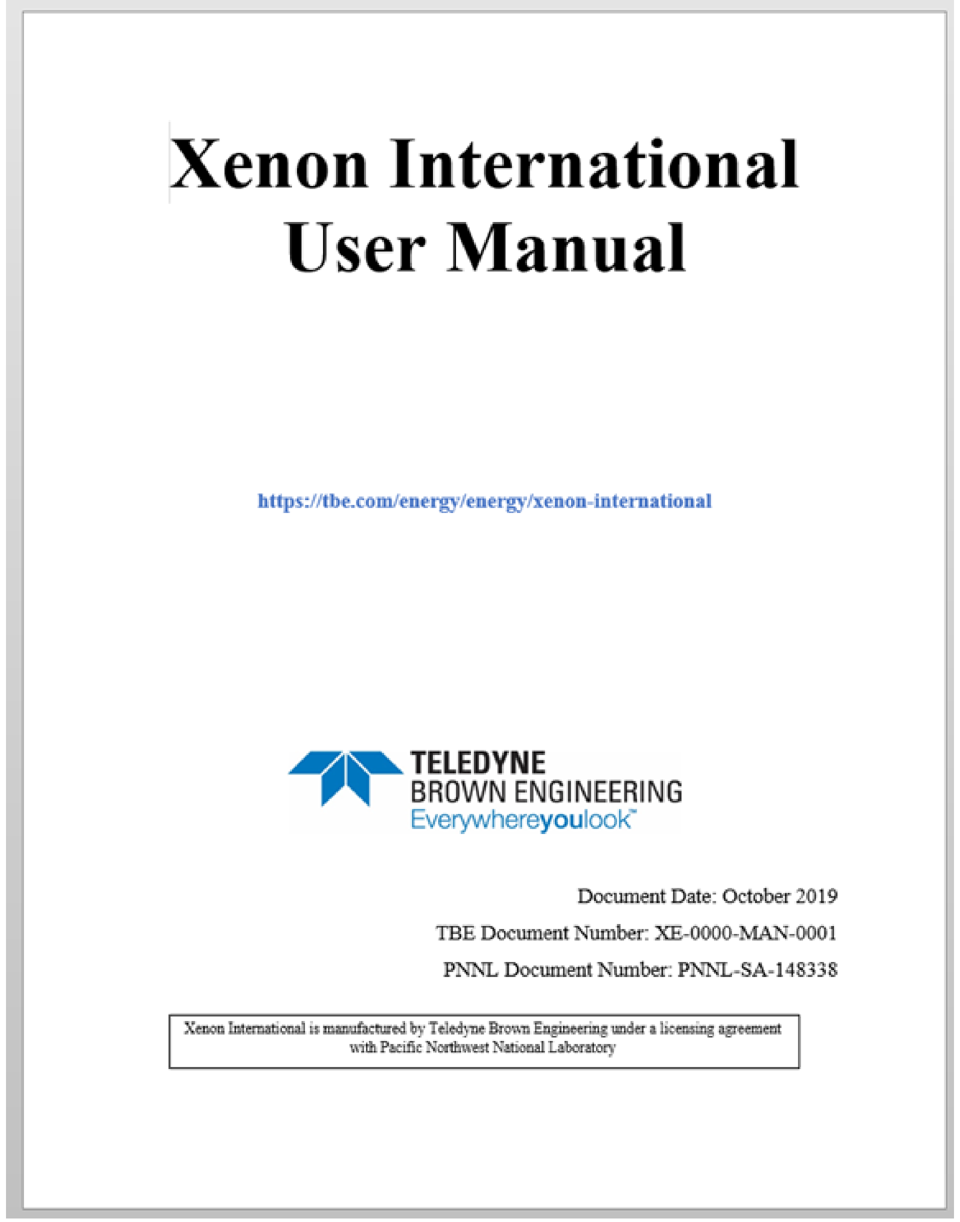
PNX01



USX75

Xenon International Acceptance Testing

- Timeline:
  - Oct, 2019; User Manual sent to the PTS keyed to Acceptance Visit Questionnaire
  - Nov, 2019; Data being sent to PTS for format verification
  - Nov-Dec, 2019; Factory Acceptance Test
  - Jan 26 - 30, 2020; PTS Acceptance Visit to TBE
  - Spring 2021; System shipment to Germany for the second 6-months of testing



Xenon International
User Manual

https://tbe.com/energy/energy/xenon-international

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Document Date: October 2019
TBE Document Number: XE-0000-MAN-0001
PNNL Document Number: PNNL-SA-148338

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