XENAH

XENAH: Xenon and Environmental Nuclide Analysis at Hartlepool

M.A. Goodwin, D.L. Chester, G. Galvin (**AWE**)

B. Milbrath, J. Friese, T.W. Bowyer, L. Lidey, J.C. Hayes, P.W. Eslinger, M. Mayer, D. Keller, R. Sarathi, J.L. Burnett (**PNNL**)

A. Petts, M. Arnold (**EDF Energy UK**)

A. Ringbom, M. Aldener, T. Fritioff, J. Kastlander, S. Liljegren (**FOI**)

S. Leadbetter (**Met Office**)

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Matthew.Goodwin@awe.co.uk

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An overview of the XENAH project and a deep-dive into some of the results

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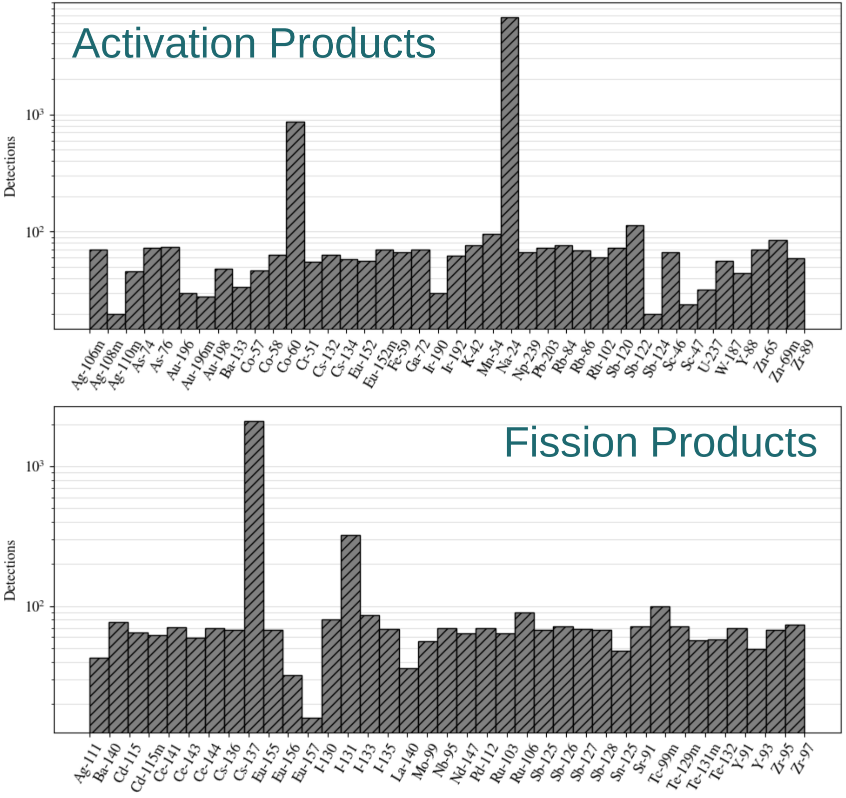
Background

Figure 1.



Radionuclides are detected on the International Monitoring System every day.

Fig 1. Shows the radionuclides detected on the IMS particulate network during 2021, as reported by IDC analysts.

Many of the particulate activation and fission products detected originate from Nuclear Power Plants (NPPs). This is also true for isotopes of radioxenon.

As a community, we are thirsty for more knowledge on the impact of NPPs. The civil nuclear science community (dominated by safety and regulatory work) and the nuclear test monitoring community can benefit from interactions – an opportunity to compare apples with apples. XENAH is one such opportunity to learn about the impact of a NPP.

Hartlepool Nuclear Power Station

Figure 2. Location of Hartlepool Nuclear Power Station in the North of England.

Advanced Gas-Cooled Reactor (AGR)

Hartlepool NPP has two Advanced Gas-cooled Reactors (AGR) designed in the 1960s, built in the 1970s and operational from the 1980s to present.

- *Active core diameter: 9.3 m x 8.2 m high*
- *Total core diameter: 11.9 m x 12.7 m high*
- *81 boronated steel control rod channels*
- *324 fuel channels are eight stacked fuel elements, each containing 36 clustered fuel pins arranged in concentric rings of 18, 12 and 6 pins within a graphite sleeve*
- *The stainless-steel-cladded fuel pins are approximately 1 m in length with a diameter of 14.48 mm and contain stacked ceramic UO_2 pellets of either 3.2% or 3.78% ^{235}U. The total core inventory of uranium is approximately 130 tonnes.*

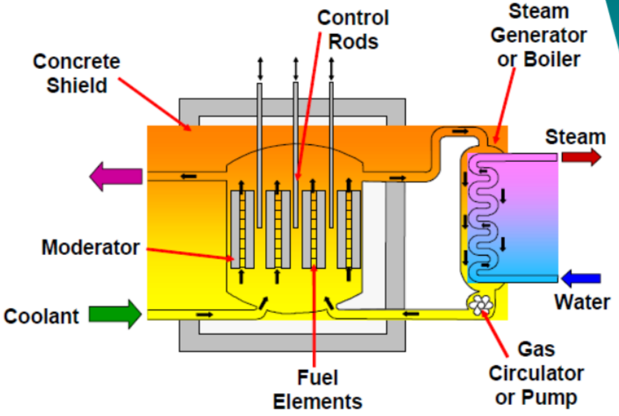


Figure 3. AGR schematic

The primary coolant (CO_2) is driven around the core by eight gas circulators which each have a constant-speed motor running at 3000 rpm, resulting in a total gas mass flow of 3600 kg s^{-1}. In full-power operation, the CO_2 operates at 39 bar with temperatures at the bottom of the active core around 270 ◦C and at the top 650 ◦C

In-core monitoring

Installed at Hartlepool is a **Gaseous Activity Monitor (GAM)** system – a custom-designed HPGe-based measurement system for continuous monitoring of in-core activities using γ-ray spectroscopy. Fig. 4 shows a spectrum obtained from one of the measurements, with the identified radionuclides labelled. This system was already present at the power station.

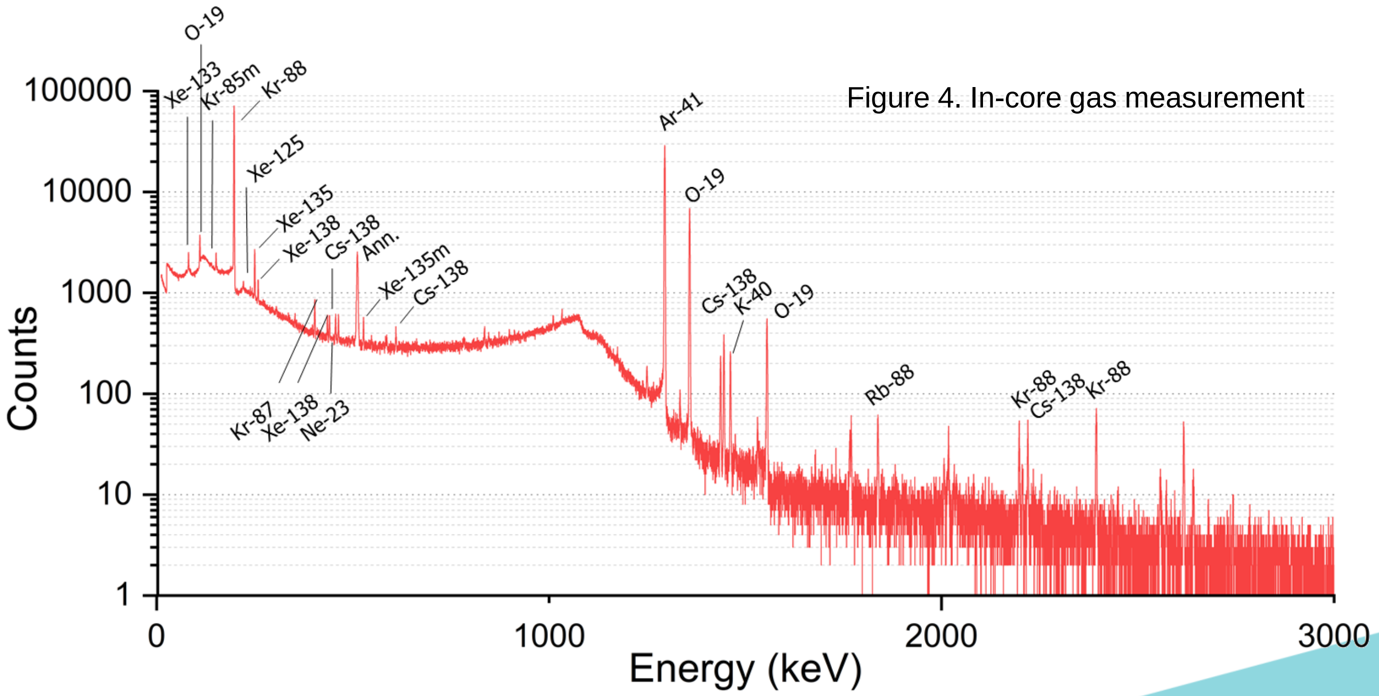


Figure 4. In-core gas measurement

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Figure 5. XENAH collaboration visit to Hartlepool NPP

In January 2023, AWE organised a meeting for the XENAH collaboration, including representatives from AWE, PNNL, EDF, FOI, NNSA, STFC & Met Office.

The group visited EDF Hartlepool, toured the reactor building, including the GAM system (and recently installed STAX[1] system), as well as a visit to Boulby Underground Laboratory, where the AWE SAUNA Q_B[2] *was* installed (above-ground!).

[1] STAX: Source Term Analysis of Xenon – PNNL-led project installing stack-monitoring systems into nuclear facilities
[2]SAUNA Q_B: A radioxenon sensor

XENAH: 3 Tranches of Work

Sample Measurements	Stack Monitoring	Radioxenon Sampling
Charcoal and filter paper samples collected from in-line filtration systems at Hartlepool HPGe measurement systems at AWE and PNNL Ultra-sensitive gamma spectroscopy	HPGe stack monitor system installed and operating through 2022 Measure multiple blowdowns (refuelling on both reactors) Quantify radioxenon isotopes of interest at source. Data used to supplement ATM simulations	Three SAUNA Q_B systems installed 25-95 km away Systems operating during 2022 and part of 2023 Measurements of radioxenon sampled from the atmosphere in 12-hour sampling periods

Tranche 1

XENAH Process Sample Measurements

- Charcoal maypack and paper filters used at Hartlepool for monitoring environmental emissions have been prepared and shipped to AWE and PNNL for further γ-spectroscopy analysis.

- More sensitive measurements have been completed and other radionuclides identified. The first two rounds of measurements (2020 and 2021) were completed following a few months delay between reactor blow-down and measurement. The third round of measurements aims to have the samples shipped to AWE for measurement soon after the blow-down, with the aim of detecting shorter-lived radionuclides.

Figure 6. Charcoal samples as arrived (left) and pushed into a container for counting (middle). Filter paper samples (right) prepared for measurements using small plastic vial containers.

Tranche 2

XENAH STAX system

The STAX system used at Hartlepool is a modified NGM-2000 system, produced by VF Nuclear. It utilises a HPGe detector. The only modification of the system from the base unit is the continuous airflow through the measurement cell.

Gas from the stack is pumped though the cell in front of the detector, and a spectrum is acquired every 15 minutes.

Figure 7. NGM-2000 stack-monitoring system (left) and installed at EDF Hartlepool (right)

Tranche 3

SAUNA Q_B Overview

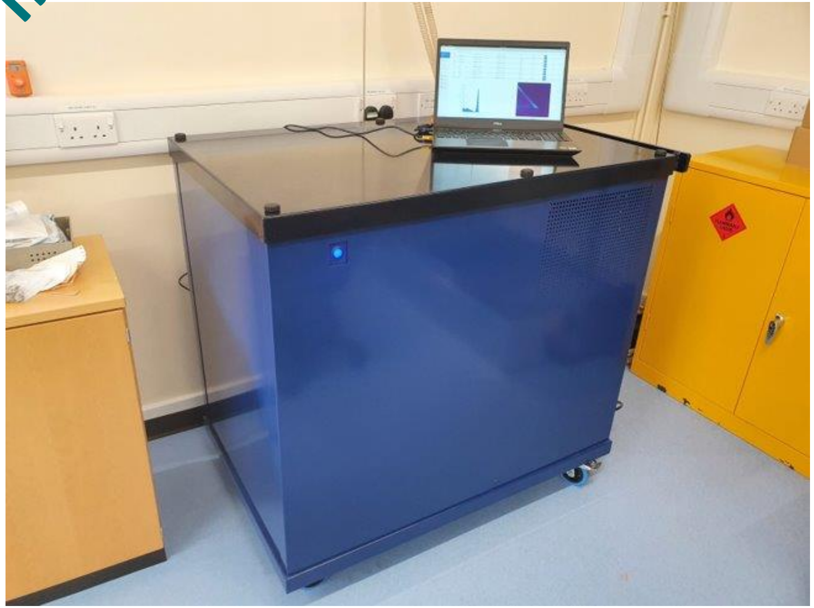
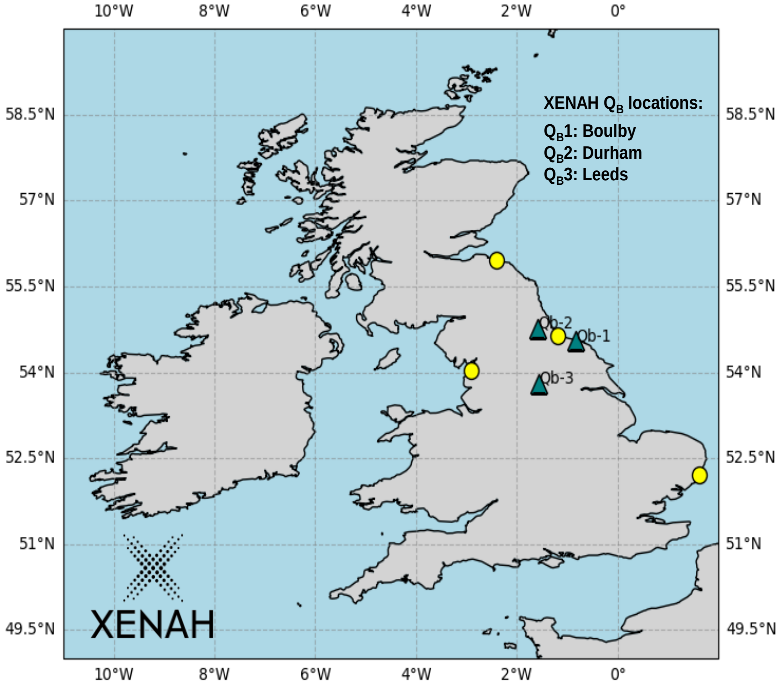


Figure 8. Photograph of the AWE SAUNA Q_B during XENAH deploym



The SAUNA Q_B operated between 2022-03 and 2023-02. Custom software was deployed to remotely monitor the system and retrieve data. For the XENAH work, analysis is completed by FOI using OpenSpex (Beta-gamma matrix method).

Figure 9. Map of the UK showing the XENAH Q_B array (green) and active nuclear power stations (yellow)

Preliminary Results

SAUNA Q_B measurements

Results

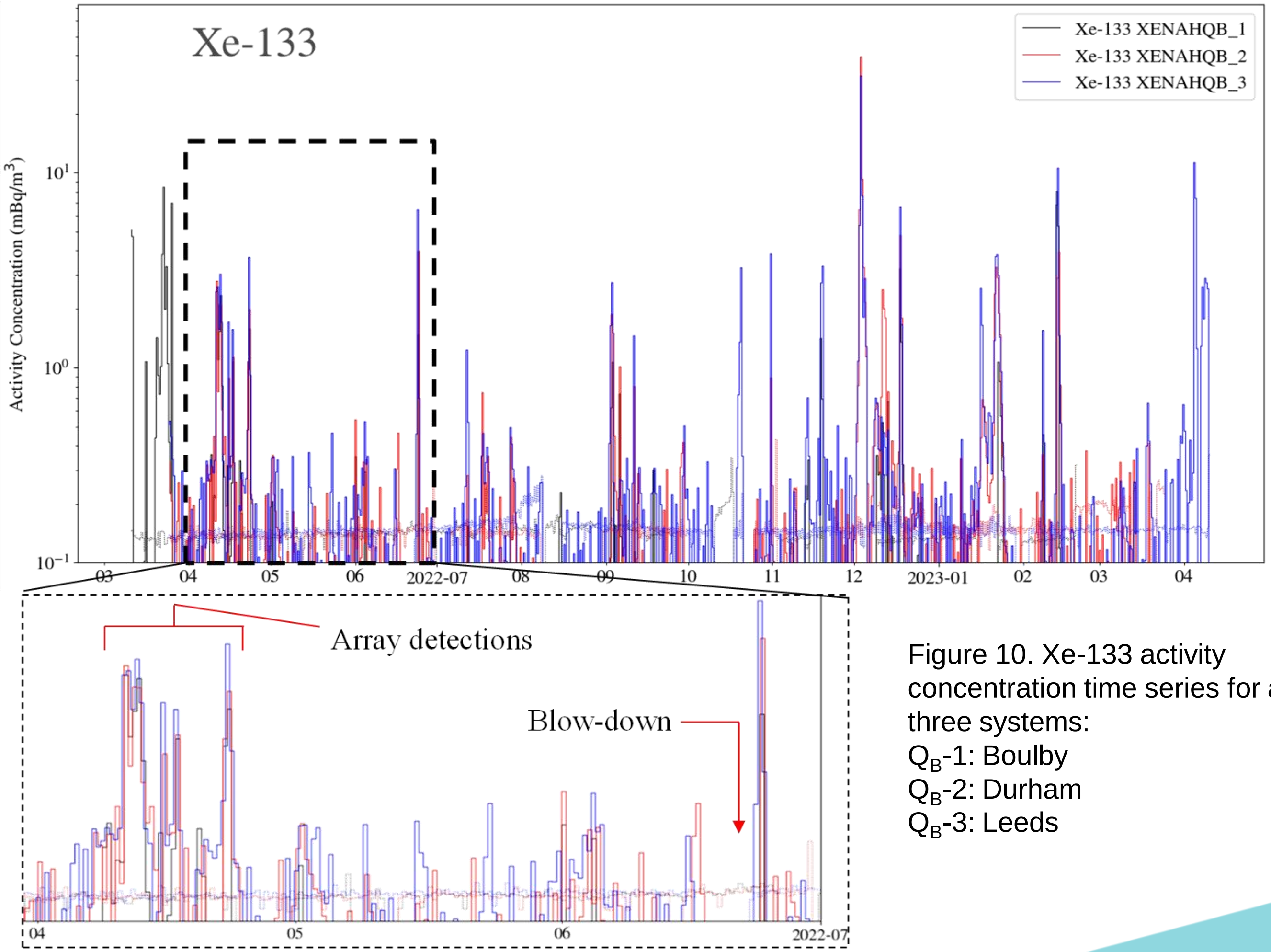
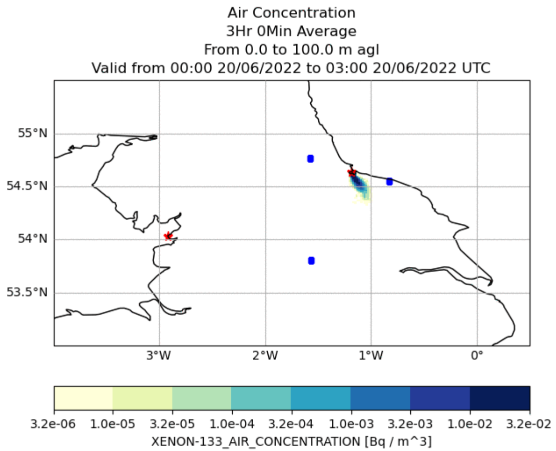


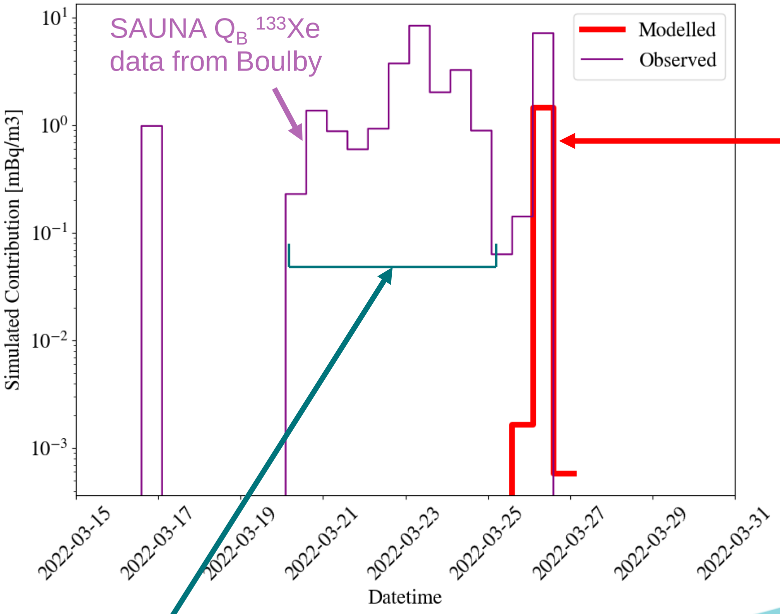
Figure 10. Xe-133 activity concentration time series for all three systems:
Q_B-1: Boulby
Q_B-2: Durham
Q_B-3: Leeds

STAX data + ATM + SAUNA Q_B data

Results

Figure 11. (Left) simulated release from Hartlepool using NAME - Met Office ATM dispersion code.
(right) Comparison of observed and simulated detections. STAX data was used to adjust the emission profile.





Hartlepool emission data + stack measurements

STAX data and ATM simulations suggest this plume is from IRE, which precedes the blowdown and subsequent detections.

Preliminary Results

Charcoal/Filter measurements

Results

Ag-110m was detected in some of the samples

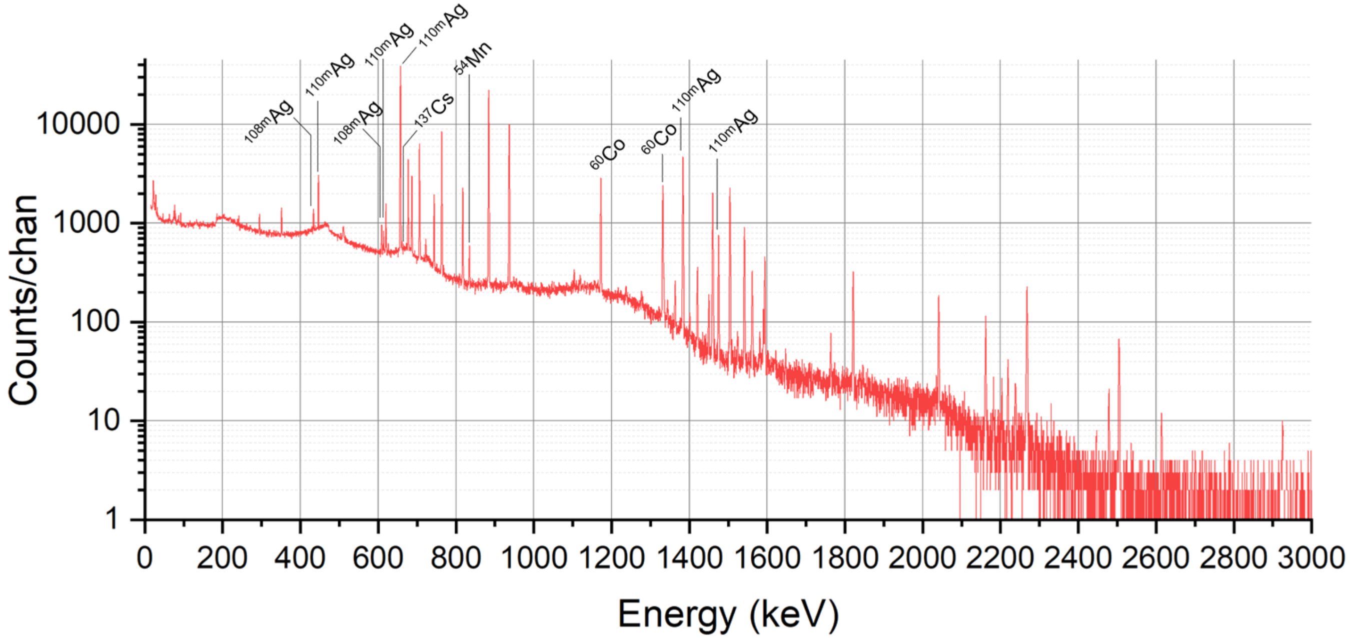


Figure 12. γ-ray spectrum from measurement of a charcoal sample at PNNL. The sample contained ^{108m}Ag, ^{110m}Ag, ^{137}Cs, ^{54}Mn and ^{60}Co.

Results

Summary of detected radionuclides in "fresh" charcoal samples

Radioxenon isotopes

Isotope	Production Mode
Xe-133	Fission
Xe-135	Fission
Xe-131m	Fission
Xe-133m	Fission
Xe-125	Activation
Xe-127	Activation
Xe-129m	Activation

Other isotopes

Isotope	Production Mode
Cs-137	Fission
Co-60	Activation
Se-75	Activation

Preliminary Results

Stack monitoring measurements

Stack measurements

Results

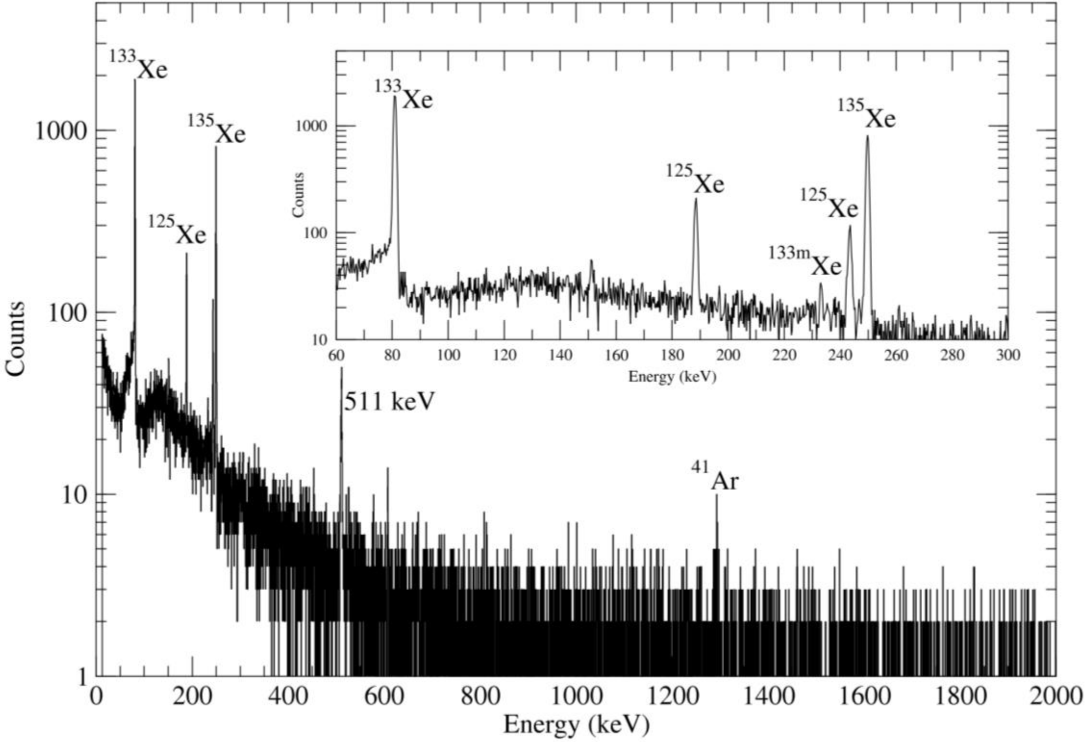


Figure 13. Stack measurement using a high-purity germanium detector, showing identified gamma lines

Figure from Andrew Petts

Results

STAX Analysis Comparison

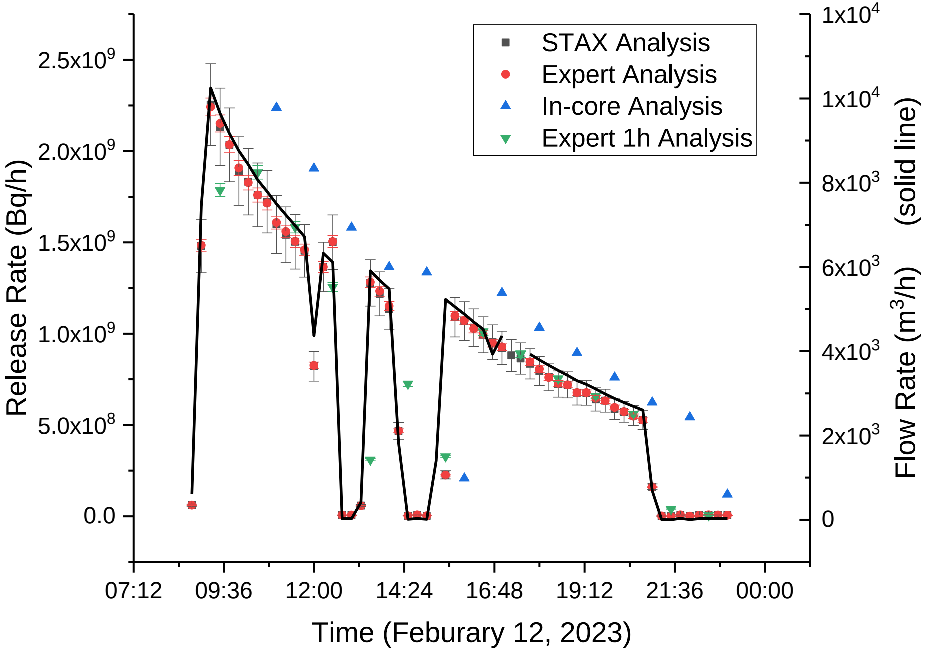


Figure 14. Analysis results comparison using STAX data, Expert Re-analysis (15 min and 1 h) (PNNL/USL16) and GAM system results (In-core)

Figure from Judah Friese

XENAH

Summary

- XENAH project has been active since 2020
- SAUNA Q_B array measurement campaign is now **complete**
- STAX system is still installed and operational
- More sample measurements are planned
- Analysis and write-ups are underway!
- Exciting conclusions to be drawn from the various measurements completed.
- We know a lot more about AGRs (and their impact) than we did before
- Much of this may be applicable to Small Modular Reactors (SMRs)
- This is a useful experiment model, which could be applied to other cooperating nuclear facilities

Emissions from a well-operating AGR are binary – they are either emitting or they are not. As such, they are not a good fit for the model of a daily average emission magnitude.

Questions?

Thank you to:

Support from Met Office (UK ATM modelling) and Q_B hosts: STFC Boulby, U. Durham, U. Leeds (NCAS).

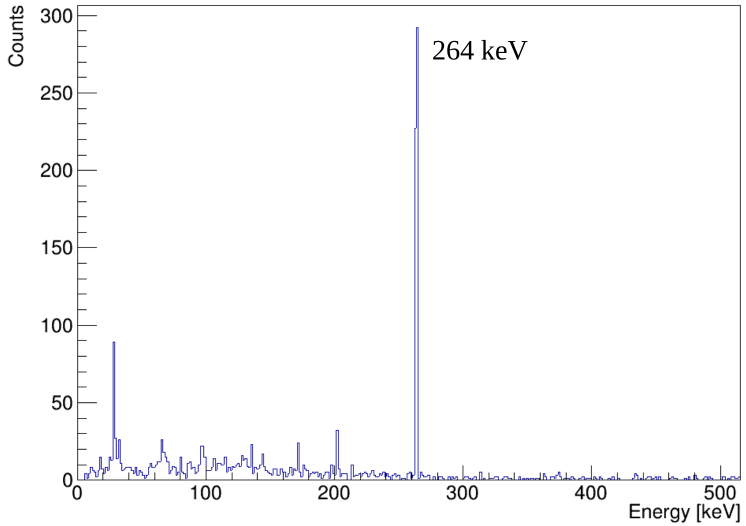
Matthew.Goodwin@awe.co.uk

Extra Slides

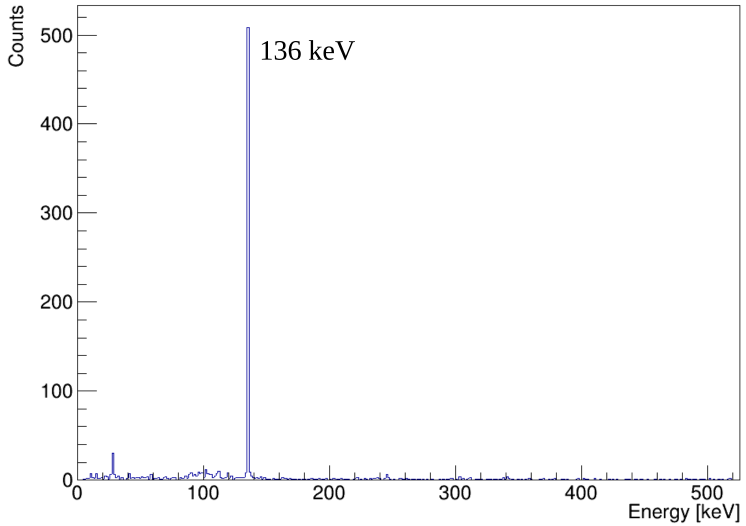
Se-75 confirmed in charcoal samples with coincidence measurement

Strong g-g coincidence signature 264 keV + 136 keV

136 keV Energy gate



264 keV Energy gate



Worldwide reactors

Reactor Type	Main Countries	Number	Fuel	Coolant	Moderator
Pressurised Water Reactor (**PWR**)	USA, France, Japan, Russia, China, South Korea	306	Enriched UO_2	Water	Water
Boiling Water Reactor (**BWR**)	USA, Japan, Sweden	60	Enriched UO_2	Water	Water
Pressurised Heavy Water Reactor (**PHWR**)	Canada, India	47	Natural UO_2	Heavy water	Heavy Water
Light Water Graphite Reactor (**LWGR**)	Russia	11	Enriched UO_2	Water	Graphite
Advanced Gas-cooled Reactor (**AGR**)	UK	8	Natural U (metal), enriched UO_2	CO_2	Graphite
Fast Neutron Reactor (**FNR**)	Russia	2	PuO_2 and UO_2	Liquid sodium	None
High-Temperature Gas-cooled Reactor (**HTGR**)	China	1	Enriched UO_2	Helium	Graphite

Information from World Nuclear Association
www.world-nuclear.org

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