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XENAH – Xenon Environmental Nuclide Analysis at Hartlepool

A. Petts[1], M.A. Goodwin[2], B.Milbrath[3], J. Burnett[3], T.W. Bowyer[3], J.Friese[3], A. Ringbom[4],S.Leadbetter[5]

[1]EDF Energy, [2]AWE, [3]PNNL, [4]FOI, [5]Met Office

INTRODUCTION

The XENAH collaboration involving scientists from the U.K., U.S and Sweden are performing measurements at Hartlepool Power Station using a suite of monitoring techniques to better understand radionuclide emissions from a nuclear power reactor and how those might affect the IMS.

METHODS/DATA

Three distinct measurement programs are underway:

- Reactor stack emission monitoring (source)
- Remote detections after atmospheric transport
- Sample measurements and in-core coolant analysis

START

RESULTS

- Measurements of stack emissions during planned refueling periods presented and compared to in-core measurements
- Analysis of filtration media presented in time series and contextualized with plant maneuvers

CONCLUSION

- Emissions small compared to isotope production facilities
- Measured stack emissions in agreement with measured in-core activity
- Activities from filtration media dominated by steel activation products and increase during plant maneuvers

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P2.4-049

XENAH Collaboration and Hartlepool Power Station

The Xenon Environmental Nuclide Analysis at Hartlepool (XENAH) collaboration involving scientists from the U.K., U.S and Sweden are performing measurements at Hartlepool Power Station in the North-East of England using a suite of monitoring techniques to better understand radionuclide emissions from a nuclear power reactor and how these might affect the IMS. The XENAH collaboration will perform these measurements with strong cooperation of the reactor operator, EDF Energy.

XENAH

Hartlepool Power Station – Advanced Gas-cooled Reactor (AGR)

- The Station operates 2 Advanced Gas-cooled Reactors (AGRs)
- Has been on-line since 1983 and is currently licenced to April 2026
- Each generates ~ 600 MW(e), runs at ~1570 MW(th)
- AGR is a graphite-moderated reactor, an evolution of the MAGNOX reactors
- Utilises low-enrichment uranium fuel, 3.2% - 3.78%
- Pressurised CO_2 as primary coolant

Key Facts/Figures

- 324 fuel channels on lattice pitch
- 81 control rods (37 used for auto control of reactor power)
- 90 tonnes of CO_2 coolant at 40 bar
- Primary coolant flow ~3600 kg/s
- UO_2 fuel pellets within stainless steel fuel pins
- 130 tonnes of uranium per reactor
- Fuel discharged around 30 GWd/te

Hartlepool power station, located on the North-East coast of England

Operation

- Reactors operate at full load and are constant – do not change to match grid requirements
- Reactor shuts down approx. every 4-5 months for off-load, depressurised batch refuelling
- Once shutdown, reactor is depressurised over a 24 hour period releasing primary gas coolant though a filtered route. Exhausted gas is routinely monitored for environmental regulation compliance.
- Circa 20 channels from 324 are refuelled during each outage
- Outages last ~14 days, after which load is steadily increased to ~1570 MW(th)
- Usually have 5 refuelling outages across the 2 reactors in a year. Operator avoids having both reactors shut down in coincidence

The Hartlepool power station fuelling machine

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XENAH – Objectives and measurement methods

XENAH – Scientific Objectives

XENAH

XENAH collaboration aims to undertake three distinct measurement programs:

- Reactor stack emission monitoring (source)
- Remote detections after atmospheric transport
- Sample measurements and in-core coolant analysis

The aim being to better understand radionuclide emissions from a nuclear power reactor and how these might affect the IMS

XENAH collaboration standing on top of the Hartlepool Reactor 1 pile cap

Reactor stack monitoring - STAX

STAX system installed at the R6 tower in Hartlepool Power Station on the main blowdown route

NGM-2000 System

- 30% HPGe detector
- MDC for ^{133}Xe: 270 Bq/m^3
- Flow through system: 1.25 m^3/hr
- Continuous monitoring (15 minute acquisitions, looped)
- System aims to primarily measure radio xenon isotopes, but is sensitive to all gamma-emitting gaseous fission products
- Gas extracted from stack flows through Marinelli. Measured concentration is adjusted total stack flow.
- Stack flow peaks ~7000 m^3/hr during blowdowns and is measured continuously by plant systems.
- **System installed at R6 tower on the main blowdown route to monitor emissions just prior to refueling. Final phase of blowdown not monitored by STAX system due to change in blowdown route configuration**

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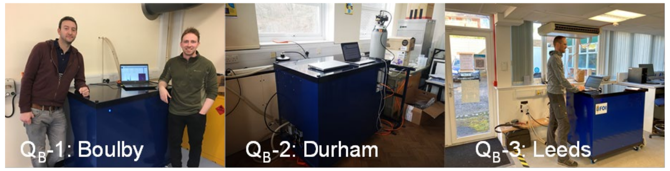
XENAH – measurement methods

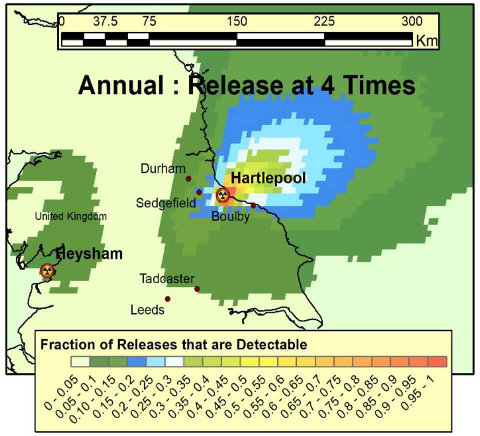
Remote measurements after Atmospheric Transport

Scienta SAUNA Qb specs

- Intakes atmospheric sample
- Sample time of 12 hours (includes gas conditioning)
- Qb consists of single beta-gamma detector consisting of 18ml plastic scintillator detector inside a 4 inch NaI crystal
- ^{133}Xe MDC ~ 0.4 mBq/m^3



SAUNA QB commissioning at Boulby laboratory, Durham University and Leeds



ATM Q_B sensitivity calculations, using emissions from Hartlepool reactor. Simulations performed using HYSPLIT with GFS 0.25° met data. ***Ref: CTBT SnT 2023 P2.4-370***

Locations and aims

- Evaluate advantages of an array network over single station and how this could improve the IMS
- 3 detectors (1 each from U.K., U.S. and Sweden) at different locations a few 10's of km around Hartlepool: **Boulby, Durham, Leeds**
- **Array aims to detect emissions from Hartlepool released just prior to refuelling**
- **Comparisons of the stand-off measurements with predictions based on atmospheric transport of stack monitor results are a key measurement goal of the project.** Predicted response will be based on actual release data from STAX with detailed ATM provided by Met Office *Ref*: ***CTBT SnT 2023 P1.1-588***

In-core measurements and Environmental samples

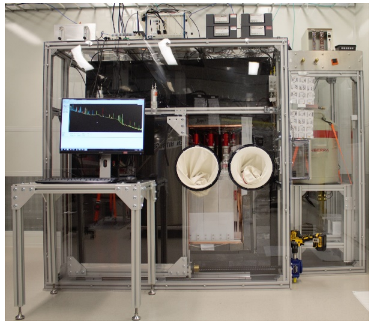
In-Core measurements

- Gaseous Activity Monitoring (GAM) measures in-core coolant activity to assess fuel condition
- ICS cooled, Ortec P-type 40% HPGe detector feeding Ortec DSPEC 50 MCA for isotopic analysis and Ortec NIM modules for analogue Control Room indications and alarms
- 1 hour acquisition, continuous flow of 1 litre/s
- Used to monitor for fuel performance – particularly during blowdowns

Gaseous Activity Monitoring (GAM) system at Hartlepool power station

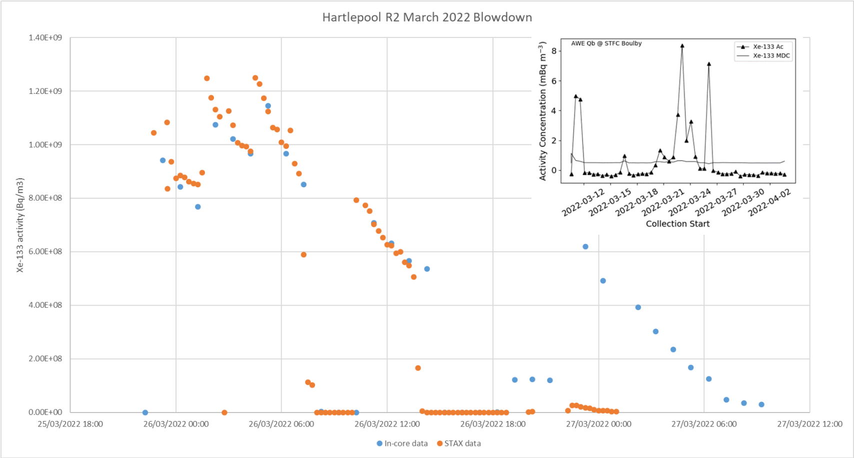
Environmental measurements

- Maypack charcoal and paper filters provided from various locations at Hartlepool (pond stack, R6 blowdown Stack, etc)
- Samples measured at Boulby underground laboratory and the Shallow Underground Laboratory at PNNL.
- Laboratories able to perform ultra-sensitive g-ray spectroscopy. Usually used to measure treaty-relevant radionuclides.
- ARGO at PNNL combines low background, cosmic veto, Compton suppression and coincidence functionality

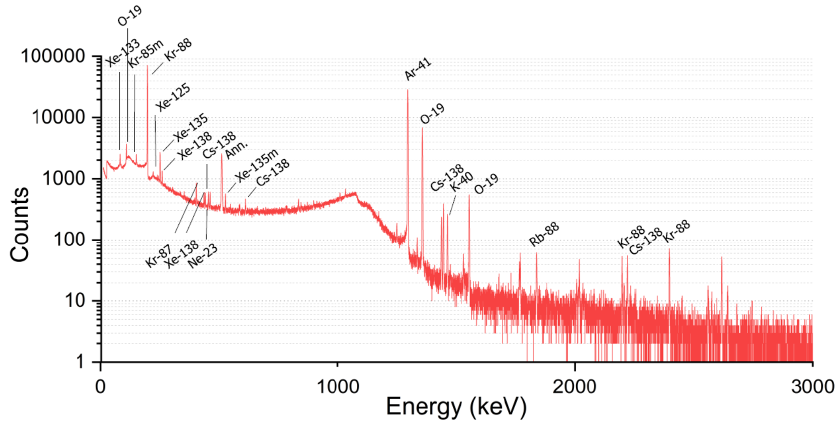


ARGO at PNNL used to perform ultra-sensitive analysis of Hartlepool filtration media

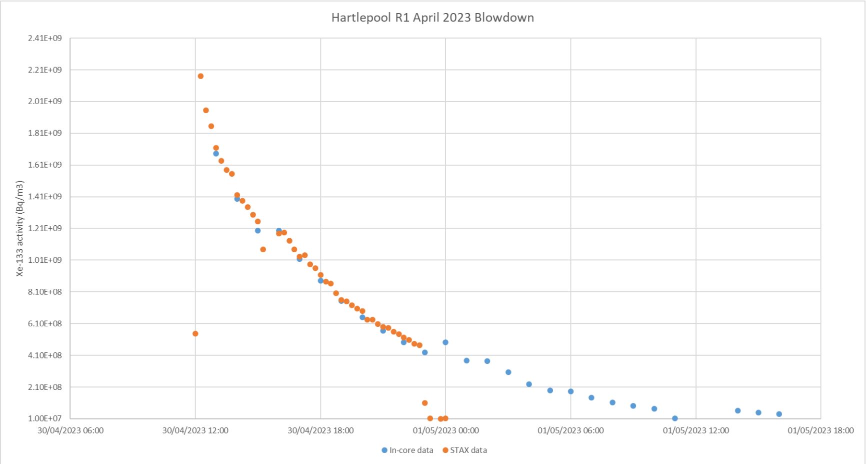
Results and Conclusions – In core data, STAX measurements and remote detections



Released ^{133}Xe activity during R2 March 2022 Refuelling Blowdown. Figure compares STAX emission measurements and emission estimates using in-core coolant activity measurements from the GAM system scaled with measured stack flows. Insert ***(Ref: CTBT SnT 2023 P2.4-370)*** *shows coincident detection at Boulby with SAUNA Qb*



Typical spectrum obtained from a one-hour acquisition on the R1 GAM system whilst on-load at full power. Identified fission products and coolant activation products labelled.



Released ^{133}Xe activity during R1 April 2023 Refuelling Blowdown. Figure compares STAX emission measurements and emission estimates using in-core coolant activity measurements from the GAM system scaled with measured stack flows.

Results and conclusions

- R2 March 2022 blowdown atypical – pauses in reactor depressurising due to plant faults. This blowdown was one of the first to be measured with both the STAX system running and the SAUNA Qb array live. Peak ^{133}Xe release measured to be 1.14 GBq/hr . Total ^{133}Xe release ~14.6 GBq.
- Coincident measurement on the Boulby SAUNA Qb whilst Hartlepool reactor was emitting. Work ongoing to assess whether Qb detection is from Hartlepool. Detailed analysis presented in ***CTBT SnT 2023 P2.4-370 and CTBT SnT 2023 P1.1-588***
- R1 April 2023blowdown is more typical – no plant faults during this operation. Peak ^{133}Xe release measured to be 1.68 GBq/hr . Total ^{133}Xe release ~13.0 GBq.
- **Very good agreement between measured emissions using STAX system and estimates of emission from the scaling of in-core measurements using the GAM system with measured stack flows for all 6 measured blowdowns.**
- STAX system does not measure final portion of the blowdown due to a change in plant configuration that results in gas being emitted through a different route. Emission can be estimated with high confidence using the measured in-core activity data and the measured stack flows. Full profile (STAX + in-core estimate) can be used for Forward ATM
- STAX data from Hartlepool presented in more detail in ***CTBT SnT 2023 2.4-341***.

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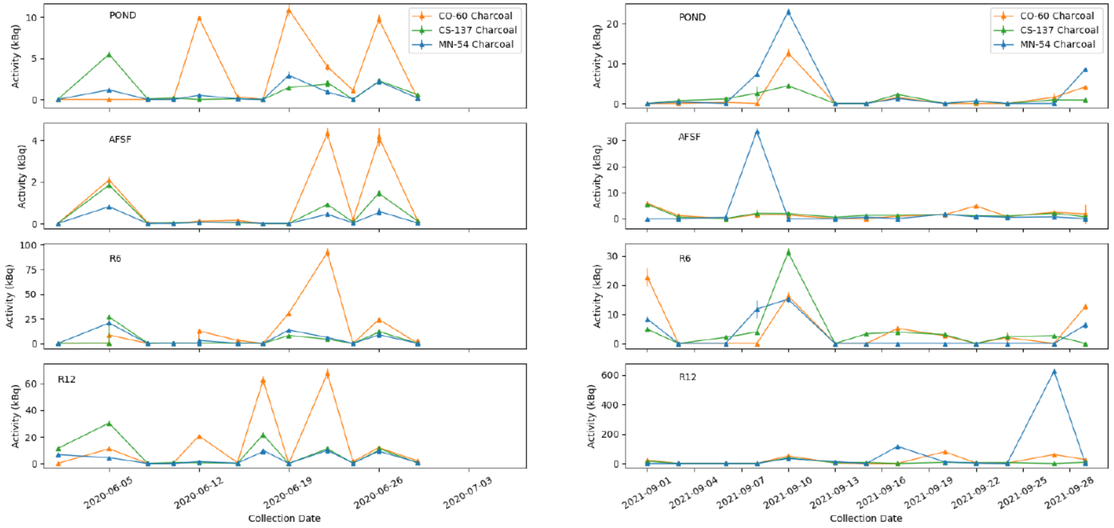
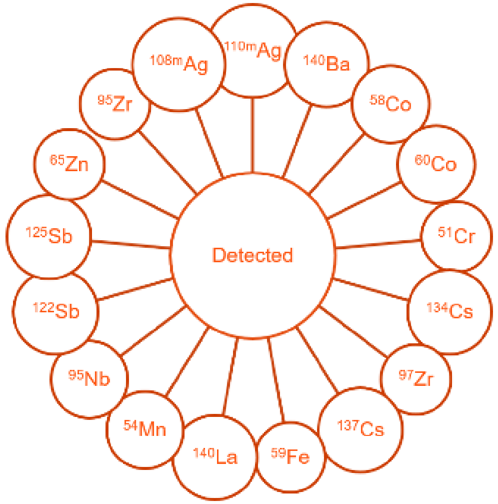
Results and Conclusions – Ultra-sensitive analysis of filtration media from Hartlepool stacks



Time series plot showing the measured charcoal activities of ^{60}Co, ^{137}Cs and ^{54}Mn in four locations, in June 2020 (left) and September 2021 (right)

Isotope	Production Type	Half-life	Filter detections	Charcoal detections	IMS detections
^{137}Cs	Fission	30.1 a	62 (100)	109 (100)	7739 (31.3)
^{58}Co	Activation	70.9 d	2 (3.23)	18 (16.5)	17 (0.069)
^{60}Co	Activation	5.3 a	41 (66.1)	91 (83.5)	1044 (4.22)
^{54}Mn	Activation	312 d	48 (77.4)	88 (80.7)	62 (0.25)
^{108m}Ag	Activation	438 a	0 (0)	1 (0.92)	NR
^{110m}Ag	Activation	250 d	0 (0)	1 (0.92)	NR
^{51}Cr	Activation	27.7 d	2 (3.23)	4 (3.67)	12 (0.049)
^{57}Co	Activation	272 d	2 (3.23)	0 (0)	2 (0.008)
^{59}Fe	Activation	44.5 d	1 (1.61)	4 (3.67)	17 (0.069)
^{75}Se	Activation	120 d	1 (1.61)	2 (1.83)	NR
^{65}Zn	Activation	244 d	1 (1.61)	13 (11.9)	17 (0.069)
^{46}Sc	Activation	83.8 d	0 (0)	11 (10.1)	4 (0.016)

List of radionuclides detected and measured, showing the number of samples containing each radionuclide. The number of IMS detections of each radionuclide since 2012 are listed for comparison. Values in parenthesis denote the percentage of samples containing each radionuclide. Note that NR denotes nuclides not reported by the IMS.



Results and conclusions

- Prior to measurement at PNNL and AWE, each sample is measured using conventional gamma-spectrometry systems at EDF Energy for environmental compliance.
- The ultra-sensitive measurements have identified trace levels of fission and activation products, including ^{108m}Ag, ^{110m}Ag, ^{51}Cr, ^{54}Mn, ^{58}Co, ^{60}Co, ^{97}Zr and ^{137}Cs. Some of these isotopes have not been recorded before in IMS data.
- Analysis focused on longer-lived radionuclides (e.g. ^{54}Mn, ^{58}Co, ^{60}Co, ^{137}Cs) at fuel handling locations. These isotopes occurred in a high proportion of the samples measured.
- Activation products have been attributed to the austenitic stainless steel of the fuel pins and reactor internals.
- **Measurements reveal increases in radionuclide activities during fuel handling**
- It is postulated that information from activation-product discharges could possibly infer if a facility is handling nuclear material.

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References and Further Work

Further work

- Continue to measure emissions during blowdowns using installed STAX system
- Analyse current STAX data sets looking particularly at xenon ratios, comparing with Kalinowski plot.
- Submit paper to Phys. Rev. Applied covering Environmental sample analysis (currently under internal review)
- Ship and measure ‘fresh’ samples of filtration media immediately after blowdown to measure short-lived isotopes, in particular iodine species.
- **Analysis 5 years worth of in-core coolant activity data specifically xenon ratios**
- Obtain/produce AGR ‘fingerprint’ from emissions data
- Compare Qb array performance and detections to ATM predictions and publish data

References

- ***CTBT SnT 2023 P2.4-370***
- ***CTBT SnT 2023 P1.1-588***
- ***CTBT SnT 2023 P2.4-341***

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