Welcome

Hartlepool Nuclear Power Station - Overview of the Design, Operation and recent scientific collaborations

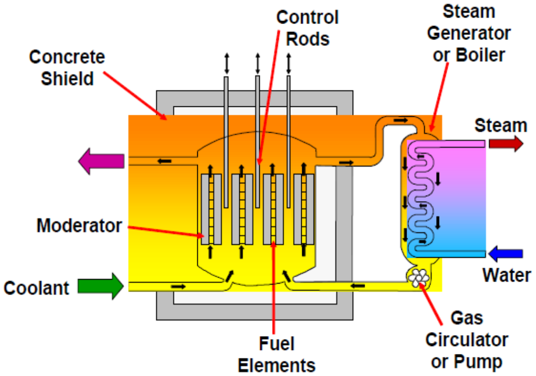
Dr. Andrew Petts, EDF, Applied Anti-neutrino Physics workshop, York, September 2023

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

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

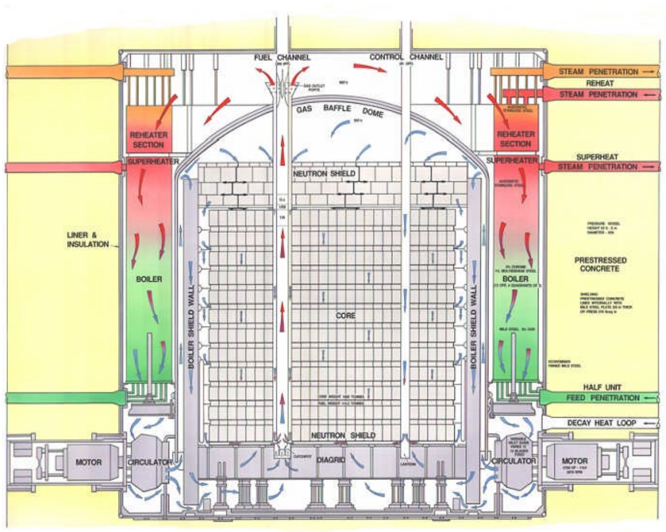
Hartlepool power station, pile cap with fuelling machine in background



Cartoon schematic of a typical AGR

- 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

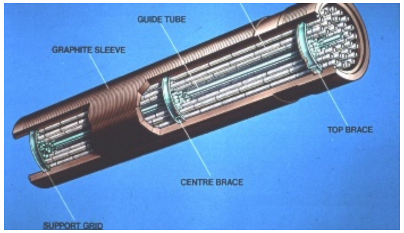
Advanced Gas-cooled Reactor (AGR) Design

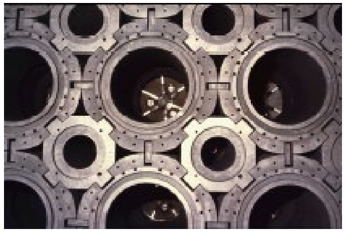


Reactor	
Moderator	Graphite
Primary Coolant	CO_2 @ 41 bar, 3623 kg/s
Number of Fuel Channels	324 with 460mm pitch
Number of Control Rods	81
Active Core Dimensions	9.3m x 8.2m
Mean Temps	T1: 286 °C, T2 648 °C

Fuel design	
Material	UO_2, 3.2 – 3.78% enriched, 130 tonnes per reactor
Disposition	36 pin cluster, graphite sleeve. 8 elements per fuel channel
Cladding	Stainless steel, 0.37mm thick
Average discharge irradiation	30 GWd/tU

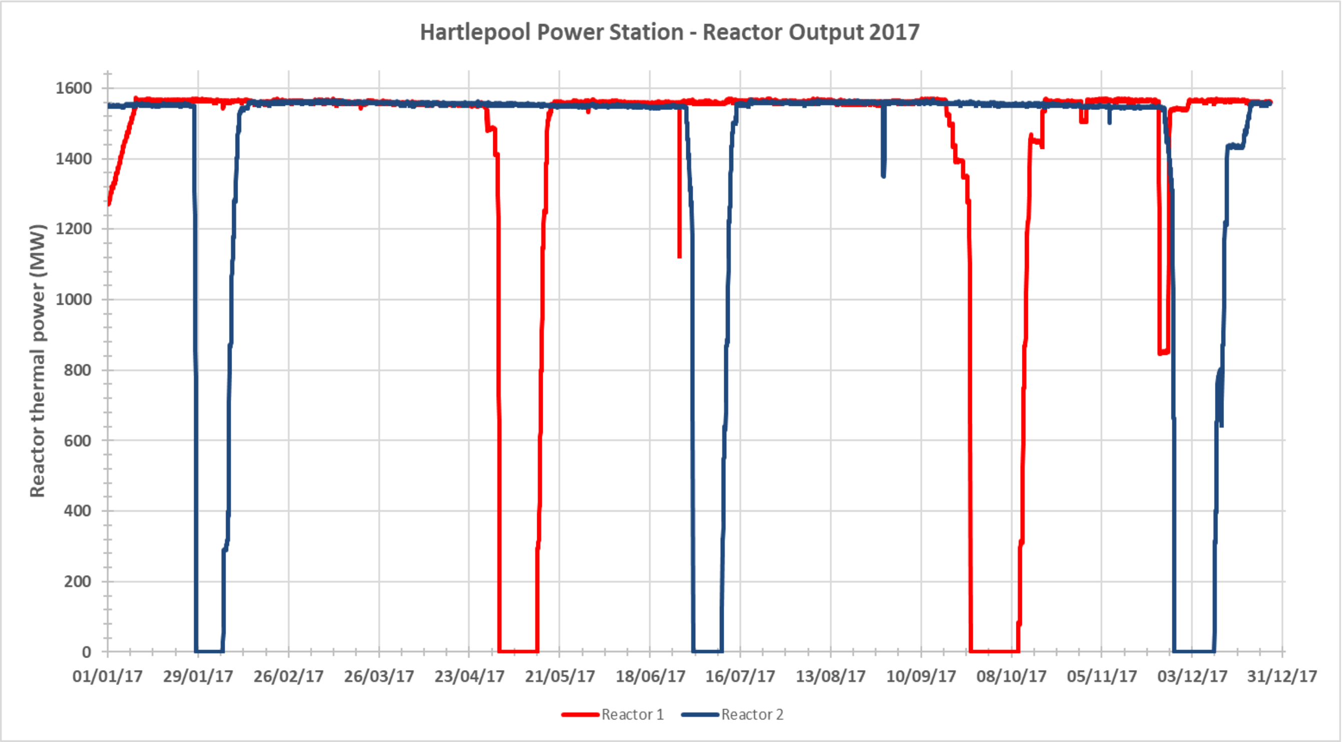
Pressure vessel	
Material	Pre-stressed concrete with stainless steel inner liner
Dimensions (Internal)	18.3m x 13.1m
Dimensions (External)	29.3m x 25.9m



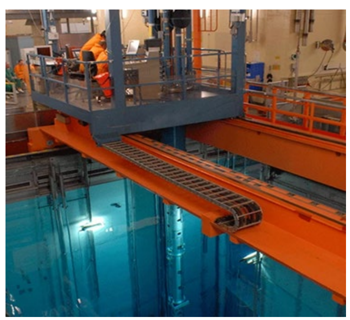


Hartlepool power station operation

- 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



Journey of the nuclear fuel



- Fuel spends ~ 8 years in the reactor
- Once out of the reactor, fuel must be below 16 kW before it can be dismantled at the IFDF – this typically takes around 2 weeks, during which the fuel is housed in special ‘buffer stores’
- Once below 16 kW, fuel is dismantled at the IFDF and sent to the cooling ponds
- Fuel must cool to < 12 kW decay heat and spend at least 90 days within the ponds
- Fuel elements are placed in a ‘flask’ for transport
- Flask with irradiated fuel is transported by train to Sellafield for reprocessing and long-term storage

Hartlepool Power Station Collaborations

Scientific projects underway and preliminary findings

XENAH

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 collaboration standing on top of the Hartlepool Reactor 1 pile cap

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 used for CTBT monitoring.

Collaborators: Atomic Weapons Establishment (AWE), UK, EDF, UK Pacific North-west National Laboratory (PNNL), USA, Swedish Defence Agency (FOI), Sweden, Met Office, UK, STFC Boulby, UK, Durham University, UK

Reactor stack monitoring - STAX

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

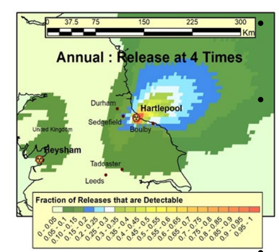
- 30% HPGe detector
- MDC for ^{133}Xe: 270 Bq/m^3
- Flow through system: 1.25 m^3/hr
- Continuous monitoring (15 minute acquisitions, looped)
- **System installed at R6 tower on the main blowdown route to monitor emissions just prior to refueling.**

In-core measurements and samples

Gaseous Activity Monitoring (GAM) system at Hartlepool power station

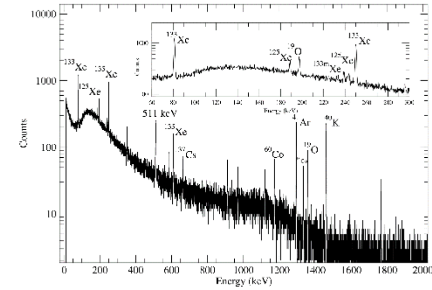
- Gaseous Activity Monitoring (GAM) measures in-core coolant activity to assess fuel condition ICS cooled, Ortec P-type 40% HPGe detector feeding Ortec DSPEC 50 MCA for isotopic analysis Used to monitor for fuel performance – particularly during blowdowns

Remote measurements after ATM



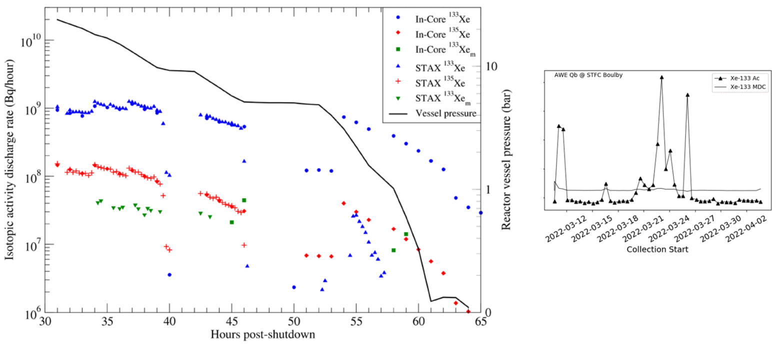
ATM Q_B sensitivity calculations, using emissions from Hartlepool reactor. Simulations performed using HYSPLIT with GFS 0.25° met data

- 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

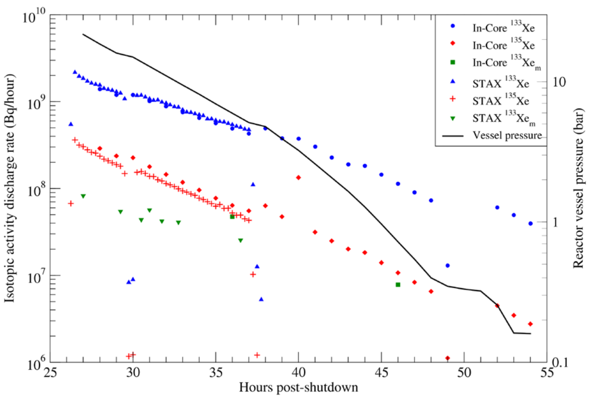


Typical spectrum obtained from a one-hour acquisition on the R1 GAM system whilst on-load at full power. Identified fission products and coolant activation products labelled.

XENAH – Preliminary results



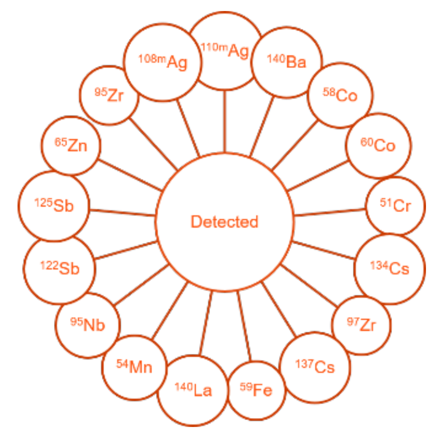
Released ^{133}Xe activity during R2 March 2022 Refuelling Blowdown. Figure compares STAX emission measurements and emission estimates using in-core coolant activity measurements from the GAM system scaled with measured stack flows. Insert shows coincident detection at Boulby with SAUNA Qb



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. R1 April 2023 blowdown 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



Anti-neutrino projects

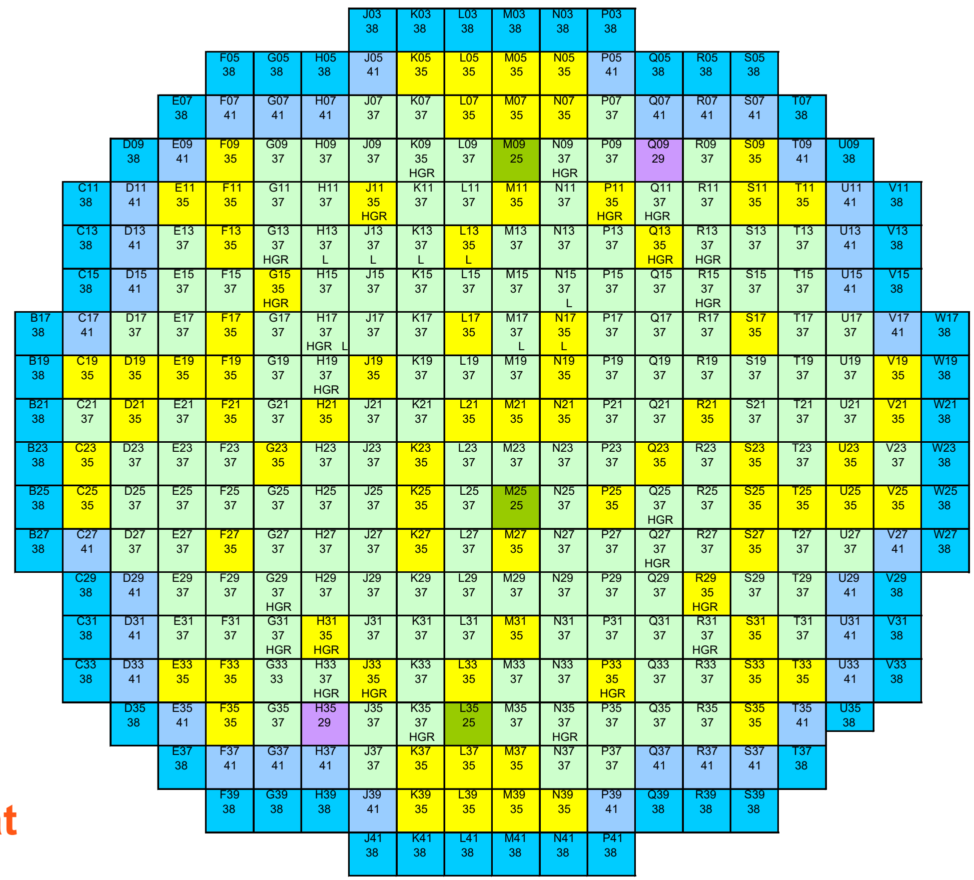
Anti-Neutrino flux from Hartlepool Nuclear Power Plant

- Operational data including loading information, power ratings, enrichments, power history provided
- Data obtained using thermal hydraulics code HEYPEX and neutronics code PANTHER

The aim was to calculate the anti-neutrino flux that could be expected from an operating Advanced gas-cooled Reactor (AGR)

Collaborators: Lawrence Livermore Nation Laboratory (LLNL), USA, University of Tennessee, USA, National Nuclear Laboratory (NNL), University of Liverpool, EDF

Results discussed in detail in Dr. Robert Mills' presentation



Reactor map of Fuel type loadings used as part of fission product calculations and anti-neutrino flux calculations

Following the success of this collaboration, future work is ongoing that aims to deploy a near-field anti-neutrino detector at Hartlepool

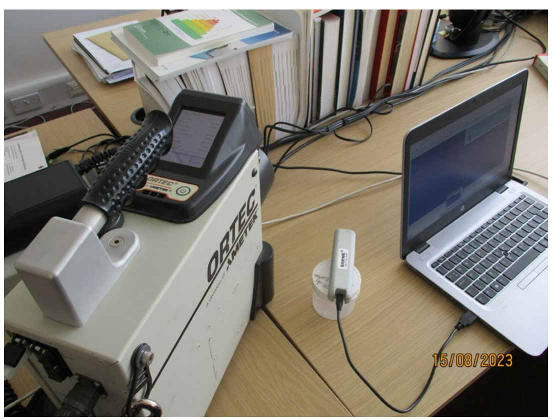
Anti-neutrino projects

Potential deployment of a small-scale detector for near-field measurements

- Aim to secure funding for deployment of Li-doped detector to perform near-field measurements at Hartlepool
- Anti-neutrino emission modelled using real reactor data and previously reported
- Neutron and Gamma background measurements have been undertaken at candidate locations to assess viability
- Gamma and neutron flux will be calculated based on in-situe measurements

Collaborators: Lawrence Livermore Nation Laboratory (LLNL), USA, University of Tennessee, USA, National Nuclear Laboratory (NNL), University of Liverpool, EDF

Design and pictures of sections of the proposed Li doped liquid scintillator detector.



Gamma and neutron detectors measuring in Admin 1 NSG office.

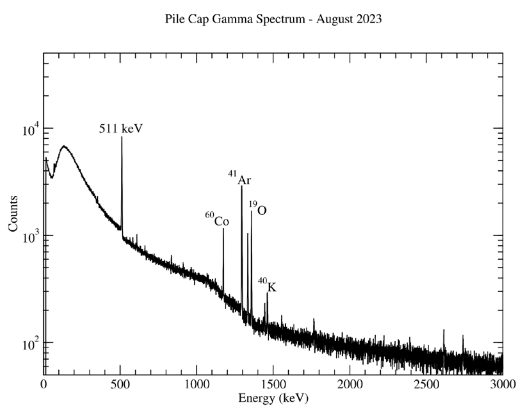
Gamma detector: Ortec TranSPEC DTX-100. 40% eff. HPGe detector

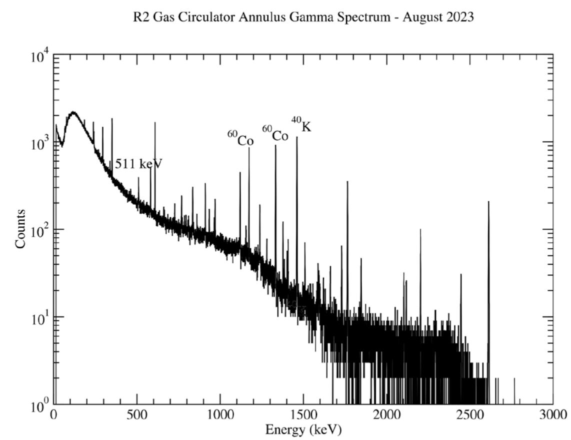
Neutron detector: Kromek TN-15. SiPM array with >50% thermal neutron sensitivity

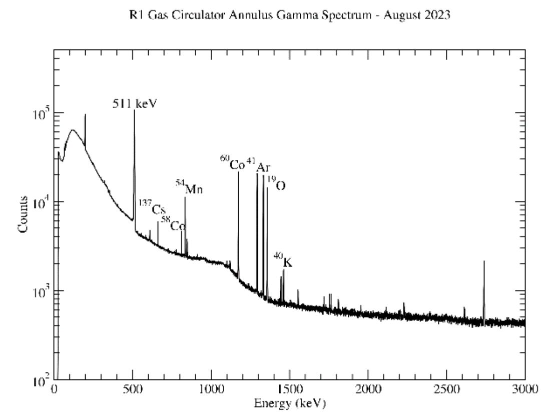
4 hour measurement at each location obtained

Measurement locations	Distance from active core
District Survey Lab	~1.6 km
Admin 1 NSG office	~ 300 m
Pile Cap	~14 m
R1 Gas Circ annulus (running unit)	~9 m
R2 Gas Circ annulus (shutdown unit)	~9m

Anti-neutrino projects – preliminary results



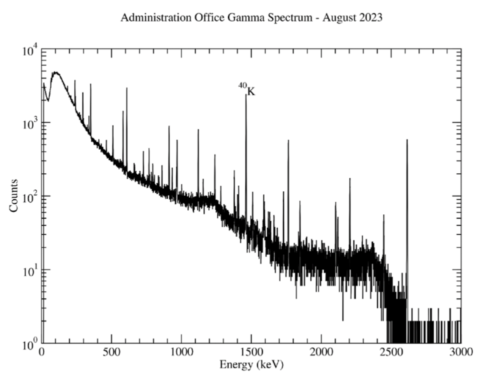


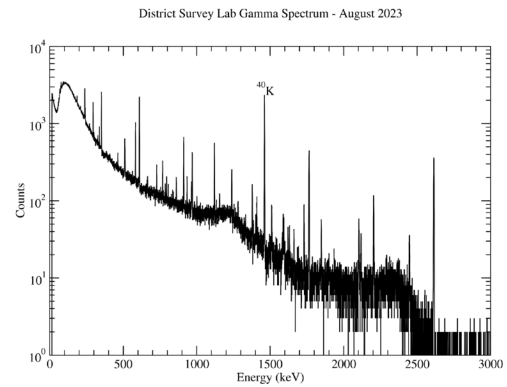


Pile Cap measurement location

Gas Circ annulus measurement location

Anti-neutrino projects– preliminary results





District Survey Lab with a view of the Power Station

Admin 1 NSG office – my desk

Preliminary conclusions

- Admin and DSL give 'background' readings
- Gamma spectrum at position underneath a running reactor is dominated by in-core fission and activation products
- Gamma spectrum at position underneath a shutdown reactor is close to background
- Neutron flux elevated on a running unit vs shutdown
- Pielcap reading requires repeat – significantly elevated. Possibly due to stored reactor components

Measurement locations	Neutron Counts
District Survey Lab	154
Admin 1 NSG office	162
Pile Cap*	3614
R1 Gas Circ annulus (running unit)	592
R2 Gas Circ annulus (shutdown unit)	18

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Thank You