UNITED KINGDOM – NORWAY INITIATIVE

Use of Gamma Spectrometry in the UKNI Information Barrier Project

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on behalf of the UKNI Collaboration

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Participants

- Collaboration began in 2007
- Participating institutions
  - UK: Atomic Weapons Establishment (AWE), Ministry of Defence
  - Norway: Institute for Energy Technology (IFE), Norwegian Defence Research Establishment (FFI), NORSAR, Norwegian Radiation Protection Authority (NRPA)
  - NGO: Verification Research Training and Information Centre (VERTIC) participated until 2009

AWE VERTIC Statens strålevern Norwegian Radiation Protection Authority

IFE Institutt for energiteknikk

FFI Forsvarets forskningsinstitutt Norwegian Defence Research Establishment

MINISTRY OF DEFENCE NORSAR

Outline

- Will cover a few key topics:
  - Project background and information barrier concept
  - IB algorithm design & test
  - Major issues to consider & where next
- All project information – design drawings, software, analyses etc. – is available at http://ukni.info

UKNI

Part 1

BACKGROUND AND CONCEPT

The Information Barrier project

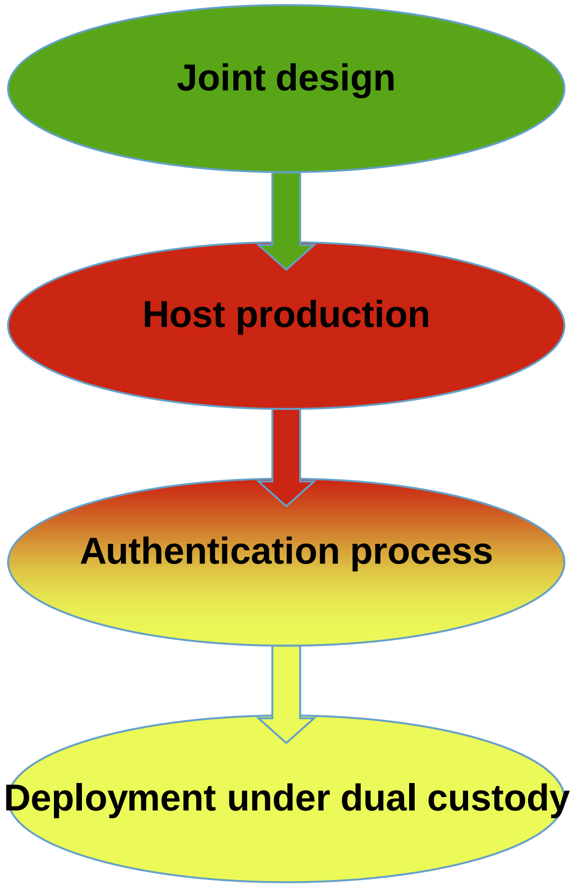
- Project objective: Understand how to build and maintain **mutual confidence** in verification equipment.
  - Investigate joint hardware/software design
  - Design for equipment authentication
- (Fictional) monitoring objective: Allow inspectors to verify that an object declared to be a Treaty Accountable Item (TAI) has the attributes it should, without revealing any other details:
  - TAIs **contain plutonium**; and
  - Plutonium in TAIs has a **^{240}Pu:^{239}Pu ratio of <0.1**
- UKNI pursued these objectives by designing and building an information barrier consisting of a high resolution gamma detector and custom electronics

Information Barrier project steps

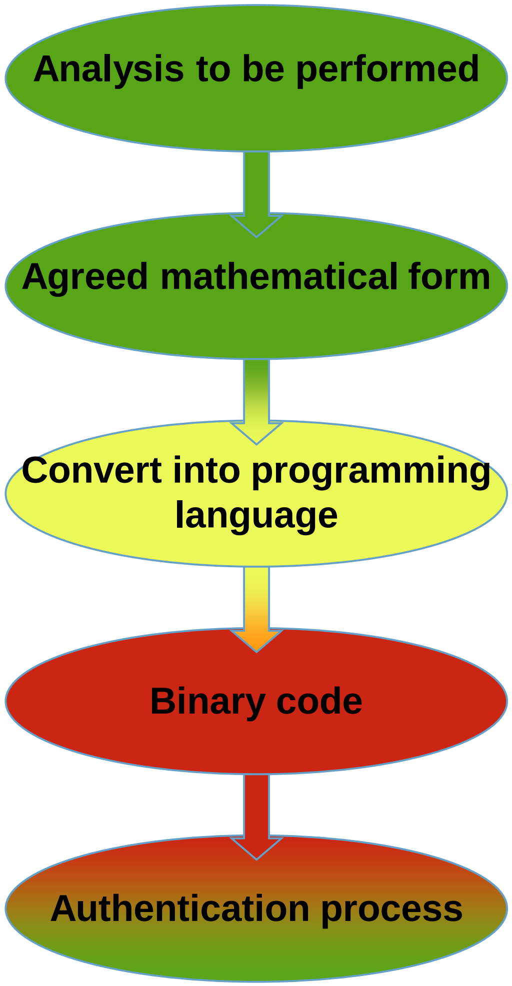
- Phase 1: Identification of ^{60}Co
- Phase 2: Ratio calculation of ^{60}Co and ^{22}Na
- Phase 3: Plutonium identification, $^{240}Pu/^{239}Pu$ ratio calculation, comparison vs. preset threshold of 0.1
  - Phase 3a: Area calculation algorithm
    - Performance tested using data collected at Dounreay civil nuclear facility
  - Phase 3b: Peak fitting algorithm
    - Performance tested using data collected at AWE

Authentication concept

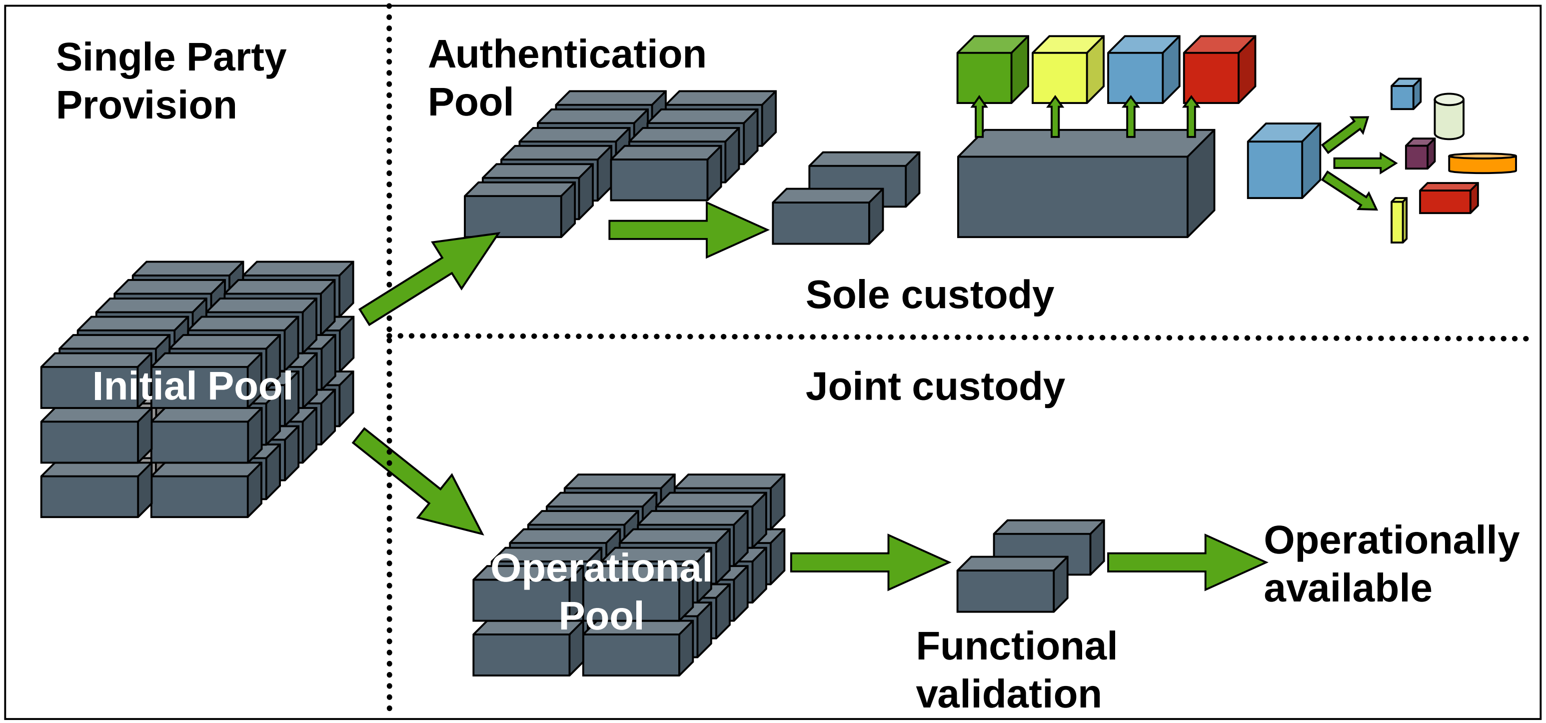
Overall design and implementation



Software



Authentication process



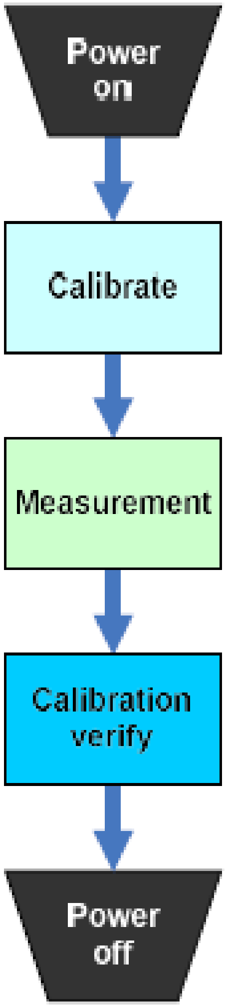
- Initial concept: Give equipment to inspectors after use
- ‘Post-use’ authentication difficult to achieve in practice
- Reliance on random selection and authentication ‘by association’

Part 2

ALGORITHM DESIGN & TEST

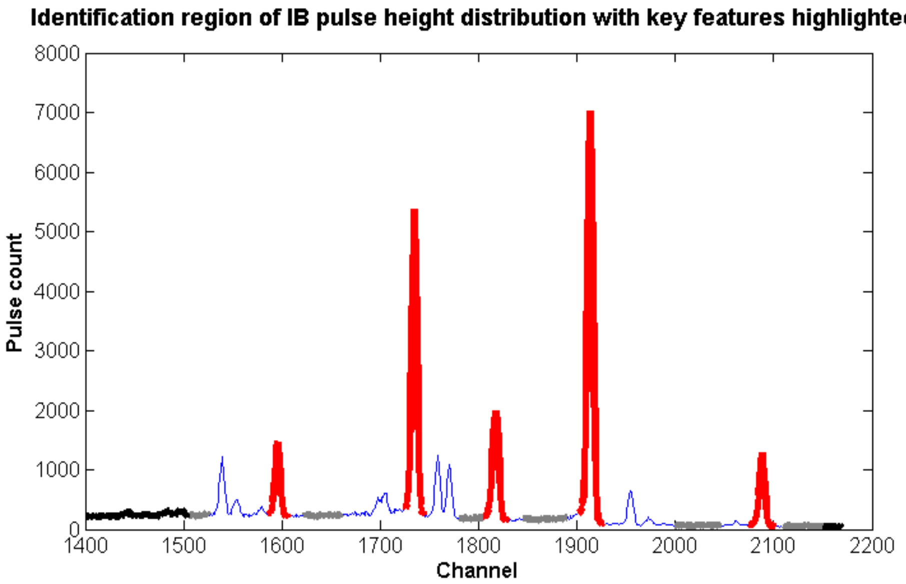
Algorithm flow

- Calibration is performed nearly identically in both Phase 3a and Phase 3b algorithms:
  - IB software locates two prominent gamma peaks from a ^{152}Eu source
  - Only proceeds to measurement if successful
- Measurement
  - Stage 1: Pu identification (300 – 500 keV ROI)
  - Stage 2: Isotopic ratio calculation (630 – 670 keV ROI)
- Calibration verify identical to calibration
  - Parameters might drift over time due to e.g. heating or a change in environmental background
  - Failure at this stage casts doubt on measured result



Plutonium identification

- Choose suitable peaks: 345 keV, 375 keV, 392/3 keV, 413 keV, 451 keV
- How to ensure peaks are from plutonium?
- Originally discussed five tests
  1. Peak location
  2. Peak shape
  3. Peak presence
  4. Relative peak height
  5. Relative peak location



- Only first three deemed suitable
  - No gamma background information so 'relative peak height' is not useful
  - Relative peak location unnecessary as absolute location needs to be hard-coded in software

Phase 3a testing

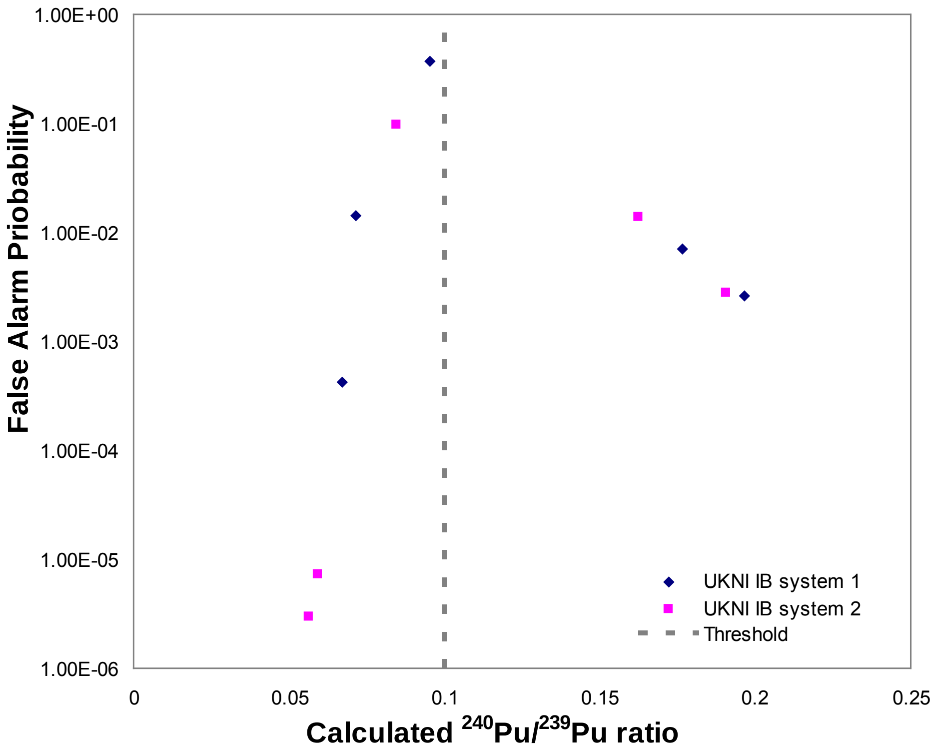
- Plutonium measurements at Dounreay – different types & quantities
  - Varying isotopic content around threshold (0.1 $^{240}Pu/^{239}Pu$)
  - Relatively large mass (200 – 900 g)
  - Standard container design (minimal shielding)
- Multiple IBs deployed on signal from single HPGe detector
- Results: Accuracy & precision insufficient, developed improved algorithm → Phase 3b

Part 3

ISSUES TO CONSIDER

Threshold setting

- **False positives,** identification of Pu (with $^{240}Pu/^{239}Pu < 0.1$) if such material is not present
- **False negatives,** confirmation not given when material with suitable attributes is present
- Error rate clearly greatest around the threshold value
- The threshold can only be set using results from unclassified, jointly-understood test objects
  - Real objects might not exhibit the same gamma spectrum
  - Up to the Host to ensure statistics are at least as good as test objects



Understanding results

- What does an individual result mean?
  - Statistical process
  - Population determination
- Could multiple objects of different isotopic profiles present an ‘acceptable’ pass rate?
  - Motivates repeated measurements
  - But could repeated measurements reveal sensitive information?
- Also suggests the need for an agreed process for resolving ambiguous situations
  - Quarantine?
  - Re-test procedures?

Impact of operational issues

- Need to prevent tampering with items and equipment once deployed
  - Multi-day process for a single measurement
    - Sweep facility: could be multi-hour
    - Set-up & introduction of TAIs into facility: could be multi-hour
    - Initial detector cooling: 8 hours minimum
    - Measurement time of ~1 hour per measurement
  - Engineering port allows real-time download of data for debugging and analysis – needs protection
- Finite length inspections, so must also plan activities carefully
- Wider authentication requirements
  - Can we trust the detector? Onboard electronics, cooling?
  - Functional verification as yet unspecified – how do we authenticate the equipment used for that? Is COTS enough?
  - What about any other support equipment?

The “simple design” fallacy

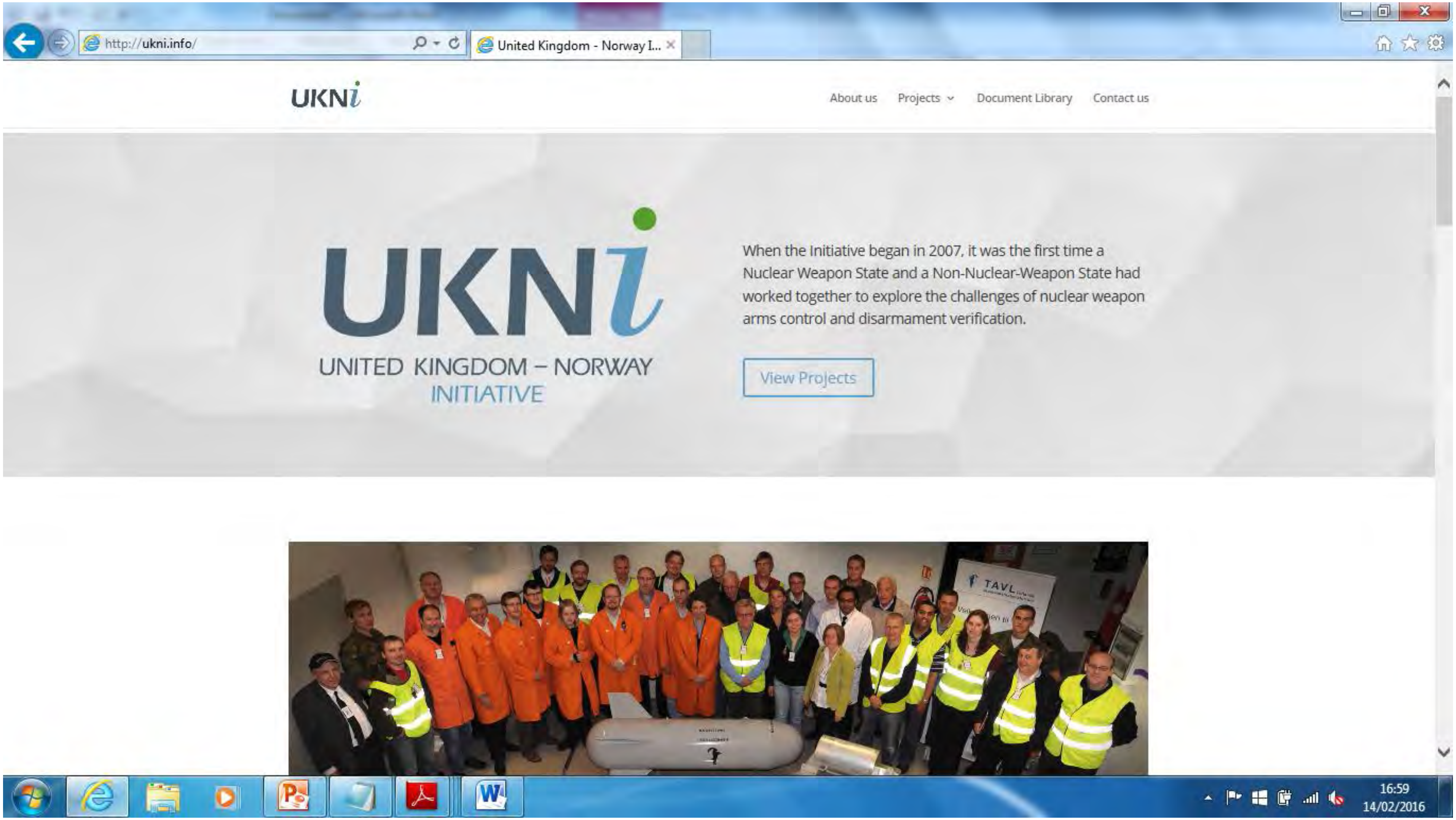
- The UKNI assumed that a simple hardware design would be easier to authenticate than a more complex design
- However, simplicity limits capability and data processing:
  - Computations broken into parts: not as straightforward to follow
  - Impact on deployment process
  - Harder to implement data security measures
- Simplicity is a means, not an end – transparency of design and purpose more important than ‘simple’
  - Equipment must be capable of performing tasks efficiently
  - Deep understanding of design provides basis for authentication

Where next?

- The information barrier is a research and development vehicle, not a production system – no Phase 4 planned
- BUT… others may benefit from replicating our work, studying and improving the IB hardware & software, and finding our mistakes!
  - **Visit http://ukni.info** for all the IB documentation
  - **UK willing to build and donate a limited number of Phase 3b IB systems**, with UK software, to interested parties who wish to use them to kick-start their own work on verification
- More broadly, there is clearly more work to be done on authentication techniques for software and hardware - access to nuclear weapons is not required to make progress here

UKNi

Thanks for your attention!

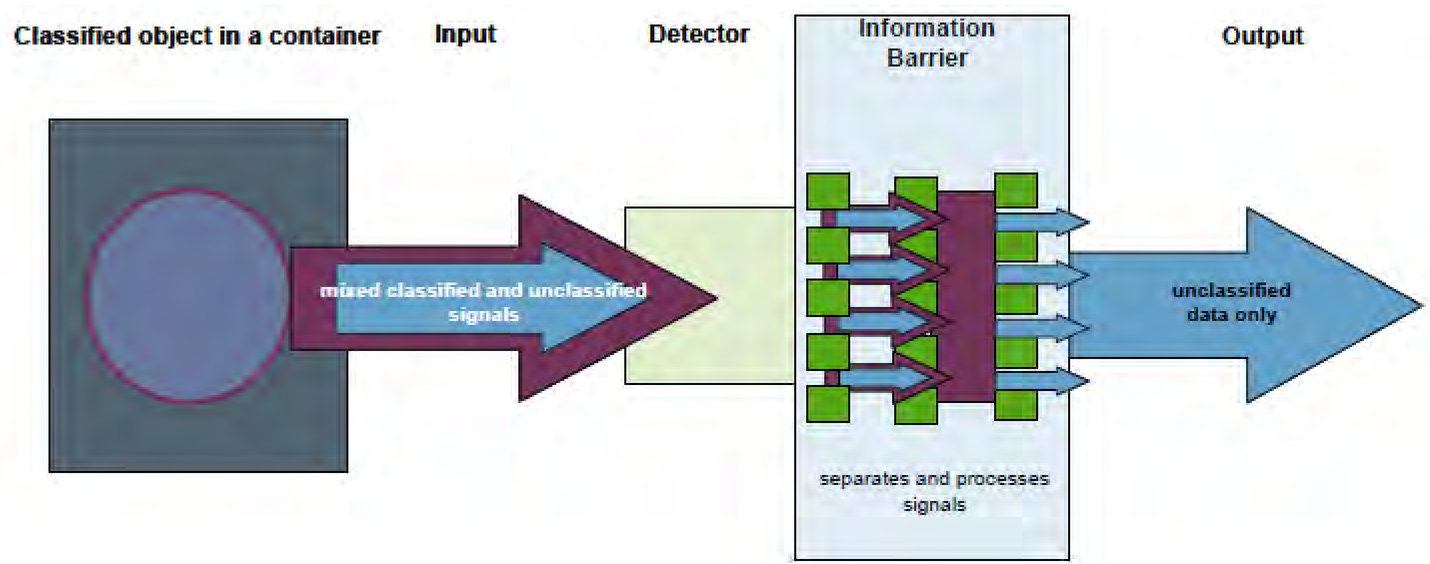


Part 4

BACKUP SLIDES

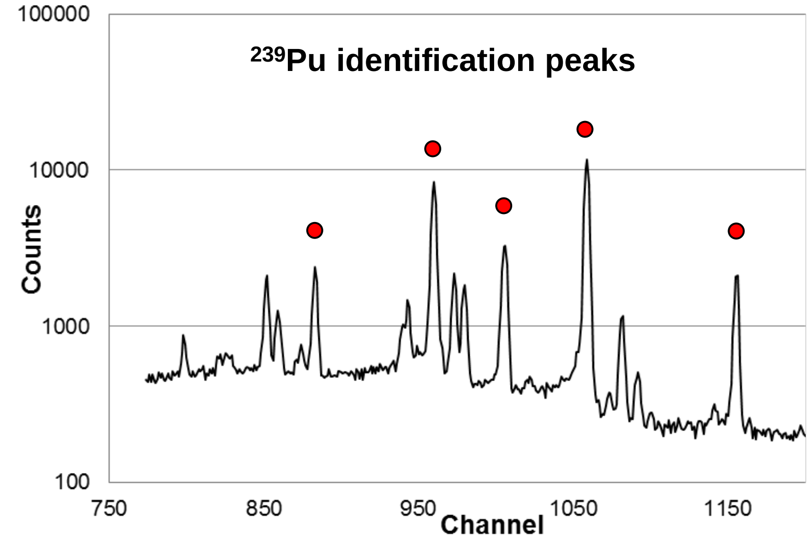
What is an Information Barrier?

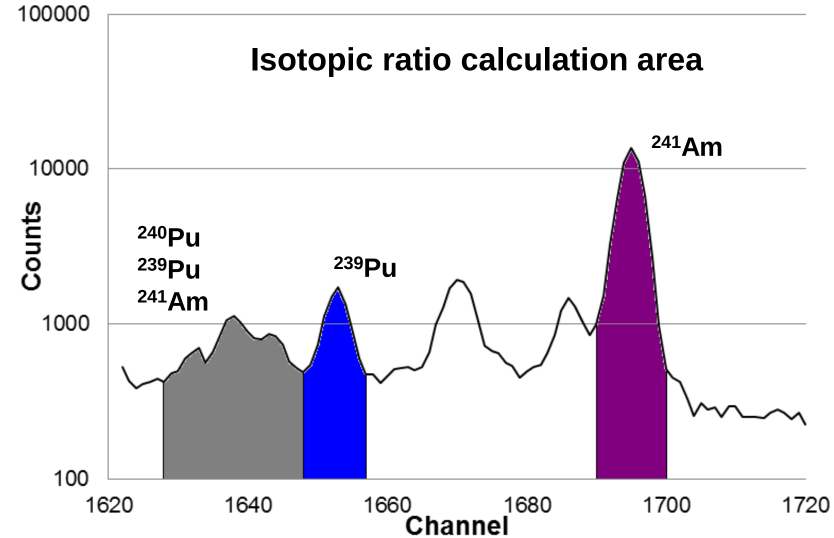
- A combination of **technology** and **procedures** designed to allow declared information to be verified while protecting all other information
- The UKNI IB measures the isotopic ratio of plutonium in a test object by using gamma spectrometry, compares to pre-agreed criteria and returns a present/not proven result



Phase 3a algorithm

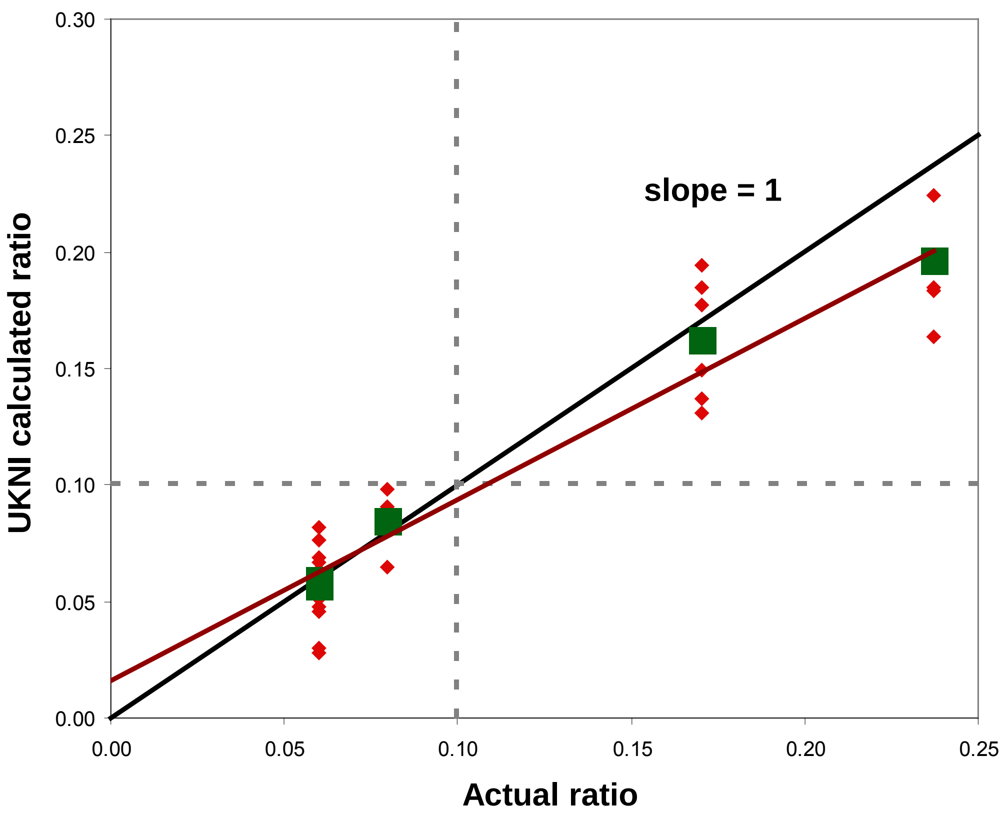
- Based on collection up to 15 minutes
- **^{239}Pu identification**
  - Five gamma peaks chosen: 345, 375, 392/393, 413, 451 keV
  - If test passed, proceed to next stage
- **^{240}Pu/^{239}Pu isotopic ratio**
  - Limited choice due to limited ^{240}Pu emissions; 600 keV region chosen
- **Threshold comparison**
  - Ratio set to 0.1 (^{240}Pu/^{239}Pu)





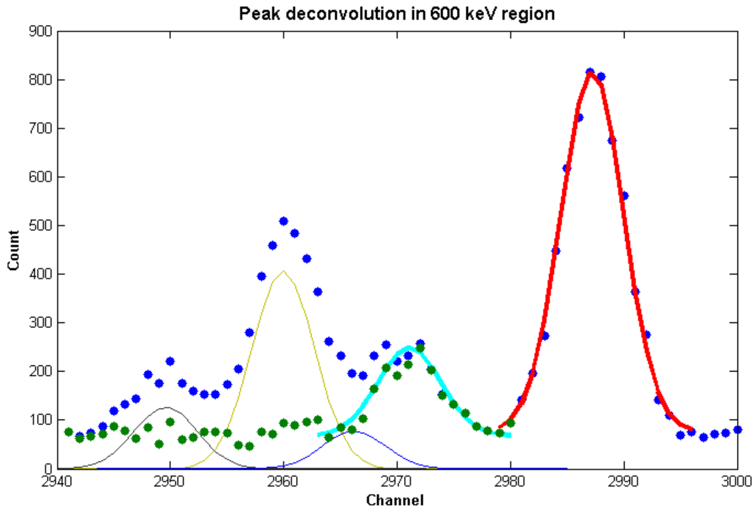
Dounreay results

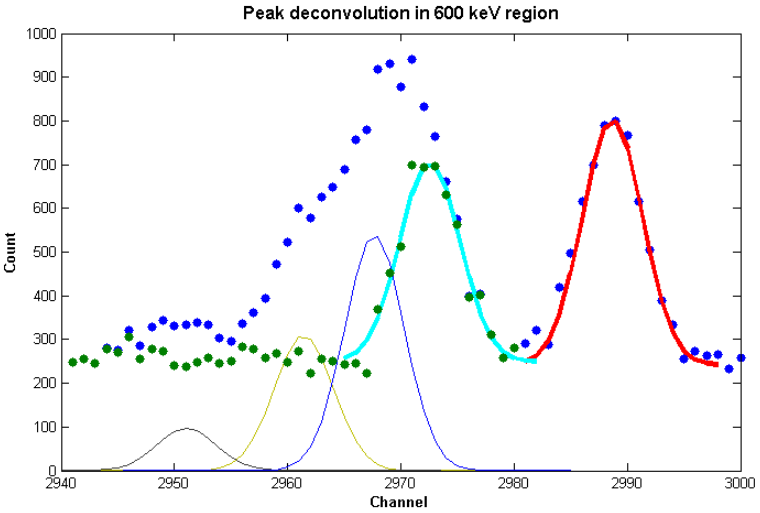
- Multiple measurements of same samples (σ not shown for clarity)
- Considerable variation in results: total counts attributed to ^{240}Pu is low
- Visual: under-estimation of ^{240}Pu content at high ratios (^{240}Pu/^{239}Pu greater than 0.2)
- Linear fit appears inappropriate
- Sum results (longer count time) also suggest under-estimation of algorithm at high ^{240}Pu/^{239}Pu ratios
  - Spread of results consistent with PU600



Phase 3b algorithm

- Based on collection of up to an hour (up from 15 minutes)
- ^{239}**Pu** identification unchanged
- ^{240}**Pu/**^{239}**Pu isotopic ratio** no longer area calculation – now using peak-fitting
- Algorithm recently tested against PIDIE standards, results under analysis at present but show improved performance vs Phase 3a
- Further test & characterisation planned, results to be published on UKNI website





Peak-fitting algorithm

1. Estimate background radiation contribution for ^{241}Am peak (662 keV)
2. Superimpose a normalised Gaussian curve onto ^{241}Am peak
    a. Optimise curve parameters using a least-squares fit
    b. Check that the fit is good enough to validate subsequent analysis
3. Superimpose a normalised Gaussian curve onto ^{239}Pu peak (645 keV)
    a. Optimise curve parameters using a least-squares fit
    b. Check that the fit is good enough to validate subsequent analysis
4. Calculate and subtract contributions to ^{240}Pu peak (642 keV) from ^{239}Pu and ^{241}Am
    a. ^{239}Pu at 637 keV and 640 keV
    b. ^{241}Am at 641 keV
5. Superimpose a normalised Gaussian curve onto subtracted ^{240}Pu peak
    a. Optimise curve parameters using a least-squares fit
    b. Check that the fit is good enough to validate subsequent analysis
6. Calculate ^{240}Pu:^{239}Pu isotopic ratio using:
    a. Height of ^{239}Pu peak (645 keV)
    b. Height of ^{240}Pu peak (642 keV)
    c. Constant parameter, calculated from the half lives of the two isotopes, and the emission probability of the two gamma rays.

In order to obtain a value for isotopic ratio, the relative heights of the gamma-ray peaks from ^{239}Pu (at 645 keV) and ^{240}Pu (at 642 keV) are used. This value is compared with the threshold (0.1) to determine the pass/fail output.