Verification of fissile materials

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GammaSem seminar 2010

28/09/2010 - 29/09/2010

Statens strålevern

Norwegian Radiation Protection Authority

Overview

- Introduction
- Background
- The Black Sea Experiment
- Trilateral Initiative
- The Uk-Norway Initiative
- Detection of Plutonium
- In house developments
- Summary

Fissile materials

- **Fissile** Materials that can sustain a fission chain reaction - notably highly enriched uranium (^{235}U) or plutonium (^{239}Pu).
  - Fission weapon materials:
    - WGU – 93.3 % ^{235}U, 5.5% ^{238}U, 1% ^{234}U
    - WGPu

$$^{238}U \xrightarrow{(n,\gamma)} {}^{239}U \xrightarrow[23.5\ min]{(\beta^-)} {}^{239}Np \xrightarrow[2.3565\ d]{(\beta-)} {}^{239}Pu \quad (24.11\ y)$$

$$^{239}Pu \xrightarrow{(n,\gamma)} {}^{240}Pu \quad (6.56\ y)$$

Pu grade	**% ^{240}Pu**
Weapon grade	<= 7%
Fuel grade	> 7% < 18%
Reactor grade	> 18%

- **Fissionable** Materials that can undergo fission when struck by neutron, which however can not sustain fission e.g., ^{238}U, ^{240}Pu and ^{232}Th.

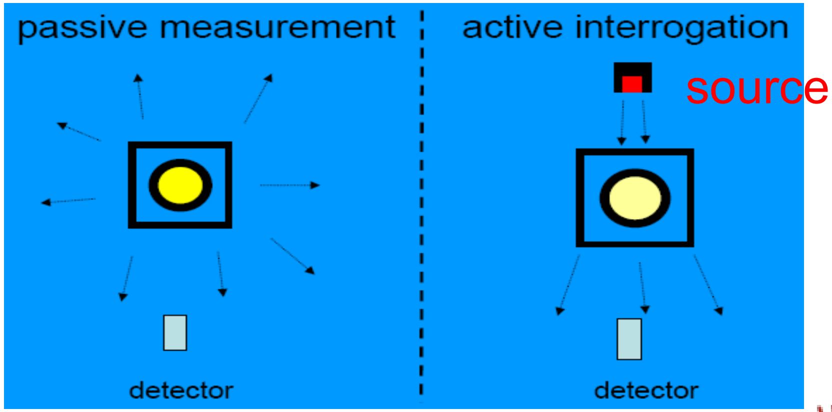
Monitoring Techniques

There are two basic classes of Non-destructive assay radiation monitoring techniques:

passive measurements, the results are derived directly from analyzing the radiation of the object.

active interrogation, the object is stimulated by a neutron or high-energy photon source, and the results are derived by analyzing the induced emissions.

non-destructive assay (NDA)

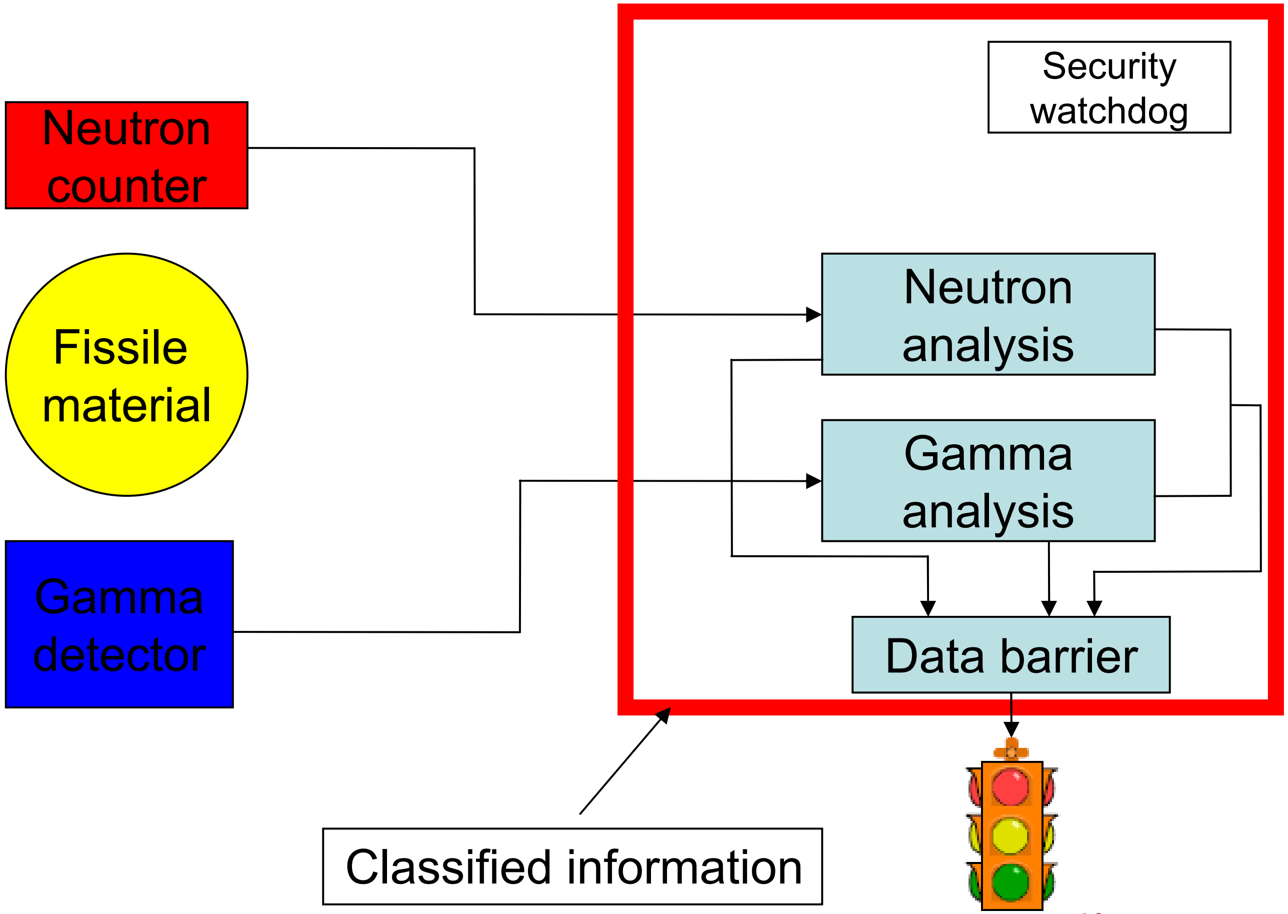


Information Barrier

- An information Barrier consists of technology and procedures that:
  - used for attribute verification of excess fissile materials
  - prevent the accidental or intentional release of classified information
  - Authenticate the measurement / accurate assessment that unclassified display reflects the true state of measured item.
- Each element – simple, transparent and justifiable
- Source code of all soft- and hardware should be available for inspection
- System design: modular, conceptual design, authenticateable, and well documented.

Information Barrier

- IB role in γ-ray measurements is to pass only those attributes of the part of spectrum chosen for inspection and to conceal all others.



Motivation and Background

- Safeguarding the fissile materials.
- Non-Nuclear Proliferation Treaty article – VI

  "Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control".
- Verifying the disarmament procedures.

The Black Sea Experiment

OCCASIONAL REPORT

The Black Sea Experiment

US and Soviet Reports from a Cooperative Verification Experiment

On 5 July 1989, in a remarkable display of military glasnost, a team of US scientists organized by the National Resources Defense Council (NRDC) and a team of Soviet scientists from the I.V. Kurchatov Institute of Atomic Energy measured the radiation emitted by the nuclear warhead of a cruise missile aboard the Soviet ship Slava. *The measurements took place in the Black Sea off Yalta. We publish here two papers that summarize the results of these experiments: the first, by Steve Fetter and Frank von Hippel, is adapted with permission from an article that appeared in* Physics Today, *November 1989. A technical research paper describing the results of the experiment is forthcoming in* Science.

The second paper, by S.T. Belyaev, V.I. Lebedev, B.A. Obinyakov, M.V. Zemlyakov, V.A. Ryazantsev, and V.M. Armashov of the Kurchatov Institute, and S.A. Voshchinin of the Soviet Navy, briefly describes the Soviet helicopter-mounted neutron-detection detection system and its use in the detection of nuclear warheads, including the experimental results in the Black Sea.

MEASUREMENTS OF RADIATION FROM A SOVIET WARHEAD

Steve Fetter and Frank von Hippel

The Black Sea Experiment

- Strategic Arms Reduction Treaty SART b/w US and USSR
- Verification of nuclear armed sea launched cruise missiles
- Tests were carried on a USSR warhead on a cruiser in the Black Sea
- The detection and observations made here became the basis for the future developments in the verification projects
- Gamma and neutron detection
- Ge detectors - placed on the launcher at the warhead location.
- ^{235}U – 186 keV peak and ^{239}Pu – 375, 414 keV peaks.

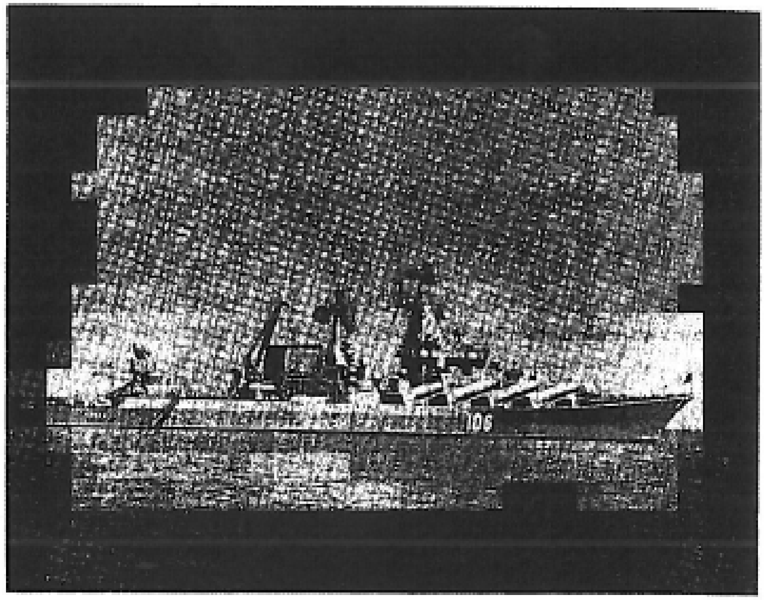


Figure 2: The Soviet cruiser *Slava*

The Black Sea Experiment

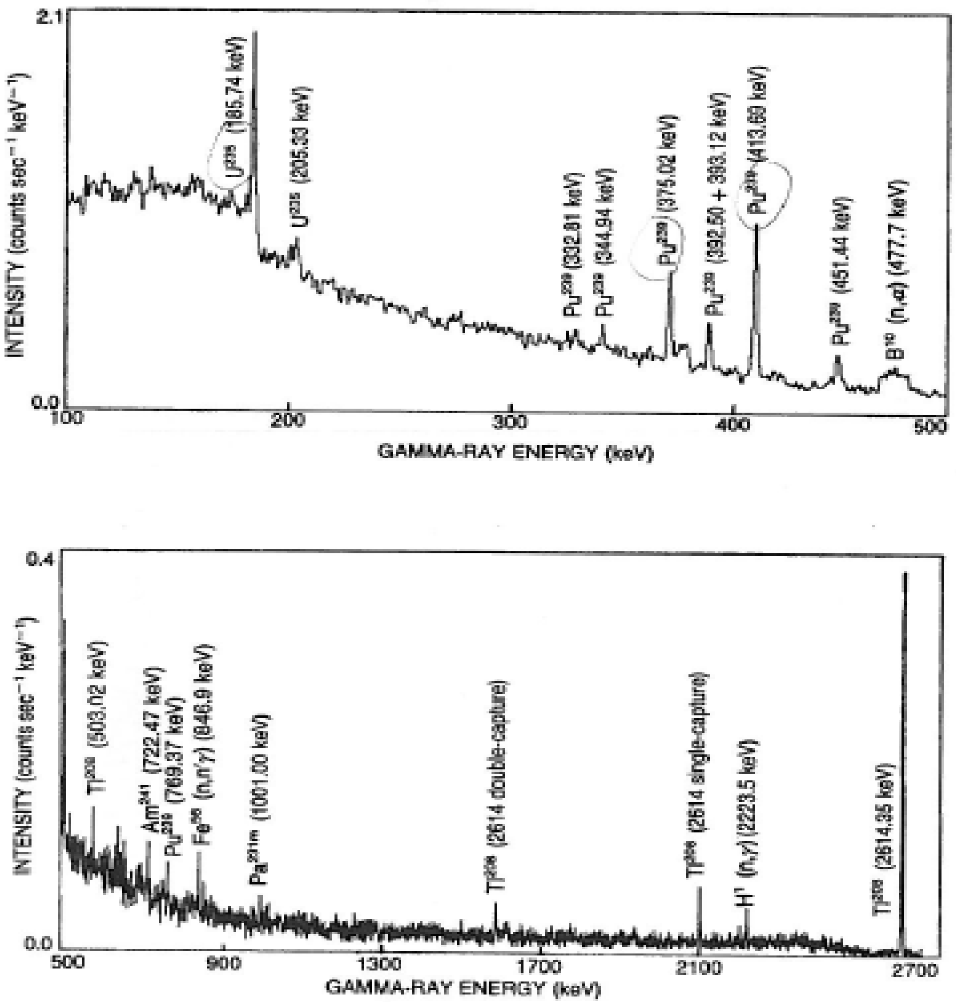


Figure 1: The gamma-ray signal recorded by a germanium detector placed on top of a cruise-missile launcher 3.4 meters from the lid for 10 minutes

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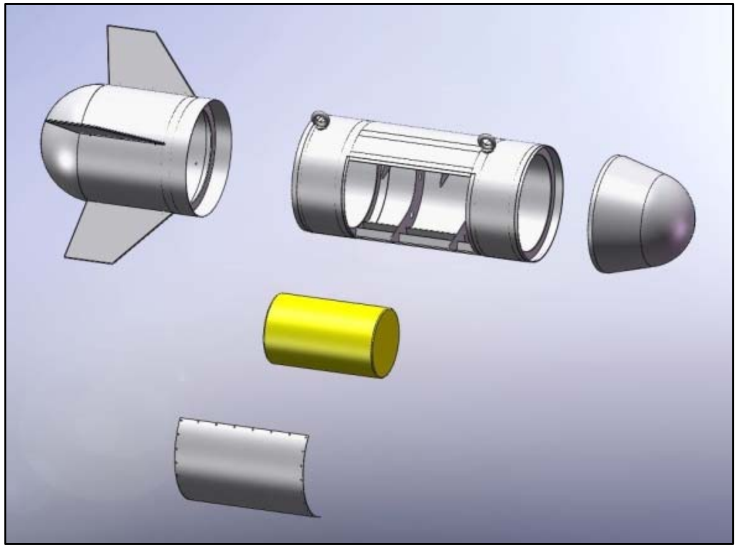
Trilateral Initiative

- US, Russia and IAEA
- Launched in Sept. 1996 to investigate the technical, legal and financial issues associated with the IAEA verification of classified forms of weapon origin
- It was concluded in 2002
- The initiative was intended to establish a system of verification under which NWS might submit excess fissile material to IAEA monitoring.
- IAEA traditional verification techniques could not be considered as proliferation-sensitive information was the issue.

The UK-Norway initiative

- Project name:
- The United Kingdom – Norway Initiative: A NNWS – NWS cooperation into disarmament verification



- Research in methods and
- tools needed by an inspection
- team to verify dismantlement
- of nuclear warheads

- The main parts of this project:
  - The Managed Access project
  - The Information Barrier system (IB) development project

UK-Norway IB – prototype

Digital electronic Module
(micro-proc. & memory)

Analogue electronics
(for signal processing)

Low voltage supply to
IB & detector

High voltage supply
to detector &

Detection of WGU

WGU neutron activity

mass number (A)	*spontaneous fission half-life (years)*	*spontaneous fission neutron activity (n/kg/s)*	*alpha-induced activity (n/kg/s)*	*WGU composition*	*WGU neutron activity (n/kg/s)*	*percent activity*
234	1.50×10^{16}	9.43	50	1.0%	0.594	38.3%
235	1.00×10^{19}	0.01	0.012	93.3%	0.024	1.6%
238	8.20×10^{15}	16.95	0.001	5.5%	0.932	60.1%

references: [Browne, 1986], [Fetter, 1990], [Holden, 2000]

Detection of WGU

Gamma – ray activities per Kg of WGU

mass number	**232**[a]		**233**		**234**		**235**		**236**		**238**[b]	
half-life (years)	68.9		1.59×10^{05}		2.45×10^{05}		7.04×10^{08}		2.34×10^{07}		4.47×10^{09}	
activity (Bq/kg)	8.28×10^{14}		3.57×10^{11}		2.30×10^{11}		8.00×10^{07}		2.39×10^{09}		1.24×10^{07}	
WGU Composition[c]	0.0001%		0.01%		1.00%		93.30%		0.20%		5.50%	
	energy (keV)	*activity* $(kg\text{-}s)^{-1}$	*energy E(keV)*	*activity* $(kg\text{-}s)^{-1}$	*energy E(keV)*	*activity* $(kg\text{-}s)^{-1}$	*energy E(keV)*	*activity* $(kg\text{-}s)^{-1}$	*energy E(keV)*	*activity* $(kg\text{-}s)^{-1}$	*energy E(keV)*	*activity* $(kg\text{-}s)^{-1}$
Strongest	**238.59**	**3.61×10^{08}**	117.16	9.99×10^{02}	**454.97**	**5.99×10^{02}**	**143.79**	**7.84×10^{06}**	**112.75**	**9.10×10^{02}**	258.18	3.88×10^{02}
Gammas	277.28	5.63×10^{07}	118.97	1.14×10^{03}	508.2	3.39×10^{02}	163.38	3.51×10^{06}			742.82	3.87×10^{02}
> 110 keV	**510.61**	**1.79×10^{08}**	120.81	7.49×10^{02}	581.78	2.77×10^{02}	**185.74**	**3.96×10^{07}**			**766.41**	**1.42×10^{03}**
	583.02	**7.12×10^{08}**	135.33	7.85×10^{02}			202.14	7.47×10^{05}			786.29	2.34×10^{02}
	727.25	5.51×10^{07}	145.29	5.71×10^{02}			205.33	3.51×10^{06}			**1001**	**4.45×10^{03}**
	860.3	9.93×10^{07}	**146.35**	**2.25×10^{03}**			221.4	8.96×10^{04}			1193.74	6.16×10^{01}
	2614.35	**8.26×10^{08}**	**164.51**	**2.35×10^{03}**			279.5	2.02×10^{05}			1510.11	6.23×10^{01}
			187.94	7.14×10^{02}							1737.8	9.72×10^{01}
			208.15	8.92×10^{02}							1831.7	7.67×10^{01}
			217.13	1.25×10^{03}								
			245.29	1.25×10^{03}								
			291.32	1.86×10^{03}								
			317.13	**3.14×10^{03}**								
			320.51	1.11×10^{03}								

[a] ^{232}U in equilibrium with ^{228}Th (1.9 years half-life) and subsequent short-lived decay products.
[b] ^{238}U in equilibrium with ^{234m}Pa (1.17 minutes half-life)
[c] representative compositions for WGU, actual compositions will vary
reference: [Browne,1986]

Plutonium detection

- Six important Pu attributes
    1. Presence of ^{239}Pu: characteristic gamma lines
    2. Presence of WGPu: The ratio of ^{240}Pu and ^{239}Pu
    3. Pu mass: Neutron counting
    4. Identifying the Pu age since last seperation: The raio of ^{241}Am to ^{241}Pu
    5. Absence of PuO_2: The presence of O_{17} excites states
    6. Axial symmetry of Pu source

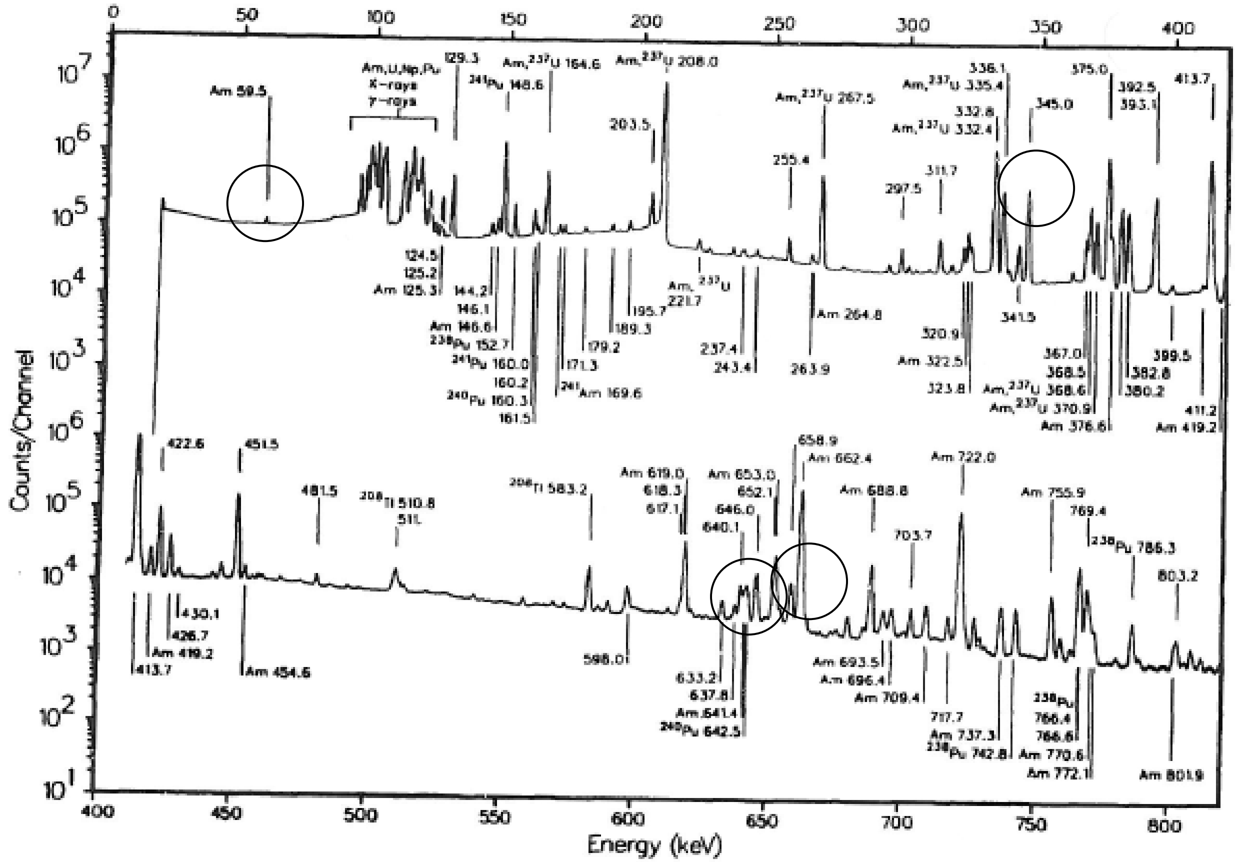


Fig. 4. Spectrum from 530 g plutonium as PuO_2 with isotopic composition (wt%): 238, 0.202%; 239, 82.49%; 240, 13.75%; 241, 2.69%; 242, 0.76%; Am, 11 800 µg/g Pu. Detector is a 10.2% relative efficiency coax with 1.65-keV resolution at 1332 keV. Energies not labeled with a specific isotope are from ^{239}Pu.

Ref. *Plutonium Isotopic Composition*, T.E. Sampson, LA-10750-MS (1986)

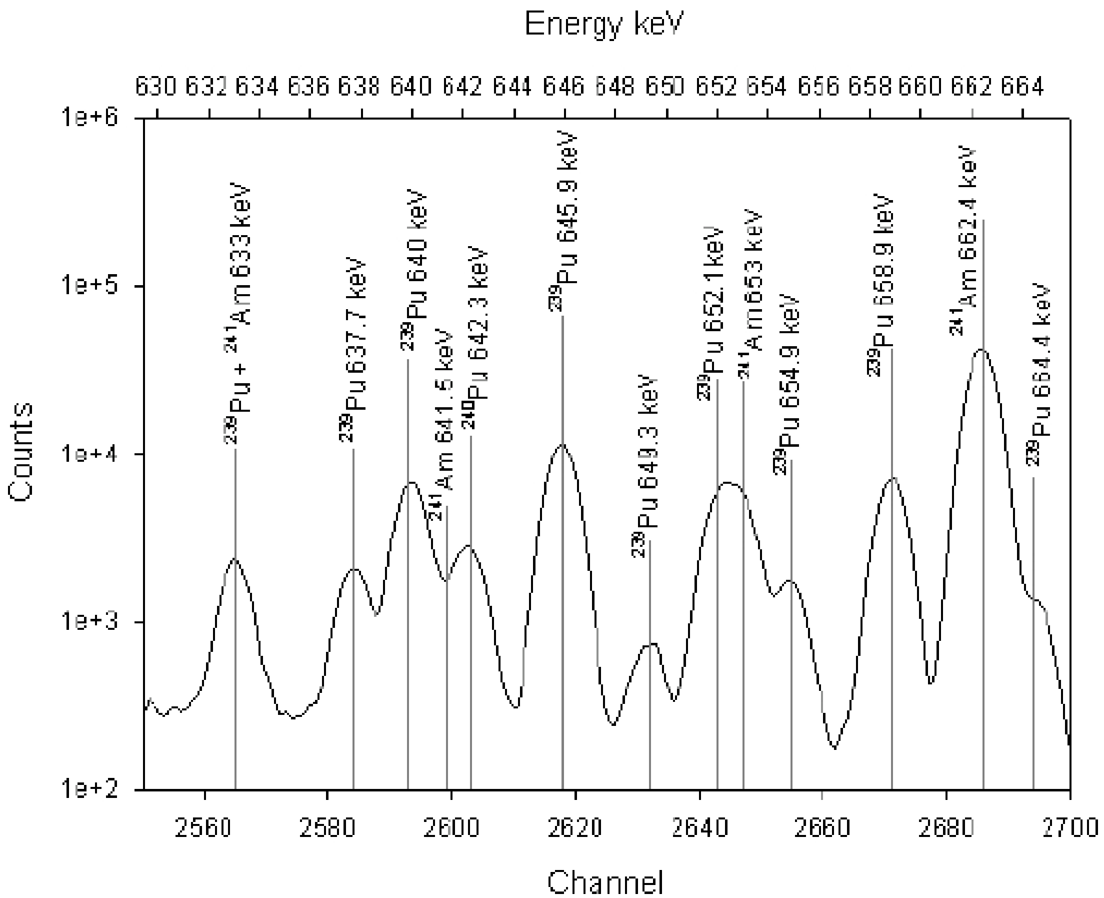
Verification of WGPu

- Estimating the grade of Pu - weapon grade (low burnup) or reactor grade (high burnup)
  - Assessing the $^{240}Pu/^{239}Pu$ ratio
  - Assessment of the $^{240}Pu/^{239}Pu$ ratio in the region 640 – 650 keV
  - 642.3 keV from ^{240}Pu and 645.9 keV from ^{239}Pu.
  - ^{240}Pu line is interfered by a line from ^{241}Am at 641.5 keV, so de-convolution is required
  - The photopeak counts for specific γ-ray *j* and given isotope *i:*

$$C(E_j^i) = \lambda^i N^i BR_j^i \eta(E_j)$$

$$\frac{N^i}{N^k} = \frac{C(E_j^i)}{C(E_l^k)} \frac{T_{1/2}^i}{T_{1/2}^k} \frac{BR_l^k}{BR_j^i} \frac{RE(E_k)}{RE(E_j)}$$

Verification of WGPu



Verification of Pu age

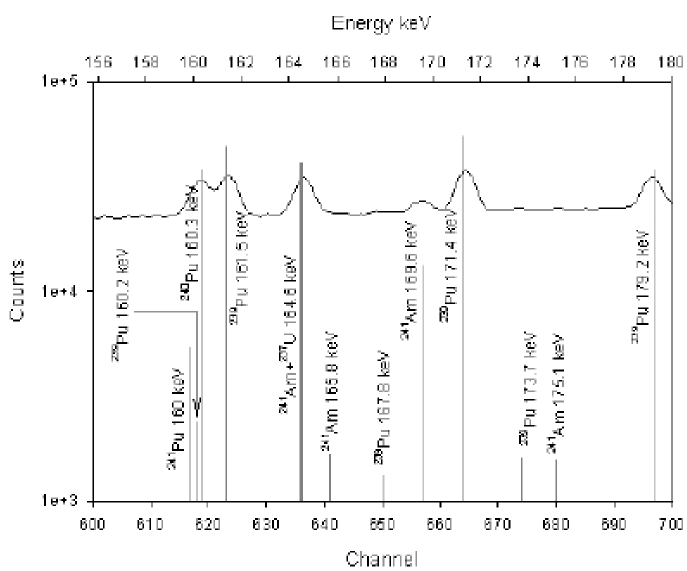
- Estimating the age of the material since last separation
  - Ratio of $^{241}Pu/^{241}Am$
  - Direct measurement of the ratio is difficult
  - Interested region may be between 140-150 keV and 160-180 keV
  - The ratio of $^{239}Pu/^{241}Pu$ is determined in the 140 - 150 keV region
  - The ratio of $^{241}Am/^{239}Pu$ is determined in the 160-180 keV region
  - Thus the ratio of $^{241}Am/^{241}Pu$ is determined
  - Expression for mass ratio:

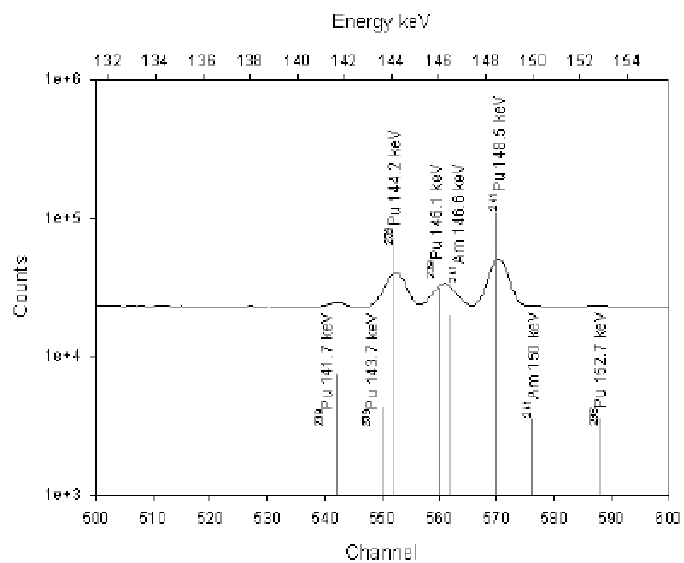
$$M^i / M^k = (C(E^i_j) / C(E^k_l)) (Y^k_l / Y^i_j) (RE(E_l)/RE(E_k))$$

  - Relation between mass ratio and age:

$$M^i / M^k = 20.159 X^{-1,207}$$

Verification of Pu age





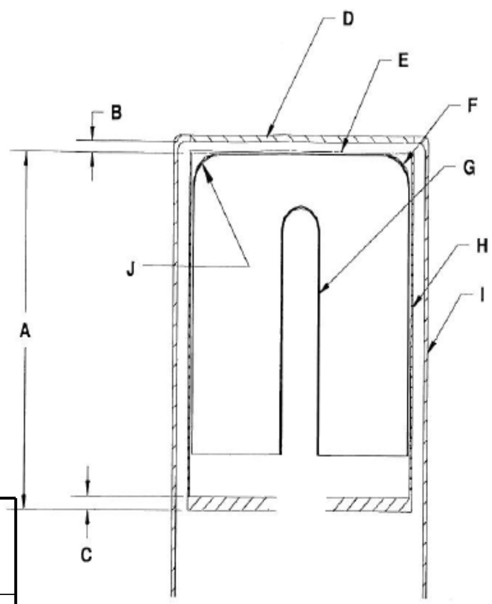
Work in Progress

- A detailed study of the Pu spectrum
- Simulation of the Pu spectrum
  - variable geometries
  - Variable shielding (thicknesses and materials)
- Verifying the spectrum with experimental data?
- Developing the algorithm for a proposed IB
- The determination of uncertainties of the analysis

Simulation of ^{152}Eu

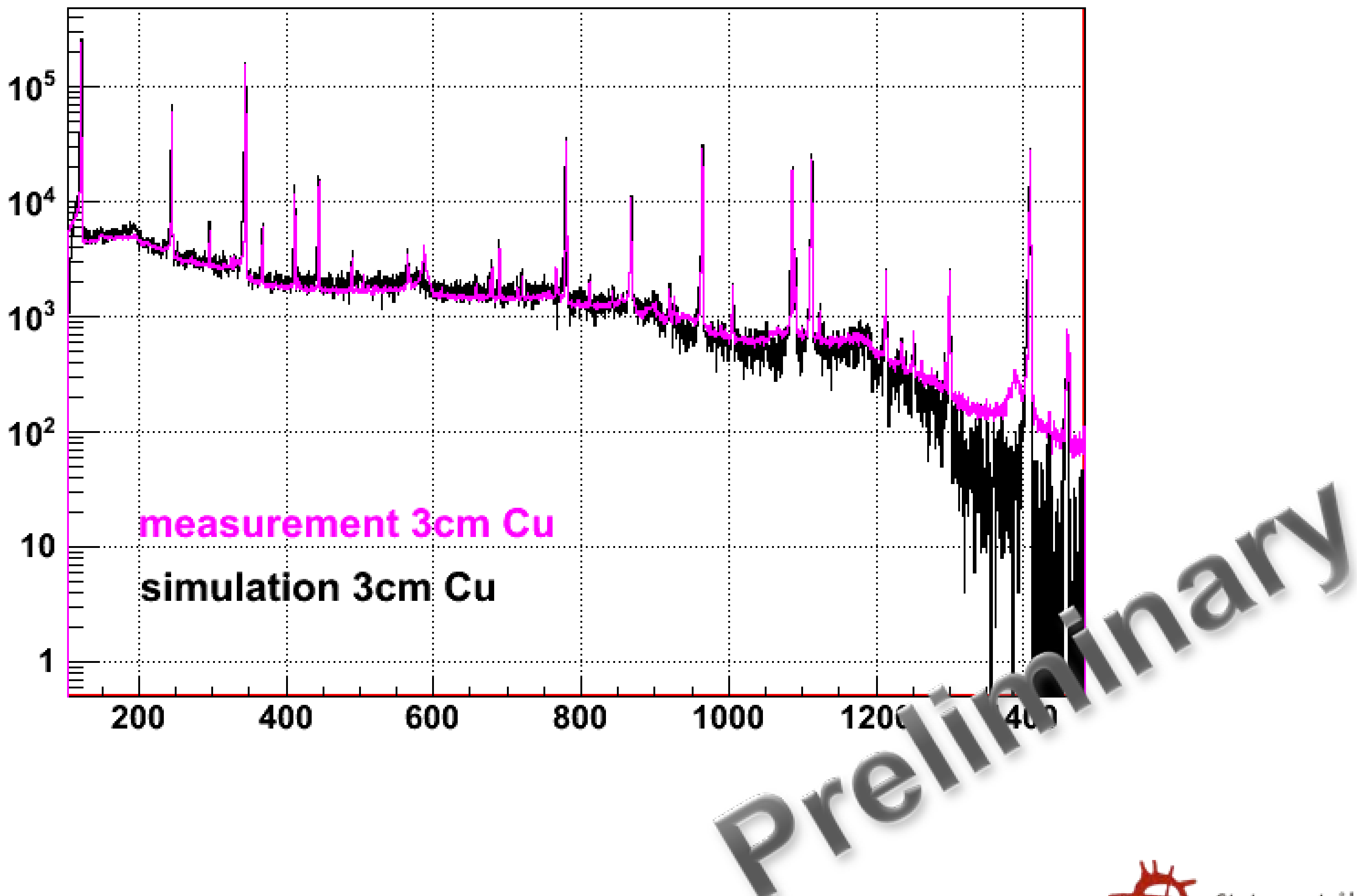
- ^{152}Eu has been simulated.
- Geant4: Monte Carlo simulation technique
- Geometry:
  - Source
  - Detector
- Acquisition setup:
  - schemetic
  - background

ID	Dim [mm]	Desc.	Material
A	94	Mount cup, length	Al
B	3	End cap to crystal gap	
C	3.2	Mount cup base	Al
D	1.3	End cap window	Al
H	0.76	Mount cup wall	Al
I	1.3	End cap wall	Al

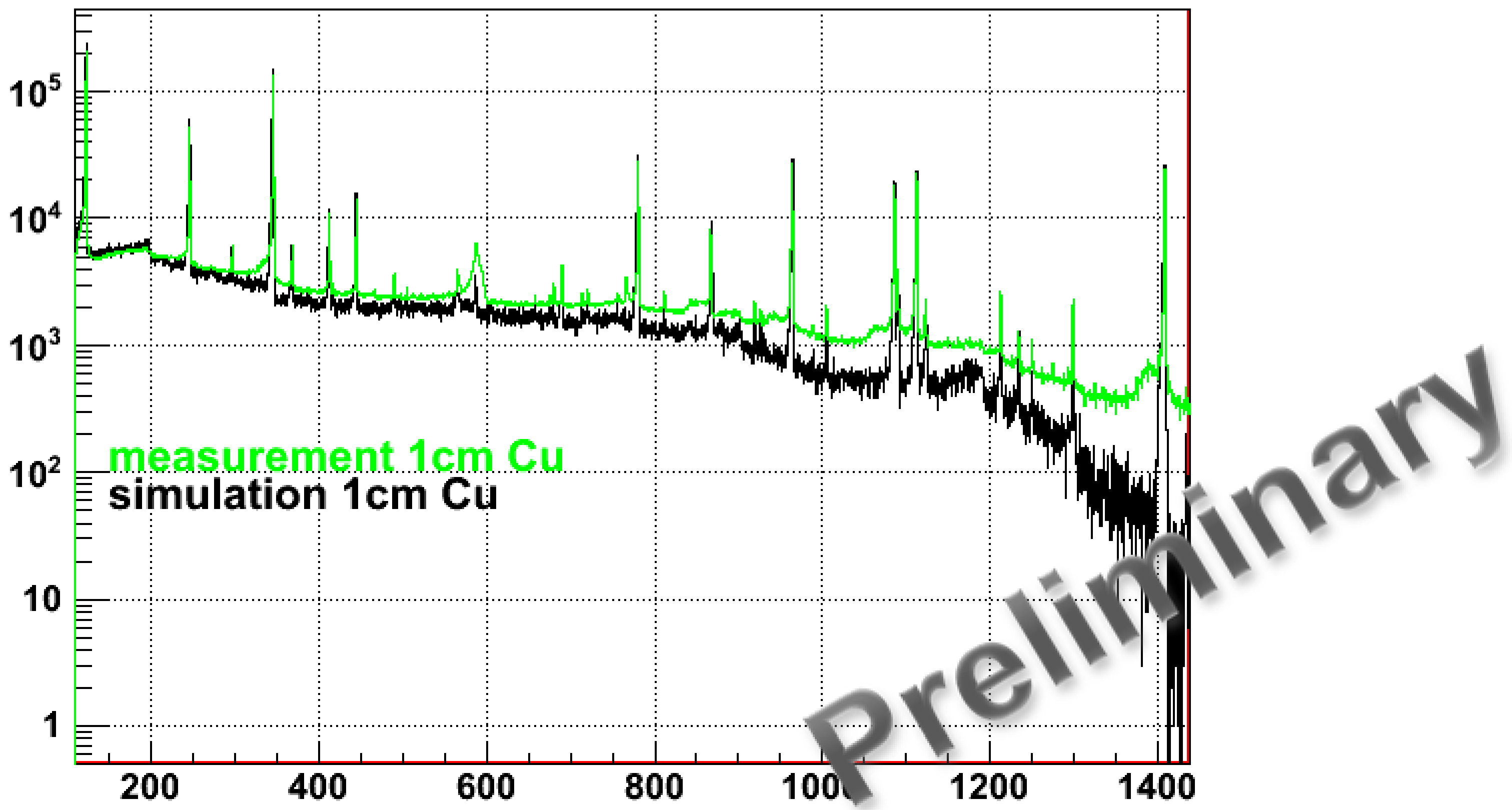


- *Pure ^{152}Eu*
- *standard physics processes*
- *gammas & electrons (ENDSF)*

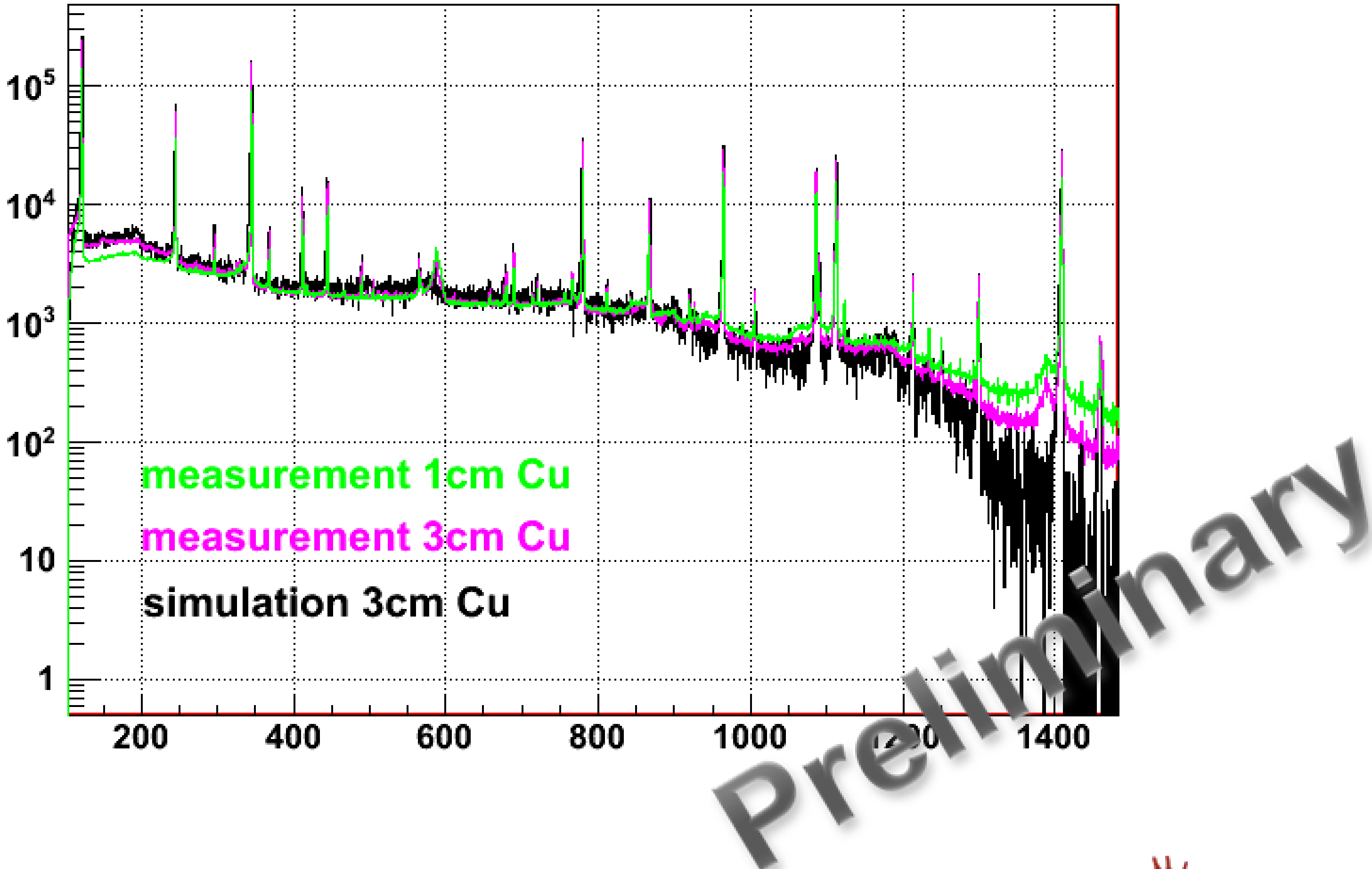
Experiment vs simulation



Experiment vs simulation



Experiment vs simulation



Summary

- Information Barriers
- The Black sea experiment
- Trilateral Initiative
- UK - Norway Initiative
- Verification of the ^{239}Pu
- Simulated spectra of ^{152}Eu

THANK YOU