Soreq

A method for applying measurement restrictions in a HPGe detector

Ofer Aviv
Soreq Nuclear Research Centre, Israel

CTBT Science and Technology
June 26, 2017

Background

- The purpose of radiation measurements during an OSI is to determine the presence or absence of certain radionuclides that indicate the occurrence of a nuclear explosion.
- The treaty allows restricting radionuclide measurements to protect confidential information during OSI (para. 89, Part II, Protocol).
- "Measurement restrictions" refer to technological methods that limit radionuclide information. Radionuclides of interest were defined specifically for OSI (CTBT/WGB/TL-4/42, 2012):

^{37}Ar, ^{131m}Xe, ^{133}Xe, ^{133m}Xe,	→ β-γ coin. systems
^{95}Nb, ^{95}Zr, ^{99}Mo , ^{99m}Tc, ^{103}Ru, ^{106}Rh , ^{131}I, ^{132}Te, ^{132}I, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{141}Ce, ^{144}Ce, ^{144}Pr & ^{147}Nd.	→ High-resolution HPGe detector

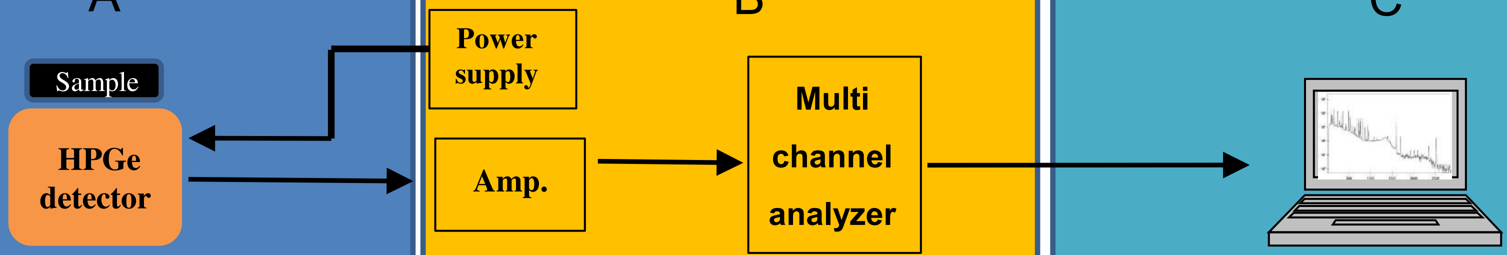
- A restricted system should balance between security issues and the reliability of data obtained from radiation surveys.
- Although some studies were conducted, there is no accepted technology that accomplishes measurement restrictions.

Approaches for measurement restrictions

A

B

C



Filter out specific gamma energies using shielding layers placed between the detector and the sample.

Not physically possible.

Spectral information is partially blocked. Spectrum is displayed and analyzed by standard gamma spec. methods.

Aviv et al., in preparation.

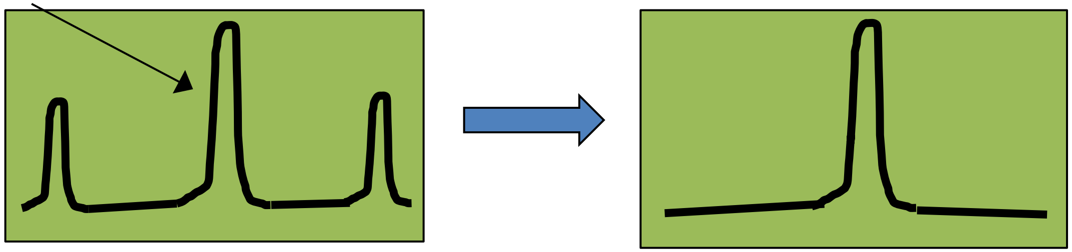
Measured spectrum is unavailable to the user. Analysis is performed fully automatically.

Caffrey et al., NIM A 785, 405-411 (2015).

Method principles

Keep only data within a certain region of interest (ROI):

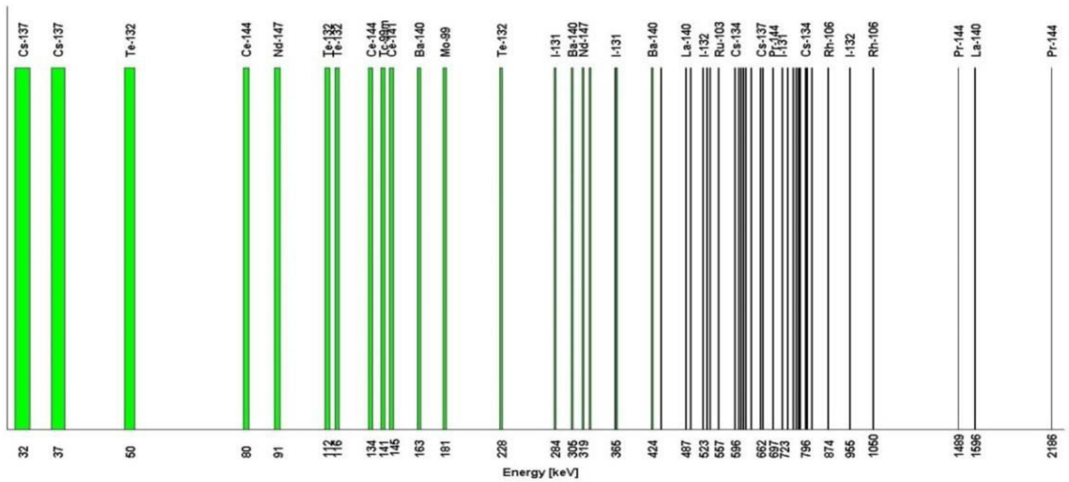
$$[E_\gamma - \Delta E_\gamma \;, E_\gamma + \Delta E_\gamma]$$



OSI-relevant radionuclides: ^{95}Nb, ^{95}Zr, ^{99}Mo , ^{99m}Tc, ^{103}Ru, ^{106}Rh , ^{131}I, ^{132}Te, ^{132}I, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{141}Ce, ^{144}Ce, ^{144}Pr and ^{147}Nd.

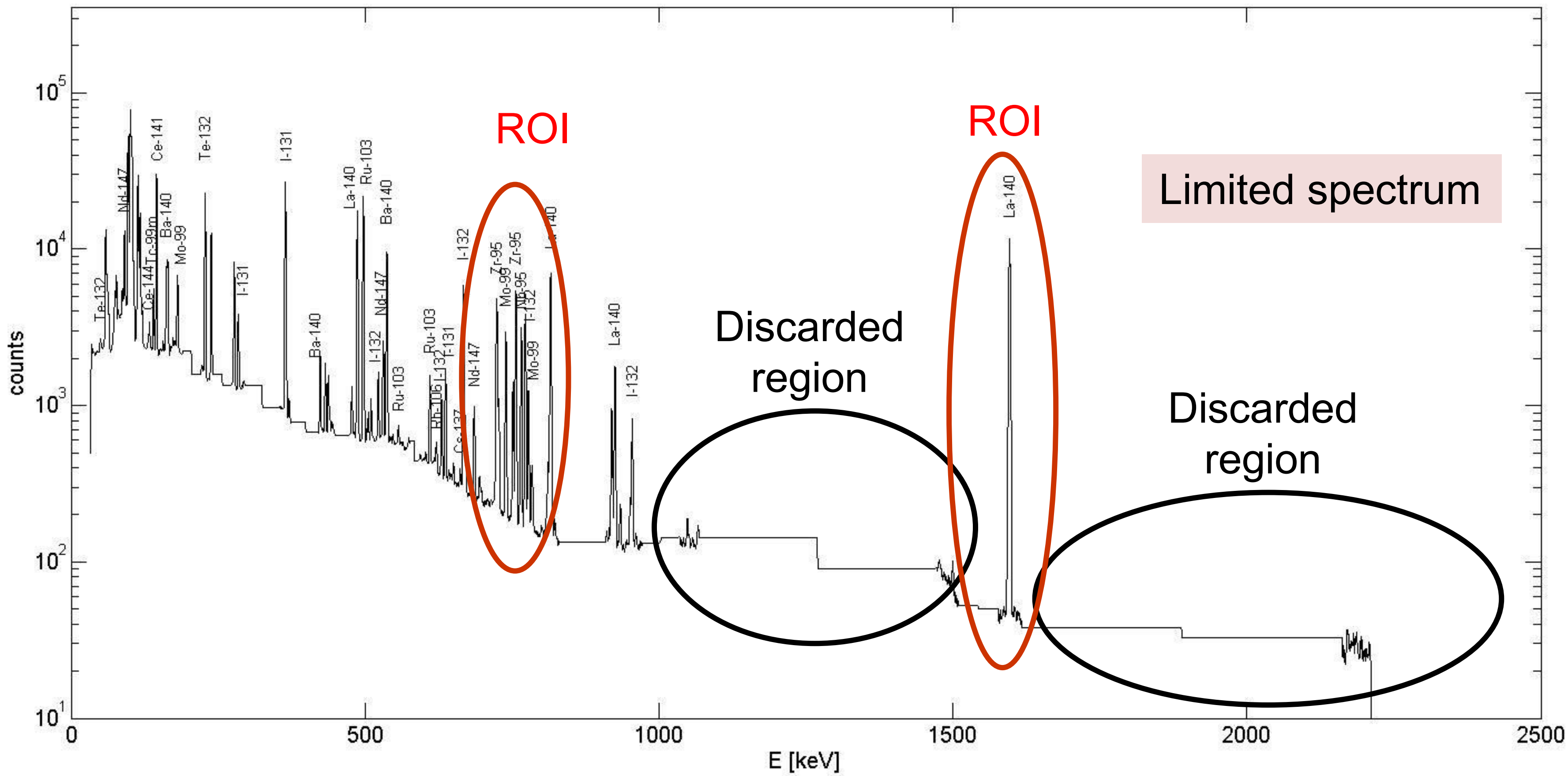
- These radionuclides have ~360 gamma lines of various energies.

- Use the strongest and less interfered lines.



- Altogether, 23 ROI's were used that block >75% of the spectrum.

Method principles-example



Method testing

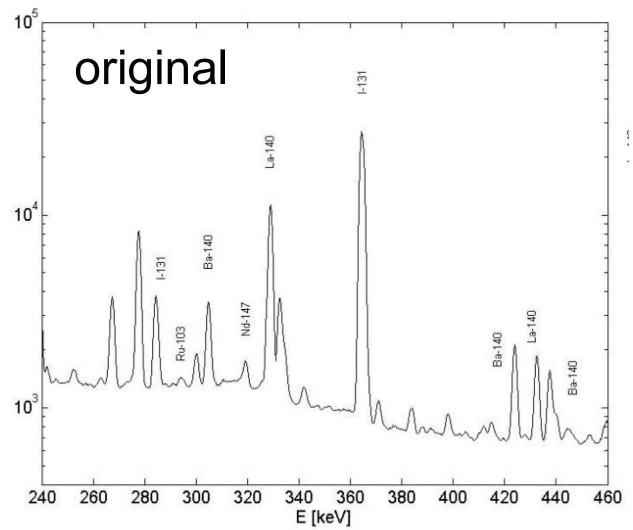
- Spectra simulating various triggering event scenarios were used.
- Each spectrum was analyzed in the limited and the original version using a commercial gamma spectrometry software (Genie2k).
- Pre-defined parameters were used to evaluate the differences between the analysis of the limited spectrum and the original spectrum:

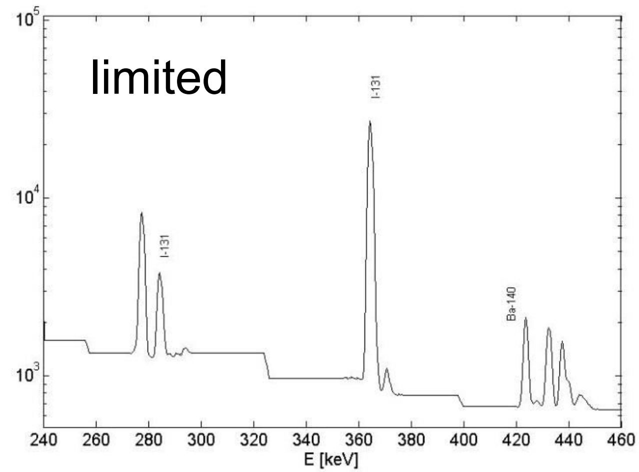
	Parameter	Acceptance criteria
Peak by peak	Peak detection	100.0% (no FN)
	Peak shape*	Relative deviation <15%
	Peak association**	>95%
	Net peak area	Relative deviation <5%
OSI-relevant lines	Minimal Detection Activity	Relative deviation <5%

*Full-width-half-max.
**Only the difference is checked (i.e. equal false detection is a “pass”).

Peak-by-peak comparative analysis

#	Energy [keV]	Peak FWHM deviation %	Peak identification		Peak area deviation %
			original	limited	
1	328.76	-	NOID	NOID	-
2	332.38	-	NOID	NOID	-
3	334.37	-	NOID	NOID	-
4	342.08	-	NOID	NOID	-
5	364.48	0%	I-131	I-131	0%
6	370.87	-	NOID	NOID	-
7	383.78	-	NOID	NOID	-
8	398.01	-	NOID	NOID	-
9	411.77	-	NOID	NOID	-
10	414.93	-	NOID	NOID	-
11	423.75	0%	Ba-140	Ba-140	0%
12	432.49	0%	La-140	La-140	0%
13	437.59	5%	Ba-140	Ba-140	0%
14	439.86	-	NOID	NOID	-
15	452.97	-	NOID	NOID	-
16	459.51	-	NOID	NOID	-
17	467.52	-	NOID	NOID	-
18	472.98	-	NOID	NOID	-
19	477.61	-	NOID	NOID	-
20	487.04	0%	La-140	La-140	0%
21	497.08	0%	Ru-103	Ru-103	0%





Soreq

Method testing results

- 400+ spectra were used, originating from measurements and from simulations.
- The spectra represent various nuclear events of treaty compliant/non-compliant scenarios, with various sample ages (from 1 day and up to 2 years after the event), e.g.,

  Near ground atmospheric nuclear explosion

  Underground nuclear explosion with strong/weak particulate venting

  Reactor accident

  Nuclear waste site

- A wide range of signal-to-noise ratio was modeled by adding natural background spectra.
- Results:

Parameter	Acceptance criterion	Results - Success level
Peak identification	All peaks in ROI	100.0%
Peak association	All peaks in ROI	100.0%
Deviation in peak resolution	<15%	99.9%
Deviation in peak area	<5%	99.8-100.0%
Deviation in MDA	<5%	100.0%

➡ **Practically identical reliability as a standard system**

False positive study

- The reduction in spectral information may lead to false positives. OSI relevant lines may overlap (or interfere) with other radionuclides existing in the sample.
- A study of all possible radionuclide associations* (or interferences) was carried out using comprehensive nuclear libraries (*Lund/LBNL*, *Nucleide.org*).
- Search criteria:

(Energy **±2 keV** w.r.t. OSI relevant lines) & (Line intensity **> 0.05%**) & (Half-life**>12 h**)

- For 40 OSI relevant lines, 770 overlapping cases** were identified:

OSI relevant	4	(^{131}I ←→ ^{144}Ce)
Fission and activation products	180	(^{126}Sb, ^{110m}Ag,…)
Natural radionuclides (NORM)	66	(^{226}Ra, ^{238}U,…)
Other	520	(^{151}Tb, ^{171}Hf,…)

*including escape peaks.
Of which, only **6% are FP & AP with emission probability >5%.

NORM

FP/AP

Various

False Positive study

- Examples for OSI relevant RN with very low potential for interferences:

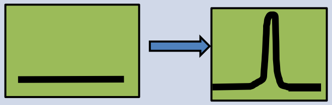
OSI-Relevant Radionuclide	#interferences	Potential false positives
^{144}Pr (2186 keV)	5	^{90}Nb, ^{154}Tb, ^{186}Ir, ^{156}Eu, ^{131m}Te
^{131}I (364 keV)	11	^{166m}Ho, ^{181}Re, ^{126}Sb, ^{130}I, ^{132}Cs, ^{131m}Te, ^{148m}Pm
^{140}La (1596 keV)	7	^{206}Bi, ^{170}Lu, ^{146}Eu, ^{152}Tb, ^{194}Au, ^{154}Eu, ^{72}Ga

- Examples for OSI relevant RN lines with potential for interferences:

OSI-Relevant Radionuclide	#interferences	Potential false positives
^{134}Cs (604 keV)	17	^{156}Tb, ^{135}Ce, ^{124}Sb, ^{125}Sb, ^{127}Sb, ^{190}Ir, ^{192}Ir
^{144}Ce (80 keV)	30	^{226}Ra, ^{232}Th, ^{131}Ba, ^{170}Hf, ^{172}Tm, ^{172}Lu ^{131}I, ^{131m}Te
^{147}Nd (91 keV)	30	^{226}Ra, ^{227}Ac, ^{235}U, ^{238}U, ^{120m}Sb, ^{172}Lu, ^{82}Br, ^{153}Sm

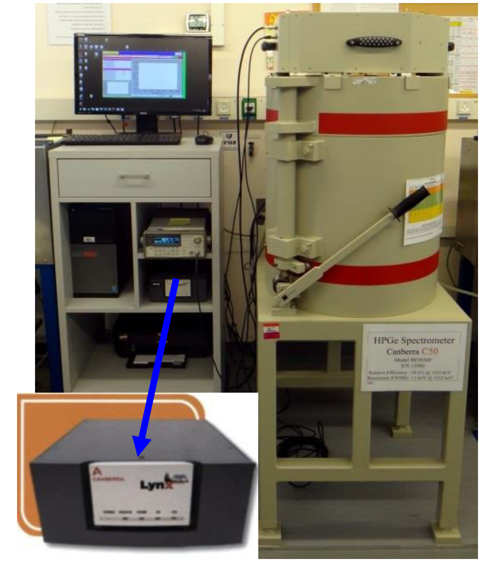
Standard gamma spectrometry methods can be employed (use of other lines, background signal subtraction, decay etc.) to resolve >95% of the cases.

Challenges

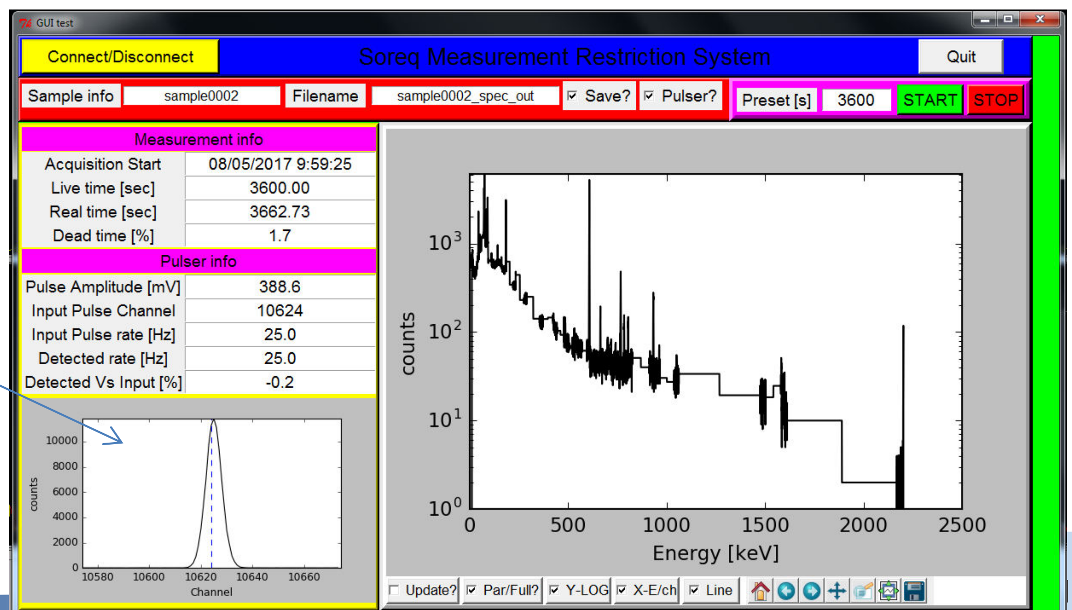
Description	Solution
Gain changes in amplifier cause data to shift into restricted zones (and vice versa) 	(i) Electronic components will be unavailable to the user. (ii) Limited access to acquisition parameters and rigid settings. (iii) Calibration is continuously monitored by a pulse generator.    ❖ Commercially available. ❖ Highly reliable, exhibiting stable energy calibration. ❖ In operational during OSI exercises (e.g., IFE14).
Detector QA/QC	Use dedicated set of calibration sources (e.g., ^{154}Eu & ^{166m}Ho) and standard procedures.
False positive detection	In progress study - ~95% cases can be resolved.

Proof of principle

- A restricted system based on a HPGe, all-in-one electronic box (“Lynx”) and a PC was established.
- Data was limited in real time using dedicated communication protocols.
- A graphic user interface was developed (Python).
- The acquired data is stored to a text file (easily converted to any format).



Energy calibration is continuously monitored using a pulse generator.



Summary and Outlook

- ✓ A method for measurement restrictions was developed based on limiting parts of the spectral data.
- ✓ The limited spectrum can be displayed in real time and analyzed using standard gamma spectrometry methods.
- ✓ Restrictions can be incorporated in commercial systems using hardware and software.
- ✓ The method was tested extensively and exhibited high feasibility for application with practically identical reliability as can be reached with a standard gamma spectrometry system.

- **Test additional spectra that simulate possible measurement scenarios during an OSI.**
- **Further optimize the number of blocked channels.**
- **Examine data security issues.**
- **Carry out field tests with a mockup system.**