ThermoFisher SCIENTIFIC

The world leader in serving science

Test Adapters based on Natural Lutetium – A Discussion of Benefits versus Conventional Check Sources

Dr. Michael Iwatschenko
Thermo Electron (Erlangen) GmbH

IRMF-Meeting

NPL, May 28, 2008
updated version July 3, 2008

Lutetium Test Adapters

Psychological and numerical aspects of radioactive sources

Disadvantages of conventional check sources

Nuclear properties and natural abundance of Lu-176

Design and production of typical test adapters

Examples of applications and measured data

Exempt or not exempt – a review of legal implications

Summary and outlook

What is the difference between a car and a radiation source?

?

What is the difference between a car and a radiation source?

Let us start with what is common:

- man-made
- can create a health risk
- (might) pollute the environment
- use is regulated
- loose value over time
- disposal cost may apply

What is the difference between a car and a radiation source?

Magnitude of ranges:
For a car, size, weight, speed, price, consumption, expected lifetime is all in a very narrow range.
➔ *common good understanding and rules*

For a man-made radioactive source, the activity can range from 100 Bq to 10^{18} Bq.

For the use of **check** sources we see:

- **Inappropriate Fear**
- **Overregulation**
- **Risk by Non-Use**

Disadvantages of conventional check sources

- Paperwork, administration, training cost
- Individual activity, may be different from engraved activity
- Error prone half-life correction
- Cost of disposal
- Cost of repetitive purchase (if half life is short)
- Transport issues
- …

Traditional workarounds

- Lantern mantle
- Piece of rock
- Fertilizer
- Radium watch
- KCl
- Natural Background Radiation
- Training Simulators
- Sophisticated circuitry to stabilize on e.g LEDs
- …

Proposed Alternative - Primordial Isotope in Natural Abundance

Psychological, practical, legal and scientific advantages:

- ➔ Non man-made
- ➔ No decay correction
- ➔ Low specific activity
- ➔ Low total activity
- ➔ inherently 100 % reproducible
- ➔ Inherently homogeneous activity concentration
- ➔ Inherently homogeneous surface emission rate
- ➔ Inherently traceable

Nuclear Data of Lu-176

Natural Lutetium contains 2.6% of the isotope Lu-176 with a 3.6 E+10 years half life and emits x-ray and low energy gamma radiation.

1 g Lutetium = 50 Bq

For Comparison:
Potassium contains 0.012 % of K-40 with a 1.3 E+9 years half life.

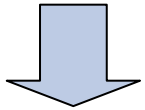
1 g Potassium = 30 Bq

Advantage Lutetium:

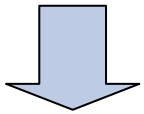
High gamma yield
Useful gamma energies
Medium beta energy
Ultra hard ceramics can be made

Manufacturing Challenges

Commercially available Lutetium Oxide
is a white powder of low density…



Sophisticated high pressure sinter
process at > 1500°C



Stable ceramics material
with scratch resistant surface

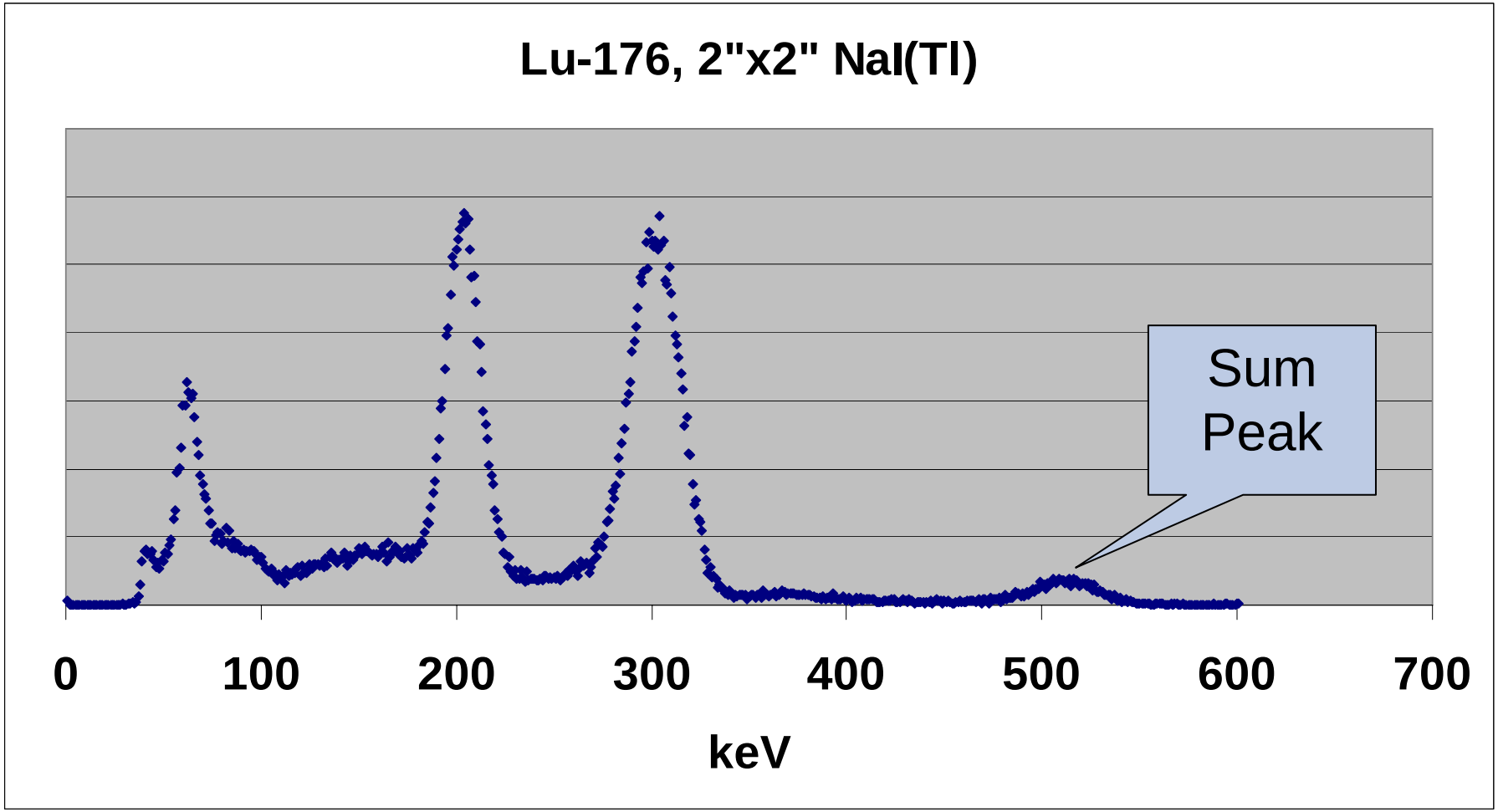
Lu-176 Energy Spectrum is Ideal for Gamma Detector Testing

Gamma Energy	55 keV	63 keV	88 keV	202 keV	307 keV	401 keV
Emission	25.9 %	6.9 %	13 %	84 %	93 %	0.8 %

- 220 % gamma yield
- Low to medium energy

Ideal for
- small sensitive gamma detectors
- large plastic scintillators
- high resolution detectors
- coincidence circuitry
- tutorials (sum peaks vs. distance)

Energy Spectrum Lu-176



Lu-176 Energy Spectrum is Ideal for Gamma Detector Testing

Gamma Energy	55 keV	63 keV	88 keV	202 keV	307 keV	401 keV
Emission	25.9 %	6.9 %	13 %	84 %	93 %	0.8 %

Isotopes of interest:

Am-241: 59.5 keV

U-235: 186 keV

Pu-239: 119, 375 keV

Conventional Check Sources:

Am-241 (Alpha-Emitter)

Co-57: 271 days half life!

Ba-133: 10 years half life

Lu-176 covers critical energy range for security applications

Comparison Sheet for Scintillation Detector Check Sources

	Lu-176	Am-241	Co-57	Ba-133	Cs-137
Realistic Energy for Security and Industrial		Single energy, shielding			
Paperwork			Exempt Quantity	Exempt Quantity	
Replacement cost, decay correction required	**3.7 E10 a**	**433 a**	**270 d**	**10 a**	**30 a**
Simplicity of Procedures (individual variation of emission rate)	**< +/- 3%**	**Typ. +/- 20 %**	**Typ. +/- 20 %**	**Typ. +/- 20 %**	**Typ. +/- 20 %**

Lu-176 Beta Source – affordable global standard

-Beta Emitter: 589 keV (99 %)

- Surface emission rate is **totally** constant & reproducible:

  constant natural abundance of Lu-176
  chemically pure (99,99 %) Lu_2O_3
  infinite thickness for beta particles
  controlled geometrical dimensions

Specific beta surface emission rate is about 0,8 s^{-1}/cm^2

Lutetium Source for Pancake Friskers

50 mm diameter, 3 mm height (acrylic glass housing)
40 mm diameter, 1 mm height (Lu_2O_3 ceramics inlet)
Typical net count rate for RadEye B20: 6 cps

Infinite thickness for beta radiation ➔
Totally reproducable surface emission rate from the ceramics!

Lutetium Source for Surface Contamination Monitors (110 cm²)

Homogeneous “calibration sources” can be manufactured to practically any (rectangular) size.

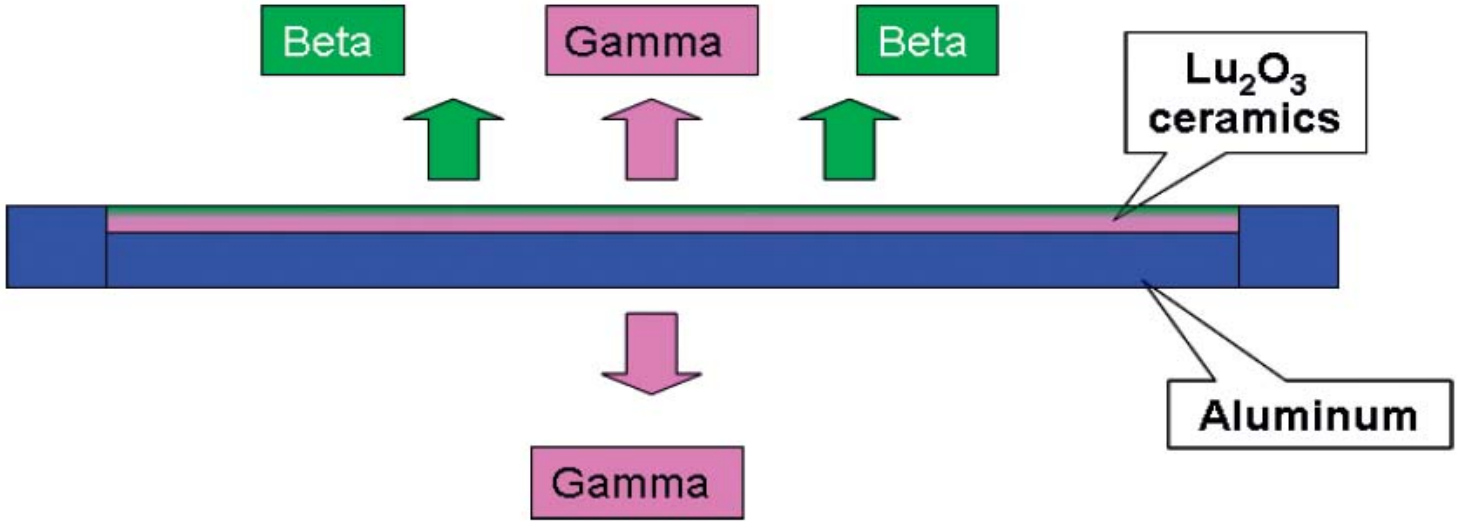
Soon available:

Scratch resistant active area:
110 cm² (app. 74 mm x 148 mm) for:

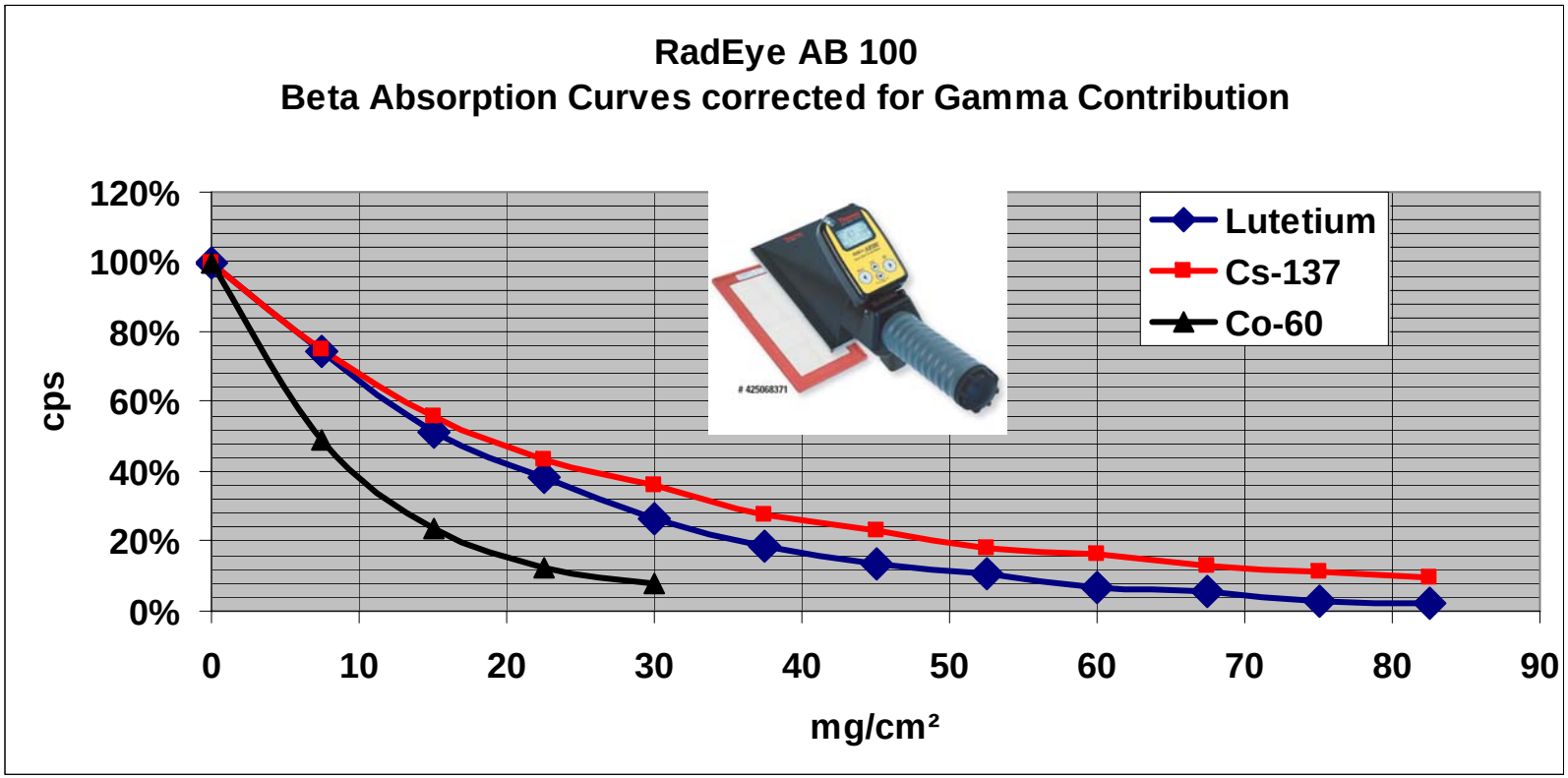
DP6, BP 19, HP 380, FHT 382, RadEye AB 100

Lutetium Source for Surface Contamination Monitors (110 cm²)

Weight	200g total, thereof 80g Lu_2O_3
Size	12 cm x 20 cm x 0.5 cm total 7.4 cm x 14.8 cm Lu_2O_3 surface



Comparison of Absorprion Curves



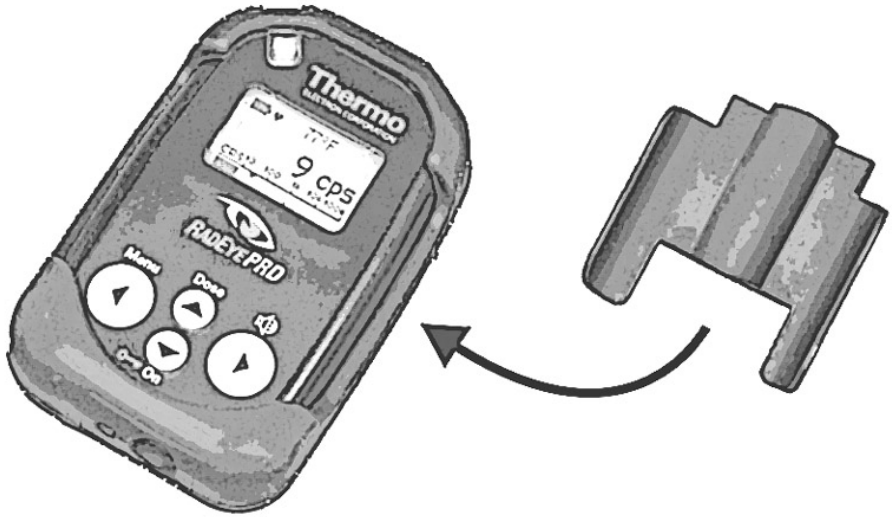
Effective maximum beta energy:
480 keV from Lu_2O_3 surface

RadEye PRD Test Adapter (36 g Lu_2O_3)

- **Special shape minimizes distance to detector**
- **Lu_2O_3 compressed to 9 g/cm³**
- **High Response to Lu-176 energies = 100 cps**

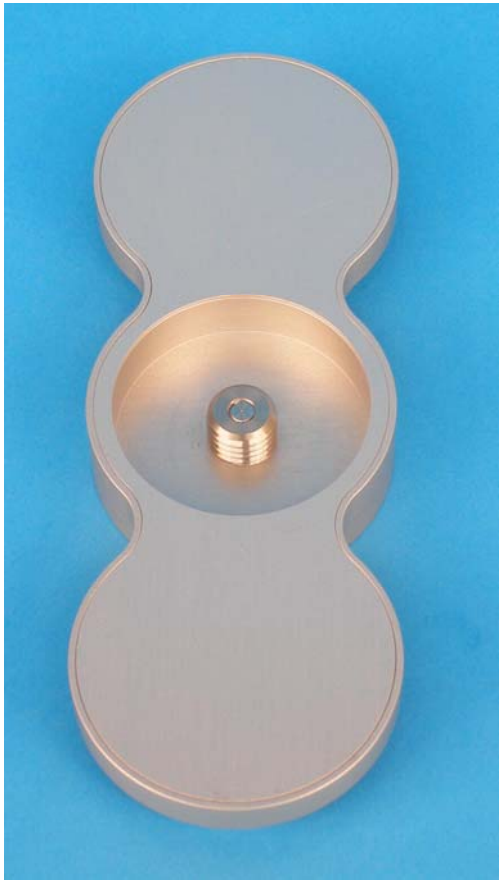
Same activity as

3 kg bananas



Large Test Adapter (100g and 200 g Lu_2O_3) for Gate Monitors

2x and 4x 50 mm diameter discs



App. 4,5 kBq

App. 9 kBq

Mounting Options for Gate Monitors

Legal Considerations

In the good old days
(US prior 2004, EU prior 1996)

US: < 74 Bq/g	**Exempt**
EU: < 100 Bq/g (< 500 Bq/g for NORM)	**Exempt**

Basis of Isotope Specific Exemption Values

1993:

Radiation Protection – 65, Principles and Methods for Establishing Concentrations and Quantities (Exemption Values)

300 isotopes considered,

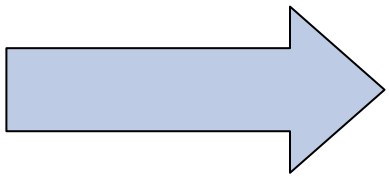
Lu-176 not included

1998:

NRPB-R306 „Exempt Concentrations and Quantities for Radionuclides not included in the Basic Safety Standards Directive", National Radiation Protection Board

800 isotopes considered,

Lu-176 included

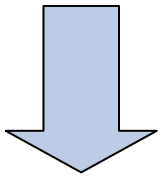


100 Bq/g exempt activity concentration

1 MBq exempt quantity

Regulations explicitly including Lu-176

Germany, Spain, Netherlands, Japan:
Lu-176 exemption values are explicitly included.



Natural Lutetium-Oxide can be considered as exempt Material, since 45 Bq/g < 100 Bq/g

UK, IRR 1999:
Lu-176 exemption values are explicitly included as "concentrations and quantities of notification"

EU – Outlook / Recommendation

"Exemption levels for extra nuclides are available in NRPB R306 (Mobbs et al, 1999) and have been used by Germany and UK in their legislation. The Spanish Official Journal, BOE of 10th April 2003, has also published the exemption values for extra nuclides from this NRPB report. It is suggested that where Member States have not included these extra radionuclides then reference is made to this document as a supplement to existing legislation."

Radiation protection 134, Evaluation of the Application of the Concepts of Exemption and Clearance for Practices according to title III of Council Directive 96/29/Euratom of 13 May 1996 in EU Member States, **2003**

IATA: Lu-176 not listed

LBA (Luftfahrt-Bundesamt, Germany):

Natural Lutetium is exempt, since it is natural material, i.e.

10 x 10 Bq/g = 100 Bq/g

US: Lu-176 not listed

1. Industrial and Medical Licensees.

   a. Use of The Table of Exempt Material Activity Concentrations and Exempt Consignment Activity Limits for Radionuclides in 49 CFR 173.436 or 10 CFR Part 71 Appendix A, Table A-2 to define material as radioactive for transport.

      (1). For over 30 years, licensees have used the single value of 70 Bq/gram (0.002 uCi/gram) to define material as radioactive for transport.

      (2). On October 1, 2004, the single value is replaced with the exempt material activity concentrations and exempt consignment activity limits for radionuclides found in 49 CFR 173.436 or 10 CFR Part 71 Appendix A, Table A-2.

      (3). When both the exempt material activity concentration and the exempt consignment activity limit are exceeded, the material is regulated in transportation.

      (4). The values and limits adopted in DOT and NRC regulations establish a consistent dose-based model for minimizing public exposure.

…but natural Lutetium would be exempt

3. Shippers - General

Requirements for Shipments and Packagings. Within Part 173 Subpart I, the following changes have occurred:

a. 49 CFR 173.401 Scope.
(1). The regulations in this subpart do not apply to

(c) Class 7 (radioactive) material in natural material and ores containing naturally occurring radionuclides provided the material does not exceed 10 times the exemption values listed in § 173.436

Summary of General Advantages of Lutetium

- no error-prone half life correction by the user required

- no reoccurring purchase of the (decayed) check source required

-extremely small variation of the activity content (+/- 3 %)

- no individual activity numbers for individual check sources:
every RadEye PRD Test-Adapter contains same amount of Lu-176

- dose rate in 10 cm (4”) distance is less than 10 nSv/h for the Test-Adapter

- gamma energies of Lu-176 are ideal to simulate Am-241, Pu-239 and U-235

- the use of a special shape enclosure and high density Lu2O3 results in a sufficient number of counting events using a minimum of total activity