VIRTUAL GAMMA-RAY SPECTROMETRY FOR TEMPLATE-MATCHING NUCLEAR WARHEAD VERIFICATION

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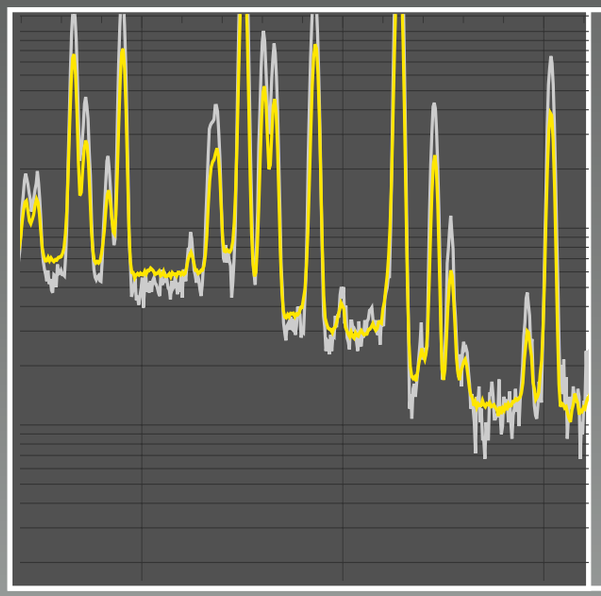
BACKGROUND

PASSIVE GAMMA SPECTROMETRY FOR WARHEAD VERIFICATION

Successfully demonstrated as a verification technology "to confirm the identities of treaty accountable items" — both with attribute and template approaches (e.g. TRIS and TRADS developed at Sandia)

However, gamma spectrometry (alone) is not suited to determine fissile material mass due to self shielding effects; strictly speaking also not suited to confirm identity of any two items



THIS PAPER ...

Characterize the potential (capabilities and limits) of gamma spectrometry for verification applications (using the template-approach)

Use simulated spectra for a basic test item with simple "diversion" scenarios

Identify possible areas of future research

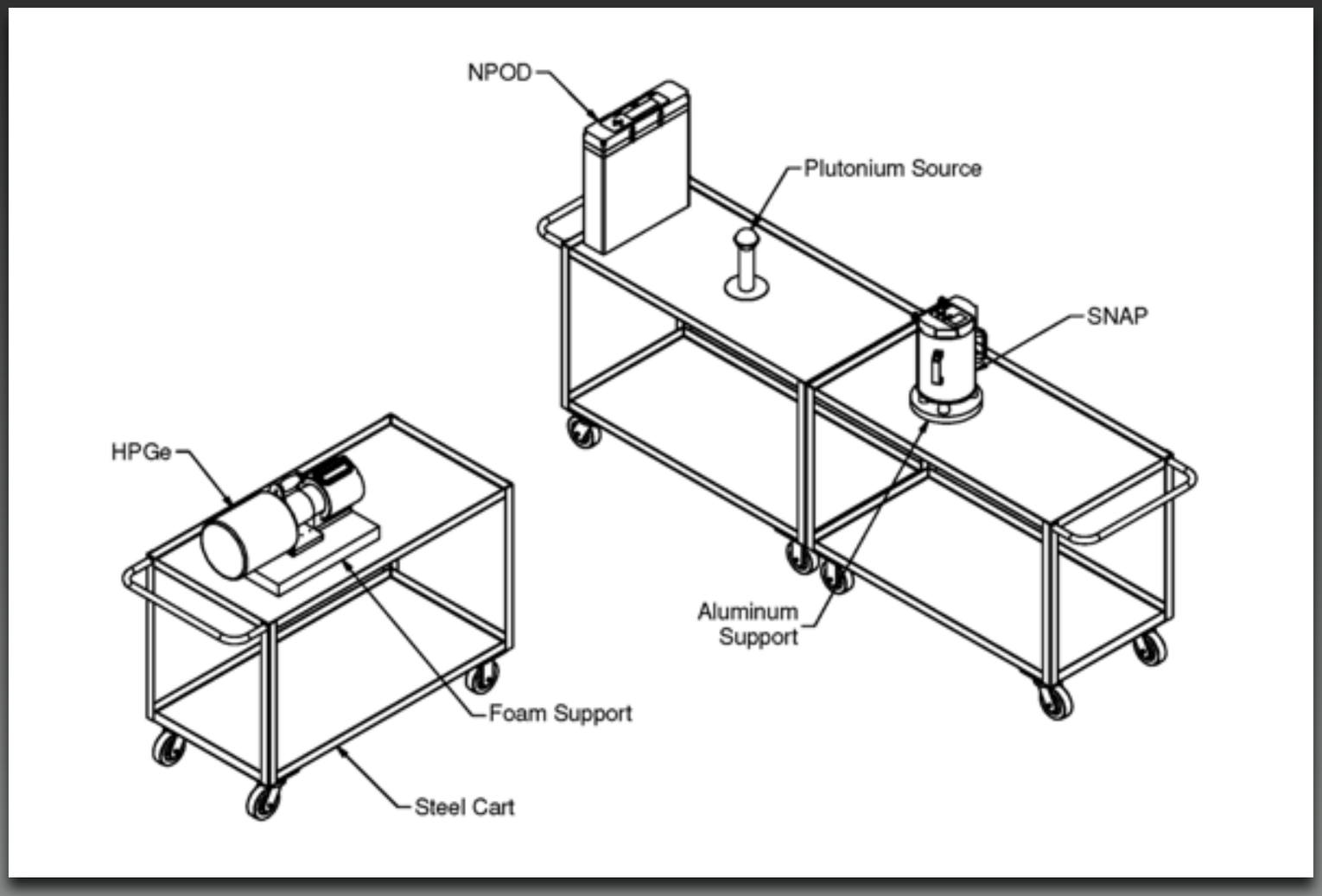
Source: U.S. Department of Energy (photo); K. Seager et al., "Trusted Radiation Identification System," 42nd INMM Meeting, 2001 (quote)

COMPUTER MODEL

AND BENCHMARK WITH EXPERIMENTAL DATA

MODEL EXPERIMENTAL SETUP

OF PLUTONIUM SOURCE (BeRP BALL) AND HIGH-PURITY GERMANIUM DETECTOR

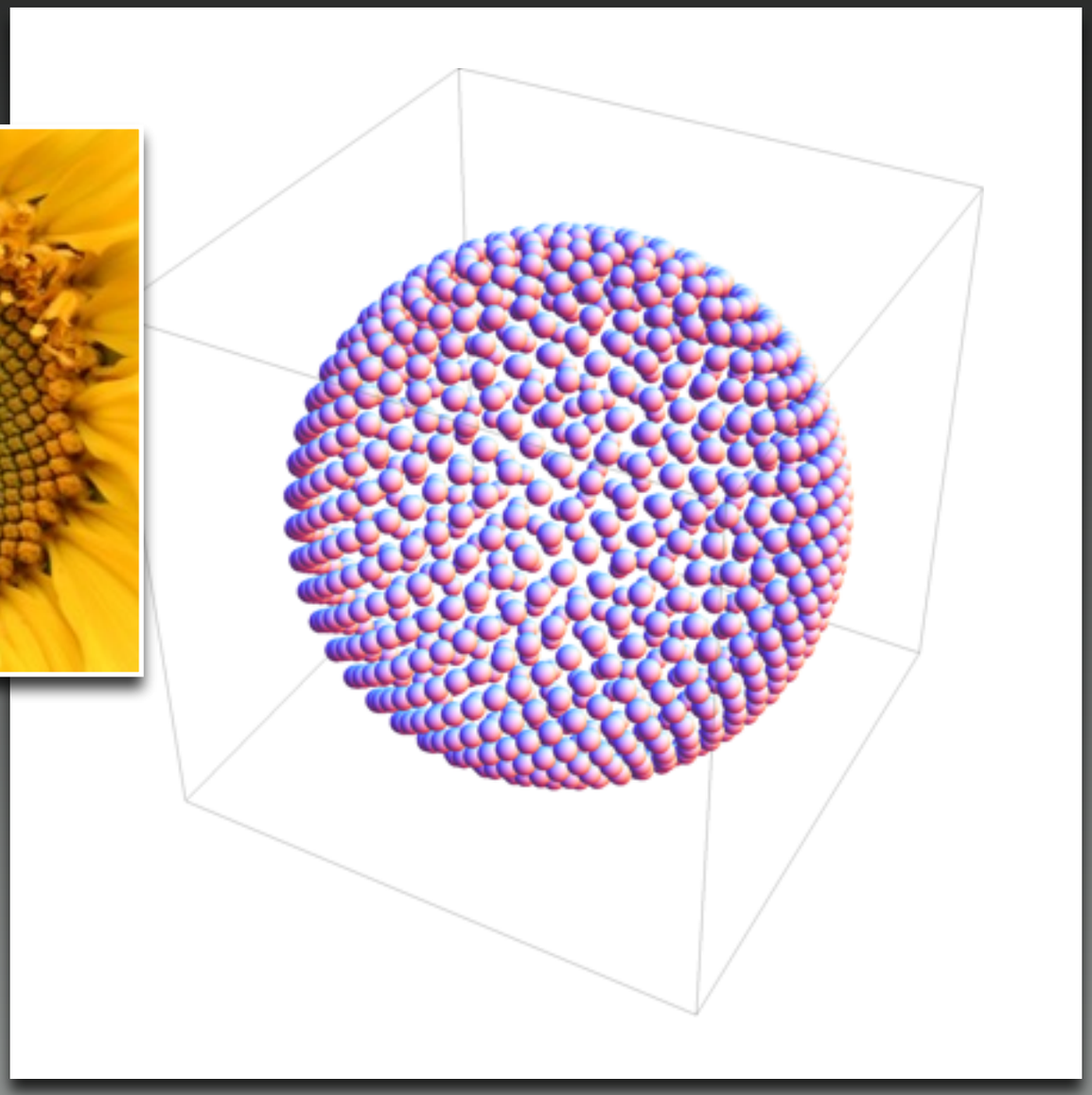


John Mattingly, *Polyethylene-Reflected Plutonium Metal Sphere: Subcritical Neutron and Gamma Measurements* SAND2009-5804 Revision 1 (Unclassified Unlimited Release), November 2009

See also J. Mattingly and D. J. Mitchell, *Applied Radiation and Isotopes,* 70 (2012), 1136–1140

DISTRIBUTING N POINTS ON A SPHERE

(1000 IDENTICAL DETECTORS TO INCREASE EFFICIENCY OF MCNP CALCULATIONS)



Helmut Vogel, “A Better Way to Construct the Sunflower Head,” *Mathematical Biosciences,* 44 (3–4), June 1979, pp. 179–189
See blog.marmakoide.org/?p=1 for Python implementations in 2D and 3D

ENERGY BROADENING

USING BENCHMARK DATA FROM SINBAD (FOR HPGE DETECTOR) AND OWN MEASUREMENTS (FOR NAI DETECTOR) TO "BLUR" MCNP TALLIES

ESTIMATED FULL-WIDTH HALF-MAXIMUM FOR HPGE DETECTOR USED IN SINBAD EXERCISE

$$\mathrm{FWHM}_1(E) \approx 0.00125\sqrt{E(\mathrm{MeV}) + 0.00090\left(E(\mathrm{MeV})\right)^2}$$

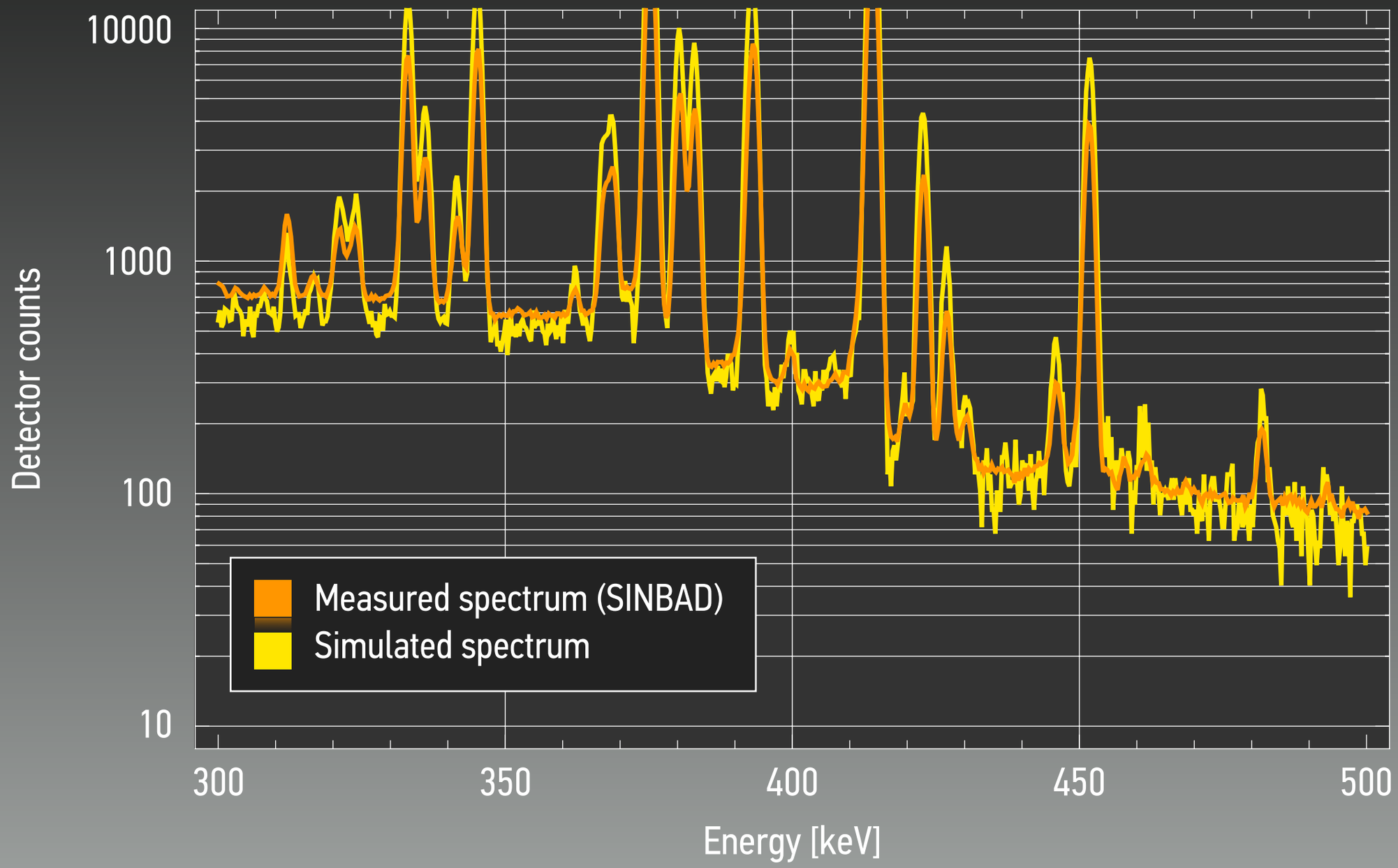
ESTIMATED FULL-WIDTH HALF-MAXIMUM FOR NAI DETECTOR (CANBERRA MODEL 802)

$$\mathrm{FWHM}_2(E) \approx 0.05086\sqrt{E(\mathrm{MeV}) + 0.30486\left(E(\mathrm{MeV})\right)^2}$$

These numerical values can be used directly in the GEB card for the MCNP F8 tally

Alternatively, the F8 tally data can be energy-broadened post simulation (using these expressions) providing much more flexibility (one MCNP run, many detectors); thanks to John Mattingly for this hint

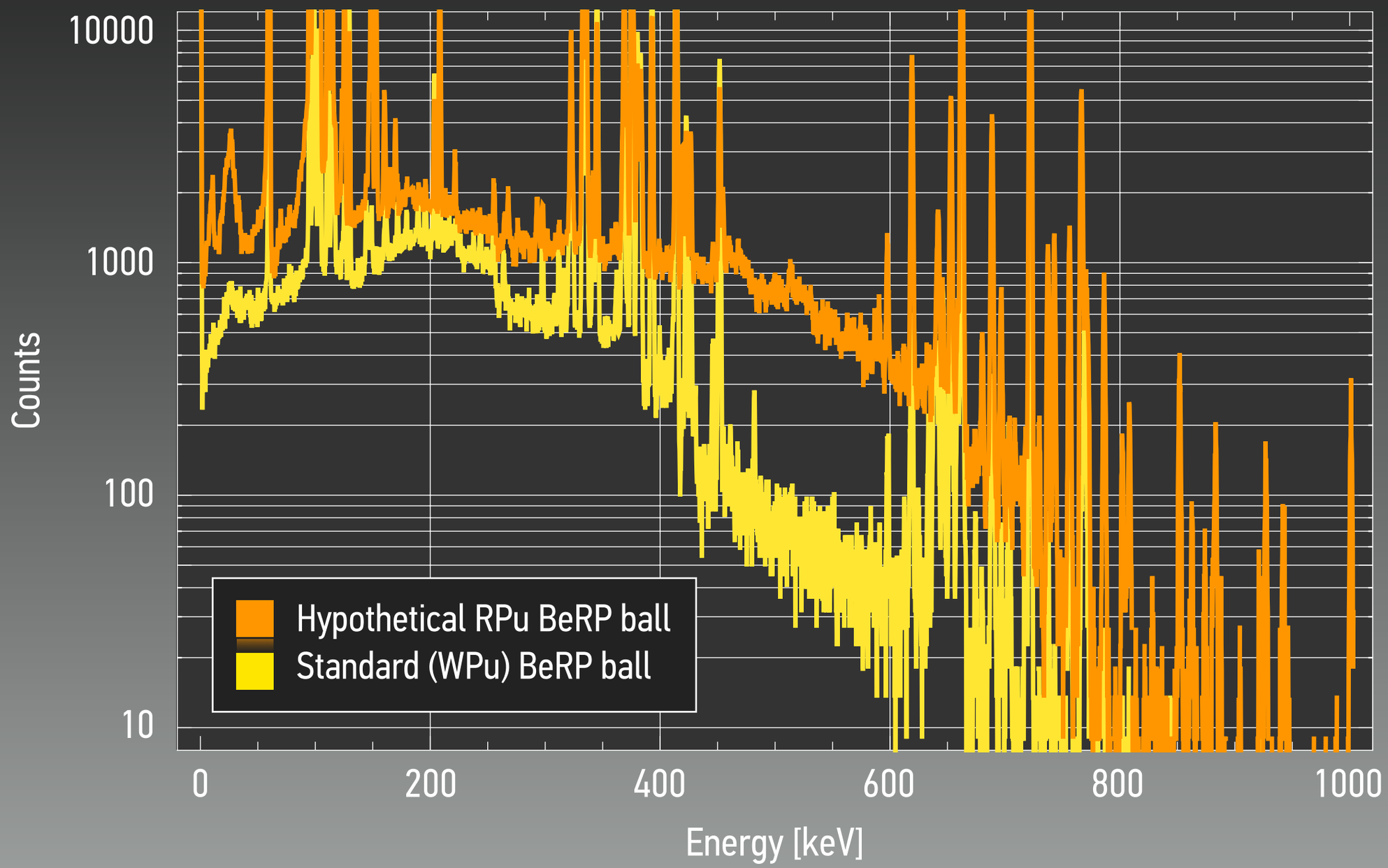
MEASURED AND SIMULATED HIGH-RESOLUTION SPECTRA OF THE BeRP BAL



SCENARIOS AND RESULTS

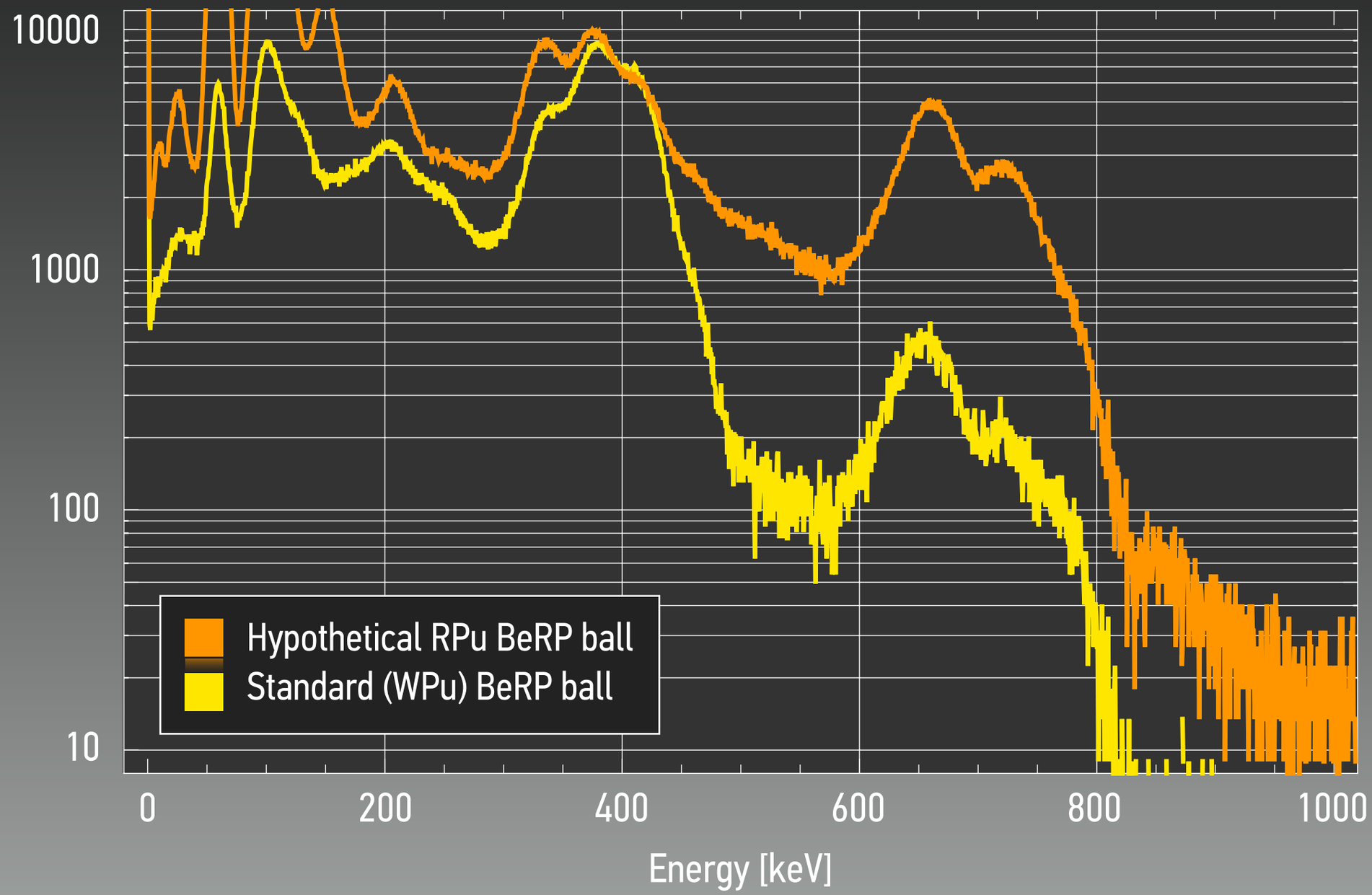
SIMULATED SPECTRA

WEAPON-GRADE VS REACTOR-GRADE PLUTONIUM BALL, HPGE DETECTOR



SIMULATED SPECTRA

WEAPON-GRADE VS REACTOR-GRADE PLUTONIUM, NaI DETECTOR

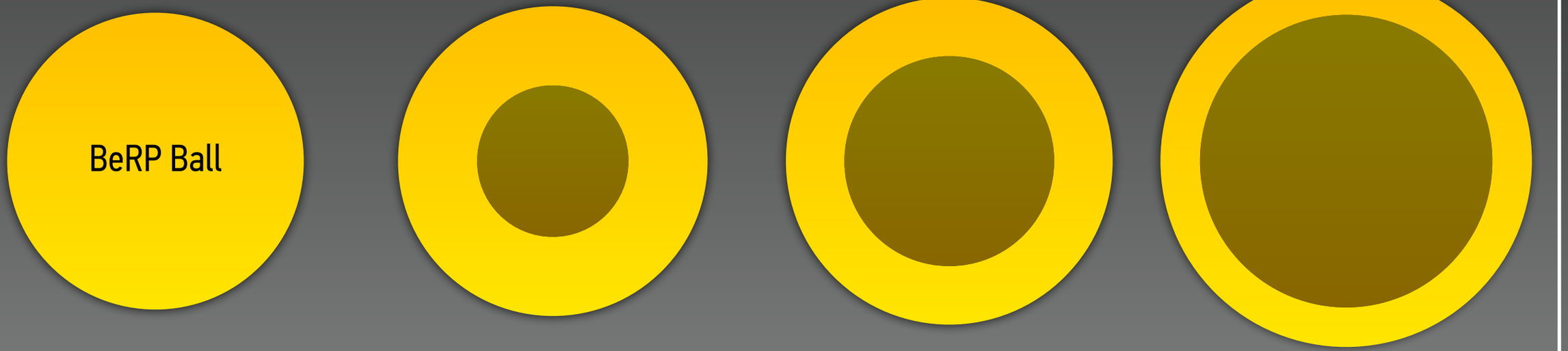


THIS IS APPARENTLY TOO EASY

NOTIONAL DIVERSION SCENARIOS

FOR THE 4484-GRAM BERP BALL

SCENARIO TYPE B: MASS UNCHANGED; INCREASING OUTER DIAMETER



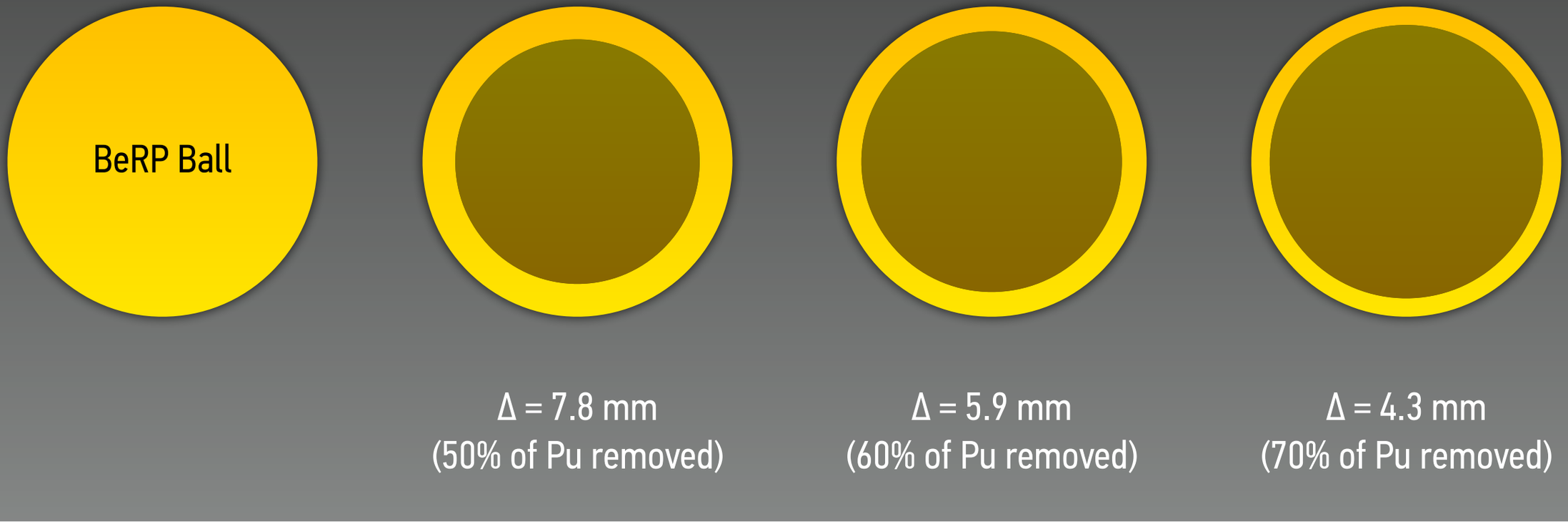
Total count rate increases (essentially linearly) with surface area of item; straightforward to detect

NOT FURTHER DISCUSSED HERE

NOTIONAL DIVERSION SCENARIOS

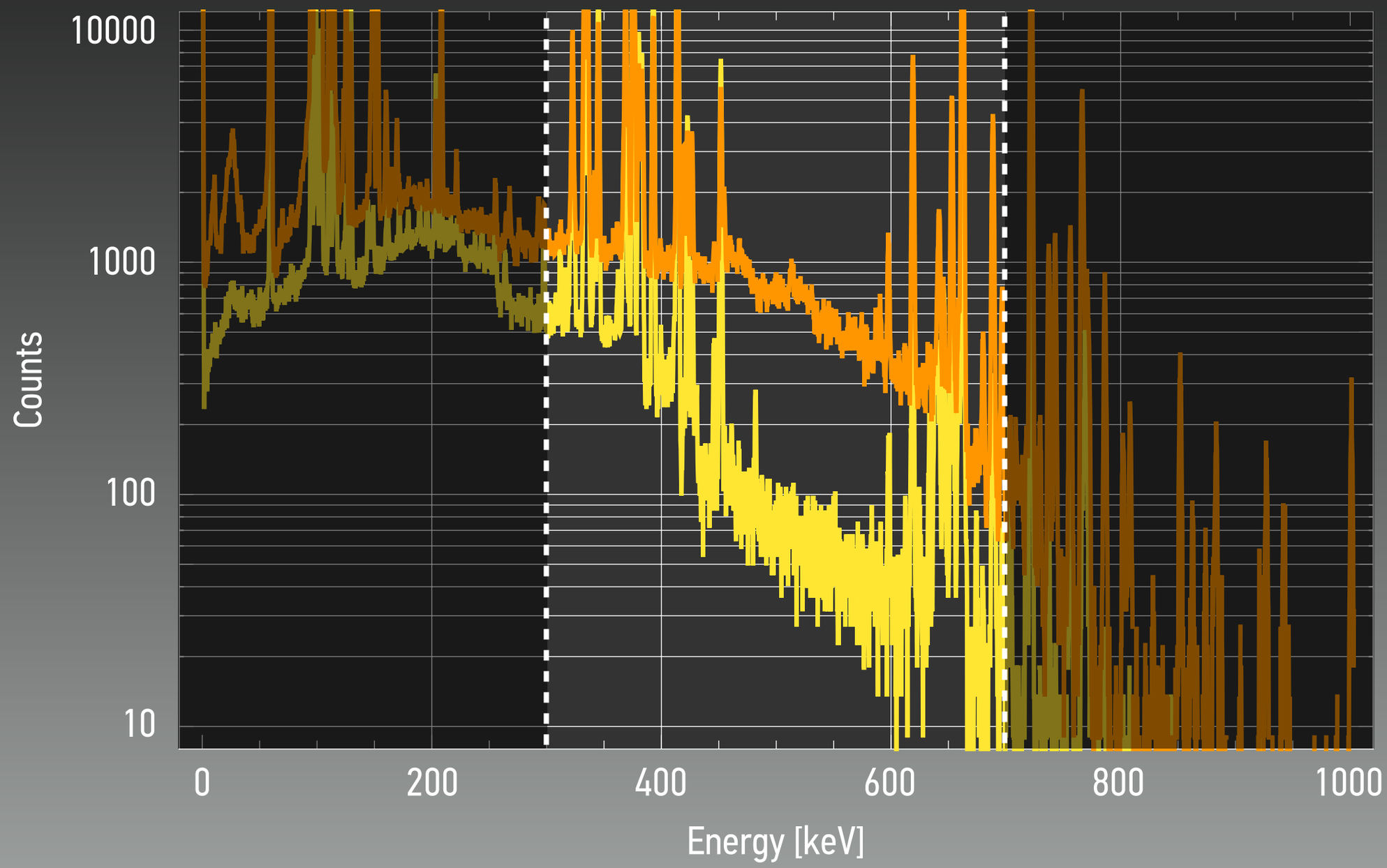
FOR THE 4484-GRAM BERP BALL

SCENARIO TYPE A: OUTER DIAMETER UNCHANGED; REMOVING MATERIAL FROM THE INSIDE



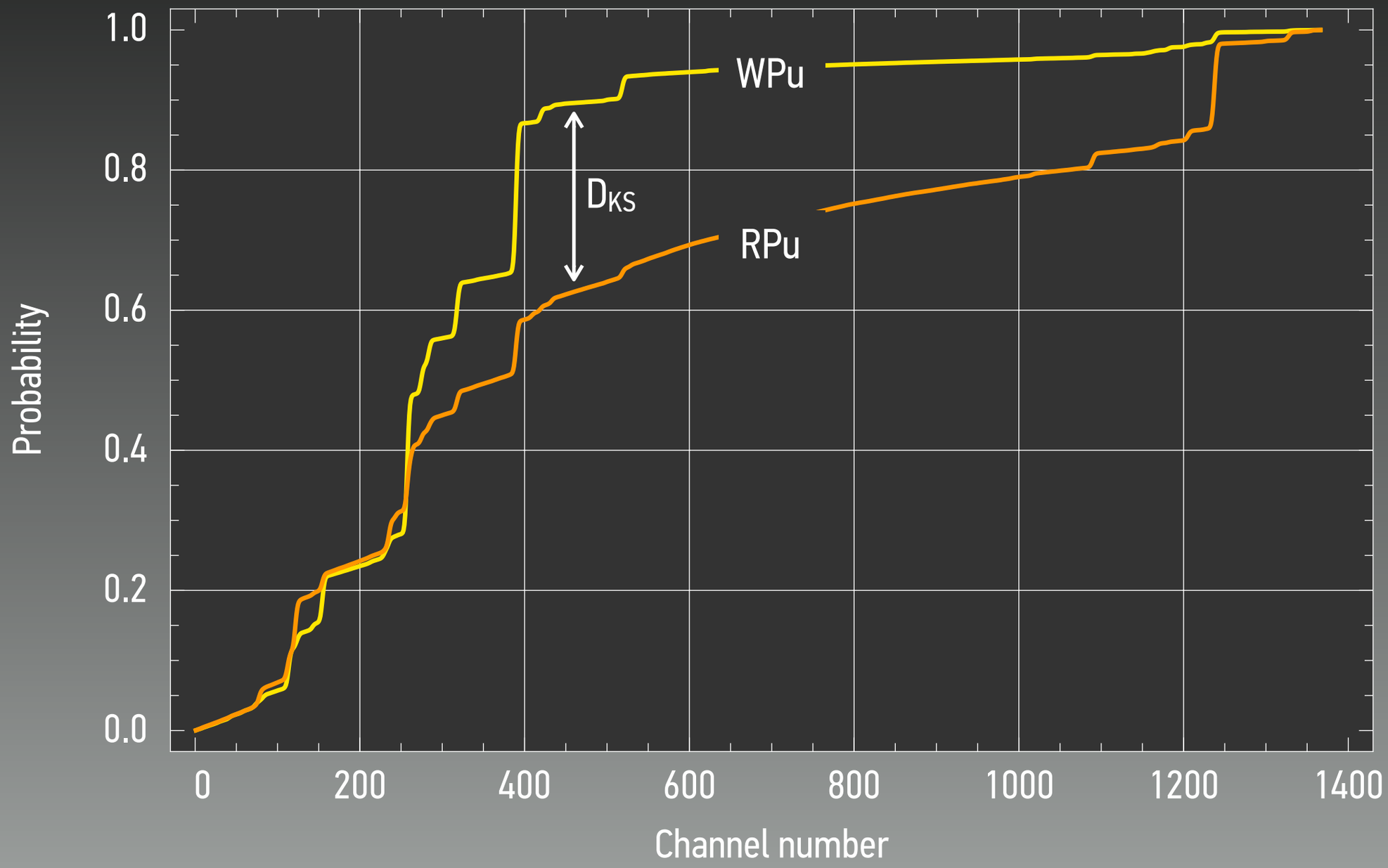
300–700 keV RANGE

INTERPRET GAMMA SPECTRUM AS PROBABILITY DENSITY FUNCTION



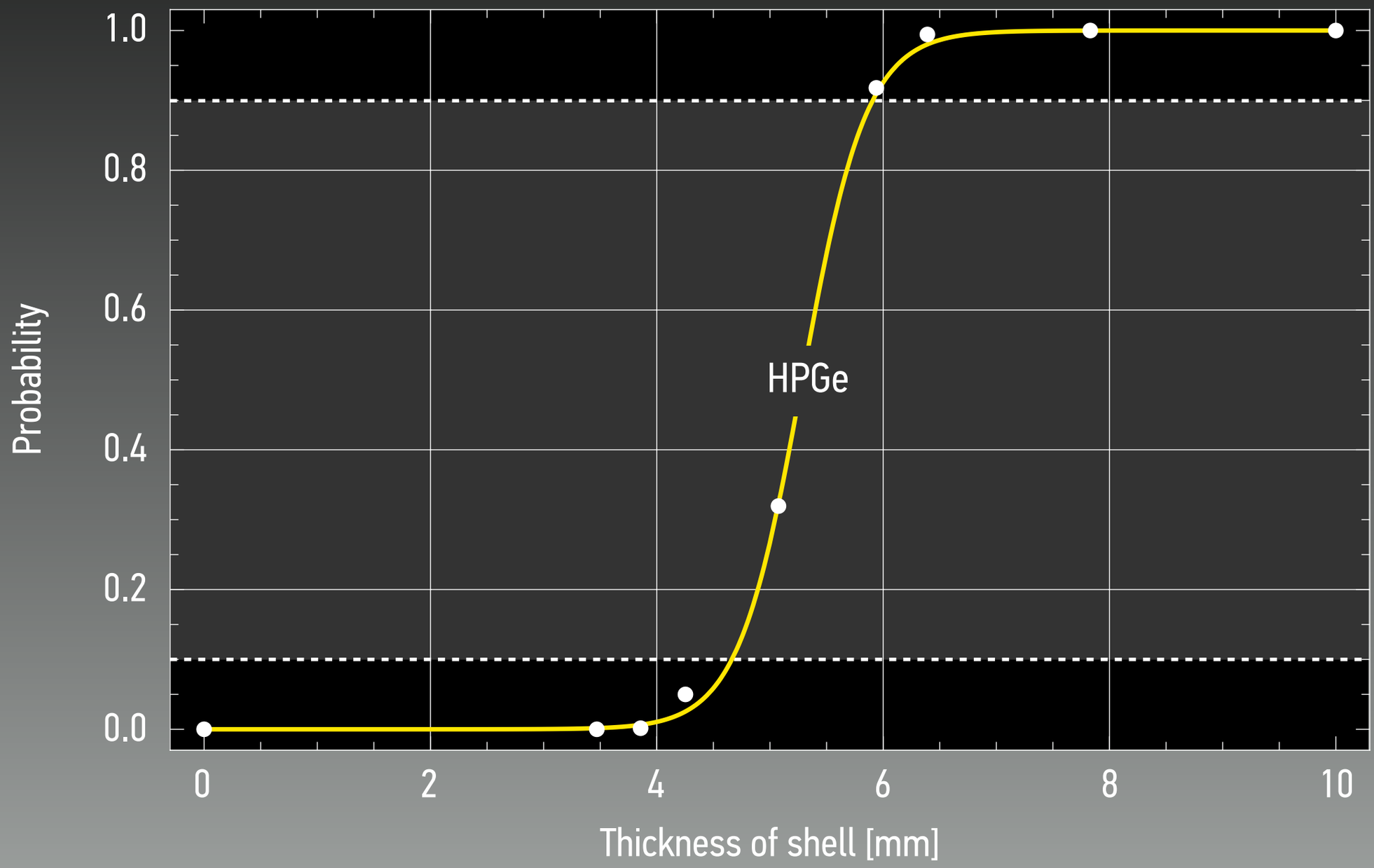
CUMULATIVE DISTRIBUTION FUNCTION

300–700 KeV, REACTOR-GRADE VS WEAPON-GRADE PLUTONIUM



ARE TWO OBJECTS (CONSIDERED) EQUIVALENT?

RESULTS OF A KOLMOGOROV-SMIRNOV TEST COMPARING RADIATION SPECTRA OF ORIGINAL BERP AGAINST MODIFIED BERP (300–700 keV RANGE)



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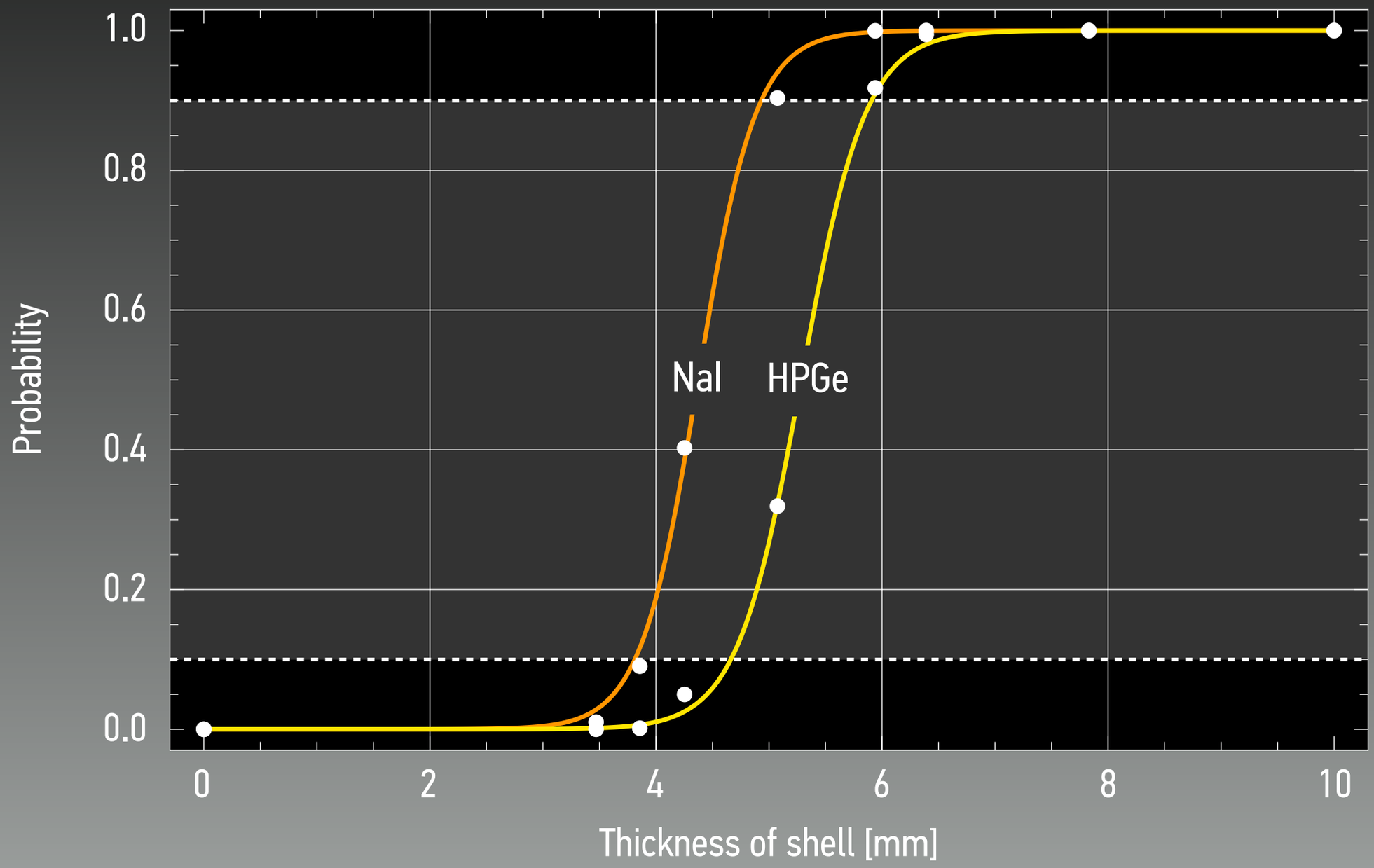
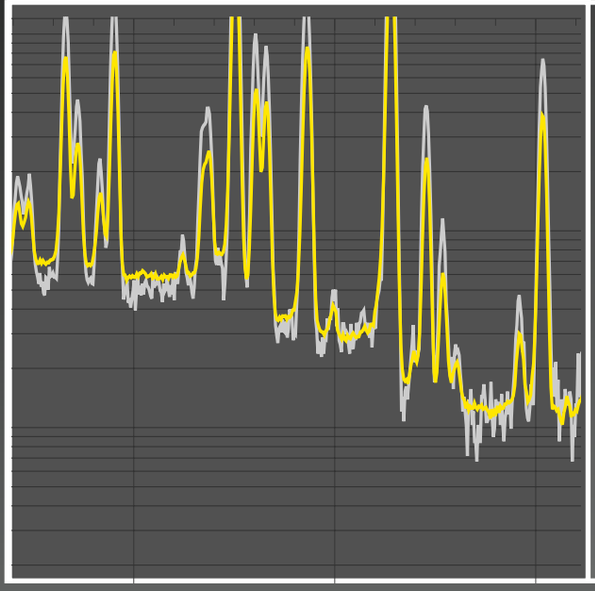
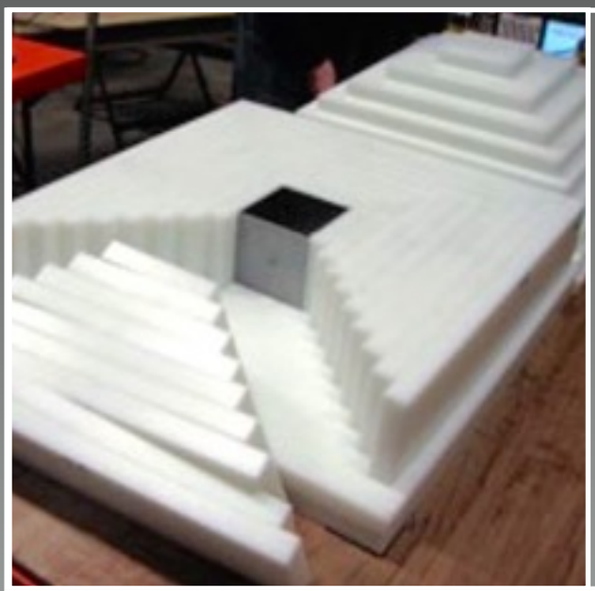


CONCLUSION



SUMMARY AND FINDINGS

- Notional diversion scenarios using template-matching approach
- Items with different surface areas, straightforward
- Items with same outside dimensions, more challenging
- Difficult/impossible for thick objects
- Sensitivity of NaI and HPGe not too different for template matching



AREAS OF POSSIBLE FUTURE WORK

Propose and agree on “universal test objects” (and their respective gamma spectra) for computational and experimental benchmarks

Propose and agree on reference match/diversion scenarios
to further develop and validate algorithms
(for example: Item should pass if age within ±10 years of template age)

Photo: Joint U.S.-U.K. Report on Technical Cooperation for Arms Control, U.S. Department of Energy, Washington, DC, 2015