UCRL-PRES-216936

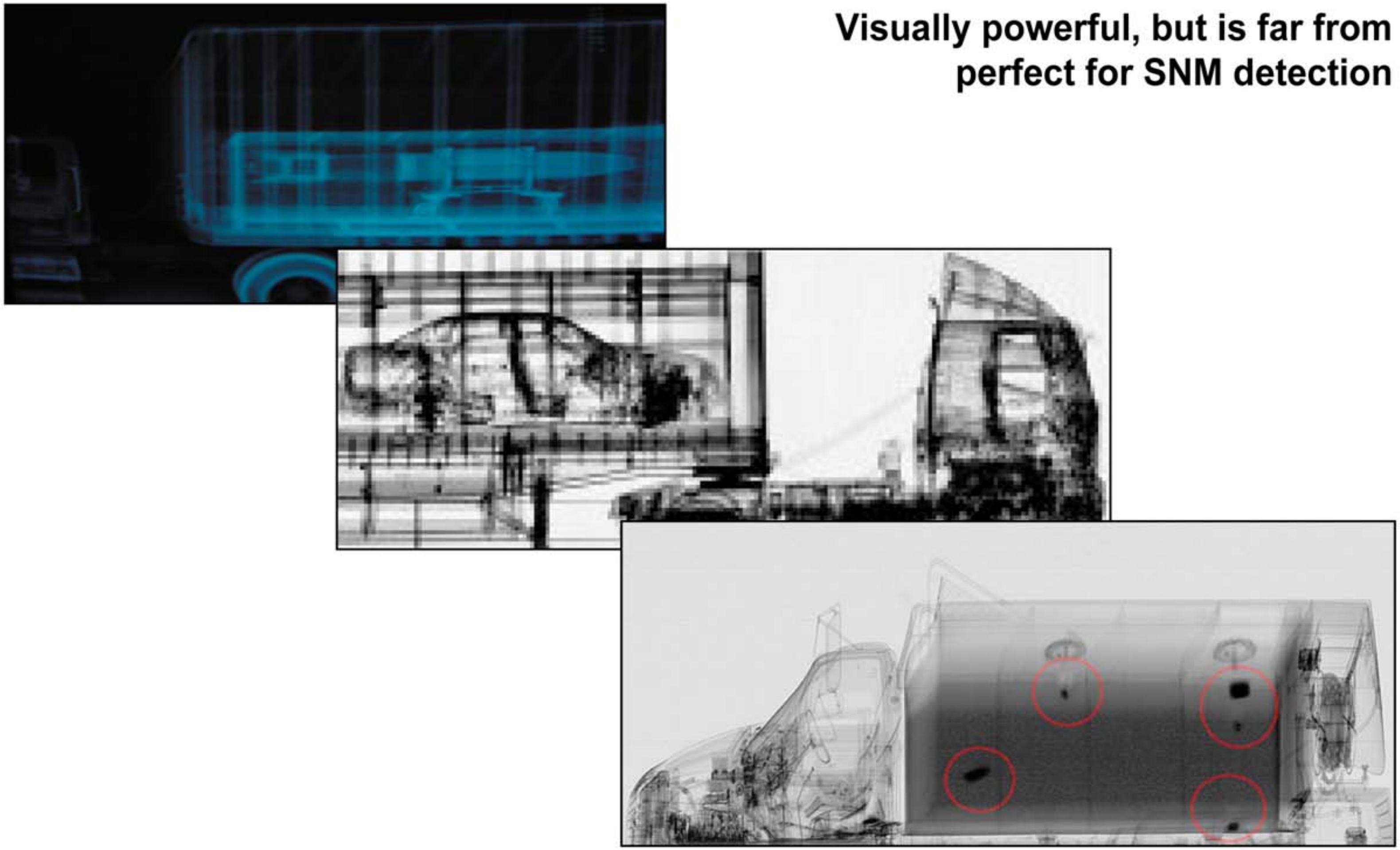
Motivation for including (g, g’) resonances in ENDF data files

Dennis McNabb

*This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Active radiographic inspection systems have limitations

Visually powerful, but is far from perfect for SNM detection



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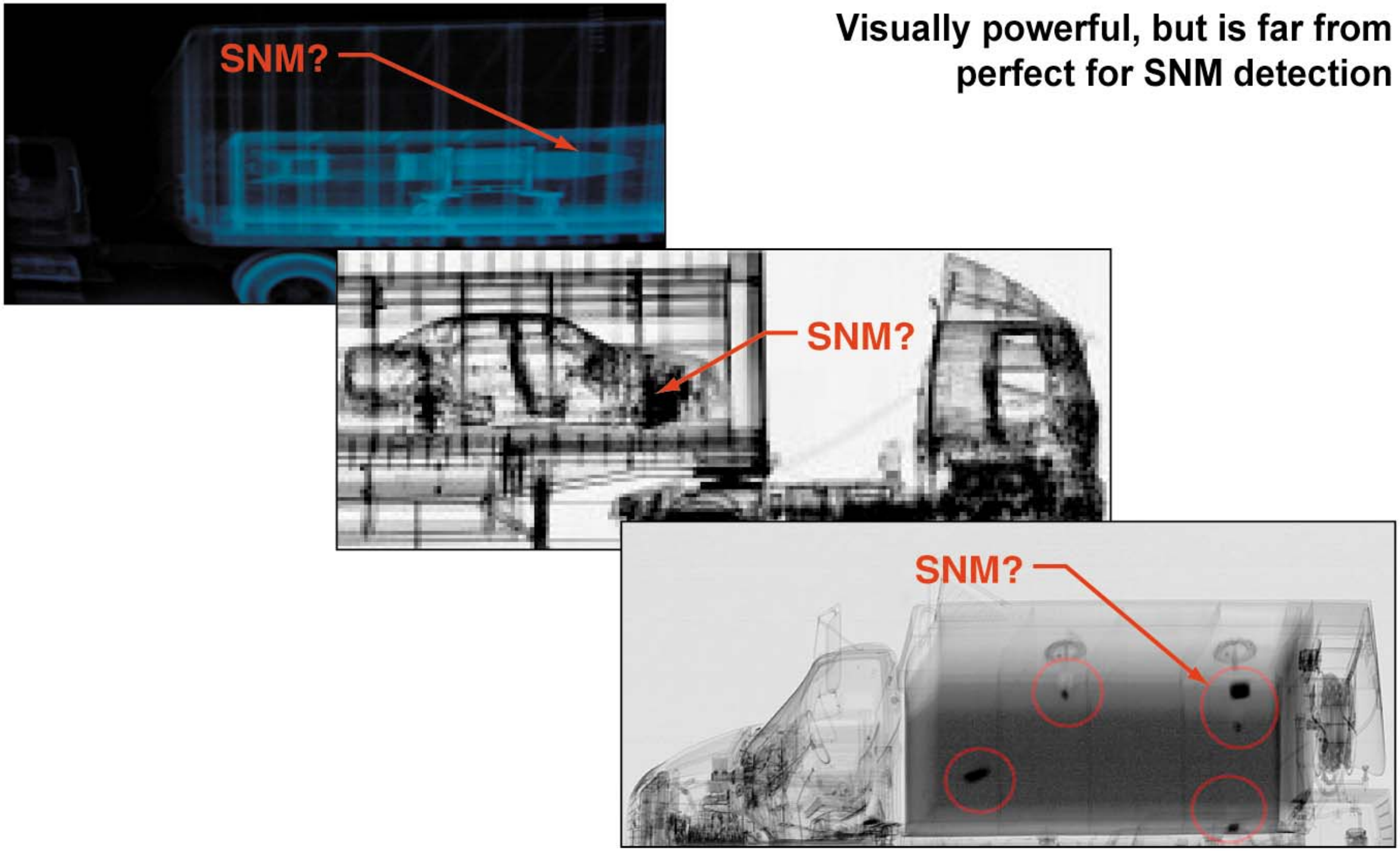
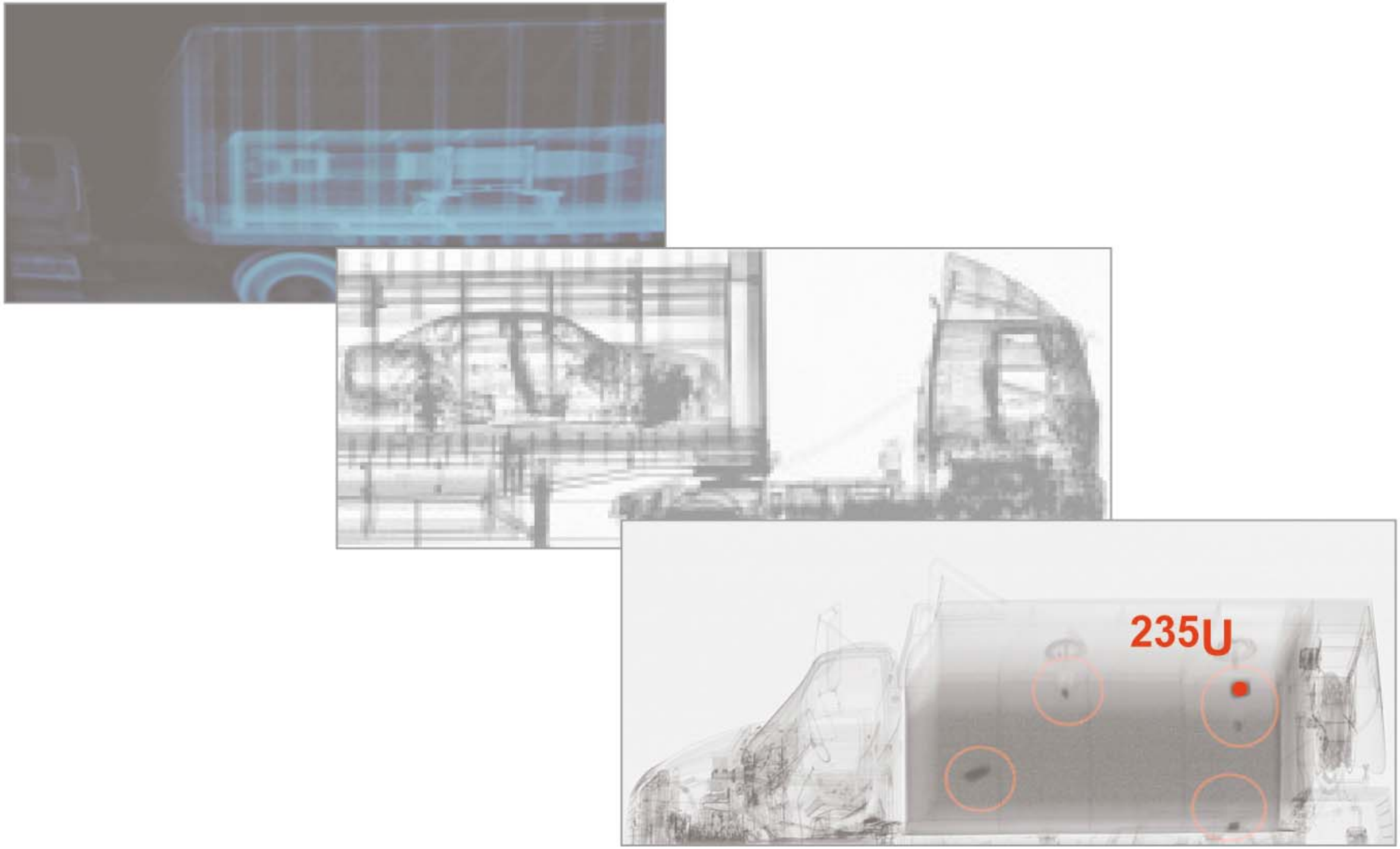
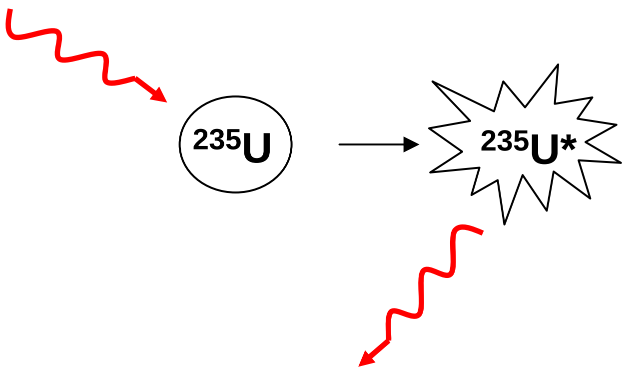


Nuclear resonance fluorescence provides isotopic sensitivity



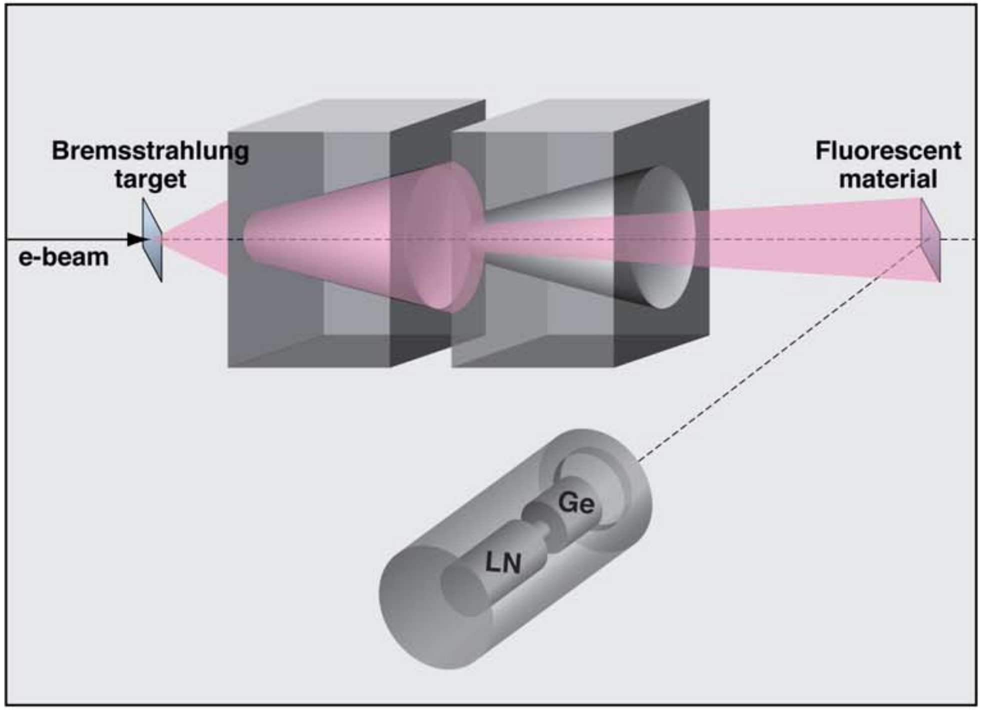
Nuclear resonance fluorescence (NRF) defined

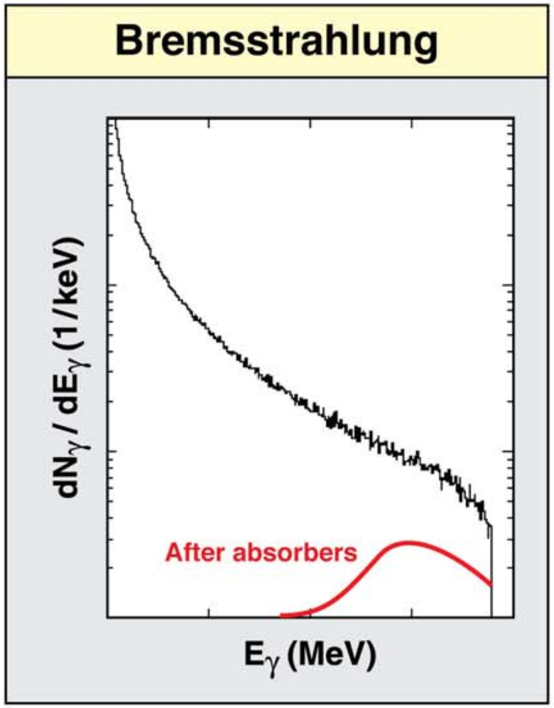


- Incident photon absorbed by nucleus
  At certain resonance energies
- Excited state quickly re-emits photons at the same or different frequencies
- Energy scale is MeV

In complete analogy with atomic fluorescence

Search for resonances is best done with a broadband source because you don't know where the lines are

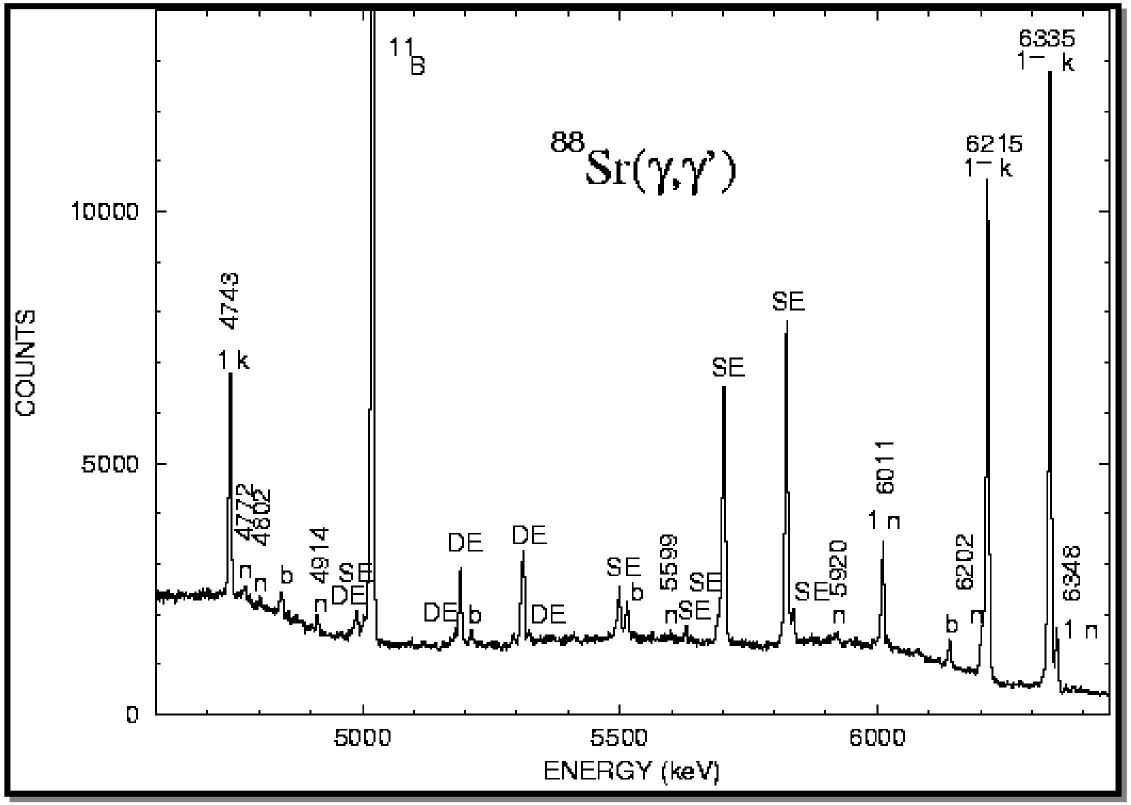




Experiments will be count-rate limited
- **Absorbers are low-energy filter**
- **Increase beam energy until max count rate**
- **Step through excitation energy, changing absorbers**

NIF-0905-11355L2

Nuclear resonance fluorescence (NRF) can enable isotopic detection of dangerous materials



NRF benefits:

- Unique fingerprint for each isotope
- Cross sections can be large enough to detect gram quantities

NRF-based interrogation technologies are relatively unexplored, qualitatively different, and potentially very powerful

Fluorescent imaging with Thomson radiation is a new concept for isotopic detection of SNM

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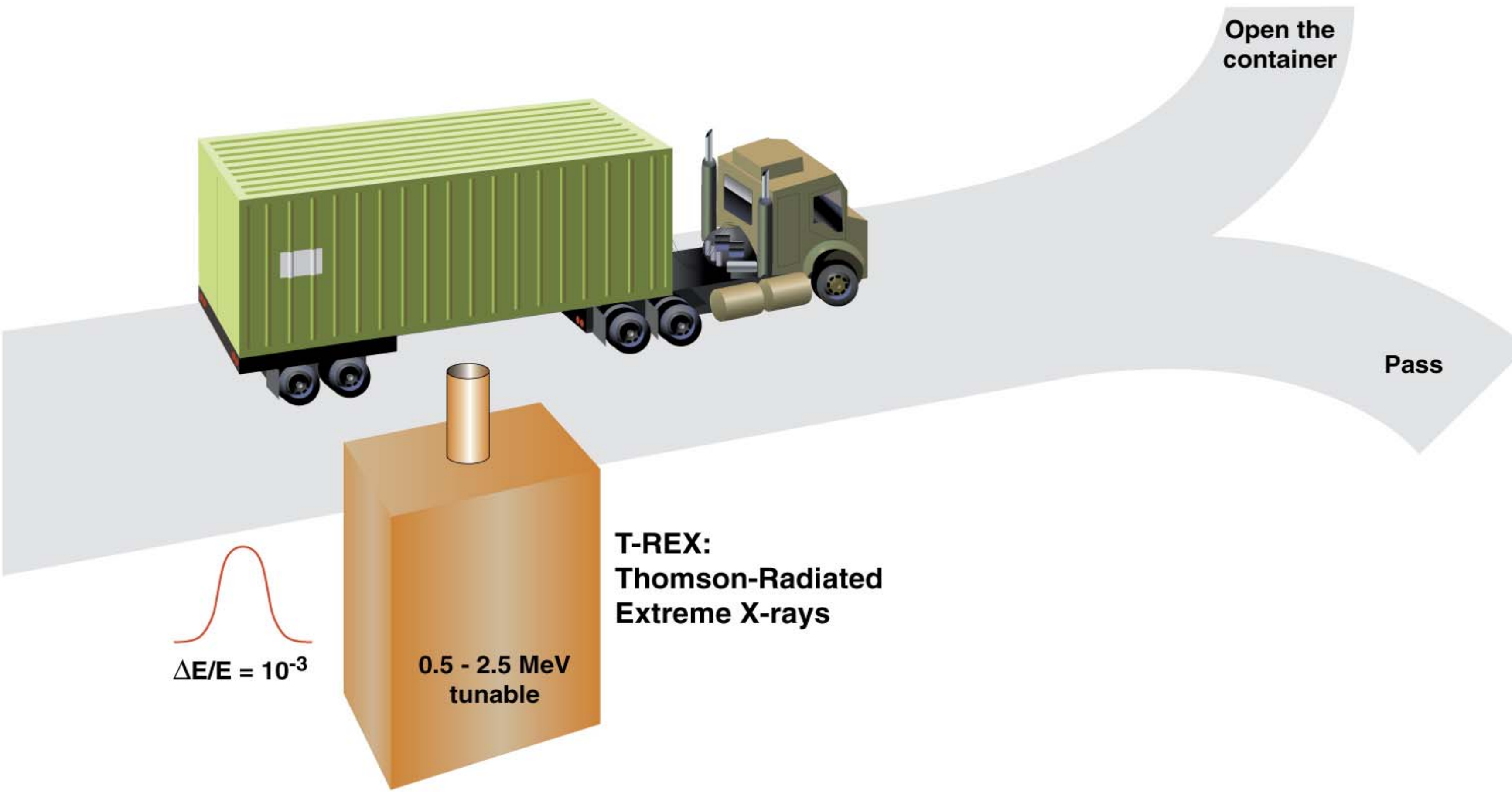
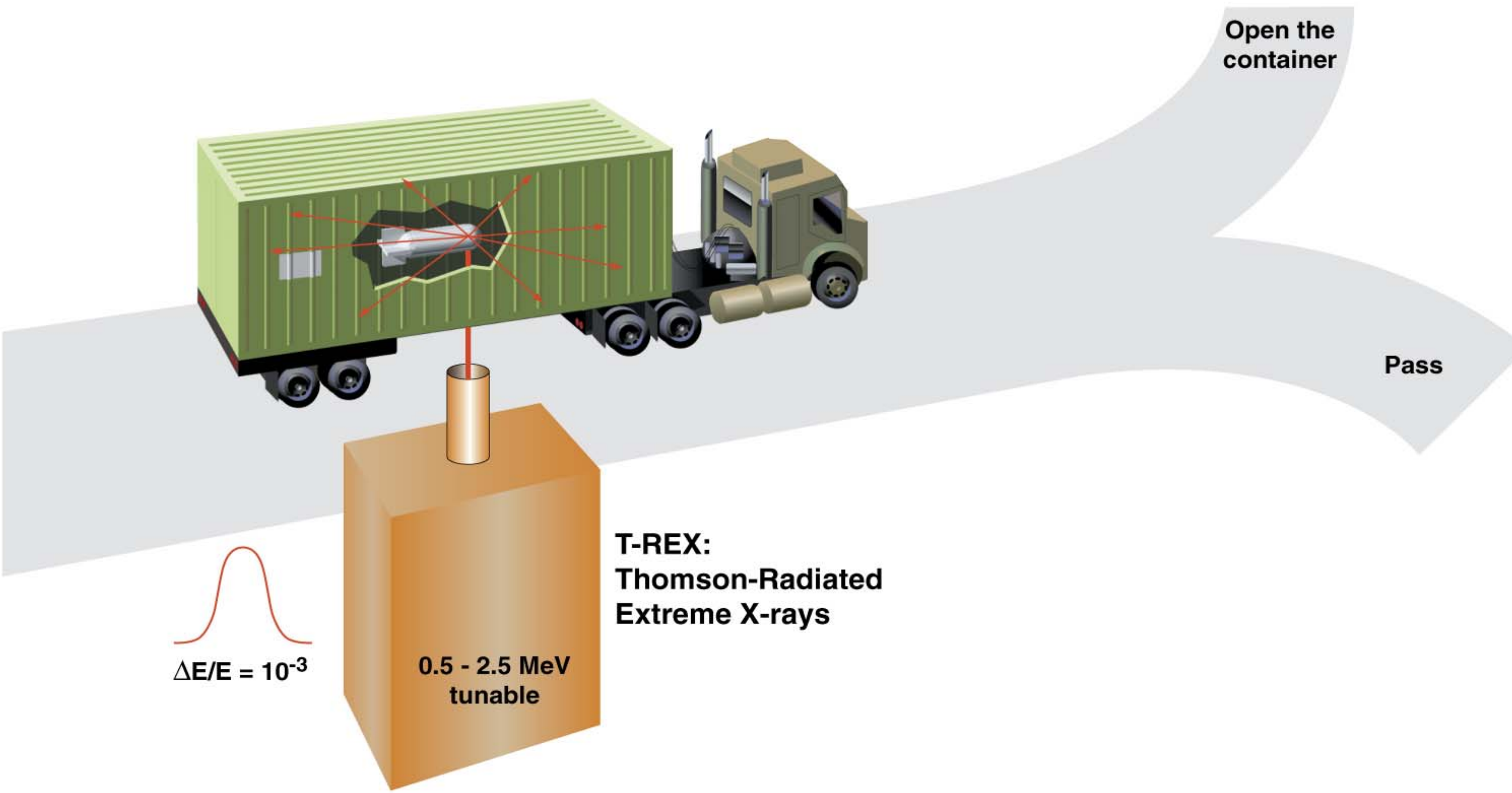


NIF-0905-11350 L2
13CB/tr

Fluorescent imaging with Thomson radiation is a new concept for isotopic detection of SNM



NIF-0905-11350 L3
13CB/tr

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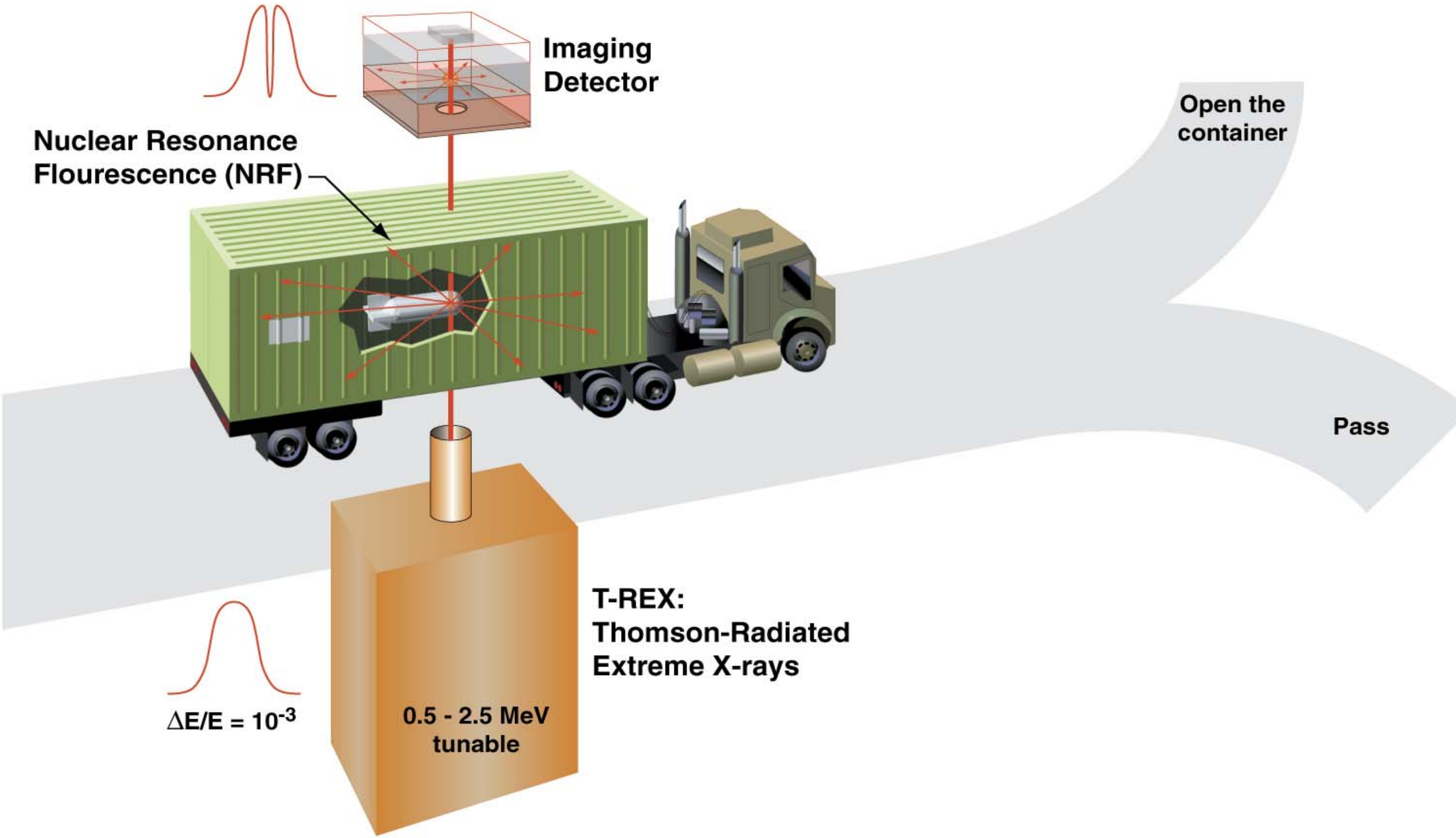
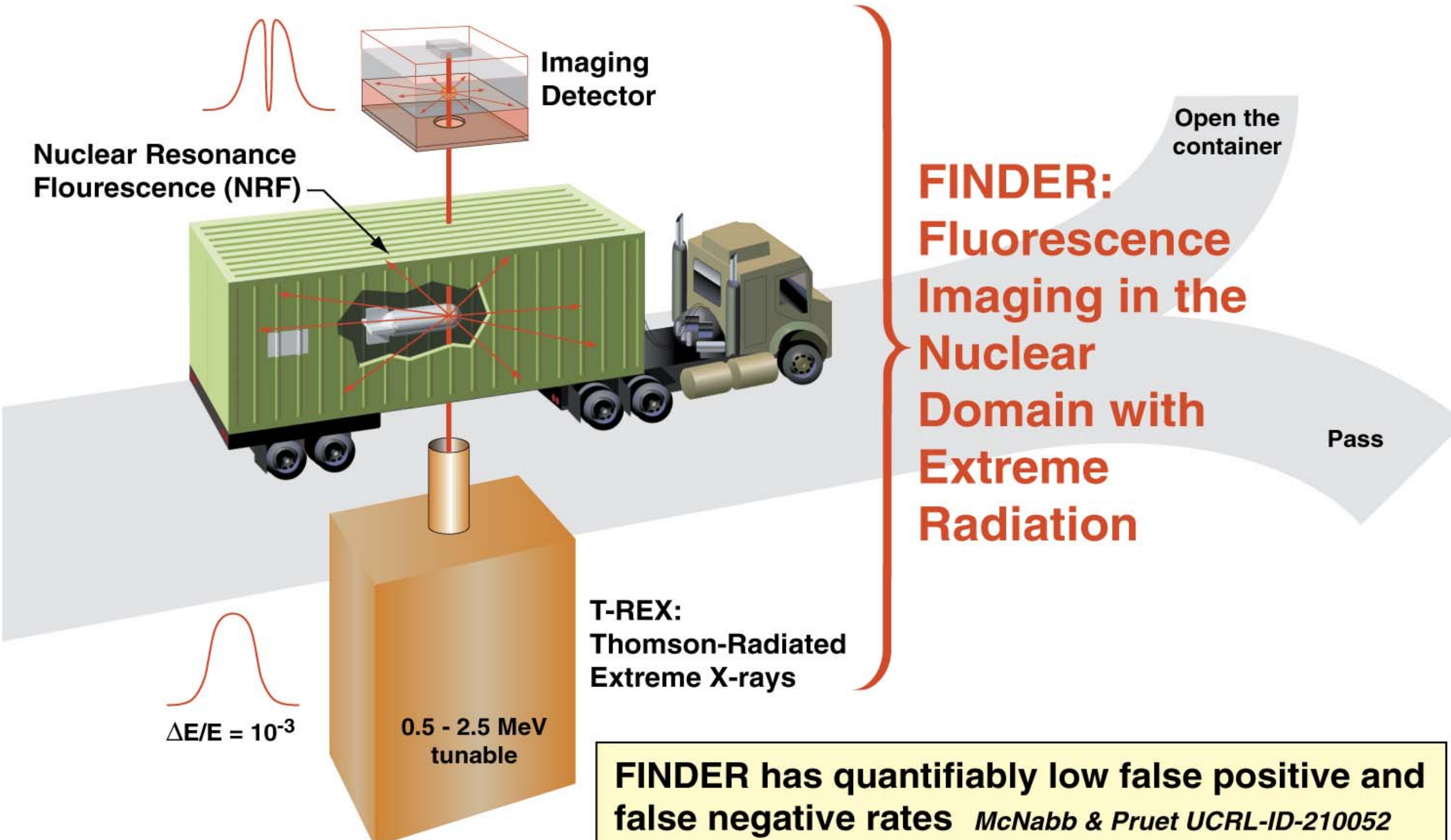


NIF-0905-11350 L4
13CB/tr

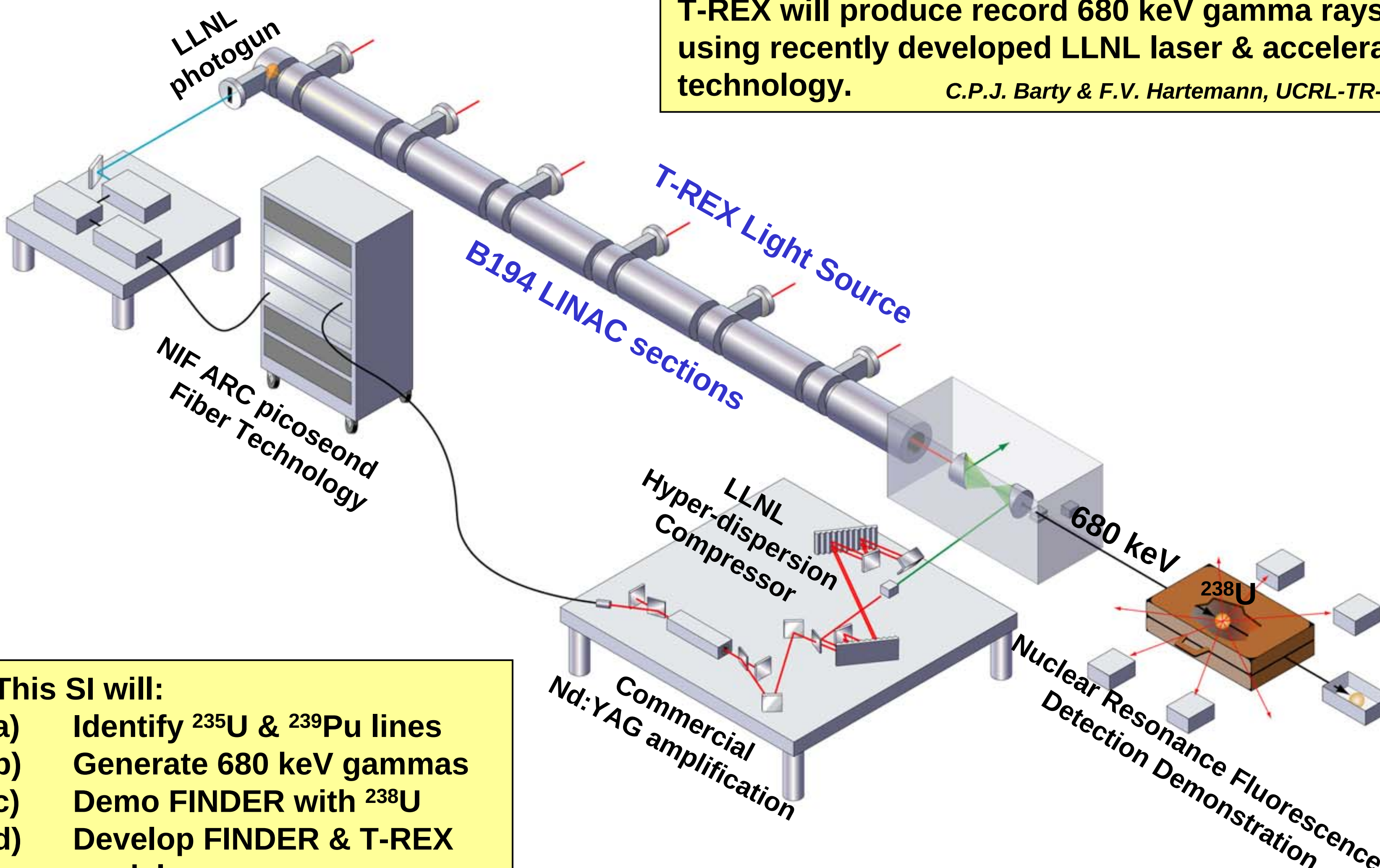
Fluorescent imaging with Thomson radiation is a new concept for isotopic detection of SNM



FINDER has quantifiably low false positive and false negative rates *McNabb & Pruet UCRL-ID-210052*

We have LDRD funding to demonstrate this concept

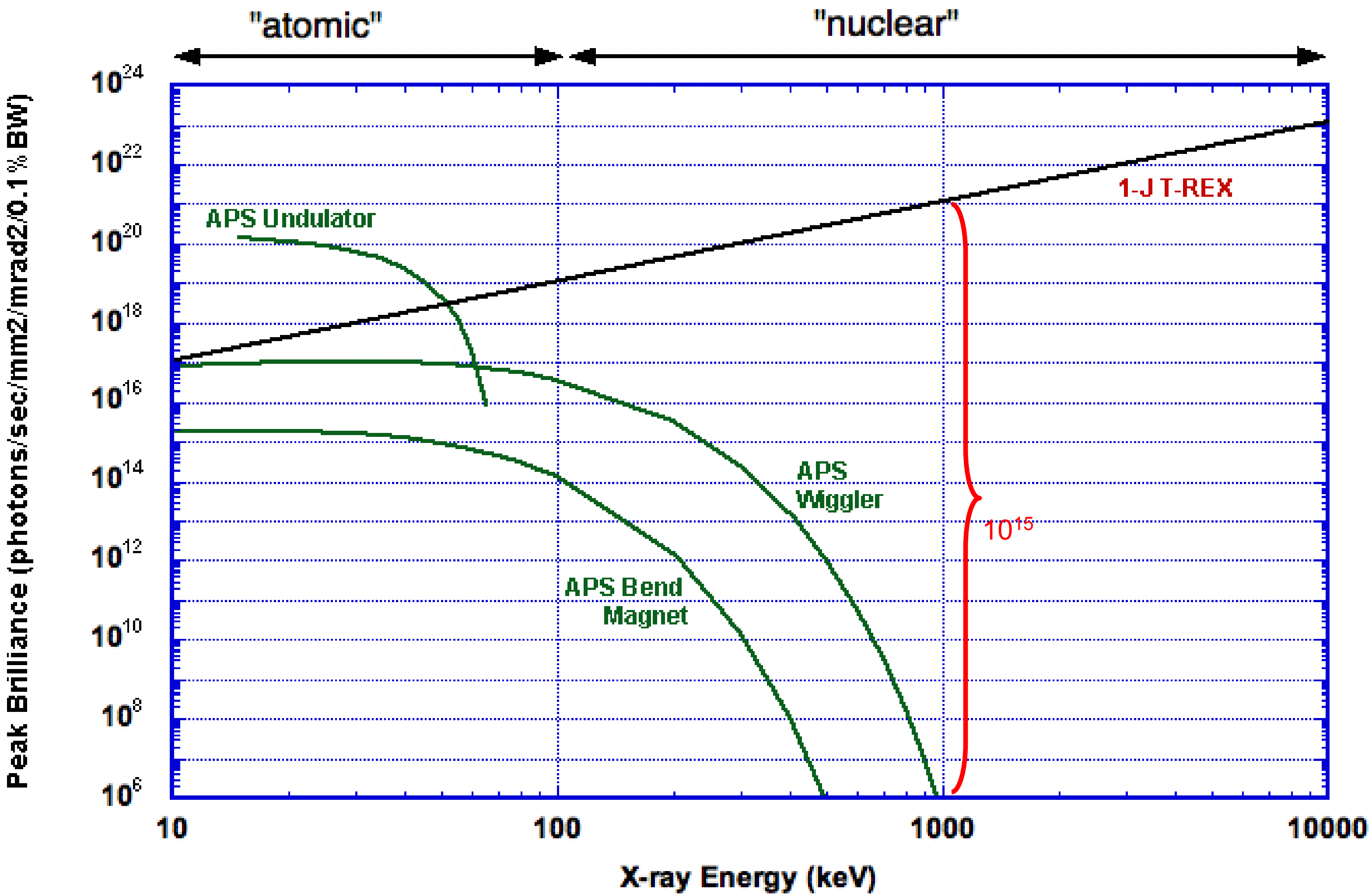
T-REX will produce record 680 keV gamma rays using recently developed LLNL laser & accelerator technology. *C.P.J. Barty & F.V. Hartemann, UCRL-TR-206825*



This SI will:

a) **Identify ^{235}U & ^{239}Pu lines**
b) **Generate 680 keV gammas**
c) **Demo FINDER with ^{238}U**
d) **Develop FINDER & T-REX models**

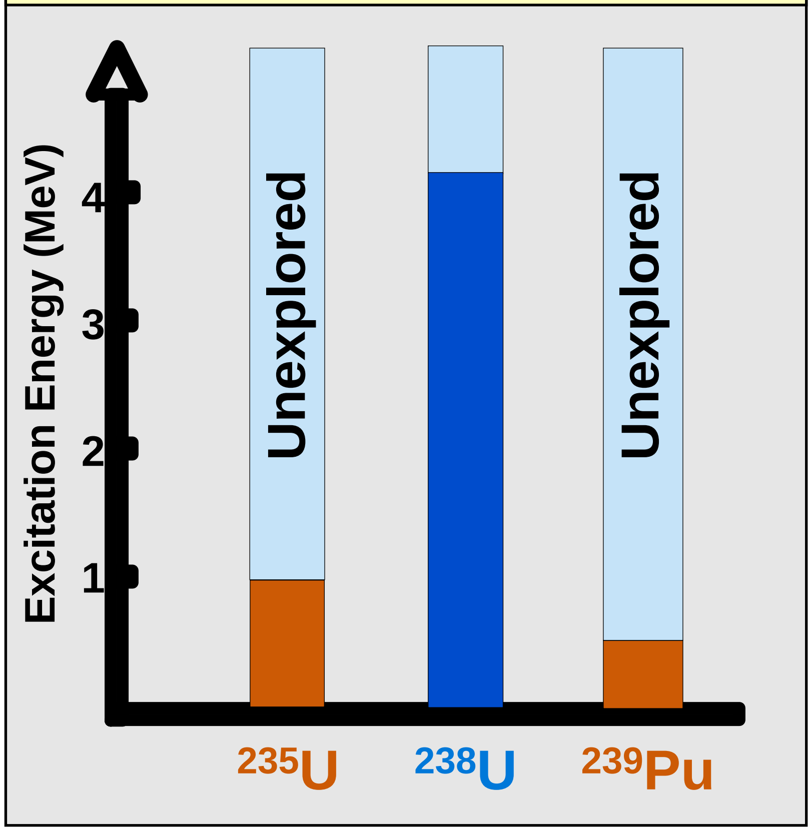
Thomson light sources have the capability to revolutionize “nuclear” photo-science

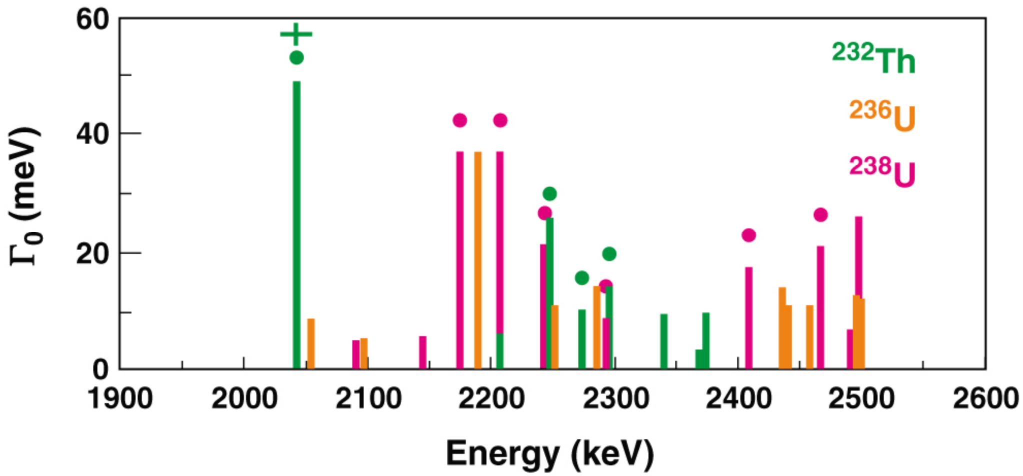


T-REX Peak Brilliance at 1 MeV will exceed the world’s best synchrotron by 15 orders of magnitude

NRF detection of SNM cannot be done without knowledge of useful resonances in ^{235}U, ^{238}U, ^{239}Pu

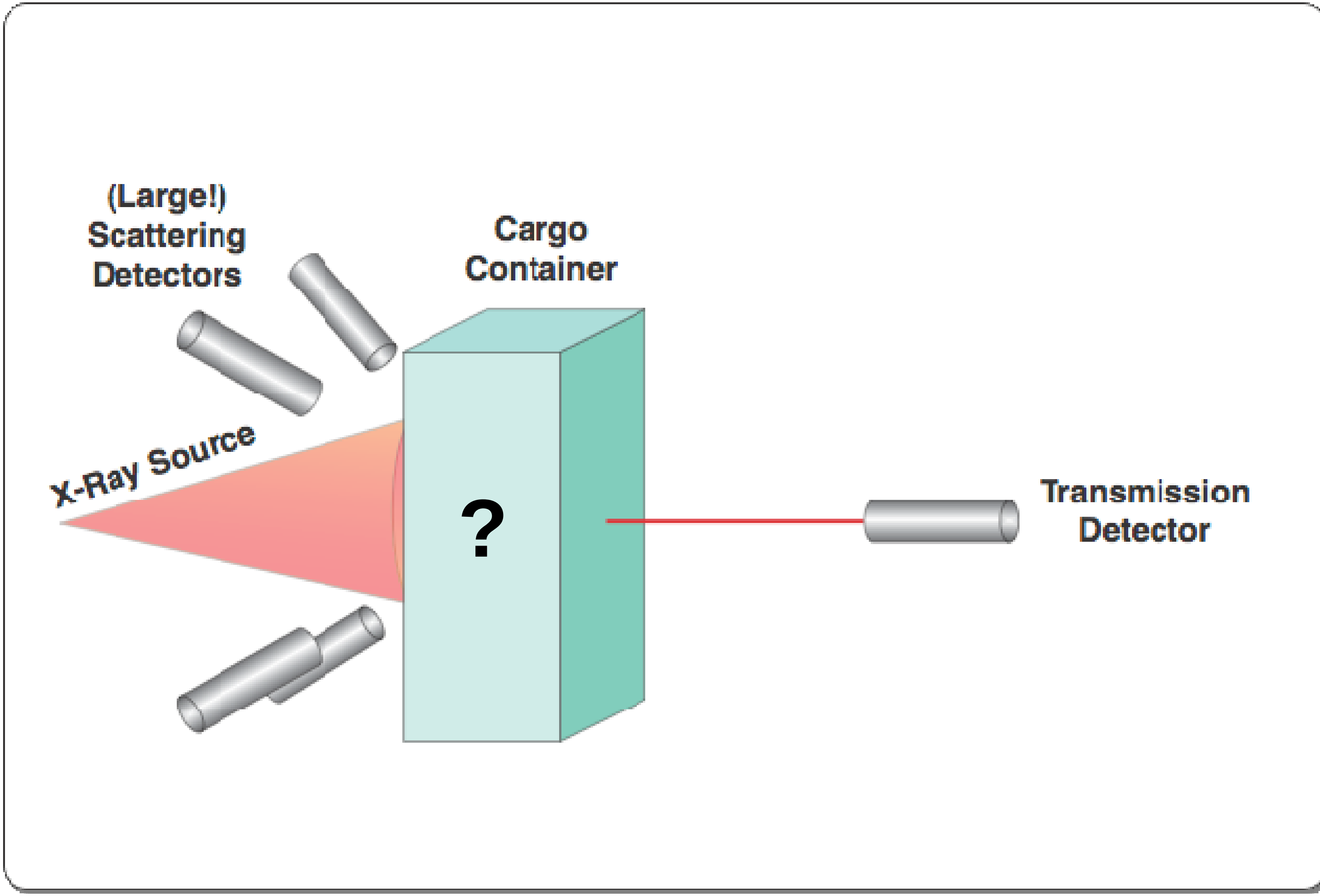
Current Experimental Coverage of Resonances



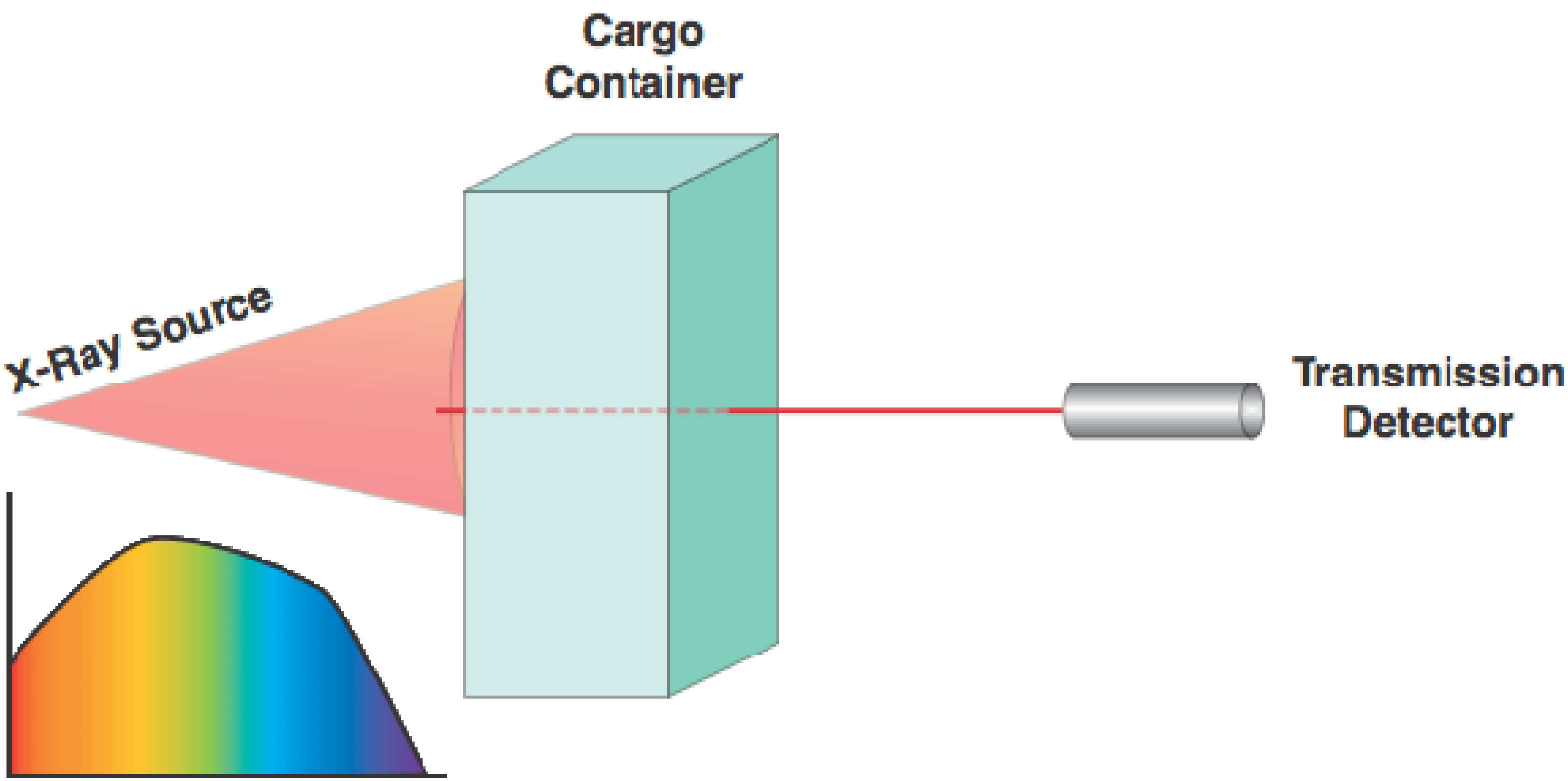


Surprisingly to most non-nuclear physicists,
The levels of interest have never been measured

There are different ways to learn what's inside



How do we use NRF for detection and imaging?



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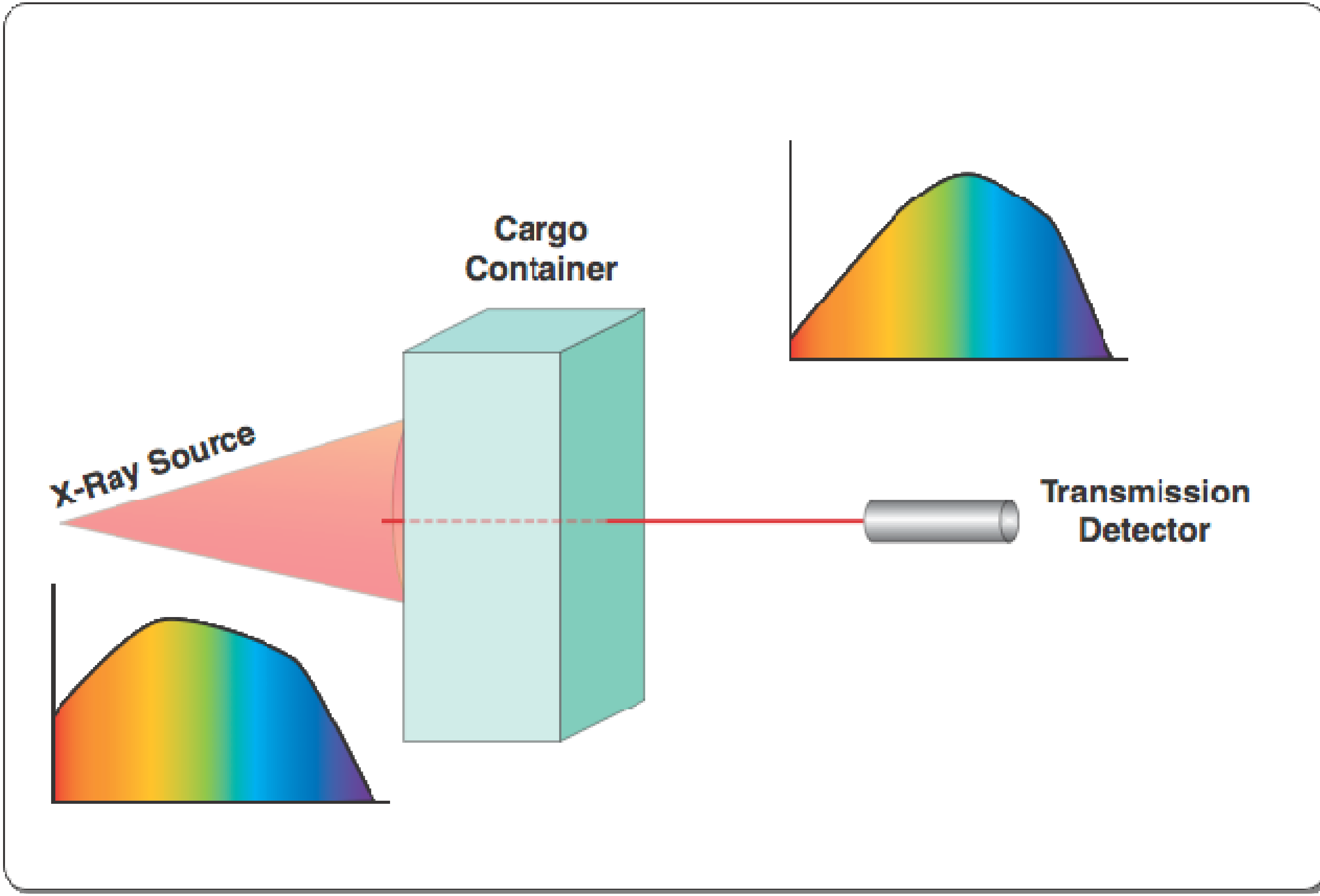

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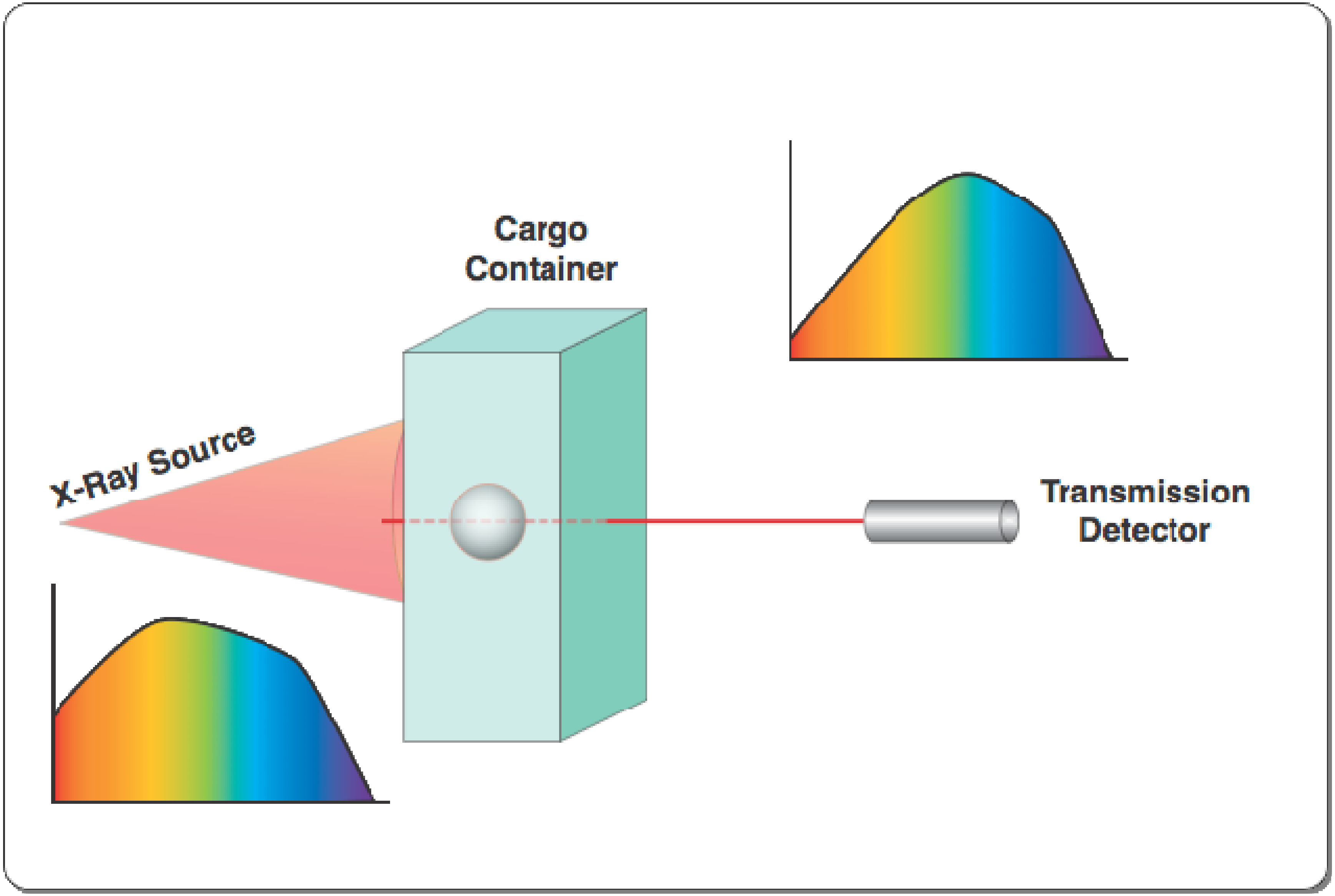

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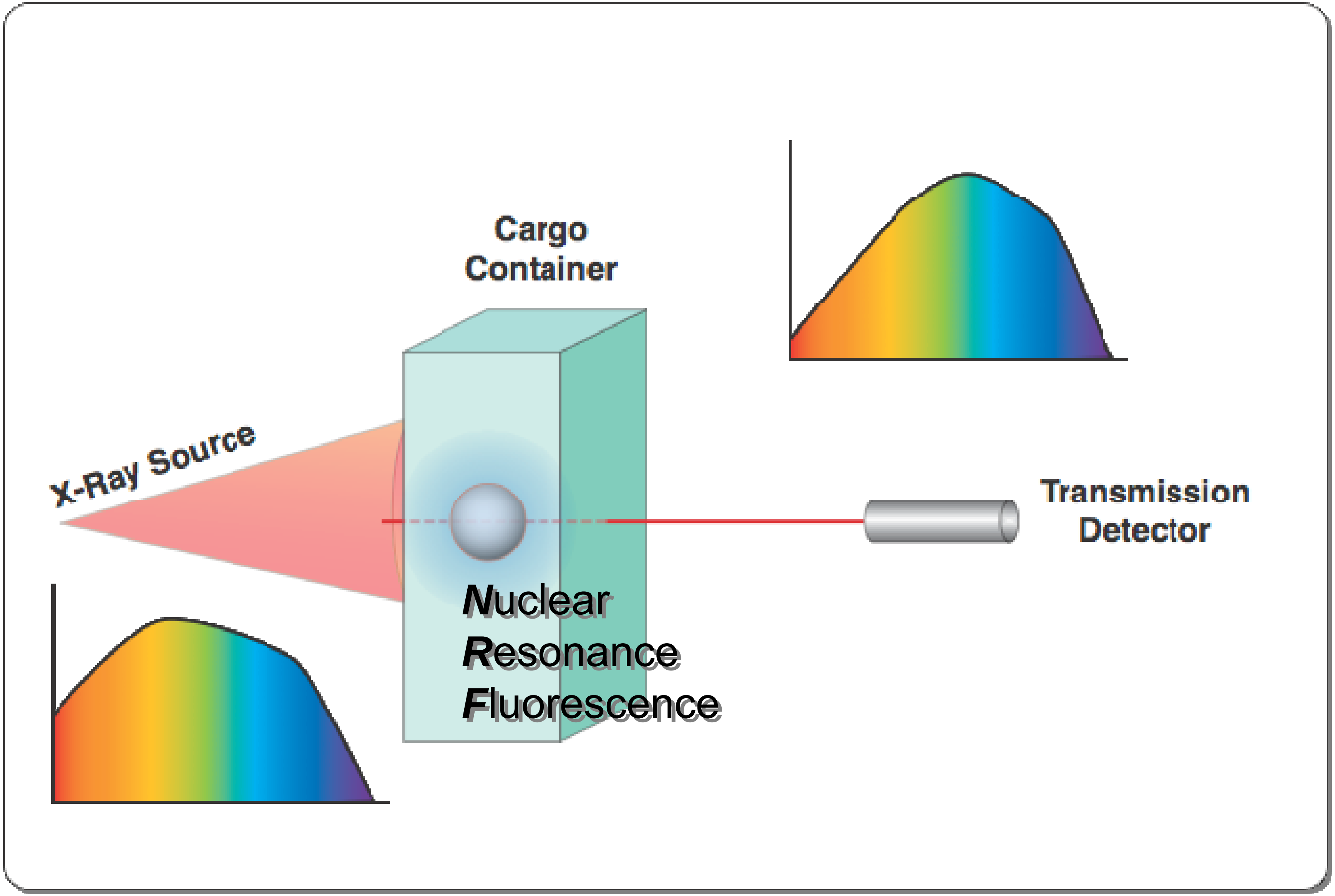

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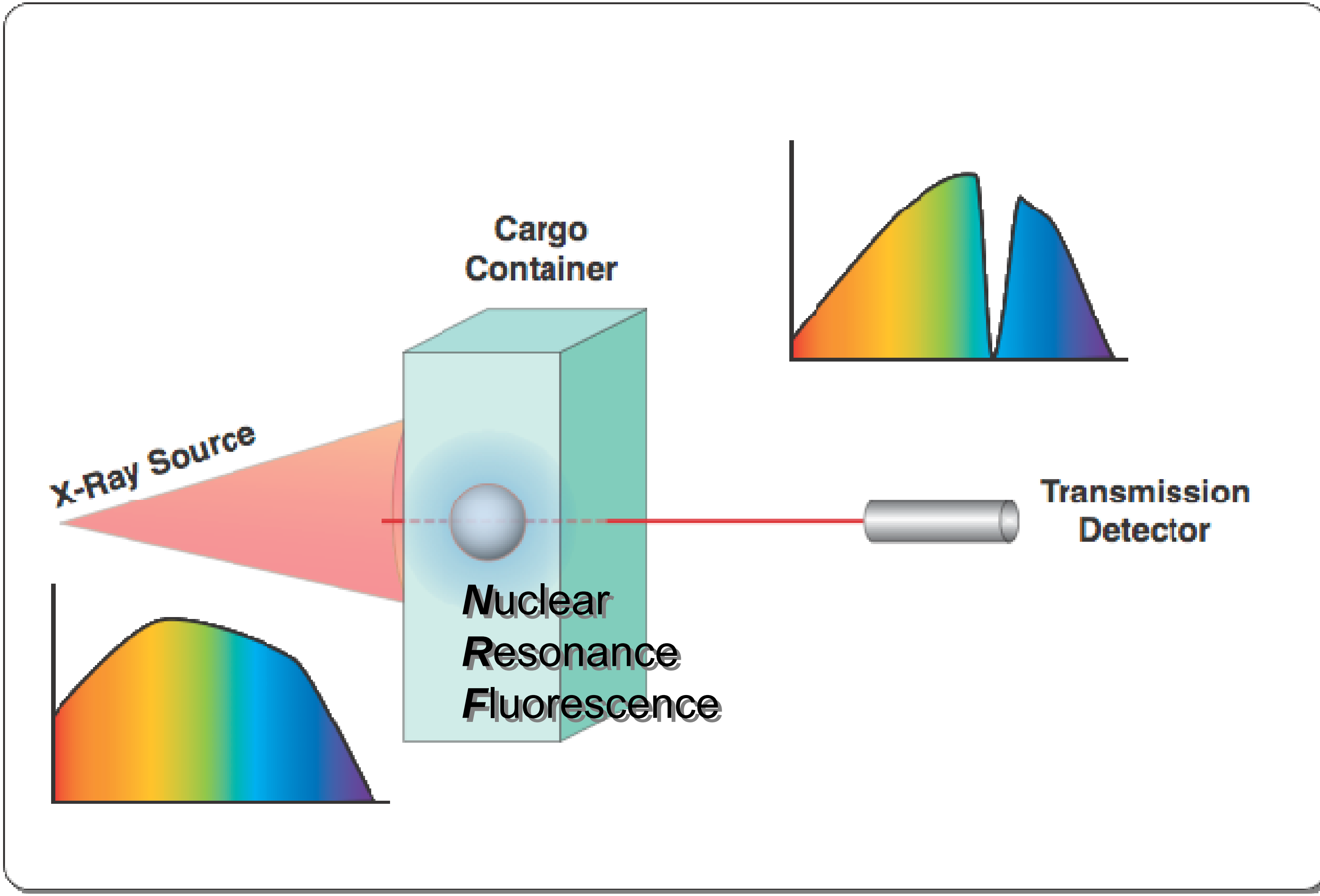
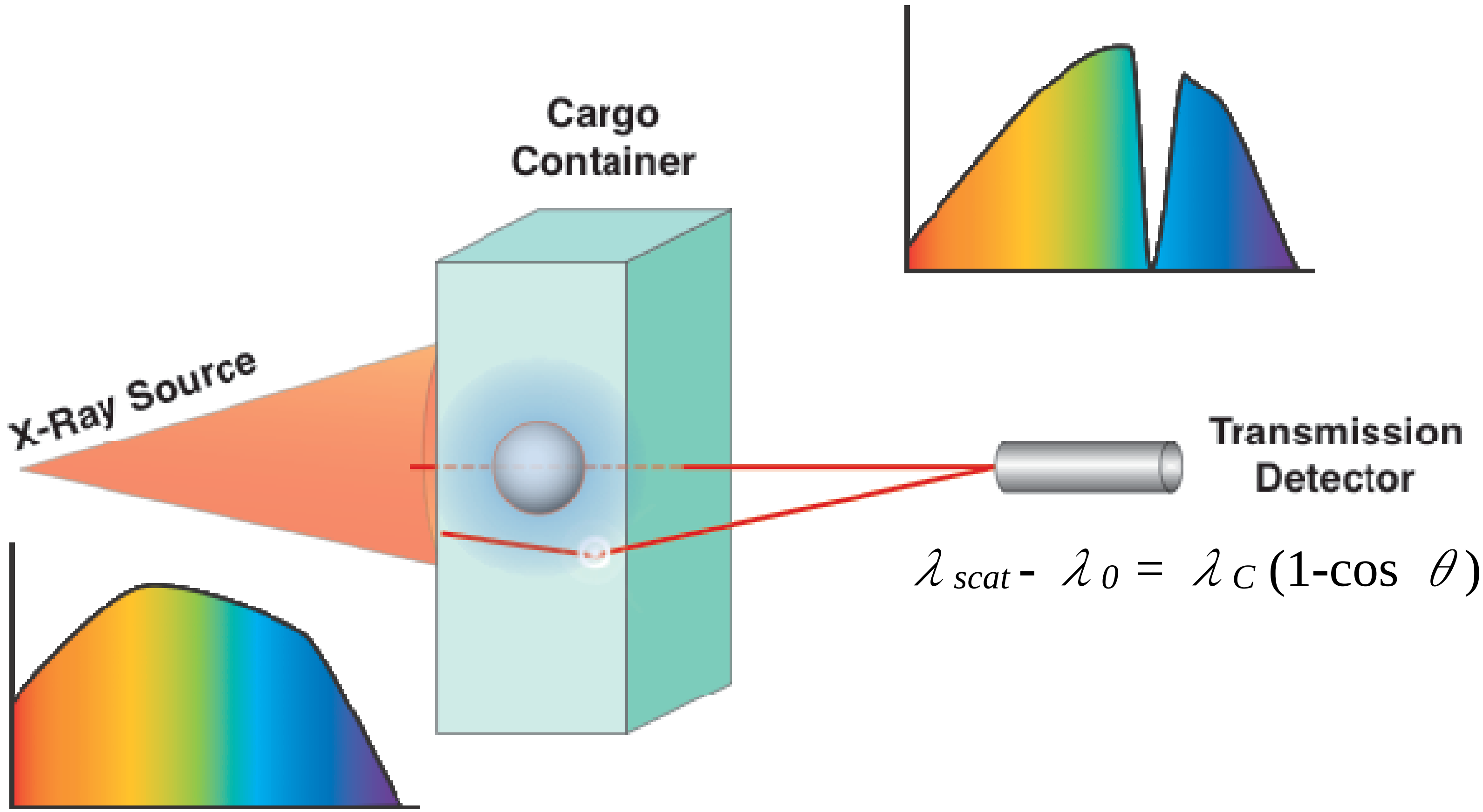


Notch detection: *Solid-angle matters*



$$\lambda_{scat} - \lambda_0 = \lambda_C (1-\cos\ \theta)$$

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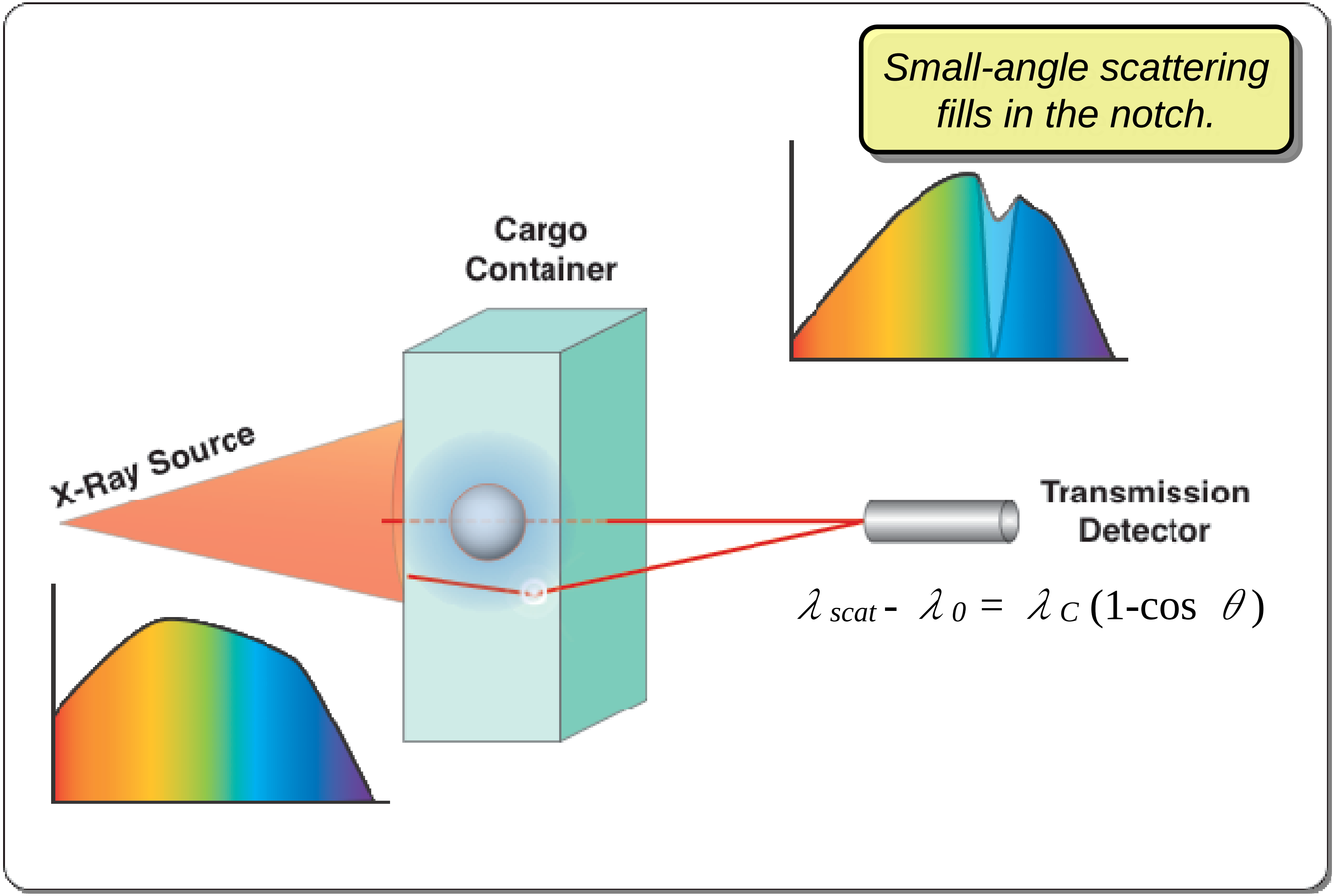
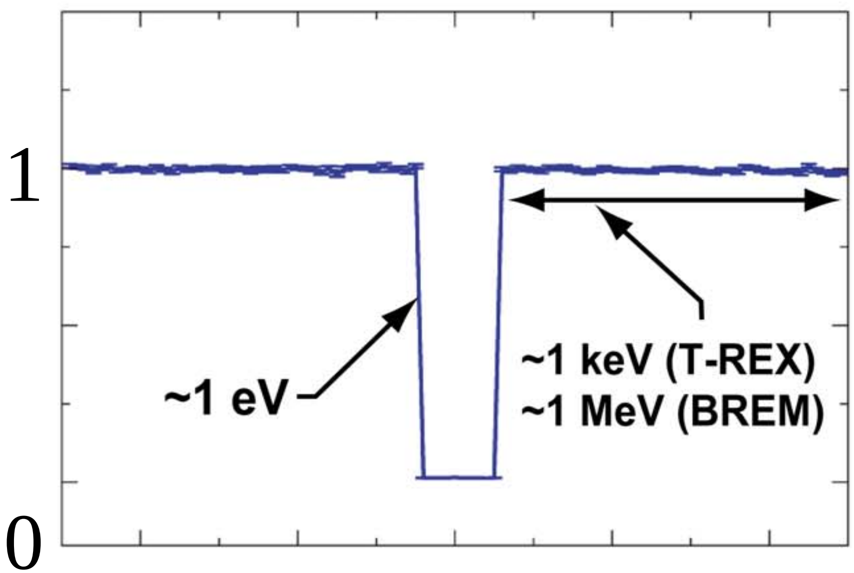


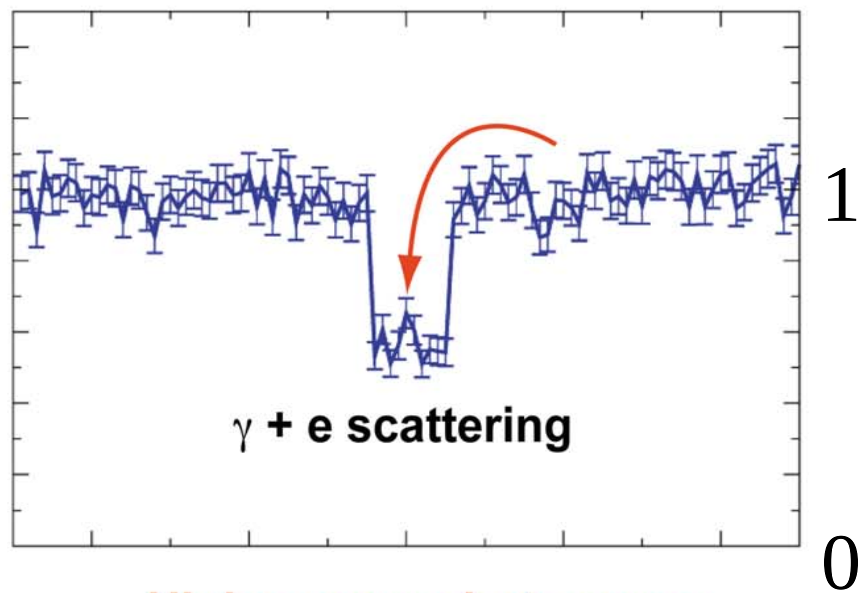
Very narrow notch can survive through a thick object

After SNM



Notch is narrow and deep

After more shielding

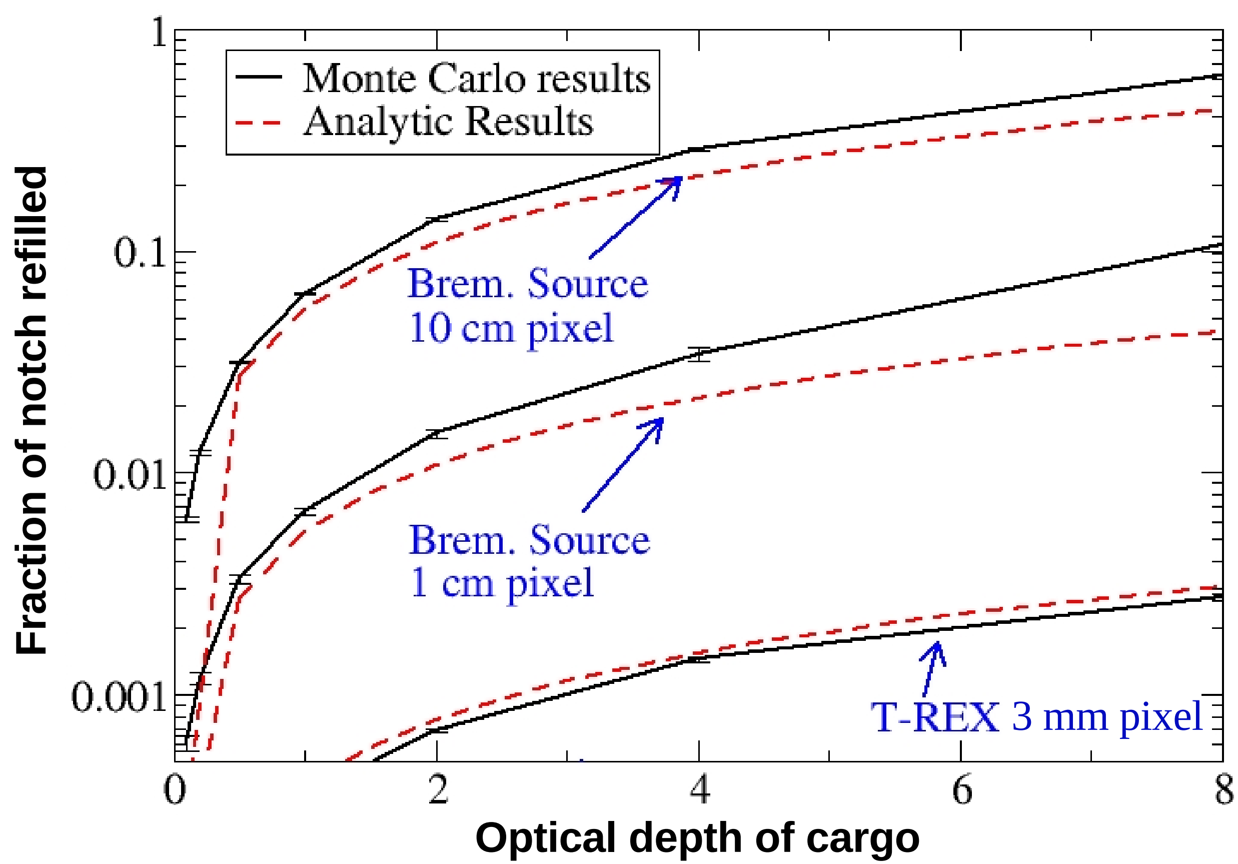


High energy photons can refill the notch

NIF-0905-11354
13CB/tr

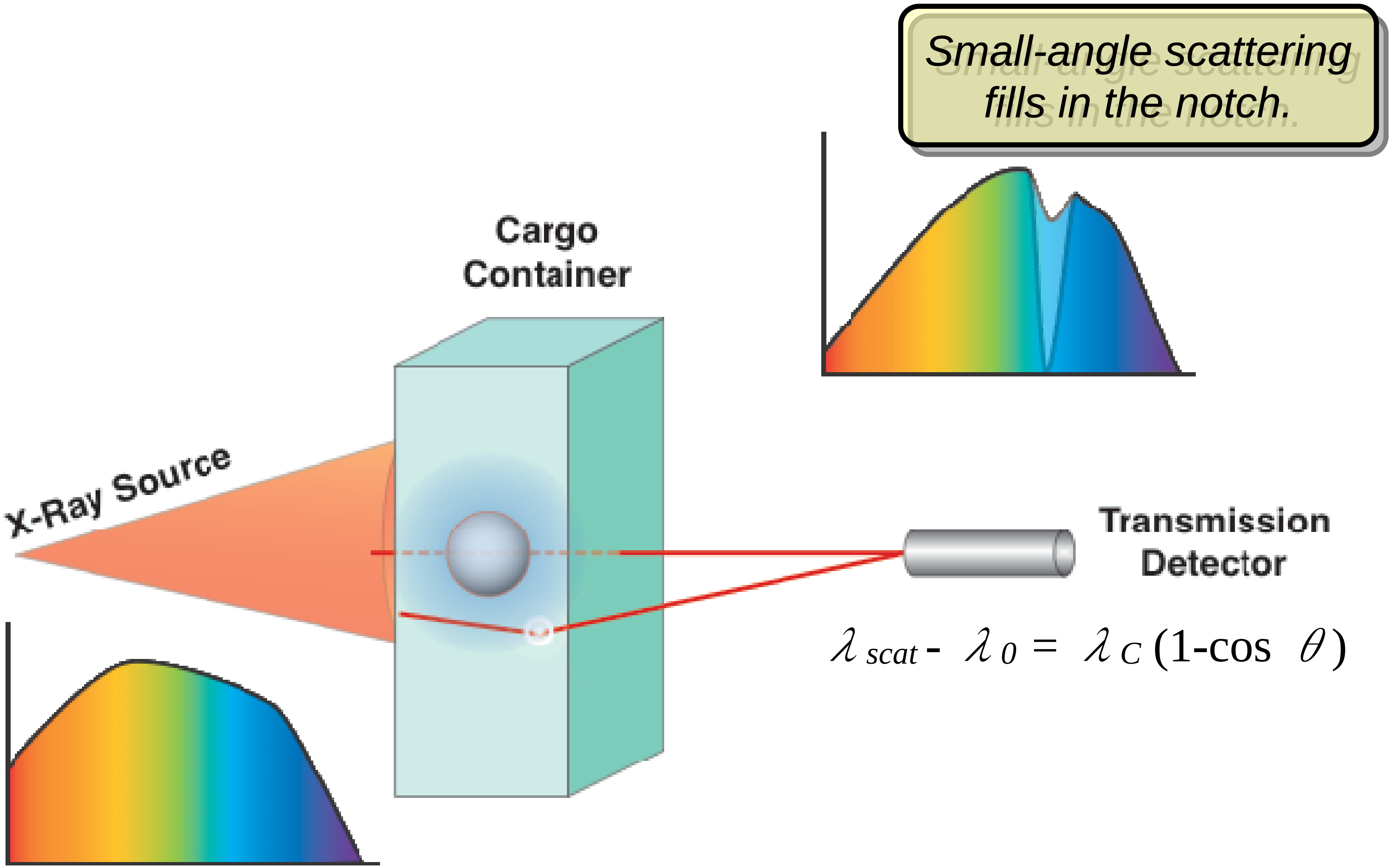
A systematic modeling effort was devoted to notch-refilling:
J. Pruet et al., to be submitted to J. Appl. Phys.

Notch Filling from Scattering



Notch refilling is small collimated sources

Notch detection: *Solid-angle matters*



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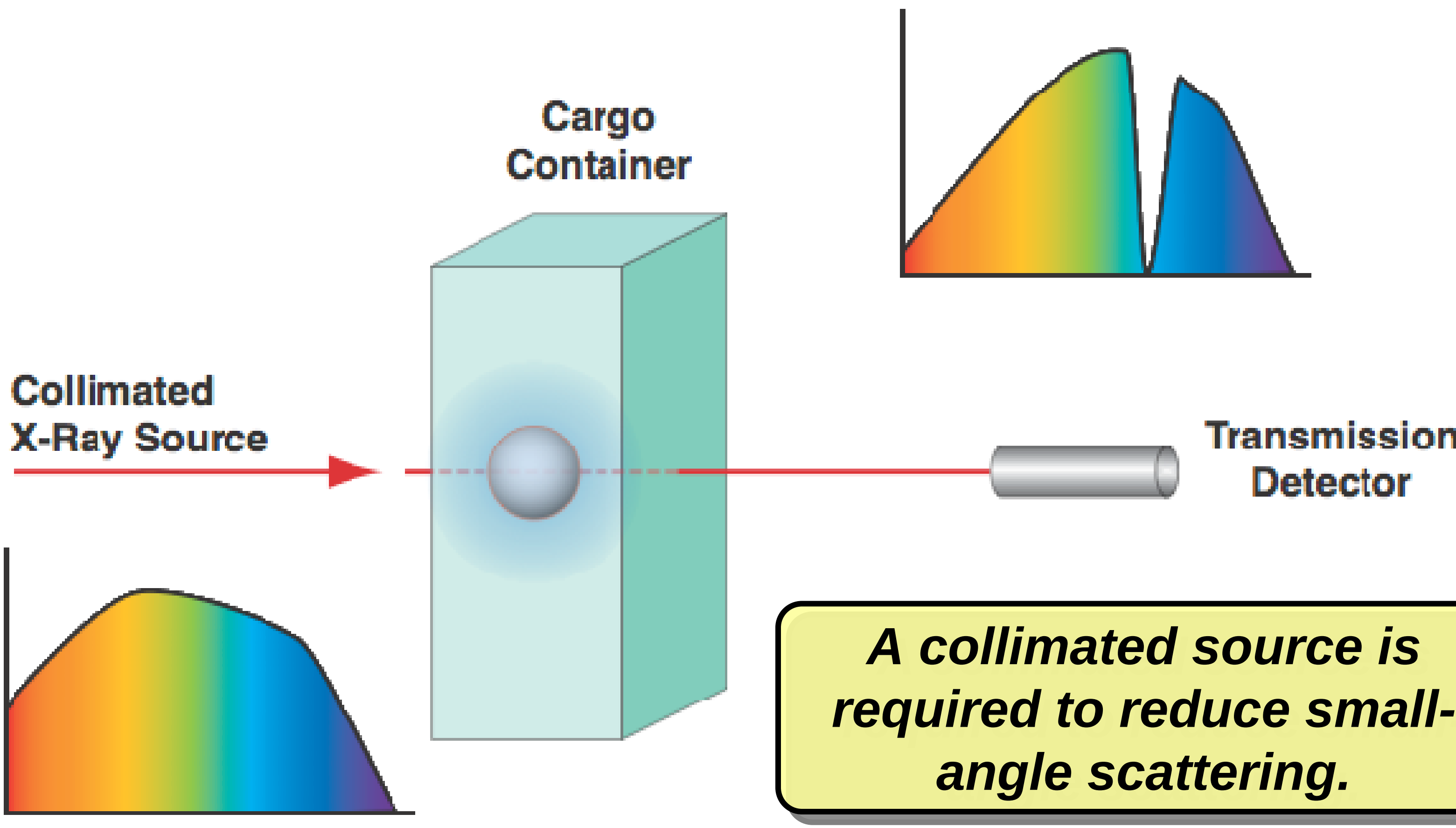
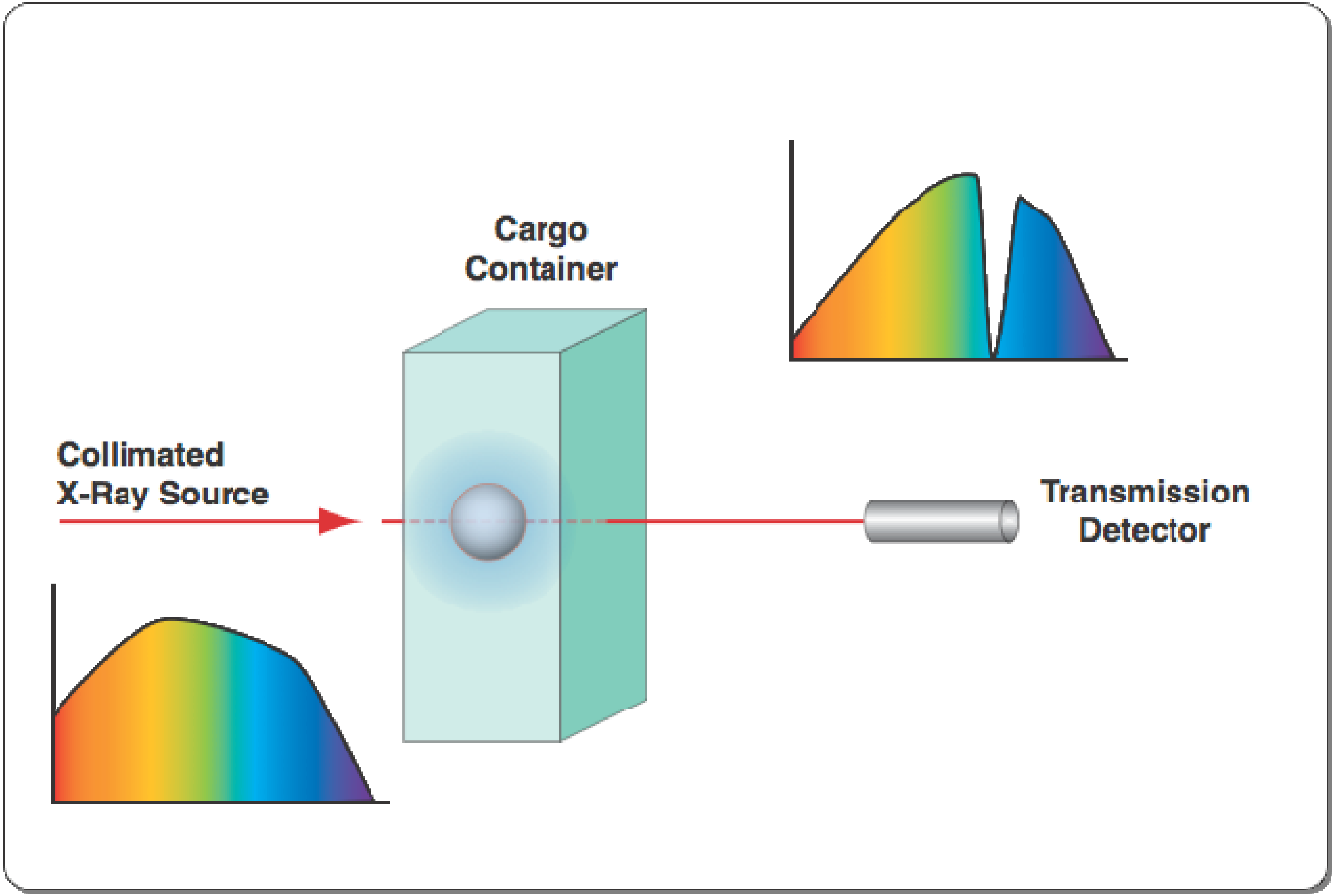


A collimated source is required to reduce small-angle scattering.

Notch Detection: *Direct Spectroscopy Fails*



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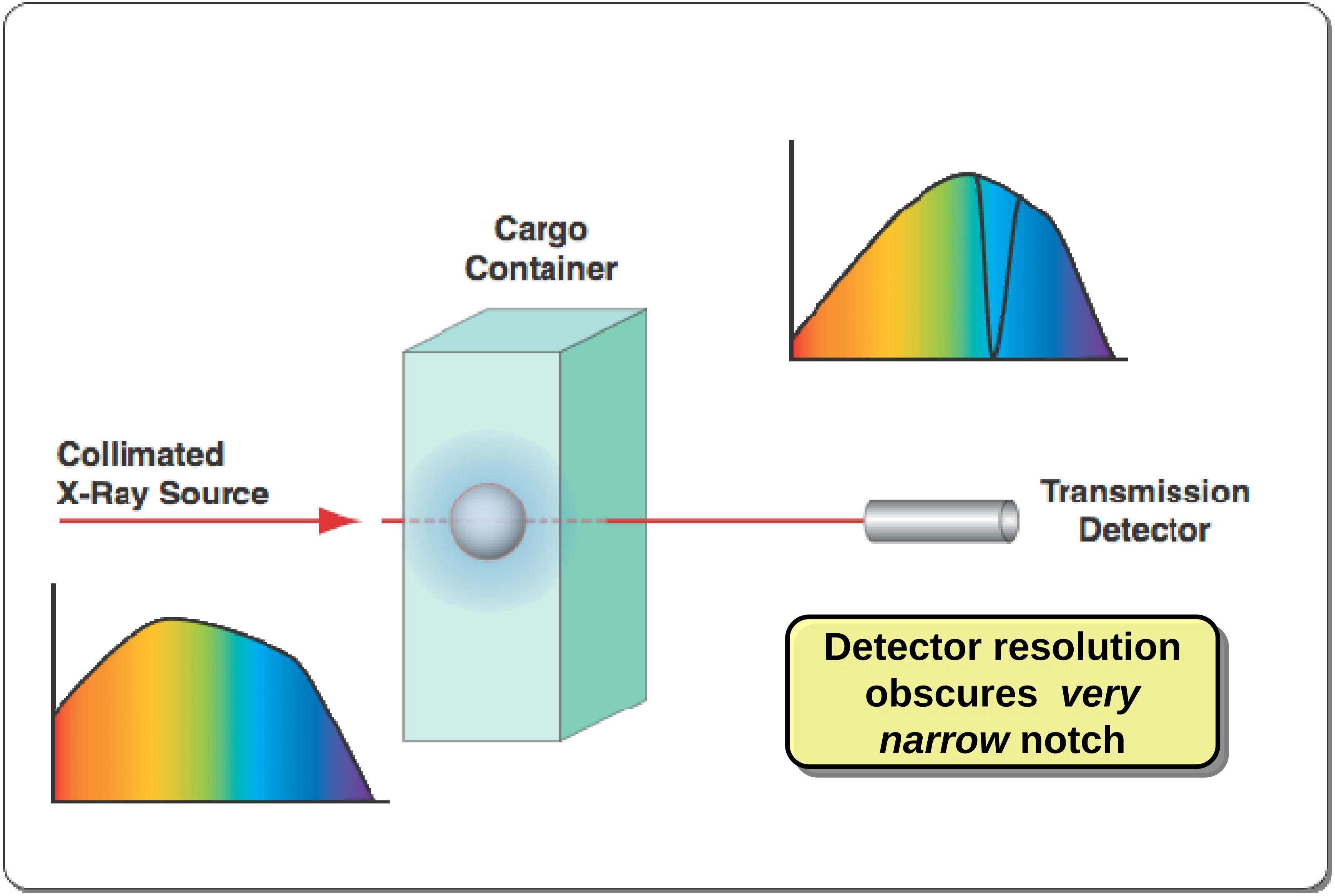
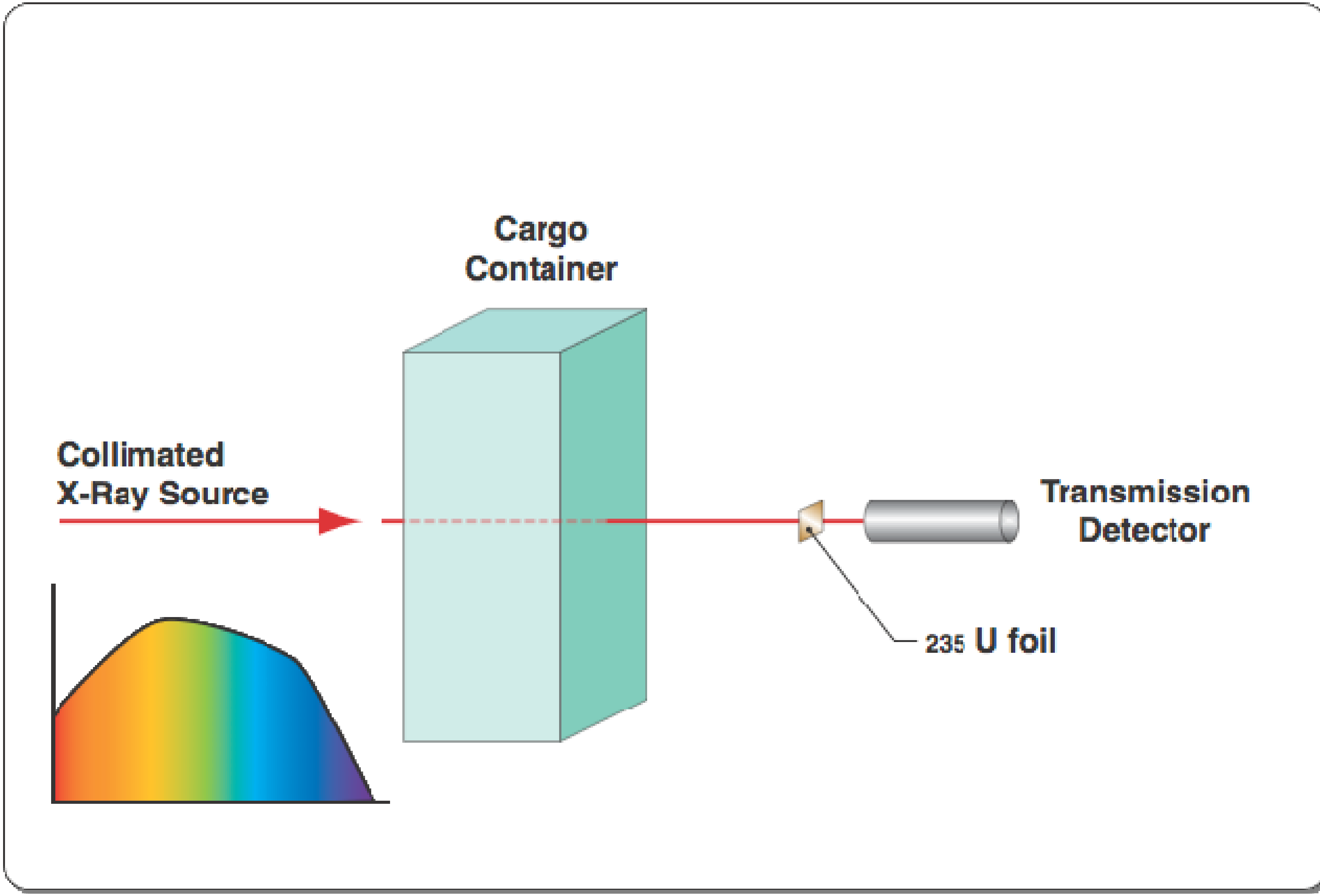


Notch Detection: *Bertozzi Method*



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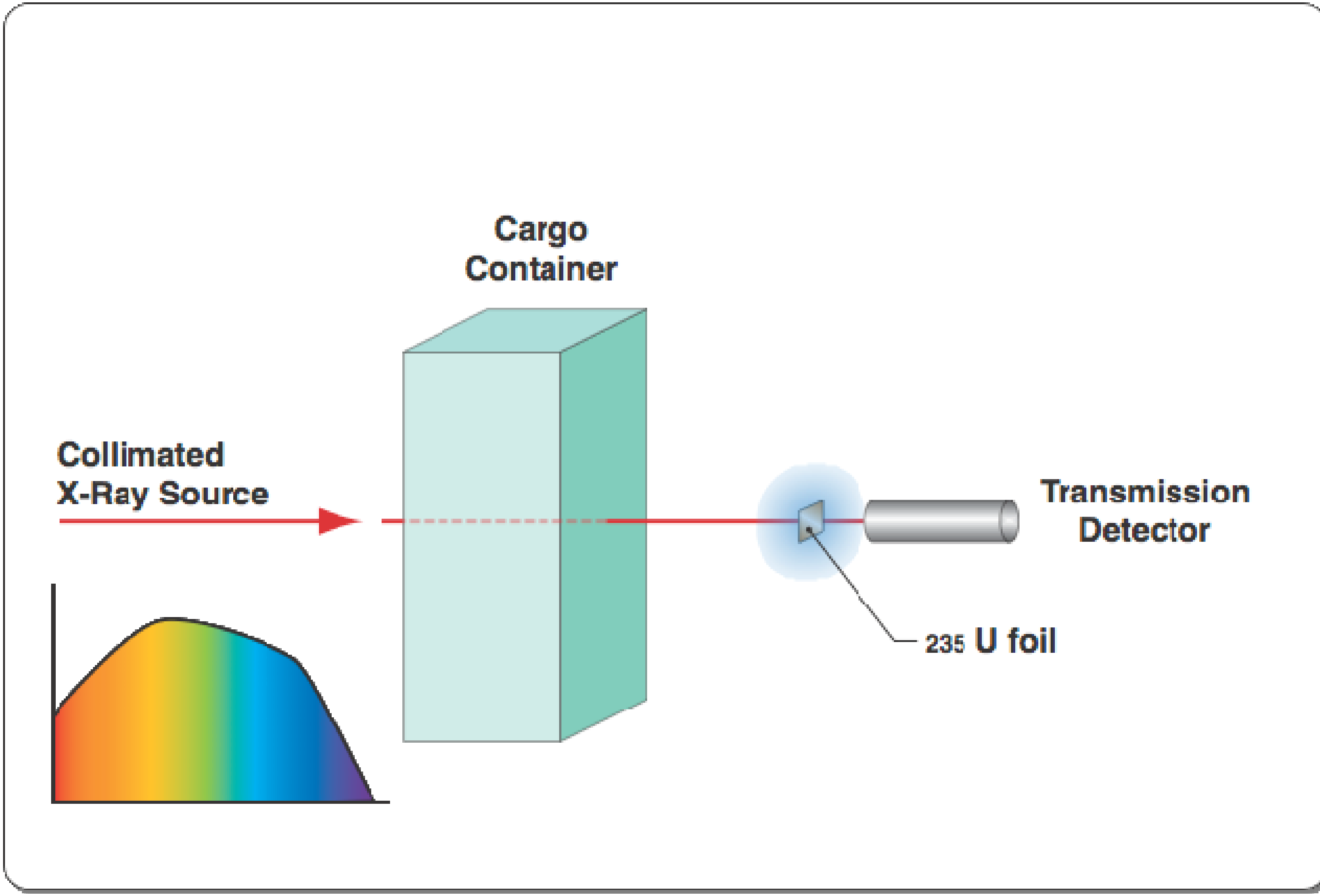

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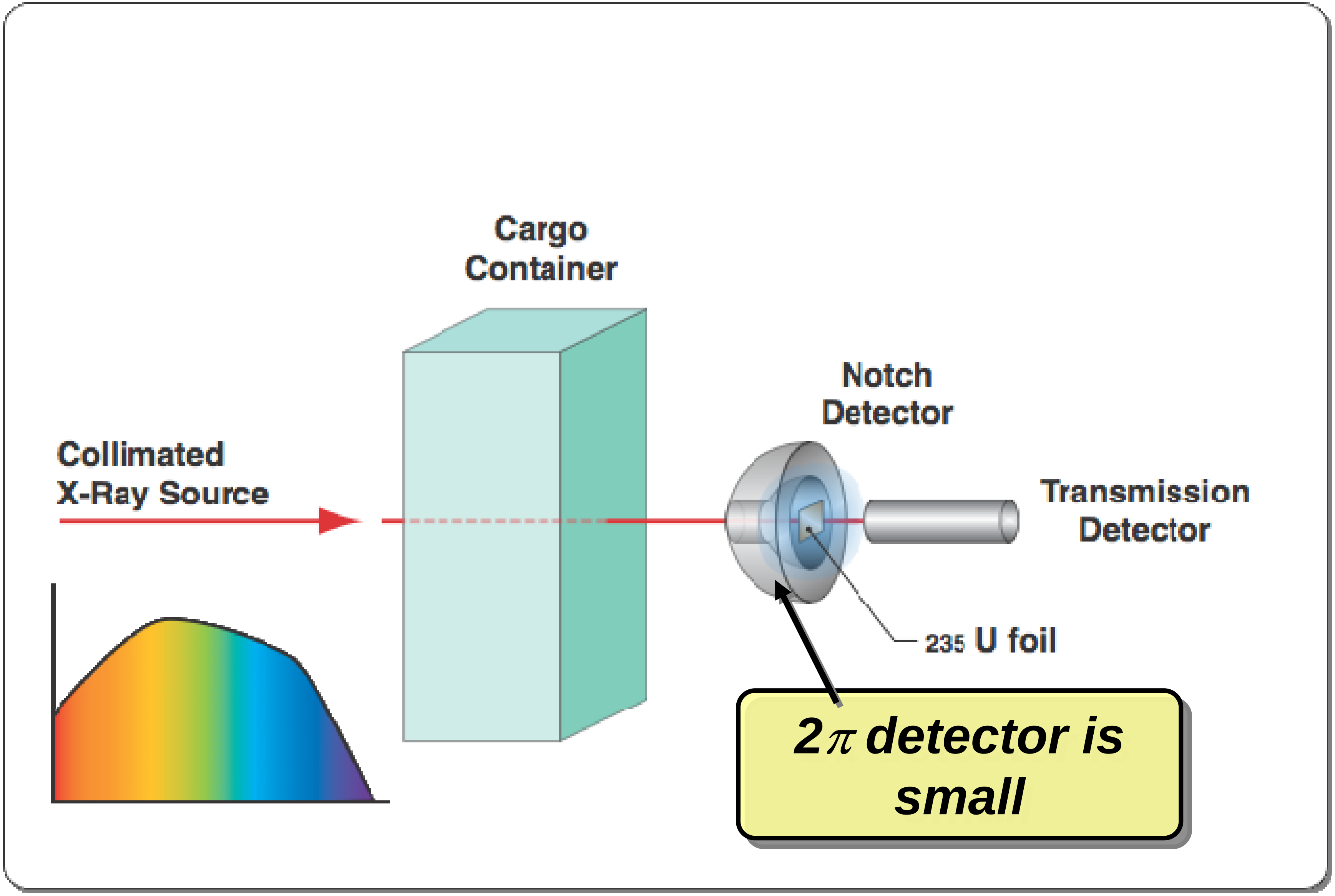

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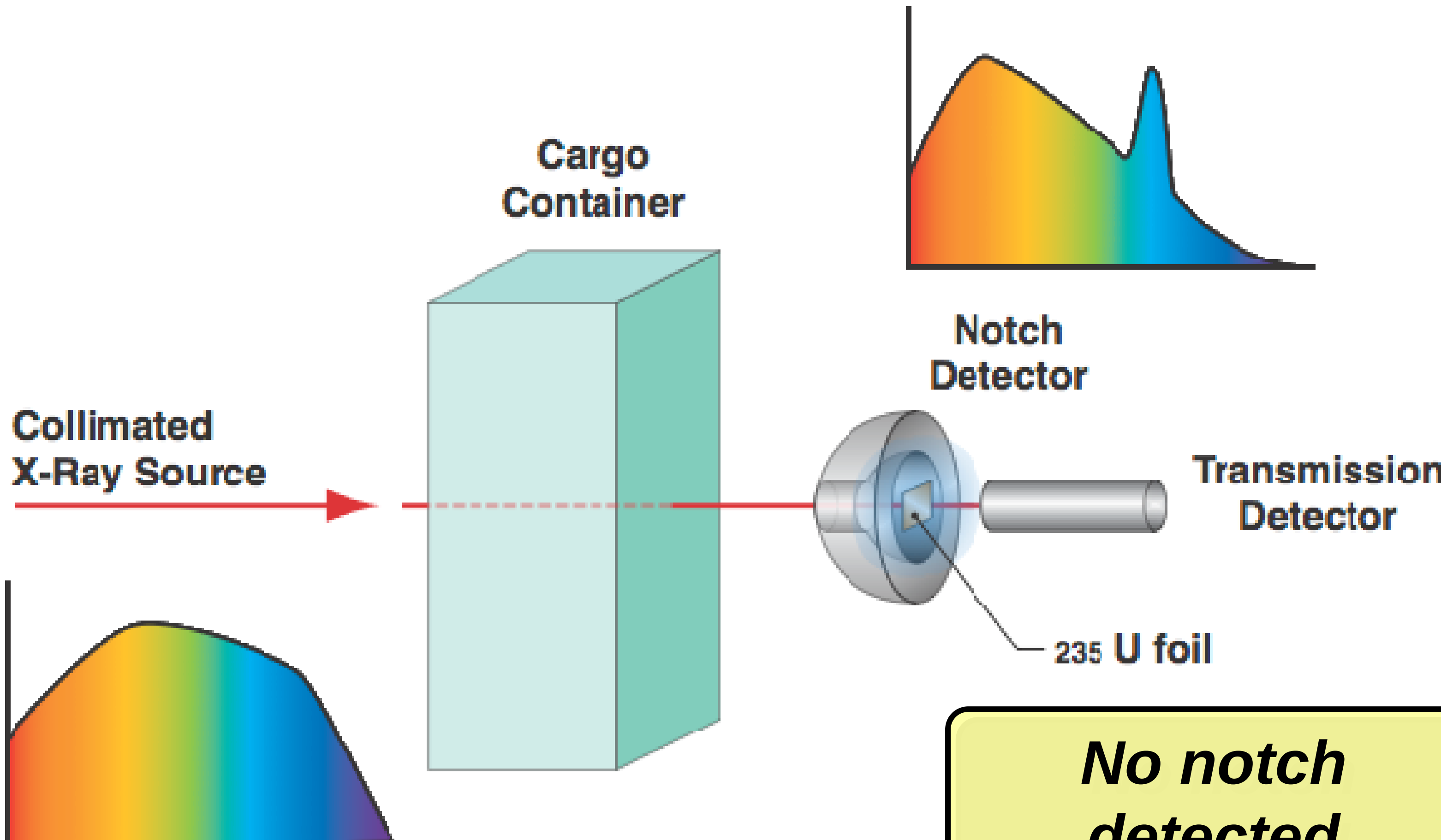
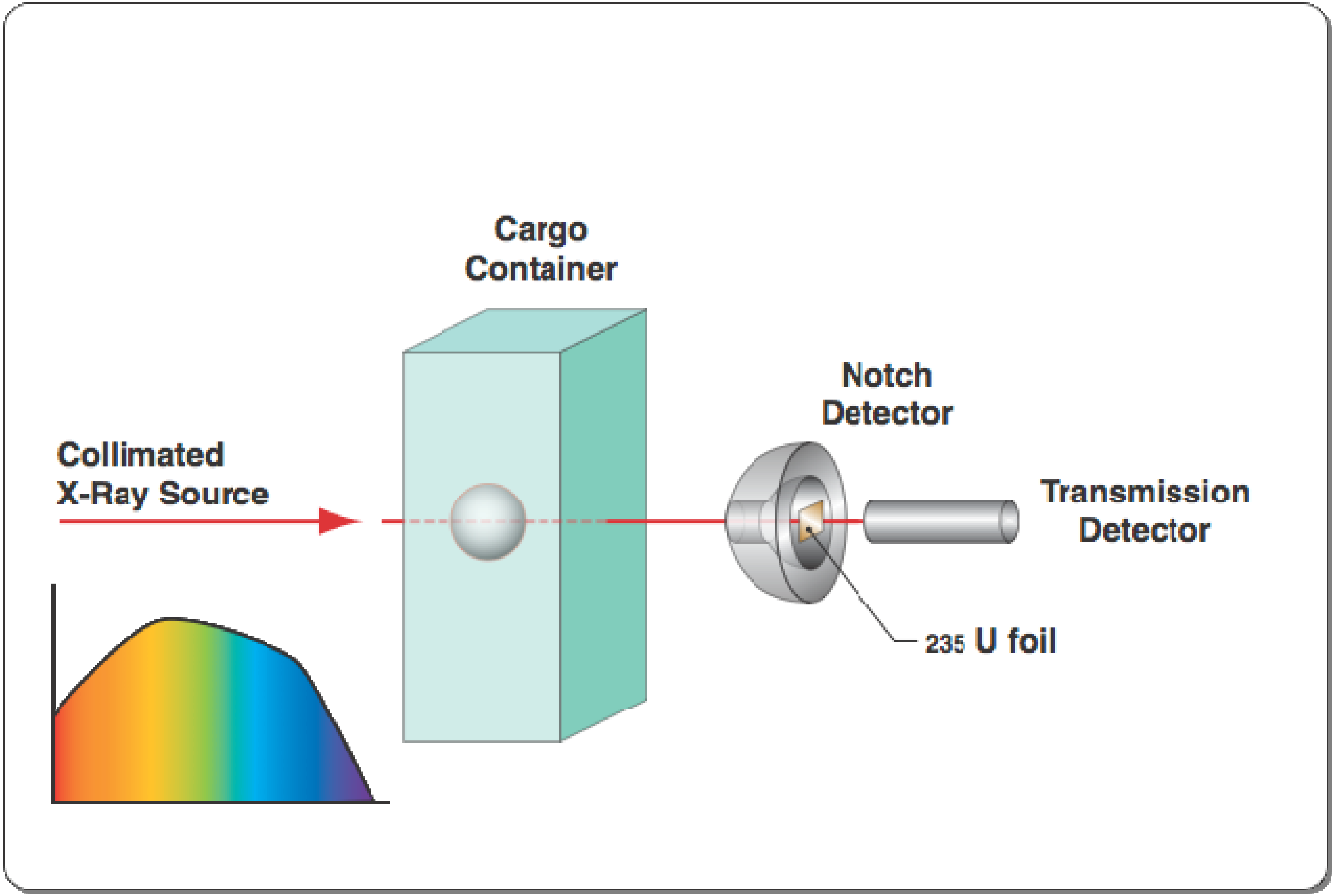


No notch detected

Notch Detection: *Bertozzi Method*



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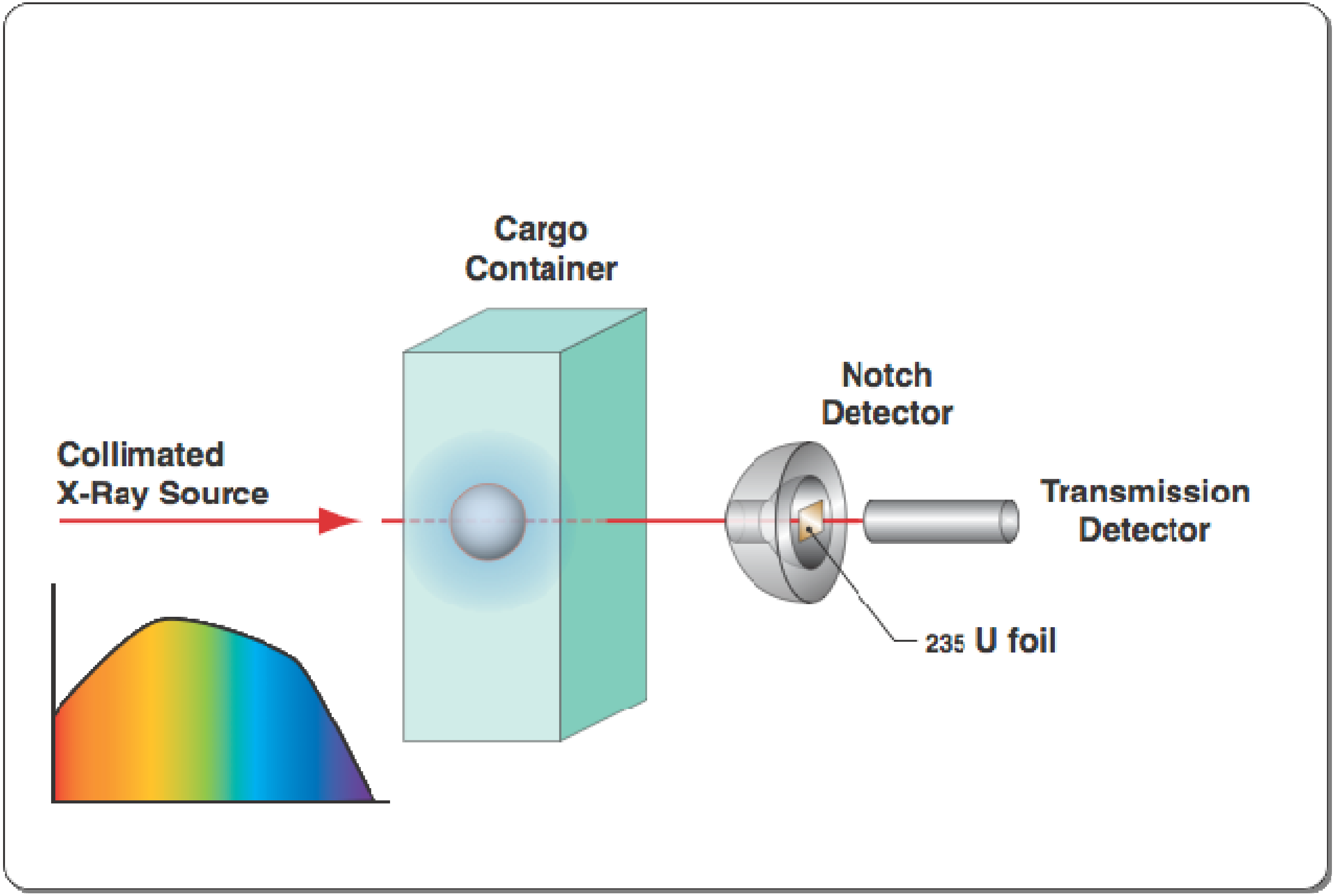

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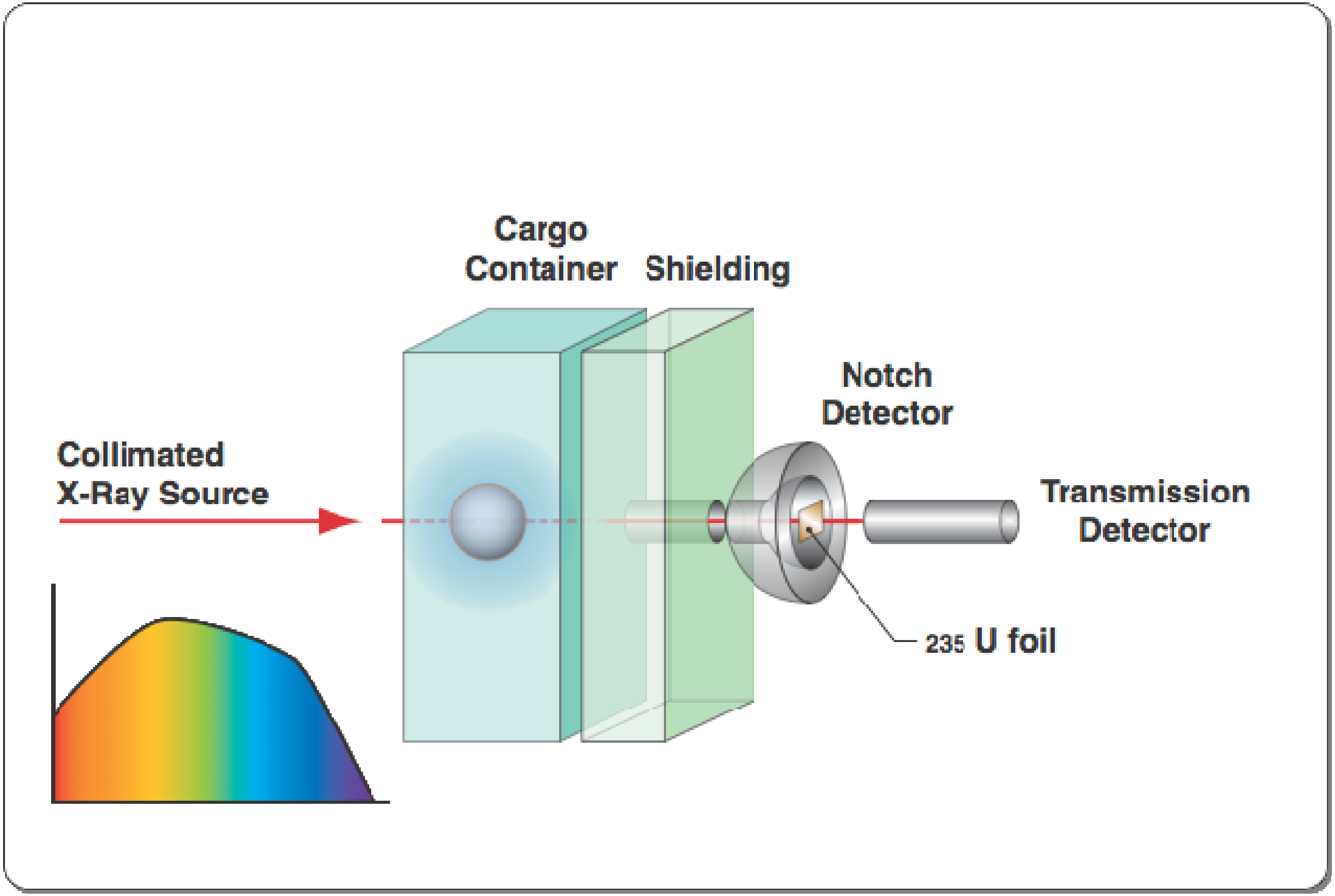

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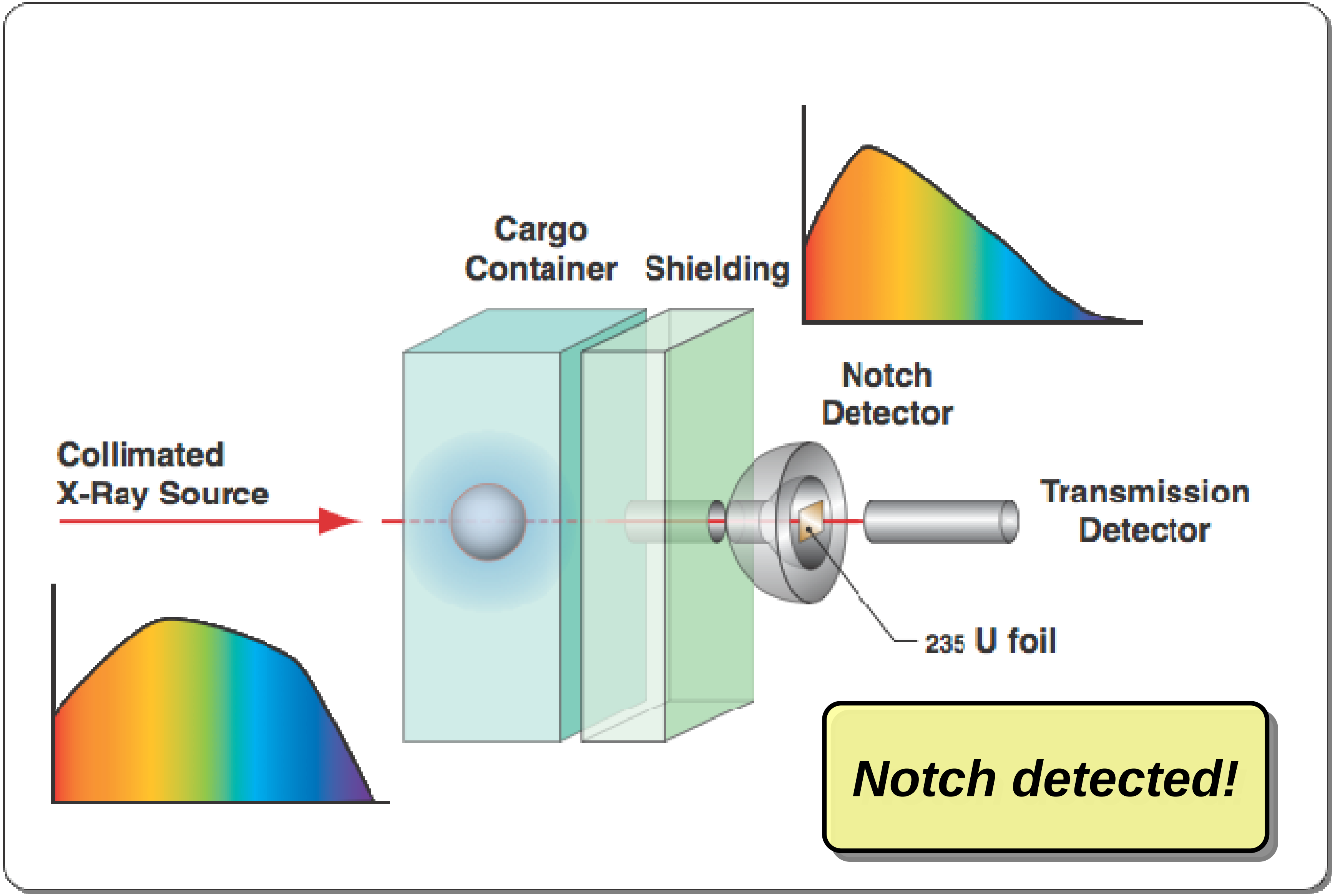

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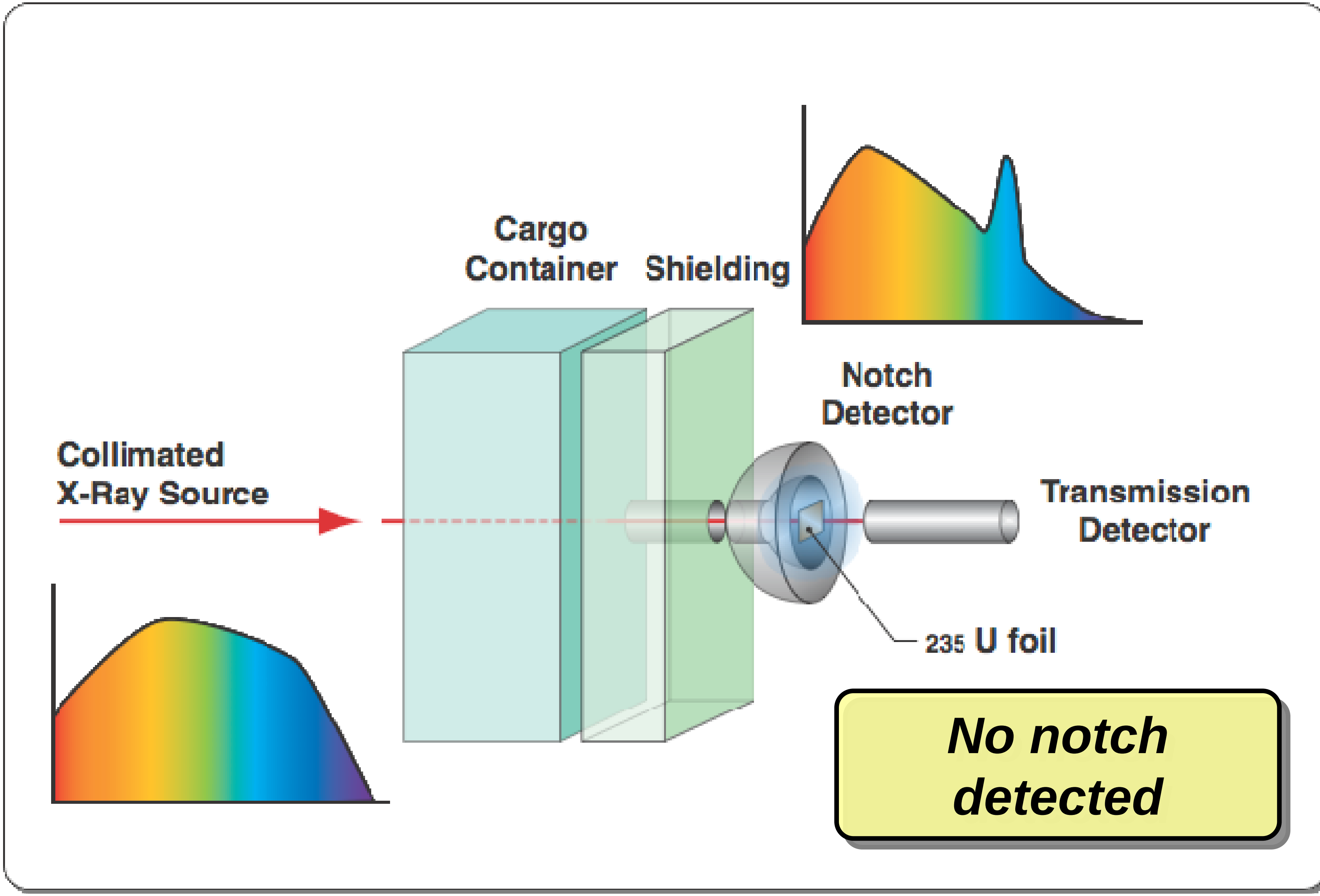

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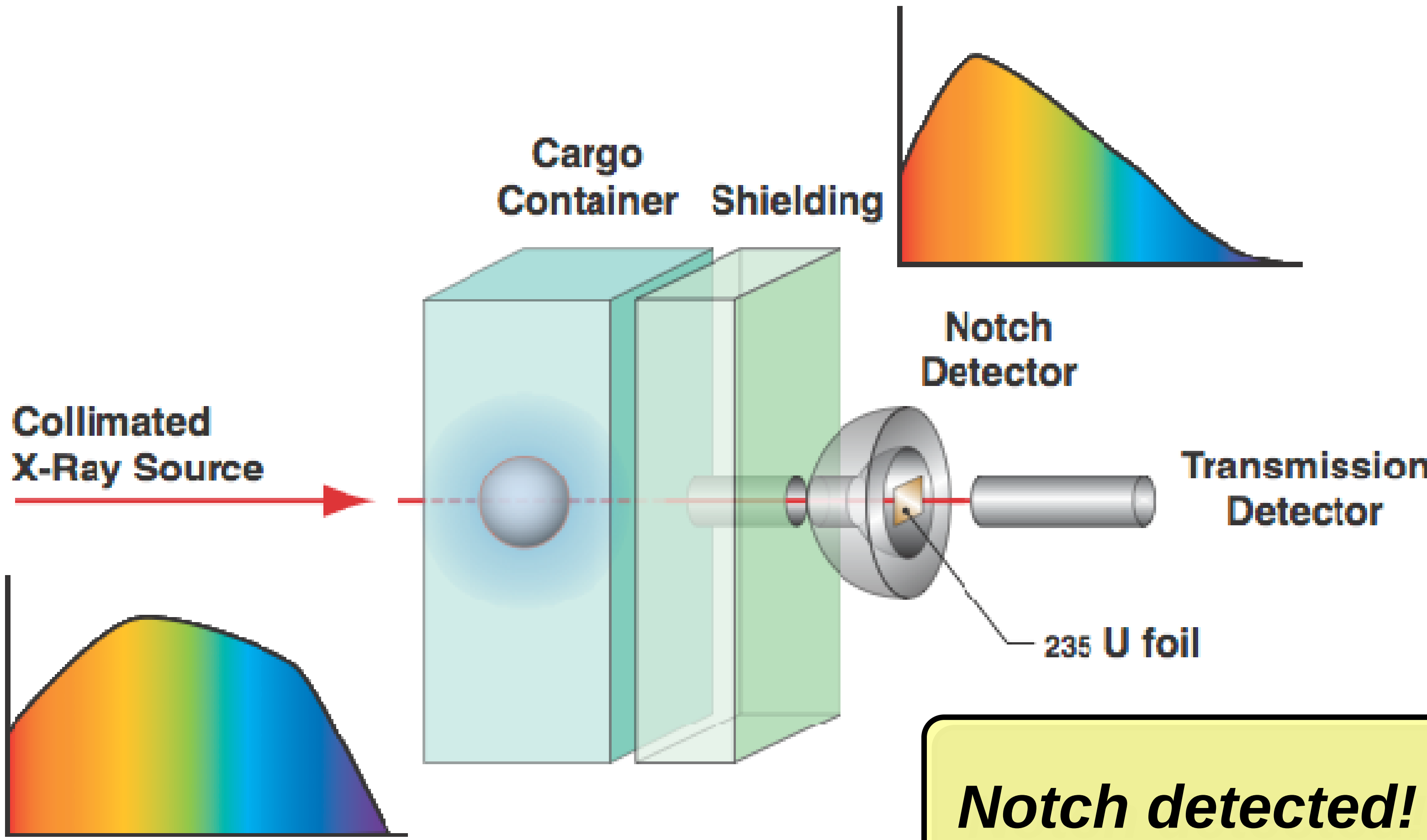
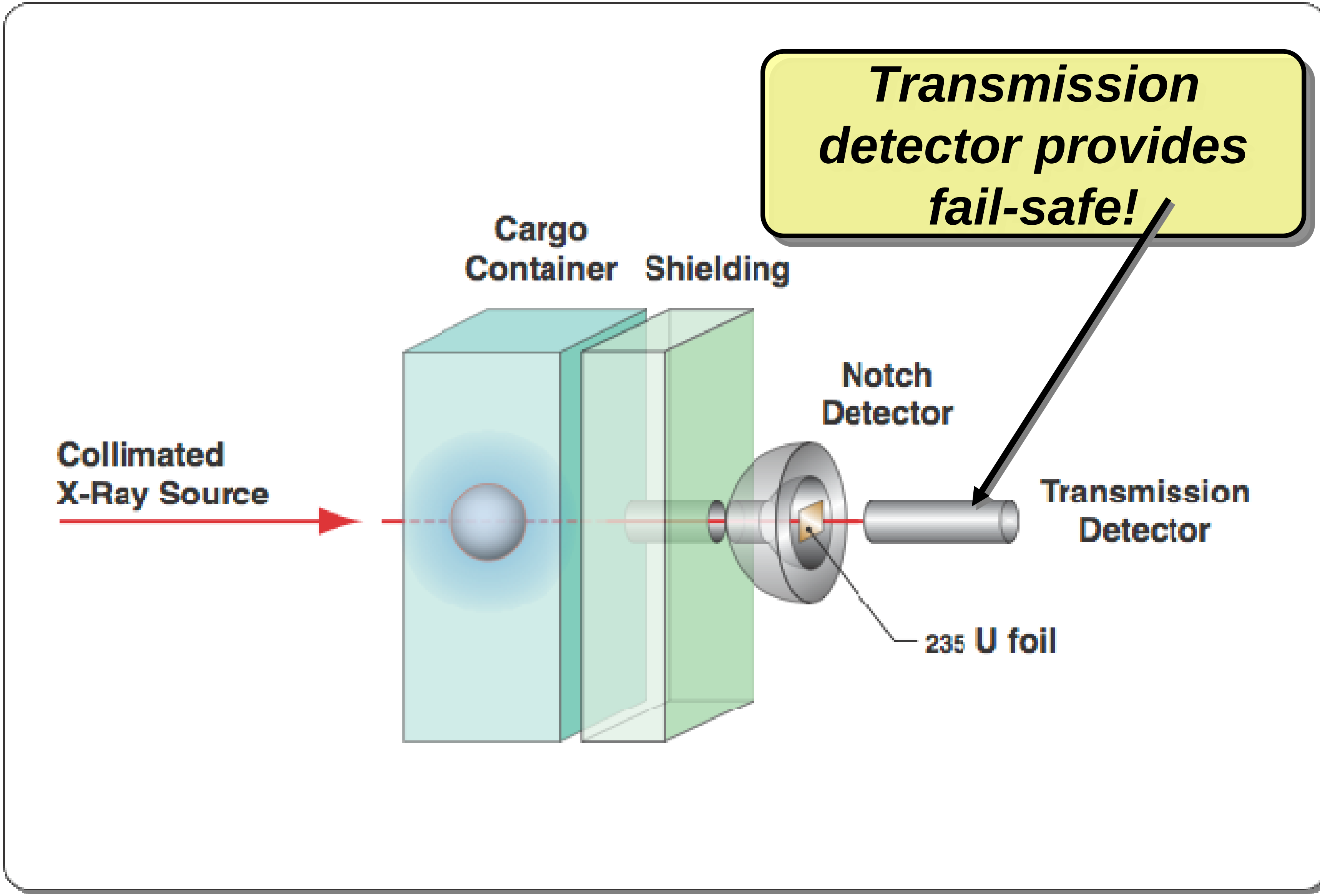
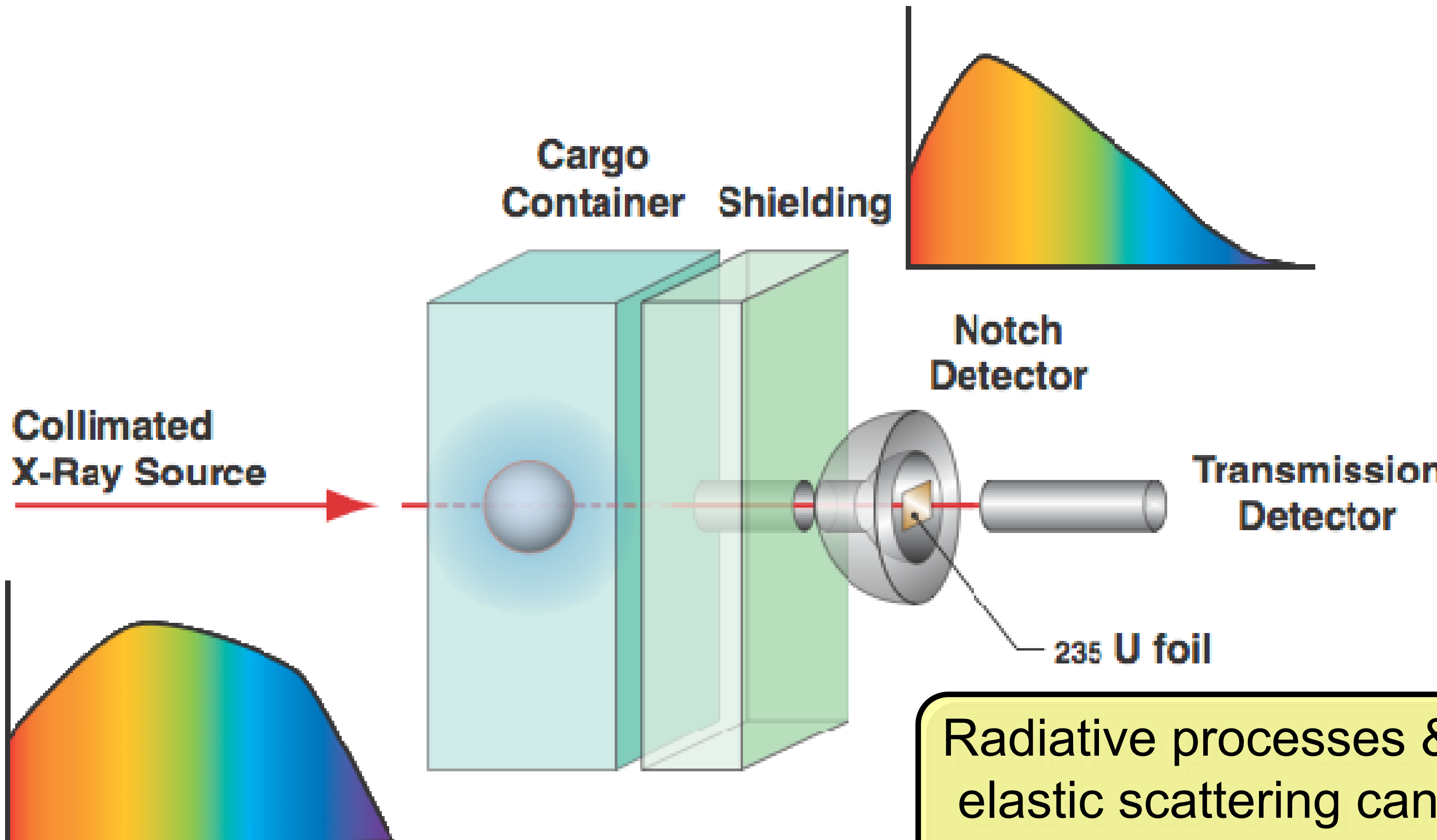


Notch detected!

Notch Detection: *You know when you don't know*



Notch Detection: *Bandwidth matters*



Radiative processes & elastic scattering can add background

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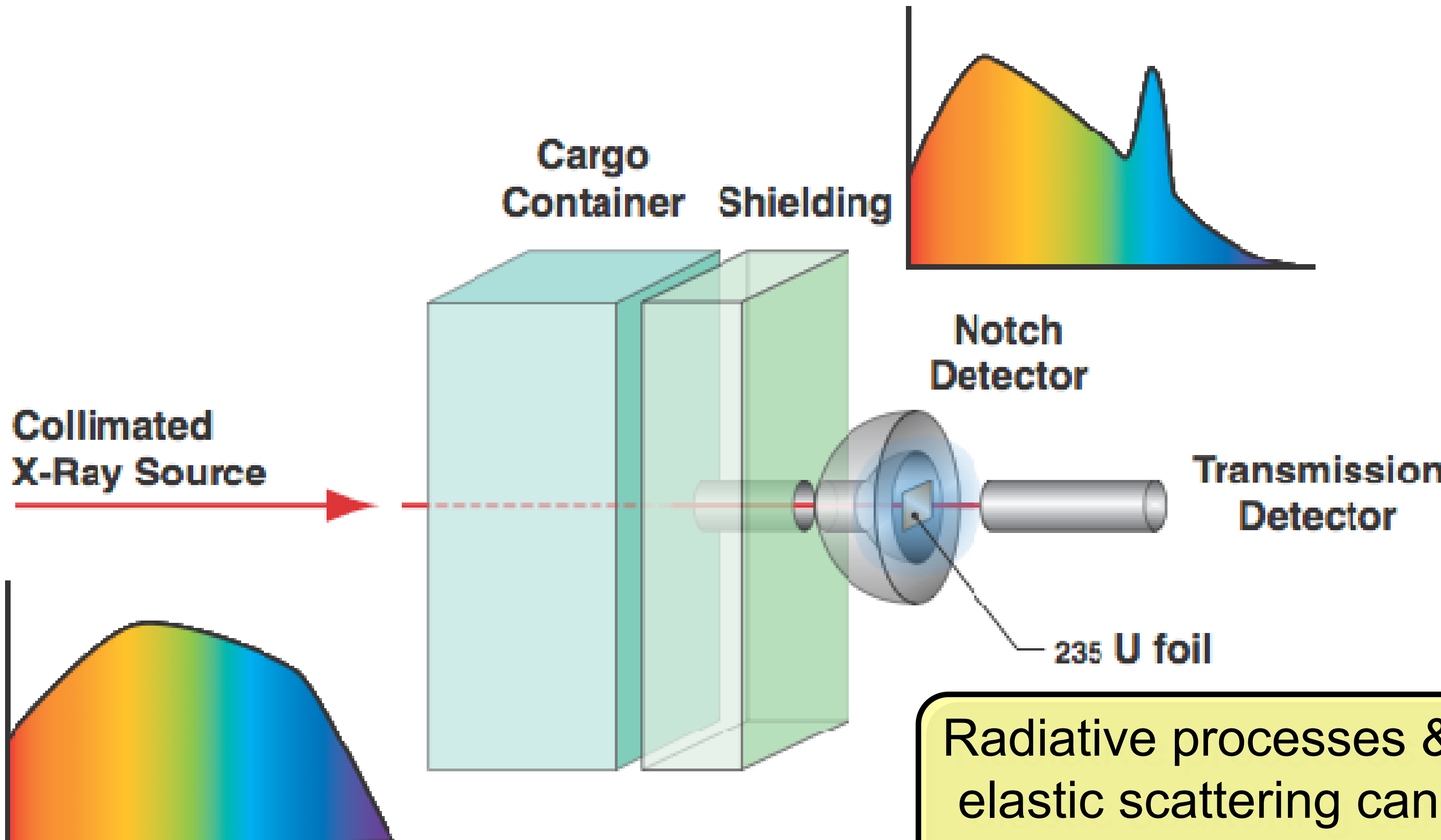

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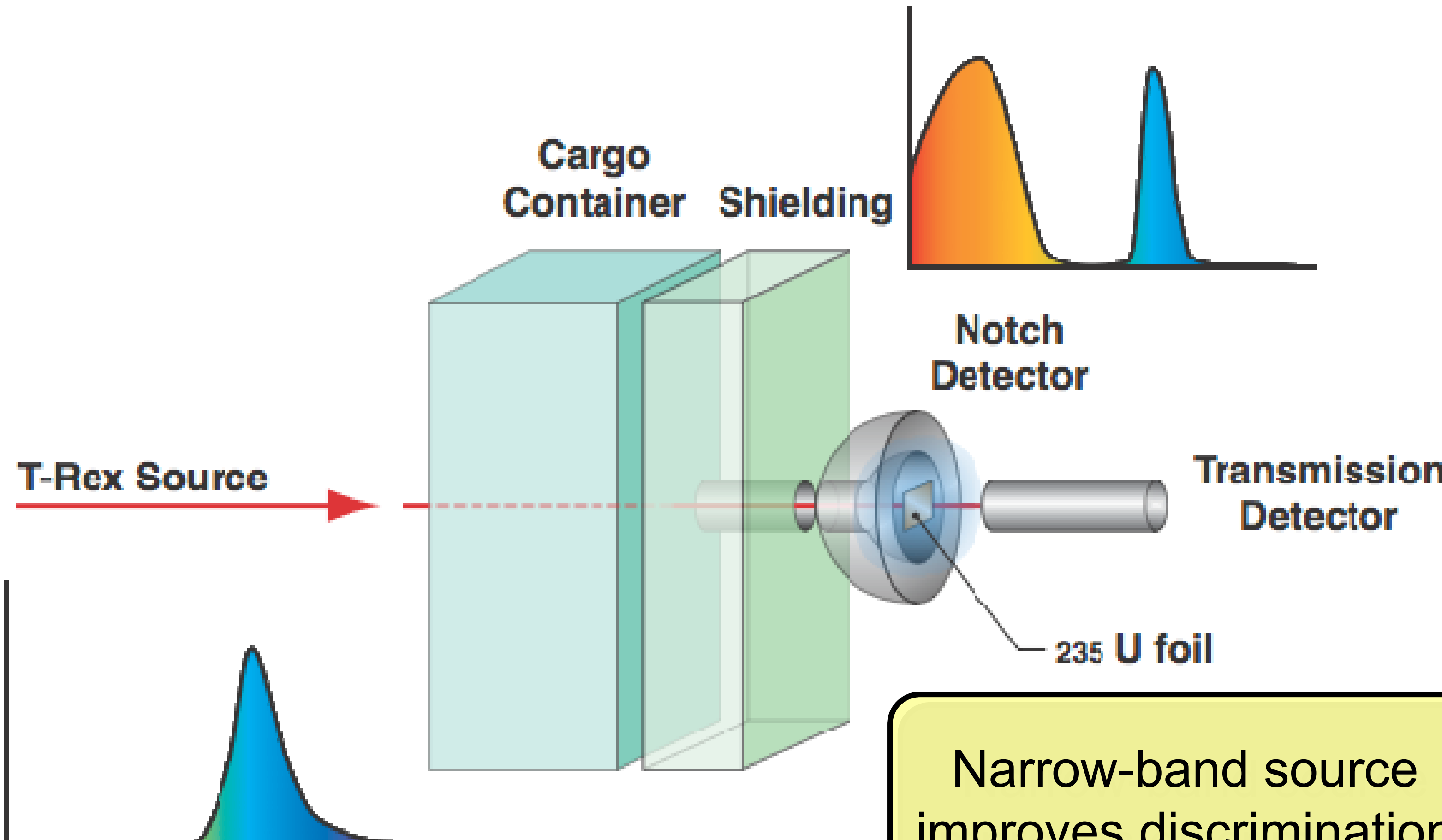
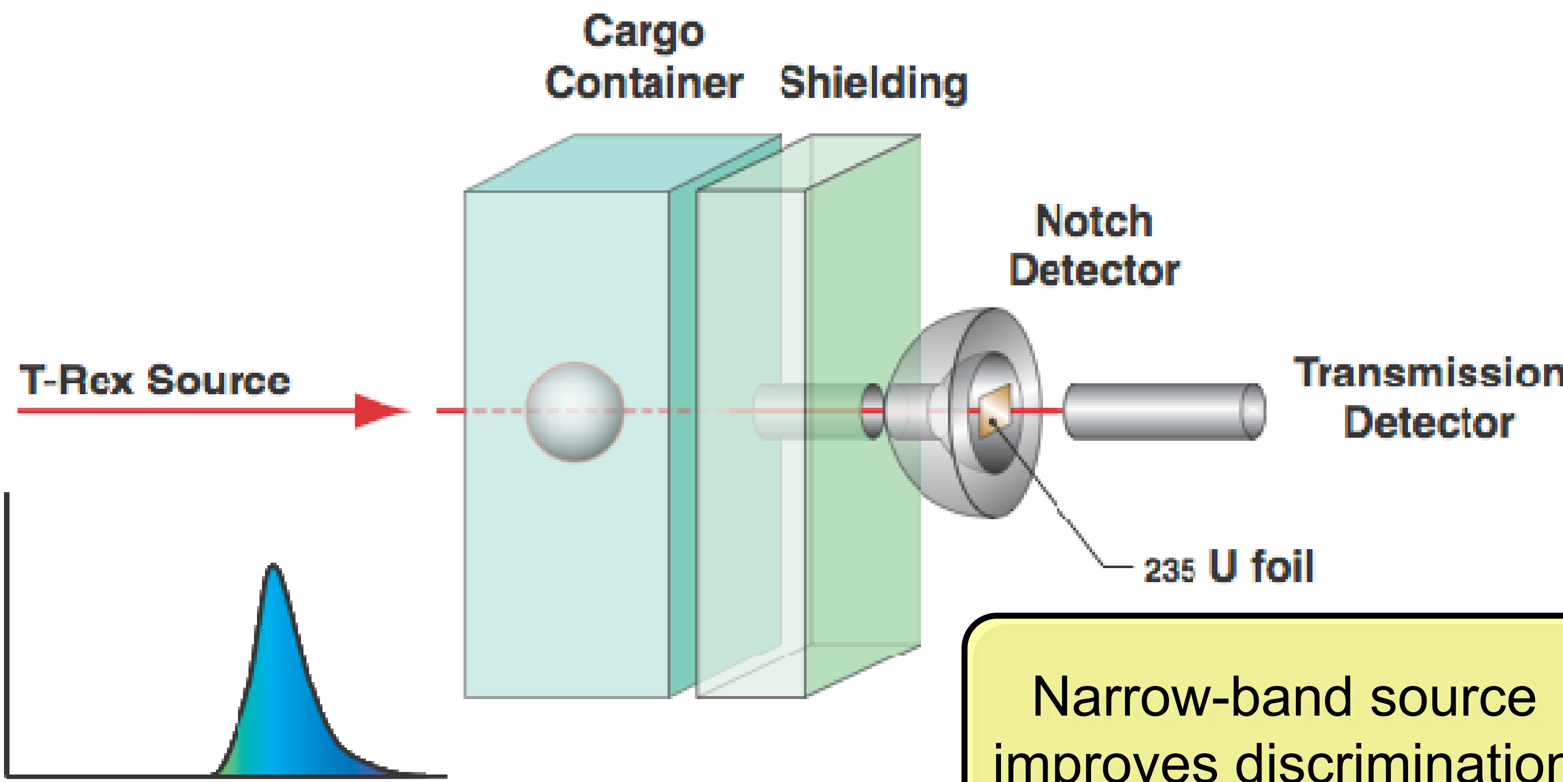


Real bandwidth: 0.1%

Narrow-band source improves discrimination

Notch Detection: *Bandwidth matters*



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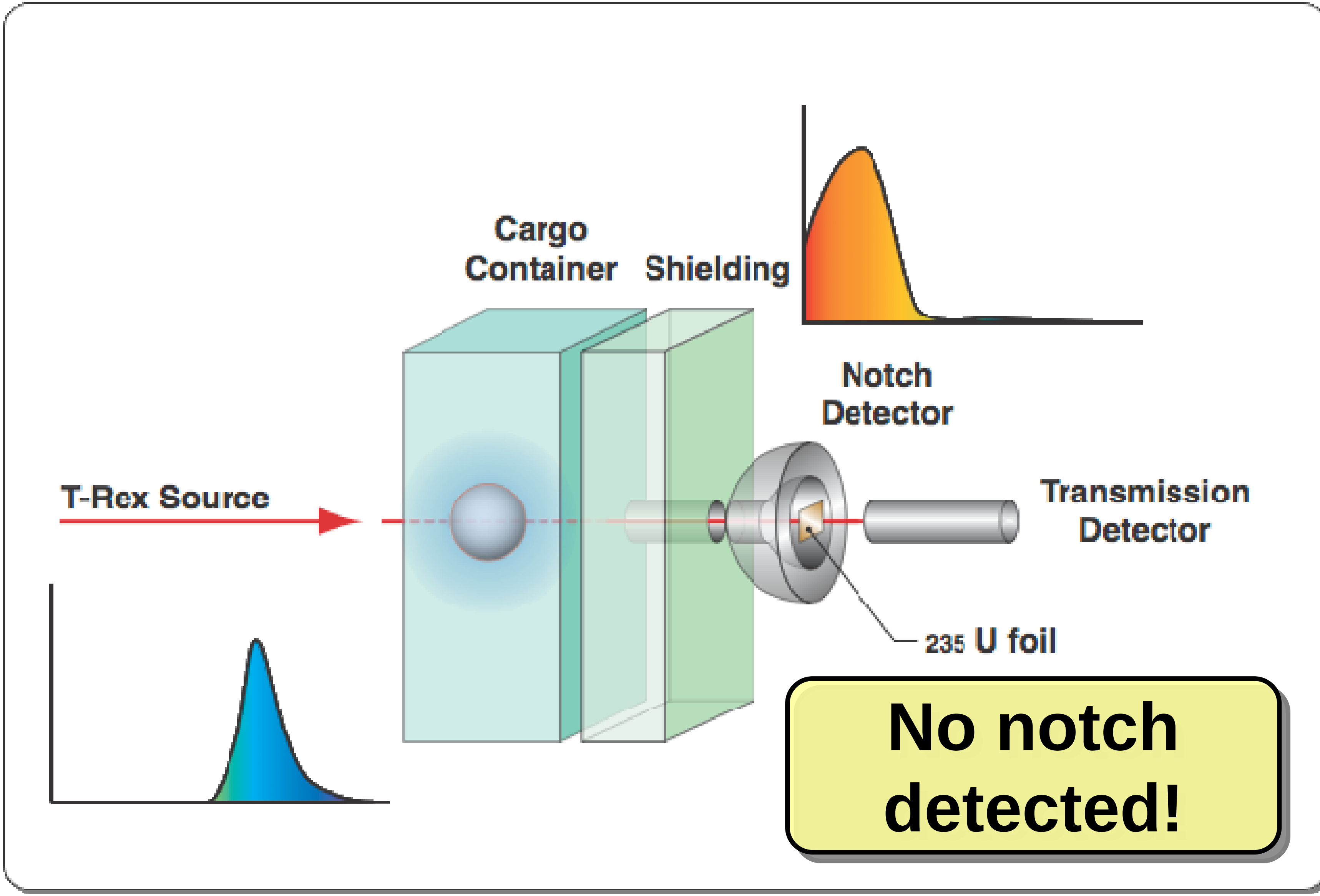
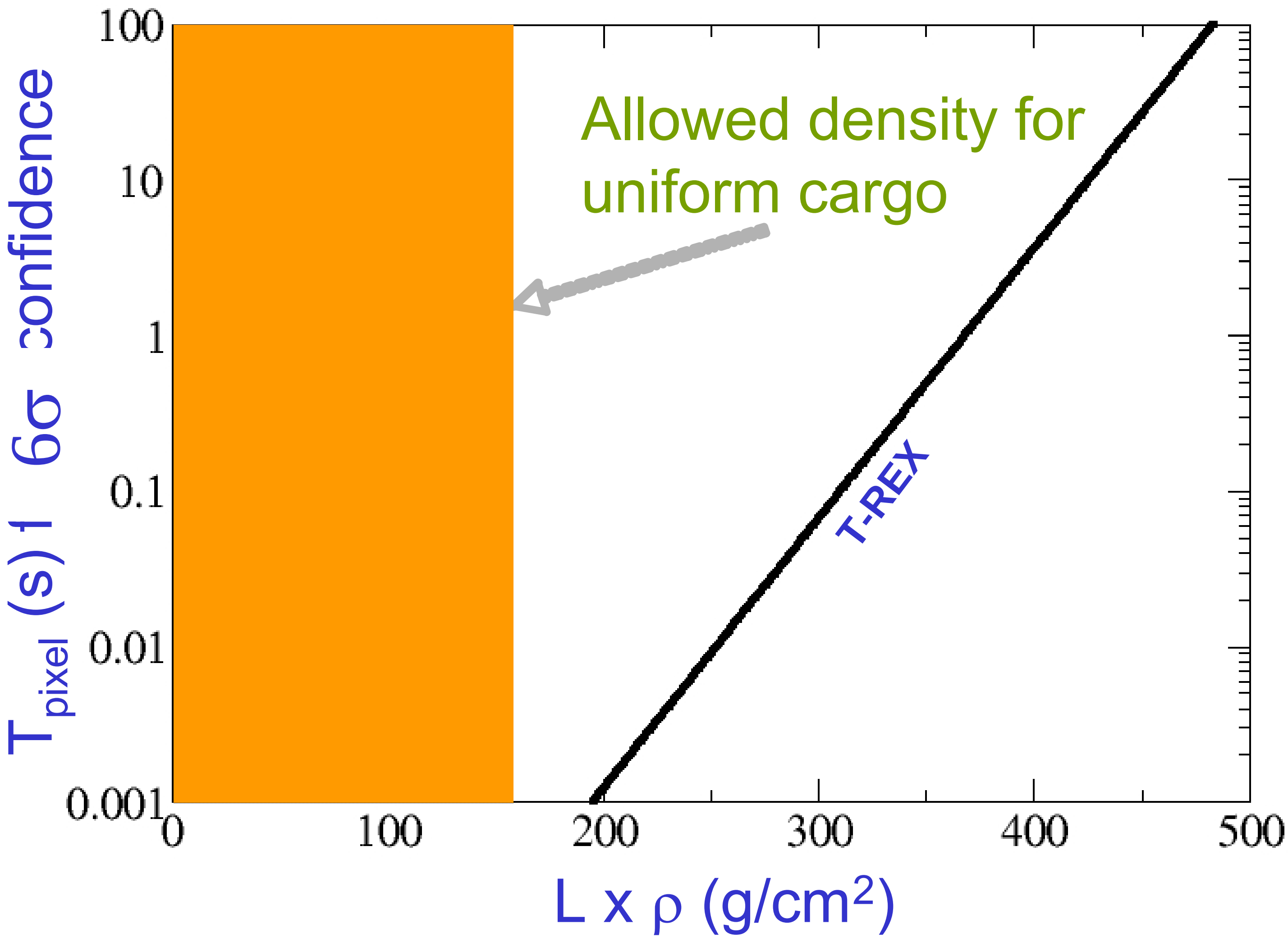


There are several reasons for including these resonances in ENDF/B

- Plenty of applications use bremsstrahlung sources to irradiate materials
  - Being able to model these processes is useful
- Homeland security applications are front and center at the moment
  - Bertozzi and Ledoux have a DHS-funded company exploring technique
- Approach is generally useful for applications of material characterization
- First crack wouldn't be too hard
  - The known resonances are tabulated in ENSDF

T-REX + NRF enables rapid, accurate cargo inspection



• see McNabb & Pruet for detailed comparison with other techniques

Our ability to quantify the sensitivity of the technique speaks highly of concept and team

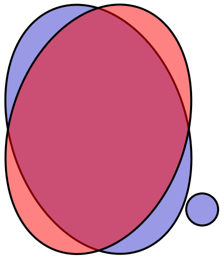
The intrinsic width of resonances is the key parameter determining the sensitivity of the method

- Scale set by the optical depth of attenuation on resonance

$$\frac{I_{res}}{I_{off-res}} \approx e^{-\Gamma_0/4\,meV} \approx e^{-10}$$

(for ^{238}U, Γ_0 ~ 40meV)

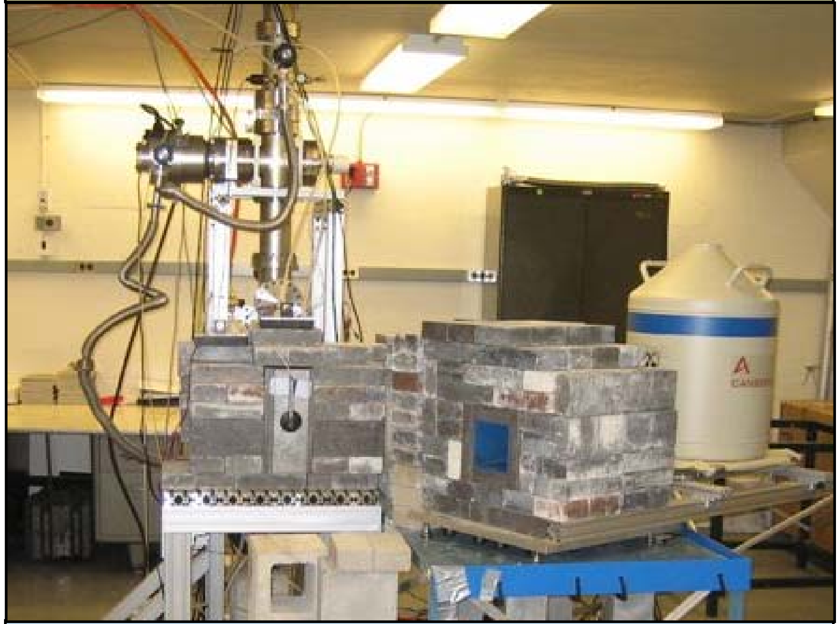
- Strength is fragmented in odd isotopes (by 15 worst case)
  Larger level density and number of substates
- Rare-earth region indicate fragmentation is ≈ 3 times less
  e.g. A. Nord et al., Phys. Rev. C67, 034307 (2003)



Our best guess is that the width of largest resonance in ^{235}U is ≈ 8 meV

We have established partnerships for NRF measurements with interested collaborators

Passport Systems

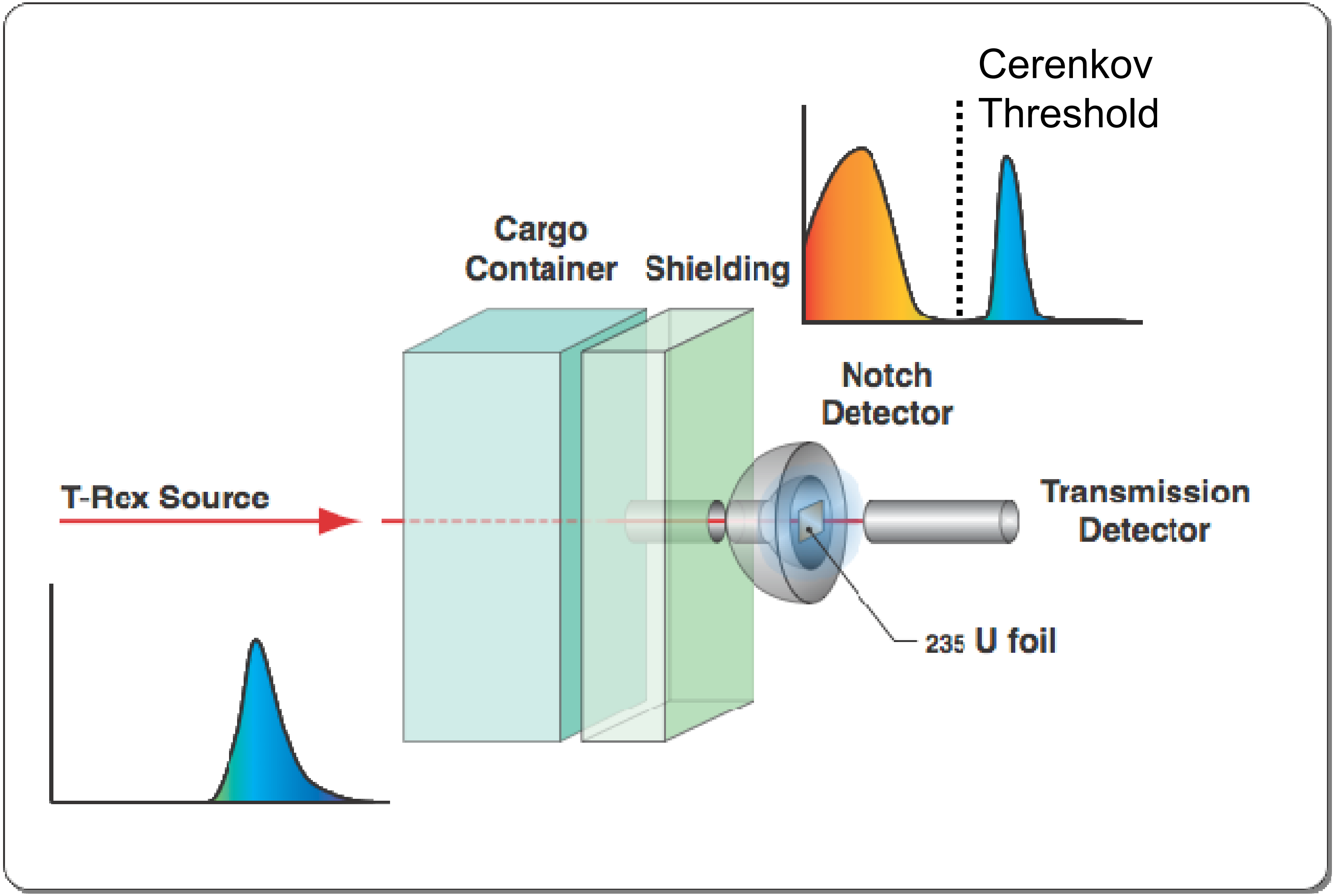


- HSARPA-funded company pursuing NRF imaging technologies (broadband)
- NDA has been signed
- NRF end station at MIT's High Voltage Research Laboratory
- CW machine at ≈ 3 MeV

Idaho Accelerator Center

- User facility with well-shielded experimental halls at Idaho State U.
- MOU has been signed
- Interested in applications to Advanced Fuel Cycle Initiative
- 1-kHz machines at 3-6 MeV

Notch Detection: *Cheap and easy with T-REX*



Notch Detection: *Cheap and easy with T-REX*