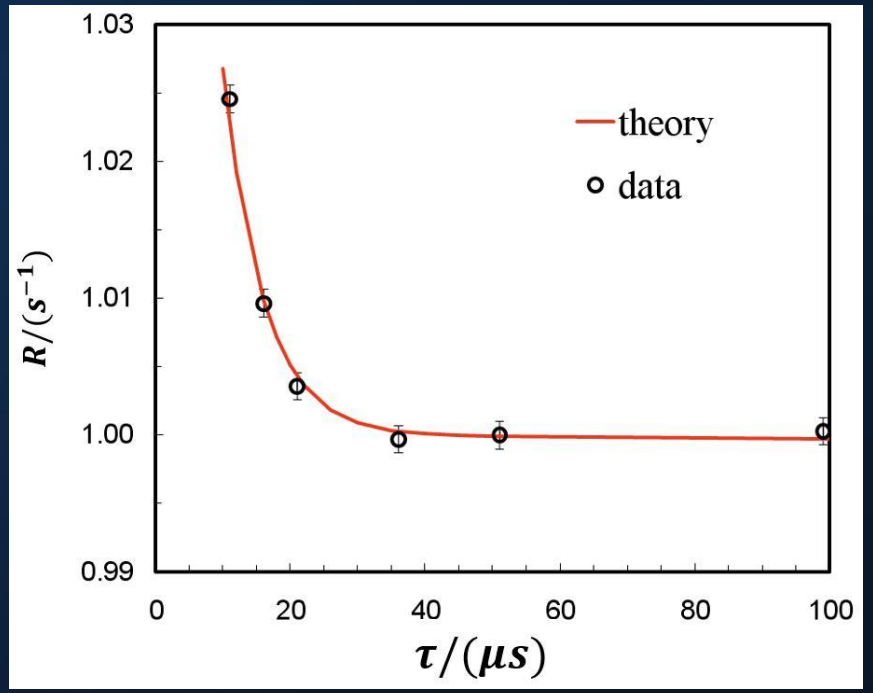
The metrology of quantities which can be counted in radionuclide metrology



https://doi.org/10.1016/j.apradiso.2010.01.007

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Radiation Physics Division
Physical Measurement Laboratory

National Institute of Standards and Technology
U.S. Department of Commerce

CCU/CCQM Workshop on "The metrology of quantities which can be counted"

Bureau International des Poids et Mesures

6 workshop questions for speakers

Question 1 of 6

What are the quantities within your technical discipline that relate to counting?

activity of a radionuclide

massic activity (ditto)

particle emission rate

particle emission probability

branching ratio

detection efficiency

count rate

minimum detectable activity

Question 2 of 6

Do you express your measurement results using the unit one or other SI units?

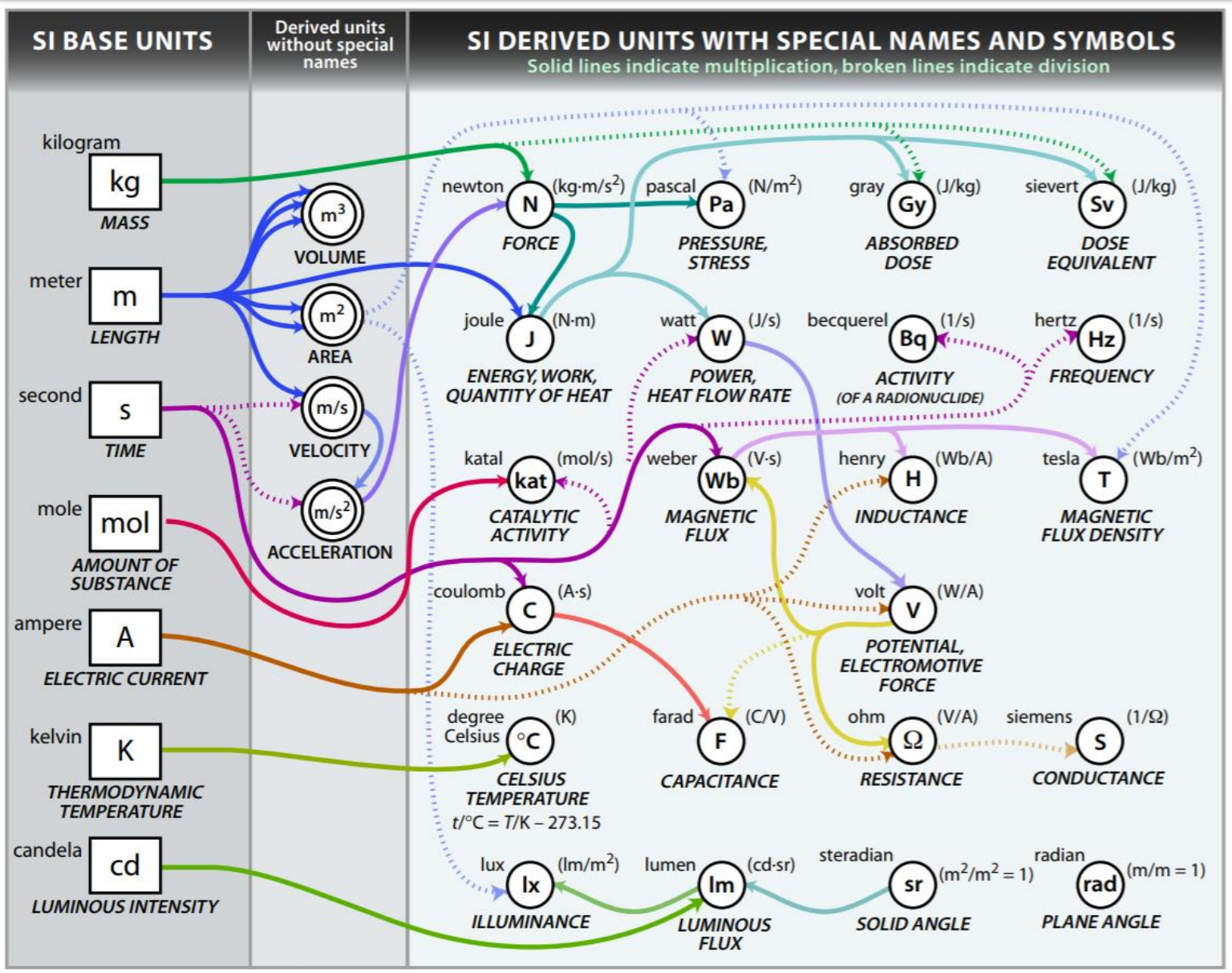
For activity of a radionuclide, we report the SI derived unit, becquerel, which is equivalent to (1/s).

What are the reasons?

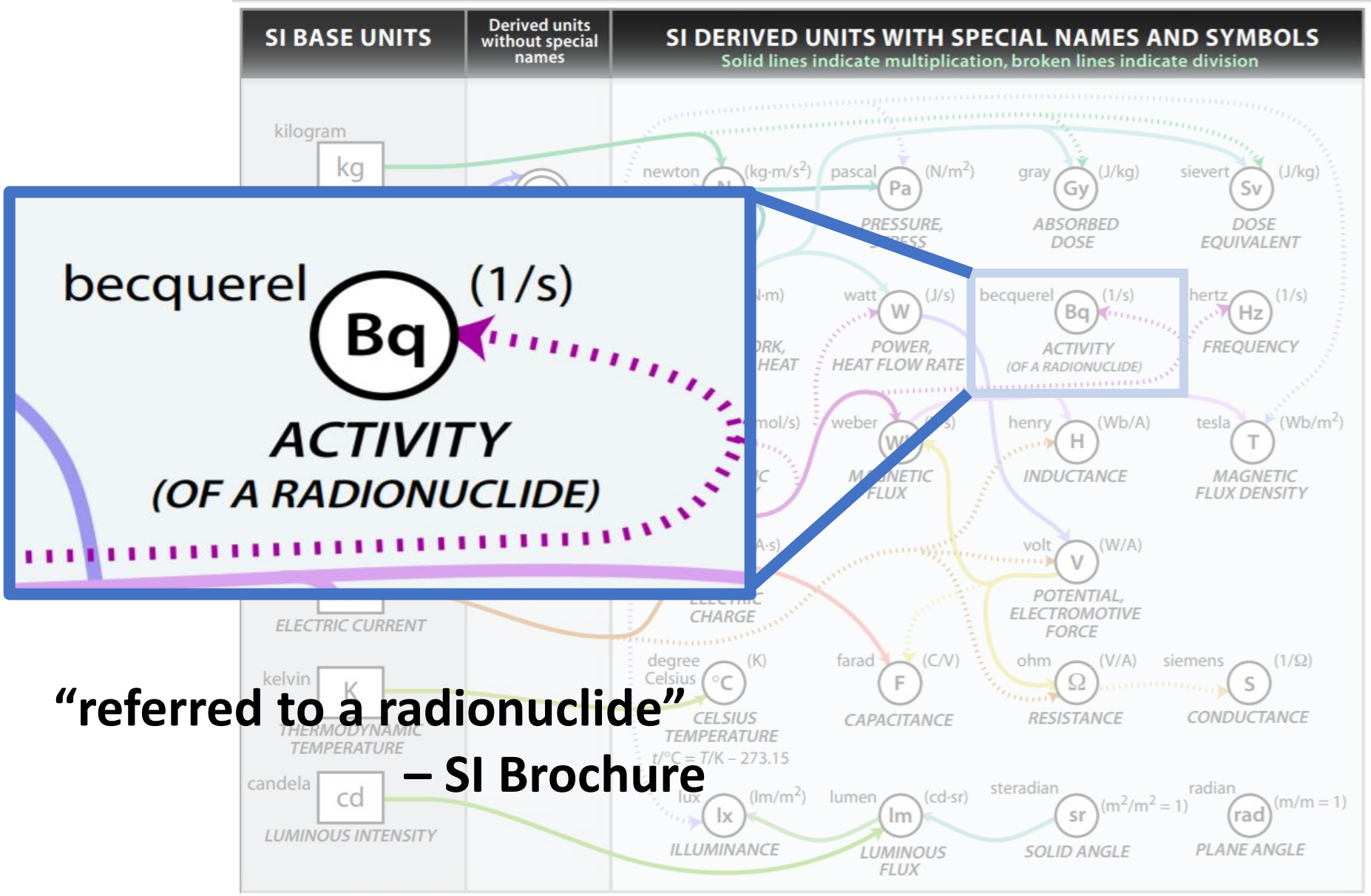
The measurand is rarely a count. The count is an input quantity. The output quantities are listed in answer 1. A unit for the count is not usually considered.

SI base units

SI derived units



SI derived units



“referred to a radionuclide”

– SI Brochure

Going back to… Question 1 of 6

What are the quantities within your technical discipline that relate to counting?

Activity of a radionuclide (Bq = s^{-1})

- Activity in a sample or container

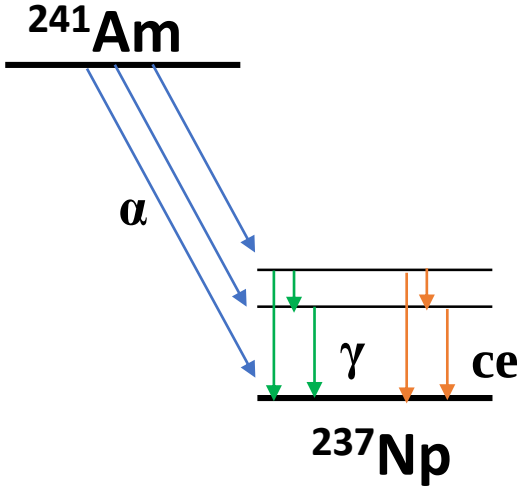
Massic activity of a radionuclide (Bq/g)

- Activity of a radionuclide per gram of a material

Emission probabilities and detection efficiencies (1)

- Measure total activity, A
- Measure emission rate, R_i, of a particular particle (i)
- Measurand, $P_i = \frac{R_i}{A}$

Simplified ^{241}Am decay scheme



Question 1 of 6

What are the quantities within your technical discipline that relate to counting?

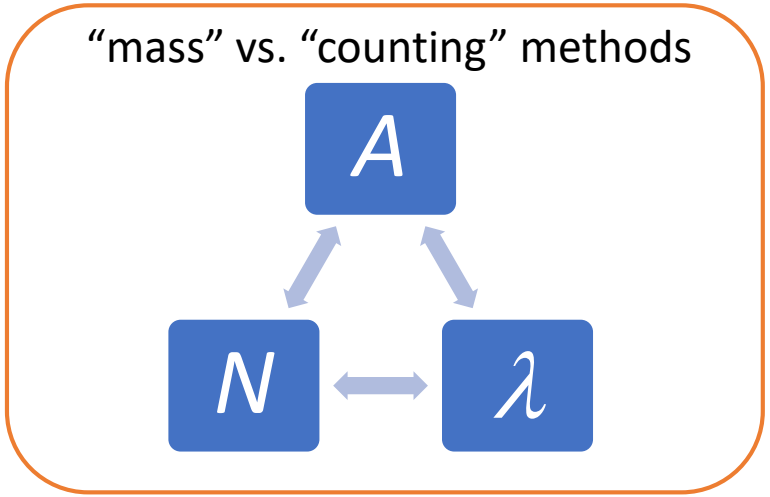
IN THEORY

A = activity of a radionuclide
N= number of atoms of a radionuclide
t = time
λ= decay constant of a radionuclide

$$A = \frac{dN}{dt}$$

$$A = N\lambda$$

$$A = A_0 e^{-\lambda t}$$



IN PRACTICE

C= count of decays of a radionuclide
ε = detection efficiency
t_m= duration of counting
A_0= activity at the start time of the duration

$$A_0 = \frac{C}{t_m}\frac{1}{\varepsilon}\left(\frac{\lambda t_m}{1 - e^{-\lambda t_m}}\right)\prod_i k_i$$

Question 3 of 6

What improvements could be made to clarify the status and traceability of the unit one within the SI?

Revise the statement “Counting quantities are also quantities with the associated unit one.” [SI Brochure, V2.0.1, 2022]

Consider applying the concept of cardinality.

https://commons.wikimedia.org/wiki/File:Male_Northern_Cardinal_in_Hudson,_Ohio.jpg

Question 4 of 6

Does your community use special units for counting, which are currently not covered by the SI?

Not when best practices are followed. However, some authors report:

- non-periodic count rates (s^{-1}) in units of Hz
- the measurand in the unit, especially when counting is involved. Units of “cps” (counts per second) or “cpm” or even “dpm” (decays per minute) are reported
- confusing percentages:

  -“the detector efficiency is 23.5 % with an uncertainty of 1.2 %”

  - ambiguous uncertainty (percent of a percent?)

  - ambiguous measurand (“counts per decay” would clarify, but not SI units)

  See Mohr & Phillips **Metrologia** 52, 1 (2014)

Could they be harmonised, in documentary standards for instance?

Need coherence between metrology standards and practical usage

Question 4 of 6

Does your **community** use special units for counting, which are currently not covered by the SI?

Let us recall the reasons for the existence of the becquerel (and gray) within the SI

"by reason of the need to make as easy as possible the use of the units for nonspecialists, taking into consideration also the grave risks of errors in therapeutic work"

-SI Brochure, quoting CCU (1976), approved by CIPM

Examples from a conference this week:

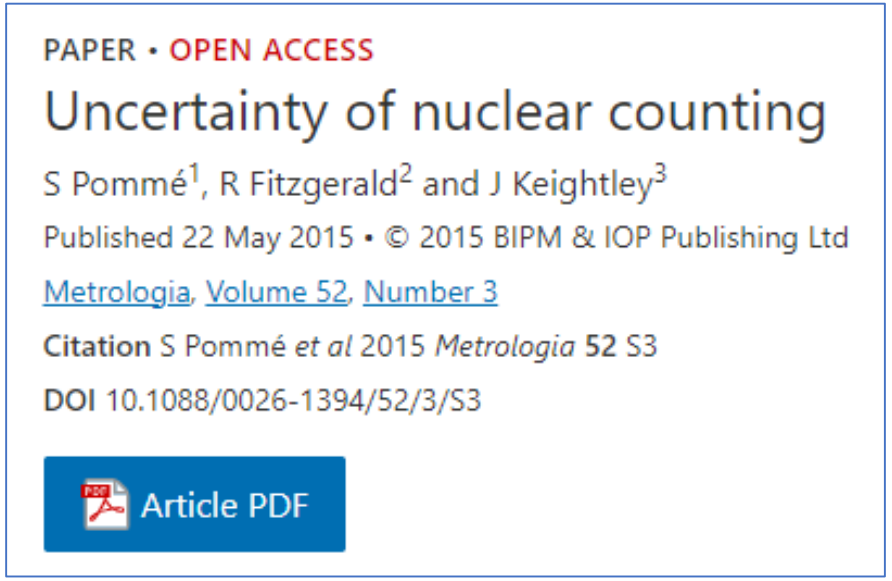
#1: radon sensitivity of $100\,\frac{\mathrm{cpm}}{k\mathrm{Bq/m^3}}$

#2: comparison result changed due to an error in converting from cpm to cps

Question 5 of 6

Is the counting process covered within the technical activities of a specific Consultative Committee?

Yes. For example, the CCRI Section II (Measurement of Radionuclides) sponsored a special issue in Metrologia on radionuclide metrology, the first paper of which was titled “Uncertainty of Nuclear Counting”.



PAPER • OPEN ACCESS

Uncertainty of nuclear counting

S Pommé[1], R Fitzgerald[2] and J Keightley[3]

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Metrologia, Volume 52, Number 3

Citation S Pommé *et al* 2015 *Metrologia* **52** S3

DOI 10.1088/0026-1394/52/3/S3

Article PDF

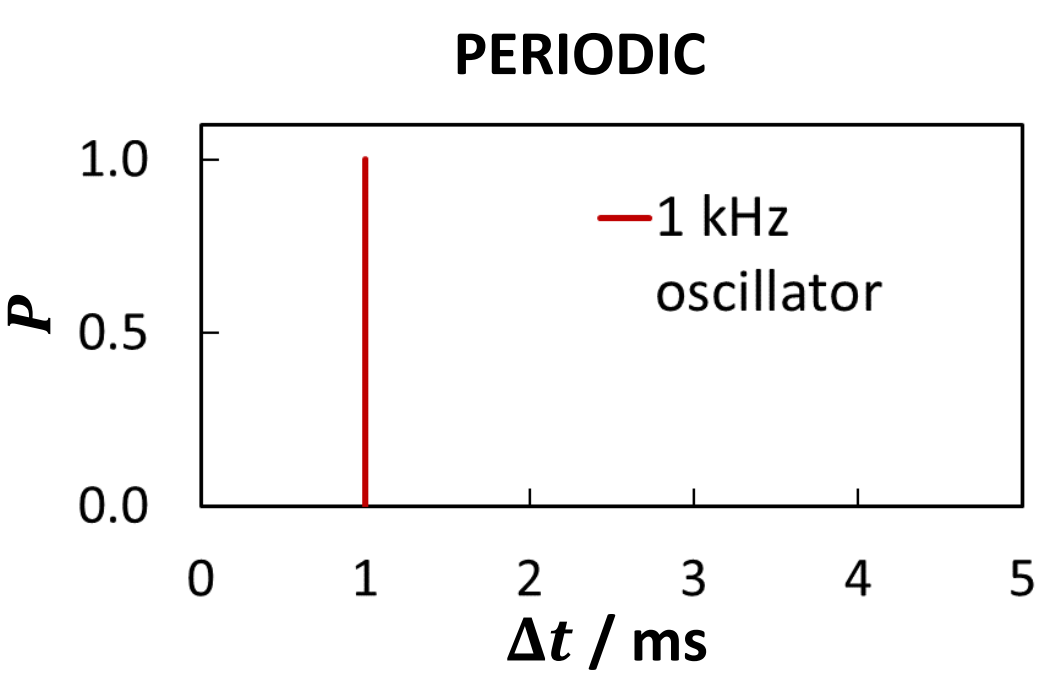
Question 6 of 6

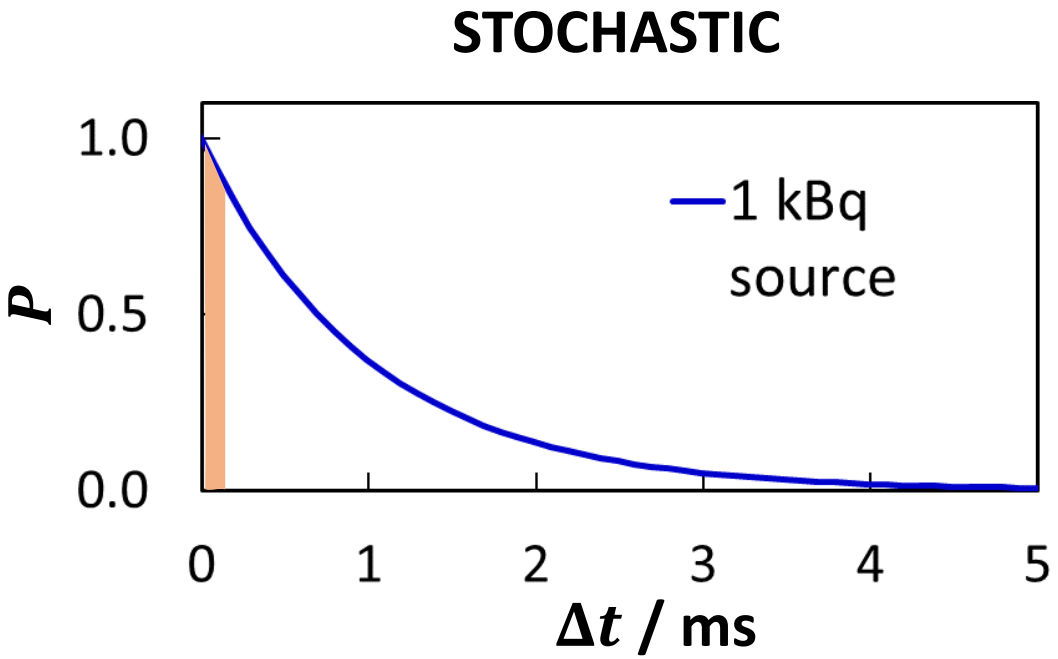
What are the technical challenges for measuring these quantities…

Detector dead-time and pileup

Assigning a particular count to a particular radionuclide (interferences)

Periodic vs. stochastic count rates



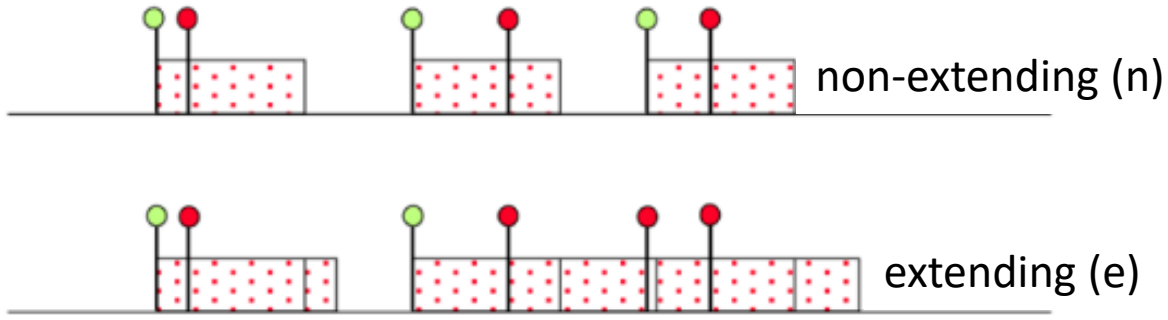


https://www.vecteezy.com/png/1208034-marching-band

https://www.goodfreephotos.com/people/people-marching-in-pride-parade.jpg.php

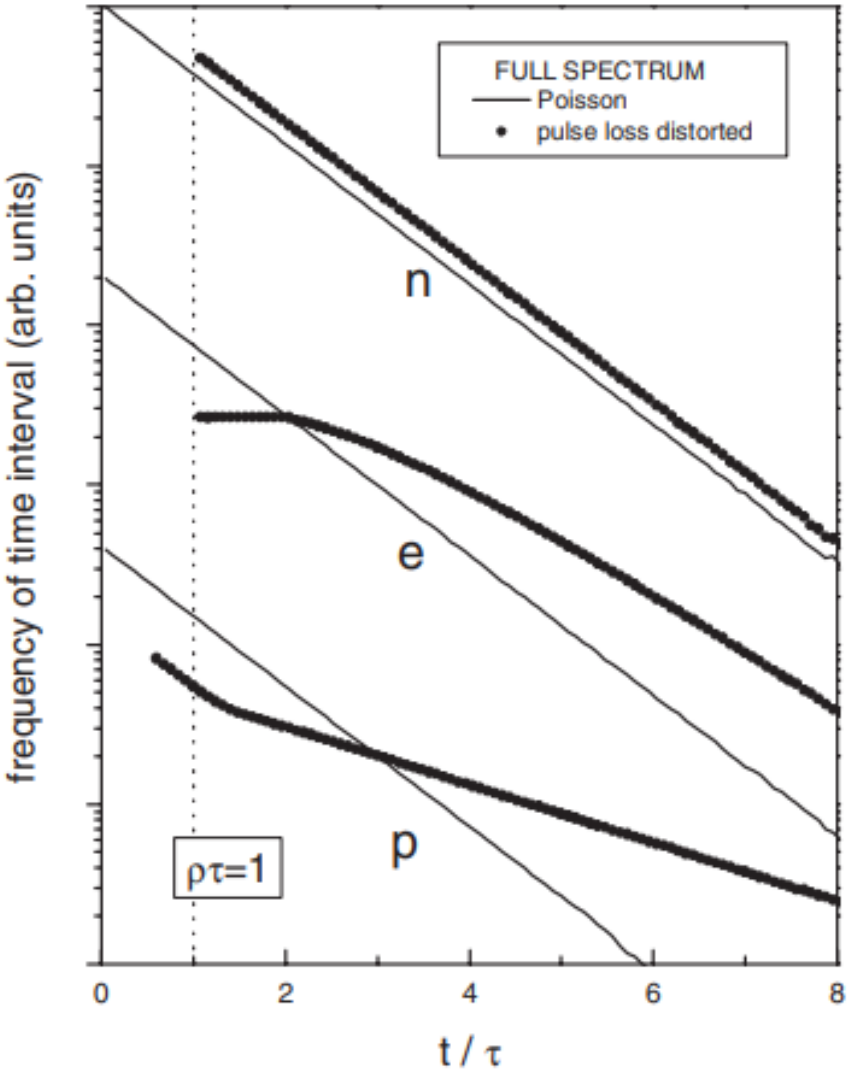
Dead-time and pileup

Dead-time models



Solutions

- Time interval distribution can diagnose type of dead time
- Apply appropriate corrections and tricks



Metrologia 52, S3 (2015)

Interferences

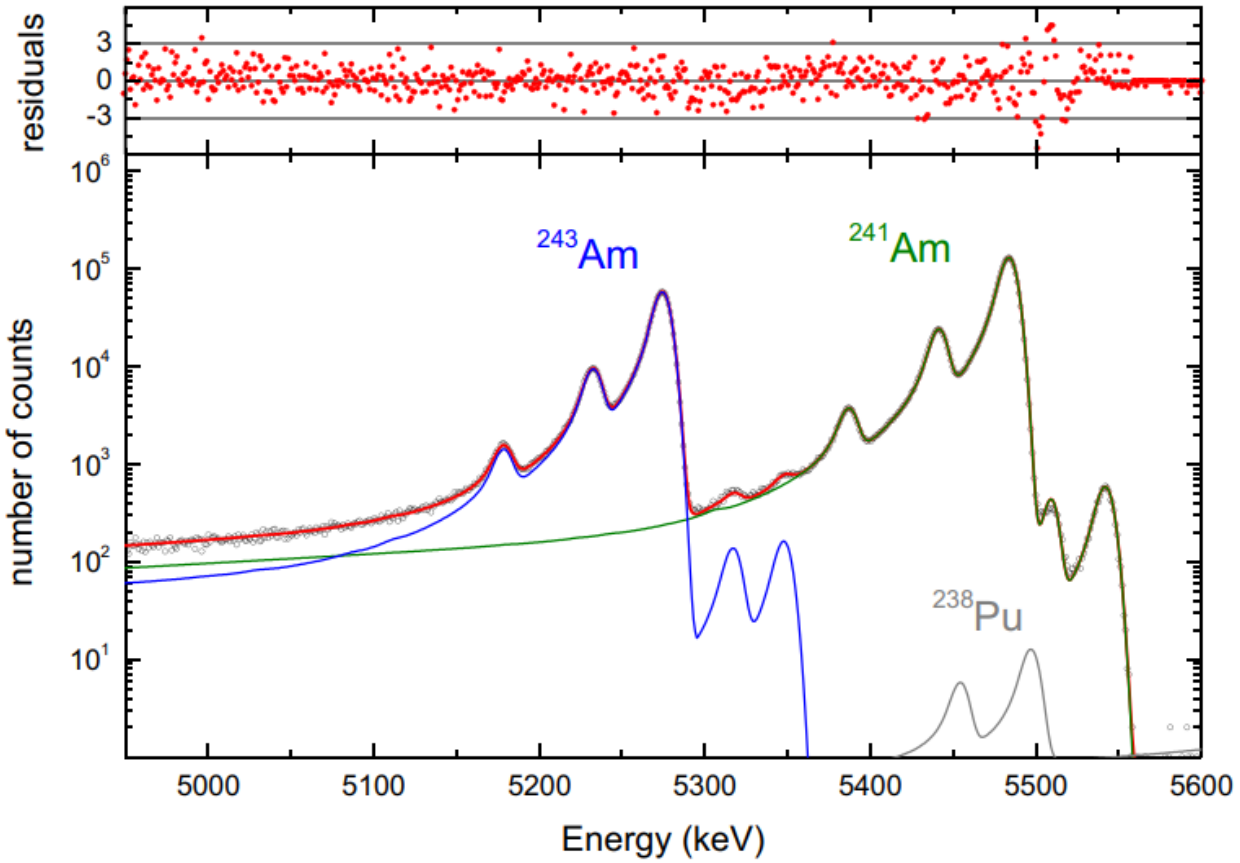
But which counts count?

$$A_0 \propto \frac{C}{t_m}$$

C determination requires knowledge of:

- Decay schemes (multiple nuclides)
- Detector response (peak shape)

^{241}Am activity measurement by α spectrometry

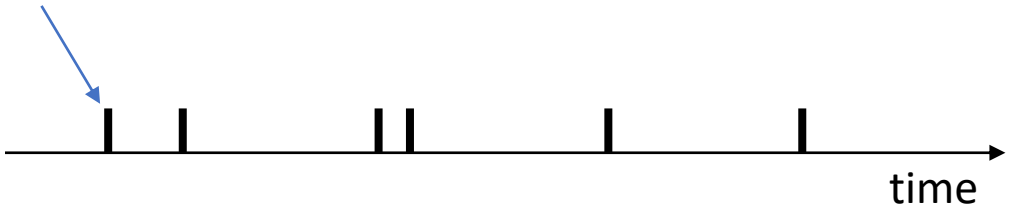


Marouli, et al., JRNC **326**, 1785–1793 (2020)

Now a question from me ☺

What is the definition of “count”?

radioactive decay event
(We call this a “count”)



The SI Brochure* would say that the *count* was 6

We would say the *number of counts* was 6

SI Brochure 2.3.3 “…a count (for example number of photons or decays)”

Summary

- The becquerel (s^{-1}) is the SI derived unit for activity of a radionuclide
- Activity measurements usually involve counting of decays
- Challenges:
  - Reports of units of “dpm” instead of Bq for activity and “cps” or “Hz” for count rates
  - Unitless (or unit 1) measurands are sometimes reported as percentages
  - Spectral interferences, pulse pileup and deadtime
- CCRI works to educate the field on proper use of the SI

Thank you

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