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Status and inspection of isotopic decay data for normalization

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11th ICI Conference, Saskatoon, Canada, July 23-27, 2023

Outline:

- Motivation
- Decay data
  - Table of Radioactive Isotopes, ENSDF, DDEP, etc.
- Recent work
- Research opportunities
- Decay data dissemination/retrieval
- Summary

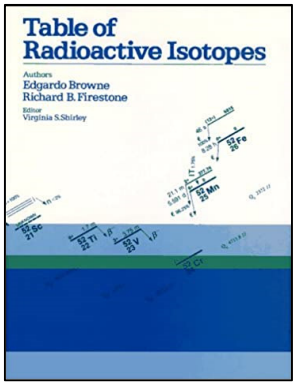
Motivation

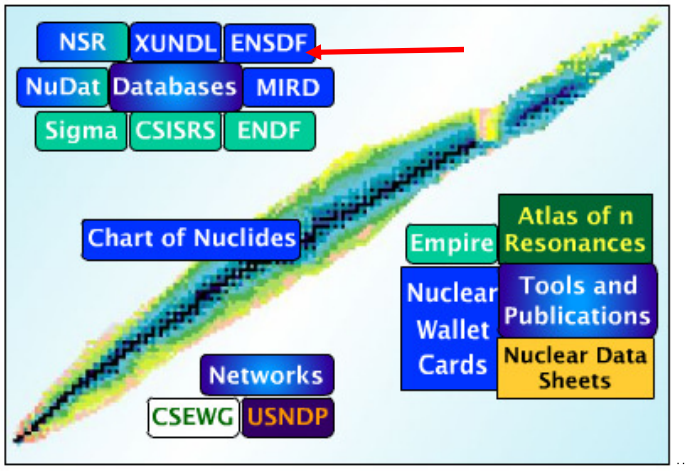
- Accurate and precise isotopic decay (α, β, γ, etc.) data are important for applied and basic sciences.
- Decay data normalization
  - Provides radiation emission probabilities
- Several methods have been used to normalize the decay scheme
  - Measured emission probability P_{γ}, $P_{\beta-}$, $P_{\beta+}$, or I_{511}, $I_{x\text{-}ray}$
  - Also from a complete γ-decay scheme (g.s. β-feeding is known)
    - ✓ Parent, daughter properties
    - ✓ Level energy, spin and parity (J^{π}), half-life ($t_{1/2}$), etc.
    - ✓ α, β, γ, γ-multipolarity, mixing ratio (δ), conversion coefficient (α), etc.

It is important to check the normalization by more than one method

Decay data

- Table of Radioactive Isotopes (1986) – a product of LBNL compilation of nuclear data since 1940s - initiated by Prof. Glenn Seaborg
- Nuclear Data Sheets/ENSDF - similar effort since mid 1940's at Clinton Lab/ORNL by Prof. Katherine Way (Nuclear Data Sheets since 1966)
- Currently more than 3,200 experimental decay data sets available in the Evaluated Nuclear Structure Data File (ENSDF)
- Decay Data Evaluation Project (DDEP) – at LNHB, France - since mid 1995s





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Recent work (1): ^{86g}Y ($t_{1/2}$=14.7 h) (β^+)

theranostic pair of ^{90}Y (= 2.7 d) (β^-)

Data need: accurate %β^+

Q^+=5240 (14) keV

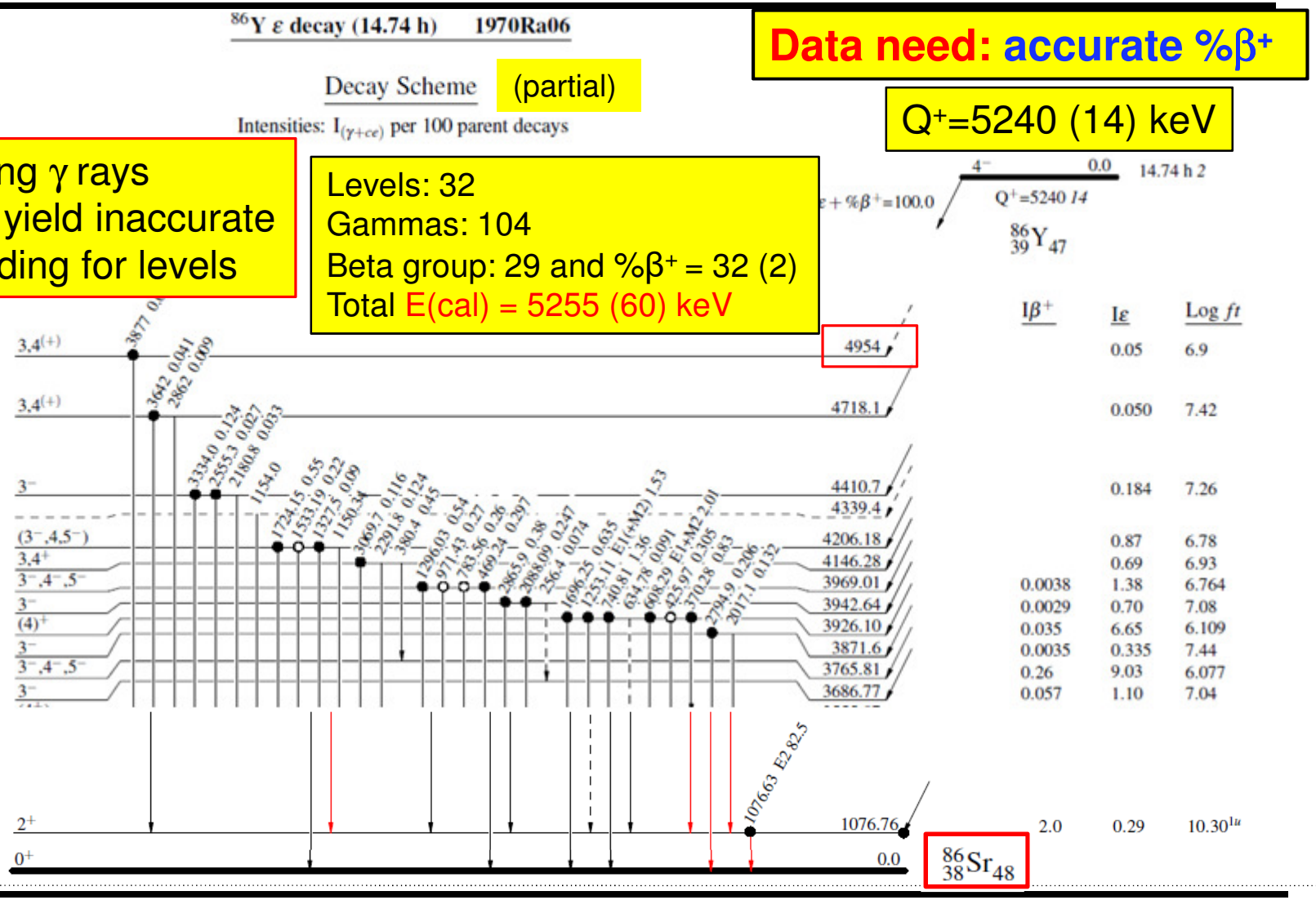
Missing γ rays often yield inaccurate I_β feeding for levels

Levels: 32
Gammas: 104
Beta group: 29 and %β^+ = 32 (2)
Total E(cal) = 5255 (60) keV

^{86}Y ε decay (14.74 h) 1970Ra06

Decay Scheme (partial)

Intensities: $I_{(\gamma+ce)}$ per 100 parent decays



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Recent work (2): ^{86g}Y

PHYSICAL REVIEW C **102**, 034316 (2020)

State-of-the-art γ-ray assay of ^{86}Y for medical imaging

A. C. Gula,[1,2] E. A. McCutchan,[2] C. J. Lister,[3] J. P. Greene,[4] S. Zhu,[2,4] P. A. Ellison,[5] R. J. Nickles,[5] M. P. Carpenter,[4] Suzanne V. Smith,[6] and A. A. Sonzogni[2]

[1]*Department of Physics Computer Science, Houghton College, Houghton, New York 14744, USA*

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A 27.6 MBq source of ^{86}Y was produced at the University of Wisconsin and assayed with the Gammasphere array at Argonne National Laboratory. Over 200 γ-ray transitions were identified, more than double that which was previously known. The positron emission probability inferred from the present level scheme leads to 27.9(12)%, an important (≈14%) reduction with respect to the previously recommended value.

molecules *Molecules* **2022**, *27*, 768 MDPI

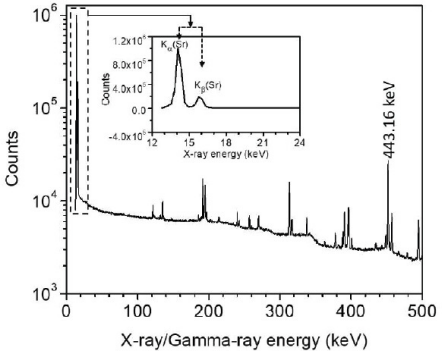
Forschungszentrum Jülich, Jülich, Germany

Article

Positron Emission Intensity in the Decay of ^{86g}Y for Use in Dosimetry Studies

M. Shuza Uddin [1,2], Syed M. Qaim [1,*], Bernhard Scholten [1], M. Shamsuzzoha Basunia [3], Lee A. Bernstein [3,4], Ingo Spahn [1] and Bernd Neumaier [1]

In this work, an ^{86g}Y source of high radionuclidic purity was prepared and the positron emission intensity per 100 decay of the parent (hereafter "positron emission intensity") was determined by measuring the 511 keV annihilation γ-ray using high-resolution HPGe detector. The total source activity was obtained from known γ-ray emission probabilities. The electron capture (EC) intensity was also determined as an additional check by measuring the K_α and K_β X-rays of energies 14.1 and 15.8 keV, respectively, using a low energy HPGe detector. From those measurements, normalized values of 27.2 ± 2.0% for β^+-emission and 72.8 ± 2.0% for *EC* were deduced. These results are in excellent agreement with values recently reported in the literature based on a detailed decay scheme study.



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Equations and features:

- Several methods have been used to normalize the decay scheme
  - 511 (annihilation) and x-ray measurements – provide opportunities for independent check
  - For cases: %β^+ + %ε (EC) = 100

$$\beta^+ = \frac{A_{0(\beta^+)}}{A_{0(\beta^+)} + A_{0(EC)}}$$

From 100 (independent)

$$\beta^+ = \frac{A_{0(\beta^+)}}{A_0} = \frac{CPS_{511\ keV\ \gamma-ray}/2\cdot\varepsilon}{CPS_{\gamma-ray}/I_\gamma\cdot\varepsilon}$$

$$EC = \frac{A_{0(EC)}}{A_0} = \frac{CPS_{X-ray}/\varepsilon\cdot FY\cdot P_K}{CPS_{\gamma-ray}/I_\gamma\cdot\varepsilon}$$

From known %I_γ (dependent)

A_0(activity), CPS(count/s),ε(detector efficiency),I_γ(emission probability), Pk(capture from k-shell), FY(fluorescence yield)

Results: ^{86g}Y

- From two samples:

$\%\beta^+ = 27.1 \pm 1.9$ and $\%\varepsilon = 72.6 \pm 5.2$

Using $\%I\gamma$ (1076.6)	Using $\%I\gamma$ (443.1)	For 100
72.4	73.5	72.0
71.7	73.3	72.9

- Average (of 2 values for 100) = 72.5
- Average (of 4 values using $\%I\gamma$) = 72.7

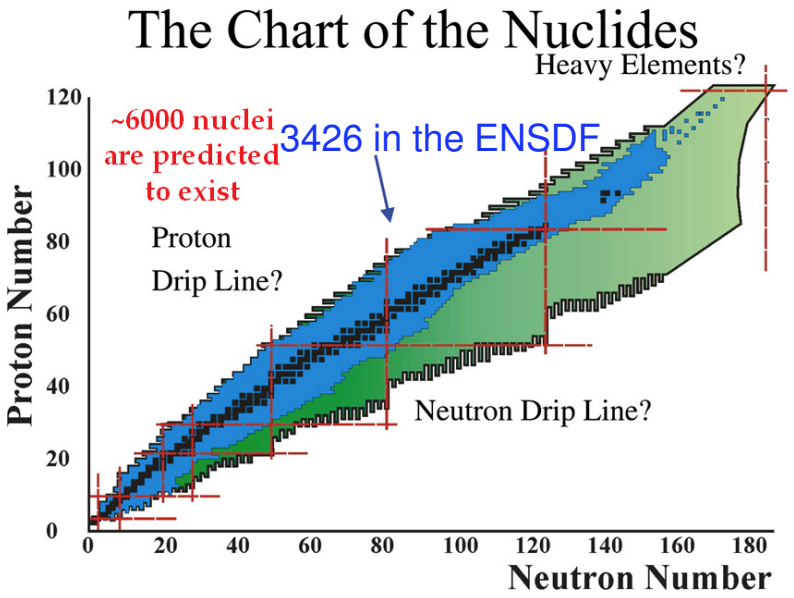
Consistency between independent and dependent approaches

- Uncertainty: Propagated uncertainties of peak area, in-flight annihilation, detector efficiency, x-ray attenuation, fluorescence yield, electron capture from k-shell, etc.

Research opportunities:

For radioisotopes: $\%\beta^+ + \%\varepsilon = 100$

- Total $\%\beta^+$ by 511 (annihilation) and x-ray measurements provides independent data
- 511 and x-ray measurements – provide opportunities for checking $\%I\gamma$ or confirming any assumptions, if used
- More than 3,200 decay datasets in the ENSDF
  - About 2,400 represent β^- and β^++EC decay, about 1920 are normalized
  - We checked a group of applied isotopes to benefit from 511 and x-ray measurements



First step for further studies

Example: ^{72}As ($t_{1/2}$ = 26 h) (β^+)

theranostic pair of ^{77}As ($t_{1/2}$ = 38.8 h) (β^-)

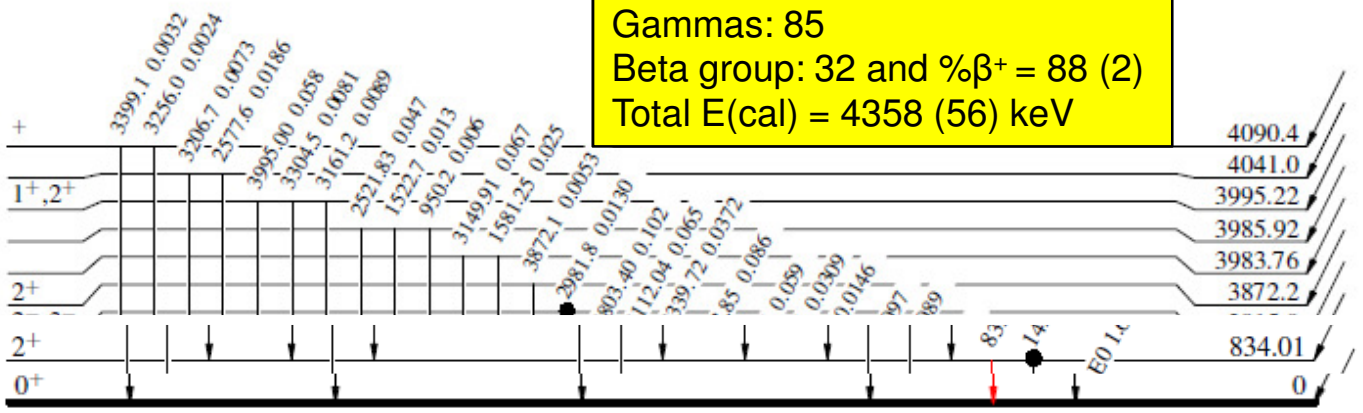
^{72}As ε decay 1968Ca20,1971Re05

Decay Scheme (partial)

Intensities: $I_{(\gamma+ce)}$ per 100 parent decays

Q^+ = 4356 (4) keV

Levels: 33
Gammas: 85
Beta group: 32 and %β^+ = 88 (2)
Total E(cal) = 4358 (56) keV



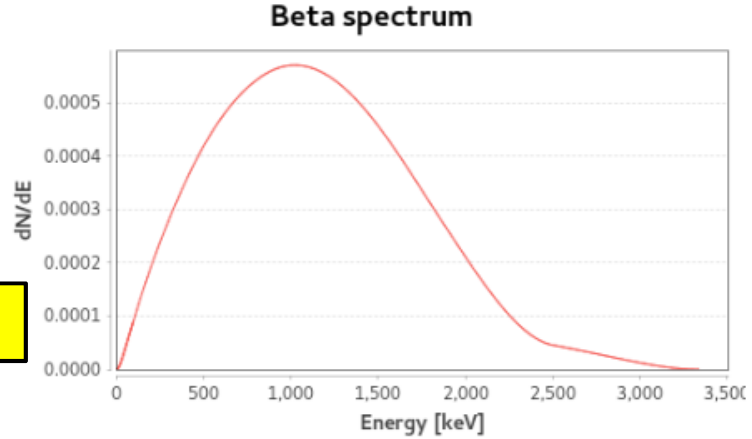
	Iβ+	Iε	Log ft
		0.0056	7.74
		0.025	7.25
		0.0644	6.959
		0.064	6.98
		0.091	6.84
		0.0052	8.31
	64.2	3.63	7.208
	16.3	0.94	9.84 1u

Iγ normalization: From Iβ(834)/Iβ(g.s.)=3.9 4 (1968Vi05) and theoretical ε/β+ ratios.

%Iγ(834)=82 (2)

Other method: Σ total transition to g.s. would yield:
%Iγ(834)=79.5 (19)

In general %Iγ is less affected compared to total %β^+



Decay data dissemination/retrieval:

- Sometimes published results take time to get to the ENSDF database and would miss in retrieval through web applications (like NuDAT and LiveChart)

PHYSICAL REVIEW C **92**, 044330 (2015)

2015Ch57

Precise absolute γ-ray and β^--decay branching intensities in the decay of $^{67}_{29}$Cu

J. Chen,[1,*] F. G. Kondev,[1,†] I. Ahmad,[2] M. P. Carpenter,[2] J. P. Greene,[2] R. V. F. Janssens,[2] S. Zhu,[2] D. Ehst,[1] V. Makarashvili,[1] D. Rotsch,[1] and N. A. Smith[1]

Precision measurement of relative γ-ray intensities from the decay of ^{61}Cu

D.L. Bleuel [a,*], L.A. Bernstein [b,c], R.A. Marsh [a], J.T. Morrell [c], B. Rusnak [a], A.S. Voyles [c]

[a] *Lawrence Livermore National Laboratory, Livermore, CA 94551, USA*
[b] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[c] *University of California, Berkeley, CA 94720, USA*

2021Bl04 - Appl.Radiat.Isot. 170, 109625 (2021)

Resolution of a discrepancy in the γ-ray emission probability from the β decay of ^{137}Ce^g

M. S. Basunia,[1] J. T. Morrell,[2] M. S. Uddin,[3] A. S. Voyles,[1,2] C. D. Nesaraja,[4] L. A. Bernstein,[1,2] E. Browne,[1] M. J. Martin,[4] and S. M. Qaim[5]

2020Ba30 - Phys.Rev. C 101, 064619

Check literature, the XUNDL database at nndc.bnl.gov or contact database manager or nuclear structure data evaluator

Summary:

- Accurate and precise isotopic decay data are important for applied and basic sciences
- We have determined $\%\beta^+$ (^{86}Y(14.7 h)) = 27.2 ± 2.0 by measuring 511-keV annihilation radiation and x-rays. Excellent agreement with the value (27.9 ± 1.2) deduced using the latest decay scheme (2020Gu18)
- Several methods have been used to normalize the decay scheme
  - 511 (annihilation) and x-ray measurements – provide opportunities for independent check for cases: $\%\beta^+ + \%\varepsilon = 100$
  - We plan to continue measurements with 511 and x-rays
- For the latest decay data – please check the literature, the XUNDL database or contact the ENSDF database manager or any nuclear structure evaluators

Collaborators:

- Forschungszentrum Jülich, Germany

  Syed M. Qaim
  Bernhard Scholten
  Ingo Spahn and
  Bernd Neumaier

- Lawrence Berkeley National Laboratory, USA

  M. Shasmuzzoha Basunia
  Lee A. Bernstein
  Aaron M. Hurst and
  Andrew S. Voyles

- Bangladesh Atomic Energy Commission, Bangladesh

  Md. Shuza Uddin

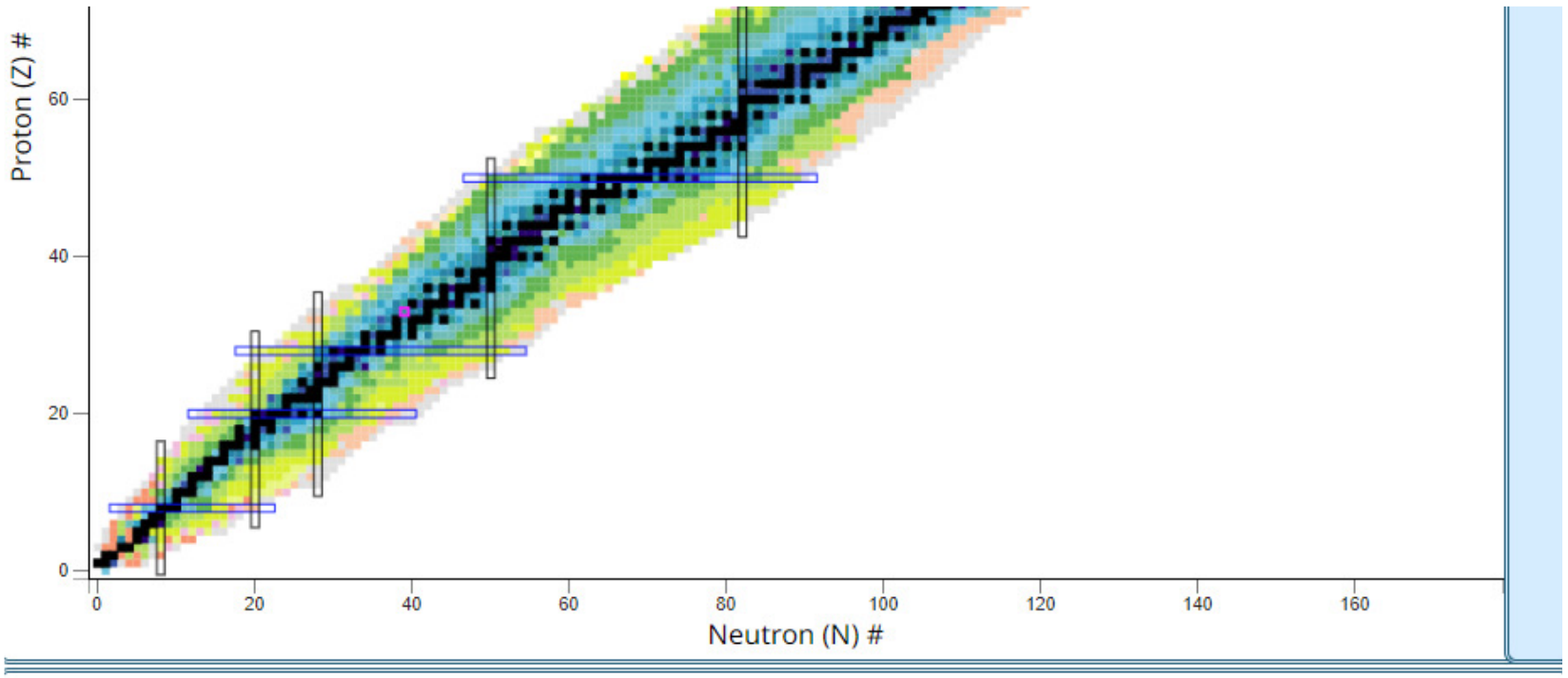
Thank you for your attention

Acknowledgements:

The research at LBNL was supported by the U.S. Department of Energy Isotope Program, managed by the Office of Science for Isotope R&D and Production, carried out under Lawrence Berkeley National Laboratory (Contract No. DE-AC02-05CH11231)

Back-up slides

Retrieval using NuDat:



Ground and isomeric state information for $^{72}_{33}As$

E(level) (MeV)	Jπ	Mass Excess (keV)	$T_{1/2}$	Decay Modes
0.0	2-	-68230 *4*	26.0 h *1*	ε = 100.00%

The following are available

List of levels | Interactive Level Scheme (Beta) | Level Scheme | J vs. E^* plot | J vs. E(γ) plot | E(γ)/J plot | Band parameters

Decay radiation information

Retrieval using NuDat:

Dataset #1:

Authors: D. Abriola, A.A. Sonzogni Citation:Nuclear Data Sheets 111,1 (2010)

Parent Nucleus	Parent E(level)	Parent Jπ	Parent $T_{1/2}$	Decay Mode	GS-GS Q-value (keV)	Daughter Nucleus	Decay Scheme	ENSDF file
$^{72}_{33}As$	0	2-	26.0 h 1	ε: 100 %	4356 4	$^{72}_{32}Ge$		

Beta+:

Energy (keV)		End-point energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
107.2 17		240 4	0.00126 % 14	1.35E-6 15
131.7 17		298 4	0.0066 % 4	8.7E-6 5
167.5 17	?	384 4	5E-4 % 5	8E-7 8
170.5 17		391 4	0.0203 % 10	3.46E-5 17
171.9 17		394 4	0.063 % 3	1.08E-4 5
250.5 17	?	580 4	0.008 % 8	1.9E-5 19
353.4 18		819 4	0.466 % 18	0.00165 6
402.3 18		932 4	0.170 % 10	6.8E-4 4
551.6 18		1269 4	0.032 % 10	1.8E-4 6
730.5 18		1606 4	0.056 % 14	4.1E-4 10