Decay Data in ENSDF

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a passion for discovery

U.S. DEPARTMENT OF ENERGY | Office of Science

Reference Material

γ-ray Intensity Normalization for Radioactive Decays in

Nuclear Data Sheets

J. K. Tuli

National Nuclear Data Center
Brookhaven National Laboratory
Upton, NY 11973, U.S.A.

(September 1987)

Calculated Uncertainties of Absolute γ-ray Intensities and Decay Branching Ratios Derived from Decay Schemes.*

E. Browne

Lawrence Berkeley Laboratory, University of California, Berkeley, California, USA

March 1986

ENSDF Evaluators' Workshops

Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, March 24-28, 2014
Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, August 6-17, 2012
Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, October 11-15, 2010
Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data: Theory and Evaluation	ICTP, April 28-May 9, 2008
Workshop on Nuclear Structure and Decay Data: Theory and Evaluation Manual Addendum - 2006	ICTP, February 20-March 3, 2006 (INDC(NDS)-496)
Workshop on Nuclear Structure and Decay Data: Theory and Evaluation Manual Addendum - 2005	ICTP, April 4-15, 2005 (INDC(NDS)-473)
Workshop on Nuclear Structure and Decay Data: Theory and Evaluation Manual - Part 1	ICTP, November 17-28, 2003 (INDC(NDS)-452)
Workshop on Nuclear Structure and Decay Data: Theory and Evaluation Manual - Part 2	ICTP, November 17-28, 2003 (INDC(NDS)-452)
Workshop on Nuclear Structure and Decay Data Evaluation	NDS, November 18-22, 2002 (INDC(NDS)-439. Summary Report)
ENSDF Evaluators' Training Workshop	NNDC, April 16-17, 2001 (Contributions)

Get your calculators ready

Today will be less talking and more working through examples

Will focus on beta decay and IT decay, since alpha decay has hopefully been well covered in A=217 evaluation work

Go with the flow

What goes in must come out

100

100

Relevant Quantities Needed to Deduce

NR – relative photon intensity to photons / 100 decays

NT – relative transition intensity to transitions / 100 decays

Above are through the particular decay branch

BR – Convert intensity / 100 decay through this decay branch to intensity per 100 decays of the parent

NB – relative beta and ec intensities to intensities per 100 decays through this decay branch

NP – convert per 100 delayed transition intensities to per 100 decays of the precursor

Decay Scheme Normalization Quantities

```
83BR     83SE B- DECAY (70.1 S)        1973FE08,1976KR20         01NDS     200105
83BR  N 0.170      4  1.0         1.0        1.0
```

NR NT BR NB NP

Relative Intensity	Normalization Factor	Absolute Intensity
$I\gamma$ x	NR x BR	=%$I\gamma$
I (tot) x	NT x BR	=%I (tot)
$I\beta$ (or ε or α) x	NB x BR	= % $I\beta$ (or ε or α)
$I\beta n$ (or $I\varepsilon p$) x	NP	= % $I\beta n$ (or $I\varepsilon p$)

Beta and ec are usually given as per 100 parent decays.

Since NBxBR, NB=1/BR

The definitions

NR Multiplier for converting relative *photon* intensity (**RI** in the **GAMMA** record) to *photons* per 100 decays of the parent through the decay branch or to *photons* per 100 neutron captures in an (n,γ) reaction. *Required* if the absolute photon intensity can be calculated.

BR Branching ratio multiplier for converting intensity per 100 decays through this decay branch to intensity per 100 decays of the parent nuclide. *Required if known.*

NB Multiplier for converting relative β^- and ϵ intensities (**IB** in the **B-** record; **IB**, **IE**, **TI** in the **EC** record) to intensities per 100 decays through this decay branch. *Required if known.*

NP Multiplier for converting per hundred delayed-transition intensities to per hundred decays of precursor

My advice

- There is good documentation on how to normalize decay schemes … but information on how that translates in use of NR, BR, NB, etc is lacking
- Particle decays are very tricky… take care and always check processed output
- Read the policies and go back and read again

Beta and electron-capture intensities are per 100 decays of the parent and are usually deduced from γ intensity imbalance for the levels fed. The separation of $I(\varepsilon+\beta^+)$ into $I(\varepsilon)$ and $I(\beta^+)$ is based on theoretical ε/β^+ ratios. The log *ft* values for nonunique transitions are calculated as for allowed transitions.

Particle transition intensities (other than β's) are per 100 particle decays. The total particle branching is given both in the drawings and in the tables.

Times have changed

From earlier ENSDF talk on decay

1. Relative intensity is what is generally measured

2. Multipolarity and mixing ratio (δ).

3. Internal Conversion Coefficients

- Theoretical Values:
  - From BRICC

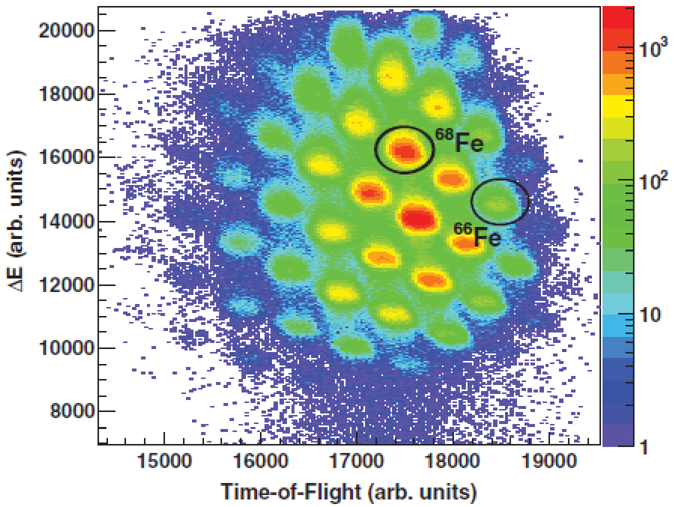
The Future

PHYSICAL REVIEW C **85**, 014328 (2012)

Low-energy structure of $^{66}_{27}Co_{39}$ and $^{68}_{27}Co_{41}$ populated through β decay

S. N. Liddick,[1,2] B. Abromeit,[1] A. Ayres,[3] A. Bey,[3] C. R. Bingham,[3] M. Bolla,[1] L. Cartegni,[3] H. L. Crawford,[4] I. G. Darby,[5] R. Grzywacz,[3] S. Ilyushkin,[6] N. Larson,[1,2] M. Madurga,[3] D. Miller,[3] S. Padgett,[3] S. Paulauskas,[3] M. M. Rajabali,[5] K. Rykaczewski,[7] and S. Suchyta[1,2]

# of ions counted individually

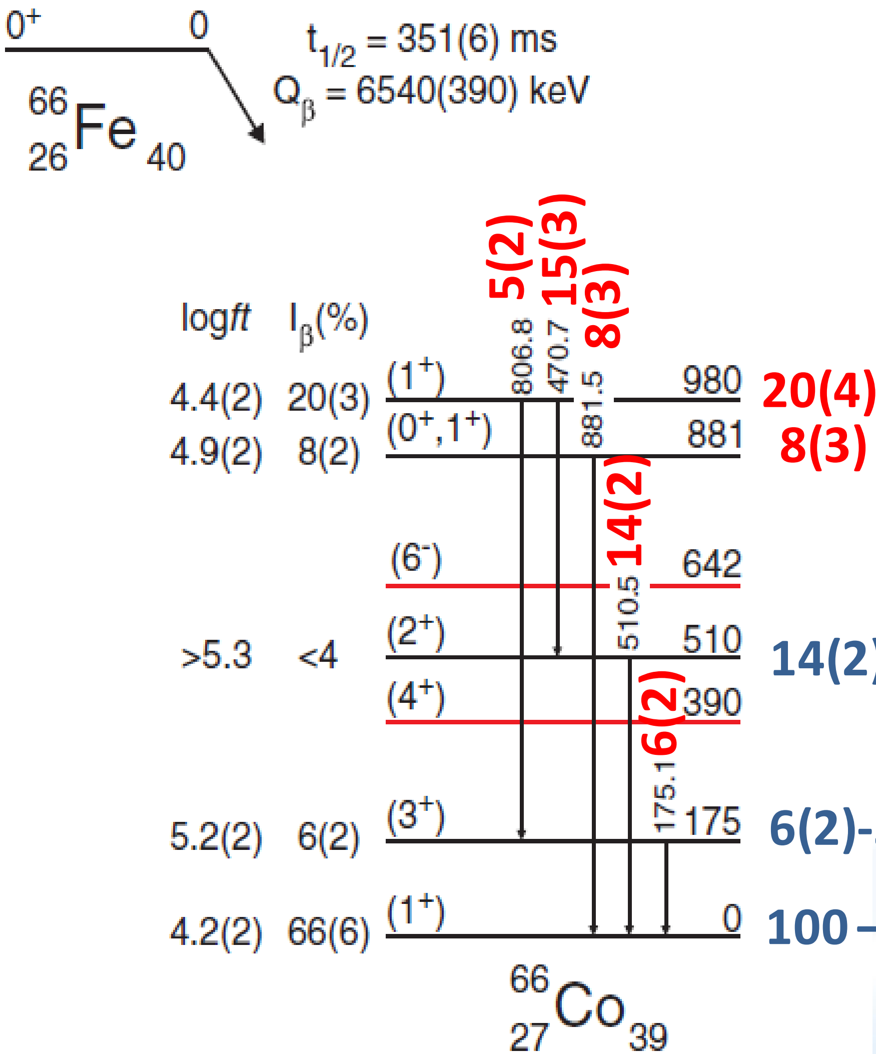


Beta-decay apparatus allows the correlation of exotic ion implants with their subsequent decays on an event-by-event basis

But a Careful Review is Still Required

NR=1 BR= 1

E (keV)	Absolute intensity (%)	E (keV)	Absolute intensity (%)
175.1(3)	6(2)	806.8(4)	5(2)
470.7(3)	15(3)	881.5(3)	8(3)
510.5(5)	14(2)[a]		



For excited levels:

Iβ=ΣI(γ+ce)(out)-ΣI(γ+ce)(in)

For ground state :

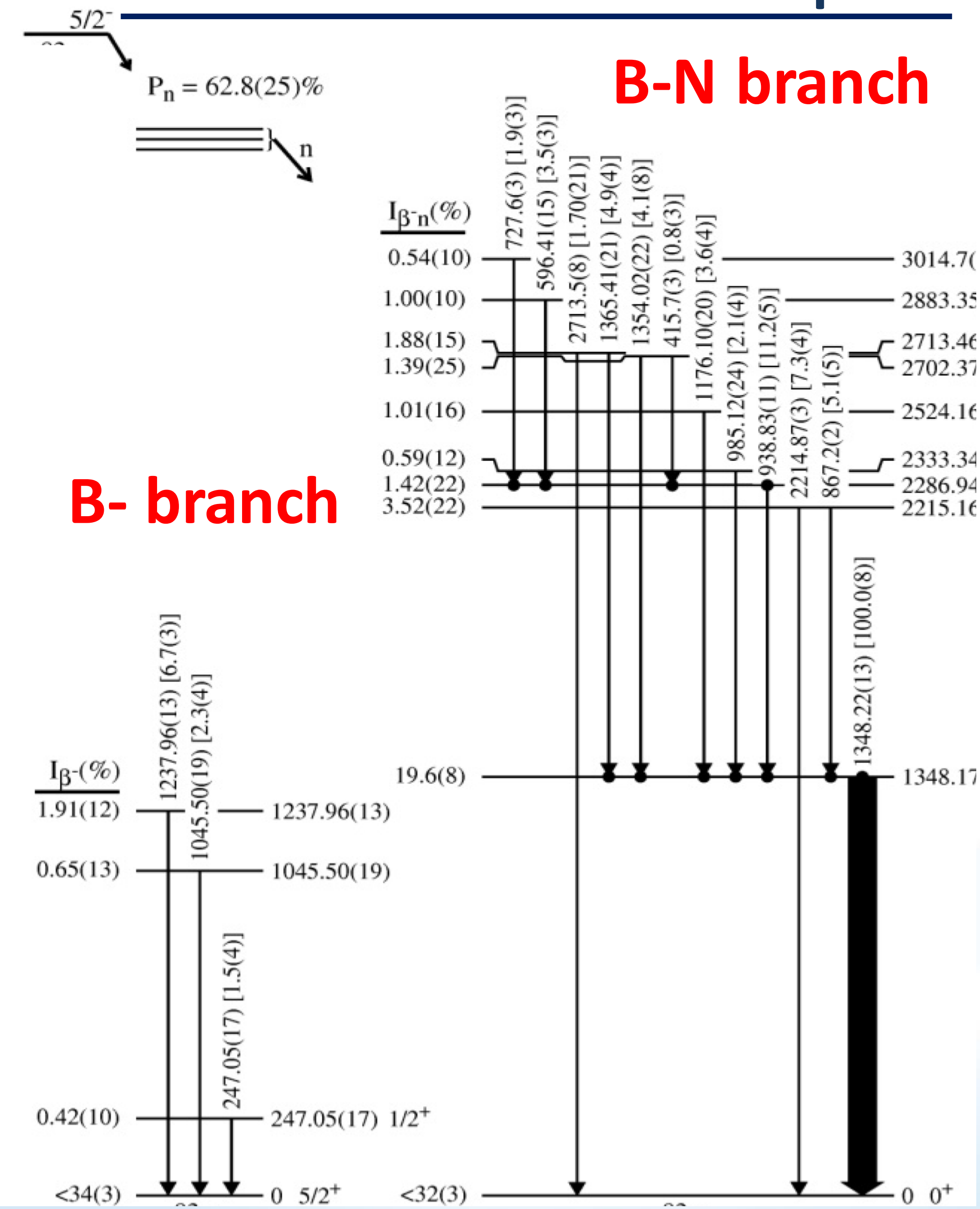
Iβ=100-ΣI(γ+ce)(gs)

14(2)-15(3) = -1 (4) → <3

6(2)-5(2) = 1 (3) → <4

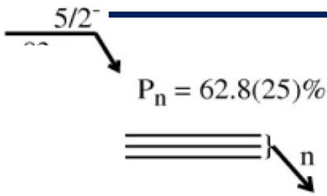
100 – 6(2) – 14(2) – 8(3) = 72 (5)

B- and B-N Example



Absolute Intensity
1348γ = 28.4(10) %

The easy B- branch

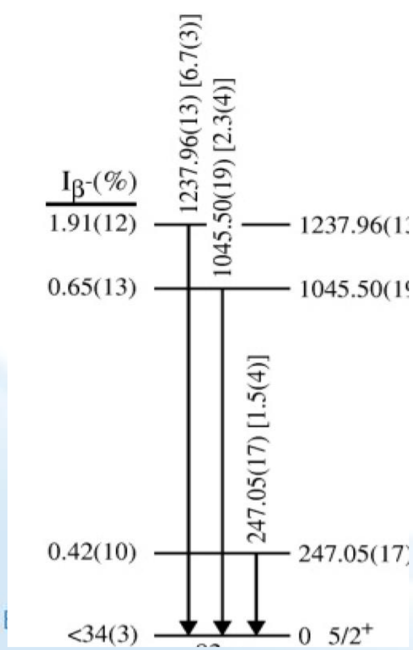


Absolute Intensity
1348γ = 28.4(10) %

NR= 0.284 (10)

BR= 1.0

Beta feedings are
6.7*0.284 = 1.9
2.3*0.284 = 0.65
1.5*0.284 = 0.42



GS feeding:
Here you need to consider B-N branch
100-Pn-ΣI(γ+ce)(gs):
100-62.8-1.9-0.65-0.42
<34

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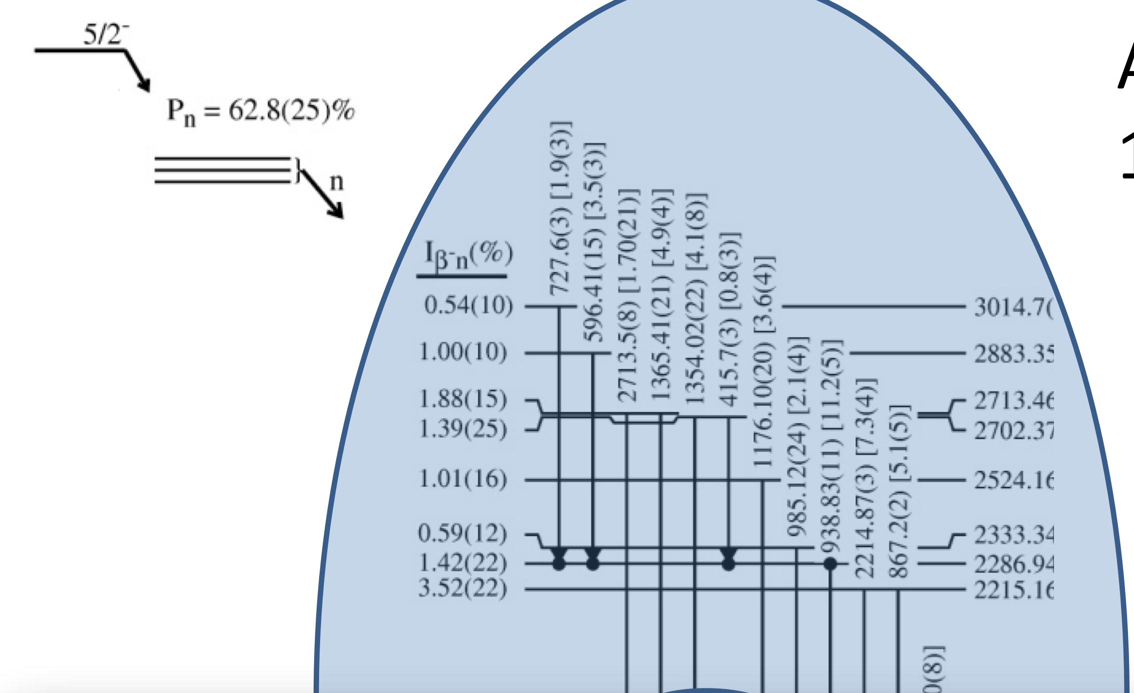
Absolute Intensity of 1348γ = 28.4(10) %

NR= 0.284 ?

BR= 0.628 ?

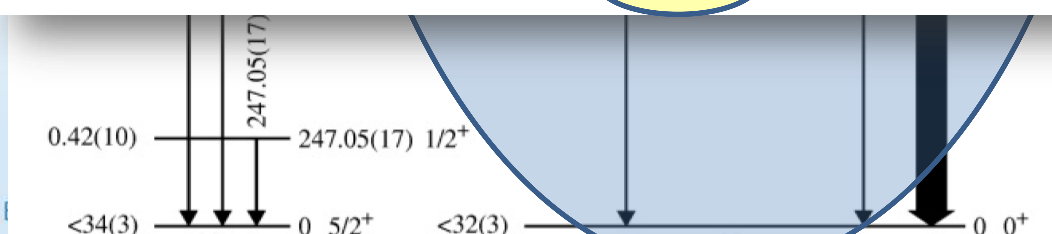


I_γ **Normalization:** From measured absolute intensity=28.4% 10 for 1348γ.

Branching Ratio: %β⁻n=62.8 25 (2010Wi03).

E_γ	E_{level}	I_γ#	E_γ	E_{level}	I_γ#	E_γ	E_{level}	I_γ#
415.7 *3*	2702.27	0.8 *3*	938.83 *11*	2286.87	11.2 *5*	1354.02 *22*	2702.27	4.1 *8*
596.41 *15*	2883.28	3.5 *3*	985.12 *24*	2333.2	2.1 *4*	1365.41 *21*	2713.50	4.9 *4*
727.6 *3*	3014.5	1.9 *3*	1176.10 *20*	2524.19	3.6 *4*	2214.87 *3*	2214.91	7.3 *4*
867.2 *2*	2214.91	5.1 *5*	1348.22 *13*	1348.08	100.0 *8*	2713.5 *8*	2713.50	1.70 *21*

#For absolute intensity per 100 decays, multiply by 0.178 *10*.



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The details

BR Branching ratio multiplier for converting intensity per 100 decays through this decay branch to intensity per 100 decays of the parent nuclide. *Required if known.*

NR Multiplier for converting relative *photon* intensity (**RI** in the **GAMMA** record) to *photons* per 100 decays of the parent through the decay branch or to *photons* per 100 neutron captures in an (n,γ) reaction. *Required* if the absolute photon intensity can be calculated.

This is Pn
BR=0.628

28.4 is Iγ per 100 decays

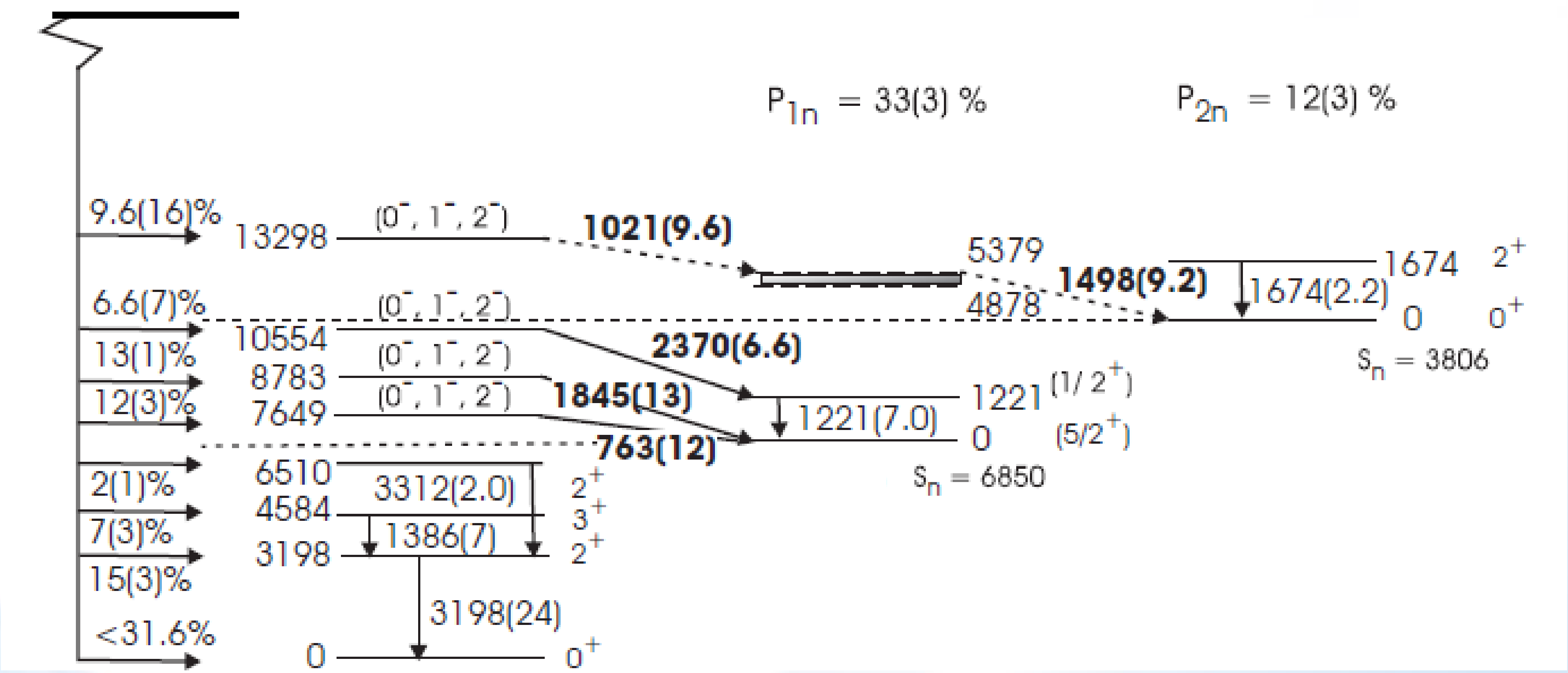
Through the decay branch, you need :

0.284/0.628 = 0.425

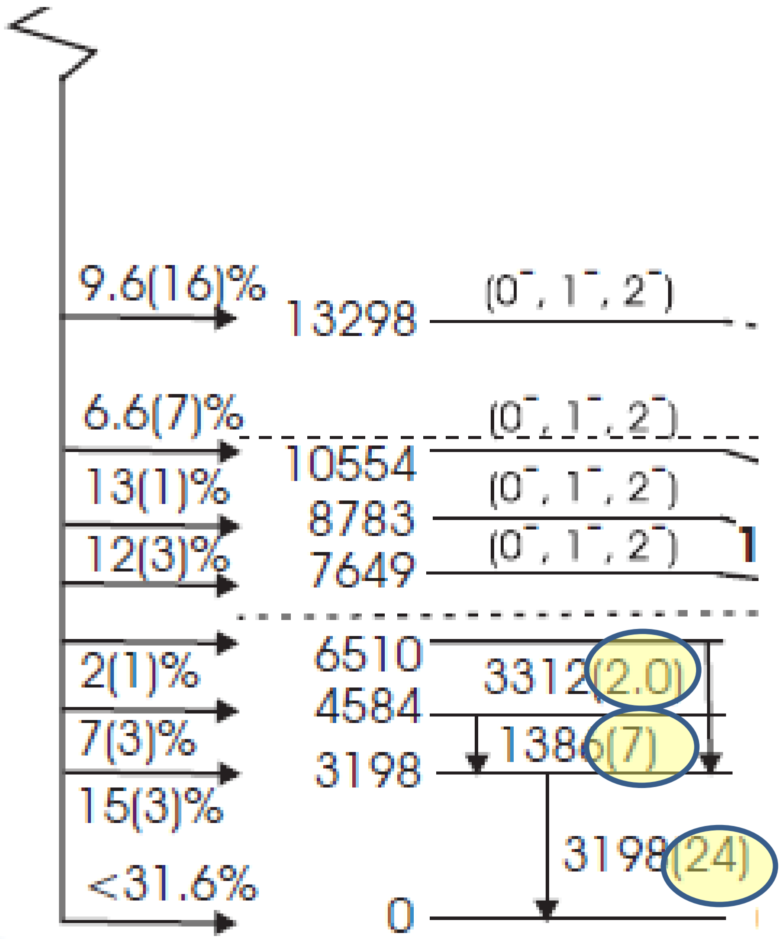
NR=0.425

How to define NP?

Example of B-N and B-2N Decay



Start with the “easy” beta-decay



Intensities are again given as Absolute Ig / 100 decays

NR = 1

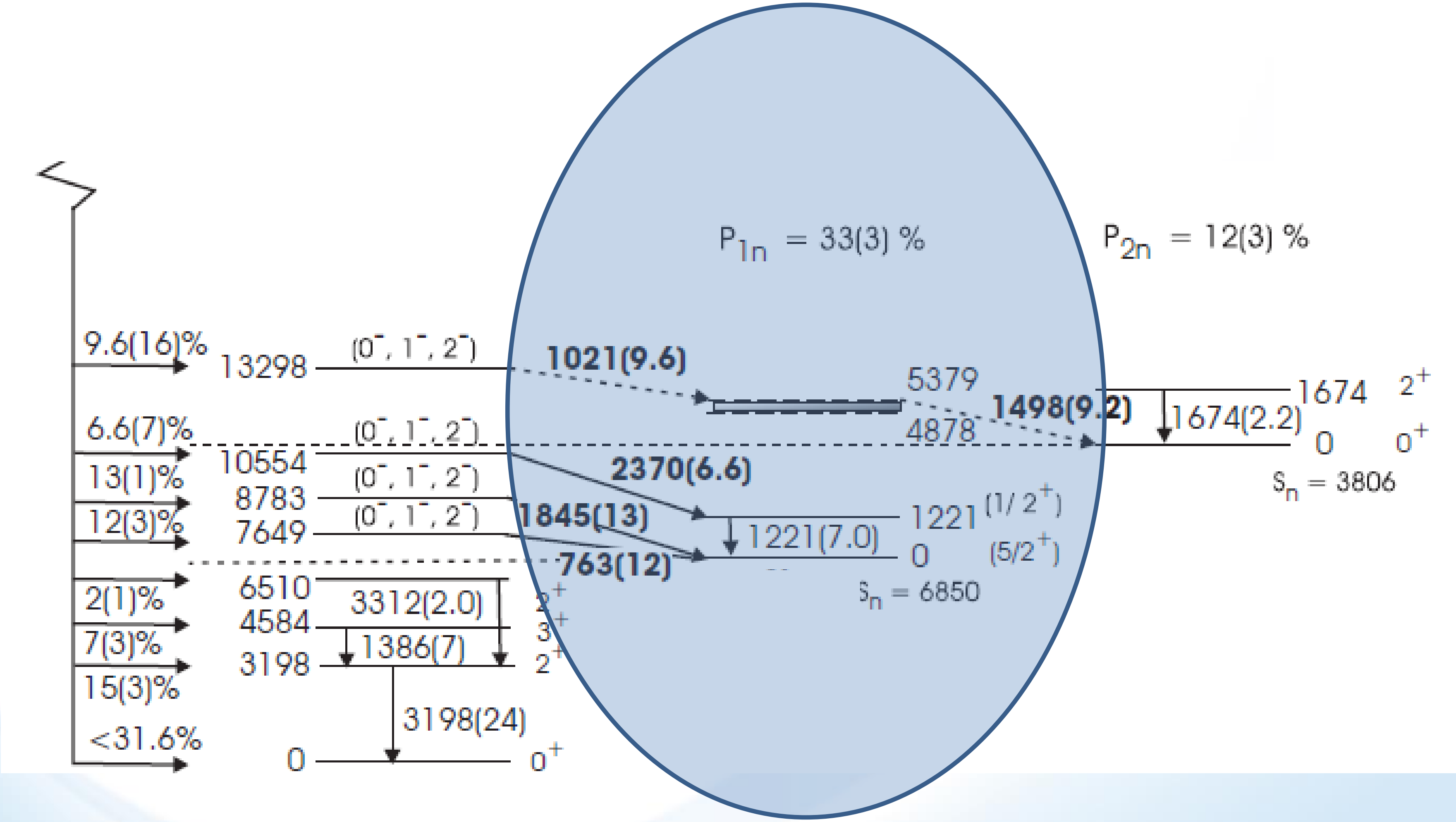
BR = 1

Keeping in mind that Pn=33% and P2n=12%

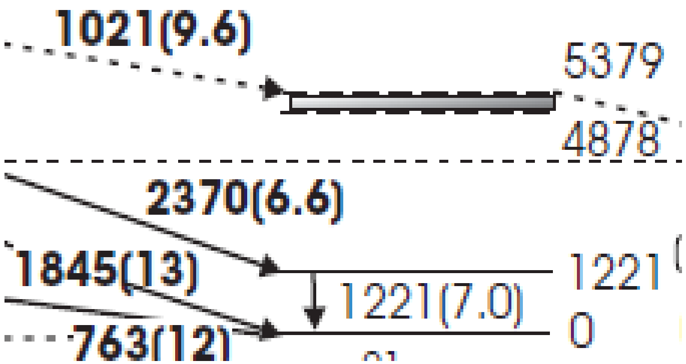
GS Beta Feeding is

100-Pn-P2n-ΣIγ(to gs)
100-33-12-24
< 32

The B-N Branch



P_{1n} = 33(3) %



Branching ratio is given
BR=0.33 3

Neutron and Gamma Intensities given in absolute units

What is NR ?

E_γ	E_{level}	I_γ[#]
1221 *3*	1221	7.0 *11*

[#]For absolute intensity per 100 decays, multiply by 0.33 *3*.

NR=1.0

The details

BR	Branching ratio multiplier for converting intensity per 100 decays through this decay branch to intensity per 100 decays of the parent nuclide. *Required if known.*
NR	Multiplier for converting relative *photon* intensity (**RI** in the **GAMMA** record) to *photons* per 100 decays of the parent through the decay branch or to *photons* per 100 neutron captures in an (n,γ) reaction. *Required* if the absolute photon intensity can be calculated.

This is Pn
BR=0.33

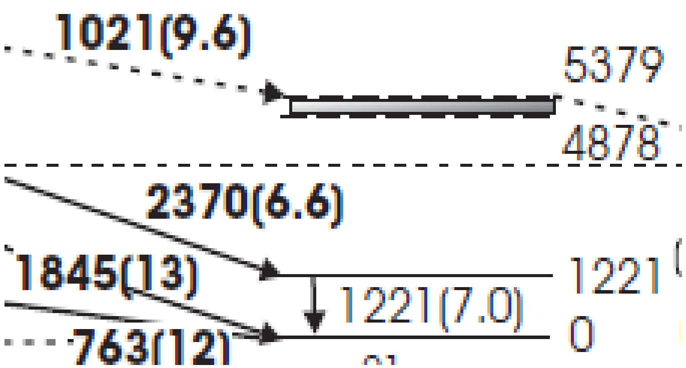
Iγ is given per 100 decays
Through the decay branch,
you need :

NR = 1.0/0.33

NR=3.03

P_{1n} = 33(3) %

# Branching ratio is given
BR=0.33 3



Neutron and Gamma Intensities given in absolute units

What is NP?

n Radiations

Branching Ratio: %β⁻n=33 3 (2010Su03).

E_n	E_{level}	I_n#	$E_{daughter}$	Comments
763 *1*	0.0	12 *3*	7649	
1021 *2*	5379	9.6 *16*	13298	E_n: assignment of 1021 and 1498 neutron groups
1845 *4*	0.0	13 *1*	8783	
2370 *6*	1221	6.6 *7*	10554	

For absolute intensity per 100 decays, multiply by 3.03.
@Placement in the level scheme is uncertain.

NP=3.03

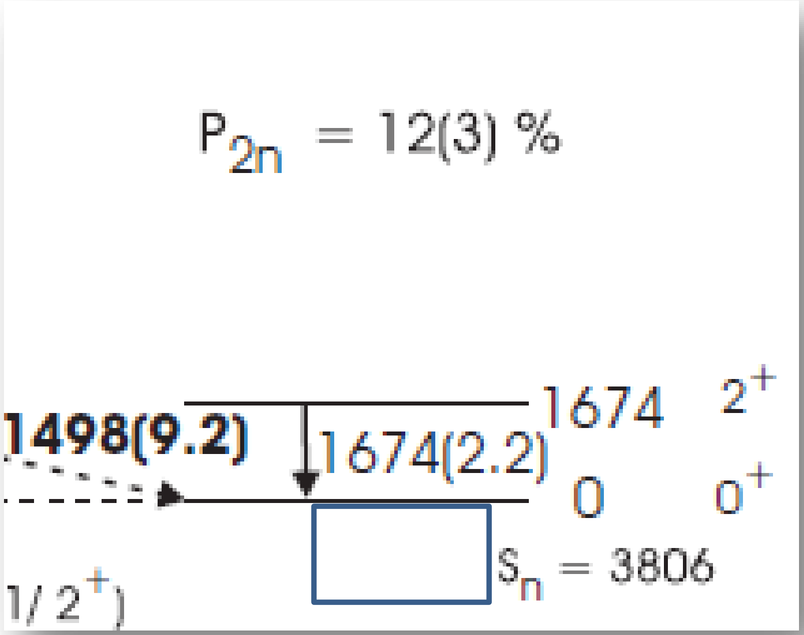
The details

Relative Intensity	Normalization Factor	Absolute Intensity
Iγ x	NR x BR	=%Iγ
I (tot) x	NT x BR	=%I (tot)
Iβ (or ε or α) x	NB x BR	= % Iβ (or ε or α)
Iβn (or Iεp) x	NP	= % Iβn (or Iεp)

Particle decays are treated differently

NP=1

Finally the B-2N Branch



NR = ?   1÷0.12

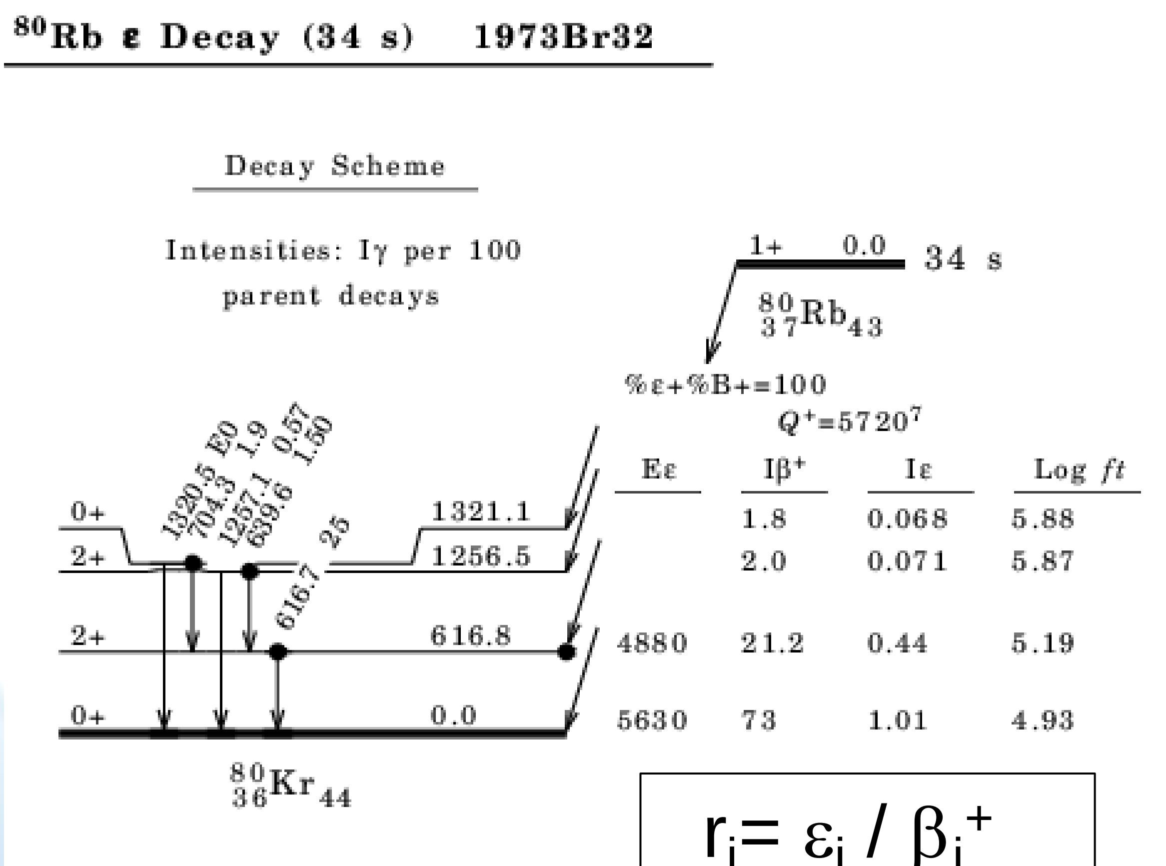
BR = ?   0.12

NP = ?   1.0

Use of Annihilation Radiation

I(γ±) = relative annihilation radiation intensity

X_i = intensity imbalance at the ith level



$r_i = \varepsilon_i / \beta_i^+$
(theoretical)

We want to isolate the β_i^+ feeding

$$X_i = \varepsilon_i + \beta_i^+$$

$$X_i = \beta_i^+ (1+r_i)$$

$$\beta_i^+ = X_i / (1+r_i)$$

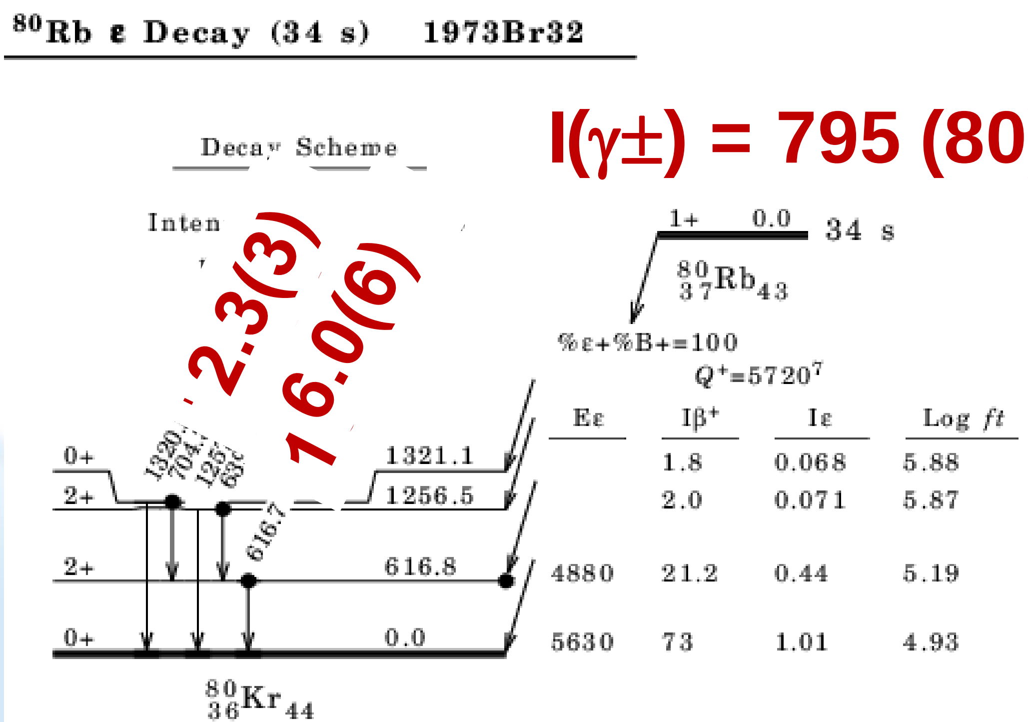
Use of Annihilation Radiation

$r_i = \varepsilon_i / \beta_i^+$ (theoretical)

How many $\gamma\pm$ do we expect?

$$I(\gamma\pm) = 2*[\ \beta_o^+ + \Sigma\ \beta_i^+\ ]$$

$$I(\gamma\pm) = 2*[\ X_o/(1+r_o) + \Sigma\ X_i/(1+r_i)\ ]$$



I(γ±) = 795 (80)

7.5/(1+0.068/1.8) = 7.23

8.3/(1+0.071/2.0) = 8.02

(100-6.0-7.5)/(1+0.44/21.2) = 84.7

7.2+8.0+84.7 = 99.9

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Use of Annihilation Radiation

Solve for X_o

$$I(\gamma\pm) = 2\,[\, X_o/(1+r_o) + \Sigma X_i/(1+r_i)\,]$$ **99.9**

$$X_o/(1+r_o) = (795/2) - 99.9 = 297.6$$

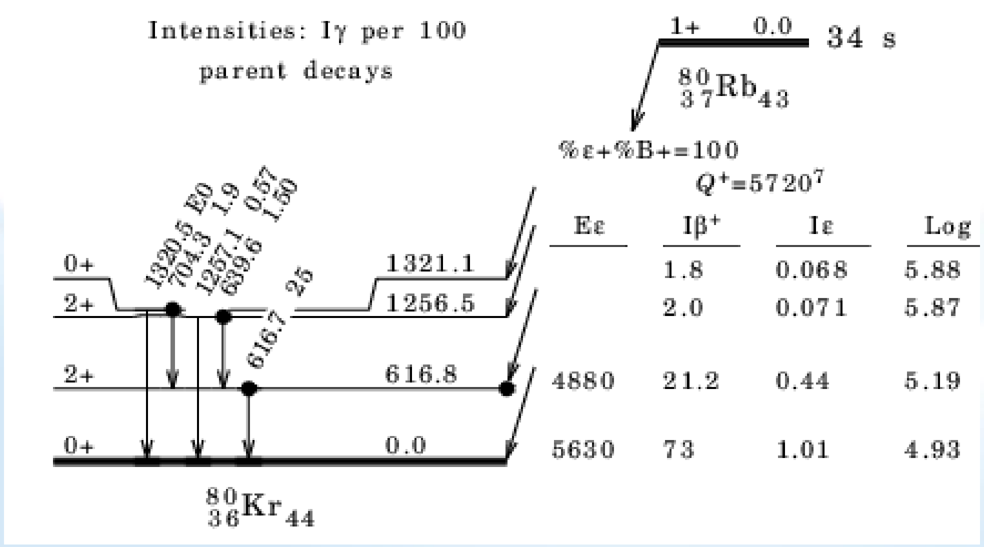
$$X_o = 297.6*(1+[1.01/73]) = 301.8$$

^{80}Rb ε Decay (34 s) 1973Br32

Decay Scheme

I(γ±) = 795 (80)

Intensities: Iγ per 100 parent decays



$$(X_o + \Sigma\, I(\gamma+ce)(\text{to gs}))*N = 100$$

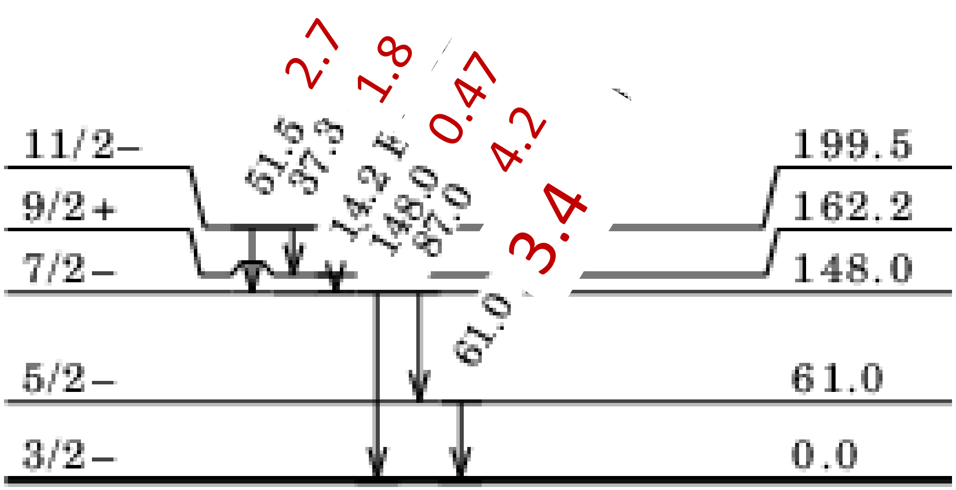
$$(301.8+100)*N = 100$$

$$N = 0.25$$

IT Decay Normalization

Usually easy, since whatever comes out of the isomer has to reach the g.s.

I(γ+ce) values



Many options:

ΣI(γ+ce)(to gs) = 100

N=100/(3.4+0.47) = **25.8**

ΣI(γ+ce)(out 199) = 100

N=100/(2.7+1.8) = **22.2**

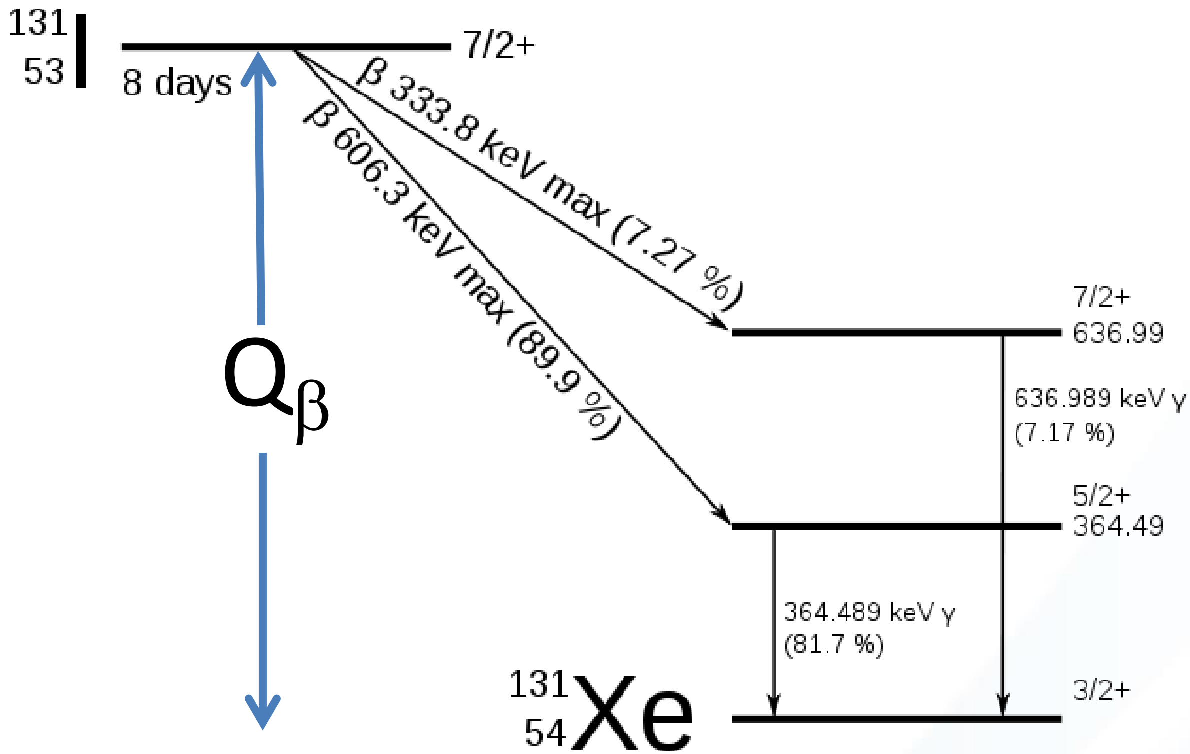
ΣI(γ+ce)(out 148) = 100

N=100/(4.2+0.47) = **21.4**

What's N?

Does it matter if not balanced?

Energy released in beta decay



$$\text{Electromagnetic (EM)} = \Sigma I_\gamma E_\gamma + \Sigma I_{x\text{-}ray} E_{x\text{-}ray}$$

$$\text{Light Particle (LP)} = \Sigma I_{\beta\text{-}} E_{\beta\text{-}} + \Sigma I_{ce} E_{ce} + \Sigma I_{Auger} E_{Auger}$$

$$\text{Total Energy} = EM + LP + E_{neutrino} = Q(\beta\text{-})$$

RADLIST

Program to analyze decay radiation (radiation list)
Few options

- Calculate energy release for each radiation type
- Generate ENDF file
- Generate NuDat file
- Generate MIRD output

RADLIST

Output from the program directly

```
                                                                                NO "2   " CARD
ALPHA         BETA         CE+AUGER     PHOTON       UNPL/GAM        RECOIL       NEUTRINO     ABSORBED      TOTAL        Q*BR

 0.000       267.321        0.000        2.398        0.000           0.002       491.694      269.721      761.414      769.000
 0.000         6.481        0.000        1.019        0.000           0.000        11.627        6.561       13.350        4.000
    INTENSITY SUMS
 0.000        49.568        0.000        1.118        0.000
 0.000         1.193        0.000        0.500        0.000
```

RADLIST

Output from the EVP editor

Parent Nucleus	Parent E(level)	Parent Jπ	Parent $T_{1/2}$	Decay Mode	GS-GS Q-value (keV)
$^{52}_{25}Mn$	0.0	6+	5.591 D *3*	EC: 100 %	4711.2 *19*

Energy Balance (keV)	
Gammas	3.46E+3 *5*
X-Rays	0.92 *3*
β minus	0
β plus	84 *14*
Conversion Electrons	0.510 *7*
Auger electrons	2.62 *5*
Neutrinos	1.17E+3 *3*
Recoil	0
Neutrons	0
Protons	0
Alphas	0
Sum	4.72E+3 *6*
Q-effective	4711.2 *19*
Missing Energy	0 *AP*
Ratio	0 % *AP*

Radiation Type	Energy (keV)	Absolute Intensity
γ XR l	0.57	0.26 *9*
γ XR ka2	5.405	5.1 *3*
γ XR ka1	5.415	10.1 *5*
γ XR kb1	5.947	1.13 *5*
γ XR kb3	5.947	0.58 *3*
γ 1	200.86 *10*	0.063 *7*
γ 2	346.02 *10*	0.865 *20*
γ 3	398.14 *10*	0.164 *19*
γ 4	399.61 *10*	0.160 *10*
γ 5	501.44 *10*	0.161 *18*
γ Annihil.	511.0	63 *5*
γ 6	600.13 *10*	0.360 *10*
γ 7	647.52 *10*	0.378 *13*
γ 8	744.06 *10*	87.8 *20*
γ 9	848.08 *10*	3.43 *8*
γ 10	901.48 *20*	0.037 *9*
γ 11	935.52 *10*	94.8 *21*
γ 12	1246.27 *10*	4.17 *10*