

# **Online Global Heavy Charged Particle Database/Horizontal Evaluation**

**Jon "Batch" Batchelder**

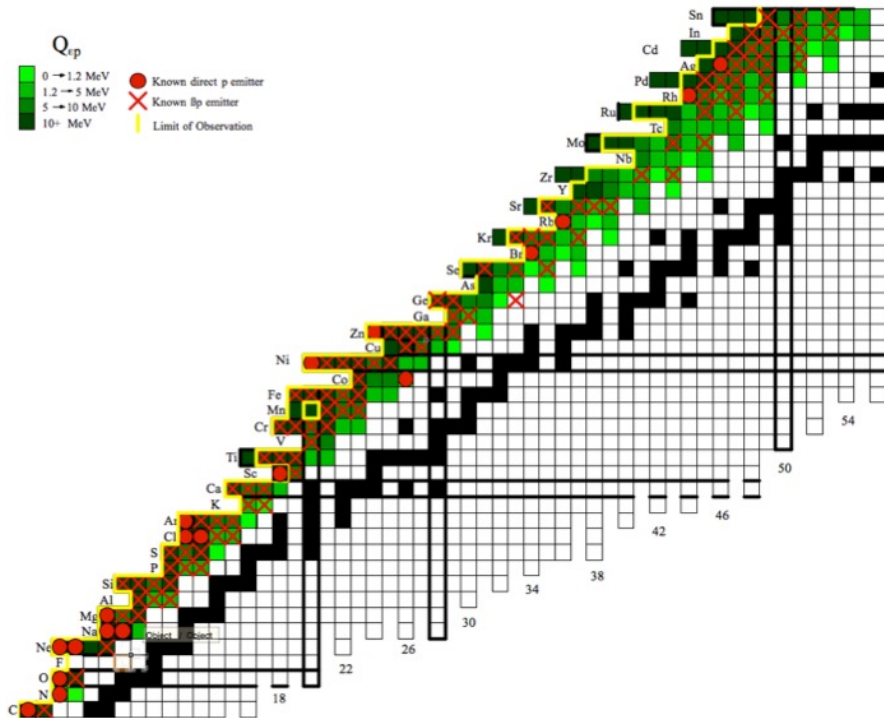
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# Direct and Beta-delayed proton emission is known from Li to Bi



# Currently known:

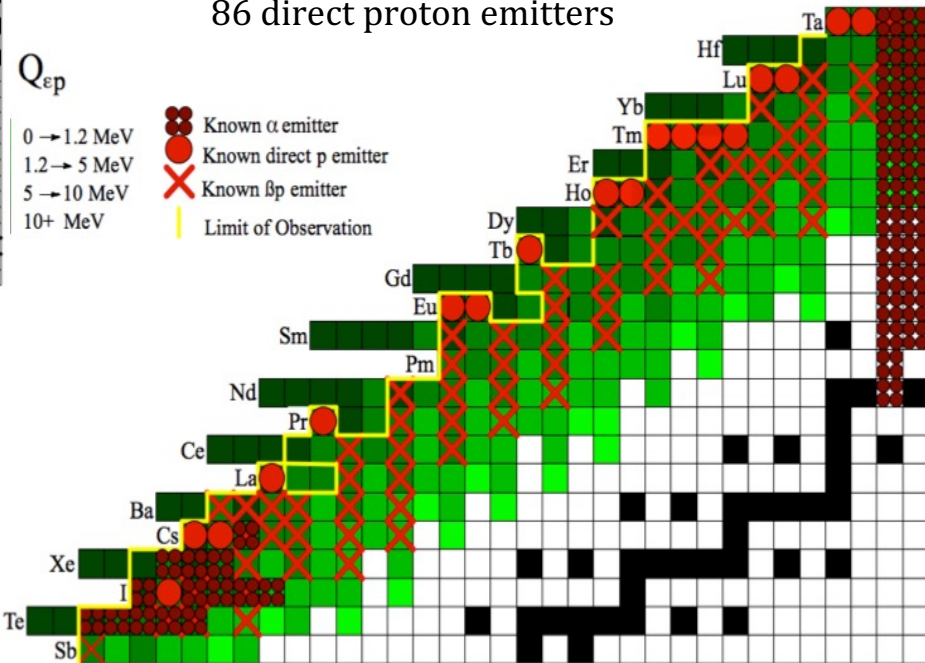
216  $\beta$ -p emitters

13  $\beta$ -2p emitters

3  $\beta$ -3p emitters

23  $\beta$ - $\alpha$  emitters

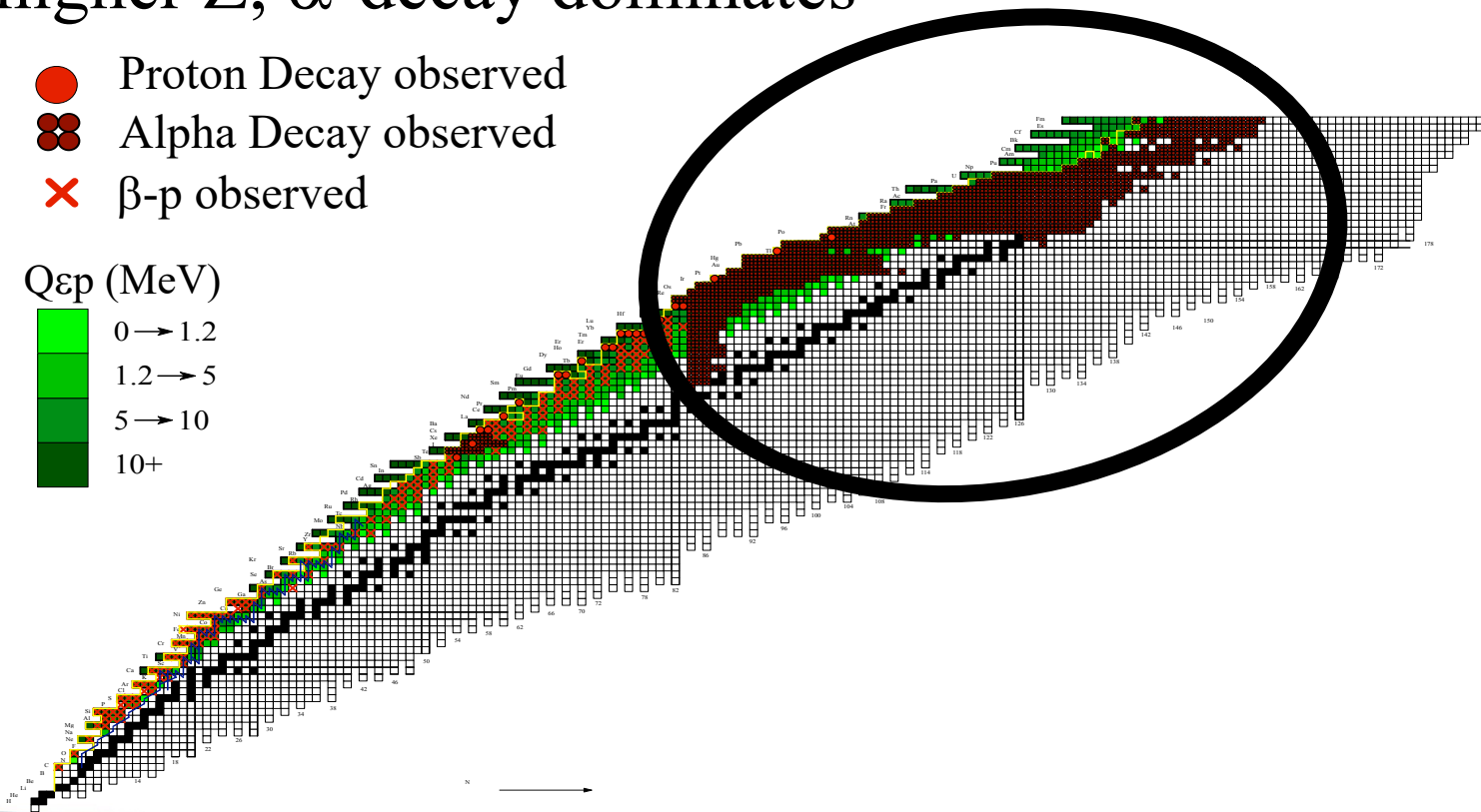
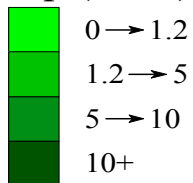
86 direct proton emitters



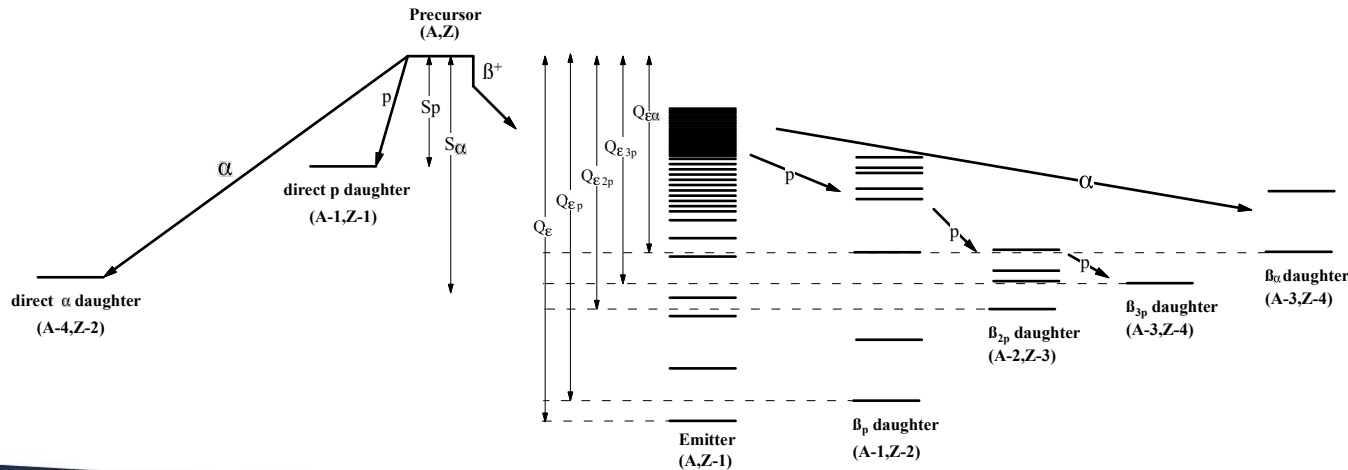
# At higher $Z$ , $\alpha$ -decay dominates

- Proton Decay observed
- Alpha Decay observed
- ×  $\beta$ -p observed

$Q_{\beta p}$  (MeV)



Schematic of a proton-rich nucleus that is energetically open to direct and  $\beta$ -delayed proton and alpha emission.



High lying levels are only populated by beta decay and can only be deduced by observing the emitted protons.

Near the drip-line this can be a very large percentage of the overall decay.

Energy levels in the emitter can be determined with the proton energies and masses of Emitter and  $\beta p$  daughter.

# Purpose of this horizontal evaluation/database

Provides an up to date database of relevant information on nuclei that decay by heavy charged particles  
- It will be updated as new results are published.

Designed for use by both experimenters and evaluators. Also useful as a teaching tool.

Builds on ADNDT article for beta-delayed p and  $\alpha$  emitters. Greatly expanding it to include direct p and  $\alpha$  decays.

Uses the latest mass evaluation used for level energies. All **Q and S values** taken or derived from from:

**2021Wa16** M. Wang, W. J. Huang, F. G. Kondev, G. Audi, S. Naimi, Chin. Phys. C 45, 030003 (2021).  
The current (and future) gold standard!

## What is included (and what is not)

All  $Q_{\beta\text{exp}}$ ,  $Q_{\alpha}$ ,  $S_p$ ,  $S_{2p}$  values for nuclei where these decays are energetically possible.

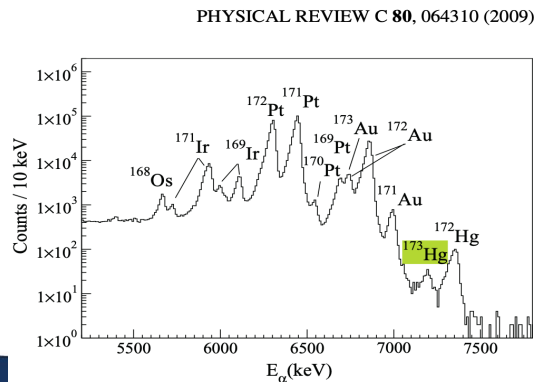
All known charged particle decays – BR,  $T_{1/2}$ , individual transitions (E, initial and final states)

Complete listing of relevant references for all direct and beta delayed

Alpha and p emitters in one place.

- targeted (and complete) – different from NSR – Example:

$^{173}\text{Hg}$   $\alpha$  decay- NSR lists 2009Ha42  $^{173}\text{Hg}$  only appears as a bg peak in a figure.



Only references with information relevant to the given nucleus are included.

All papers with information on the given nucleus including conference proceedings and reports.

Explicit refs for  $T_{1/2}$ , Energy, BR, etc.

## What is included (and what is not)

Organized by Tz (-4 to +32, even and odd – 145 datasets!), and A  
Simple decay chain figure included for each Tz.

Isomers ( $> 10$  ns) are treated separately.

- only decay from “long-lived” states included, not high energy states that emit p or  $\alpha$ .

No attempt is made at adding theoretical predictions or references.

## Timeline

Datasets from -4 to +7 (45 datasets with  $> 950$  references) done!  $\sim 1/3$  finished

All beta-delayed and nearly all direct proton emitters

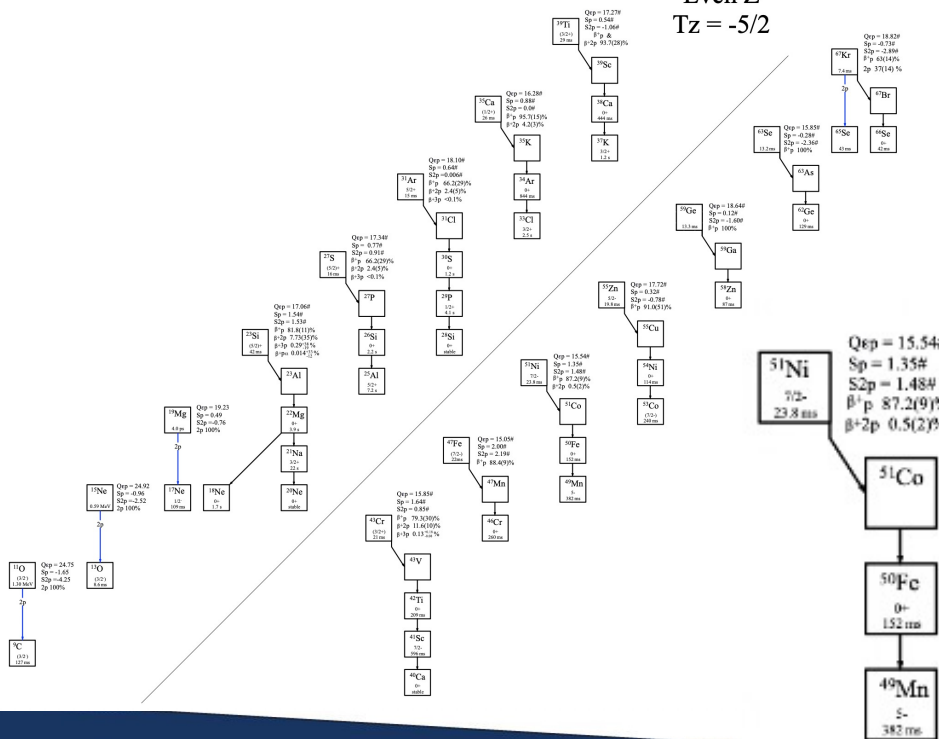
Most of the rest are alpha emitters

$\sim$  rate of 1 Tz dataset per week. Should be finished next fall – after that only updates/corrections

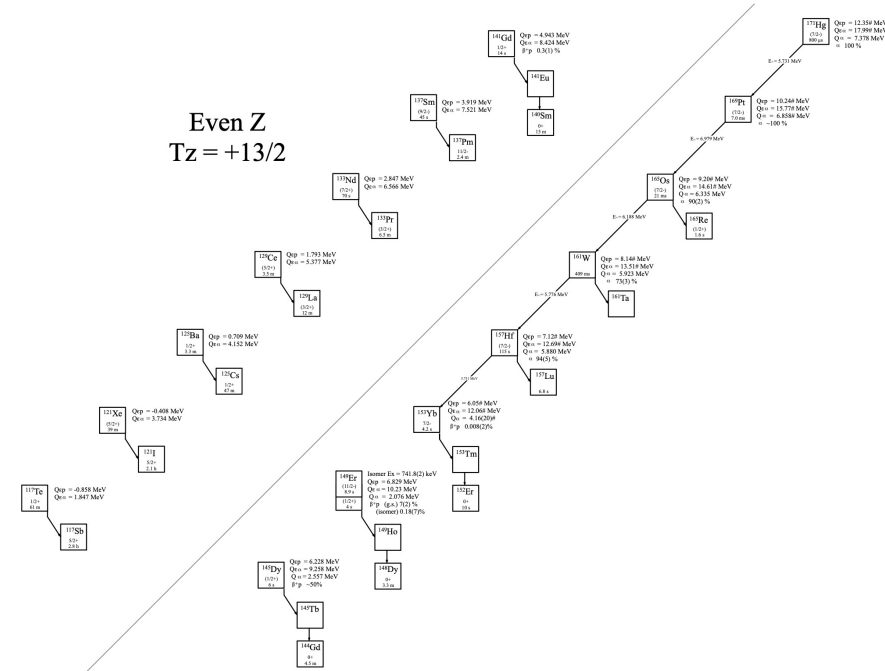
Will be begin sending update emails bimonthly soon.

Each Tz is broken into even and odd databases  
 Starts with a decay chain (with Q, S, T<sub>1/2</sub>, BR values)

Even Z  
 Tz = -5/2



Even Z  
 Tz = +13/2





Nuclide	$J^\pi$	$T_{1/2}$	$Q_\alpha$	$Q_{\beta p}$	$BR_{\beta p}$	$Q_{\alpha p}$	Experimental
<sup>117</sup> Te	1/2 <sup>+</sup>	61(2) m	3.544(13)	-0.858(13)	—	-10.137(13)	[1961Ff05]
<sup>121</sup> Xe	(5/2 <sup>+</sup> )	38.8(6) m	3.765(11)	-0.408(10)	—	-7.583(12)	[1969Bu07]
<sup>125</sup> Ba	1/2 <sup>+</sup>	3.3(4) m*	4.421(13)	0.709(11)		-6.304(12)	[1975Ar31, 1968Da09]
<sup>129</sup> Ce	(5/2 <sup>+</sup> )	3.5(3) m	5.040(40)	1.793(28)		-4.625(28)	[1993Al03]
<sup>133</sup> Nd	(7/2 <sup>+</sup> )	70(10) s	5.610(50)	2.847(51)		-3.141(54)	[1977Bo02]
<sup>137</sup> Sm	(9/2 <sup>-</sup> )	45(1) s	6.080(30)	3.919(31)		-1.634(31)	[1983AlZO]
<sup>141</sup> Gd	1/2 <sup>+</sup>	14(4) s	6.701(23)	4.943(23)	0.3(1)%	-0.301(24)	[1989Gi06, 1986Wi15]
<sup>145</sup> Dy	(1/2 <sup>+</sup> )	6(2) s	8.16(11)	6.228(29)	≈50%	1.421(13)	[1993To04, 1984ScZT]
<sup>149</sup> Er	(1/2 <sup>+</sup> )	4(2) s	7.900(30)	6.829(29)	7(2)%	2.423(29)	[1989Fi01, 1984ScZT]
<sup>149m</sup> Er**	(11/2 <sup>-</sup> )	8.9(2) s	8.642(30)	7.571(29)	0.18(7)%	3.165(29)	[1989Fi01, 1984To07, 1984ScZT]
<sup>155</sup> Yb	7/2 <sup>-</sup>	4.2(2) s	6.81(20)#	6.05(20)#	0.008(2)%	1.89(20)#	[1988Wi05]
<sup>157</sup> Hf	(7/2 <sup>-</sup> )	115(1) s	7.59(20)#	7.12(20)#		3.19(20)#	[1996Pa01]
<sup>161</sup> W		409(18) ms	8.27(20)#	8.14(20)#		4.62(20)#	[1996Pa01]
<sup>165</sup> Os	(7/2 <sup>-</sup> )	21(1) ms	8.91(20)#	9.20(20)#		6.21(20)#	[1996Pa01]
<sup>169</sup> Pt	(7/2 <sup>-</sup> )	7.0(2) ms	9.63(20)#	10.24(20)#		7.79(20)#	[2004Ke04]
<sup>173</sup> Hg	(7/2 <sup>-</sup> )	0.80(8) ms	10.17(20)#	11.16(20)#		9.17(20)#	[2012Od01]

\* Weighted average of 3.5(4) m [1975Ar31] and 3.0(5) m 1968Da09].

\*\* Excitation energy = 741.8(2) keV [1989Fi01].

**Table 2**  
Particle separation and  $\beta$ - $\alpha$  emission from the even-Z,  $T_z = +13/2$  nuclei

Nuclide	$S_p$	$S_{2p}$	$Q_\alpha$	$BR_\alpha$	$Q_{\epsilon\alpha}$	Experimental
<sup>117</sup> Te	5.562(14)	9.640(13)	0.808(14)		1.847(13)	
<sup>121</sup> Xe	6.023(18)	9.876(13)	0.190(17)		3.734(13)	
<sup>125</sup> Ba	5.217(14)	8.999(15)	0.387(15)		4.152(12)	
<sup>129</sup> Ce	4.951(61)	8.047(30)	0.957(30)		5.377(29)	
<sup>133</sup> Nd	4.394(55)	7.202(57)	1.530(54)		6.566(51)	
<sup>137</sup> Sm	4.111(75)	6.356(34)	1.916(55)		7.521(31)	
<sup>141</sup> Gd	3.527(55)	5.422(23)	2.343(35)		8.424(24)	
<sup>145</sup> Dy	3.163(29)	4.59(20)	2.557(21)		9.258(14)	
<sup>149</sup> Er	3.039(88)	4.12(29)	2.076(29)		10.23(11)	
<sup>149m</sup> Er*	3.781(88)	4.86(29)	2.818(29)		10.97(11)	
<sup>153</sup> Yb	2.73(21)#	3.47(20)#	4.16(20)#		12.06(20)#	
<sup>157</sup> Hf	2.44(21)#	2.93(20)#	5.880(3)	94(5)%**	12.69(20)#	[1996Pa01, 1979Ho10, 1989Wo02, 1981HoZM] 1973Ea01, 1965Ma14]
<sup>161</sup> W	1.972(208)#	2.23(20)#	5.923(4)	73(3)%	13.51(20)#	[1996Pa01, 1981Ho10, 1989Ho02, 1981HoZM]
<sup>165</sup> Os	1.563(208)#	1.42(21)#	6.335(6)	90(2)%	14.61(20)#	[2008Bi15, 1996Pa01, 2013Dr06, 2002Pa03] [1997Da07, 1991Se01, 1981Ho10, 1978Ca11, 1978CaZF, 1977Ca23]
<sup>169</sup> Pt	1.087(208)#	0.54(22)#	6.858(5)	≈ 100%	15.77(20)#	[2004Ke06, 1999Se14, 2012Od01, 2009Go16] [2008Bi15, 1996Pa01, 1981Ho10]
<sup>173</sup> Hg	0.632(208)#	-0.23(22)#	7.378(4)	100%	17.001(20)#	[2012Od01, 2009Sa27, 2004Ke04, 1999Se14] [1998NiZW1]

Table 1 – parent  $J_p$ ,  $T_{1/2}$ ,  $Q_{\beta xp}$  info

Table 2 – Direct proton and alpha info

If individual transitions are known,  
Energy, initial and final states  
branching, and explicit references for  
each number given.

**Table 4**  
direct  $\alpha$  emission from  $^{161}\text{W}^*$ ,  $T_{1/2} = 409(18)$  ms,  $BR_\alpha = 73(3)\%$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (abs)	$E_{daughter} (^{157}\text{Hf})$	coincident $\gamma$ -rays
5.923(5)	5.776(5)**	73(3)%	0.0	—

\* All values from [1996Pa01], except where noted.

\*\* Weighted average of 5.775(5) MeV [1996Pa01] and 5.777(5) MeV [1979Ho10].

**Table 5**  
direct  $\alpha$  emission from  $^{165}\text{Os}^*$ ,  $T_{1/2} = 21(1)$  ms,  $BR_\alpha = 90(2)\%^{**}$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (abs)	$E_{daughter} (^{161}\text{W})$	coincident $\gamma$ -rays
6.342(7)	6.188(7)	90(2)%**	0.0	—

\* All values from [1996Pa01], except where noted.

\*\* [2008Bi15].

**Table 6**  
direct  $\alpha$  emission from  $^{169}\text{Pt}^*$ ,  $T_{1/2} = 7.0(2)$  ms,  $BR_\alpha \approx 100\%^{**}$ .

$E_\alpha$ (c.m.)	$E_\alpha$ (lab)	$I_\alpha$ (abs)	$E_{daughter} (^{165}\text{Os})$	coincident $\gamma$ -rays
7.148(7)	6.979(7)	$\approx 100\%^{**}$	0.0	—

**Table 5**  
 $\beta$ -p emission from  $^{27}\text{S}^*$ ,  $T_{1/2} = 16.3(2)$  ms<sup>b</sup>,  $BR_{\beta p} = 62.2(29)\%$

$E_\beta$ (c.m.)	$I_\beta$ (rel)	$I_\beta$ (abs)	$E_{emitter} (^{27}\text{P})^a$	$E_{daughter} (^{26}\text{Si})^a$	coincident $\gamma$ -rays <sup>a</sup>
0.318(8)	100.0(9.1)	23.1(2.1)	1.125(12)	0	—
0.762(8)	38.5(6.1)	8.9(1)	1.569(12)	0	—
0.913(9)	6.5(1.8)	1.5(0.3)	4.507(13)	2.7871(1)	0.9889, 1.7922, 2.7870
1.054(9)	7.8(1.8)	1.8(0.3)	1.861(13)	0	—
1.282(9)	4.8(1.2)	1.1(0.2)	4.876(13)	2.7871(1)	0.9889, 1.7922, 2.7870
1.676(9)	2.6(1.8)	0.6(0.3)	5.270(13)	2.7871(1)	0.9889, 1.7922, 2.7870
1.86(12)	1.3(1.8)	0.3(0.3)	4.464(15)	1.7973	1.7973
1.951(11)	3.5(1.8)	0.8(0.3)	5.545(14)	2.7871(1)	0.9889, 1.7922, 2.7870
2.128(10)	4.3(1.8)	1(0.3)	5.722(13)	2.7871(1)	0.9889, 1.7922, 2.7870
2.264(9)	24.7(4.9)	5.7(0.8)	5.858(13)	2.7871(1)	0.9889, 1.7922, 2.7870
2.417(11)	6.9(2.4)	1.6(0.4)	5.021(14)	1.7973	1.7973
2.576(11)	5.6(2.4)	1.3(0.4)	6.170(14)	2.7871(1)	0.9889, 1.7922, 2.7870
2.717(10)	2.6(1.2)	0.6(0.2)	3.524(13)	0	—
2.808(10)	8.7(3.1)	2(0.5)	6.402(13)	2.7871(1)	0.9889, 1.7922, 2.7870
2.953(12)	4.8(2.4)	1.1(0.4)	6.547(15)	2.7871(1)	0.9889, 1.7922, 2.7870
3.03(12)	4.3(1.8)	1(0.3)	6.624(15)	2.7871(1)	0.9889, 1.7922, 2.7870
3.121(11)	4.8(2.4)	1.1(0.4)	6.715(14)	2.7871(1)	0.9889, 1.7922, 2.7870
3.238(11)	6.1(2.4)	1.4(0.4)	5.842(14)	1.7973	1.7973
3.475(12)	3.5(1.8)	0.8(0.3)	7.069(15)	2.7871(1)	0.9889, 1.7922, 2.7870

# Global Charged Particle Database - JSON format

# Why JSON?

- Direction of travel of ENSDF modernization
- Light-weight data format
- Human-readable
- Easily parsed
- Complete language with independent format

# STRUCTURE

JSON	Raw Data	Headers
Save	Copy	Collapse All   Expand All   Filter JSON
parentID:	"35Ca"	
parentA:	35	
parentZ:	20	
parentN:	15	
spinParity:	{...}	
▶ 0:	{...}	
isospinProjectionZ:	{...}	
▶ 0:	{...}	
halfLife:	{...}	
▶ 0:	{...}	
electronCapture:	{...}	
▶ 0:	{...}	
betaPlusDelayedOneProtonEmission:	{...}	
▶ 0:	{...}	
betaPlusDelayedTwoProtonEmission:	{...}	
▶ 0:	{...}	
betaPlusDelayedThreeProtonEmission:	{...}	
▶ 0:	{...}	
directOneProtonEmission:	{...}	
▶ 0:	{...}	
directTwoProtonEmission:	{...}	
▶ 0:	{...}	
directAlphaEmission:	{...}	
▶ 0:	{...}	
betaPlusDelayedAlphaEmission:	{...}	
▶ 0:	{...}	

$J^\pi$

$T_Z$

$T_{1/2}$  or width: in "best" units, seconds , MeV

# STRUCTURE

JSON	Raw Data	Headers
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Filter JSON		
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parentZ:	20	
parentN:	15	
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isospinProjectionZ:		
▶ 0:	{...}	
halfLife:		
▶ 0:	{...}	
electronCapture:		
▶ 0:	{...}	
betaPlusDelayedOneProtonEmission:		
▶ 0:	{...}	
betaPlusDelayedTwoProtonEmission:		
▶ 0:	{...}	
betaPlusDelayedThreeProtonEmission:		
▶ 0:	{...}	
directOneProtonEmission:		
▶ 0:	{...}	
directTwoProtonEmission:		
▶ 0:	{...}	
directAlphaEmission:		
▶ 0:	{...}	
betaPlusDelayedAlphaEmission:		
▶ 0:	{...}	



Q value, daughter nucleus information

# STRUCTURE

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parentN:	15	
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▼ isospinProjectionZ:		
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▼ halfLife:		
▶ 0:	{...}	
▼ electronCapture:		
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▼ betaPlusDelayedOneProtonEmission:		
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▼ betaPlusDelayedTwoProtonEmission:		
▶ 0:	{...}	
▼ betaPlusDelayedThreeProtonEmission:		
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▼ directOneProtonEmission:		
▶ 0:	{...}	
▼ directTwoProtonEmission:		
▶ 0:	{...}	
▼ directAlphaEmission:		
▶ 0:	{...}	
▼ betaPlusDelayedAlphaEmission:		
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Q value, branching ratio,  
proton emitter & daughter nucleus  
information

# STRUCTURE

JSON	Raw Data	Headers
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parentZ:	20	
parentN:	15	
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▼ halfLife:		
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▼ electronCapture:		
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▼ betaPlusDelayedOneProtonEmission:		
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▼ betaPlusDelayedTwoProtonEmission:		
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▼ betaPlusDelayedThreeProtonEmission:		
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▼ directTwoProtonEmission:		
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▼ directAlphaEmission:		
▶ 0:	{...}	
▼ betaPlusDelayedAlphaEmission:		
▶ 0:	{...}	

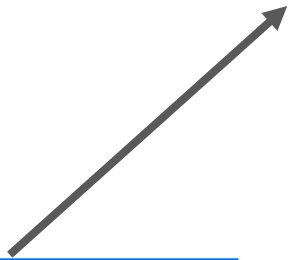
Separation energy, branching ratio,  
daughter nucleus information



# STRUCTURE

JSON	Raw Data	Headers
Save	Copy	Collapse All   Expand All   Filter JSON
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parentN:	15	
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isospinProjectionZ:		
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halfLife:		
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electronCapture:		
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betaPlusDelayedOneProtonEmission:		
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betaPlusDelayedTwoProtonEmission:		
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▶ 0:	{...}	
directOneProtonEmission:		
▶ 0:	{...}	
directTwoProtonEmission:		
▶ 0:	{...}	
directAlphaEmission:		
▶ 0:	{...}	
betaPlusDelayedAlphaEmission:		
▶ 0:	{...}	

Q value, branching ratio,  
alpha emitter & daughter nucleus  
information



# STRUCTURE

JSON	Raw Data	Headers
Save	Copy	Collapse All Expand All Filter JSON
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parentZ:	20	
parentN:	15	
spinParity:	{...}	
isospinProjectionZ:	{...}	
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betaPlusDelayedThreeProtonEmission:	{...}	
directOneProtonEmission:	{...}	
directTwoProtonEmission:	{...}	
directAlphaEmission:	{...}	
betaPlusDelayedAlphaEmission:	{...}	

If there are known individual transitions:  
charged particle energy,  
relative & absolute intensities,  
emitter energy,  
daughter energy,  
coincident gamma-ray energies

# STRUCTURE

JSON	Raw Data	Headers
Save	Copy	Collapse All Expand All Filter JSON
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parentZ:	20	
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▶ 0:	{...}	
▼ halfLife:		
▶ 0:	{...}	
▼ electronCapture:		
▶ 0:	{...}	
▼ betaPlusDelayedOneProtonEmission:		
▶ 0:	{...}	
▼ betaPlusDelayedTwoProtonEmission:		
▶ 0:	{...}	
▼ betaPlusDelayedThreeProtonEmission:		
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▼ directOneProtonEmission:		
▶ 0:	{...}	
▼ directTwoProtonEmission:		
▶ 0:	{...}	
▼ directAlphaEmission:		
▶ 0:	{...}	
▼ betaPlusDelayedAlphaEmission:		
▶ 0:	{...}	

If there are known individual transitions:  
charged particle energy,  
relative & absolute intensities,  
daughter energy,  
coincident gamma-ray energies

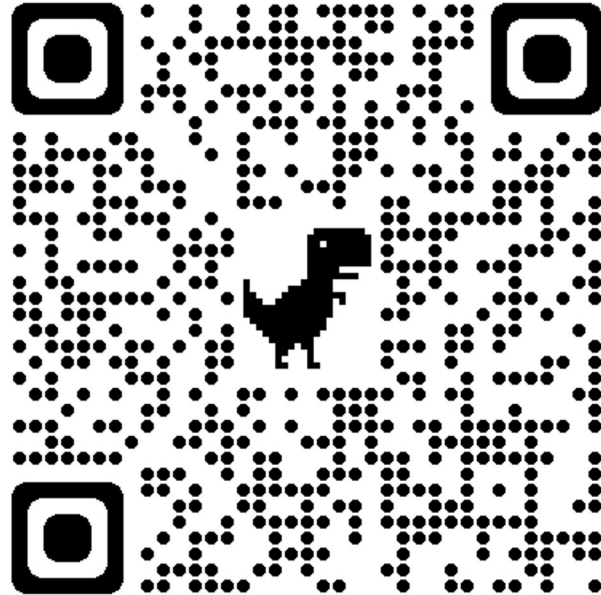
# STRUCTURE

- For each value: operator, uncertainty, reference(s)  $11.83(40)\#$
- Limit: less than, greater than, etc.  $<0.1\%$
- Range: lower and upper bounds  $1.909-2.647$
- Asymmetrical uncertainty:  
asymmetrical and symmetrized (mean, mode, median) values and uncertainties

$$0.029^{+38}_{-19}$$

# Jupyter Notebook Demonstration

# Where is the database?



Thank you for your attention!