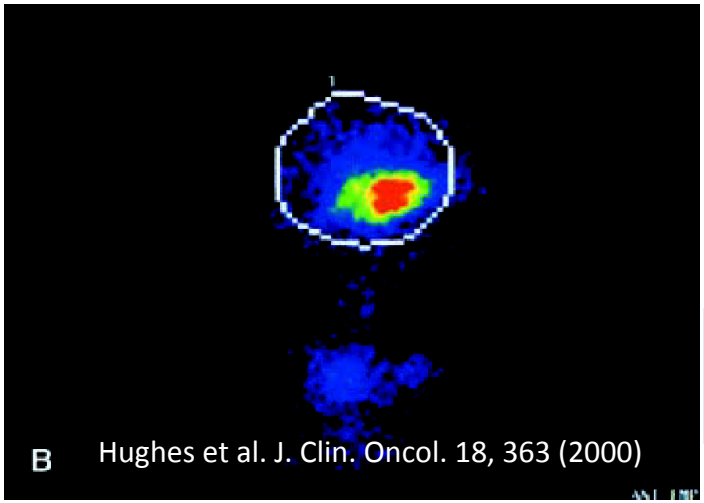
Why we need new measurements & evaluation on ^{67}Cu?

J. Chen & F.G. Kondev

Nuclear Medicine is a rapidly growing filed – needs high-accurate data (and their uncertainties) for **production**, imaging and therapeutic applications of many radionuclides.

This is an area where nuclear decay data and ENSDF in particular are of vital importance and the demand for high-quality data will even grow in the foreseeing future

Decay data properties of ^{67}Cu



Excellent properties: E_γ, $E_{\beta-}$ & $T_{1/2}$

- ✓ therapeutic: β− emitter
- ✓ imaging: 184-keV γ ray

^{67}Cu production:

(p,2p), (p,α),(n,p), (γ,p) @BNL, LANL, FRIB (future)

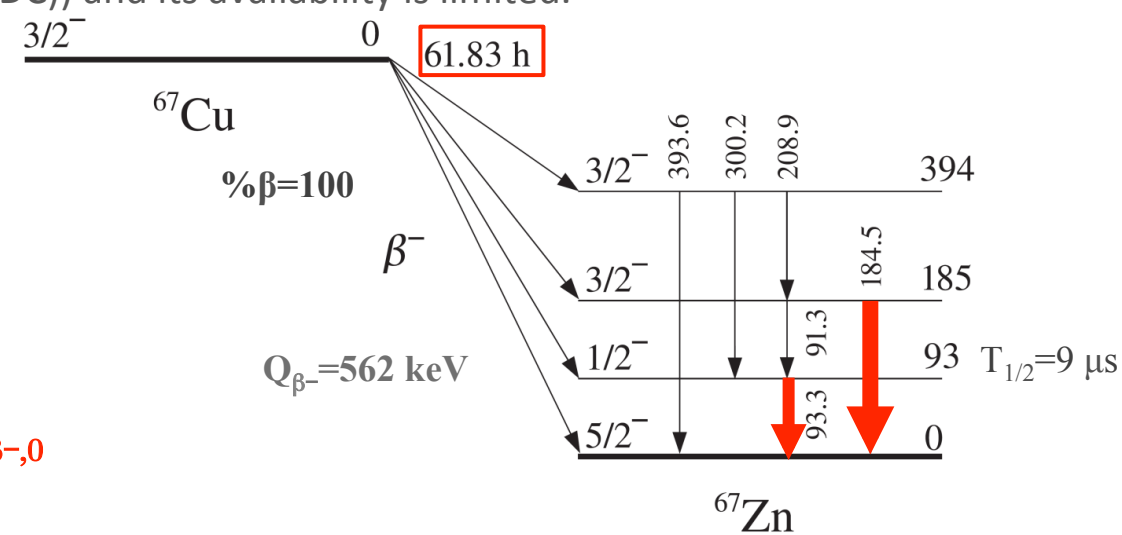
But it's expensive (~$295/mCi (DOE-NIDC)) and its availability is limited.

I_γ (abs) = N*I_γ(rel)

N=(100 – $I_{\beta-,0}$)/SUM[I_γ(tot) to gs]

Need to know:

I_γ(rel), Mult., MR (ICC) & $I_{\beta-,0}$



Ground-state to Ground-state β− branch

ENSDF	~20%
NUDAT	20 **(2)**%
MIRD (NNDC)	20%
MIRD (med)	20 **(2)**%
JEFF3.1	20 **(2)**%
ENDF/B-VII.1	20 **(2)**%

I_γ (185 keV) = 48.7 **(3)**% - used in all????, but … one should get 48.7 **(13)*** if $I_{\beta-,0}$=20 (2)%?

* - using the same ICCs as in the ensdf evaluation

BUT it is deduced with some (important) assumptions!!!!
the only place to find them is … ENSDF

Huo Junde, Huang Xiaolong, J.K. Tuli Nuclear Data Sheets 106, 159 (2005)

ENSDF & TOI

^{67}Zn levels

E_{level} #	J^{π} @	$T_{1/2}$	Comments
0.0	5/2-	stable	
93.311 *5*	1/2-	9.10 μs *7*	$T_{1/2}$: from 1973Le18.
184.577 *6*	3/2-		
393.530 *7*	3/2-		

From a least-squares fit to the Eγ data.
@From adopted levels.

β⁻ Radiations

E_{β^-}	E_{level}	I_{β^-} #	Log *ft*	Comments
(168.2)	393.530	≈1.1	≈5.8	av Eβ=51.0 *25*
(377.1)	184.577	≈57	≈5.2	av Eβ=121 *3*
(468.4)	93.311	≈22	≈6.0	av Eβ=154 *3*
(561.7)	0.0	≈20	≈6.3	av Eβ=189 *3*
				I_{β^-}: from 1953Ea11.

#From γ-ray intensity balance at each level, except as indicated.

γ(^{67}Zn)

I_γ Normalization: Based on a g.s. β⁻ branching of ≈20% (1953Ea11) and 10% E2 for the 184γ corresponding to the δ=0.34 4 derived from the ce data of 1966Fr12.

very precise … , BUT

$I_{\beta-,0}$ = 20.0 (6) from GTOL

E_γ @	E_{level}	I_γ #@	Mult. &	δ &	α	Comments
91.266 *5*	184.577	7.0 *1*	M1+E2	+0.06 *5*	0.083 *8*	α(K)exp=0.066 10(1969Li04) α(K)=0.073 *7*; α(L)=0.0076 *8*
93.311 *5*	93.311	16.1 *2*	E2		0.873	α(K)exp=0.77 8(1966Fr12) α(K)=0.751; α(L)=0.0920
184.577 *10*	184.577	48.7 *3*	M1+E2	0.34 *4*	0.0180 *13*	α(K)exp=0.0156 10(1966Fr12) α(K)=0.0158 *11*; α(L)=0.00165 *12* **δ:** from α(K)exp+α(L1)exp=1.72×10⁻² 10(1966Fr12).
208.951 *10*	393.530	0.115 *5*	M1+E2	-0.034 *21*	0.00913 *6*	α(K)=0.00804 *6*; α(L)=0.00082
300.219 *10*	393.530	0.797 *11*	M1+E2	+0.20 *8*		

NUDAT

Authors: HUO JUNDE, HUANG XIAOLONG, J.K. TULI Citation:Nuclear Data Sheets 106, 159 (2005)

Parent Nucleus	Parent E(level)	Parent Jπ	Parent $T_{1/2}$	Decay Mode	GS-GS Q-value (keV)	Daughter Nucleus	Decay Scheme	ENSDF file
$^{67}_{29}Cu$	0.0	3/2-	61.83 h *12*	β^-	561.7 *15*	$^{67}_{30}Zn$		

Beta-:

Energy (keV)	End-point energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
51.0 *25*	168.2 *15*	1.10 % *11*	5.6E-4 *6*
121 *3*	377.1 *15*	57 % *6*	0.069 *7*
154 *3*	468.4 *15*	22.0 % *22*	0.034 *3*
189 *3*	561.7 *15*	20.0 % *20*	0.038 *4*

different than ENSDF …????

Mean beta- energy: 141 keV *13*, total beta- intensity: 100 % *6*, mean beta- dose: 0.141 MeV/Bq-s *16*

JEFF3.1

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*****************************************************************
**            JEFF-3.1 Radioactive Decay Data File             **
**         Compiled at the NEA Data Bank - Feb 2005            **
**            Original data taken from:  UKPADD64              **
*****************************************************************
         J N MO, S SEN          NUCL DATA SHEETS 39 (1983) 741
         M R BHAT               NUCL DATA SHEETS 64 (1991) 875
         S A REYNOLDS ET AL     NUCL SCI ENG 32 (1968) 46:
                                HALF-LIFE
         N MARCEAU ET AL        INT J APPL RAD ISOT 21 (1970) 667:
                                HALF-LIFE
         F LAGOUTINE ET AL      INT J APPL RAD ISOT 23 (1972) 219:
                                HALF-LIFE
         S J ROTHMAN ET AL      PHYS REV 9C (1974) 2272:
                                HALF-LIFE
         H T EASTERDAY          PHYS REV 91 (1953) 653
         M S FREEDMAN ET AL     PHYS REV 151 (1966) 886
         S RAMAN, J J PINAJIAN NUCL PHYS A131 (1969) 393
         R A MEYER ET AL        PHYS REV 17C (1978) 1822
```

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DECAY SCHEME DERIVED FROM THE GAMMA-RAY MEASUREMENTS OF RAMAN AND
PINAJIAN, AND MEYER ET AL, COMBINED WITH THE BETA-PARTICLE
STUDIES OF EASTERDAY (GROUND STATE TRANSITION OF 0.20(2) WAS
ADOPTED).  INTERNAL CONVERSION COEFFICIENTS WERE CALCULATED FROM
THE DATA OF FREEDMAN ET AL, WITH A MAJORITY OF THE GAMMA-RAY
TRANSITIONS DEFINED AS M1+E2.
```

```
   MEAN BETA- ENERGIES:-
END POINT(MEV)= 0.1820  SHAPE= 0  MEAN= 0.0509  INT= 0.0110
END POINT(MEV)= 0.3910  SHAPE= 0  MEAN= 0.1207  INT= 0.5710
END POINT(MEV)= 0.4830  SHAPE= 0  MEAN= 0.1541  INT= 0.2180
END POINT(MEV)= 0.5760  SHAPE= 0  MEAN= 0.1893  INT= 0.2000

   MEAN GAMMA ENERGY                =    114.8352  KEV
   MEAN BETA- ENERGY                =    140.9306  KEV
   BETA- + NEUTRINO ENERGY          =    445.7570  KEV
   MEAN X-RAY ENERGY                =      0.5733  KEV
   MEAN AUGER ELECTRON ENERGY       =      0.7813  KEV
   MEAN CONVERSION ELECTRON ENERGY=     13.9548  KEV
   EFFECTIVE Q VALUE                =    576.0000  KEV
   UNCERTAINTY IN EFFECTIVE Q (%) =      1.3889
   CALCULATED Q VALUE               =    575.9016  KEV
   % DEVIATION                      =      0.0171
```

ENDF/B-VII.1

```
************************ Begin Description ************************
**          ENDF/B-VII.1 RADIOACTIVE DECAY DATA FILE             **
**          Produced at the NNDC from the ENSDF database         **
**                Translated into ENDF format by:                **
**     T.D. Johnson, E.A. McCutchan and A.A. Sonzogni, 2011      **
*******************************************************************
ENSDF evaluation authors: HUO JUNDE, HUANG XIAOLONG, J.K. TULI
Parent Excitation Energy: 0.0
Parent Spin & Parity: 3/2-
Parent half-life: 61.83 H 12
Decay Mode: B-
************************ Energy  Balance ************************
Mean Gamma Energy:       1.148E2 +- 5.933E-1 keV
Mean X-Ray+511 Energy:   5.425E-1 +- 3.646E-2 keV
Mean CE+Auger Energy:    1.439E1 +- 2.263E-1 keV
Mean B- Energy:          1.412E2 +- 8.778E0 keV
Mean B+ Energy:          0.000E0 +- 0.000E0 keV
Mean Neutrino Energy:    2.910E2 +- 1.792E1 keV
Mean Neutron Energy:     0.000E0 +- 0.000E0 keV
Mean Proton Energy:      0.000E0 +- 0.000E0 keV
Mean Alpha Energy:       0.000E0 +- 0.000E0 keV
Mean Recoil Energy:      0.000E0 +- 0.000E0 keV
Sum Mean Energies:       5.619E2 +- 1.997E1 keV
Q effective:             5.617E2 keV
Missing Energy:          -2.324E-1 keV
Deviation:               -4.137E-2 %
```

Radiation type: beta-minus
Average decay energy: 1.4121E+05 (8.5638E+03) eV
Discrete spectrum normalization: 1.0000E+00 (0.0000E+00)
4 discrete endpoints given

```
1.6817E+05 (1.5000E+03)     0.0110 ( 0.0011)     allowed, nonunique
3.7712E+05 (1.5000E+03)     0.5700 ( 0.0570)     allowed, nonunique
4.6839E+05 (1.5000E+03)     0.2200 ( 0.0220)     allowed, nonunique
5.6170E+05 (1.5000E+03)     0.2000 ( 0.0200)     allowed, nonunique
```

PHYSICAL REVIEW VOLUME 91, NUMBER 3 AUGUST 1, 1953

The Radioactivity of Cu^{67}

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(Received March 4, 1953)

The β spectrum of Cu^{67} is found to contain three groups with maximum energies and relative intensities of 577 kev, 20 percent; 484 kev, 35 percent; 395 kev, 45 percent. Conversion electrons from 92- and 182-kev transitions were observed. These results and the absence of the 296-kev γ ray indicate that the β transitions go to the ground and first two excited states of the known Zn^{67} levels.

TABLE I. Beta and gamma rays of Cu^{67}.

	Transition energy (kev)	Relative intensity (percent)	*ft* values
Beta	577	20	6.26 (*l*-forbidden)
	484	35	5.73
	395	45	5.35
Gamma	92		
	182		

no uncertainty - approximate value?

a multi-million $ question: What is the ground-state $\beta-$ feeding intensity in decay of ^{67}Cu?