Decay Data Evaluation Project: Updating the evaluations of nuclear decay data and their importance in radionuclide metrology

Aurelian LUCA [1] and Xavier MOUGEOT [2]

[1] Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), DRMR/LMRI, Magurele, Ilfov county, RO-077125, ROMANIA

[2] Université Paris-Saclay, CEA, List, Laboratoire National Henri Becquerel (LNHB), F-91120 Palaiseau, FRANCE

SUMMARY:

-Nuclear decay data and their applications

-Nuclear decay data evaluation and the DDEP collaboration

-Updating evaluations of nuclear decay data for radionuclides of interest in nuclear medicine

-Two examples: ^{52}Mn and ^{52m}Mn

-Work in progress and future developments: ^{226}Th, ^{230}U

-Criteria for nuclear decay data evaluation updates and conclusions

Nuclear decay data and their applications

- Reliable and precise nuclear decay data are needed in many applications: medicine, research, nuclear industry, metrology services, radiation protection, environmental monitoring etc.
- In ionizing radiation metrology, which involves radioactivity measurements using absolute and relative activity standardization methods, the nuclear decay schemes have been carefully evaluated for the last 50 years.

Nuclear decay data evaluation and the DDEP collaboration

- The Decay Data Evaluation Project (DDEP) international initiative started in 1995, with the aim to provide carefully produced recommended data for applied research and detector calibrations, http://www.lnhb.fr/ddep_wg/ (peer review evaluations)
- The DDEP database is hosted by the Laboratoire National Henri Becquerel (LNHB) from CEA Saclay, France (about 220 nuclides in 2017), *Kellett and Bersillon (2017)*
- Decay data for radionuclides of interest: half-life, decay energy, decay modes and branching fractions, radiation energies and emission probabilities. Decay schemes consistency checks are performed.

Updating evaluations of nuclear decay data for radionuclides (DDEP approach)

- Decay data for several radionuclides with applications in nuclear medicine were initially evaluated (DDEP procedures and tools) in the frame of the IAEA CRP F41029 „Nuclear data for charged-particle monitor reactions and medical isotope production” (2012-2018), *R. Capote et al. (2017)*
- NEW developments become available recently:

-**New Atomic Mass Evaluation** (AME 2020, *Meng Wang et al., 2021*): updated decay energies (Q-values) which influence the beta endpoint energies in the decay schemes.

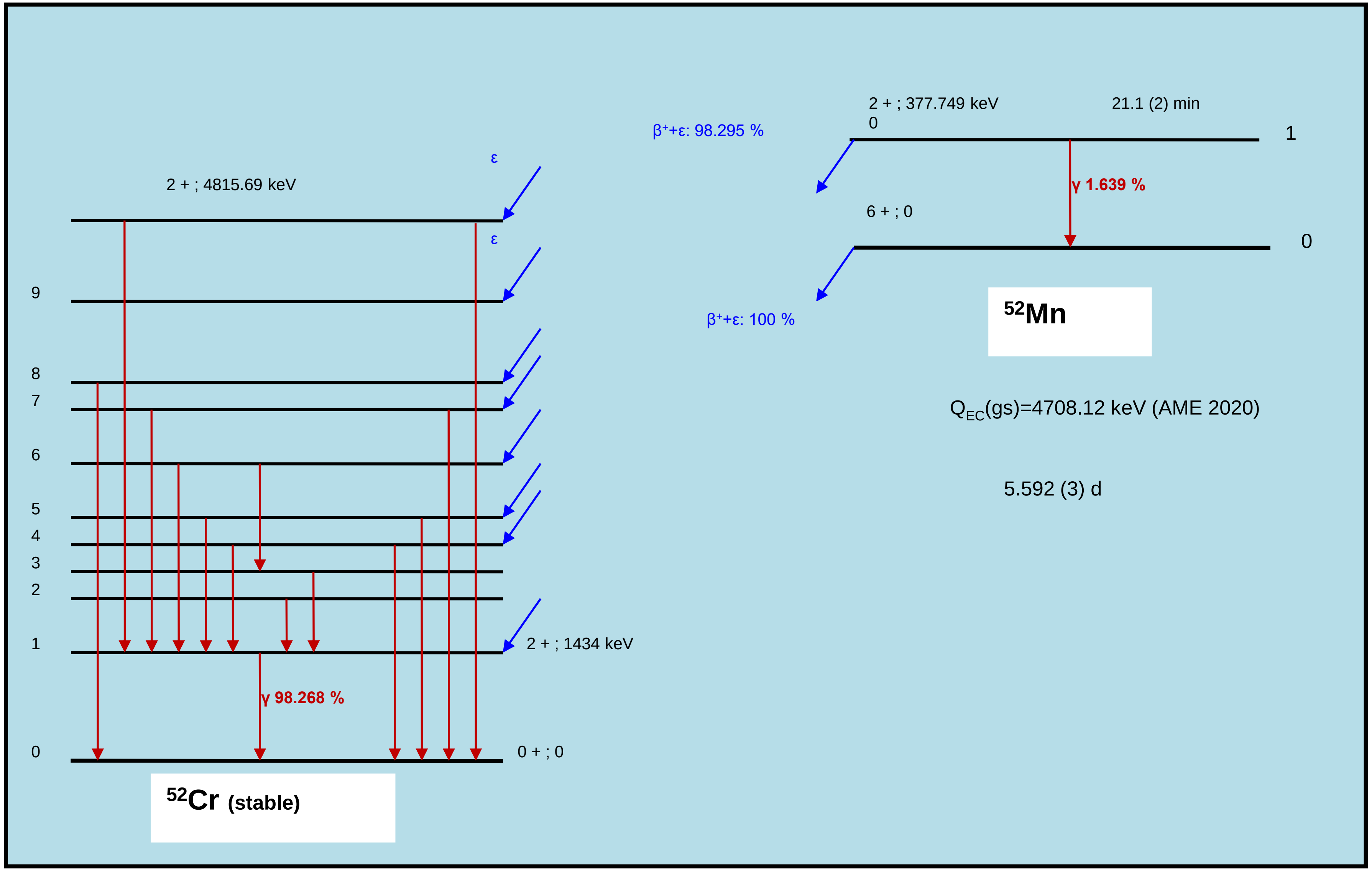
Updating evaluations of nuclear decay data for radionuclides (DDEP approach)

- **BetaShape code – release of a new improved version (2.2/2021):** very useful for beta transitions and electron captures (EC); it provides improved and validated calculations for single transition and total β spectra, EC probabilities and their ratios for all subshells, mean energies, log ft values, EC/β+ ratios and branch splitting (*X. Mougeot, 2015 and 2019*)
- **In some cases, new data from literature can become available** as the number of international scientific articles published each year is increasing.

Examples: ^{52}Mn and ^{52m}Mn

- **Decay data for ^{52}Mn and ^{52m}Mn** (*good potential to be used for PET myocardial perfusion, SPECT medical applications, Manganese-Enhanced Magnetic Resonance Imaging for stem-cell tracking and neural tractography, see C.M. Lewis et al. (2015), S.A. Graves et al. (2015)*) were evaluated in the frame of the IAEA CRP F41029, with the main results published by A. Luca in 2017 (based on AME 2012). Both radionuclides decay by EC/β+, while the ^{52m}Mn decay also by isomeric transition (IT) to the ground state of ^{52}Mn.
- UPDATED EVALUATIONS (2020-2021) based on the AME 2016 and the **new AME 2020** (released in March 2021) and the BetaShape code led to some important changes and improvements, regarding the decay energy, main EC transitions and β+ emissions (less important changes about the Auger K and L electron emissions), as shown in the following tables:

The nuclear decay scheme of ^{52m}Mn



Nuclear Decay Data for ^{52}Mn	Evaluation 2017	Updated Evaluation 2020	Updated Evaluation 2021 (new only)
Half-life	5.592 (3) days	5.592 (3) days	See eval. 2020
Decay Energy (Q)	4711.2 (19) keV (AME 2012)	4712.0 (19) keV (AME 2016)	**4708.12 (6) keV** (AME 2020)
Main EC transitions (energy,probability)	1597.3 (19) keV: 61.1 (9) % 1095.3 (19) keV: 7.67 (6) % 695.7 (19) keV: 1.07 (5) %	1598.1 (19) keV: 59.9 (7) % 1096.1 (19) keV: 7.67 (6) % 696.5 (19) keV: 1.07 (5) %	1598.1 (19) keV: 60.4 (7) %
Main β+ emissions (max. Energy, prob.)	575.6 (19) keV: 29.7 (4) %	576.1 (19) keV: 30.85 (43) %	576.1 (19) keV: 30.41 (29) %
Main γ-rays emissions (Energy, intensity)	511 keV: 59.4 (8) % 744.213 (6) keV: 90.0 (8) % 848.134 (26) keV: 3.36 (3) % 935.519 (10) keV: 94.89 (30) % 1246.36(12) keV: 4.229(40) % 1333.614(11) keV: 5.079(30) % 1434.06(15) keV: 99.9866(2) %	511 keV: 62.3 (15) % 744.213 (6) keV: 90.0 (8) % 848.134 (26) keV: 3.36 (3) % 935.519(10) keV: 94.887 (30) % 1246.36(12) keV: 4.229 (40) % 1333.614(11) keV: 5.079 (30) % 1434.06(15) keV: 99.9866 (19) %	See eval. 2020
Auger K, L electrons Cr (Energy, prob.)	K: (4.55-5.98) keV: 44.3 (7) % L: (0.42-0.69) keV: 6.52 (18) %	K: (4.55-5.98) keV: 43.4 (7) % L: (0.42-0.69) keV: 6.74 (10) %	See eval. 2020
X_K rays of ^{52}Cr (Energy, probability)	K_α: 5.41 keV: 15.86 (26) % K_β: (5.95+5.99) keV: 2.14 (6) %	K_α: 5.41 keV: 15.55 (26) % K_β: (5.95+5.99) keV: 2.09 (5) %	See eval. 2020

Nuclear Decay Data for ^{52m}Mn	Evaluation 2017	Updated Evaluation 2020	Updated Evaluation 2021 (new only)
Half-life	21.1 (2) minutes	21.1 (2) minutes	See eval. 2020
Decay Energy (Q)	5088.9 (19) keV (AME 2012)	5089.7 (19) keV (AME 2016)	**5085.87 (6) keV** (AME 2020)
Main EC transitions (energy, probability)	3655.2 (19) keV: 1.55 (7) %	3655.7 (19) keV: 1.466 (11) %	3655.7 (19) keV: 1.4725 (25) %
Main β+ emissions (max. Energy, prob.)	2633.2 (19) keV: 96.41 (5) %	2633.7 (19) keV: 96.474 (45) %	2633.7 (19) keV: 96.467 (46) %
Main γ-rays emissions (Energy, intensity)	511 keV: 193.25 (10) % 377.738 (5) keV: 1.64 (4) % 1434.06 (1) keV: 98.254 (42) % 1727.53 (7) keV: 0.216 (10) %	511 keV: 193.42 (9) % 377.749 (5) keV: 1.639 (40) % 1434.06 (1) keV: 98.268 (42) % 1727.53 (7) keV: 0.216 (10) %	See eval. 2020
Auger K, L electrons Cr (Energy, prob.)	K: (4.55-5.98) keV: 1.06 (5) % L: (0.42-0.69) keV: 0.157 (8) %	K: (4.55-5.98) keV: 1.003 (13) % L: (0.42-0.69) keV:0.1549 (17) %	See eval. 2020
X_K rays of ^{52}Cr (Energy, probability)	K_α: 5.41 keV: 0.380 (13) % K_β: (5.95+5.99) keV: 0.0512 (24) %	K_α: 5.41 keV: 0.359 (6) % K_β: (5.95+5.99) keV: 0.0484 (11) %	See eval. 2020

Decay data consistency check

- Comparison between the decay energy Q (AME 2020) and the energy computed from the evaluated decay scheme (SAISINUC software, LNHB)
- **^{52}Mn**: Q(eval. 2017)=4701 (16) keV, Q(eval. 2021)=4711 (21) keV, Q^+(AME 2016)=4712.0 (19) keV, Q^+(AME 2020)=4708.12 (6) keV. Improvement: relative difference from -0.23% (2017) to 0.06% (2021).
- **^{52m}Mn:** Q(eval. 2017)=5088.9 (19) keV and Q(eval. 2021)=5086.91 (14) keV, Q^+(AME 2016)=5089.7 (19) keV, Q^{IT}=377.749 (5) keV (*ref. 2015Ya15*); Q^+(AME 2020)=5085.87 (6) keV.

Relative difference: from -0.016% (2017) to 0.020% (2021)

Work in progress: updated evaluations for ^{230}U and ^{226}Th

- ^{230}U and its daughter ^{226}Th are two alpha-particle emitting radionuclides, evaluated in the frame of the above mentioned IAEA CRP (*A. Luca, 2020; A. Luca and M.-R. Ioan, 2018*). These nuclides are of interest for targeted alpha therapy (TAT).
- For ^{226}Th a review of the alpha-particle energies and transition probabilities is underway in collaboration with Dr. Balraj Singh (Canada). New data published recently about the level spins and parity (*P.A. Butler et al., 2020*) are considered, too. This is an interesting attempt to harmonize the evaluation procedures used in ENSDF and DDEP evaluations. The update of the ^{230}U evaluation will follow in the future.

How often should nuclear decay data evaluations be updated ?

- When new experimental data, reviewed data and evaluation studies are published
- When new improved versions of computer codes used for evaluations are available
- When the evaluation procedures are updated
- When there is a special interest for a new emerging radionuclide with important applications (e.g. in nuclear medicine); sometimes, there are no decay data evaluations for such radionuclides.
- **When man power and funding are available for this work!**
- A tentative TIME INTERVAL for updates: 10 to 15 years.

CONCLUSIONS

- New developments (AME 2020, BetaShape code ver. 2.2/2021) allowed to perform updated decay data evaluations for ^{52}Mn and ^{52m}Mn.
- For two other updated evaluations (^{226}Th and ^{230}U –alpha-particle emitters) a harmonized collaboration based on DDEP and ENSDF procedures in underway.
- Nuclear decay data evaluations should be updated according to several criteria, especially based on the users needs.

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THANK YOU !

Ciucas Mountains (Romania)