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Decay data evaluation project: Evaluation of ^{52}Mn and ^{52m}Mn nuclear decay data

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Abstract. All nuclear decay data within the ^{52}Fe-^{52m,52}Mn-^{52}Cr decay chain have been evaluated at IFIN-HH, Romania, as part of an IAEA coordinated research project (F41029) and incorporated into the Decay Data Evaluation Project (DDEP). Both ^{52}Fe and daughter ^{52}Mn are two potentially promising radionuclides to be incorporated into suitable radiopharmaceuticals for PET and SPECT imaging. The decay data evaluation of ^{52}Fe has previously been published and reported to the IAEA Nuclear Data Section. Equivalent DDEP evaluations for ^{52}Mn and ^{52m}Mn have also been completed recently, and are presented in summary form below. These improved decay data sets have also been reported to the IAEA in detail, and are highly suitable in dose rate calculations for their application in nuclear medicine.

1. Introduction

Established in 1995, the Decay Data Evaluation Project (DDEP) is an international initiative with the main objective "to provide carefully produced recommended data for applied research and detector calibrations", `www.nucleide.org/DDEP.htm`. This is achieved by performing peer-review evaluations for the following nuclear decay data of the radionuclides of interest: half-life, decay energy, decay modes and branching fractions, and radiation energies and emission probabilities. The complete DDEP database is hosted by the Laboratoire National Henri Becquerel (CEA/LNE-LNHB) from France.

^{52}Mn and ^{52m}Mn are two radionuclides with potential to be used in PET and SPECT medical applications. While ^{52m}Mn has been used to monitor myocardial perfusion by PET, ^{52}Mn can also be applied to dual modality manganese-enhanced magnetic resonance imaging (MEMRI) applications, such as neural tractography and stem-cell tracking, [1,2]. The aim of the present work was a complete characterization of the ^{52}Fe-^{52m,52}Mn-^{52}Cr decay chain. The presently reported results complement the evaluation of the ^{52}Fe nuclear decay data which was recently published [3]. The work was done under the IAEA Coordinated Research Project "Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production".

2. Evaluation steps and tools

The most recent ENSDF evaluation for the mass chain A=52 was studied [4]. The energy of the nuclear levels, and the spin and parity values were adopted from this evaluation, while the total decay energies are from the atomic mass evaluation [5]. All relevant published experimental data for ^{52m}Mn and ^{52}Mn were identified and copies stored for subsequent use (eight and seventeen references, respectively). The cut-off dates for the references were January and March 2016, respectively. Both the compilation and evaluation of the nuclear decay data sets were then undertaken. Finally, the decay scheme parameters were analyzed and tested.

The two evaluations were done according to the DDEP procedures. Several recommended software tools were used (produced by specialists from CEA/LNE-LNHB, BNL/NNDC (USA), PTB (Germany) or ANU (Australia)): SAISINUC, LWEIGHT4, LOGFT, EC-Capture, Emission, BrIcc etc..

3. Results

^{52m}Mn decays 98.295(42)% by electron capture and $\beta+$ to excited levels of ^{52}Cr, and by isomeric transition (IT) to the ground state of ^{52}Mn (1.705(42)%), Fig. 1. ^{52}Mn decays 100% by electron capture and $\beta+$ to excited levels of ^{52}Cr. Both radionuclides have important emissions of positrons (allowed transitions) and gamma-rays on a wide energy range. The half-life values adopted represent the weighted averages of three and seven experimental values for ^{52m}Mn and ^{52}Mn, respectively.

3.1. Recommended decay data

The results obtained for the main decay data of ^{52m}Mn and ^{52}Mn are presented in Table 1: half-life, decay energy, and energies and emission probabilities of the different transitions. Other evaluated data: fluorescence yields: $\omega_K(^{52}\text{Mn}) = 0.289(5)$. The conversion electrons have very low emission probabilities of the order of 10^{-4} (K shell) and less.

3.2. Normalization factor for the γ-ray transitions

The Normalization factor (F) is used to calculate the absolute γ-ray emission probabilities from the adopted γ-ray

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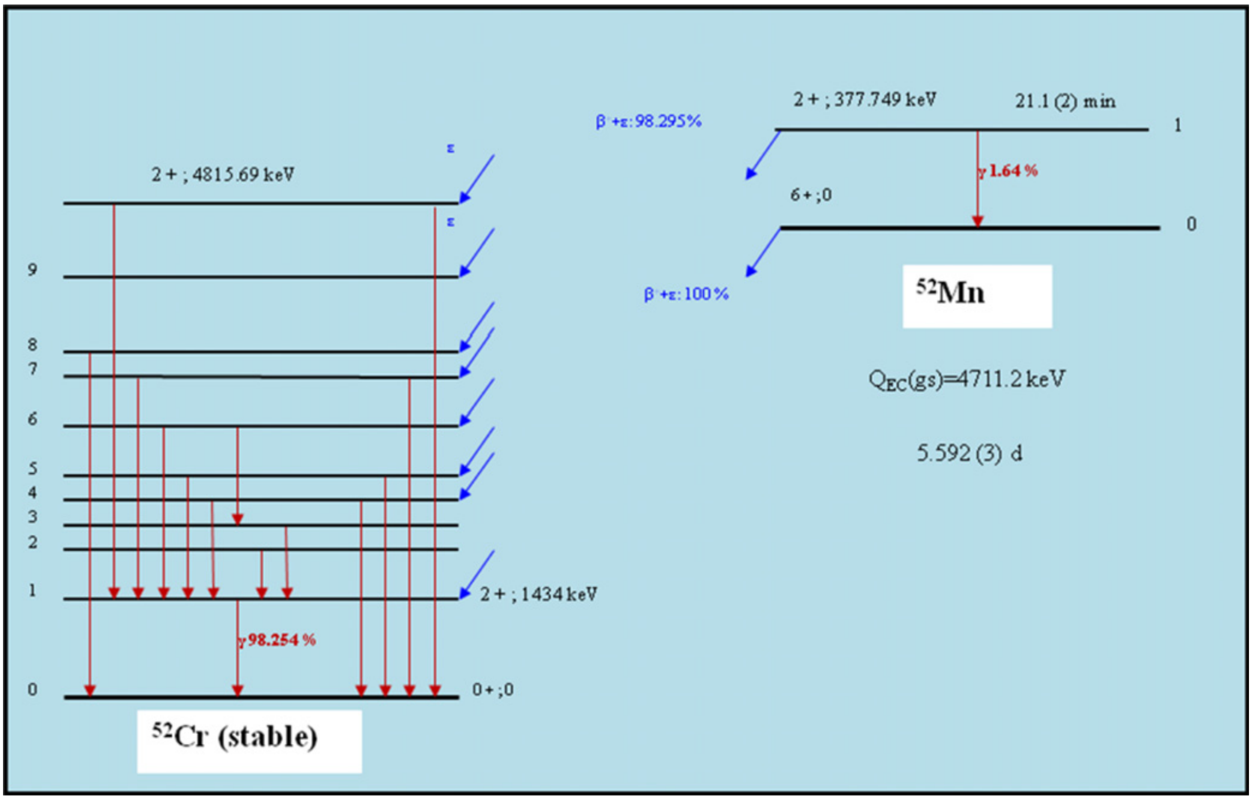

Figure 1. Decay scheme of ^{52m}Mn.

Table 1. Evaluated decay data for ^{52m}Mn and ^{52}Mn.

Nuclear Data	^{52m}Mn	^{52}Mn
Half-life ($T_{1/2}$)	21.1 (2) minutes	5.592 (3) days
Decay Energy (Q)	5088.9 (19) keV	4711.2 (19) keV
Main Electron Capture transitions (energy, probability)	3655.2 (19) keV; 1.55 (7) %	1597.3 (19) keV; 61.1 (9) % 1095.3 (19) keV; 7.67 (6) % 695.7 (19) keV; 1.07 (5) %
Main β^+ emissions (max. energy, probability)	2633.2 (19) keV; 96.41 (5) %	575.6 (19) keV; 29.7 (4) %
Main gamma-rays emissions (energy, emission 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; 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) %
Auger K and L Electrons (energy, probability)	K: (4.55 – 5.98) keV; 1.06 (5) % L: (0.42 – 0.69) keV; 0.157 (8) %	K: (4.55 – 5.98) keV; 44.3 (7) % L: (0.42 – 0.69) keV; 6.52 (18) %
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; 15.86 (26) % K_β: (5.95 + 5.99) keV; 2.14 (6) %

relative intensities. The Normalization Factor was calculated by imposing the following two conditions. ^{52m}Mn: 98.295(42)% of the transitions (all, with the exception of the IT transition) populate the ground state of the ^{52}Cr daughter: $F = 0.98254(42)$. For ^{52}Mn: 100% of the transitions (with the exception of the IT decay) populate the ground state of the ^{52}Cr daughter: $F = 0.999866(2)$.

3.3. Testing the consistency of decay schemes

According to the SAISINUC testing tools, the sum of all the energies involved in the ^{52m}Mn decay (EC, γ, etc.), with the exception of the gamma-ray isomeric transition, is 5089.1 (36) keV, which is in very good agreement with the Q_{EC} value: 5088.9 (19) keV.

For ^{52}Mn, the adopted Q_{EC} value from Wang et al. (2012) is 4711.2 (19) keV, while the value calculated by SAISINUC from the decay data recommended by the present work is 4701 (16) keV. These two values agree within the stated uncertainties (the relative difference is about 0.22%); however, this difference of about 10 keV might be explained by two gamma-rays of high energy and very low emission intensity that are not yet placed in the decay scheme [4]: 1441(1) keV and 1839.14(17) keV.

New accurate experimental data, such as half-lives, maximum positron energies and gamma-ray energies and emission probabilities, are strongly needed for both radionuclides. Improved measurements of positron and gamma-ray spectra (gamma singles and gamma-gamma coincidences) could solve the inconsistency mentioned above and lead to a better knowledge of the ^{52}Mn decay scheme.

4. Conclusions

Two new DDEP evaluations for ^{52m}Mn and ^{52}Mn nuclear decay data have been performed. These improved recommended decay data sets will be made available to the users through the DDEP database and the IAEA.

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