DECAY-DATA: Coding of 511 keV Annihilation Decay Data

(N. Otsuka, 2020-12-07, Memo CP-D/1005)

Note added to this Working Paper

There are two questions for discussion:

Q1) Do we always use AR for coding of annihilation gamma-ray intensity?

Solution 1: Use DG when the γ-ray intensity is given in the article. Use AR when the γ-γ coincidence intensity (=β^+-ray intensity) is given in the article.

Solution 2: Always use AR. Code the intensity given by the author multiplied by two when the author gives the β^+-ray intensity instead of the γ-ray intensity.

Q2) Rename the subfield name from "Abundance" into "Intensity"?

These two questions are followed by a proposal for addition of decay data related reference to LEXFOR "Decay Data".

1. Radiation type and intensity of annihilation decay data coded under DECAY-DATA

Here are two examples of the DECAY-DATA code string for ^{11}C annihilation γ-ray detection:

EXFOR 20348.002 (B.Anders+, J,ZP/A,301,353,1981
511 keV γ-ray-511 keV γ-ray coincidence counting is reported with its β+ intensity $I_{\beta+}$=99.76%

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DECAY-DATA (6-C-11,20.25MIN,AR,511.,.9976)
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2. Experimental

The excitation functions of the reactions listed in Table 1 were measured at the Hamburg Isochronous Cyclotron with activation techniques via the 20.4 m β^+ activity (branching: 99.76%, *EC:* 0.24% [14]) of ^{11}C. All irradiations were performed with single target plus catcher foils and the cyclotron being tuned to

The ^{11}C production cross section in this experiment was determined by

$$\sigma = [N(511\ \text{keV}\ \gamma\text{-}511\ \text{keV}\ \gamma\ \text{coincidence}) / I_{\beta+}] \ldots$$

EXFOR 22702.002 (Y.Uno, J,NSE,122,247,1996)
Detection of 511 keV γ counting reported with its γ intensity I_γ=199.518%

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DECAY-DATA (6-C-11,20.39MIN,DG,511.0,1.99518)
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TABLE IV

Measured Reactions and Decay Data

Target Nuclide	Reaction	Product Nuclide	*Q* Value (MeV)	Half-Life	E_γ (keV)	I_γ (%)
^{12}C	$(n,2n)$	^{11}C	−18.72	20.39 min	511.0	199.518
^{30}Si	(n,np)	^{29}Al	−13.51	6.56 min	1273.4	89.1

The ^{11}C production cross section in this experiment was determined by

$$\sigma = [N(511\ \text{keV}\ \gamma) / I_\gamma] \ldots$$

Note that $I_\gamma = 2I_{\beta+}$.

We observe two ambiguities in coding of the 511 keV annihilation gamma decay data:

1. Choice of the radiation type – DG (decay gamma) or AR (annihilation radiation)?
2. Choice of the abundance (intensity) – number of gammas or coincidences?

The appendix of this memo lists the abundances of all DECAY-DATA code strings having (1) "DG" or "AR" in the radiation type subfield and (2) "511" in the energy subfield, and compared them with the annihilation gamma intensities extracted by Marco Verpelli (NDS) from the ENSDF library. It shows no consistency for both radiation type and abundance.

We may have the following two solutions for coding of decay data for annihilation γ detection:

Solution 1
Use DG when the γ-ray intensity is coded. Use AR when the γ-γ coincidence intensity (=β^+-ray intensity) is coded.

Solution 2
Always use AR. Code the intensity written by the author by two when the author gives the β^+-ray intensity instead of the γ-ray intensity.

2. DECAY-DATA subfield name: "Abundance" or "Intensity"

Rename of the subfield "Abundance" to "Intensity" is additionally proposed by Viktor Zerkin (NDS) since he considers that many users believe "abundance" usually means "isotopic abundance" in EXFOR. Indeed we routinely see "intensity" in decay data compilations, and ENSDF and ENDF manuals adopt it. On the other hand, this renaming would add confusion for those who are familiar with the current EXFOR convention.

3. Reference to decay data under REL-REF

LEXFOR "DECAY-DATA" mentions that "If the data given are taken from a known source, the reference for it may be coded under the keyword REL-REF". I think it is rather important to code the decay data reference when the author cites a decay data reference (e.g., Table of Isotopes) but without providing the decay data themselves in the EXFOR source article.

Proposed change in LEXFOR "Decay Data"

(Many thanks to Otto Schwerer for formulating these sentences)

Decay Data
(See also **Half Lives**)
…
Free text explanation is often desirable, for example, a statement on whether the decay data were obtained from the experiment or quoted from another source.

- If the data given are taken from a known source, the reference for it may be coded under the keyword REL-REF (see Reference).

- If the authors quote only the source of the decay data but not their numerical values, the source should always be coded under REL-REF.

Appendix: 511 keV γ-rays (DG or AR) under DECAY-DATA in EXFOR Master (Ver.2020-09-25)

- "Type" (radiation type) shaded by green shows DG (AR) coded with the number of coincidences (γ-rays) per decay, i.e., against the proposed new rule.
- "Intensity (ENSDF)" is displayed as its upper boundary on the LiveChart of Nuclides.
- "Ratio" gives the intensity (EXFOR)/ intensity (ENSDF).
- "Remark" is given when the ratio is not within 1.0±0.1 or 2.0±0.1.

Nuclide	Type	Eγ	Intensity (EXFOR)	Intensity (ENSDF)	Ratio	EXFOR #	Remark
6-C-11	DG	511.0	0.995	1.995	2.0		
6-C-11	AR	511.	1.000	1.995	2.0		
6-C-11	DG	511.0	1.995	1.995	1.0		
6-C-11	AR	511.	1.995	1.995	1.0		
6-C-11	AR	511.	1.920	1.995	1.0		
6-C-11	AR	511.0	2.000	1.995	1.0		
6-C-11	AR	511.	2.000	1.995	1.0		
6-C-11	AR	511.	0.998	1.995	2.0		
7-N-13	AR	511.	1.996	1.996	1.0		
7-N-13	AR	511.0	1.996	1.996	1.0		
7-N-13	AR	511.0	2.000	1.996	1.0		
7-N-13	AR	511.	2.000	1.996	1.0		
7-N-13	DG	511.	2.000	1.996	1.0		
7-N-13	AR	511.	1.000	1.996	2.0		
8-O-14	AR	511.	0.994	1.998	2.0		
8-O-15	AR	511.	1.998	1.998	1.0		
8-O-15	AR	511.	1.000	1.998	2.0		
9-F-17	AR	511.	1.000	1.998	2.0		
9-F-18	AR	511.	1.000	1.935	1.9		
9-F-18	AR	511.	0.970	1.935	2.0		
9-F-18	DG	511.	0.967	1.935	2.0		

9-F-18	AR	511.0	1.940	1.935	1.0		
9-F-18	AR	511.0	1.934	1.935	1.0		
9-F-18	AR	511.	1.940	1.935	1.0		
9-F-18	AR	511.	1.930	1.935	1.0		
9-F-18	AR	511.0	1.938	1.935	1.0		
9-F-18	DG	511.	1.935	1.935	1.0		
9-F-18	AR	511.	2.000	1.935	1.0		
9-F-18	AR	511.	1.934	1.935	1.0		
10-NE-19	AR	511.	1.000	1.998	2.0		
11-NA-22	AR	511.	0.898	1.808	2.0		
11-NA-22	AR	511.	0.900	1.808	2.0		
11-NA-22	AR	511.	1.810	1.808	1.0		
11-NA-22	AR	511.	0.905	1.808	2.0		
11-NA-22	DG	511.	1.000	1.808	1.8	A0523.004	(Ok)
11-NA-22	AR	511.	1.800	1.808	1.0		
11-NA-22	DG	511.	1.811	1.808	1.0		
11-NA-22	AR	511.	1.797	1.808	1.0		
13-AL-26-M	AR	511.	2.000	1.998	1.0		
15-P-30	AR	511.0	2.000	1.997	1.0		
15-P-30	AR	511.	2.000	1.997	1.0		
17-CL-34-M	DG	511.0	0.600	1.085	1.8	C2008.017	(Ok)
19-K-38	AR	511.	2.000	1.992	1.0		
21-SC-43	AR	511.	1.760	1.762	1.0		
21-SC-43	AR	511.0	0.880	1.762	2.0		
21-SC-44-G	AR	511.0	0.915	1.885	2.1		
21-SC-44-G	AR	511.	0.915	1.885	2.1		
21-SC-44-G	AR	511.	1.880	1.885	1.0		
22-TI-45	AR	511.	1.720	1.696	1.0		
22-TI-45	AR	511.	1.000	1.696	1.7	C0256.003	(Ok)
22-TI-45	AR	511.	1.680	1.696	1.0		

22-TI-45	AR	511.	0.170	1.696	10.0	30962.002	Typo? Question sent to Bhoraskar (2020-11-24).
22-TI-45	AR	511.	1.700	1.696	1.0		
22-TI-45	AR	511.	0.850	1.696	2.0		
22-TI-45	AR	511.	0.172	1.696	9.9	30640.004	AR -> DG and 0.172 -> 1.72 in DECAY-DATA
22-TI-45	AR	511.0	0.850	1.696	2.0		
22-TI-45	AR	511.	0.700	1.696	2.4	33001.007	.70 -> 1.70
22-TI-45	AR	511.0	1.700	1.696	1.0		
22-TI-45	AR	511.0	1.720	1.696	1.0		
23-V-47	AR	511.0	1.930	1.931	1.0		
23-V-47	AR	511.0	0.970	1.931	2.0		
23-V-47	AR	511.	0.970	1.931	2.0		
23-V-47	AR	511.	1.920	1.931	1.0		
23-V-47	DG	511.	1.000	1.931	1.9		
23-V-47	AR	511.0	1.920	1.931	1.0		
23-V-48	AR	511.	0.560	0.998	1.8	C0274.010	(Ok. Both B+ and AR counting performed.)
24-CR-49	AR	511.	0.860	1.856	2.2	33001.006	.86 -> 1.86
24-CR-49	AR	511.	1.860	1.856	1.0		
24-CR-49	AR	511.	0.920	1.856	2.0		
24-CR-49	AR	511.	1.880	1.856	1.0		
24-CR-49	DG	511.0	0.930	1.856	2.0		
24-CR-49	AR	511.	0.922	1.856	2.0		
24-CR-49	AR	511.	0.180	1.856	10.3	30962.003	Typo? Question sent to Bhoraskar (2020-11-24).
25-MN-51	AR	511.	0.960	1.942	2.0		
25-MN-52-G	AR	511.	0.290	0.588	2.0		
25-MN-52-M	AR	511.	0.980	1.932	2.0		
26-FE-53-G	AR	511.	1.960	1.937	1.0		
26-FE-53-G	AR	511.	1.760	1.937	1.1		
26-FE-53-G	DG	511.	1.960	1.937	1.0		
26-FE-53	AR	511.	0.960	1.937	2.0		
27-CO-55	AR	511.	0.790	1.518	1.9		

27-CO-56	AR	511.	0.181	0.394	2.2	C0274.005	(Ok. Both B+ and AR counting performed.)
27-CO-58-G	AR	511.	0.300	0.298	1.0		
27-CO-58	DG	511.	0.300	0.298	1.0		
28-NI-57	AR	511.	0.470	0.872	1.9		
28-NI-57	AR	511.	0.800	0.872	1.1		
28-NI-57	AR	511.	0.990	0.872	0.9		
28-NI-57	AR	511.	0.920	0.872	0.9		
28-NI-57	DG	511.	0.938	0.872	0.9		
28-NI-57	AR	511.0	1.000	0.872	0.9		
29-CU-60	AR	511.0	1.840	1.852	1.0		
29-CU-60	AR	511.	0.936	1.852	2.0		
29-CU-60	AR	511.	0.935	1.852	2.0		
29-CU-61	AR	511.0	1.220	1.229	1.0		
29-CU-61	AR	511.	0.620	1.229	2.0		
29-CU-61	AR	511.	0.621	1.229	2.0		
29-CU-62	AR	511.0	1.960	1.957	1.0		
29-CU-62	AR	511.0	1.940	1.957	1.0		
29-CU-62	DG	511.	2.000	1.957	1.0		
29-CU-62	AR	511.	1.956	1.957	1.0		
29-CU-62	AR	511.	1.940	1.957	1.0		
29-CU-62	AR	511.	0.980	1.957	2.0		
29-CU-62	AR	511.	2.000	1.957	1.0		
29-CU-62	AR	511.	0.987	1.957	2.0		
29-CU-62	AR	511.	1.960	1.957	1.0		
29-CU-62	AR	511.	0.950	1.957	2.1		
29-CU-64	DG	511.	0.343	0.352	1.0		
29-CU-64	DG	511.	0.340	0.352	1.0		
29-CU-64	AR	511.	0.190	0.352	1.9		
29-CU-64	DG	511.	0.190	0.352	1.9		
29-CU-64	DG	511.	0.386	0.352	0.9		

29-CU-64	AR	511.	0.356	0.352	1.0		
29-CU-64	DG	511.0	0.350	0.352	1.0		
29-CU-64	DG	511.	0.358	0.352	1.0		
29-CU-64	DG	511.	0.772	0.352	0.5	D0162.007, D0162.013	(Ok)
29-CU-64	AR	511.0	0.190	0.352	1.9		
29-CU-64	DG	511.	0.352	0.352	1.0		
29-CU-64	DG	511.006	0.386	0.352	0.9		
29-CU-64	DG	511.	0.357	0.352	1.0		
29-CU-64	DG	511.	0.370	0.352	1.0		
29-CU-64	DG	511.0	0.358	0.352	1.0		
29-CU-64	AR	511.	0.187	0.352	1.9		
29-CU-64	DG	511.0	0.386	0.352	0.9		
29-CU-64	DG	511.00	0.386	0.352	0.9		
29-CU-64	AR	511.0	0.357	0.352	1.0		
29-CU-64	DG	511.	0.380	0.352	0.9		
29-CU-64	AR	511.	0.357	0.352	1.0		
29-CU-64	AR	511.	0.370	0.352	1.0		
29-CU-64	DG	511.	0.360	0.352	1.0		
29-CU-64	DG	511.0	0.357	0.352	1.0		
29-CU-64	AR	511.	0.380	0.352	0.9		
29-CU-64	AR	511.	0.386	0.352	0.9		
30-ZN-62	AR	511.	0.180	0.164	0.9		
30-ZN-63	AR	511.0	0.904	1.855	2.1		
30-ZN-63	AR	511.	0.930	1.855	2.0		
30-ZN-63	DG	511.	1.860	1.855	1.0		
30-ZN-63	AR	511.	1.860	1.855	1.0		
30-ZN-65	DG	511.0	0.028	0.028	1.0		
30-ZN-71-G	DG	511.6	0.320	No β+ decay		14468.006, 14468.007	(Ok. 511.6 keV gamma line irrelevant to annihilation.)

30-ZN-71-G	DG	511.6	0.130	No β+ decay		21892.003, 21892.006	(Ok. 511.6 keV gamma line irrelevant to annihilation. ENSDF gives 32.00%.)
31-GA-65	AR	511.	0.810	1.803	2.2	C0269.021, C0296.002, C0296.003	(Ok. Two gammas detected in coincidence.)
31-GA-66	AR	511.	0.513	1.136	2.2	C0269,020, C0269.023	(Ok. Two gammas detected in coincidence.)
31-GA-66	AR	511.	0.505	1.136	2.2	C0296.002, C0296.003	(Ok. Two gammas detected in coincidence.)
31-GA-66	AR	511.	0.879	1.136	1.3	C0831.005, C0831.008, C0831.011	0.879 -> 0.5654
31-GA-68	AR	511.	0.875	1.778	2.0		
31-GA-70	AR	511.	1.000	0.000	0.0	C0269.011	AR -> B- and delete 511.
31-GA-72	AR	511.00	0.386	No β+ decay		C0492.002	64Cu decay data are wrongly coded.
32-GE-66	AR	511.	0.760	0.472	0.6	C0296.002	(Ok. Two gammas detected in coincidence.)
32-GE-67	AR	511.	0.930	1.806	1.9		
32-GE-68	AR	511.	0.875	0.000	0.0	C0296.002	The radiation field must be under 31-GA-68.
32-GE-68	AR	511.	0.879	0.000	0.0	C0831.002, C0831.016	The radiation field must be under 31-GA-68.
32-GE-69	AR	511.	0.350	0.471	1.3	11825.002	(Ok)
32-GE-69	AR	511.	0.680	0.471	0.7	20770.002	(Ok)
32-GE-69	AR	511.	0.330	0.471	1.4	C0296.002	(Ok. Two gammas detected in coincidence.)
32-GE-69	AR	511.	0.705	0.471	0.7	20536.013	(Ok)
32-GE-69	AR	511.	0.240	0.471	2.0		
33-AS-74	DG	511.	0.590	0.582	1.0		
33-AS-74	AR	511.	0.590	0.582	1.0		
34-SE-73-G	AR	511.	0.690	1.292	1.9		
35-BR-75	DG	511.	0.154	1.492	9.7	D0082.002	0.1536 -> 1.536
35-BR-76-G	AR	511.	1.330	1.112	0.8	O0327.014	(Ok)
35-BR-76-G	AR	511.	0.650	1.112	1.7	C0300.002, C0300.003	(Ok)
35-BR-78	AR	511.	0.930	1.850	2.0		

35-BR-78	AR	511.	0.840	1.850	2.2	33001.005	0.840 -> 1.84
35-BR-78	AR	511.	1.000	1.850	1.9		
36-KR-77	AR	511.	1.600	1.683	1.1		
36-KR-79	AR	511.	0.150	0.140	0.9		
37-RB-84-G	AR	511.	0.206	0.514	2.5	20891.003	(Ok)
37-RB-84-G	DG	511.	0.380	0.514	1.4	A0011.003	(Ok)
38-SR-82	AR	511.	1.920	0.000	0.0	C0339.002, C0339.004	The radiation field must be under 37-RB-82-G.
39-Y-88	AR	511.	0.004	0.004	1.0		
39-Y-91-M	DG	511.	0.950	No β+ decay		O0594.012, O0594.016	(Ok. 555.57 keV gamma line irrelevant to annihilation.)
39-Y-91-M	AR	511.	0.950	No β+ decay		O0594.004	AR -> DG
40-ZR-89-G	AR	511.	0.440	0.455	1.0		
42-MO-91-G	AR	511.	1.882	1.875	1.0		
42-MO-91-G	AR	511.	1.880	1.875	1.0		
42-MO-91-G	DG	511.	1.870	1.875	1.0		
42-MO-91-G	AR	511.	1.870	1.875	1.0		
42-MO-91-G	AR	511.	1.874	1.875	1.0		
42-MO-91-G	AR	511.	0.940	1.875	2.0		
42-MO-91-M	AR	511.	1.000	0.8816	0.9		
42-MO-91-M1	AR	511.	0.756	0.882	1.2	30601.002	M1 -> M
44-RU-95	AR	511.	0.195	0.279	1.4	R0048.002	(Ok)
44-RU-106	DG	511.9	0.210	No β+ decay		13286.002	The radiation field must be under 45-RH-106-G. (511.86 keV gamma line irrelevant to annihilation).
44-RU-106	DG	511.8	0.206	No β+ decay		32636.001	The radiation field must be under 45-RH-106-G. (511.86 keV gamma line irrelevant to annihilation).
44-RU-106	DG	511.9	0.204	No β+ decay		22425.001	The radiation field must be under 45-RH-106-G. (511.86 keV gamma line irrelevant to annihilation).
44-RU-106	DG	511.9	0.864	No β+ decay		30787.001	The radiation field must be under 45-RH-106-M. (511.7 keV gamma line irrelevant to annihilation).
45-RH-102-G	AR	511.	0.280	0.294	1.1		
45-RH-102-G	DG	511.	0.141	0.294	2.1		

45-RH-102-G	AR	511.	0.141	0.294	2.1		
45-RH-106-G	DG	511.80	0.205	No β+ decay		30691.002	(Ok. 511.86 keV gamma line irrelevant to annihilation.)
45-RH-106-M	DG	511.7	0.860	No β+ decay		O0768.138	(Ok. 511.7 keV gamma line irrelevant to annihilation.)
47-AG-106-G	AR	511.	1.000	1.182	1.2	21400.005	Delete both half-life and intensity (not in the article).
47-AG-106-M	DG	511.9	0.880	0.000	0.0	O0768.053	(Ok. 511.85 keV gamma line irrelevant to annihilation.)
47-AG-106-M	DG	511.8	0.883	0.000	0.0	21709.006	(Ok. 511.85 keV gamma line irrelevant to annihilation.)
47-AG-106-M	DG	511.842	0.880	0.000	0.0	F1269.003	(Ok. 511.85 keV gamma line irrelevant to annihilation.)
49-IN-112-G	DG	511.0	0.470	0.480	1.0		
49-IN-112-G	AR	511.0	0.436	0.480	1.1		
49-IN-112-G	DG	511.	0.240	0.480	2.0		
49-IN-112-G	AR	511.	0.218	0.480	2.2	21106.003	(Ok)
49-IN-112-G	AR	511.0	0.430	0.480	1.1		
49-IN-112-G	DG	511.	0.440	0.480	1.1		
49-IN-112-G	DG	511.	0.436	0.480	1.1		
49-IN-112-G	AR	511.	0.440	0.480	1.1		
50-SN-111	DG	511.	0.706	0.604	0.9		
51-SB-118-G	DG	511.	1.550	1.470	0.9		
51-SB-118-G	AR	511.	1.000	1.470	1.5	A0121.003	1.00 -> 1.55
51-SB-118	AR	511.	1.550	1.470	0.9		
51-SB-120-G	AR	511.	0.437	0.820	1.9		
51-SB-120-G	AR	511.	1.000	0.820	0.8	21400.006	Delete both half-life and intensity (not in the article).
52-TE-118	AR	511.0	1.500	0.000	0.0	C0094.002, C0094.003	The radiation field must be under 51-SB-118.
53-I-119	AR	511.	1.020	1.150	1.1		
53-I-120-G	AR	511.	1.800	1.366	0.8	C0347.012.1, C0347.013.1	(Ok)
53-I-120-G	AR	511.	0.920	1.366	1.5	O0327.015	(Ok)
53-I-121	AR	511.	0.180	0.212	1.2	O0327.015	(Ok)
53-I-122	AR	511.	1.300	1.563	1.2	O0327.015	(Ok)
53-I-124	AR	511.	0.600	0.454	0.8	C0347.006.2, C0347.007.2	(Ok)

55-CS-125	AR	511.	0.490	0.795	1.6	C0375.008, C0375.014, C0375.016, C0375.018	(Ok. Two gammas detected in coincidence.)
55-CS-127	AR	511.	0.035	0.061	1.7	C0375.002, C0375.004, C0375.008, C0375.014, C0375.015, C0375.016, C0375.018, C0375.019	(Ok. Two gammas detected in coincidence.)
55-CS-130-G	AR	511.	0.920	0.872	0.9		
59-PR-139	AR	511.	0.158	0.166	1.1		
59-PR-140	AR	511.	1.000	1.020	1.0		
59-PR-140	DG	511.	1.000	1.020	1.0		
60-ND-140	AR	511.	1.000	0.000	0.0	C0321.002	The radiation field must be under 59-PR-140.
60-ND-140	DG	511.0	1.000	0.000	0.0	C0378.002	The radiation field must be under 59-PR-140.
60-ND-140	AR	511.	1.016	0.000	0.0	O1352.007	The radiation field must be under 59-PR-140.
60-ND-141-G	AR	511.	0.025	0.052	2.1		
60-ND-141-G	AR	511.	0.060	0.052	0.9		
60-ND-141-G	DG	511.	0.050	0.052	1.0		
60-ND-141-G	DG	511.	0.055	0.052	0.9		
62-SM-143-G	AR	511.	0.740	0.898	1.2	10477.015	(Ok)
62-SM-143-G	DG	511.	1.000	0.898	0.9		
62-SM-143-G	DG	511.	0.740	0.898	1.2	20541.019, 30682.007	(Ok)
62-SM-143-G	DG	511.	0.800	0.898	1.1		
73-TA-174	AR	511.	0.760	0.472	0.6	C0402.002	(Ok)
73-TA-178-G	AR	511.	0.022	0.0248	1.1		
84-PO-206	DG	511.	0.244	0.000	0.0	A0026.089	(Ok. 511.36 keV gamma line irrelevant to annihilation.)