NUCLEAR DATA LIBRARIES FOR GAMMA ANALYSIS PROGRAMS, INCLUDING SPECIAL PURPOSE LIBRARIES

W. Westmeier, U. Reus, K. Siemon, H. Westmeier
Gesellschaft fuer Kernspektrometrie mbH,
Ebsdorfergrund-Moelln, Germany

Abstract. A complete set of gamma ray and other data relating to the decay of all known nuclides has been compiled from the literature and electronic sources. The data were critically reviewed, evaluated and the consistency was checked. The total catalogue is comprised of data-sets for 3841 nuclides and isomers with 106,355 gamma ray and 19,347 X ray entries. A subset of 1,627 nuclides with 32,456 gamma ray entries is extracted into a database, which provides the basis for the generation of nuclide libraries for the application in spectrometry programmes. The WINDOWS based program NUC_MAN was developed which serves for the updating and editing of the database as well as the generation of task-specific user libraries for special purposes. The literature cut-off date for this catalogue is January 1, 1998.

Introduction

A compilation of gamma rays originating from radioactive decay is primarily designed for the use of workers engaged in quantitative assay of radionuclides such as activation analysis, contamination control, environmental supervision and cross-section measurements. It should also be a helpful tool in nuclear spectrometry where, for example, it can be used to identify gamma rays emitted from daughter nuclei or source impurities.

As an update of an earlier catalog of gamma rays from radioactive decay [1] we have compiled and evaluated the data published since then and generated a database of gamma ray and other data for all known nuclides. The data are comprised of nuclide name and half-life, spin and parity, decay modes and branching intensities, Q-values, (n,γ) cross sections, gamma- and X ray energies with their intensities and associated information, precursor information, literature references as well as comment and text lines. Uncertainties are given for most numerical values.

A short explanation of the compilation and evaluation policies and of the library data is given in the following.

Literature coverage

The data are obtained from literature referenced in Nuclear Data Sheets [2] and publications, which we received before January 1, 1998. At present, the catalogue contains data on 3841 nuclides and isomers with more than 120,000 photon energies.

Data selected

Preference is given to data which have been consistently determined in several different studies. In cases of conflicting results, data which are confirmed by the majority of researchers are chosen. Reference to the data omitted is then explicitly given in a comment.

Gamma ray energies

Up to 350 gamma ray energies are included for each nuclide or isomer. Usually, gamma rays with very low abundance are not included, except for a few nuclides where only weak gamma lines are present. Annihilation radiation from positron emitters is listed only in cases where no gamma or X rays of the respective nuclide are readily discernible. Gamma ray energies above 10 MeV are not listed. Notice should be taken that the applied intensity cutoff is on the absolute intensity and that in the case of relative intensities a different cutoff may have been used.

Gamma ray abundances

Gamma ray abundances are listed as number of photons per 100 disintegrations. Relative abundance values are marked with an asterisk (*). In the latter cases the strongest line is normalized to 100%.

Normalization

Relative photon intensities are converted to number of photons per 100 decays, provided that decay schemes are sufficiently well determined. For the calculations, the internal conversion coefficients are interpolated from the tables of Hager and Seltzer [3]. If no experimental information about the intensity of the beta decay or electron capture branch to the ground state of the daughter nucleus is available, log-ft values from comparison with similar decay schemes are assumed, and intensity estimates are obtained using the log-f tables of Gove and Martin [4]. With these estimates one calculates at least the order of magnitude of the normalization factor, which then is given in a comment.

X rays

X ray information, which allows the identification of the emitting element, is supplied. X rays listed here are labelled by atomic species only. X ray energies are taken from the tables of Bearden [5].

Data on K x rays accompanying the decay of individual nuclides are given whenever possible. Components listed are: $K_{\alpha 1}$, $K_{\alpha 2}$, $K'_{\beta 1}$ (=$K_{\beta 1}$ + $K_{\beta 3}$), and $K'_{\beta 2}$ (=$K_{\beta 2}$ + $K_{\beta 4}$). For elements with atomic number $Z < 50$, the separation is made into K_{α} and K_{β} X rays only.

Quoted abundances of K X rays are based on measurements, where possible. However, since the number of measurements reported in the literature is small, many abundances had to be calculated. These calculations yield reliable results provided that the decay scheme of the nuclide is well established. Quantities used for the calculation are: internal conversion coefficients from the tables of Hager and Seltzer [3], ratios of electron capture to positron decay (ε/β^+) and the fractions of K capture ($\varepsilon_K/\varepsilon$) from the tables of Gove and Martin [4], fluorescence yields from an empirical fit by Bambynek et al. [6], and relative X ray intensities from tables of Salem et al. [7]. L X rays are listed if measured abundances are known. They are calculated only for a few nuclides emitting no K X rays and no strong gamma rays. The same references as stated above have been used. It should be noted, however, that for L X rays the calculations are afflicted with large systematic uncertainties and that calculated L X ray abundances should be considered as tentative. Calculated L X ray abundances are accompanied by a comment. Omitting X rays in connection with a specific nuclide does not imply that no x rays are emitted in the decay. There are two reasons for the omission of X rays:

- X ray abundances are negligible, which is true for many nuclides decaying by negatron emission;
- the existing decay scheme data are insufficient for the calculation of X ray abundances. These cases are not separately indicated.

Stable nuclei

Isotopic abundances of naturally occurring isotopes are taken from the tabulation of Holden [8]. Thermal neutron cross sections are adopted from Mughabghab et al. [9]. Spins and other details are from Nuclear Data Sheets [2] if no other reference is given. These three references are implied in the literature abbreviation KNK [10], which is used in the catalog. The authors of KNK refer to essentially the same three references as quoted above.

References (literature sources)

The literature sources from which data were taken are indicated with the data sets. There may be different references for e.g. the gamma ray data, spin and parity, Q-values or half-life. Large differences encountered in various publications are noted in a comment.

The table below lists the most frequently used journals and sources of information for this Gamma-Ray Catalogue.

TABLE 1. LITERATURE SOURCES FROM WHICH THE MAJORITY OF THE GAMMA RAY DATA LISTED ARE TAKEN.

APPOB	Acta Physica Polonica B
CERN	CERN report (see below)
CJPH	Canadian Journal of Physics
CZJPB	Czechoslovak Journal of Physics B
IANFA	Izvestija Akademii Nauk SSSR, Serija Fizika
IJARA	International Journal of Applied Radiation and Isotopes
JINC	Journal of Inorganic and Nuclear Chemistry
JPHG	Journal of Physics (London) G
JPHP	Journal of Physique (Paris)
JPSJ	Journal of the Physical Society of Japan
KNK	Karlsruher Nuklidkarte, 6. Auflage 1995
NDS	Nuclear Data Sheets
NIM	Nuclear Instruments and Methods in Physics Research
NPA	Nuclear Physics A
PHSC	Physica Scripta
PRC	Physical Review C
PRLT	Physical Review Letters
PYLB	Physics Letters B
RAAC	Radiochimica Acta
RAAL	Radiochemical and Radioanalytical Letters
ZPA	Zeitschrift für Physik A - Atoms and Nuclei

Literature in the form of laboratory reports is not included in the compilation except for: CERN Reports 76-13 and 81-09, Proceedings of the International Conference on Nuclei For from Stability. The number of literature sources actually scanned for the compilation of this catalogue was greater than that represented by the list of abbreviations given above.

Daughter nuclides

In the decay of a parent nucleus, a daughter whose half-life is short compared to that of the parent may be formed. Provided that the difference in half-lives is large, transient equilibrium will be reached after some time. For practical purposes we define the parent's half-life to be at least twice as long as that of the daughter in order to consider the decay as being in transient equilibrium. If this condition is fulfilled, gamma rays from the decay of the daughter are also listed with the parent. Abundances of these daughter gammas are calculated for the case of transient equilibrium, that is:

$$I_E = I_D \frac{\lambda_D}{\lambda_D - \lambda_P} BR \qquad (1)$$

where I_E is the abundance observed in the case of transient equilibrium; I_D is the abundance of the same transition in the decay of the daughter alone; λ_P and λ_D are the decay constants of parent and

daughter, respectively; and BR is the branching ratio for the decay from parent to daughter. The quoted abundance of daughter lines thus corresponds to the abundance actually measured. It can be used directly in calculations (for example, to determine the yield of the parent in nuclear reactions) without further corrections, provided that transient equilibrium has been reached in the experiment. The same algorithm applies to gamma rays labelled G which partially arise from the decay of an isomeric state of the daughter. In cases where the parent's half-life is less than twice that of the daughter, the comment "DAUGHTER GAMMAS FROM..." is given in the catalog and the daughter gammas are not listed with the parent.

The catalog contains extensive data for each nuclide together with the relevant references, supplementary information and comments. In some cases, where data from different literature sources are in disagreement, we have made every effort to choose the results which seem most reasonable. If we could not find any reason for discrepancies, we have included a comment about those publications which have been omitted from the data compilation. We believe that these comments are of great importance, because they point out uncertainties and inconsistencies in the data and may help to solve some of the user's problems.

Gamma spectrometry libraries

The initial goal of this research agreement was the creation of a database and a managing computer program that could fit the needs of all workers in gamma ray spectrometry and all its applications. The program should be able to create libraries to be used in all spectrometry programs on the market. However, it was found that such universal library creation under the conditions of this CRP research agreement is an unmanageable task and that very stringent restrictions are needed. There is a common set of data needed by researchers in for example: reaction cross sections or in prompt gamma assay or in environmental surveys or in nuclear level systematics. For each of these tasks there is another set of very specific data that is also needed but which is of no relevance to the others. Furthermore, in each spectrometry programme there is a different structure and completeness of the nuclide library, sometimes the internal data are pre-processed for specific applications and often the library structure is proprietary and not accessible. Therefore it was decided that the library facility provided by this work should supply the basic information for each nuclide and that each user according to need must add application-specific information.

A master library (MASTER.LIB) was generated which holds data for all gamma-emitting radionuclides with a half-life in excess of 10 seconds. For each nuclide the name is listed in the usual representation: IUPAC symbol for the element, followed by a hyphen, followed by the mass number of the nuclide, and where applicable followed by the letter m (metastable state). The letter m may be followed by a running number 1,2,... if several long-lived metastable states exist. Examples of nuclide names in the library are Be-7, Na-22, V-50, Co-54m or Pm-152m1. The half-life of each nuclide is stored with up to five significant digits in scientific (exponential) notation and the units are Second, Minute, Hour, Day or Year. For each nuclide a maximum of 32 gamma ray energies and the concurrent absolute intensities are provided. There are several nuclides that have very many intense and important lines. For these nuclides Eu-152, Eu-154, Bi-214, Ac-227, Ac-228, Ra-226, Th-228, and Th-232 a second data set with up to 32 lines is created where the nuclide name is extended by -x; example : Th-232-x. The intensity cut-off for all nuclides is set at an absolute intensity of 0.005%. X ray energies are omitted from the master library.

For practical purposes the lines in the library are sorted in the order of falling "detectability", i.e. the typical efficiency function of a p-type germanium detector and the typical relative height of the baseline distribution are considered. Thus, a line should only be assigned to a nuclide if the other lines prior in the list are also detected in the spectrum.

The MASTER.LIB at present holds data for 1627 nuclides with a total of 32456 gamma ray entries. All energies in the master library were compared to the recommended "best" data given in a recent publication by Helmer et al. [11]. There are small differences encountered between the data in the MASTER.LIB and the data from Helmer; however, as the differences are within uncertainties we have not modified our data sets.

A 32-bit WINDOWS programme named NUC_MAN was developed which allows the very easy handling of the library data. The programme is written so that it is operative under all current versions of WINDOWS 95, 98 and NT. Standard options and structures from WINDOWS are used wherever possible. Thus NUC_MAN is a programme that is very easy to use for all who are already familiar with WINDOWS programmes. There are two folders in the display page of NUC_MAN; one folder serves for the creation of a new (target) library or the extension of an existing (target) library through excerpting of data from another (source) library. The other folder provides the tools to edit the data in a library and to delete, create or re-order nuclides. The open access to nuclide library data is a frequent request from users that has also been provided. It is particularly useful when the user wants to generate his own setup-specific library, for example, with data that quantitatively consider summing effects or absorption losses through apparent line intensities. We of course are not responsible for the correctness of data that were edited or otherwise modified.

In order to simplify work for many users we have created several special purpose libraries containing only data for those nuclides that are relevant in a field. Libraries supplied with the NUC_MAN programme are:

MASTER.LIB	Containing data for 1627 nuclides with 32456 gamma ray entries, i.e. all nuclides with a half-life ≥ 10 seconds. This library must always be present in the same directory where NUC_MAN is started and it is automatically opened at program start.
INAA.LIB	Containing data for 221 nuclides with 3260 gamma ray entries. This library holds data for all nuclides that can be produced by activation with thermal and epithermal neutrons.
KKW.LIB	Containing data for 134 nuclides with 3162 gamma ray entries. This library holds data for all negatron emitting nuclides with a half-life ≥ 10 minutes whose isobaric yield in the fission of ^{235}U induced with thermal neutrons exceeds 0.01%. A few nuclides frequently found as activation products are also included. The library is mainly provided for nuclear power plant applications.
STANDARD.LIB	Containing data for 105 nuclides with 1596 gamma ray entries. This library holds data for nuclides that are frequently used for calibration purposes, that are commercially available, or that are listed in publications which recommend standards [11,12].
IMIS.LIB	Containing data for 76 nuclides with 1570 gamma ray entries. This library holds data for nuclides used for the environmental supervision in Germany.
SIPPING.LIB	Containing data for 34 nuclides with 642 gamma ray entries. This library holds data for nuclides assayed in sipping analyses in nuclear power plants.
NUCMED.LIB	Containing data for 17 nuclides with 120 gamma ray entries. This library holds data for nuclides frequently used in nuclear medicine applications.
NATURE.LIB	Containing data for 10 nuclides with 280 gamma ray entries. This library holds data for nuclides found in the environment and in external background spectra.

When the NUC_MAN program is delivered with the above libraries all files are "zipped" into the self-extracting file NUCL_ZIP.EXE. This file of ca. 620k bytes length is to be copied into the target directory (e.g. C:\NUCLIB) and started there. The program NUCL_ZIP will automatically come up in the DOS shell of your WINDOWS system and extract all files. The user can then start the NUC_MAN program from the WINDOWS environment. When the NUC_MAN program is linked to the desktop it will automatically provide its own icon.

In the following the handling of libraries and data with the NUC_MAN program is briefly explained. For simplification, the operator will be guided in the "you" form which allows for easier and more understandable explanations:

When the programme is started you will see the Company Identification page and you must click OK to enter the programme. There are two dialog pages (folders) indicated by the indexing labels "Make Library" and "Edit Library". On entering the programme the "Make Library" page is active with the MASTER.LIB loaded as shown in Figure 1.
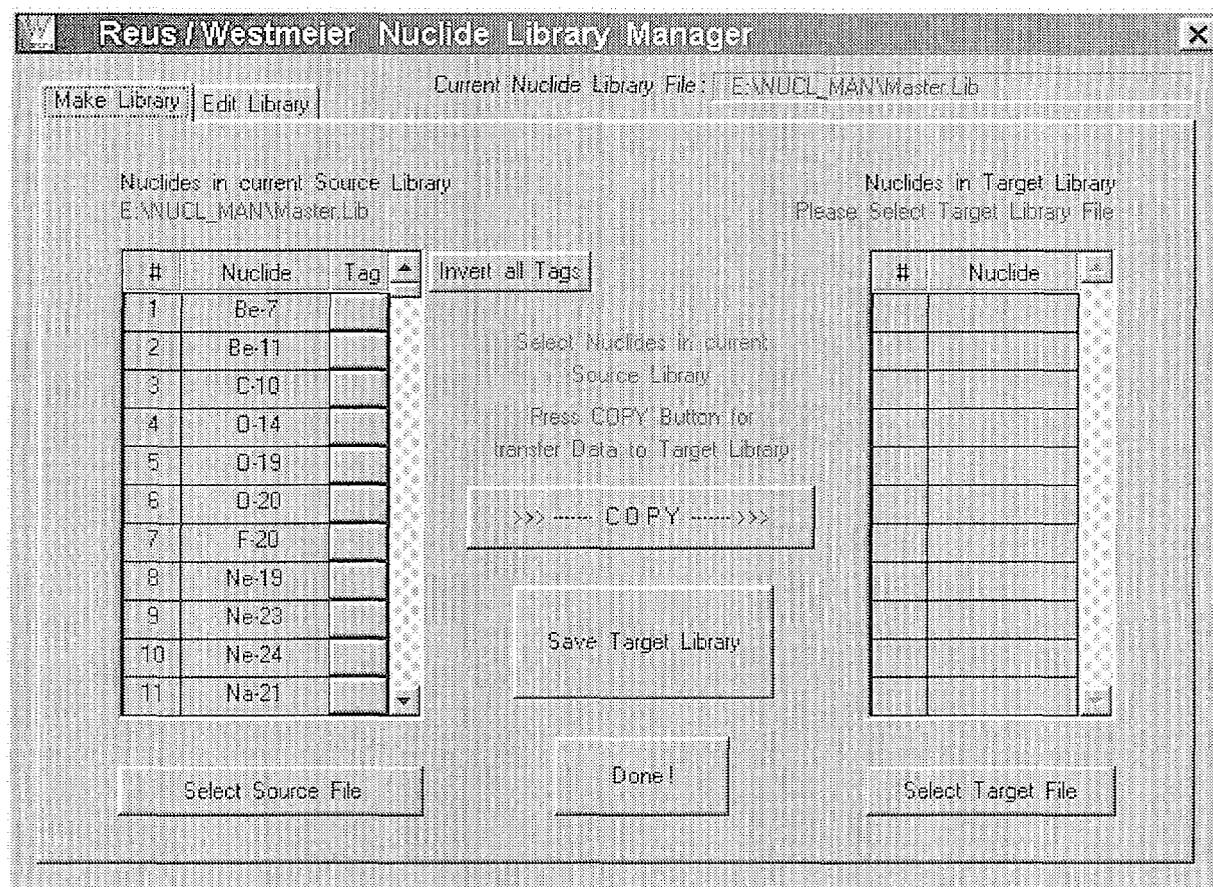

Fig. 1. Opening window of the NUCL_MAN programme used for creating new libraries.

Basically the page consists of two scroll boxes, one for a source library on the left and the other for a target library on the right, plus several buttons to operate the libraries.

You may select another source library with the "Select Source File" button on the left side under the box listing the nuclides. The standard WINDOWS file-handling window will then open and you can select the source library from any desired unit and path. The name of the current (source) library file is listed in the top right corner of the window under the Programme Identification bar. The names of nuclides in that library are listed in the scroll box on the left and you can browse through the sequentially numbered list by pulling the scroll button or clicking the up/down arrows.

Creation of new libraries

You may create a new user (target) library from data in any other (source) library. On the right end of each nuclide name in the source library is a toggle button called "Tag" which is activated when clicked, i.e. the button is white, and deactivated with the second click. In a first step you may activate all nuclides that you want to transfer into the new user library. Then you click the "COPY" button and data for all activated nuclides are copied into the target library. You will see the names of the copied nuclides in the right (target) scroll box. If you want to add nuclides from another source library you may Select Source Library, Tag the required nuclides and COPY to the target library. All nuclides that exist in a target library will be automatically tagged in the source library as well. When the target library is complete it may be saved with the "Save Target Library" button which will again open the WINDOWS file handling window. You may also select any existing library file as the target library with the "Select Target Library" button and extend this library from other source libraries.

When you exit the NUC_MAN programme with the "Done" button the program will for safety reasons always ask if you want to save the target library.

Viewing and editing of data

The "Edit Library" page serves for the viewing and editing of data in a library. In this folder you see the data for one nuclide at a time where the gamma ray energy and intensity data are listed in a scroll box as shown in Figure 2. Over the box you will see the index number of this nuclide in the library, the Nuclide name and the halflife. The name of the active library is listed on the top in the right half of the page. The active library in the "Edit" page is the same as the source library in the "Make" page. Below the name are buttons for saving the current library file or opening a new library for editing.
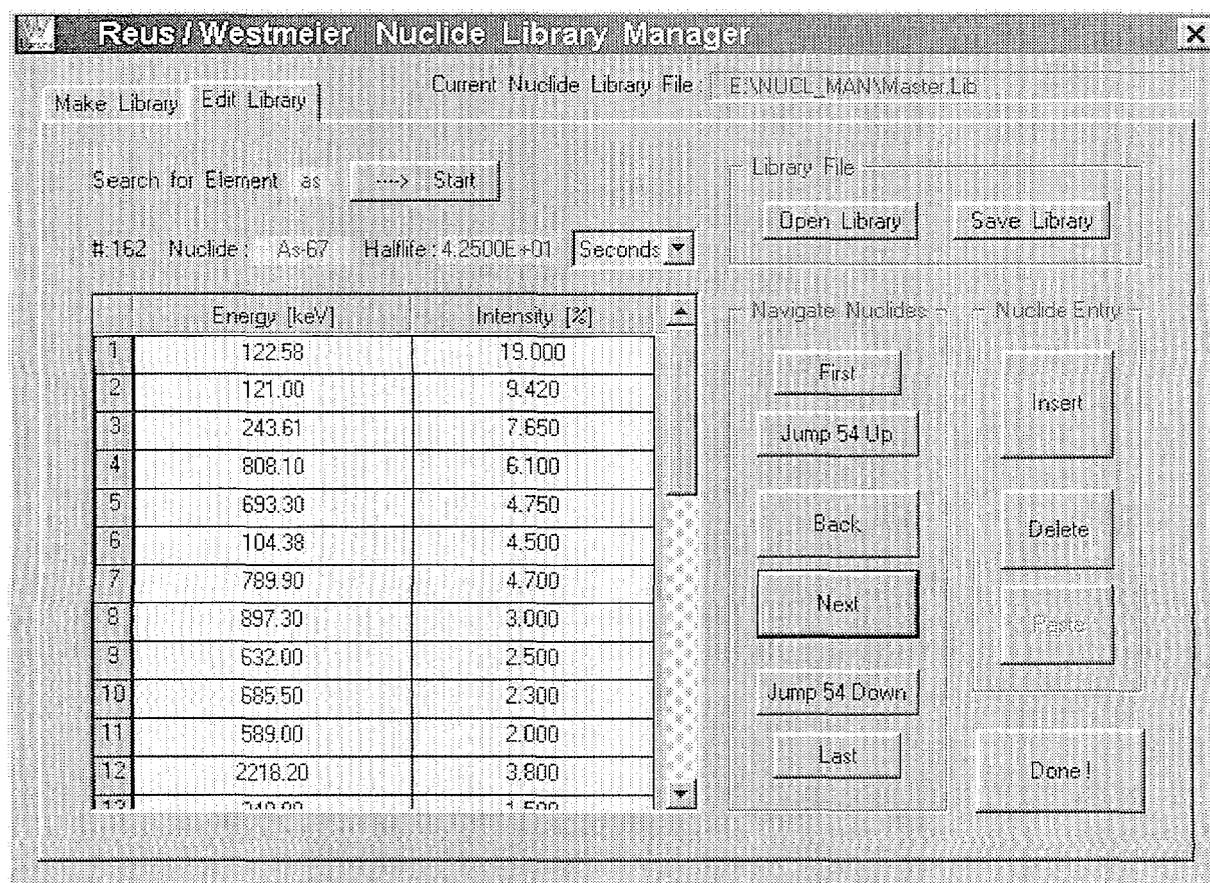

Fig. 2. "Edit Library" screen of the NUC_MAN programme.

The buttons in the "Navigate Nuclides" section are used to:

- select the first or last nuclide in the list (top and bottom button)
- select the following (Next) or preceding(Back) nuclide or
- jump through the library in bigger steps (Jump Up or Jump Down).

For the jump function the library is divided into 30 steps of equal length, thus a library containing 121 nuclides will allow Jump steps over 4 nuclides. Another useful feature for scanning larger libraries is the "search for element". You may enter the symbol for an element in the box over the nuclide name (**not** case sensitive) and search for the next following nuclide of this element in the library with the "start" button. When the end of the library is reached during the search, the programme will continue searching from the beginning of the library.

The buttons in the "nuclide entry" section serve for the re-ordering of nuclides or for deleting complete data sets.

❏ **To edit data** of a nuclide you just click into the respective data field and erase or modify the data as desired. There is no check as to whether the new data are meaningful or not. The unit for the halflife is selected from the drop-down box.

❏ **To delete a line** from the list just delete the energy value, i.e. blank the energy field; the line will be deleted when the next nuclide is selected or when the library is saved.

❏ **To delete a nuclide** from the library use the "delete" button. The data set is then taken out of the library and stored in an internal one-nuclide buffer for retrieval. When you delete a second nuclide the data from the first deleted nuclide are overwritten in this buffer.

❏ **To move a nuclide** entry to another place within the library you must first delete this nuclide. You may note that the "paste" button is activated when a nuclide was deleted. Then select the nuclide **after** which you want to place the nuclide and push the "paste" button. The retrievable nuclide is now listed in the selected place.

❏ **To create a new nuclide** entry in the library select that nuclide after which the new entry shall be found and press the "insert" button. The program will create empty space for one nuclide which can be filled with data as described above under "To edit data".

❏ **To save the library** use the "save library" button and define the filename and destination for the file in the WINDOWS file managing window.

When you exit from the NUC_MAN program with the "done" button the program will for reasons of safety always ask if you want to save the current library.

❏ **To export data for other programmes** the NUC_MAN programme has a built-in ASCII-file feature. Whenever a library is read into the programme it will automatically write an ASCII file with the dedicated filename NUC_MAN.OUT in which all data from the currently open library are listed in a fixed, pre-defined format (see listing of the NATURE.LIB below). The last NUC_MAN.OUT file is always overwritten when the programme is restarted. If you want to keep the ASCII data from the last session you must rename the file. You may use these ASCII data to create libraries according to the specifications of your spectrum analysis programme.

Listing of the library NATURE.LIB as found in the ASCII transfer file NUC_MAN.OUT is given below as example of user created library.

Reading Library : E:\NUCL_MAN\Nature.lib
Number of Nuclides in Library : 13

Be-7 5.3150E+01 D
1 477.603 10.520

K-40 1.2770E+09 Y
1 1460.830 10.670

Cs-134 2.0648E+00 Y
1 604.722 97.620
2 795.865 85.530
3 569.331 15.380
4 563.245 8.350
5 801.951 8.690
6 1365.193 3.014
7 475.364 1.486
8 1167.964 1.789
9 1038.607 0.988
10 242.743 0.027
11 326.589 0.016
12 847.040 3.00E-04

Cs-137 3.0070E+01 Y
1 661.660 85.100
2 283.410 5.80E-04

Bi-214 1.9900E+01 M
1 609.315 45.300
2 1120.292 14.950
3 1764.490 15.480
4 1238.111 5.830
5 768.357 4.890
6 1377.670 3.960
7 934.056 3.120
8 2204.120 4.980
9 1729.604 2.970
10 1407.980 2.370
11 1509.230 2.130
12 665.440 1.470
13 1155.183 1.633
14 1847.422 2.070
15 1280.970 1.420
16 806.171 1.210
17 1401.490 1.290
18 1661.270 1.120
19 2447.680 1.543
20 2118.541 1.169
21 1385.310 0.761
22 1583.240 0.688
23 703.060 0.468
24 388.940 0.386
25 1207.690 0.446
26 719.870 0.380
27 964.090 0.364
28 454.850 0.302
29 386.823 0.290
30 1538.460 0.383
31 786.420 0.310
32 1051.960 0.309

Bi-214-x 1.9900E+01 M
1 1599.350 0.321
2 1070.020 0.268
3 1543.369 0.300
4 1838.380 0.349
5 1133.660 0.249

6 1594.810 0.271
7 405.730 0.166
8 2293.330 0.307
9 273.790 0.130
10 1684.020 0.215
11 821.180 0.156
12 469.756 0.126
13 1873.130 0.210
14 752.850 0.128
15 349.010 0.100
16 474.520 0.106
17 826.450 0.098
18 1895.880 0.146
19 1303.730 0.107
20 1103.610 0.095
21 351.936 0.070
22 572.670 0.077
23 683.200 0.080
24 333.350 0.067
25 280.890 0.065
26 542.850 0.071
27 710.730 0.074
28 904.320 0.075
29 536.780 0.066
30 1104.780 0.078
31 1316.920 0.077
32 649.180 0.059

Ra-226 1.6000E+03 Y
1 609.315 45.300
2 351.932 36.270
3 295.220 18.600
4 1120.292 14.950
5 1764.490 15.480
6 241.997 7.360
7 1238.111 5.830
8 768.357 4.890
9 186.211 3.530
10 1377.670 3.960
11 934.056 3.120
12 2204.120 4.980
13 1729.604 2.970
14 1407.980 2.370
15 1509.230 2.130
16 665.440 1.470
17 1155.183 1.633
18 1847.422 2.070
19 1280.970 1.420
20 806.171 1.210
21 1401.490 1.290
22 785.770 1.080
23 1661.270 1.120
24 2447.680 1.543
25 2118.541 1.169
26 1385.310 0.761
27 258.870 0.511
28 839.000 0.571
29 1583.240 0.688
30 274.800 0.440
31 703.060 0.468
32 487.070 0.419

Ra-226-x 1.6000E+03 Y
1 388.940 0.386
2 1207.690 0.446
3 46.539 4.310
4 719.870 0.380

```
5 580.130 0.350
6 480.440 0.322
7 9.470 5.00E-04
8 964.090 0.364
9 454.850 0.302
10 386.823 0.290
11 1538.460 0.383
12 786.420 0.310
13 1051.960 0.309
14 1599.350 0.321
15 461.970 0.224
16 1070.020 0.268
17 1543.369 0.300
18 1838.380 0.349
19 53.227 1.050
20 1133.660 0.249
21 1594.810 0.271
22 533.670 0.180
23 405.730 0.166
24 2293.330 0.307
25 273.790 0.130
26 1684.020 0.215
27 821.180 0.156
28 469.756 0.126
29 1873.130 0.210
30 752.850 0.128
31 349.010 0.100
32 474.520 0.106

Th-232 1.4050E+10 Y
1 13.520 1.600
2 12.880 0.300
3 238.632 43.300
4 583.192 30.511
5 911.207 25.800
6 2614.533 35.870
7 968.966 15.800
8 338.319 11.270
9 510.650 8.090
10 727.329 6.580
11 240.982 4.100
12 209.255 3.890
13 463.010 4.400
14 964.766 4.990
15 860.560 4.460
16 270.244 3.460
17 794.947 4.250
18 300.089 3.280
19 328.000 3.070
20 129.064 2.420
21 277.370 2.320
22 1588.189 3.220
23 409.452 1.920
24 835.702 1.610
25 772.296 1.490
26 99.495 1.260
27 1630.629 1.510
28 1620.731 1.490
29 84.373 1.220
30 785.370 1.100
31 755.314 1.000
32 562.505 0.870

Th-232-x 1.4050E+10 Y
1 153.983 0.722
2 840.370 0.910
3 904.192 0.770
```

```
 4 1495.980 0.860
 5 1459.126 0.830
 6 115.183 0.592
 7 763.280 0.647
 8 726.872 0.620
 9 830.485 0.540
10 1078.630 0.564
11 508.946 0.450
12 782.144 0.485
13 1580.519 0.600
14 332.369 0.400
15 1247.043 0.500
16 340.962 0.369
17 452.820 0.378
18 288.080 0.337
19 199.407 0.315
20 1501.566 0.460
21 893.406 0.378
22 1638.278 0.470
23 215.985 0.254
24 252.630 0.259
25 1110.612 0.305
26 321.644 0.226
27 958.640 0.280
28 1512.690 0.290
29 278.910 0.191
30 478.394 0.209
31 546.469 0.201
32 145.848 0.158

U-234 2.4550E+05 Y
 1 120.900 0.034
 2 53.220 0.123
 3 454.910 2.50E-05
 4 508.130 1.50E-05
 5 581.680 1.20E-05
 6 677.510 9.00E-07
 7 503.390 8.00E-07
 8 624.290 8.00E-07

U-235 7.0380E+08 Y
 1 185.714 57.200
 2 6.380 0.090
 3 269.480 13.800
 4 235.970 12.400
 5 351.060 12.990
 6 143.762 10.960
 7 271.230 10.900
 8 14.380 0.016
 9 9.920 0.014
10 256.245 6.800
11 401.810 6.400
12 154.180 5.640
13 163.357 5.080
14 205.309 5.010
15 84.216 6.600
16 300.032 4.580
17 329.919 4.080
18 323.890 3.950
19 404.854 4.040
20 144.260 3.240
21 831.951 3.770
22 302.670 2.800
23 338.270 2.810
24 286.103 1.720
25 427.099 1.840
26 283.690 1.660
```

```
27 109.180 1.540
28 79.722 1.990
29 210.600 1.180
30 445.030 1.280
31 93.930 1.460
32 122.310 1.200


U-238 4.4680E+09 Y
1 609.315 45.300
2 351.932 36.200
3 295.220 18.600
4 1120.292 14.950
5 1764.490 15.480
6 241.997 7.360
7 1238.111 5.830
8 768.357 4.890
9 186.211 3.539
10 1377.670 3.960
11 934.055 3.110
12 92.370 2.800
13 2204.120 4.980
14 92.800 2.770
15 63.300 4.800
16 1729.604 2.970
17 1407.980 2.370
18 1509.230 2.130
19 665.440 1.470
20 1155.183 1.633
21 1847.422 2.070
22 1280.970 1.420
23 806.171 1.210
24 1401.490 1.290
25 785.770 1.080
26 1661.270 1.120
27 1001.030 0.839
28 2447.680 1.543
29 2118.541 1.169
30 1385.310 0.761
31 258.870 0.511
32 839.000 0.571
```

Conclusion

A compilation of up-to-date gamma ray and other data relating to the decay of radionuclides has been completed. Data that were taken from recent publications in the scientific literature and other sources were critically reviewed, evaluated and the consistency was checked. A sub-set of data was defined for inclusion in a smaller database for the generation of specific user-libraries. With the aid of a newly developed programme NUC_MAN the user can create his own task-specific libraries or edit and update the data in the database. The programme is developed to run in the 32-bit WINDOWS environment, i.e. all versions of WINDOWS 95, 98 and NT. The programme employs standard features of WINDOWS programmes wherever possible, thus enabling all users to operate it without major instruction. A brief documentation of the policies of data collection and evaluation as well as the handling of the NUC_MAN programme has been provided.

REFERENCES

[1]   REUS, U., WESTMEIER, W., Catalog of Gamma-Rays from Radioactive Decay, Part I and Part II, Atomic Data and Nuclear Data Tables, **Vol. 29**, Nos. 1&2 (1983).

[2]   Nuclear Data Sheets, edited by The National Nuclear Data Center for The International Network for Nuclear Structure Data Evaluation (Academic Press, New York).

[3]   HAGER, R.S., SELTZER, E.C., Nuclear Data Tables **A4** (1968) 1.

[4]   GOVE, N.B., MARTIN, M.J., Nuclear Data Tables **A10** (1971) 205.

[5]   BEARDEN, J.A., Rev. Mod. Phys. **39** (1967) 78.

[6]   BAMBYNEK, W., CRASEMANN, B., FINK, R. W., FREUND, H.-U., MARK, H., SWIFT, C.D., PRICE, R.E., VENUGOPALA RAO, P., Rev. Mod. Phys. **44** (1972) 716.

[7]   SALEM, S.I., PANOSSIAN, S. L., KRAUSE, R.A Atomic Data and Nuclear Data Tables **14** (1974) 91.

[8]   HOLDEN, N.E., IUPAC, Commission on Atomic Weights and Isotopic Abundances, Pure Appl. Chem. **52** (1980) 2349.

[9]   MUGHABGHAB, S.F., GARBER, D.I., National Neutron Cross Section Centre, BNL-325, 3rd ed., **Vol. 1** (1973); for Z≤ 60: MUGHABGHAB, S.F., DIVADEENAM, M., HOLDEN, N.E., Neutron Cross Sections (Academic Press, New York), 1981, **Vol.1**.

[10]   PFENNIG, G., KLEWE-NEBENIUS, H., SEELMANN-EGGEBERT, W.*, Nuklidkarte, 6. Auflage, Kernforschungszentrum Karlsruhe GmbH, Karlsruhe, Germany (1995).

[11]   HELMER, R.G., VAN DER LEUN, C. *, Recommended Standards for γ-Ray Energy Calibration, Nucl. Instr. And Meth. , to be published

[12]   HERMAN, M., NICHOLS, A., Update of X-Ray and γ-Ray Decay Data Standards for Detector Calibration and Other Applications, IAEA RCM Summary Report, INDC(NDS)-403, July 1999.