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Technical Report on

FORMATTING OF CROSS SECTIONS FOR PRODUCTION OF DIAGNOSTIC RADIONUCLIDES IN ENDF-6 FORMAT

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Summary documentation

Abstract: This report sets out the procedure undertaken to prepare and verify a set of evaluated nuclear data files in ENDF-6 format from the charged particle cross-section database for medical radioisotope production.

The report is available online on http://www-nds.iaea.org/nds-210.pdf

The data in ENDF-6 format are available on http://www-nds.iaea.org/medical/

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1. Introduction

The IAEA Coordinated Research Project (CRP) "Charged particle cross section database for medical radioisotope production: Diagnostic radioisotopes and monitor reactions" was completed in 1999. The results were published as an IAEA-TECDOC [1] and they are also available in tabular and graphical form on the IAEA/NDS web page http:/www-nds.iaea.org/medical/. Although this format is sufficient for many users, a more general format as ENDF-6 is strongly recommended for exchanging cross section data and for modern production optimization techniques. Therefore, there was a need to convert the cross section data for medical radioisotope production into ENDF-6 format.

2. Formatting of evaluated nuclear data files

The evaluation methods applied for the reactions of interest are well described in reference [1]. The procedure was divided in three main steps:

- Compilation of experimental data available.
- Nuclear model calculations and experimental data fitting.
- Selection of the recommended values.

A total of 22 monitor reactions, 16 gamma emitter reactions and 10 positron emitter reactions were evaluated in the frame of the CRP (Table 1). To convert the tabular data into ENDF-6 format [2], additional information had to be supplemented from other data sources. It was necessary to supply the reaction Q values, relative mass AWR of the target and the threshold energy E_{thr} of the reaction. Furthermore, the traditional ENDF-6 formatted files parameters such as ZA, MAT, AWI among others, were also defined for each case. A brief description of the main procedure used to generate the evaluated data files is given below.

2.1 Calculation of reaction Q values and threshold energies

Table 2 shows the mass-difference Q values (QM) and threshold energies adopted for each reaction. The values were calculated using the web application QCALC (http://www.nndc.bnl.gov/nndc/qcalc/) from the Brookhaven National Laboratory nuclear data services. Threshold energies for endothermic reactions are calculated by the expression:

$$E_{th} = \frac{m_3 + m_4}{m_3 + m_4 - m_1}|Q|$$

where m_3 and m_1 are the masses of the outgoing and incident particles respectively and m_4 is the mass of the product nuclide. Q represents the mass-difference Q-value (QM).

ENDF-6 format rules state that if the value of Q is not well defined (as in elements or for summation reactions like MT=5), the least negative value of Q should be selected taking into account the different component and possible reactions. For non-threshold reactions the highest positive Q-value was used.

2.2 Masses in neutron mass units (AWR)

Values of AWR were also calculated using the application QCALC based on the recommended masses given in reference [3]. For incident particles the relative mass in neutron units (AWI) was taken from reference [2].

Table 1. Charge particle reactions for medical radioisotope production

No.	Reaction	Type	$T_{1/2}$	E_γ [KeV]	I_γ or β^+ [%]	Energy range [MeV]	Base of recommended values
1	27Al(p,x)22Na	monitor	2.60y	1274.5	99.94	30 - 100	Spline fit
2	27Al(p,x)24Na	monitor	14.96h	1368.6, 2754.0	100, 99.94	30 -100	Spline fit
3	natTi(p,x)48V	monitor	15.98d	983.5, 1312.0	99.99, 97.49	5 -30	Pade fit
4	natNi(p,x)57Ni	monitor	1.50d	1377.6	77.9	15 -50	Spline fit
5	natCu(p,x)56Co	monitor	77.70d	846.8, 1238.3	99.9, 67.0	50 -100	Spline fit
6	natCu(p,x)62Zn	monitor	9.26h	596.7	25.7	14 - 60	Spline fit
7	natCu(p,x)63Zn	monitor	38.1m	669.8, 962.2	8.4, 6.6	4.5 - 50	Pade fit
8	natCu(p,x)65Zn	monitor	244.1d	1115.5	50.75	2.5 - 100	Pade fit
9	27Al(d,x)22Na	monitor	2.60y	1274.5	99.94	29.5 - 80	Pade fit
10	27Al(d,x)24Na	monitor	14.96h	1368.6, 2754.0	100.0,99.94	15 - 80	Pade fit
11	natTi(d,x)48V	monitor	15.98d	983.5, 1312.0	99.99, 97.49	9 - 50	Pade fit
12	natFe(d,x)56Co	monitor	77.70h	846.8, 1238.3	99.9, 67.0	8 - 80	Spline fit
13	natNi(d,x)61Cu	monitor	3.40h	283.0, 656.0	12.5, 10.66	2.5 - 50	Pade fit
14	27Al(3He,x)22Na	monitor	2.60y	1274.5	99.94	10 - 100	Spline fit
15	27Al(3He,x)24Na	monitor	14.96h	1368.6, 2754.0	100.0,99.94	25 - 100	Spline fit
16	natTi(3He,x)48V	monitor	15.98d	983.5, 1312.0	99.99, 97.49	16 - 100	Spline fit
17	27Al(a,x)22Na	monitor	2.60y	1274.5	99.94	29 - 100	Spline fit
18	27Al(a,x)24Na	monitor	14.96h	1368.6, 2754.0	100.0,99.94	50 - 100	Pade fit
19	natTi(a,x)51Cr	monitor	27.70d	320.1	9.83	5 - 40	Pade fit
20	natCu(a,x)66Ga	monitor	9.49h	1039.3	37.9	8 - 30	Pade fit
21	natCu(a,x)67Ga	monitor	3.26d	93.3, 184.6	37.0, 20.4	15 - 50	Spline fit
22	natCu(a,x)65Zn	monitor	244.1d	1115.5	50.75	15 - 50	Pade fit
23	67Zn(p,n)67Ga	gamma	3.26d	93.3, 184.6	37.0, 20.4	2 - 25	Pade fit
24	68Zn(p,2n)67Ga	gamma	3.26d	93.3, 184.6	37.0, 20.4	13 - 30	Pade fit
25	123Te(p,n)123I	gamma	13.2h	159.0	83.3	4 - 20	ALICE IPPE nor.
26	124Te(p,2n)123I	gamma	13.2h	159.0	83.3	12 - 30	ALICE IPPE nor.
27	124Te(p,n)124I	gamma	4.18d	602.7	61.0	5 - 30	ALICE IPPE nor.
28	82Kr(p,2n)81Rb	gamma	4.58h	190.4	64.3	14.5 - 80	Spline fit
29	natKr(p,2n)81Rb	gamma	4.58h	190.4	64.3	14.5 - 80	Spline fit
30	203Tl(p,3n)201Pb	gamma	9.33h	331.2	79.0	18 - 36	Spline fit
31	203Tl(p,2n)202Pbm	gamma	3.62h	422.2	86.0	9 - 27	Pade fit
32	203Tl(p,4n)200Pb	gamma	21.5h	147.6	37.7	27.5 - 36	Spline fit
33	111Cd(p,n)111In	gamma	2.8d	171.3, 245.4	90.24, 94.0	4 - 30	ALICE IPPE
34	112Cd(p,2n)111In	gamma	2.8d	171.3, 245.4	90.24, 94.0	11.5 - 35	Spline fit
35	127I(p,5n)123Xe	gamma	2.08h	148.9	49.0	16.5 - 40	Spline fit
36	127I(p,3n)125Xe	gamma	16.9h	188.4	54.9	20 - 100	ALICE IPPE
37	124Xe(p,2n)123Cs	gamma	5.87m	97.4	14.5	15.5 - 40	Pade fit
38	124Xe(p,np)123Xe	gamma	2.08h	148.9	49.0	16.5 - 40	Pade fit
39	14N(p,a)11C	positron	20.39m		99.8	4 - 25	Pade fit
40	16O(p,a)13N	positron	9.96m		99.8	6 - 20	Pade fit
41	15N(p,n)15O	positron	2.04m		99.9	1 - 15	Pade fit
42	14N(d,n)15O	positron	2.04m	Two 511 KeV	99.9	4 - 20	Pade fit
43	18O(p,n)18F	positron	109.8m	gamma rays	97.0	2.5 - 20	Pade fit
44	natNe(d,x)18F	positron	109.8m	formed in the	97.0	1.5 - 21	Spline fit
45	69Ga(p,2n)68Ge	positron	270.8d(68.3m)	annihilation of	(89.0)	13 - 40	Pade fit
46	natGa(p,x)68Ge	positron	270.8d(68.3m)	β^+		11.5 - 60	Spline fit
47	85Rb(p,4n)82Sr	positron	25.55d(1.3m)		(95.0)	36.5 - 70	Spline fit
48	natRb(p,4n)82Sr	positron	25.55d(1.3m)				Spline fit

*The long lived ^{68}Ge and ^{82}Sr are produced commonly by spallation. Within parenthesis the data for ^{68}Ga(68.3m) & ^{82}Rb(1.3m)

Table 2. Q and energy thresholds values

No.	Reaction	Selected for QM	QM [MeV]	Eth [MeV]	Target AWR	E_{els} [MeV]	E_0 [MeV]
1	27Al(p,x)22Na	27Al(p,npa)22Na	-22.5110	23.5920	26.749754	0	25.2000
2	27Al(p,x)24Na	27Al(p,p3He)24Na	-23.7104	24.7501	26.749754	0	27.7820
3	NatTi(p,x)48V	47Ti(p,g)48V	6.8319	0.0000	47.467127	0	4.5000
4	NatNi(p,x)57Ni	58Ni(p,np)57Ni	-12.2190	12.4390	58.189157	0	13.0000
5	NatCu(p,x)56Co	63Cu(p,4na)56Co	-39.0980	39.8150	62.999756	0	45.0000
6	NatCu(p,x)62Zn	63Cu(p,2n)62Zn	-13.2620	13.4820	62.999756	0	14.0000
7	NatCu(p,x)63Zn	63Cu(p,n)63Zn	-4.1492	4.2168	62.999756	0	4.3000
8	NatCu(p,x)65Zn	65(p,n)65Zn	-2.1341	2.1679	62.999756	0	2.2000
9	27Al(d,x)22Na	27Al(d,ta)22Na	-16.2537	17.8922	26.749754	0	19.0000
10	27Al(d,x)24Na	27Al(d,pa)24Na	-5.3574	5.8485	26.749754	0	10.0000
11	NatTi(d,x)48V	47Ti(d,n)48V	4.6073	0.0000	47.467127	0	2.0000
12	NatFe(d,x)56Co	54Fe(d,g)56Co	16.1602	0.0000	55.367067	0	7.8460
13	NatNi(d,x)61Cu	60Ni(d,n)61Cu	2.5759	0.0000	58.189157	0	2.2000
14	27Al(3He,x)22Na	27Al(3He,2a)22Na	-1.9333	2.2407	26.749754	0	8.0000
15	27Al(3He,x)24Na	27Al(3He,6Be)24Na	-12.2220	13.9800	26.749754	0	20.0000
16	NatTi(3He,x)48V	46Ti(3He,p)48V	7.9920	0.0000	47.467127	0	4.5000
17	27Al(a,x)22Na	27Al(a,n2a)22Na	-22.5110	27.5190	26.749754	0	29.0000
18	27Al(a,x)24Na	27Al(a,7Be)24Na	-22.1238	26.5540	26.749754	0	33.0000
19	NatTi(a,x)51Cr	47Ti(a,g)51Cr	8.9379	0.0000	47.467127	0	5.0000
20	NatCu(a,x)66Ga	63Cu(a,n)66Ga	-7.5010	7.9860	62.999756	0	8.0000
21	NatCu(a,x)67Ga	63Cu(a,g)67Ga	3.7254	0.0000	62.999756	0	12.7000
22	NatCu(a,x)65Zn	63Cu(a,d)65Zn	-10.3792	11.0611	62.999756	0	15.0000
23	67Zn(p,n)67Ga	67Zn(p,n)67Ga	-1.7828	1.8101	66.352194	0	2.0000
24	68Zn(p,2n)67Ga	68Zn(p,2n)67Ga	-11.9810	12.1642	67.341340	0	13.0000
25	123Te(p,n)123I	123Te(p,n)123I	-2.0167	2.0332	121.848465	0	3.8000
26	124Te(p,2n)123I	124Te(p,2n)123I	-11.4420	11.5360	122.838434	0	12.0000
27	124Te(p,n)124I	124Te(p,n)124I	-3.9419	3.9743	122.838434	0	5.8000
28	82Kr(p,2n)81Rb	82Kr(p,2n)81Rb	-13.9860	14.1620	81.209808	0	14.4000
29	NatKr(p,2n)81Rb	82Kr(p,2n)81Rb	-13.9860	14.1620	83.080141	0	14.3000
30	203Tl(p,3n)201Pb	203Tl(p,3n)201Pb	-17.4035	17.4900	201.228698	0	18.0000
31	203Tl(p,2n)202Pbm	203Tl(p,2n)202Pbm	-8.6810	8.7250	201.228698	2.16983	9.0000
32	203Tl(p,4n)200Pb	203Tl(p,4n)200Pb	-24.5180	24.6420	201.228698	0	27.5000
33	111Cd(p,n)111In	111Cd(p,n)111In	-1.6480	1.6630	109.951461	0	3.6000
34	112Cd(p,2n)111In	112Cd(p,2n)111In	-11.0460	11.1470	110.941458	0	11.4000
35	127I(p,5n)123Xe	127I(p,5n)123Xe	-36.7960	37.1000	125.814297	0	37.3000
36	127I(p,3n)125Xe	127I(p,3n)125Xe	-18.7230	18.8750	125.814297	0	20.0000
37	124Xe(p,2n)123Cs	124Xe(p,2n)123Cs	-15.4620	15.5900	122.841484	0	16.5000
38	124Xe(p,np)123Xe	124Xe(p,np)123Xe	-10.4700	10.5560	122.841484	0	16.4000
39	14N(p,a)11C	14N(p,a)11C	-2.9231	3.2175	13.882781	0	4.0000
40	16O(p,a)13N	16O(p,a)13N	-5.2184	5.6567	15.857511	0	5.8000
41	15N(p,n)15O	15N(p,n)15O	-3.5363	3.7910	14.871251	0	3.7200
42	14N(d,n)15O	14N(d,n)15O	5.0724	0.0000	13.882781	0	0.6000
43	18O(p,n)18F	18O(p,n)18F	-2.4358	2.5824	17.844539	0	2.5000
44	NatNe(d,x)18F	20Ne(d,a)18F	2.7954	0.0000	20.006690	0	1.5400
45	69Ga(p,2n)68Ge	69Ga(p,2n)68Ge	-11.1980	11.3660	68.333477	0	12.5000
46	NatGa(p,x)68Ge	69Ga(p,2n)68Ge	-11.1980	11.3660	69.124117	0	12.5000
47	85Rb(p,4n)82Sr	85Rb(p,4n)82Sr	-31.1550	31.5430	84.182356	0	34.0000
48	NatRb(p,4n)82Sr	85Rb(p,4n)82Sr	-31.1550	31.5430	84.733554	0	34.0000

Table 3. Additional data for formatting an evaluated nuclear data file

No.	Reaction	NSUB	MAT	ZA	MF	MT	MATP	ZAP	LSF
1	27Al(p,x)22Na	10010	1325	13027	10	5	1122	11022	1
2	27Al(p,x)24Na	10010	1325	13027	10	5	1128	11024	2
3	natTi(p,x)48V	10010	2200	22000	10	5	2319	23048	0
4	natNi(p,x)57Ni	10010	2800	28000	10	5	2822	28057	0
5	natCu(p,x)56Co	10010	2900	29000	10	5	2716	27056	1
6	natCu(p,x)62Zn	10010	2900	29000	10	5	3019	30062	2
7	natCu(p,x)63Zn	10010	2900	29000	10	5	3022	30063	3
8	natCu(p,x)65Zn	10010	2900	29000	10	5	3028	30065	4
9	27Al(d,x)22Na	10020	1325	13027	10	5	1122	11022	1
10	27Al(d,x)24Na	10020	1325	13027	10	5	1128	11024	2
11	natTi(d,x)48V	10020	2200	22000	10	5	2319	23048	0
12	natFe(d,x)56Co	10020	2600	26000	10	5	2716	27056	0
13	natNi(d,x)61Cu	10020	2800	28000	10	5	2919	29061	0
14	27Al(3He,x)22Na	20030	1325	13027	10	5	1122	11022	1
15	27Al(3He,x)24Na	20030	1325	13027	10	5	1128	11024	2
16	natTi(3He,x)48V	20030	2200	22000	10	5	2319	23048	0
17	27Al(a,x)22Na	20040	1325	13027	10	5	1122	11022	1
18	27Al(a,x)24Na	20040	1325	13027	10	5	1128	11024	2
19	natTi(a,x)51Cr	20040	2200	22000	10	5	2428	24051	0
20	natCu(a,x)66Ga	20040	2900	29000	10	5	3116	31066	1
21	natCu(a,x)67Ga	20040	2900	29000	10	5	3119	31067	2
22	natCu(a,x)65Zn	20040	2900	29000	10	5	3028	30065	3
23	67Zn(p,n)67Ga	10010	3034	30067	3	4	3119	31067	0
24	68Zn(p,2n)67Ga	10010	3037	30068	3	16	3119	31067	0
25	123Te(p,n)123I	10010	5234	52123	3	4	5313	53123	0
26	124Te(p,2n)123I	10010	5237	52124	3	16	5313	53123	0
27	124Te(p,n)124I	10010	5237	52124	3	4	5316	53124	0
28	82Kr(p,2n)81Rb	10010	3637	36082	3	16	3713	37081	0
29	natKr(p,2n)81Rb	10010	3600	36000	3	16	3713	37081	0
30	203Tl(p,3n)201Pb	10010	8125	81203	3	17	8216	82201	0
31	203Tl(p,2n)202Pbm	10010	8125	81203	3	16	8220	82202	1
32	203Tl(p,4n)200Pb	10010	8125	81203	3	37	8213	82200	0
33	111Cd(p,n)111In	10010	4840	48111	3	4	4919	49111	0
34	112Cd(p,2n)111In	10010	4843	48112	3	16	4919	49111	0
35	127I(p,5n)123Xe	10010	5325	53127	3	47	5422	54123	0
36	127I(p,3n)125Xe	10010	5325	53127	3	17	5428	54125	0
37	124Xe(p,2n)123Cs	10010	5425	54124	3	16	5595	55123	0
38	124Xe(p,np)123Xe	10010	5425	54124	3	28	5422	54123	0
39	14N(p,a)11C	10010	725	7014	3	107	622	6011	0
40	16O(p,a)13N	10010	825	8016	3	107	722	7013	0
41	15N(p,n)15O	10010	728	7015	3	4	822	8015	0
42	14N(d,n)15O	10020	725	7014	3	4	822	8015	0
43	18O(p,n)18F	10010	831	8018	3	4	922	9018	0
44	NatNe(d,x)18F	10020	1000	10000	3	5	922	9018	0
45	69Ga(p,2n)68Ge	10010	3125	31069	3	16	3219	32068	0
46	natGa(p,x)68Ge	10010	3100	31000	3	5	3219	32068	0
47	85Rb(p,4n)82Sr	10010	3725	37085	3	37	3819	38082	0
48	natRb(p,4n)82Sr	10010	3700	37000	3	37	3819	38082	0

2.3 Additional general data

Material numbers (MAT), ZA numbers for target nuclides as well as for product nuclides (MATP, ZAP) were defined following the ENDF-6 conventions. Similarly the reaction types were assigned according to the ENDF-6 formats rules. Table 3 shows the selected values for these parameters.

2.4 Evaluated nuclear data file generation

An evaluated nuclear data file was generated for each material and incident particle. For all materials the general information file MF=1 was always prepared from the information available from the IAEA-TECDOC [1] and the corresponding web page.

The production cross sections of the monitor reactions were included on the ENDF-6 file 10 (MF=10). Some targets from this group of reactions have several final products for the summation reaction type MT=5. The structure of MF=10 allows a correct description of these cases. For the gamma and positron emitter groups the cross section file MF=3 was used. In all cases the radioactive decay data file MF=8 is given to specify the end products of the reaction. In Table 3 information concerning the files (MF) and sections (MT) used to define the cross section data is presented.

A FORTRAN-77 code (w2e6.f) was written to perform the conversion into the ENDF-6 format from text- formatted input. The main procedures built in the code are briefly described below. Definition of the ENDF-6 format parameters is given in reference [2].

2.4.1 MF=1 general information file

Section MT=451 is given. The resonance indicator LRP was set equal to –1, no resonance file (MF=2). The fission indicator LFI was set to zero. It means that the material does not fission. NLIB=51, NMOD=1, LDRV=0 and NFOR=6 were used for all materials. The sub-library number NSUB was selected according to the incident particle. Table 3 also shows the values assigned to NSUB. The parameters ELIS, STA, LIS and LISO were properly selected. The reaction directory is also included. A typical MF=1 is given in Annex 1.

2.4.2 MF=3 cross section file or MF=10 nuclide production

As mentioned above for all gamma and positron emitters the cross sections are given in file MF=3.

The reaction Q-value (QI) was given equal to the mass-difference Q-value (QM) for reactions with no intermediate states in the residual nucleus and without complex breakup (LR=0). For the reaction ^{203}Tl(p,2n)^{202m}Pb the value of QI was calculated as QM for the ground state of the residual nucleus minus the energy of the excited level in this system. The energy of the excited state was calculated using the IAEA/NDS Nuclear Data Services, particularly the web application NUDAT. Table 2 presents the values of the excitation energy ELFS.

Cross sections are given from the threshold energy to an upper common energy limit. In case of exothermic reaction the lower limit is set to 1.0e-5 eV. Table 2 includes the value of $E_{0,}$ which is the lower energy given by evaluators. Below this value towards the threshold the cross section was extrapolated using the ENDF-6 interpolation law 6 for charged particles [2]. This law is based on the limiting forms of the Coulomb penetrabilities for exothermic reactions at low energy and for endothermic reactions near the threshold.

A cross section of 0.0 is specified at the threshold energy, and also at the pseudo-threshold energy above which the cross section becomes significant. This point is double valued. Below pseudo-threshold energy the constant (INT=1) interpolation law is applied. Between the effective threshold and the next specified cross-section at E_0 the INT=6 interpolation law is used and few points (5-10) are introduced to give an idea of the cross section shape.

The evaluators gave a set of recommended values according to the method presented in the last column of Table 1. Three new equidistant points were introduced in each original energy subinterval keeping the intention of evaluators. A cubic spline fit based on the recommended values was applied to obtain these new points, except in the first subinterval where the interpolation law INT=6 was used. For all other points up to the upper energy limit the interpolation law INT=2 (lin-lin) was assumed.

There are some reactions of the same material with an apparent upper energy limit lower than the upper limit for the material. Such cross sections were double valued at the highest energy for which the cross section is non-zero. The value of the cross section at the discontinuity was set to zero, and was followed by another zero value at the upper energy limit. Interpolation law INT=1 was set in this extra energy range.

2.4.3 MF=8 decay data file

Information about the reaction products is given following ENDF-6 rules. For all cases the NO parameter was set equal to one, implying that decay data for the product nucleus are given elsewhere.

2.5. Verification of the evaluated nuclear data files

The program `w2e6` was run over all materials. A tape file for each material and for each type of incident particle was generated. Different plots were prepared using the program PLOTTAB [4]. The processing codes PREPRO-2002 [5] were not extensively used due to limitations of treatment of the interpolation law INT=6 for endothermic reactions. Annex 2 shows a set of such a plots.

3. Conclusions

A set of evaluated nuclear data files in ENDF-6 format from the charged particle cross-section database for medical radioisotope production was prepared and verified.

The data is available from the IAEA/NDS in ENDF-6 format for exchange cross section data.

4. Recommendations

Continue with the data verification and validation program.

5. References

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ANNEX-1: Sample MF=1 data file for ^{27}Al

```
IAEA-NDS-CRP LIBRARY FOR MEDICAL RADIOISOTOPE PRODUCTION          900 0  0    0
 1.302700+4 2.674975+1         -1          0         51         11325 1451    1
 0.000000+0 0.000000+0          0          0          0         61325 1451    2
 9.986235-1 1.000000+8          1          0      10010         11325 1451    3
 0.000000+0 0.000000+0          0          0        161         31325 1451    4
 13-AL- 27  IAEA-CRP  EVAL-DEC99 ELEVEN EXPERTS FROM THE IAEA-CRP 1325 1451    5
 IAEA-NDS-CPXS-LIB    DIST-DEC03 REV1-DEC03                       1325 1451    6
---- IAEA-NDS-CRP-LIB MATERIAL 1325         REVISION 1            1325 1451    7
----- INCIDENT-PROTON DATA                                        1325 1451    8
------ ENDF-6 FORMAT                                              1325 1451    9
                                                                  1325 1451   10
**************************************************************    1325 1451   11
FILE DESCRIPTION                                                  1325 1451   12
                                                                  1325 1451   13
 13-AL- 27  EVALUATION FOR MEDICAL RADIOISOTOPE PRODUCTION        1325 1451   14
                                                                  1325 1451   15
EVALUATED REACTIONS:                                              1325 1451   16
                                                                  1325 1451   17
27Al(p,x)22Na   T1/2=2.602y  G=1275.5KeV(99.94%)                  1325 1451   18
MT=  5  MF=10  MF= 8                                              1325 1451   19
                                                                  1325 1451   20
27Al(p,x)24Na   T1/2=14.96h  G=1368.6KeV(100%),2754.0KeV(99.94%)  1325 1451   21
MT=  5  MF=10  MF= 8                                              1325 1451   22
                                                                  1325 1451   23
                                                                  1325 1451   24
THE EVALUATION IS BASED ON THE WORK DEVELOPED IN THE FRAME        1325 1451   25
OF THE IAEA CO-ORDINATED RESEARCH PROJECT: ON DEVELOPMENT OF      1325 1451   26
REFERENCE CHARGED PARTICLE CROSS-SECTION DATABASE FOR             1325 1451   27
MEDICAL RADIOISOPE PRODUCTION, 1995-1999.                         1325 1451   28
                                                                  1325 1451   29
FOR COMPLETE DESCRIPTION OF THE EVALUATED METHODS SEE             1325 1451   30
IAEA-TEC-DOC-1211, CHARGED PARTICLE CROSS-SECTION FOR             1325 1451   31
MEDICAL RADIOISOTOPE PRODUCTION: DIAGNOSTIC RADIOISOTOPES AND     1325 1451   32
MONITOR REACTIONS, IAEA, VIENNA, MAY 2001, (285 PP.), BY          1325 1451   33
 S. M. QAIM (FZ JULICH, GERMANY)                                  1325 1451   34
 T. F. TARKANYI (ATOMKI, HUNGARY)                                 1325 1451   35
 K. GUL (PINST, PAKISTAN)                                         1325 1451   36
 A. HERMANNE (VUB, BELGIUM)                                       1325 1451   37
 M. G. MUSTAFA (LLNL, USA)                                        1325 1451   38
 F. M. NORTIER (NAC, SOUTH AFRICA)                                1325 1451   39
 B. SCHOLTEN (FZ JULICH, GERMANY)                                 1325 1451   40
 Y. SHUBIN (FEI, RUSSIAN FEDERATION)                              1325 1451   41
 S. TAKACS (ATOMKI, HUNGARY)                                      1325 1451   42
 Y. ZHUANG (CIAE, CHINA)                                          1325 1451   43
 P. OBLOZINSKY (IAEA)                                             1325 1451   44
                                                                  1325 1451   45
CONVERSION INTO ENDF-6 FORMAT BY                                  1325 1451   46
 D. L. ALDAMA (IAEA/NDS CONSULTANT), NOV. 2003                    1325 1451   47
                                                                  1325 1451   48
THE CROSS SECTION VALUES WERE TAKEN FROM THE RECOMMENDED ONES     1325 1451   49
GIVEN IN THE IAEA-TECDOC-1211. TOWARDS LOWER ENERGIES THE         1325 1451   50
ORIGINAL EVALUATION WAS COMPLEMENTED BY EXTRAPOLATION             1325 1451   51
USING ENDF-6 INTERPOLATION LOW 6 FOR CHARGED PARTICLES            1325 1451   52
                                                                  1325 1451   53
REFERENCES                                                        1325 1451   54
                                                                  1325 1451   55
(A) References for 27Al(p,x)22Na                                  1325 1451   56
                                                                  1325 1451   57
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                                                                  1325 1451   65
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Exfor: B0095                                                       1325 1451
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27Al. Nucl. Phys. 69 (1965) 362                                    1325 1451
Exfor: P0016                                                       1325 1451
                                                                   1325 1451
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and 24Na production cross sections with 100- 400 MeV protons.      1325 1451
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Exfor: C0253                                                       1325 1451
                                                                   1325 1451
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production of PET radionucleides: 18F (109.77min; b+ 96.9%; EC     1325 1451
3.1%) from high-energy protons on metallic aluminium targets.      1325 1451
Appl. Radiat. Isot. 39 (1988) 41                                   1325 1451
Exfor: A0445                                                       1325 1451
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functions for p-induced reactions Report NEANDC (E) -202 U         1325 1451
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Meyer B.R.: Production of 52Fe via proton-induced reaction on      1325 1451
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nucleaires induites par protons, deutons, particules alpha. I      1325 1451
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production of PET radionuclides:18F (109.77 min, b+ 96.9%, EC      1325 1451
3.1 %) from high-energy protons on metallic aluminum targets.      1325 1451
Applied Radiation Isotopes 39 (1988) 41                            1325 1451
Exfor: A0445                                                       1325 1451
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for proton induced reactions in the energy range 15 to 72 MeV    1325 1451  150
and at 1820 MeV. Thesis (1979), Universitat Bern, unpublished    1325 1451  151
Exfor: D0053                                                     1325 1451  152
                                                                 1325 1451  153
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radioactive isotopes produced by protons below 60 MeV in Al, Fe, 1325 1451  155
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Exfor: B0073                                                     1325 1451  157
                                                                 1325 1451  158
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(p,pn) reaction in complex nuclei in the 80-450-MeV range.       1325 1451  160
Physical Review 118 (1960) 1591                                  1325 1451  161
Exfor: P0049                                                     1325 1451  162
                                                                 1325 1451  163
**************************************************************   1325 1451  164
                                                                 1325 1451  165
                               1         451         168        11325 1451  166
                               8           5           3        11325 1451  167
                              10           5         235        11325 1451  168
                                                                    0 0  099999
                                                                    0 0  0    0
```
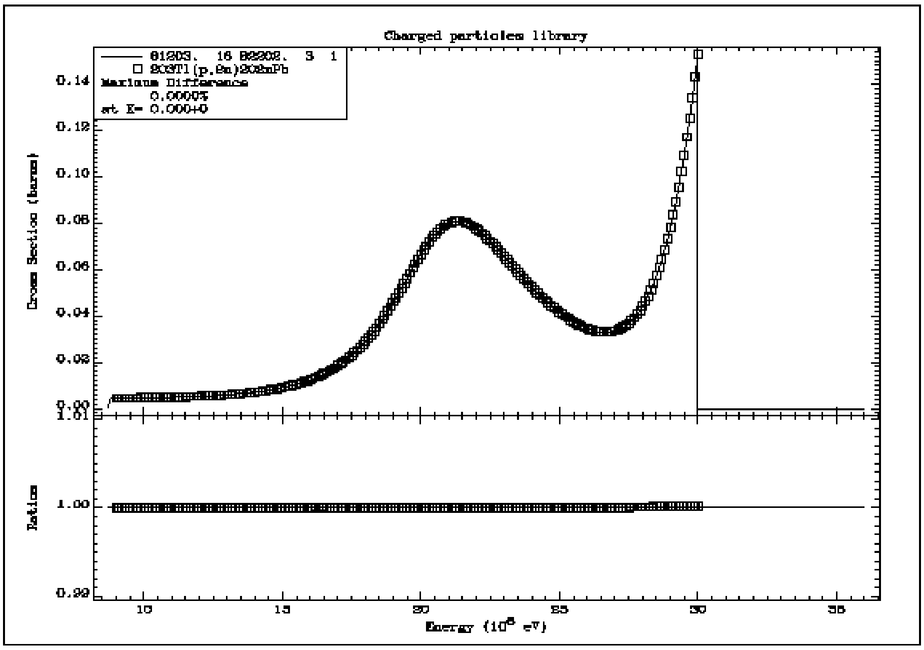
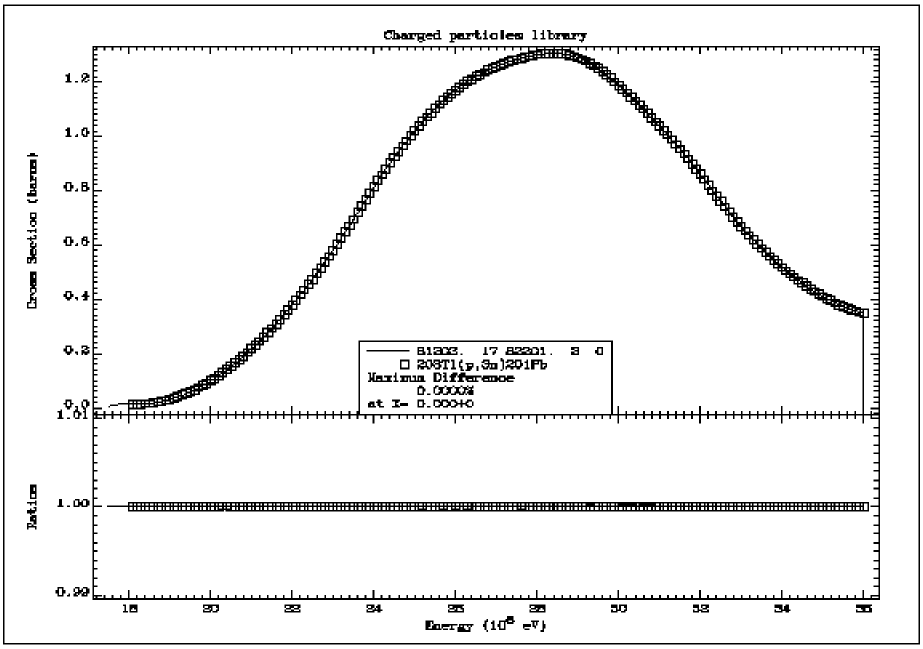
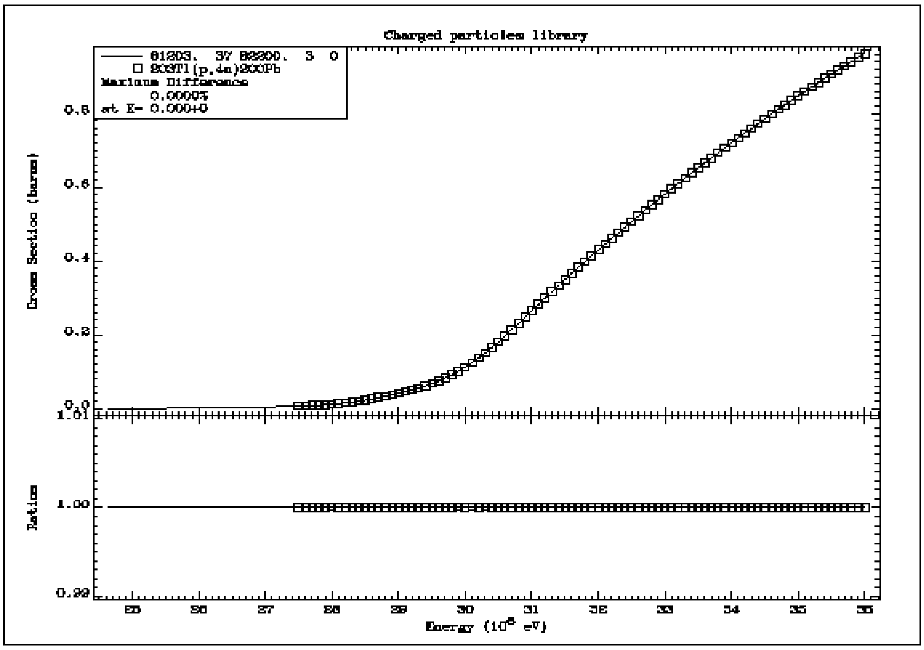

ANNEX-2 Sample verification plots






Charged particles library
203Tl(p,4n)200Pb
Maximum Difference
0.000%
at E= 0.000+0
Cross Section (barns)
Ratios
Energy (10^6 eV)