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Status Report to the Consultants' Meeting on Technical Aspects of Co-operation of the Nuclear Reaction Data Centres
18 - 20 May 1999

General

The Debrecen Nuclear Data Group is working within the Cyclotron Application Department of the Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI).

The staff, five "professional" members, working in part-time on the Nuclear Data Group related programs.

Since the last meeting we have continued the compilation and the critical comparison of several selected reactions used for production of medically important radioisotopes, for monitoring charged particle beams and for thin layer activation measurements. New experimental cross section determination was made as the part of a systematic investigation of the above-mentioned type of reactions.

In last year one person participated at a training course of the BNL NNDC to study the practical aspects of the compilation of Charged Particle Nuclear Data in EXFOR format.

Computer Facilities for EXFOR compilation

For data handling and storage we use Personal Computers (PC) and their environments. Since the last meeting we have installed an other PC (Pentium), which is used to handle EXFOR data. For data input and editing text editors are used. For checking the new entries the Chukreev's checking codes are applied.

Recent Progress

Since the last meeting first priority was given to the preparation of an evaluated CP reactions database for medical isotope production and monitoring CP beams. The work was done in the frame of a Co-ordinated Research Program (CRP) titled "Development of reference charged particle cross section database for medical radioisotope production". The project includes 7 laboratories among them our Nuclear Data Group and focuses on to compile and evaluate selected charged particle reactions for monitoring proton, deuteron, ^{3}He- and alpha particle beams and for production of medically important radioisotopes. The project includes 22 monitor reactions, 16 gamma emitter reactions and 10 positron emitter reactions. (The full list of reactions is given at the end of this document in the Appendix.) This evaluated CP database will be published in an IAEA Technical Document and also an electronic version for Internet presentation, which are under preparation.

Experimental measurements

To clear the discrepancies and to complete the existing experimental data base new measurements were also performed. Excitation functions of **16 reactions** were measured for the first time or were remeasured.

- Additional measurements were done on $^{68}Zn(p,2n)^{67}Ga$ nuclear reaction in collaboration with VUB Brussels. The obtained new result was included in the compiled data base.
- New measurements were done in Jülich-Debrecen collaboration on the $^{18}O(p,n)^{18}F$ reaction.
- New measurements were done in Brussels-Debrecen collaboration on $^{nat}Ti(p,x)^{48}V$, $^{nat}Cu(p,x)^{62}Zn$ monitor reactions.
- New series of measurements were performed on $^{nat}Cu(\alpha,x)$ reactions up to 40 MeV in Brussel-Debrecen collaboration. The new results were included into the data base of present CRP compilation.
- To complete the unsatisfactory experimental database of deuteron induced reactions new series of measurements were performed on iron, copper, aluminum, titan and nickel up to 50 MeV deuterons in Brussels-Debrecen collaboration.

Compilation in EXFOR format

A list of all nuclear reactions related to the evaluated CP project and still not compiled into accepted international data base EXFOR format were prepared. About **150 work** used in the CRP was collected for further compilation in EXFOR. The list was transferred to Data Centers for additional checking. Part of the references was already compiled by the Debrecen Charged Particle Data Group. The remaining publications were redistributed between CP Data Centers according to Data Center agreement.
A list will be reviewed again for those works not yet compiled for EXFOR.

Summary of our activity in the project of evaluated CP database

Excitation functions of monitor reactions:

According to the adopted work plan of the evaluation procedure the ATOMKI group has compiled the following monitor reactions for protons, deuterons, ^{3}He- and alpha particles:

Reaction	Number of compiled work	Number of selected work
$^{nat}Al(p,x)^{24}Na$	22	11
$^{nat}Al(d,x)^{22}Na$	4	2
$^{nat}Al(d,x)^{24}Na$	16	13
$^{nat}Ti(d,x)^{48}V$	4	4
$^{nat}Fe(d,x)^{56}Co$	8	6
$^{nat}Ni(d,x)^{61}Cu$	5	3
$^{nat}Al(^{3}He,x)^{22}Na$	7	6
$^{nat}Al(^{3}He,x)^{24}Na$	5	5
$^{nat}Ti(^{3}He,x)^{48}V$	3	3
$^{nat}Cu(^{3}He,x)^{66}Ga$	6	5
$^{nat}Cu(^{3}He,x)^{67}Ga$	3	3
$^{nat}Cu(^{3}He,x)^{65}Zn$	5	5
$^{nat}Al(\alpha,x)^{22}Na$	13	10
$^{nat}Al(\alpha,x)^{24}Na$	16	11

$^{nat}Ti(\alpha,x)^{51}Cr$	9	6
$^{nat}Cu(\alpha,x)^{66}Ga$	17	10
$^{nat}Cu(\alpha,x)^{67}Ga$	14	8
$^{nat}Cu(\alpha,x)^{65}Zn$	15	9

Excitation functions of gamma-emitters

The experimental data of the following reactions were investigated:

Reaction	Number of compiled work	Number of selected work
$^{67}Zn(p,n)^{67}Ga$	9	6
$^{68}Zn(p,2n)^{67}Ga$	11	8
$^{124}Xe(p,x)^{123}I$	2	2

Excitation functions of positron emitters

In collaboration with the INC, Forschungszentrum Jülich, Jülich, Germany the following reactions were also compiled.:

Reaction	Number of compiled work	Number of selected work
$^{14}N(p,\alpha)^{11}C$	12	9
$^{16}O(p,\alpha)^{13}N$	11	10
$^{14}N(d,n)^{15}O$	4	4
$^{18}O(p,n)^{18}F$	5	5
$^{20}Ne(d,\alpha)^{18}F$	6	6

Preparation of TECDOC

The preparation of the related chapters of the TECDOC for the evaluate CP databese is in progress. During the preparation it was concluded that to avoid duplications and to make more practical the use of the TECDOC for every-day users, small modification of the outline seems to be necessary. According to the evaluation process and the methods have to be discussed in the first part only briefly and the experimental data, the results of the theoretical calculations, recommended cross section and yield data have to be presented for each investigated reaction together. Taking into account the minimal number of required figures and tables and the number of the investigated reactions, the TECDOC can reach 500 pages. An electronic version also prepared, which can be accessed through Internet. The electronic version will contain the a short summary for each of the reactions and figures and tables about the experimental and recommended data. Separate figures will show the available experimental data, the selected work and results of theoretical calculations, the recommended cross section values and the calculated yield. The recommended cros section data and the calculated yield data will be presented in tables included in the web-page and also in download format. Samples of the suggested layout of the different web pages are presented in the Appendix.

Publications of 1998 -99

A. Hermanne, M. Sonck, S. Takács, F, Szelecsényi, F. Tárkányi,
Excitation Functions of Nuclear Reactions Induced by Alpha Particles up to 42 MeV on ^{nat}Ti for Monitoring Purposes and TLA,. Nuclear Instruments and Methods B 152 (1999) 187-201

S. Takács, A. Azzam, M. Sonck, F. Szelecsényi, A. Hermanne, F. Tárkányi
Excitation function of $^{122}Te(d,n)^{123}I$ nuclear reaction: Production of ^{123}I at low energy cyclotron;
Applied Radiation and Isotopes **50** (1999) 535-540.

M. Sonck, S. Takács, F, Szelecsényi, A. Hermanne, F. Tárkányi,
Excitation Functions of Deuteron Induced Nuclear Reactions on ^{nat}Mo up to 21 MeV: An Alternative Route for the Production of ^{99m}Tc and ^{99}Mo,
IAEA TECDOC 1065, (1999) 113-131

M. Sonck, S. Takács, F, Szelecsényi, A. Hermanne, F. Tárkányi,
Excitation Functions of Deuteron Induced Nuclear Reactions on ^{nat}Mo and $^{100}Mo(90\%)$ up to 50 MeV: An Alternative Route for the Production of ^{99}Mo, Proc. of 15th Int. Conf. on Applications of Accelerators in Research and Industry, Denton, Texas, 4-7 November, 1998, will be published.

A.Hermanne, F. Szelecsényi, M. Sonck, S. Takács, F. Tárkányi, P. Van den Winkel
New Cross Section Data on $^{68}Zn(p,2n)^{67}Ga$ and $^{nat}Zn(p,xn)^{67}Ga$ Nuclear Reactions for Development of Reference Data Base; Journal of Radioanalitycal and Nuclear Chemistry, 240 (1999) 623 - 630.

F, Szelecsényi, S. Takács, F. Tárkányi, M. Sonck, A. Hermanne,
Study of Production Possibility of No-Carrier-Added ^{186}Re via Proton Induced Reaction on Tungsten for use in Radiotherapy, Synthesis and Applications of Isotopically Labelled Compounds 1997, ed. J.R. Heys, John Wiley & Sons, New York, 1998; Proc. of 6th Int. Symp., Philadelphia, USA, 14-18 Sept. 1997, , p.701- 704

F. Tárkányi, L. Andó, A. Fenyvesi, I. Mahunka, Z. Kovács, F. szelecsényi, S. Takács, *Application of the* *Debrecen Low Energy Multiparticle MGC-20E Cyclotron for Isotope Production for Medicine and Biology.*, Proceedings of XV. Int. Conf. on Cyclotrons and their Applications, Caen, France, 14-19 June, 1998, (in print)

S. Takács, F. Tárkányi, F Szelecsényi, M. Sonck, A. Hermanne, J. Van hoyweghen, B. Scholten, *The Use of* *Cross Section Data for Monitoring Charged Particle Beam Parameters*
Proceedings of XV. Int. Conf. on Cyclotrons and their Applications, Caen, France, 14-19 June, 1998, (in print)

F. Ditrói, S. Takács, I. Mahunka, F. Tárkányi,
Application of Small Energy Cyclotrons for Thin Layer Activation Technique
Proceedings of XV. Int. Conf. on Cyclotrons and their Applications, Caen, France, 14-19 June, 1998, (in print)

Z. Szucs, W. Hamkens, S. Takács, F. Tárkányi, H.H. Coenen, S.M. Qaim
Ecitation Function of $^{14}N(d,t)^{13}N$ and $^{14}N(d,\alpha n)^{11}C$ Reactions from Threshold to 12.3 MeV: Radionuclidic Purity of ^{15}O Produced via the $^{14}N(d,n)^{15}O$ Reaction
Radiochimica Acta, 80 (1998) 59-63

F. Szelecsényi, T.E. Boothe, S. Takács, F. Tárkányi, E. Tavano
Evaluated Cross Section and Thick Target Yield Data Bases of Zn+p Processes for Practical Applications,
Applied Radiation and Isotopes **49** (1998)1005-1032.

F Tárkányi, Z. Kovács L. Andó, F. Szelecsényi, S. Takács
Production of ^{123}I at a small cyclotrons, Proceedings of 2nd School and Workshop on Cyclotrons and Applications 15 - 19 March 1997, Cairo, Egypt, p. 230. (1998)

M. Sonck, A. Hermanne, F, Szelecsényi, S. Takács, F. Tárkányi
Study of the $^{nat}Ni(p,x)^{57}Ni$ process up to 44 MeV for monitor purposes;
Applied Radiation and Isotopes **49** (1998) 1533 - 1536.

Planned activities

- We continue to work on the CRP related to the evaluated CP databes
- As part of the CRP all the references included in the project will be reviewed to select the works not yet compiled in the EXFOR database.
- We continue to compile new entries for EXFOR from the papers published by the INC, Forschungszentrum Jülich, Jülich, Germany, and Institute of Nuclear Research, Debrecen, Hungary.
- Continue to measure new experimental data to clear the discrepancies and to complete the existing experimental database for different CP reactions.

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APPENDIX-A

LIST OF REACTIONS INCLUDED IN THE CRP PROJECT

Monitor Reactions

$^{27}Al(p,x)^{22}Na$
$^{27}Al(p,x)^{24}Na$
$^{nat}Ti(p,x)^{48}V$
$^{nat}Ni(p,x)^{57}Ni$
$^{nat}Cu(p,x)^{56}Co$
$^{nat}Cu(p,x)^{62}Zn$
$^{nat}Cu(p,x)^{63}Zn$
$^{nat}Cu(p,x)^{65}Zn$
$^{27}Al(d,x)^{22}Na$
$^{27}Al(d,x)^{24}Na$
$^{nat}Ti(d,x)^{48}V$
$^{nat}Fe(d,x)^{56}Co$
$^{nat}Ni(p,x)^{61}Cu$
$^{27}Al(^{3}He,x)^{22}Na$
$^{27}Al(^{3}He,x)^{24}Na$
$^{nat}Ti(^{3}He,x)^{48}V$
$^{27}Al(\alpha,x)^{22}Na$
$^{27}Al(\alpha,x)^{24}Na$
$^{nat}Ti(\alpha,x)^{51}Cr$
$^{nat}Cu(\alpha,x)^{66}Ga$
$^{nat}Cu(\alpha,x)^{67}Ga$
$^{nat}Cu(\alpha,x)^{65}Zn$

Gamma emitters

$^{67}Zn(p,n)^{67}Ga$
$^{68}Zn(p,2n)^{67}Ga$
$^{82}Kr(p,2n)^{81}Rb$
$^{nat}Kr(p,x)^{81}Rb$
$^{111}Cd(p,n)^{111}In$
$^{112}Cd(p,2n)^{111}In$
$^{203}Tl(p,3n)^{201}Pb$
$^{203}Tl(p,2n)^{202}Pb$
$^{203}Tl(p,4n)^{200}Pb$
$^{123}Te(p,n)^{123}I$
$^{124}Te(p,2n)^{123}I$
$^{124}Te(p,n)^{124}I$
$^{127}I(p,5n)^{123}Xe$
$^{127}I(p,3n)^{125}Xe$
$^{124}Xe(p,2n)^{123}Cs$
$^{124}Xe(p,pn)^{123}Xe$

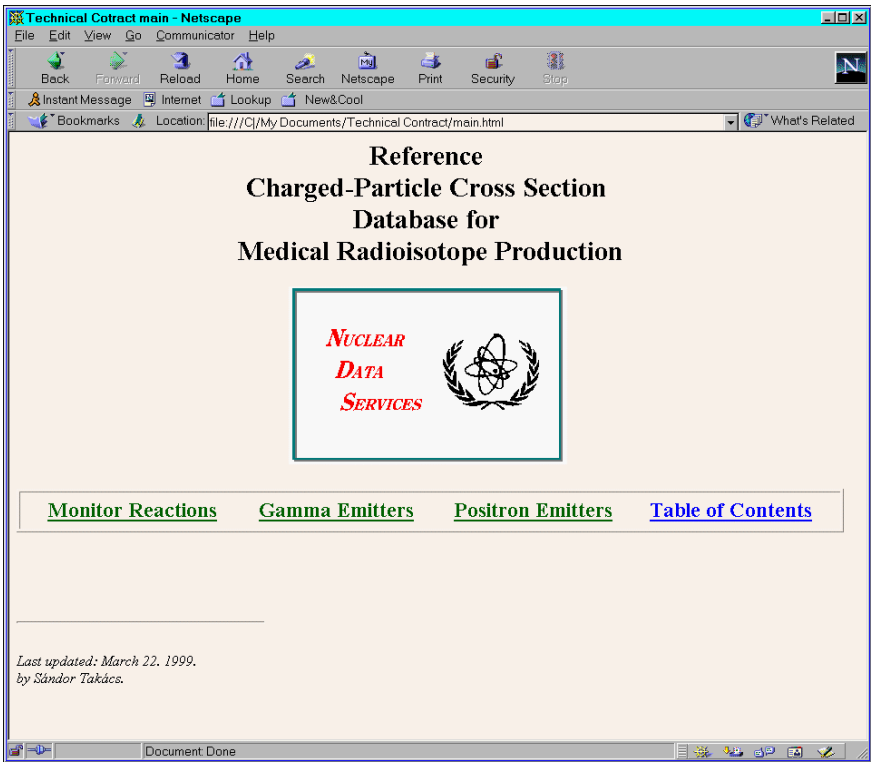
Positron emitters

$^{14}N(p,\alpha)^{11}C$
$^{16}O(p,\alpha)^{13}N$
$^{14}N(d,n)^{15}O$
$^{15}N(p,n)^{15}O$
$^{18}O(p,n)^{18}F$
$^{nat}Ne(d,\alpha)^{18}F$
$^{69}Ga(p,2n)^{68}Ge$
$^{nat}Ga(p,x)^{68}Ge$
$^{85}Rb(p,4n)^{82}Sr$
$^{nat}Rb(p,x)^{82}Sr$

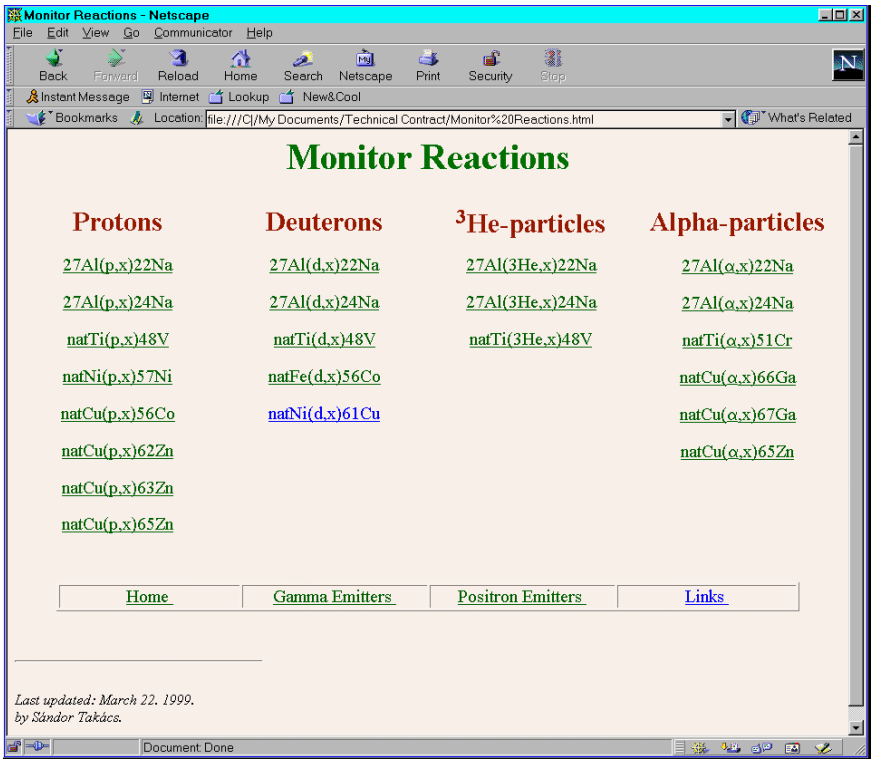
APPENDIX-B

Sample pages of the electronic version of the reference charged particle cross section database for medical radioisotope production.

Main page:



Page of Monitor Reactions



Opening page of a reaction

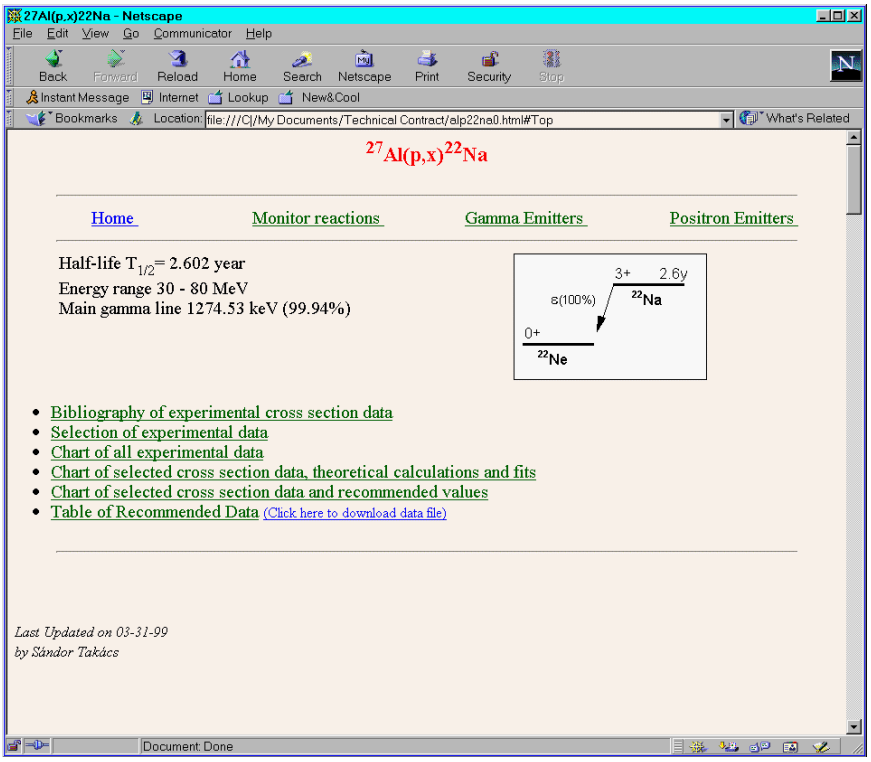


Chart of recommended data

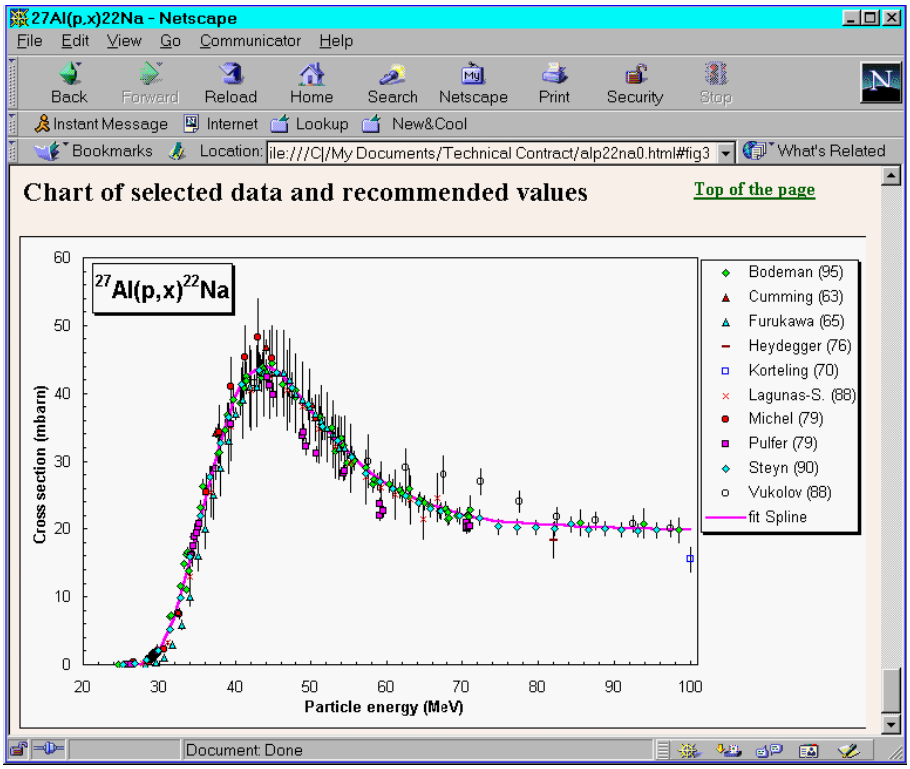
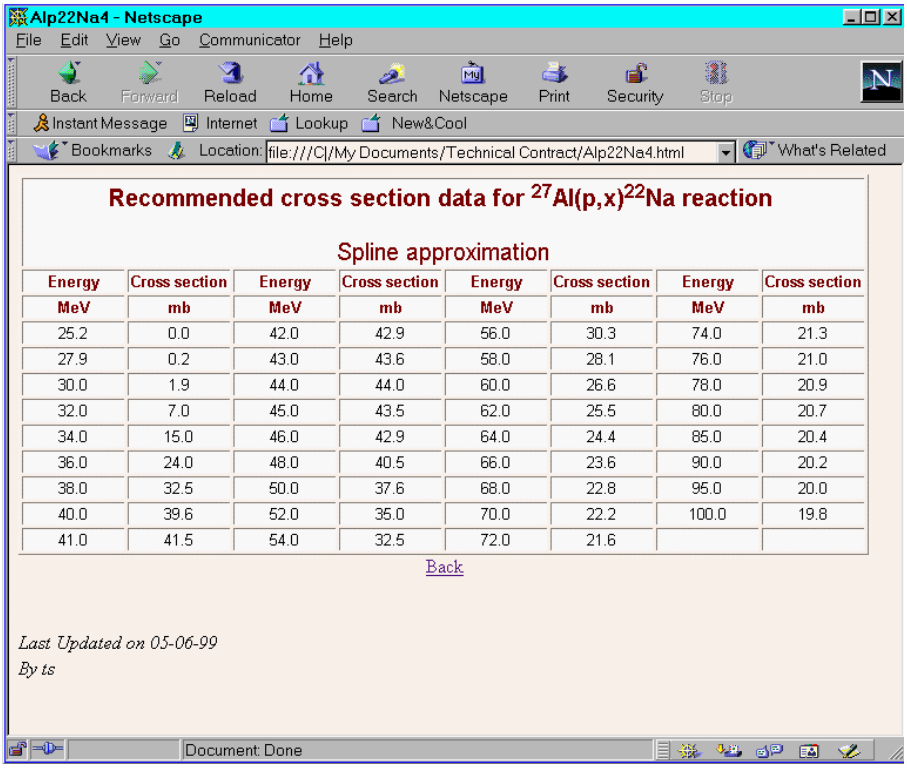


Table of recommended cross section data



Energy	Cross section	Energy	Cross section	Energy	Cross section	Energy	Cross section
MeV	mb	MeV	mb	MeV	mb	MeV	mb
25.2	0.0	42.0	42.9	56.0	30.3	74.0	21.3
27.9	0.2	43.0	43.6	58.0	28.1	76.0	21.0
30.0	1.9	44.0	44.0	60.0	26.6	78.0	20.9
32.0	7.0	45.0	43.5	62.0	25.5	80.0	20.7
34.0	15.0	46.0	42.9	64.0	24.4	85.0	20.4
36.0	24.0	48.0	40.5	66.0	23.6	90.0	20.2
38.0	32.5	50.0	37.6	68.0	22.8	95.0	20.0
40.0	39.6	52.0	35.0	70.0	22.2	100.0	19.8
41.0	41.5	54.0	32.5	72.0	21.6		