INTERNATIONAL ATOMIC ENERGY AGENCY

INDC(CCP)-434
Distr.: IE/EL
Revision 1

I N D C INTERNATIONAL NUCLEAR DATA COMMITTEE

Experimental and Theoretical Study of the Yields of Residual Product Nuclei Produced in Thin Targets Irradiated by 100-2600 MeV Protons

Yury E. Titarenko
(Project manager)
Institute for Theoretical and Experimental Physics (ITEP)

Principal executives: Yu.E. Titarenko, V.F. Batyaev, E.I. Karpikhin, R.D. Mulambetov, A.B. Koldobsky, V.M. Zhivun, S.V. Mulambetova, K.A. Lipatov, Yu.A. Nekrasov, A.V. Belkin, N.N. Alexeev, V.A. Schegolev, Yu.M. Goryachev, V.E. Luk'yashin, E.N. Firsov

February 2003

IAEA NUCLEAR DATA SECTION, WAGRAMER STRASSE 5, A-1400 VIENNA

Documents in the EL series are available in only limited quantities in hardcopy form. They may be downloaded in electronic form from http://www-nds.iaea.org/indc_sel.html or sent as an e-mail attachment. Requests for hardcopy or e-mail transmittal should be directed to services@iaeand.iaea.org or to:

Nuclear Data Section
International Atomic Energy Agency
PO Box 100
Wagramer Strasse 5
A-1400 Vienna
Austria

February 2003

Final
Project Technical Report
of ISTC 839B-99

Experimental and Theoretical Study of the Yields of Residual Product Nuclei Produced in Thin Targets Irradiated by 100-2600 MeV Protons

(1 January 1999 – 31 December 2000, 24 months)

Yury E. Titarenko
(Project manager)
Institute for Theoretical and Experimental Physics (ITEP)

Principal executives: Yu.E. Titarenko, V.F. Batyaev, E.I. Karpikhin, R.D. Mulambetov, A.B. Koldobsky, V.M. Zhivun, S.V. Mulambetova, K.A. Lipatov, Yu.A. Nekrasov, A.V. Belkin, N.N. Alexeev, V.A. Schegolev, Yu.M. Goryachev, V.E. Luk'yashin, E.N. Firsov.

February 2003
(The revised and updated version
of the Final Project Technical Report of ISTC 839B-99 of February 2001)

The work was supported financially by EU, Norway, and Japan and performed under the contract to the International Science and Technology Center (ISTC), Moscow.

Experimental and theoretical study of the yields of residual product nuclei produced in thin targets irradiated by 100-2600 MeV protons

(From 1 January 1999 to 31 December 2000 for 24 months)

Yury Efimovich Titarenko
(Project manager)
Institute for Theoretical and Experimental Physics (ITEP)[1]

The objective of the project is measurements and computer simulations of independent and cumulative yields of residual product nuclei in thin targets relevant as target materials and structure materials for hybrid accelerator-driven systems coupled to high-energy proton accelerators. The yields of residual product nuclei are of great importance when estimating such basic radiation-technology characteristics of hybrid facility targets as the total target activity, target "poisoning", buildup of long-lived nuclides that, in turn, are to be transmuted, product nuclide (Po) α-activity, content of low-pressure evaporated nuclides (Hg), content of chemically-active nuclides that spoil drastically the corrosion resistance of the facility structure materials, etc.

In view of the above, radioactive product nuclide yields from targets and structure materials were determined by an experiment using the ITEP U-10 proton accelerator in 51 irradiation runs for different thin targets: ^{182,183,184,186}W at proton energies 0.2, 0.8, and 1.6 GeV; ^{nat}W, ^{56}Fe, ^{58}Ni, and ^{93}Nb at 2,6 GeV; ^{232}Th, ^{nat}U, at 0.1, 0.2, 0.8, 1.2, and 1.6 GeV; ^{99}Tc, at 0.1, 0.15, 0.2, 0.8, 1.0, 1.2, 1.4, 1.6, and 2.6 GeV; ^{59}Co and ^{63,65}Cu at 0.2, 1.2, 1.6, and 2.6 GeV; ^{nat}Hg at 0.1, 0.2, 0.8, and 2.6 GeV and, additionally, ^{208}Pb at 1.0 GeV. As a result, 4315 cumulative and independent yields of residual radioactive product nuclei, whose lifetimes range from 8 minutes to 32 years, have been measured. Besides, the monitor ^{27}Al(p,x)^{24}Na and ^{27}Al(p,x)^{7}Be reaction cross sections have been measured at proton energies from 0.07 GeV to 2.6 GeV. The experimental nuclide yields were determined by the direct γ-spectrometry method. The γ-spectrometer resolution is of 1.8 keV at the 1332 keV γ-line. The experimental γ-spectra were processed by the GENIE2000 code. The γ-lines were identified, and the cross sections calculated, by the ITEP-developed SIGMA code using the PCNUDAT database. The proton fluence was monitored by the ^{27}Al(p,x)^{22}Na reaction.

Some of the results have been compared with the data obtained elsewhere, in particular with the recent GSI inverse kinematics experiments.

The measured data are compared with the simulations by the LAHET, CEM95, CEM2k, LAQGSM, CASCADE, CASCADE/INPE, YIELDX, HETC, and INUCL codes. The predictive power of the tested codes is different but was found to be satisfactory for most of the nuclides in the spallation region, though none of the benchmarked codes agree well with the data in the whole mass region of product nuclides and all should be improved further. On the whole, the predictive power of all codes for the data in the fission product region is worse than in the spallation region; therefore, development of better models for fission-fragment formation is of first priority.

Keywords: nuclear reaction, spallation, fission, fragmention, yields, residual nuclides, cross sections, simulation, Monte-Carlo codes, comparison

[1]B. Cheremushkinskaya 25, 117259 Moscow, Russia, Phone +7-095-123-6383, Fax +7-095-127-0543, E-mail: Yury.Titarenko@itep.ru

The work has been performed by the following institutes and collaborators:

1. Participating institutes:

   1. Leading Institute: Institute for Theoretical and Experimental Physics (ITEP), B. Cheremushkinskaya 25, 117259, Moscow, Russia, Phone +7-095-123-6383, Fax +7-095-127-0543, E-mail Yury.Titarenko@itep.ru

2. Foreign Collaborators:

   1. Dr. W. Gudowski, The Royal Institute of Technology, Dep. of Neutron & Reactor Physics, Lindstedtvgen 30, S-10044 Stockholm, Fax 46 8 105 519, 46 8 106 948.

   2. Prof. M. Salvatores, Commissariat a l'Energy Atomique, Direction des Reacteurs Nucleaires, CEN - Cadarache, F - 13108 Saint Paul Lez Durance Cedex, France, Fax 33 4 42 25 33 65.

   3. Prof. R. Michel, Zentrum fuer Strahlenschutz und Radiooekologie, University of Hannover, Am Kleinen Felde 30, D - 30167 Hannover, Germany, Fax 49 511 762 3319.

   4. Dr. G. Benamati, ENEA (Ente Nazionale per le Nuove Tecnologie L'Energia e l'Ambiente) Fusion Division, C.R. Brasimone, I-40032 Camugnano (BO) Italy, Fax 39 534 80 12 25.

   5. Dr. H. Yasuda, Accelerator Radiation Laboratory, Japan Atomic Energy Research Institute, Shirakata-shirane 2-4, Tokai-mura, Ibaraki-ken 319-11, Japan, Fax 81 29 282 64 96.

   6. Dr. H. Takada, Center for Neutron Science, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken, 319-1195, Japan, E-mail : takada@omega.tokai.jaeri.go.jp

Contents