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

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**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)**

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## 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  
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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)  $\alpha$ -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:  $^{182,183,184,186}\text{W}$  at proton energies 0.2, 0.8, and 1.6 GeV;  $^{nat}\text{W}$ ,  $^{56}\text{Fe}$ ,  $^{58}\text{Ni}$ , and  $^{93}\text{Nb}$  at 2,6 GeV;  $^{232}\text{Th}$ ,  $^{nat}\text{U}$ , at 0.1, 0.2, 0.8, 1.2, and 1.6 GeV;  $^{99}\text{Tc}$ , at 0.1, 0.15, 0.2, 0.8, 1.0, 1.2, 1.4, 1.6, and 2.6 GeV;  $^{59}\text{Co}$  and  $^{63,65}\text{Cu}$  at 0.2, 1.2, 1.6, and 2.6 GeV;  $^{nat}\text{Hg}$  at 0.1, 0.2, 0.8, and 2.6 GeV and, additionally,  $^{208}\text{Pb}$  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  $^{27}\text{Al}(p,x)^{24}\text{Na}$  and  $^{27}\text{Al}(p,x)^7\text{Be}$  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  $\gamma$ -spectrometry method. The  $\gamma$ -spectrometer resolution is of 1.8 keV at the 1332 keV  $\gamma$ -line. The experimental  $\gamma$ -spectra were processed by the GENIE2000 code. The  $\gamma$ -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  $^{27}\text{Al}(p,x)^{22}\text{Na}$  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, fragmentation, yields, residual nuclides, cross sections, simulation, Monte-Carlo codes, comparison

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# Contents

<b>1</b>	<b>INTRODUCTION</b>	<b>6</b>
<b>2</b>	<b>EXPERIMENTAL DETERMINATION TECHNIQUES</b>	<b>7</b>
2.1	Mathematical representation of the reaction product yield values . . . . .	7
2.2	Manufacture, certification, and irradiation of experimental samples . . . . .	15
2.3	$\gamma$ -spectra: measurements and processing . . . . .	24
2.4	Determination of the spectrometer characteristics . . . . .	28
2.4.1	Determination of admissible measurement conditions . . . . .	28
2.4.2	Determination of the absolute height-energy detection efficiency of spectrometer.	29
2.5	Extracted proton beam energies . . . . .	40
2.6	Neutron background . . . . .	43
2.7	Monitor reactions . . . . .	46
<b>3</b>	<b>EXPERIMENTAL RESULTS.</b>	<b>50</b>
3.1	Experimental errors . . . . .	50
3.2	Experimental yields for $^{182}\text{W}$ irradiated with 0.2, 0.8, 1.6 GeV protons. . . . .	53
3.3	Experimental yields for $^{183}\text{W}$ irradiated with 0.2, 0.8, 1.6 GeV protons. . . . .	57
3.4	Experimental yields for $^{184}\text{W}$ irradiated with 0.2, 0.8, 1.6 GeV protons. . . . .	61
3.5	Experimental yields for $^{186}\text{W}$ irradiated with 0.2, 0.8, 1.6 GeV protons. . . . .	65
3.6	Experimental yields for $^{nat}\text{W}$ irradiated with 2.6 GeV protons. . . . .	69
3.7	Experimental yields for $^{232}\text{Th}$ irradiated with 0.1, 0.2, 0.8, 1.2, 1.6 GeV protons. . . . .	73
3.8	Experimental yields for $^{nat}\text{U}$ irradiated with 0.1, 0.2, 0.8, 1.2, 1.6 GeV protons. . . . .	80
3.9	Experimental yields for $^{99}\text{Tc}$ irradiated with 0.1, 0.15, 0.2, 0.8, 1.0, 1.2, 1.4, 1.6, 2.6 GeV protons. . . . .	87
3.10	Experimental yields for $^{59}\text{Co}$ irradiated with 0.2, 1.2, 1.6, 2.6 GeV protons. . . . .	91
3.11	Experimental yields for $^{63}\text{Cu}$ irradiated with 0.2, 1.2, 1.6, 2.6 GeV protons. . . . .	93
3.12	Experimental yields for $^{65}\text{Cu}$ irradiated with 0.2, 1.2, 1.6, 2.6 GeV protons. . . . .	95
3.13	Experimental yields for $^{nat}\text{Hg}$ irradiated with 0.1, 0.2, 0.8, 2.6 GeV protons. . . . .	97
3.14	Experimental yields for $^{56}\text{Fe}$ irradiated with 2.6 GeV protons. . . . .	102
3.15	Experimental yields for $^{58}\text{Ni}$ irradiated with 2.6 GeV protons. . . . .	103
3.16	Experimental yields for $^{93}\text{Nb}$ irradiated with 2.6 GeV protons. . . . .	105
3.17	Experimental yields for $^{208}\text{Pb}$ irradiated with 1.0 GeV protons. . . . .	108
3.18	Comparison of the reported results with the results obtained elsewhere . . . . .	111
<b>4</b>	<b>SIMULATION OF EXPERIMENTAL RESULTS BY THE CODES</b>	<b>121</b>
4.1	The methods for comparing between experimental and simulated data . . . . .	121
4.2	The codes used to simulate the experimental results . . . . .	122
4.3	Comparison of experiment with simulations . . . . .	123

4.4	General conclusions on the agreement between the experimental and simulated product nuclide yields. . . . .	138
4.5	Methods for improving the simulation codes. . . . .	138
<b>5</b>	<b>Conclusion</b>	<b>139</b>
<b>6</b>	<b>Acknowledgements</b>	<b>139</b>
<b>7</b>	<b>Annex 1. Comparison between experimental and simulated data.</b>	<b>145</b>
<b>8</b>	<b>Annex 2. List of publications.</b>	<b>317</b>