# Nuclear Data for Proton Beam Radiotherapy

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**Abstract.** The need for a program of work focused on the nuclear data evaluation of charged-particle reactions has arisen recently due to their increasing use in cancer therapy. This project, as part of that program, has as its main goal the selection and comparison of nuclear data for nuclear reactions induced by protons at low to intermediate energies (E < 250 MeV). The methodology of selection was based on the data base EXFOR and the compilations of radionuclide production cross sections of N. Sobolevsky. For the purpose of comparison and evaluation, theoretical calculations with the reaction model code EMPIRE-II are being used.

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## Introduction

Proton beam therapy has been confirmed as an efficacious means for the radiation treatment of tumors, which minimizes damages caused to nearby healthy tissues as well.

This therapy was proposed by Robert Wilson in 1946, who observed that the beam had a nearly straight-line path due to the particles mass and that the bulk of the beam energy was deposited at the maximum range, in a narrow extent about the Bragg peak. This modality of cancer treatment began to be used on patients in 1954 at the Lawrence Berkeley National Laboratory in the USA.

## Data selection and analysis

The EXFOR [1] software and data library provided by the IAEA was used for the selection and extraction of experimental data for reactions involving protons or alpha particles as incident particles, to a maximum energy of 200 MeV, with carbon-12, nitrogen-14, oxygen-16, aluminium-27, silicon-28 or iron-56 atoms as targets. After selecting the characteristics desired of the data, this software provides names, reference code, author and publishing location, a short abstract and the available experimental data.

For this project, we chose experiments that furnish a reasonable number of data points for elastic or inelastic differential angular scattering of proton, neutron or alpha

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emission spectra or double differential angle/energy cross sections. We also extracted related production cross section data from EXFOR and from N. Sobolevsky's compilation [2], for comparison to theoretical model calculations.

After compiling the available data, we began to study the EMPIRE-II system [3], a set of model codes for nuclear reaction calculations. In this system, we select the reaction characteristics and theoretical models to be used for calculations. A huge library of input parameters provides everything from nuclear masses, optical model parameters, ground state deformations and branching ratios for decay to discrete levels.

## Results and Discussion

Tables were prepared in order to facilitate the comparison of the data sets. The total energy range, reaction, reference code, angular range, level energy or energy of outgoing particle and number of data points are indicated in the tables.

Discrepancies exist between experimental and theoretical model results, at both low and high nucleon emission energies. The differences at low energies are due to the fact that compound nucleus emission is not included in the spectra taken from the EMPIRE output, a defect of the code that is being remedied. We are still investigating the discrepancies at higher energies, which have the characteristics of a misplaced quasi-elastic peak.

Up to this point, we have had only partial success with this project, studying experimental methods and nuclear reactions models, collecting and selecting data from EXFOR and preparing tables. Automation of graph preparation will be the next important step in facilitating the systematic use of EMPIRE-II.

Another serious difficulty with the use of EMPIRE-II is that it was designed to calculate neutron-induced cross sections rather than proton-induced ones. As soon as graph preparation is more automatic and problems with low-energy proton-induced reactions are fixed, we plan to perform a systematic study of the compiled data. We plan to use the hybrid Monte Carlo pre-equilibrium model of Blann and Chadwick [4] as a basis for this study.

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