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## References

Ajzenbergselove F 1990 Energy-levels of light-nuclei A = 11-12 Nucl. Phys. A 506 1–158

Allison J et al 2006 GEANT4 developments and applications IEEE Trans. Nucl. Sci. 53 270-8

Bauhoff W 1986 Tables of reaction and total cross-section for proton nucleus scattering below 1 GeV *At. Data Nucl. Data Tables* 35 429–47

Belhout A *et al* 2007 Gamma-ray production by proton and alpha-particle induced reactions on C-12, O-16, Mg-24 and Fe *Phys. Rev.* C **76** 034607

Benhabiles-Mezhoud H et al 2011 Measurements of nuclear gamma-ray line emission in interactions of protons and alpha particles with N, O, Ne, and Si *Phys. Rev.* C 83 024603

Bom V, Joulaeizadeh L and Beekman F J 2012 Real-time prompt gamma monitoring in spot-scanning proton therapy using imaging through a knife-edge-shaped slit *Phys. Med. Biol.* **57** 297–308

Capote R et al 2009 RIPL—reference input parameter library for calculation of nuclear reactions and nuclear data evaluations Nucl. Data Sheets 110 3107–213

Chadwick M B 2012 ENDF nuclear data in the physical, biological, and medical sciences *Int. J. Radiat. Biol.* **88** 10–4 Chadwick M B and Young P G 1997 Proton nuclear interactions up to 250 MeV for radiation transport simulations of particle therapy *J. Brachyther. Int.* **13** 89–93

Chadwick M B et al 1999 LA150 documentation of cross sections, heating, and damage Technical Report LA-UR-99-1222, Los Alamos National Laboratory, Los Alamos, NM, USA

Dyer P, Bodansky D, Seamster A G, Norman E B and Maxson D R 1981 Cross-sections relevant to gamma-ray astronomy—proton-induced reactions *Phys. Rev.* C 23 1865–82

Espana S and Paganetti H 2010 The impact of uncertainties in the CT conversion algorithm when predicting proton beam ranges in patients from dose and PET-activity distributions *Phys. Med. Biol.* **55** 7557–71

Folger G, Ivanchenko V N and Wellisch J P 2004 The binary cascade—nucleon nuclear reactions Eur. Phys. J. A 21 407–17

Hauser W and Feshbach H 1952 The inelastic scattering of neutrons Phys. Rev. 87 366-73

Herman M et al 2007 EMPIRE: Nuclear reaction model code system for data evaluation Nucl. Data Sheets 108 2655-715

International Commission on Radiological Protection 1975 Reference man: anatomical, physiological and metabolic characteristics *Technical Report* ICRP Publication 23

Jarlskog C Z and Paganetti H 2008 Physics settings for using the GEANT4 toolkit in proton therapy *IEEE Trans. Nucl. Sci.* **55** 1018–25

Kiener J et al 1998 Gamma-ray production by inelastic proton scattering on O-16 and C-12 Phys. Rev. C 58 2174–9
Knopf A et al 2011 Accuracy of proton beam range verification using post-treatment positron-emission tomography/computed tomography as function of treatment site Int. J. Radiat. Oncol. Biol. Phys. 79 297–304

Koning A J and Delaroche J P 2003 Local and global nucleon optical models from 1 keV to 200 MeV Nucl. Phys. A 713 231–310

Lang F L, Werntz C W, Crannell C J, Trombka J I and Chang C C 1987 Cross-sections for production of the 15.10 MeV and other astrophysically significant gamma-ray lines through excitation and spallation of C-12 and O-16 with protons *Phys. Rev.* C 35 1214–27

Lesko K T *et al* 1988 Measurements of cross-sections relevant to gamma-ray line astronomy *Phys. Rev.* C **37** 1808–17 Los Alamos National Laboratory 2012 MCNP6 beta 2: Monte Carlo *N*-particle extended

Madland D G 1997 Progress in the development of global medium-energy nucleon-nucleus optical model potentials Proc. OECD/NEA Specialists' Meeting on the Nucleon–Nucleus Optical Model Up to 200 MeV p 129 (Paris)

Min C H, Kim C H, Youn M Y and Kim J W 2006 Prompt gamma measurements for locating the dose falloff region in the proton therapy *Appl. Phys. Lett.* **89** 183517

Murphy R J, Kozlovsky B, Kiener J and Share G H 2009 Nuclear gamma-ray de-excitation lines and continuum from accelerated-particle interactions in solar flares *Astrophys. J. Suppl. Ser.* **183** 142–55

Narayanaswamy J, Dyer P, Faber S R and Austin S M 1981 Production of 6.13 MeV gamma-rays from the O-16(p,p'-gamma)O-16 reaction at 23.7 and 44.6 MeV *Phys. Rev.* C **24** 2727–30

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