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Evaluation of production cross-sections for theranostic 67Cu radionuclide via proton-induced nuclear reaction on 68Zn target

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Abstract

Copper-67 (T1/2 = 61.83 h, Eβ−mean=141 keV, Iβ−total=100%; Eγ = 184.577 keV, Iγ = 48.7%) is a promising radionuclide for theranostic applications especially in radio immunotherapy. However, one of the main drawbacks for its application is related to its limited availability. Various nuclear reaction routes investigated in the last years can result in 67Cu production, although the use of proton beams is the method of choice taken into account in this work. The goal of this work is a revision of the cross-sections aimed at 67Cu yield, which were evaluated for the 68Zn(p,2p)67Cu reaction route up to 80 MeV proton energy. A well-defined statistical procedure, i.e., the Simultaneous Evaluation on KALMAN (SOK), combined with the least-squares concept, was used to obtain the evaluated data together with the covariance matrix. The obtained evaluated data were also compared to predictions provided by the nuclear reaction model codes TALYS and EMPIRE, and a partial agreement among them has been found. These data may be useful for both existing and potential applications in nuclear medicine, to achieve an improvement and validation of the various nuclear reaction models, and may also find applications in other fields (e.g., activation analysis and thin layer activation). © 2021 Elsevier Ltd

Author Keywords

67Cu; Evaluated data; Nuclear reaction cross-section; Radioimmunotherapy; SOK code; TALYS and EMPIRE codes; β-γ emitter

Index Keywords

Chemical activation, Codes (symbols), Covariance matrix, Nuclear medicine, Nuclear reactions, Petroleum reservoir evaluation; 67cu, Evaluated data, Nuclear reaction cross-section, Radioimmunotherapy, Reaction model, Reaction routes, Simultaneous evaluation on KALMAN code, TALYS and EMPIRE code, Theranostics, B-γ emitter; Radioisotopes; copper 67, radioisotope, unclassified drug, zinc 68; Article, Bayes theorem, controlled study, gamma spectrometry, global positioning system, least square analysis, measurement accuracy, nuclear energy, nuclear reaction, prediction, proton radiation, scintillation, signal processing

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References

- Aleksandrov, Y.V., A A A, Vasilev, S.K., Zelinski, A., Ivanov, R.B., Kolachkovski, A., Misiak, R., Prikhodtseva, V.P.
  Production cross sections of spallation radioactive nuclides in thin targets of Co, Ni, Cu and Zn irradiated by 660 MeV protons
  (1990) *40 Conf. Nucl. Spectroscopy Nucl. Structure*, p. 498.
  Joint Inst.for Nucl.Res. Dubna, Leningrad, USSR

- Ali, S.K.I., Khandaker, M.U., Kassim, H.A.
  Evaluation of production cross-sections for ¹⁸⁶Re theranostic radionuclide via charged-particle induced reactions on Tungsten
  (2018) *Appl. Radiat. Isot.*, 135, pp. 239-250.

- Bianchi, G., Tinnirello, I.
  Kalman filter estimation of the number of competing terminals in an IEEE 802.11 network, INFOCOM 2003
  (2003) *Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*, pp. 844-852.
  IEEE

- Bonardi, M.L., Groppi, F., Birattari, C., Gini, L., Mainardi, C., Ghioni, A., Menapace, E., Stroosnijder, M.F.
  Thin-target excitation functions and optimization of simultaneous production of NCA copper-64 and gallium-66,67 by deuteron induced nuclear reactions on a natural zinc target
  (2003) *J. Radioanal. Nucl. Chem.*, 257, pp. 229-241.

- Bonardi, M.L., Groppi, F., Mainardi, H.S., Kokhanyuk, V.M., Lapshina, E.V., Mebel, M.V., Zhuikov, B.L.
  Cross section studies on 64Cu with zinc target in the proton energy range from 141 down to 31 MeV
  (2005) *J. Radioanal. Nucl. Chem.*, 264, pp. 101-105.

- Capote, R., Herman, M., Obložinský, P., Young, P., Goriely, S., Belgya, T., Ignatyuk, A., Plujko, V.A.
  RIPL–reference input parameter library for calculation of nuclear reactions and nuclear data evaluations
  (2009) *Nucl. Data Sheets*, 110, pp. 3107-3214.

- Chursin, G., Fazio, M., Micheletti, S., Pignanelli, M., Zetta, L.
  The (n,d) reaction on Cu and Zn isotopes
  (1967) *Nucl. Phys.*, 93, pp. 209-217.

- Cohen, B.L., Newman, E., Handley, T.H.
  (p, pn)+(p, 2n) and (p, 2p) cross sections in medium weight elements
  (1955) *Phys. Rev.*, 99, pp. 723-727.

- DeNardo, S.J., DeNardo, G.L.
  Tumor therapy with radioactive labeled antitumor antibodies
  (1983) *Cell. Oncol.: New Approaches in Biology, Diagnosis and Treatment*, pp. 282-292.

- Dirks, C., Scholten, B., Happel, S., Zulauf, A., Bombard, A., Jungclas, H.
  Characterisation of a Cu selective resin and its application to the production of ⁶⁴Cu
  (2010) *J. Radioanal. Nucl. Chem.*, 286, pp. 671-674.

- Duchemin, C., Guertin, A., Haddad, F., Michel, N., Métivier, V.
  Production of medical isotopes from a thorium target irradiated by light charged particles up to 70 MeV
  (2015) *Phys. Med. Biol.*, 60, pp. 931-946.

- EXFOR
  Nuclear Database Accessed Online in
  (2020),
  The International Network of Nuclear Reaction Data Centres

- Firestone, R.B.
  Nuclear data sheets for A = 24
  (2007) *Nucl. Data Sheets*, 108, pp. 2319-2392.

- Ghoshal, S.N.
  An experimental verification of the theory of compound nucleus
  (1950) *Phys. Rev.*, 80, pp. 939-942.

- Gibbs, B.P.
  Advanced Kalman Filtering, Least-Squares and Modeling: a Practical Handbook
  (2011), John Wiley & Sons

- Han, Y., Shi, Y., Shen, Q.
  Deuteron global optical model potential for energies up to 200 MeV
  (2006) *Phys. Rev. C*, 74.
  044615

- Herman, M., Capote, R., Carlson, B., Obložinský, P., Sin, M., Trkov, A., Wienke, H., Zerkin, V.
  EMPIRE: nuclear reaction model code system for data evaluation
  (2007) *Nucl. Data Sheets*, 108, pp. 2655-2715.

- Hermanne, A., Ignatyuk, A.V., Capote, R., Carlson, B.V., Engle, J.W., Kellett, M.A., Kibédi, T., Verpelli, M.
  Reference cross sections for charged-particle monitor reactions
  (2018) *Nucl. Data Sheets*, 148, pp. 338-382.

- Hricak, H., Adelstein, S., Conti, P., Fowler, J., Gray, J., Hu, L., Karp, J., Maynard, C.
  Advancing nuclear medicine through innovation
  (2007) *Committee on State of the Science of Nuclear Medicine*,
  National Research Council

- IAEA
  (2020),
  International Atomic Energy Agency Aug/2018

- Ján, K., Kamel, A., Federica, S., Antonio, B., Uwe, H., Neil, G.
  Preparation of ⁶⁷Cu via deuteron irradiation of ⁷⁰Zn
  (2012) *Radiochim. Acta*, 100, pp. 419-424.

- Junde, H., Xiaolong, H., Tuli, J.K.
  Nuclear data sheets for A = 67
  (2005) *Nucl. Data Sheets*, 106, pp. 159-250.

- Kastleiner, S., Coenen, H.H., Qaim, S.M.
  Possibility of production of ⁶⁷Cu at a small-sized cyclotron via the (p,α)-Reaction on enriched ⁷⁰Zn
  (1999) *J. Radiochimica Acta.*, 84, pp. 107-110.

- Kawano, T., Matsunobu, H., Murata, T.
  Evaluation of Fission Cross Sections and Covariances for ²³³U, ²³⁵U, ²³⁸U, ²³⁹Pu, ²⁴⁰Pu, and ²⁴¹Pu
  (2000), Japan Atomic Energy Research Institute

- Khandaker, M.U., Ali, S.K.I., Kassim, H.A., Yusof, N.
  Evaluated cross-sections of ⁵⁵Co radionuclide, a non-standard positron emitter for clinical applications
  (2017) *Radiat. Phys. Chem.*, 140, pp. 511-520.

- Kielan, D., Marcinkowski, A.
  Cross sections for (n,p) reaction on zinc isotopes in terms of the novel multistep compound reaction model
  (1995) *Zeitschrift für Physik A Hadrons and Nuclei*, 352, pp. 137-143.

- Knogler, K., Grünberg, J., Zimmermann, K., Cohrs, S., Honer, M., Ametamey, S., Altevogt, P., Novak-Hofer, I.
  Copper-67 radioimmunotherapy and growth inhibition by anti–L1-cell adhesion molecule monoclonal antibodies in a therapy model of ovarian cancer metastasis
  (2007) *Clin. Canc. Res.*, 13, p. 603.

- Koning, A.J., Rochman, D.
  Modern nuclear data evaluation with the TALYS code system
  (2012) *Nucl. Data Sheets*, 113, pp. 2841-2934.

- Lederer, C.M., Hollander, J.M., Perlman, I.
  Table of Isotopes
  (1967),

- Leo, W.R.
  Techniques for Nuclear and Particle Physics Experiments: a How-To Approach
  (1994), Springer-Verlag Berlin Heidelberg New York, USA

- Levkovskij, V.
  Activation Cross Sections of Medium Mass Nuclide (A= 40–100) by Medium Energy Protons and Alpha Particles (E= 10–50 MeV)
  (1991), Inter-Vesi Moscow, USSR

- Li, Q., Li, R., Ji, K., Dai, W.
  Kalman Filter and its Application, Intelligent Networks and Intelligent Systems (ICINIS)
  (2015) *2015 8th International Conference on. IEEE*, pp. 74-77.

- McGee, T., Rao, C.L., Saha, G.B., Yaffe, L.
  Nuclear interactions of ⁴⁵Sc and ⁶⁸Zn with protons of medium energy
  (1970) *Nucl. Phys.*, 150, pp. 11-29.

- Meadows, J.W.
  Excitation functions for proton-induced reactions with copper
  (1953) *Phys. Rev.*, 91, pp. 885-889.

- Meinke, W.W.
  Chemical Procedures Used in Bombardment Work at Berkeley
  (1949), pp. 76-277.
  UNIVERSITY OF CALIFORNIA Radiation Laboratory

- Morrison, D.L., Caretto, A.A.
  Excitation functions of (p,xp) reactions
  (1962) *Phys. Rev.*, 127, pp. 1731-1738.

- Morrison, D.L., Caretto, A.A.
  Recoil study of the ⁶⁸Zn(p,2p)⁶⁷Cu reaction
  (1964) *Phys. Rev.*, 133, pp. B1165-B1170.

- O'Donnell, R.T., DeNardo, G.L., Kukis, D.L., Lamborn, K.R., Shen, S., Yuan, A., Goldstein, D.S., DeNardo, S.J.
  67Copper-2-iminothiolane-6-[p-(bromoacetamido)benzyl-TETA-Lym-1 for radioimmunotherapy of non-Hodgkin's lymphoma
  (1999) *Clin. Canc. Res.: an official journal of the American Association for Cancer Research*, 5, pp. 3330s-3336s.

- Pupillo, G., Sounalet, T., Michel, N., Mou, L., Esposito, J., Haddad, F.
  New production cross sections for the theranostic radionuclide ⁶⁷Cu
  (2018) *Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms*, 415, pp. 41-47.

- Qaim, S.M.
  Theranostic radionuclides: recent advances in production methodologies
  (2019) *J. Radioanal. Nucl. Chem.*, 322, pp. 1257-1266.

- Schwarzbach, R., Zimmermann, K., Bläuenstein, P., Smith, A., August Schubiger, P.
  Development of a simple and selective separation of ⁶⁷Cu from irradiated zinc for use in antibody labelling: a comparison of methods
  (1995) *Appl. Radiat. Isot.*, 46, pp. 329-336.

- Schwarzbach, R., Zimmermann, K., Novak-Hofer, I., Schubiger, P.A.
  A comparison of 67CU production by proton (67 to 12 MeV) induced reactions on NATZN and on enriched ⁶⁸ZN/⁷⁰ZN
  (2001) *J. Label. Compd. Radiopharm.*, 44, pp. S809-S811.

- Shashank, K., Ravi, N., Mukunda Rao, R., Alamelu, V.
  Implementation of Kalman Filter to Monitor the Level Fluctuations in a Dam Using FPGA
  (2013), Springer

- Skakun, Y., Qaim, S.M.
  Excitation function of the ⁶⁴Ni(α,p)⁶⁷Cu reaction for production of ⁶⁷Cu
  (2004) *Appl. Radiat. Isot.*, 60, pp. 33-39.

- Soukhovitskii, E.S., Capote, R., Quesada, J.M., Chiba, S.
  Dispersive coupled-channel analysis of nucleon scattering from ²³²Th up to 200 MeV
  (2005) *Phys. Rev. C*, 72.
  024604

- Stoll, T., Kastleiner, S., Shubin Yu, N., Coenen Heinz, H., Qaim Syed, M.
Excitation functions of proton induced reactions on ⁶⁸Zn from threshold up to 71 MeV, with specific reference to the production of ⁶⁷Cu
(2002) *Radiochim. Acta*, p. 309.

- Strominger, D., Hollander, J.M., Seaborg, G.T.
Table of isotopes
(1958) *Rev. Mod. Phys.*, 30, pp. 585-904.

- Szelecsényi, F., Steyn, G.F., Dolley, S.G., Kovács, Z., Vermeulen, C., van der Walt, T.N.
Investigation of the ⁶⁸Zn(p,2p)⁶⁷Cu nuclear reaction: new measurements up to 40MeV and compilation up to 100 MeV
(2009) *Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms*, 267, pp. 1877-1881.

- Takács, S., Tárkányi, F., Sonck, M., Hermanne, A.
Investigation of the ^{nat}Mo(p,x)^{96mg}Tc nuclear reaction to monitor proton beams: new measurements and consequences on the earlier reported data
(2002) *Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms*, 198, pp. 183-196.

- Tárkányi, F., Takács, S., Gul, K., Hermanne, A., Mustafa, M.G., Nortier, M., Oblozinsky, P., Zhuang, Y.
Beam monitor reactions
(2001) *Charged Particle Cross-Section Database for Medical Radioisotope Production*, IAEA Vienna

- Tárkányi, F., Takács, S., Ditrói, F., Hermanne, A., Sonck, M., Shubin, Y.
Excitation functions of deuteron induced nuclear reactions on natural zinc up to 50 MeV
(2004) *Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms*, 217, pp. 531-550.

- Williams, D.C., Irvine, J.W.
Nuclear excitation functions: ⁴⁰Ar,⁶⁸Zn (d,³He)
(1963) *Phys. Rev.*, 130, pp. 259-264.

- Zarchan, P.
Progress in Astronautics and Aeronautics: Fundamentals of Kalman Filtering: a Practical Approach
(2005), Aiaa

- Zimmermann, K., Gianollini, S., Schubiger, P.A., Novak-Hofer, I.
A triglycine linker improves tumor uptake and biodistributions of 67-Cu-labeled anti-neuroblastoma MAb chCE7 F(ab')2 fragments
(1999) *Nucl. Med. Biol.*, 26, pp. 943-950.

- Zimmermann, K., Grunberg, J., Honer, M., Ametamey, S., Schubiger, P.A., Novak-Hofer, I.
Targeting of renal carcinoma with 67/64Cu-labeled anti-L1-CAM antibody chCE7: selection of copper ligands and PET imaging
(2003) *Nucl. Med. Biol.*, 30, pp. 417-427.

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