

Lawrence Berkeley National Laboratory

LBL Publications

Title

Radioisotope Yields from 1.85-GeV Protons on Mo and 1.85- and 5.0-GeV Protons on Te

Permalink

<https://escholarship.org/uc/item/4489g9d8>

Authors

Bardayan, D.W.
Barghouty, A.F.
Chan, Y.D.
et al.

Publication Date

1995-05-01



Lawrence Berkeley Laboratory

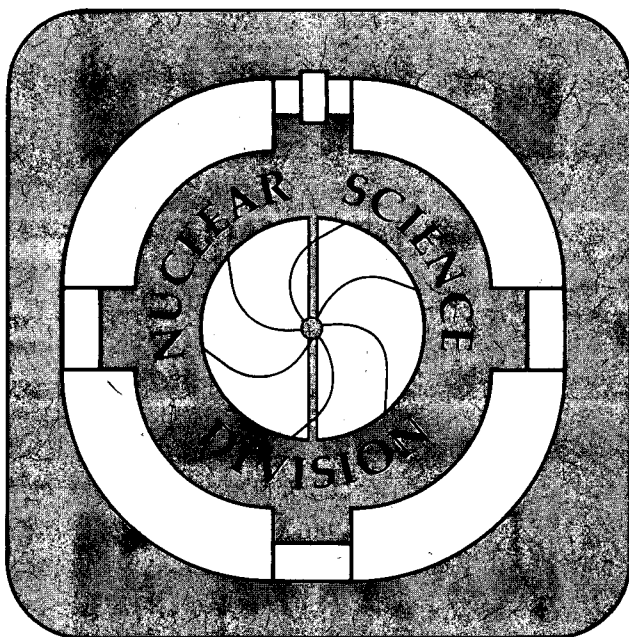
UNIVERSITY OF CALIFORNIA

To be presented at the Twentieth-Fourth International Conference—
Cosmic Ray, Rome, Italy, August 28–September 8, 1995, and
to be published in the Proceedings

Radioisotope Yields from 1.85-GeV Protons on Mo and 1.85- and 5.0-GeV Protons on Te

D.W. Bardayan, A.F. Barghouty, Y.D. Chan, M.T.F. da Cruz,
A. García, M.M. Hindi, R.-M. Larimer, K.T. Leko, E.B. Norman,
D.F. Rossi, R.G. Stokstad, F.E. Wietfeldt, and I. Zlimen

May 1995



REFERENCE COPY |
Does Not |
Circulate |
Bldg. 50 Library.

LBL-37201

Copy 1

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Radioisotope Yields from 1.85-GeV Protons on Mo and 1.85- and 5.0-GeV Protons on Te

D.W. Bardayan¹, A.F. Barghouty², Y.D. Chan³, M.T.F. da Cruz³,
A. García³, M.M. Hindi¹, R.-M. Larimer³, K.T. Leko³, E.B. Norman³,
D.F. Rossi³, R.G. Stokstad³, F.E. Wietfeldt³, and I.Zlimen³

*(1) Physics Department, Tennessee Technological University
Cookeville, TN 38505*

(2) Physics Department, Roanoke College, Salem, VA 24153

*(3) Nuclear Science Division, Lawrence Berkeley Laboratory,
Berkeley, California 94720*

May 1995

This work was supported in part by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Radioisotope Yields from 1.85-GeV Protons on Mo and 1.85- and 5.0-GeV Protons on Te

D. W. Bardayan^{1,a}, A. F. Barghouty², Y. D. Chan⁽³⁾, M. T. F. da Cruz^{3,b},
A. García^{3,c}, M.M. Hindi¹, R.-M. Larimer³, K. T. Lesko³, E. B. Norman³,
D. F. Rossi^{3,d}, R. G. Stokstad³, F. E. Wietfeldt^{3,e} and I. Žlimen³

¹*Physics Department, Tennessee Technological University,
Cookeville, TN 38505, USA*

²*Physics Department, Roanoke College, Salem, VA 24153, USA*

³*Nuclear Science Division, Lawrence Berkeley Laboratory,
Berkeley, CA 94720, USA*

Abstract

Radioisotope yields from 1.85-GeV proton interactions in a natural isotopic composition Mo target and those from 1.85- and 5.0-GeV protons in natural Te targets were measured at Lawrence Berkeley Laboratory's Bevatron. The radioisotope yields were determined by γ -counting the targets using a 100-cm³ coaxial Ge detector following the irradiations. Cross sections were determined for the production of 31 radioactive nuclides, ranging from $Z = 35$, $A = 74$, to $Z = 43$, $A = 97$, from the Mo target and for 47 radioactive nuclides, ranging from $Z = 35$, $A = 75$, to $Z = 53$, $A = 130$ from the Te targets.

1 Introduction

Cross sections for high-energy proton-induced reactions on medium to heavy weight nuclei are important for the calculation of cosmic ray transport, the confinement time of cosmic rays in the Galaxy and for the calculation of cosmic-ray-induced reactions in meteorites, lunar surfaces, and in terrestrial materials. Among the most abundant elements above $Z = 40$ are molybdenum and tellurium. With the aim of providing cross sections which would be useful for calibrating and extending the range of semi-empirical calculations into the medium-heavy element range, we measured the radioisotope yields from 1.85-GeV proton interactions in a natural isotopic composition Mo target and those from 1.85- and 5.0-GeV protons in natural Te targets at Lawrence Berkeley Laboratory's Bevatron.

2 Experiment

The Mo and Te targets were disks of diameter 3.1 cm and each a thickness of 0.67 cm for the 1.85-GeV irradiation and the Te target was 5.1 cm \times 5.1 cm with

a thickness of 1.0 cm for the 5.0-GeV irradiation. The targets were bombarded with protons from the LBL Bevatron accelerator. The irradiation was performed with the targets in air, and with the Mo and Te slabs assembled in a stack, together with Polycast Acrylic sheets (polymethyl methacrylate, $[C_5O_2H_8]_n$). These plastic sheets served to monitor the integrated beam exposure, through the production of ^{11}C , from the C and O contents of the plastic [1, 2]. The bombardment times were approximately 1 h each, with integrated currents of 60 nC and 5 nC, respectively, for the 1.85-GeV and 5.0-GeV irradiations.

Following the irradiation, γ rays from each of the targets were counted (separately) with a 100 cm³ coaxial HPGe detector inside a 5-cm thick lead shielding. Due to the widely different half-lives of the isotopes under study, we used three different lengths of time bins for counting: 5-min bins during the first two hours, 1-hour bins during the next 48 hours, and then a series of five 6-hours bins. A 1-h spectrum from the p+Mo irradiation is shown in Fig. 1.

3 Data Analysis and Results

The photo peak yields of characteristic γ -rays of each isotope were extracted using a peak fitting routine. At least two γ -ray lines were used for each isotope, when possible. After correcting for the detector efficiency, self absorption in the target, summing and dead-time effects, the time-dependent yields of each γ -ray line were fit to determine initial activities. In some cases the time yields could be fit with two time components, thus allowing the extraction of the contribution of a parent nuclide to a daughter. Effective cross sections for the production of each isotope were calculated from a knowledge of the deduced yields at the end of the irradiation, the average proton flux and the duration of the irradiation.

Table 1 shows the measured effective cross-sections for radioisotopes produced in the p+Te bombardment at 1.85 and 5.0 GeV, and Table 2 shows the cross sections for isotopes produced in p+Mo bombardment at 1.85 GeV. In those cases in which we determined the yield of a parent the direct production of the daughter isotope by spallation could be deduced. The cross section for such isotopes is marked as being direct in the Tables. A theoretical calculation

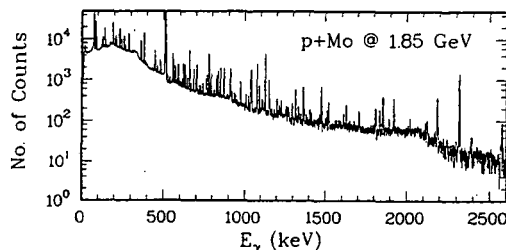


Fig 1: One-hour γ -ray spectrum from Mo target after one hour of irradiation with 1.85-GeV protons.

Table 1: Effective cross-sections for 1.85- and 5.0-GeV protons on natural Te

Isotope	1.85 GeV σ (mb) ^a	5.0 GeV σ (mb) ^a	Isotope	1.85 GeV σ (mb) ^a	5.0 GeV σ (mb) ^a
²⁴ Na	0.91(4)	4.4(2)	¹¹¹ Cd ^m	5.5(2)	7.0(1)
⁷⁵ Br	1.30(3)	2.12(16)	¹¹⁶ Sb ^m	5.6(2)	6.2(6)
⁷⁶ Br	2.8(2)	3.7(3)	¹¹⁷ Sb	30(2) ^b	38(2) ^b
⁷⁷ Br	4.6(2)	7.2(3)	¹¹⁸ Sb	8.26(3)	12.2(4)
⁸² Rb ^m	3.3(1) ^b	4.1(2) ^b	¹²⁰ Sb ^m	10.2(5)	15.7(5)
⁸⁴ Rb ^m	1.4(3) ^b	2.3(2) ^b	¹²² Sb	18.8(2)	32(2)
⁸⁷ Sr ^m	0.08(13) ^b	-	¹²⁶ Sb	4.8(4) ^b	7.9(3) ^b
⁸⁵ Y	0.9(5)	-	¹²⁶ Sb ^m	7.0(2)	10.4(2)
⁸⁶ Y ^m	5.2(1) ^b	6.1(1) ^b	¹²⁷ Sb	11.8(4)	23(1)
⁸⁶ Y	19(1) ^b	23(1) ^b	¹²⁸ Sb	2.8(6)	3.7(2)
⁸⁷ Y ^m	3.0(13) ^b	2.2(37) ^b	¹²⁸ Sb ^m	3.1(2)	3.5(6)
⁸⁷ Y	0.55(33) ^b	-	¹²⁹ Sb	5.6(2)	8.8(8)
⁹⁰ Y ^m	0.78(3)	0.76(7)	¹²³ Sn	1.65(7)	2.93(15)
⁸⁶ Zr	2.1(1)	2.8(1)	¹¹⁷ Te	4.6(3)	5.5(3)
⁸⁷ Zr	7.2(1)	10(2)	¹¹⁹ Te ^m	9.2(7)	9.9(6)
⁹⁰ Nb	8.8(4)	7.6(4)	¹¹⁹ Te	4.31(15)	6.1(5)
⁹⁷ Ru	9.9(2)	9.7(3)	¹²¹ Te ^m	14(4) ^b	22(2) ^b
¹⁰⁰ Rh	6.8(5)	6.2(2)	¹²¹ Te	8.3(4) ^b	9.5(4) ^b
¹⁰⁴ Ag	5.6(4)	4.2(4)	¹²⁹ Te	25(1) ^b	52(3) ^b
¹⁰⁴ Ag ^m	4.7(2)	4.7(3)	¹²¹ I	3.7(1) ^b	6.2(2) ^b
¹⁰⁷ In	2.6(4)	2.0(2)	¹²³ I	9.0(2) ^b	11.7(3) ^b
¹⁰⁸ In ^m	3.2(1)	2.7(2)	¹²⁴ I	9.4(3) ^b	15.2(5) ^b
¹⁰⁸ In	1.2(1)	-	¹²⁶ I	6.9(23) ^b	15.(6) ^b
¹⁰⁹ In	9.1(1)	8.0(4)	¹²⁸ I	5.7(4) ^b	10(2) ^b
¹¹⁰ In ^m	4.1(2)	7.3(3)	¹³⁰ I	3.0(1) ^b	4.6(9) ^b
¹¹⁰ In	5.7(2)	4.4(1)			
¹¹¹ In	14.6(3) ^b	16.4(4) ^b			
¹¹⁶ In ^m	4.3(3)	5.9(5)			

^aErrors shown are statistical. There is an additional 10% error in the overall normalization of the cross-sections.

^bDirect production cross-section.

of the effective cross sections was made using the semi-empirical formula given by Silberberg and Tsao [3], but these are not shown here due to lack of space. The median deviation from the experimental cross sections was about 60%.

4 Acknowledgments

We wish to thank the Di-Lepton Spectrometer Group, for the use of the Bevatron facility for the high-energy proton activations. This work was supported

Table 2: Effective cross-sections for 1.85-GeV protons on natural Mo

Isotope	σ (mb) ^a	Isotope	σ (mb) ^a	Isotope	σ (mb) ^a
⁹³ Tc	2.70(2)	⁸⁶ Zr	8.1(2)	⁷⁸ Rb	1.69(15)
⁹⁵ Tc ^m	2.0(5) ^b	⁸⁹ Zr	14.7(1.7) ^b	⁷⁹ Rb	5.1(6)
⁹⁰ Mo	7.1(4)	⁹⁵ Zr	2.0(2) ^b	⁸¹ Rb	15.9(7) ^b
⁹³ Mo ^m	2.8(1) ^b	⁹⁷ Zr	2.10(5) ^b	⁸² Rb ^m	9.6(3) ^b
⁸⁸ Nb	3.9(2)	⁸⁴ Y	7.2(2)	⁸⁴ Rb ^m	2.4(6) ^b
⁸⁹ Nb ^m	18(1)	⁸⁵ Y	5.9(2) ^b	⁷⁶ Kr	2.5(2)
⁹⁰ Nb	26.2(8) ^b	⁸⁶ Y	15.8(6)	⁷⁷ Kr	4.58(15)
⁹¹ Nb ^m	18(3)	⁸⁷ Y	44(1)	⁷⁹ Kr	12.4(7) ^b
⁹² Nb ^m	13.6(5) ^b	⁹⁰ Y ^m	2.36(8)	⁷⁴ Br ^m	2.75(11) ^b
⁹⁵ Nb	18.5(9) ^b	⁸⁰ Sr	5.3(2)	⁷⁵ Br	8.7(3)
⁹⁵ Nb ^m	5.0(4) ^b	⁸¹ Sr	3.8(2)	⁷⁶ Br	10.1(9) ^b
⁹⁶ Nb	11.2(5) ^b	⁸³ Sr	18.6(6)	⁷⁷ Br	4.17(13)
⁹⁷ Nb	9.9(5) ^b				

^aErrors shown are statistical. There is an additional 10% error in the overall normalization of the cross-sections.

^bDirect production cross-section.

by the U.S. Department of Energy, Nuclear Physics Division, via grants No. DE-AC03-76SF00098 and DE-FG05-87ER40314. M.T.F. da Cruz was supported by Fundação de Amparo à Pesquisa do Estado de São Paulo, FAPESP, São Paulo, Brasil.

References

- [a] Present address: Physics Dept. , Yale Univ. , New Haven, CT, USA.
- [b] Present Address: Instituto de Física, Universidade de São Paulo, Caixa Postal 20516, 01498 São Paulo, SP, Brasil.
- [c] Present address: Physics Dept. , Notre Dame Univ. , South Bend, IN, USA
- [d] DOE-TRAC fellow at Lawrence Berkeley Laboratory, July-August 1992.
- [e] Present address: Nat. Inst. of Sci. and Tech. , Gaithersburg, MD, USA.
- [1] Smith A. R., *et al.*, Phys. Rev. **C28** (1983) 1614.
- [2] Olson D. L., *et al.*, Phys. Rev. **C28**, (1983) 1602.
- [3] Siberberg R. and C. H. Tsao, Phys. Rep. **191** (1990) 351.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL AND ELECTRONIC
INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720