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Title: Neutron-Capture Gamma-Ray Data for Obtaining Elemental Abundances from Planetary Spectra

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NEUTRON-CAPTURE GAMMA-RAY DATA FOR OBTAINING ELEMENTAL ABUNDANCES FROM PLANETARY SPECTRA. Robert C. Reedy[1] and Stephanie C. Frankle[2], [1]Group NIS-2, Mail Stop D436, Los Alamos National Laboratory, Los Alamos, NM 87545 USA (rreedy@lanl.gov), [2]Group X-5, Mail Stop F663, Los Alamos National Laboratory, Los Alamos, NM 87545 USA (frankles@lanl.gov).

Introduction: Determination of elemental abundances is a top scientific priority of most planetary missions. Gamma-ray spectroscopy is an excellent method to determine elemental abundances using gamma rays made by nuclear reactions induced by cosmic-ray particles and by the decay of radioactive nuclides [Re73,Re78]. Many important planetary gamma rays are made by neutron-capture reactions. However, much of the data for the energies and intensities of neutron-capture gamma rays in the existing literature [e.g., Lo81] are poor [RF99,RF00]. With gamma-ray spectrometers having recently returned data from Lunar Prospector and NEAR and soon to be launch to Mars, there is a need for good data for neutron-capture gamma rays.

New Evaluations and Compilation: The data for the energies and intensities for gamma rays made by the capture of thermal neutrons have recently been compiled and evaluated for all elements up through zinc [RF00]. A detailed paper on these results for Z=1-30 is being prepared [RF01]. Similar work was also done for several other elements of interest to planetary gamma-ray spectroscopy, including germanium, samarium, and gadolinium. To make these data available now for the analyses of planetary gamma-ray spectra, the energies and intensities of major gamma rays are given here.

Table 1 gives the major gamma rays from these evaluations. The sources of the adopted gamma rays for elements up through zinc are given in [RF00,RF01]. Other isotopes and the sources of their data are Ge-70 [Is91,We72], Ge-73 [Is91], Sm-149 [Sm66] (intensities multiplied by 1.57), Gd-155 [Ba82,Kl93], and Gd-157 [He96]. Table 1 only includes prompt gamma rays made by the (n,γ) reaction. Gamma rays not included are those made by other neutron-capture reactions, such as the (n,$\alpha\gamma$) reaction with B-10 and those made by the decay of neutron-capture-produced radionuclides, such as Na-24.

Many of these gamma rays will not be useful for mapping elemental abundances. Some are from elements with very small cross sections for capturing thermal neutrons (such as oxygen). Gamma rays with low energies (below ~1000 keV) will be strongly attenuated by the ~15 g/cm^2 Martian atmosphere. Some gamma rays are outside the range of energies typically detected by planetary gamma-ray spectrometers, which have lower levels of typically about 200 keV (but ~600 keV for Lunar Prospector) and upper levels usually of ~8-10 MeV.

Summary: Table 1 has the latest data for the prompt gamma rays made by (n,γ) reactions induced by thermal neutrons. These gamma-ray energies and intensities can be used to determine elemental abundances from planetary gamma ray spectra. They also can remove contributions from interference gamma rays, both from planetary materials (e.g., the gamma rays of Ca and Ti near 6419 keV) and material in or near the gamma-ray detector (such as Ge). Similar compilations are needed for gamma rays from the decay or naturally-occurring radionuclides such as Th and from inelastic- and nonelastic-scattering reactions.

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Table 1. Energies (keV) and intensities (per 100 captures by that element) of important planetary thermal-neutron-capture gamma rays made by (n,γ) reactions. Two pair of energies and intensities are given per line.

Element	Energy	Intensity	Energy	Intensity
H	2223.3	100.		
Li	2032.5	83.		
Be	6809.9	66.	3367.4	33.
	853.9	23.5	2590.0	22.6
B	4444.0	61.	7006.7	52.
	4711.2	23.9	6738.3	17.8
C	4945.3	67.	1261.7	32.
	3683.9	32.		
N	5269.2	29.9	5297.8	21.2
	5533.4	19.6	1884.8	18.8
	6322.4	18.2	4508.7	16.7
	3677.7	14.5	10829.1	14.3

Table 1, continued. Energies (keV) and intensities (per 100 captures by that element) of important planetary thermal-neutron-capture gamma rays made by (n,γ) reactions. Two pair of energies and intensities are given per line.

Nuclide	Energy	Intensity	Energy	Intensity
O	870.7	100.	1087.9	82.
	2184.5	82.		
F	583.6	38.	656.0	20.8
	665.2	15.7	983.5	12.2
Ne	2035.6	63.	350.7	50.
	4374.1	45.	2793.9	21.5
Na	472.2	92.	91.0	45.
	6395.3	19.9	869.2	19.6
	1129.6	13.4	3054.0	12.5
Mg	3916.9	49.	585.1	48.
	2828.2	37.	1808.7	27.1
	1129.6	13.4	3054.0	12.5
Al	30.6	29.7	7724.0	26.8
	2960.1	9.6	3303.9	8.8
	3465.1	7.0	4133.4	6.9
	4259.5	6.8	4733.9	5.5
Si	3539.0	67.	4934.0	62.
	2092.9	18.5	1273.3	16.0
	6379.8	10.7	7199.2	6.68
P	512.7	46.	78.1	35.
	636.7	21.2	3899.9	17.8
S	841.0	65.	5420.6	57.
	2379.7	43.	3220.6	23.2
	2930.7	16.3	4869.6	12.2
Cl	1164.9	27.1	517.1	24.2
	6110.8	20.5	1951.1	19.3
	788.4	16.3	1959.4	12.5
	768.3	10.5	7414.0	10.5
	7790.3	8.3	6619.6	7.8
Ar	167.3	74.	4744.4	54.
	1186.7	53.	516.0	26.8
K	29.8	82.	770.3	41.
	5379.9	7.5	1158.9	7.4
	2073.8	6.2	1619.0	5.9
Ca	1942.7	82.	6419.6	42.
	4418.3	20.4	2001.8	17.6
	519.7	12.4	2010.1	10.7
	5900.0	7.4	3609.9	7.4
Sc	227.8	28.3	142.5	23.0
	147.0	21.8	295.2	17.2
	228.7	15.0	627.4	10.2
	8175.1	10.0	216.4	10.0

Nuclide	Energy	Intensity	Energy	Intensity
Ti	1381.8	81.	6760.1	44.
	6418.4	29.0	341.7	23.6
	1585.9	9.7	1762.0	5.1
	6555.9	4.8	1498.7	4.6
	4881.4	4.3	4966.8	2.74
V	125.0	27.8	6517.3	16.3
	645.7	12.8	7162.8	12.6
Cr	834.9	44.	8884.8	24.4
	749.0	16.0	7938.6	12.9
	9719.8	8.1	8513.0	7.4
	2239.1	6.1	6645.6	5.7
	1784.7	5.5	8485.0	5.2
Mn	26.6	36.	83.9	20.0
	212.0	13.0	7243.4	12.3
	7058.0	11.0	104.6	11.0
Fe	7631.2	26.8	7645.6	23.1
	6018.4	9.2	5920.4	8.9
	352.4	8.8	1725.3	5.8
	7278.8	5.6	1612.8	5.0
	692.0	4.4	122.1	3.5
	9297.8	3.5	4218.0	3.5
Co	58.9	48.	229.7	15.2
	277.1	14.0	556.0	12.0
	6877.0	8.4	6705.8	7.5
Ni	8998.4	36.	8533.4	16.9
	465.0	16.4	6837.4	9.5
	7819.4	8.9	878.0	5.4
	7536.5	5.1	339.4	5.1
Cu	7916.3	27.4	278.3	19.9
	7638.0	13.4	159.3	12.6
	7307.3	7.4	186.0	7.1
Zn	1077.3	18.8	7863.0	16.7
	93.3	11.7	6959.5	7.9
Ge	595.9	37.	867.9	21.7
	499.9	11.3	174.9	10.9
	608.4	8.2	1101.3	5.7
Sm	333.9	94.	439.4	55.
	737.4	10.2	505.5	10.2
	584.3	9.4	712.2	4.8
Gd	181.9	14.9	79.5	7.9
	944.1	7.0	199.2	5.6
	962.1	4.4	89.0	3.8
	1107.6	3.7	1186.0	3.5
	977.1	3.1	1187.1	3.1