BACKGROUNDS IN CADMIUM ZINC TELLURIDE (CZT) GAMMA-RAY SPECTROMETERS FOR PLANETARY SCIENCE.

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Summary: The gamma rays made by space energetic particles in CdZnTe detectors, such as those on the NASA Dawn Mission, are listed and discussed.

Introduction: Gamma-ray detectors in space have backgrounds in their spectra because of cosmic-ray interactions with the detector materials. A good understanding of all those backgrounds, especially discrete-energy peaks, in a gamma-ray spectrometer (GRS) is needed to correctly analyze the measured gamma-ray spectra from a planetary object of interest. Most backgrounds contribute to the continuum, but some are in peaks. Some of these peaks could possibly interfere with gamma rays used to determine elemental composition of an object. Much work has been done recently on the many backgrounds in germanium (Ge) and bismuth germanate (BGO) detectors (e.g., [1-3]) by prompt reactions and the decay of induced radionuclides.

The CZT detectors on Dawn: One of the 3 instruments on the Dawn mission is the Gamma Ray and Neutron Detector (GRaND) [4]. BGO (about 10% in energy resolution) is used for higher energies. To get better energy resolution for gamma rays below ~3 MeV, the good-energy-resolution (a few %) semiconductor cadmium zinc telluride (CZT, $Cd_{0.9}Zn_{0.1}Te$) detector is being used in an array of 16 CZT crystals. Unlike Ge and BGO detectors, there is no experience with CZT for planetary science, so basic nuclear data was used to identify possible gamma rays and peaks.

Data Sources for CZT Backgrounds: Because there are no published comprehensive compilations of backgrounds for CZT detectors in space, only basic nuclear data from nuclear data centers (like the Brookhaven National Laboratory or the International Atomic Energy Agency) were used. Gamma ray spectra acquired by GRaND's CZT sensors in cruise are presented in [4]. Gamma rays at 0.511- and 2.223-MeV are prominent features in the CZT pair spectrum (coincidence with BGO).

Sources of CZT Background Peaks: Many peaks are made by inelastic scattering of fast (E~1-20 MeV) neutrons or the capture of thermalized neutrons. The decay of radionuclides also produces gamma rays, although gamma rays in coincidence with an energetic electron or positron from beta decay will not appear as a peak in that detector's spectra. Many internal peaks from radionuclides are made by decays involving the capture of an orbiting electron or by an isomeric (or internal) transition in one nucleus [2].

Production of prompt gamma rays during events with high fluxes of solar protons was not considered because the energy loss of the proton in the detector will sum with most gamma rays.

Being a minor component, only the strongest gamma rays are given for Zn.

Peaks inside CZT Detectors: Almost all of the peaks made in CZT by these gamma rays (individually or by summing) are <2 MeV, and therefore could be at energies of many gamma rays used to map elements.

Prompt neutron-induced reactions: The main gamma rays made by fast (E~1-20 MeV) and thermal (E~0.01-0.4 eV) neutrons are given in Table 1. All energies are in keV.

Fast neutrons. Some strong peaks are made by reactions induced by fast neutrons, mainly inelastic-scattering, (n,nγ), reactions. The stronger peaks are from the first few excited levels of the more abundant isotopes, which are ^{112}Cd (24.13%), ^{114}Cd (28.73%), ^{128}Te (31.74%), and ^{130}Te (34.08%), with the strongest inelastic-scattering gamma rays from their first excited levels. Only the ^{130}Te (839) peak is near expected peaks, at 843.7 (Al) and 846.8 keV (Fe). Peaks expected to be ~0.5 as intense are the first excited levels of less abundant isotopes and the second excited levels of the above isotopes. Reactions other than (n,xnγ) are expected to be fairly weak for these elements.

Table 1. Prompt gamma rays (in keV) from neutron reactions with CdZnTe. The top 4 in the left columns are from the first excited levels of the main isotopes and are expected to be the most intense. The lower 4 in the left columns are from their second excited levels. Gamma rays from the first excited levels of the less abundant isotopes are in the right columns.

Reaction	Eγ	Reaction	Eγ
^{112}Cd(n,nγ)	617.5	^{110}Cd(n,nγ)	657.8
^{114}Cd(n,nγ)	558.5	^{111}Cd(n,nγ)	245.4
^{128}Te(n,nγ)	743.2	^{126}Te(n,nγ)	666.3
^{130}Te(n,nγ)	839.4	^{64}Zn(n,nγ)	991.6
^{112}Cd(n,nγ)	606.9	^{113}Cd(n,γ)	558.3
^{114}Cd(n,nγ)	576.1	^{113}Cd(n,γ)	651.2
^{128}Te(n,nγ)	753.8	^{111}Cd(n,γ)	245.3
^{130}Te(n,nγ)	748.8		

Neutron capture. Some peaks are made by neutron-capture reactions. Such reactions within a CZT detector occur almost entirely (99.8%) with Cd. The two strongest gamma rays are from neutron capture on ^{113}Cd at 558.3 (74% of all capture) and 651.2 (14%), which can sum, and the next strongest is 245.3 (from ^{111}Cd, 11%). Almost all neutron-capture reactions with Cd involve the emission of several gamma rays, which often sum.

Radionuclide decay. Cross sections estimated for Cd and Te for incident neutrons and protons were used with approximate particle spectra to estimate intensities of nuclide production. The solar proton incident spectrum was assumed to be flat with energy below 100 MeV as the CZT in Dawn is after enough material that the lowest-energy solar protons are stopped. The neutron spectrum in CZT made by galactic-cosmic-ray (GCR) particles was assumed to vary as E$^{-1.22}$, which is typical at the depth of CZT in GRaND [4].

Because there are many Cd and Te isotopes, many reactions produce stable isotopes. Because Zn in CZT is only about 0.1 the abundances of Cd and Te, its radionuclides are less important.

For Cd, these calculations for GCR-produced neutrons indicate that ^{109}Cd is the most abundantly GCR-produced radionuclide, with ^{107}Cd about half as abundant and ^{105g}Ag and ^{111m}Cd being ~15% as abundant. The main gamma rays from ^{109}Cd and ^{107}Cd are at 88.0 and 93.1 keV, respectively. Only a few gamma-ray-emitting radionuclides can be made from Cd by energetic neutrons because of the many stable isotopes immediately lighter than the major isotopes, although a few isomers of those stable isotopes are made (such as ^{111m}Cd). It is estimated that the most intense gamma ray made in Cd is the 245.4 keV one from ^{111m}Cd (~12% on the relative-intensity scale in Table 2.)

Neutron reactions with Te yield radionuclides that are expected to be made in relatively good amounts. The main radionuclides made from Te are estimated to be ^{129g}Te and ^{127g}Te, with ^{121g}Te $^{124-128}$Sb less likely.

When the intensities of emitted gamma rays are used with the above production likelihoods, which can vary, the relative intensities in Table 2 are obtained.

For peaks in a detector made as a result of the capture of an orbital electron (denoted by * in Table 2), the x rays from filling the vacant electron's orbital sum with any gamma ray [2]. Most (~90%) x rays are from the K shell. For most radionuclides made in Te that decay by EC, the K binding energies are about 23-27 keV. The binding energies will sum with any gamma rays made by that decay, which make identification more difficult.

Table 2. Gamma rays from the decay of radionuclides made from Cd and Te by GCR particles (left 3 columns) and solar protons (right 3 columns). Radionuclides with a * decay mainly by electron capture (see text). Estimated cross sections and particle fluxes were used to determine the expected relative intensities (Rel Int.), which are probably not better than a factor of about 2.

Radio-nuclide	Eγ (keV)	Rel Int.	Radio-nuclide	Eγ (keV)	Rel Int.
^{128}Sb	743.3	1	^{111}In*	245.4	1
^{128}Sb	754.0	1	^{111}In*	171.3	1
^{128}Sb	314.1	0.6	^{123}I*	159.0	0.9
^{126}Sb	695.0	0.4	^{109}In*	203.5	0.8
^{126}Sb	666.5	0.4	^{128}Sb	743.3	0.6
^{129g}Te	459.6	0.4	^{128}Sb	754.0	0.6
^{126}Sb	414.7	0.4	^{124}I*	602.7	0.6
^{124}Sb	602.7	0.3	^{126}Sb	695.0	0.4
^{127}Sb	685.7	0.2	^{126}Sb	666.5	0.4
^{121g}Te*	573.1	0.2	^{108g}In*	632.9	0.4
^{127}Sb	473.0	0.2	^{108g}In*	875.4	0.4

Intense solar particle events are possible now as it is now the third year of the current solar cycle, and the maximum in the solar activity cycle is expected to occur in ~1 year. Many solar-proton-produced radionuclides are expected to be made by (p,xn) reactions to In and I isotopes from Cd and Te, respectively. Those elements are not made by GCR reactions. Estimated relative gamma-ray_intensities from solar protons are in the right columns of Table 2.

Impact on Planetary Gamma Ray Spectroscopy: This survey of likely backgrounds from CZT detectors used only basic nuclear data. The survey will aid in the analysis of peaks in the CZT detector on the Dawn mission's GRaND instrument now in orbit at Vesta. Some gamma rays from CZT may also be observed in the BGO detector of GRaND. This preliminary catalogue of background peaks will be helpful in checking for possible interferences with the gamma rays used to determine elemental abundances on the surface of Vesta. Modeling of the GRaND instrument using methods described in [4], will be used to more precisely determine background spectral features for the BGO and CZT sensors, including accurate treatment of detector physics (e.g., summing), radiation sources, and materials. Preliminary peak identification for the CZT and BGO sensors will be presented.

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References: [1] Evans L. G. et al. (2007), *J. Geophys. Res., 112*, E03S04. [2] Reedy R. C. (2008) *LPS XXXIX*, #1894. [3] Reedy R. C. (2010) *LPS XLI*, #1917. [4] Prettyman T.H. et al. (2011) *Space Sci. Rev*., DOI 10.1007/s11214-011-9862-0.