Using the Psyche Anti-Coincidence Shield Veto to Help Identify Gamma-Ray Peaks in the High-Resolution Gamma-Ray Spectrometer. Morgan Burks1, David J. Lawrence2, Patrick N. Pepowski2, John O. Goldsten3.
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Introduction: NASA’s Psyche mission to the asteroid belt launched on October 13th, 2023. The Psyche Gamma-Ray Spectrometer (GRS) operated continuously for two weeks during the first months of cruise and confirmed its high-resolution performance, matching pre-launch specifications. The full gamma-ray spectrum contains over 80 peaks, with 1000 counts or more in the photopeak, providing a wealth of information about the space environment, the instrument’s performance, and the sensitivity it will have to elemental abundances when the mission reaches (16) Psyche.

The GRS consists of a high-resolution germanium detector and a low-resolution borated plastic scintillator. The scintillator is known as the Anti-Coincidence Shield (ACS) and has the primary purpose of vetoing galactic cosmic rays (GCRs) that deposit energy in the germanium detector [1]. The veto works because any GCR that passes through the germanium must necessarily have passed through the surrounding ACS. Thus, a time coincidence window is used to veto these events. This lowers the background and improves the signal-to-noise ratio of gamma-ray peaks.

The GRS produces two data products relevant to this discussion: a full gamma-ray spectrum consisting of every event that deposits energy in the germanium detector, and a veto spectrum that consists only of events that did not trigger a time coincidence in the ACS (thus the anti-coincidence events). We have found that the analysis of the gamma-ray spectrum is aided by a novel use of the veto spectrum. The ACS not only triggers on cosmic rays, but also on any event that deposits energy, such as neutron and gamma-ray interactions. Based on the physics of a particular interaction, some events will occur with a time-coincidence in the germanium detector and some will not. This difference can be used to help discriminate between different gamma-ray peaks based on physics.

Events subject to veto. Any event depositing energy simultaneously in both the germanium detector and scintillator (within a short time window) will be vetoed. These include:

1. Inelastic Scatter from fast neutrons. The only source of fast neutrons on the spacecraft during cruise is the result of spallation events from GCRs. As long as the GCR passes through the ACS, then any gamma rays resulting from inelastic scattering will be vetoed.
2. Spallation products. Any prompt emission from a spallation product will be in coincidence with the ACS and undergo veto.
3. ACS originating events. Some events originate directly in the ACS and are automatically vetoed. For example, inelastic scatter on $^{10}$B in the plastic of the scintillator releases a 718.38 keV gamma ray. When this gamma-ray is captured, either fully or partially, in the germanium detector, it is automatically vetoed by the ACS.
4. Pair Production. Pair production deposits energy and releases two 511 keV photons. Pair production has a good chance to trigger both detectors, resulting in a veto.
5. GCR-induced prompt events in the germanium. GCR-induced prompt events in the germanium will automatically occur in coincidence with the ACS trigger and be vetoed.

Events not subject to veto. Events that deposit energy only in the germanium detector, and not the scintillator, will not be vetoed. These include:

1. Naturally occurring radioisotopes. Materials used in the construction of the cryostat have trace amounts of primordial uranium, thorium and potassium isotopes. When these gamma-rays are fully captured in the germanium detector then there is no coincidence with the ACS and no veto. Note, however, that if the gamma ray deposits partial energy in both detectors then a veto occurs.
2. $^{137}$Cs calibration source. The Psyche GRS has a ~nCi $^{137}$Cs calibration source. Since this is released without coincidence from other particles then it is not vetoed when fully captured in the germanium detector.
3. Metastable states. GCR-induced spallation, as well as neutron interactions, can create metastable states with gamma-ray emissions that are delayed, rather than prompt. In this case, the emissions happen after the ACS timing window and are thus not vetoed.
4. Geometry. Some GCR-induced events happen in construction materials that are far away from the ACS. The prompt gamma-ray emissions might be still be collected by the germanium detector without triggering a veto.
Figure 1. Psyche gamma-ray spectrum, with peaks shown in the 1000 keV region. The full spectrum (blue) includes all events, while the veto spectrum (orange) contains only events that were not vetoed by the ACS. Note, the baseline of the veto spectrum has been offset to match the full spectrum, for ease of comparing peak areas.

Figure 1 shows a portion of the gamma-ray spectrum from the Psyche initial checkout in the 1000 keV region. Both the full spectrum and the veto spectrum are shown. Several gamma-ray peaks have been identified in this region and they represent a range of physics interactions, both vetoed and not vetoed, as described above. This information is used to help identify the source of each gamma-ray emission. Some examples of this analysis include:

**Inelastic neutron scattering.** $^{63}$Cu and $^{27}$Al have inelastic scatter lines at 962 and 1014 keV, respectively. The veto spectrum shows that these peaks are attenuated, indicating that they often occur in coincidence with GCR triggers in the ACS.

**Primordial isotopes.** $^{232}$Th and $^{238}$U lines are seen at 969 and 1001 keV respectively. The veto spectrum shows there is no statistically significant attenuation of these peaks, as expected.

**Spallation products.** The peak at 975 keV has been identified as belonging to $^{25}$Mg. There is no magnesium in the construction materials in or near the cryostat. Rather, magnesium is a product of spallation of GCRs on aluminum. As a result, this peak is attenuated in the veto spectrum.

**Delayed peak vs inelastic scatter.** The peak at 983.5 was originally identified as $^{48}$V, a spallation product, for a similar spectrometer that flew onboard the MESSENGER mission to Mercury [2]. It was listed as ambiguous for a similar instrument that flew on Mars Odyssey [3]. However, the veto spectrum shows significant attenuation of this line. $^{48}$V is a long-lived state with a half life of nearly 16 days. Thus, there should be no coincidence with the ACS when it decays. Therefore, it was determined that this was instead the neutron inelastic scatter line from $^{48}$Ti, which would be subject to veto. Titanium is a major construction material in the bracket holding the Psyche GRS, so this is expected.

**Delayed emission from germanium.** The peak at 1048 keV has been identified at $^{66}$Ga + K. Ga is a product of GCR spallation in the germanium detector itself. This GCR directly deposits energy in the germanium detector through ionization, along with the capture of any gamma emissions. Since the GCR necessary passed through the ACS, these events are vetoed. However, $^{66}$Ga decays through electron capture with a half life of 9.49 hours. It releases a 1039.22 keV gamma ray plus a 9.57 keV x-ray, which sum to 1048.79 keV. Because it is delayed, this line is not attenuated in the veto spectrum, as seen in the figure.