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The Gamma-Ray Advanced Detector (GRAD) is a gamma-ray detector systems consisting of a large-volume, n-type germanium detector with active shielding of bismuth germanate and plastic scintillators. It was diverted from the AFP-675 program to a balloon flight over Antarctica following the Challenger Disaster and the discovery the following year of the supernova 1987A. The present report outlines activities leading to and following the decision to go to Antarctica and summarizes the basic technological results from the project.

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Final Report

Shuttle Flight Test of an Advanced Gamma-Ray Detection System

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Abstract

The Gamma-Ray Advanced Detector (GRAD) is a gamma-ray detector system consisting of a large-volume, n-type germanium detector with active shielding of bismuth germanate and plastic scintillators. It was diverted from the AFP-675 program to a balloon flight over Antarctica following the Challenger Disaster and the discovery the following year of the supernova 1987A. The present report outlines activities leading to and following the decision to go to Antarctica and summarizes the basic technological results from the project.

1. Introduction

The Gamma Ray Advanced Detector (GRAD) (Refs 1,2,3) consists of an n-type germanium detector inside a closed-ended bismuth germanate annulus with additional plastic active shielding across the aperture. The detector was designed to be utilized as a gamma-ray telescope in the payload bay of the Space Shuttle. The technological goals of the GRAD included the evaluation of n-type germanium (nGe) and bismuth germanate(BGO) crystals as detectors in the environment of space and a study of the dynamic background in near-earth orbit. The major scientific objective was observation of the Galactic Center for evidence of the resurgence of a 511-keV gamma-ray source (4) which was last seen earlier in this decade.

Originally scheduled for launch in 1986 as a part of the AFP-675 Program on the first Space Shuttle flight out of the new Vandenberg Launch Facility, flight of GRAD and its sister experiments on AFP-675 were postponed for an indeterminate time on account of the Challenger Disaster. In the aftermath of the tragedy we investigated several options for flight other than AFP-675, should that program be unacceptably delayed by the disruption.

In the meantime the arrival of emissions from the supernova 1987A (5), the first of such magnitude to occur in 400 years, presented us with a target of opportunity having ideal technological characteristics and of monumental scientific importance. Visible from the Southern Hemisphere, this object promised to provide us with the opportunity of not only testing the sensitivity of our detector system but verifying the hypothesized sites of nucleosynthesis of the heavy elements as well. In order to take advantage of this rare opportunity we began preparations for what would be a successful flight of GRAD from Antarctica on a high-altitude balloon launched by the Air Force Geophysics Laboratory. Early feasability studies for the Antarctic mission were performed under the present contract; major modifications to GRAD, testing and mission operations were carried out under a later grant through the Office of Naval Research, which is a participant in the Florida Demonstration Project.

2. The GRAD Spectrometer

A complete description of the GRAD is provided in Refs. 1-3. In passing we note that its central detector is a 5.5 cm x 5.7 cm nGe crystal with an energy resolution of 2 keV at 1332 keV. This cylindrical detector is cooled with a space qualified liquid nitrogen dewar with a holding time of 21 days. As can be seen in Fig. 1, it is enclosed in active shielding of bismuth germanate on all sides but the top, where the 60-degree (full angle) aperture is covered with a thin plastic scintillator to veto charged particle induced events without appreciably attenuating the incoming gamma-ray The shield also has excellent Compton suppression characteristics, as can be seen from the laboratory measurements shown in Figure 2. Because the purpose of the AFOSR contract was the testing of new detector technology in the environment of Space we include here in Fig. 3 an actual measurement of the total (particle plus gamma-ray) background rejection as a function of energy, taken at 118,000 feet over Williams Field, Antarctica on January 8, 1988. Background suppression factors of about 20 are clearly evident.

Prior to the mission we estimated the sensitivity curve shown in Figure 4, assuming a background continuum intermediate to that of the HEAO-C and Apollo 15 gamma-ray detectors. It is interesting in retrospect to compare the predicted sensitivity with the gamma-ray fluxes from the supernova 1987A measured with GRAD on the Antarctic balloon flight. We note that the spectrometer was not only sensitive enough to detect these weak signals in the high radiation background over Antarctica., but provided the first detection of the weak 2598-keV gamma ray from the beta decay of Co-56 as well as the first measurement ever reported of Doppler line broadening and splitting in supernova gamma rays.

3. Modifications required for balloon flight

During the early spring of 1987 we began to assess the modifications required to redirect the GRAD experiment from the Space Shuttle to Antarctic balloon flight. In the main the changes required included the development of interface and communications boards, a mechanical support structure, a pressurized housing for the top of the detector, and new software to support an experiment controlled from the ground rather than from the aft flight deck of the Orbiter. In addition we had to install new timing circuitry to improve the background suppression of the detector.

3.1 Thermal Design. The GRAD thermal subsystem includes its own heaters and thermostats, as there were none on the EES mounting surface for AFP-675. NASA/GFSC performed thermal modelling studies to ascertain what changes would be required for the balloon-borne system.

3.2 Mechanical Design. Although GRAD was designed to operate in the hard vacuum of space, some modifications were necessary for operation at 120,000 feet. These entailed encapsulation of the high voltage power supplies to prevent coronal discharge. This was accomplished by a combination of potting and enclosure with an airtight housing over the detector elements. Gaseous nitrogen vented from the liquid nitrogen dewar was circulated through the enclosure at one atmosphere of pressure to keep the ambient pressure in the neighborhood of the high voltage supplies above the coronal discharge point. Pointing was accomplished by fixed declination and an existing azimuthal pointing system available through AFGL.

A consideration peculiar to the search for evidence of the 56-Ni decay chain in the supernova spectrum was the necessity of reducing possible man-made sources of these lines in the vicinity of the gamma-ray detector. Structural materials containing Fe, Co, Ni, or possibly Cu which could yield significant quantities of these isotopes in compound nuclear reactions with protons were therefore undesirable. Except for some steel bolts on the exterior of the shield, the structural materials holding the detector elements together were almost entirely of Al; we replaced these bolts with titanium fasteners.

3.3 Electrical Design.

3.3.1 Electrical accommodations. Approximately 11 kWh of electrical power at a nominal 28 VDC was required for 72 hours of operation. This was supplied by batteries.

3.3.2 Modifications to GRAD Avionics and GSE.

A. Software modifications
1. Serial command interface
2. Data storage during loss of communications
3. Packaging and synchronization of data in telemetry steam.
4. Interrupt handling

B. Hardware modifications
1. Redesigned telemetry board for standard balloon telemetry interface.
2. Adapted existing ground test serial interface
3. Expanded system memory for data buffering
4. Installed improved timing circuitry.

C. Ground Support Equipment (GSE) modifications
1. Software
a. command formatter
b. ancillary data message handler
c. real time data reception and storage

2. Hardware

a. redesigned spacecraft simulator board to convert ground support equipment to ground control system

b. installed second CPU for data reception and storage.

3.4 Testing and Checkout. GRAD had to undergo complete mechanical and electrical testing prior to shipping to Antarctica. The requirements for balloon flight were less stringent than those met for spaceflight; however the unique conditions prevailing at the South Pole posed additional requirements. The majority, if all, of the testing was accomplished at Holloman AFB.

3.5 Safety. GRAD was already safety certified for flight on AFP-675; safety requirements for balloon flight were less stringent. An onboard radioactive calibration source of about 2 microcuries strength was be removed from the payload in order to reduce the background level and eliminate the possibility of loss in the Antarctic environment, should the payload not have been recovered. The space in the memory devoted to storage of calibraticn spectra was used instead to log the occurrence of single-event upsets and their subsequent correction, a valuable record for the assessment of the performance of the radiation hardened software.

4 Results.

Although the eventual flight of the GRAD turned out to be under radically different circumstances that originally scoped before the Challenger disaster, quick response to an unusual opportunity allowed us to make a timely flight with the instrument and accomplish its objectives several years earlier than would have been possible had we waited for the resumption of Space Shuttle flights. Some of the early performance data have been presented above. A more complete analysis is underway, but the basic conclusions can already be stated.

1. Bismuth germanate has fewer activation lines in its background than sodium iodide or cesium iodide. It suppresses unwanted background efficiently.

2. The weight and volume savings of BGO over the conventional active shielding materials is real Early comparison of results with those of workers using a sodium iodide appears to indicate that the 80-lb BGO shield performed as well as an 800-lb shield of sodium iodide.

3. The n-type germanium detector performed well. However it was not in the space environment long enough for us to assess the rate of accumulated radiation damage, as it was negligible.

4. The hybrid design of the spectrometer functioned according to design expectations.

5. Neutron interactions in the germanium detector proved to be an important limiting factor in signal-to-noise ratio. That this is so is due at least to the very good background noise suppression of the system.

6. The computer code RCOLD and its advanced form ROBFIT functioned very well in the extraction of signals so weak that they are nearly buried in the noise. This pattern recognition approach to spectral analysis may have important practical applications.

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List of Figures

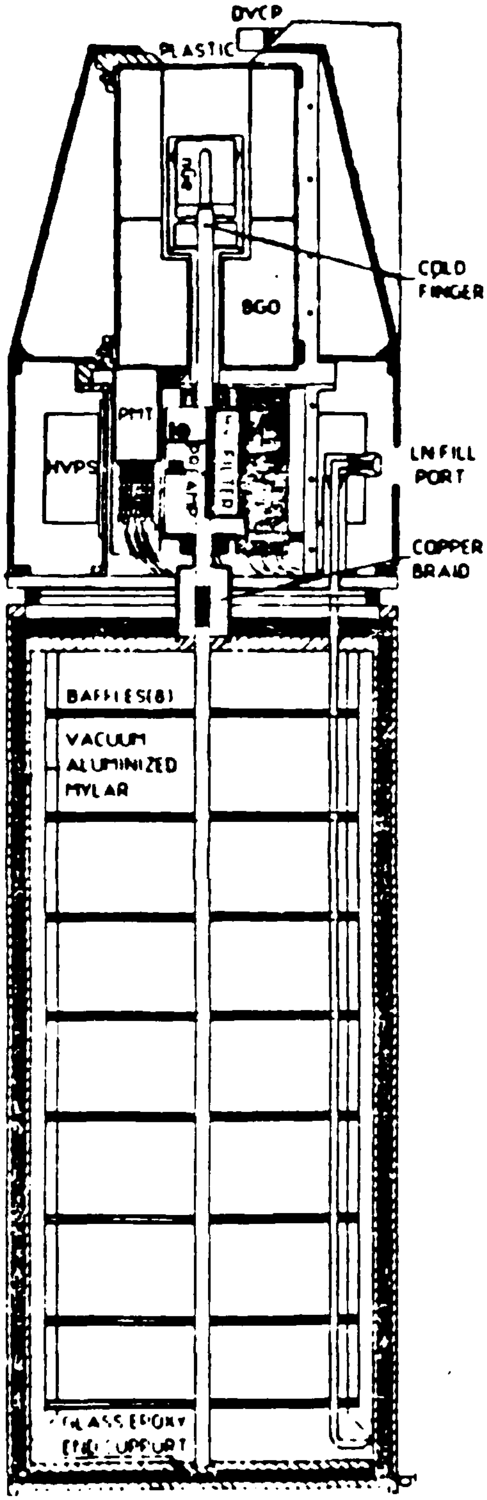

Figure 1. The Gamma Ray Advanced Detector (GRAD)

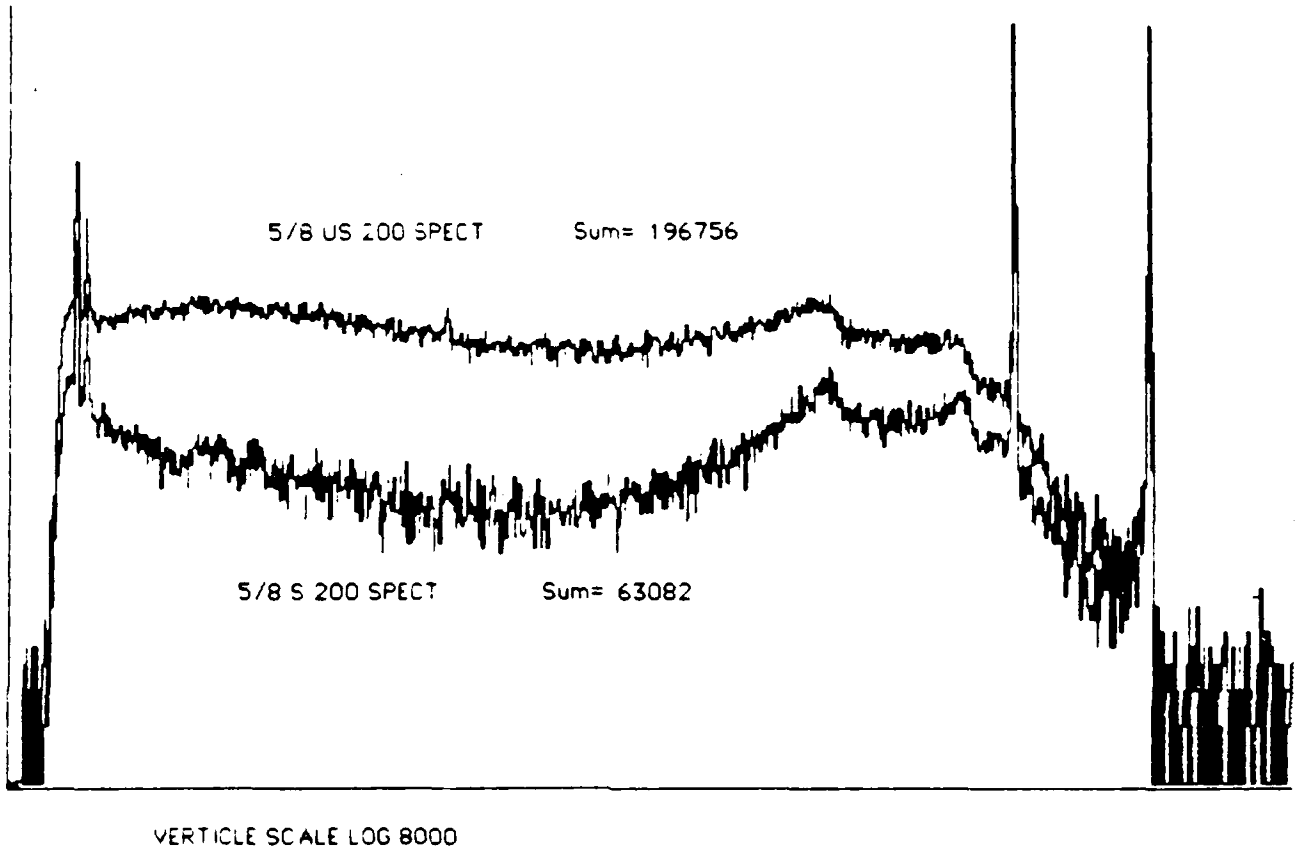

Figure 2. Compton Suppression of BGO shield.
Upper spectrum: shield off.
Lower spectrum: shield on.

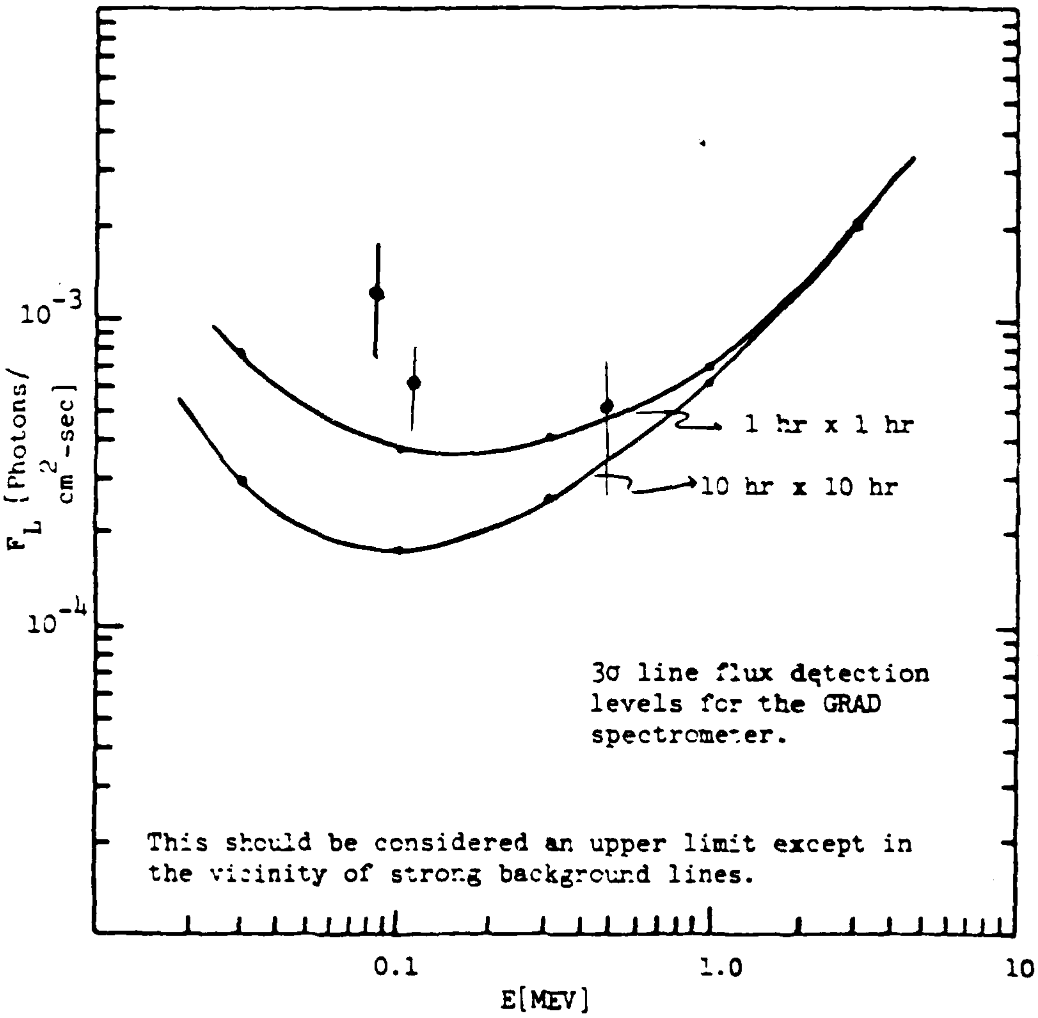

Figure 4. Estimated sensitivity of GRAD spectrometer for the detection of weak lines. The points represent actual supernova lines detected with the instrument.

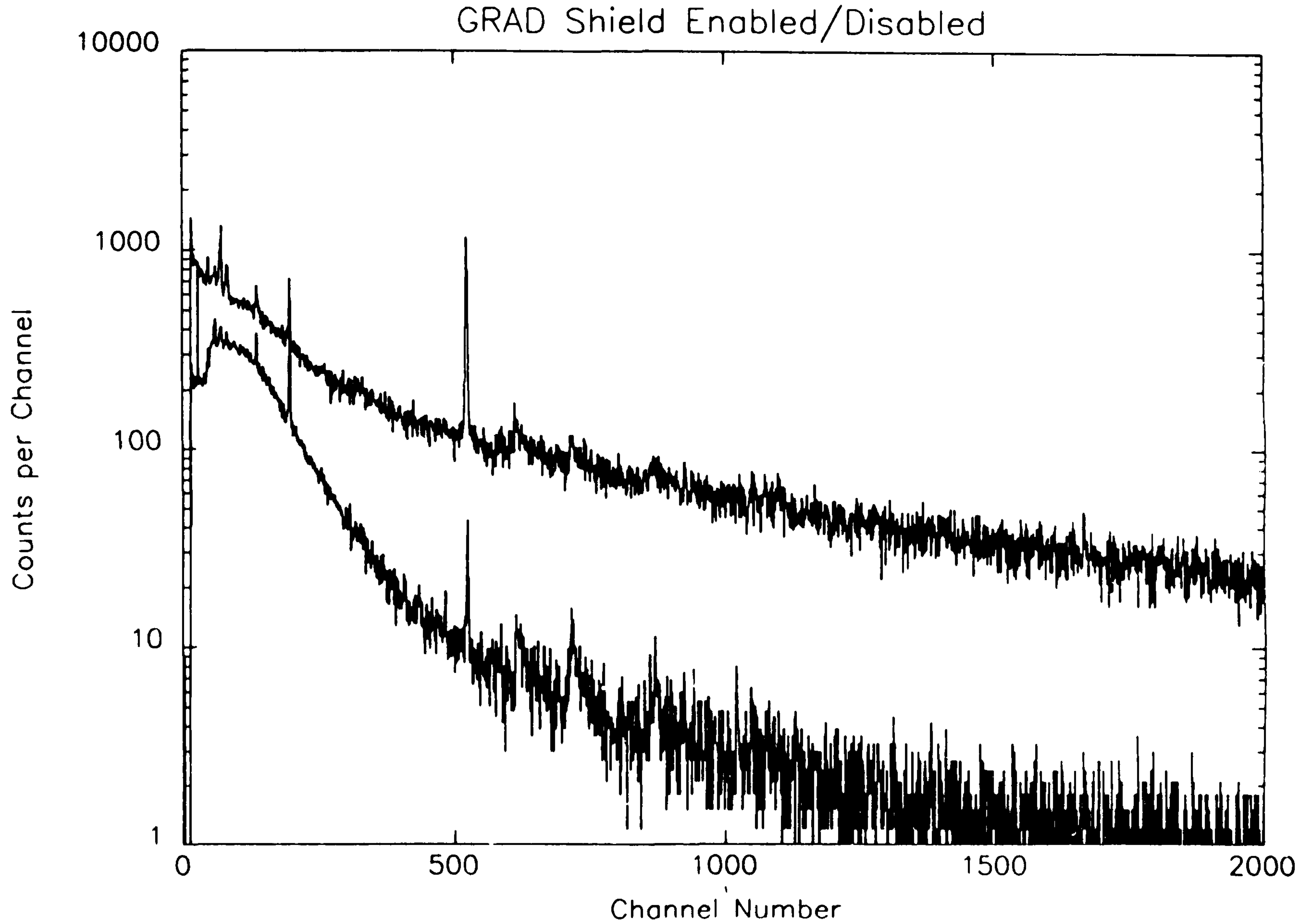

Figure 3. GRAD background spectrum taken over Antarctica on 8 Jan 1988