Semi-Annual Technical Report

SHUTTLE FLIGHT TEST OF AN ADVANCED GAMMA-RAY DETECTION SYSTEM

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February 28, 1984

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The principal changes to be made are in the avionics, as GRAD was originally designed for operation through ground-based telemetry. This complete redesigning of our avionics to accomodate operation by a Payload Specialist from the aft flight deck of the Orbiter allows us to take advantage of very recent findings on radiation-induced microprocessor failure in other space shuttle experiments in order to make the GRAD avionics less vulnerable to such latch-ups.

(continued on the back)
Advances in bismuth germanate (BGO) scintillator technology during the year since construction of the prototype GRAD now make it possible for us to construct a BGO shield with a closed-ended geometry. This improvement will enhance the signal-to-noise ratio. In addition we are experimenting with a new type of decay-vetoed calibration probe using an alpha- rather than a beta-emitting radioactive source.
SUMMARY

In August of 1983 the Gamma-Ray Advanced Detector (GRAD) Project was assigned to the AFP-675 Program for flight on a future Space Shuttle mission. In order to adapt the experiment to the requirements of AFP-675 we are making a number of changes, both in hardware and software. However, the necessity for such changes is more than affected by an expansion in scope of the experiment made possible by the introduction of a Payload Specialist into the operation.

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1. INTRODUCTION

At the annual Tri-Services Meeting in May of 1983, the GRAD experiment was rated fourth in priority out of the 37 DoD-sponsored space projects presented for review. Subsequently the experiment was assigned a place in the AFP-675 Program. A number of hardware and software changes will be required for operation of the experiment by a Manned Spaceflight Engineer (MSE) rather than by the experimenters through ground-based telemetry. This change in procedure is viewed as an advantage; however, operation of the experiment by a MSE plus the extensive requirements of the AFP-675 Program for documentation, certification, training, support of meetings, mission rehearsals and simulations have greatly increased the complexity of the GRAD Project.

Although we have just come into the AFP-675 Program, we find that our already extensive developmental work on GRAD and our previous Shuttle experience have already put us in step with the other AFP-675 experiments.

Having been assigned a specific mission we are now in a position to more clearly define our objectives and the means by which we intend to achieve them. These are outlined in the following section. The present status of GRAD and the major modifications which will be made to the system are then briefly discussed. A list of tasks and the budgets complete the report.

2. OUTLINE OF GRAD MISSION GOALS

I. Technological Goals

A. Determine the effects on bismuth germanate (BGO) and n-type germanium detector materials of exposure to the launch, space and landing environments.

How attained:
1. Determine performance characteristics of GRAD before, during and after the mission. These characteristics include energy resolution, angular resolution, response function and BGO shield efficiency.

2. Monitor housekeeping information (temperatures, voltages, counting rates, dead times)

3. Study crew-removed sample crystals as quickly as they can be removed from the returning Orbiter.

4. Do postmission activation measurements on GRAD instrument in OPP-type facility and in ORNL low-background counting laboratory.

5. Test the performance of GRAD as a gamma-ray spectrometer in space and on the ground.

   How attained:

   1. Accumulate spectra of the $^{239}$Pu calibration source plus ambient gamma-ray background.

   2. Accumulate spectra with the $^{239}$Pu calibration source switched on and switched off to determine how well one can extract a desired signal from the background.

   3. Accumulate spectra with the BGO shield switched on and off to determine effectiveness of the shield.

C. Determine radioactivation of detectors and surrounding materials and the nature of the background.

   How attained:

   1. Study initial activation of Orbiter by turning on GRAD prior to first passage through the South Atlantic Anomaly (SAA).

   2. Expose the GRAD to hard particle flux by periodic passage through the SAA and measure the decay of the induced gamma-ray background
in 30-second intervals as the Orbiter passes out of the SAA. (Two sets of 5 upward passages through SAA).

3. Measure spectra with the BGO shield turned off as well as turned on in order to identify the prompt gamma-ray background induced in the nGe and BGO detectors.

4. Measure the decay of postmission activity with intermediate half lives (15m - 24h) by low-background counting of sample crystals flown in the Crystal Sample Package (CSP).

5. Measure the radioactive background with GRAD as soon as the Orbiter is returned to an OPF-type facility.

6. Perform measurements of residual radioactivity in GRAD instrument in the ORNL low-background counting laboratory. (See p. 2).

D. Test the sensitivity of GRAD for the detection and identification of target sources in space.

How attained:

1. Measure the \(^{239}\)Pu calibration source against the Shuttle background.

2. Measure spectra from the galactic center.

3. Measure spectra from targets of opportunity, including solar flares.

E. Explore the usefulness of a gamma-ray spectrometer as a flight crew-controlled instrument for use in the detection and assessment of sources of gamma radiation in space.

How attained:

Provide experiment control and monitoring functions for MSE (see p. 1) through the Command and Monitoring Panel.
II. Scientific Goals

A. Measure the strength of the 0.511-MeV gamma-ray line emitted from the galactic center. Why the strength of this line should fluctuate so dramatically over the span of a few years in such a large astronomical source is not at all understood.

How attained:
Alternate taking spectra of galactic center and preselected background region for a total measuring time of at least 10 hours on each. These spectra would best be taken on orbits which do not pass through the SAA. Pointing accuracy should be ±10°.

B. Take solar spectra if a flare should occur during the mission.

3. STATUS OF GRAD

3.1 Delivery and Testing of Major Components

The status of the major hardware and software is summarized in Table 1. Those components of the experiment requiring modification for operation on the AFP-675 pallet are marked with asterisks.

With the exception of a cryostat vacuum problem reported in more detail below, the performance of the n-type germanium (nGe) detector and the bismuth germanate (BGO) shield has been satisfactory in every way. A response function for the integrated spectrometer is shown in Figure 1. Other performance characteristics have been described in an invited paper presented at the International Workshop on BGO at Princeton University (A.C. Rester, et al., submitted to Nuclear Instr. Methods).
Table 1

GRAD Status Report
October 1, 1983

<table>
<thead>
<tr>
<th>A. Flight Ops Hardware</th>
<th>Design</th>
<th>Construction</th>
<th>Delivery to SAL</th>
<th>Operational Testing</th>
<th>Electrical Testing</th>
<th>Mechanical Testing</th>
<th>Thermal Vacuum Testing</th>
<th>Environmental Testing</th>
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<td>4. Crew Training Procedures</td>
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<th>C. Ground Ops Hardware</th>
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<td>4. Calibration Hardware</td>
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<td>4. Monte Carlo.</td>
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Legend:
C = Completed
U = Underway

*These items will require extensive modifications for flight on the USAF P-675 pallet.
This should be considered an upper limit except in the vicinity of strong background lines.
3.2 Modifications Required on Flight Electronics

The present GRAD Flight Electronics Package was designed for interfacing with the OSS-I ground-linked telemetry system or with a self-contained recorder system for possible operation with reduced mission objectives. These electronics were delivered to SAL in August 1983 for bench testing and subsequently returned to Cedar Rapids for second-pass modifications. Interfacing GRAD with AFF-675 has required extensive changes in the controller microcomputer but not the nuclear electronics. In the new configuration the experiment will be controlled from a Command and Monitoring Panel on the aft flight deck of the Orbiter by an MSE. The GRAD microcomputer has been replaced by a more versatile computer having the capability to handle the more complex operations required for control by a flight crew member. As a result of an engineering study comparing the Rockwell 6502, INTEL 8086 and Motorola 68000 microprocessors, we have selected the 68000 microprocessor and will build at the modular, rather than the chip level.

The greater versatility of the redesigned controller will also permit us to program a "fast" data acquisition mode for better observation of targets of opportunity.

3.3 Loss of Vacuum in the nGe Detector Cryostat

On September 7, 1983 a failure of the vacuum in the germanium detector cryostat occurred. Prior to this failure the detector had been kept at room temperature for about a month while a new check valve was being installed in the nitrogen vent tube. The loss of vacuum appears to have been due to outgassing...
of some material within the cryostat over the month during which it was kept at room temperature.

A vacuum failure in the cryostat is a performance but not a safety problem. (As one can see in Figure 2, the cryostat is that part of the nGe detector housing that fits into the top of the liquid nitrogen dewar.) It causes a substantial, but not catastrophic increase in the liquid nitrogen boiloff rate and the detector becomes inoperable due to contamination of its surfaces. Neither effect would occur in orbit, as the entire system would be under vacuum.

The effect of this vacuum failure on the GRAD project is not expected to be significant; however, such a failure requiring servicing inside the cryostat within 20 days of launch would be a very serious matter. To cover this single-point failure mode, we are therefore budgeting for a backup nGe detector. Other components of the GRAD hardware are already covered. Modular construction of the electronics will permit board-by-board replacement without removal of the electronics unit from the pallet.

Under the assumption that it is not required for substitution of the Flight unit, the backup nGe detector will be used for the accumulation of high-resolution spectra in the postflight measurements at the landing site.
Figure 2. Detail of GRAD nGe Detector Cryostat

* See Figure 2A for updated detail.
4.0 GRAD PROJECT ORGANIZATION
GRAD PROJECT ORGANIZATION

For purposes of planning and management the GRAD project is organized into eight project elements:

1.0 GRAD Project Administration
2.0 GRAD Project Operations
3.0 GRAD Ground Support Equipment and Testing Facilities
4.0 GRAD Flight Hardware and Software
5.0 GRAD Calibrations
6.0 GRAD-to-ESS and -STS Integration Support
7.0 GRAD Crystal Sample Package
8.0 GRAD Data Reduction and Analysis

GRAD TASKS PLAN

TASK ITEM

1.0 GRAD Project Administration
   1.1 support technical interchange meetings
   1.2 support experimenter working group meetings
   1.3 support critical design review
   1.4 support scientific interchanges
   1.5 support professional meetings
   1.6 support DARPA meetings
   1.7 prepare semi-annual reports
   1.8 support SAL planning meetings
   1.9 coordinate activities of GRAD personnel

COMPLETION DATE
DEADLINE

as needed
as needed
as needed
as needed
as needed
as required by AFOSR
as needed
as needed
2.0 GRAD Project Operations

2.1 provide input to Lockheed for ICD preparation

2.2 provide input to Lockheed for FORD preparation

2.3 provide input to Lockheed for GORD preparation

2.4 crew training

2.4.1 write GRAD training manuals

2.4.2 provide scientific and technical training at SAL for flight crew candidates

2.5 support operations meetings

2.5.1 ground operation reviews

2.5.2 flight operation reviews

2.5.3 technical interchange meetings at launch and landing sites

2.6 support POCC training for experimenters

2.7 support CMP simulator training for PI and Project Manager

2.8 support flight rehearsals and simulations

2.9 support mission operations

3.0 GRAD Ground Support Equipment and Testing Facilities

3.1 develop electronic test stand

3.1.1 design and construct test stand

3.1.2 formulate design modifications

3.1.3 complete test chamber modifications

3.2 develop component level vacuum test chamber

3.2.1 design and construct test chamber

3.2.2 formulate design modifications

3.2.3 complete test chamber modifications

3.3 develop ground support equipment for the GRAD

3.3.1 design ground support equipment

3.3.2 formulate design modifications for GSE

3.3.3 construct and assemble GSE

3.3.4 test GSE hardware

3.3.5 design GSE and ground test software

3.3.6 complete and test GSE software

***dates classified
4.0 GRAD Flight Hardware and Software

4.1 design and construct dewar detector assembly

4.1.1 design and construct germanium detector assembly
4.1.2 design and construct liquid nitrogen dewar
4.1.3 design and construct bismuth germanate annulus
4.1.4 design decay vetoed calibration probe (DVCP)
4.1.5 construct and test DVCP
4.1.6 design cryo service panel
4.1.7 construct and test cryo service panel
4.1.8 design electrical I/F service panel
4.1.9 construct and test electrical I/F panel
4.1.10 final assembly of the dewar-detector assembly
4.1.11 construct (with ORTEC) backup germanium detector

4.2 design and construct electronic support package

4.2.1 design and construct data acquisition electronics
4.2.2 modify design of micro processor controller
4.2.3 construct micro processor controller
4.2.4 design electronic support package housing
4.2.5 construct electronic support package housing
4.2.6 assemble electronic support package
4.2.7 design and construct wiring harness
4.2.8 design controller software
4.2.9 complete and test controller software

4.3 design and construct (with Lockheed) the GRAD-SV interface

4.3.1 determine interface requirements
4.3.2 input to Lockheed preliminary specifications
4.3.3 input to Lockheed final specifications

4.4 design, construct and deliver to Lockheed a mass model

4.4.1 input to Lockheed initial GRAD characteristics
4.4.2 design and construct mass model
4.4.3 deliver mass model to Lockheed

4.5 design and construct (with Lockheed) mechanical and thermal models

4.5.1 initial mechanical model input to Lockheed
4.5.2 initial thermal model input to Lockheed
4.5.3 input intermediate mechanical parameters
4.5.4 input intermediate thermal parameters
4.5.5 input test results and final technical input to Lockheed
4.5.6 input final thermal characteristics to Lockheed

4.6 GRAD hardware-software testing and burn-in

4.6.1 subassembly functional tests
4.6.2 subassembly thermal vacuum test
4.6.3 subassembly vibration tests
4.6.4 subassembly load tests
4.6.5 subassembly burn-ins
4.6.6 GRAD dewar certification
4.6.7 GRAD electronics package housing certification
4.6.8 GRAD hardware-software functional tests
4.6.9 GRAD thermal vacuum tests
4.6.10 GRAD vibration tests
4.6.11 GRAD load tests
4.6.12 final GRAD burn-in

5.0 GRAD Calibration

5.1 preliminary calibrations

5.1.1 calibration of detector subassemblies
5.1.2 calibration of PAD-ADC-detector subassembly

5.2 GRAD calibrations at SAL with radioactive sources

5.2.1 GRAD energy and efficiency calibrations
5.2.2 GRAD compton suppression efficiency calibrations
5.2.3 GRAD directionality calibrations
5.2.4 GRAD thermal correction coefficients

5.3 GRAD calibrations at UF accelerator

5.3.1 design and construction of GRAD mounting
5.3.2 GRAD energy and efficiency calibrations
5.3.3 GRAD directionality calibrations

6.0 GRAD-to-ESS and -STS Integration Support

6.1 GRAD integration at Lockheed
6.2 perform post-integration GRAD tests
6.3 attend and support Lockheed tests
6.4 S/V integration at launch site

***dates classified

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7.0 GRAD Crystal Sample Packages

7.1 design and construct crystal sample packages
   7.1.1 flight deck package
   7.1.2 cargo bay package

7.2 input to Lockheed interface design constraints

7.3 design and construct sample package mounting bracket

7.4 preparation of counting chambers
   7.4.1 primary facility at ORNL
   7.4.2 portable facility for landing site

7.5 background and calibration measurement
   7.5.1 ORNL measurements
   7.5.2 landing site measurements

7.6 post-flight activity measurements
   7.6.1 measure sample crystal activation at landing site
   7.6.2 measure GRAD/Orbiter activation before de-integration
   7.6.3 measure long term activities at ORNL

7.7 dosimetry measurements
   7.7.1 measurements at radiation dosimetry lab, NASA-Johnson Space Center

8.0 GRAD Data Reduction and Analysis

8.1 GRAD calibration data
   8.1.1 GRAD energy and efficiency data
   8.1.2 GRAD compton-suppression efficiency data
   8.1.3 GRAD directionality data
   8.1.4 GRAD thermal correction coefficients data

8.2 crystal background and calibration measurements

8.3 preflight crystal activity measurements

8.4 postflight crystal activity measurements

8.5 dosimetry measurements

8.6 flight data
8.6.1 experimental gamma-ray spectra
8.6.2 calibration spectra
8.6.3 housekeeping data

8.7 reporting

8.7.1 professional meetings
8.7.2 scientific journals
8.7.3 agency reviews

as required  
as required  
as required