Final

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Dr. James Ling
Code SR
NASA Headquarters
Washington, DC 20546

Re: NAGW-4577 (ATIC)

Dear Dr. Ling:

This is the final report for NASA grant NAGW-4577, "Advanced Thin Ionization Calorimeter (ATIC)". This grant covered a joint project between LSU and the University of Maryland for a Concept Study of a new type of fully active calorimeter to be used to measure the energy spectra of very high energy cosmic rays, particularly Hydrogen and Helium, to beyond 10^{14} eV. This very high energy region has been studied with emulsion chamber techniques, but never investigated with electronic calorimeters. Technology had advanced to the point that a fully active calorimeter based upon Bismuth Germanate (BGO) scintillating crystals appeared feasible for balloon flight (and eventually space) experiments.

Subsequently, the grant was amended to include procurement of the materials for a BGO calorimeter and scintillator trigger plus design/development/testing of the individual components. Due to procurement difficulties (including fluctuating world market prices for Germanium oxide) several no cost extensions were necessary to complete the procurement, and we are grateful to the NASA technical and project officers who made the extensions possible.

Results from this project are summarized in the attached Bibliography which shows both publications and technical reports. The former summarize the results of the Concept Study, including the design of a balloon payload capable of utilizing the active BGO calorimeter concept to obtain new measurements in this very high energy regime to study the astrophysical questions of acceleration and transport of the particles. The technical reports were used to document the tests and evaluations and the payload designs which were developed for the project. Copies of the technical reports can be made available to anyone that is interested. A summary of some of the calorimeter results is given below.

Bismuth Germanate (BGO) is a nearly optimal material for a calorimeter. It has both a short radiation length (1.12 cm) as well as a relatively short interaction length (22 cm) due to its high Z components and its high density (7.1 g/cm^3). BGO is a relatively hard, rugged, non-hydroscopic scintillation crystal which does not cleave and does not show any significant amount of self absorption of its scintillation light. Viewed with a photomultiplier tube, there is sufficient light to cover the wide dynamic range encountered in measuring hadronic showers at a variety of energies. The calorimeter concept that has been developed envisions ten layers of

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BGO crystals, arranged alternately along the x and y axes. Each crystal is rectangular of cross section 2.5 cm x 2.5 cm and the total calorimeter includes 400 crystals in a volume of 50 cm x 50 cm x 25 cm. Vertically, this calorimeter has 22.3 radiation lengths and just over one proton interaction length.

In order that the showers are as nearly identical in "age" as possible, the calorimeter follows a carbon target of 40 cm thickness, about one proton interaction length (and only about 2 radiation lengths). The cosmic rays interact in the carbon target and the subsequent showers are measured in the calorimeter. In order to provide triggering, trajectory information and particle charge identification, three layers of (x-y) scintillator strips are located at the top, bottom and center of the carbon target. The combination of thick, homogenous target and a fully active calorimeter forms the basic concept developed for ATIC.

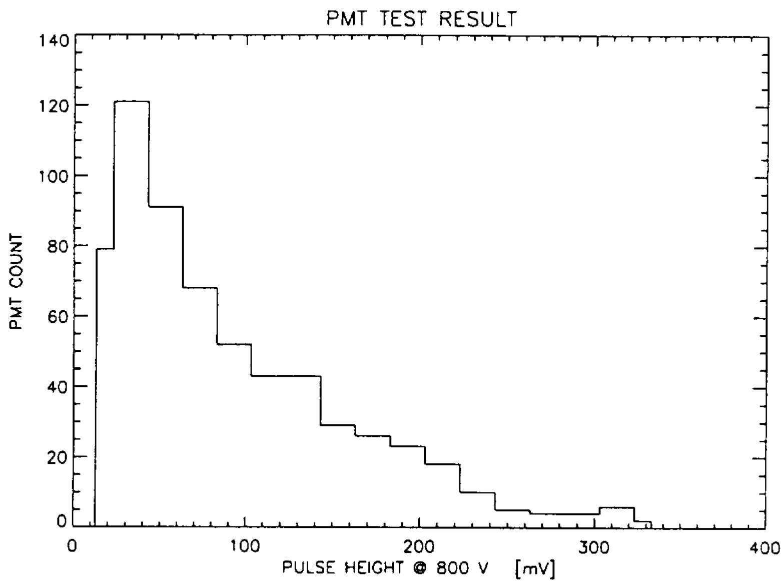

Figure 1. Test results for 630 R5611 photomultiplier tubes.

For the calorimeter, we selected the Hamamatsu R5611 pmt, which is also suitable for the trigger scintillator strips. An evaluation of a large sample of these tubes is shown in Figure 1. The data were taken in a light tight enclosure with a Light Emitting Diode (LED) and all tubes at a high voltage of 800 volts. All tubes were evaluated in the same experimental set-up. Note that most of the tubes showed an output of ~50 mV, as expected, but there is a long tail with a few tubes out-performing the average by a factor of 5-6. Data such as shown in Figure 1 allow us to select the tubes and "match" them with the scintillator units to obtain a more uniform performance over the full instrument.

The BGO procurement represented a challenge, as mentioned above. It was necessary to utilize two suppliers, MarkeTech and Bicron, to meet the schedule. The crystals provided by these companies come from overseas, Russia and China, respectively, and are of different quality, optically. The Bicron crystals are very clear. The MarkeTech product, however, has a greenish-yellow to brownish tint, and these often have complex patterns of visible bubbles. Therefore, it was necessary to measure every crystal, separately, using cosmic ray muons to ascertain both the relative light yield and the light attenuation, if any, in the crystals.

These measurements were performed in the existing Cosmic Ray Test Sand, augmented by additional electronics. The Stand combines large area scintillation paddles at the top and bottom to form the basic event trigger. Interior to these scintillators are two x + y layers of drift chambers to provide a measurement of (~1 mm resolution) of the point of incidence of the particle at the top and bottom. The drift chambers are separated by ~1.25 m, thereby providing accurate trajectory determination and a large volume (~1m x ~1m x ~1.25 m) in which test items can be mounted. The trajectory information allows the position of the event on the BGO crystal to be determined, thereby allowing attenuation investigations.

A large light-tight box was constructed with high voltage and signal feed-throughs. Inside the box are a row of R5611 pmt's each of which views a BGO crystal. The entire system is surveyed within the stand and the positions of the crystals inside the box are accurately measured. These are then used in a software program to determine the hit position. In addition, the anode of the tube is read through a LeCroy 2249 ADC for each event. The muon peak is then determined from a histogram of these ADC channels.

Figure 2 shows results for two sets of crystals, Bicron (top) and MarkeTech (bottom). Plotted is the number of crystals showing a muon peak in a given ADC channel range. There is a wide variation among individual crystals from the same supplier. In addition, there is a systematic difference between the two suppliers with the MarkeTech product giving lower relative light yields. Figure 2 shows the raw results of initial tests. In some cases, the crystal may have been located too near the edge of the test stand (which may account for the ones near zero pulse height) or the readout channel may have been intermittent. Each of the crystals near the edges of the distributions are in the process of being re-measured in a different position/channel in the test stand before a final response is assigned.

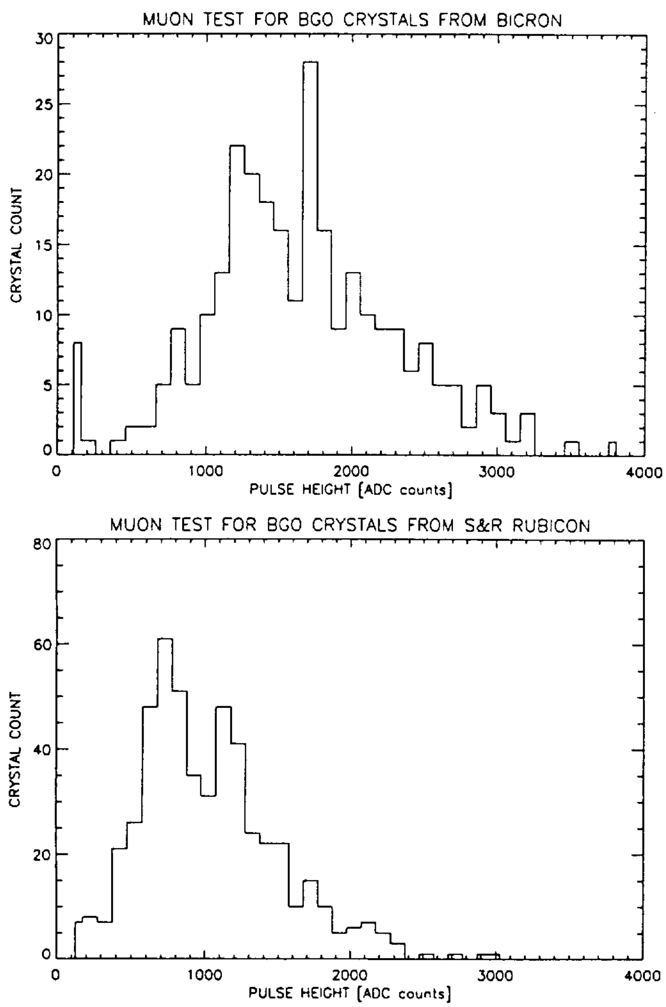

Figure 2. BGO crystal evaluation results from the Cosmic Ray Test Stand for crystals from Bicron (top) and MarkeTech (bottom).

Fortunately, the total light output, even from the low performing crystals, is more than the pmt's can accept. Therefore, we must attenuate the light prior to the pmt. The results of these detailed calibrations will allow the amount of attenuation to be determined on a crystal-by-crystal basis, so that the performance of the final crystal-pmt sub-system can be "tuned" to be nearly uniform over the volume of the calorimeter.

Calibrating/verifying the degree of uniformity must be done after the calorimeter layers are assembled and mated to the readout electronics. This will be one of the detailed tests performed during the integration/testing of a full instrument, repeated during the pre-flight calibration/testing on the ground at the launch site, and finally re-done during the flight itself. The latter is possible by utilizing non-interacting proton events to map the calorimeter response, crystal-by-crystal. Any remaining non-uniformities in performance can then be handled in post-flight corrections to the measured signals. Such an overall procedure has the advantage that the largest part of the variation is removed by design of the hardware, leaving only residual corrections to be made in the data analysis.

A proposal to construct and fly such a calorimeter concept was put forward, "ATIC Balloon Experiment," by an international collaboration (LSU, UMD, NRL and SU, in this country, SNU in Korea, MSU in Russia, and MPI in Germany) and was accepted by NASA. The flight instrument is currently under construction with a first (continental US) balloon flight to be performed in 1999. Subsequent flights will utilize the Long Duration Ballooning capability with flights from McMurdo, Antarctica and/or Fairbanks, Alaska. We are looking forward to analyzing actual cosmic ray data with the BGO calorimeter system.

Sincerely yours,

John P. Wefel, PI
Professor of Physics

Attach.

cc: NASA Center for Aerospace Information ✓
NASA Contracting Officer
C. E. Graham, OSR, LSU

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