RICE UNIVERSITY

THE DESIGN, CONSTRUCTION, AND PERFORMANCE OF A BALLOON-BORNE GAMMA-RAY TELESCOPE

by

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ABSTRACT

This thesis describes a new balloon-borne system which was designed, constructed, and flown with the purpose of increasing the sensitivity of gamma-ray observations. In an attempt to reduce the background counting rate, the detector employed a previously-untried composite shield of the following materials and depths of materials (in units of gm cm^{-2}): plastic scintillator - 4, LiF epoxy - 2, lead - 43, sodium iodide - 5, and aluminum - 7. Both the plastic and the NaI (Tl) scintillators were used in an active anticoincidence system; the plastic detects charged particles which may initiate cascades in the lead collimator, and the sodium iodide detects low energy photons which emerge from the inner surface of the lead. The LiF epoxy is a slow neutron absorber, and the aluminum was used as the supporting structure. The new telescope system is capable of remaining aloft for ~40 hours and, through radio-control, of observing several celestial objects during a given flight.

The detector proved to be a very effective collimator of gamma rays and exhibited a low counting rate at sea level. The high counting rate that was encountered at balloon altitudes, though unexpected, can, however, be explained in terms of Compton and neutron interactions in the central crystal which was composed of CsI (Na).
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I. INTRODUCTION

This thesis describes a particular approach taken to a fundamental problem of astronomy, namely that of increasing the sensitivity of the observations. Section II gives a brief review of the motivations for pursuing the field of high-energy astrophysics and a description of the trends in observational astronomy in this high-energy domain. In section III the current state of knowledge of atmospheric gamma radiation is reviewed, and the relationship between primary cosmic rays and gamma rays at balloon altitudes is discussed. The problems which currently hamper gamma-ray observations are detailed in section IV, and a particular scheme is proposed to solve some of these problems. The implementation of this solution is described in appendix A1 which gives some details of the construction of the new telescope. Appendix A2 describes the complete balloon-borne system, and A3 presents a record of the testing of the system and of the two balloon flights which were conducted in the summer of 1970. The performance of the new gamma-ray detector is described in section V, which discusses the instrumental response to three distinct environments. Section VI gives the author's interpretation of the observed properties of the telescope; and in section VII, an evaluation of the success of the project is presented along with suggestions for the long range outlook for future attempts at telescope design. A brief description of an interim course of action is also included in the final appendix, A4.
II. HIGH-ENERGY ASTRONOMY

The fields of high-energy astronomy have only come into being in the last decade or so and were not put on a firm footing until the early sixties when Arnold, Metzger, Anderson and Van Dilla (1962; see also Metzger, et al. 1964) made the first observation of extraterrestrial gamma rays and Giacconi et al. (1962) measured X-rays from beyond the solar system. It was not until 1968, with the report by Clark, et al. (1968b) of a successful satellite-borne gamma-ray experiment, that high-energy gamma rays of a cosmic nature were finally observed. Both the fundamental instruments and the means of observation, i.e., rockets, stratospheric balloons and satellites, have required a high degree of technological development. The exploitation of the high-energy region of the spectrum (beyond the near ultraviolet) was not feasible prior to this recent development in techniques.

Though still in its infancy as a field of observational inquiry, high-energy astronomy has already reaped substantial rewards. Apart from the general gains to be made from viewing celestial objects over the widest possible portion of the electromagnetic spectrum, there are many specific astrophysical questions which may be answered by thoroughly exploring the high-energy end of the spectrum.

Burbidge, et al. (1957) gave new merit to the faith that the stuff of the universe is cooked up in stellar interiors. Clayton and Craddock (1965) and Clayton, et al. (1969) have submitted that the theories of nucleosynthesis in supernovae are subject to direct experimental verification by the observation of gamma-ray line emissions from supernova remnants. Though the search for such gamma-ray lines has so far proved unsuccessful (see e.g., Ellis [1967] and Jacobson [1968]), it has provided a stimulus for gamma-ray
astronomy.

The observations have yielded the discovery of many powerful emitters of high-energy continuum radiation. Within our galaxy, the Crab Nebula and Cygnus X-1 are bright at wave lengths from the soft X-ray into the low-energy gamma regions. Long one of the most exciting objects to optical astronomers, the Crab Nebula has become, with the discovery of its broad band pulsar \((10^9 \text{ Hz to } 10^{20} \text{ Hz})\), an object of intense study by radio, optical, and X- and \(\gamma\)-ray investigators alike.

The theoretical connections between gamma rays and cosmic rays have added further impetus to the study of gamma rays. While the question of the origin of the cosmic rays is complicated by the fact that these particles travel very circuitous paths through the galactic magnetic fields, gamma rays offer a hope of identifying cosmic ray sources. These high-energy photons may be produced in conjunction with the cosmic rays and propagate rectilinearly, thereby preserving the information about their direction of origin. Hence the discovery that the galactic plane, and the center region in particular, is a strong source of gamma rays may have interesting implications. Low-energy gamma rays have even been observed to originate from outside our galaxy in the peculiar radio galaxy M87 (Fishman, 1969). The detection of these photons from a distance of 10 megaparsecs implies an enormous luminosity.

Thus there is ample incentive for carrying out more extensive observations at high photon energies. The following description of terms is given in an effort to remove some of the ambiguity that exists in the terminology. The region of the spectrum involving photons of energies from a few electron volts to a few hundred million electron volts is divided into
four main regions. Apart from the generic terminology which associates the term X ray with an atomic transition and the term gamma ray with a nuclear transition, there are distinctions based upon the observational techniques used. Soft X rays, photon energies less than 10,000 electron volts, are observed with large-area proportional counters from rockets above the atmosphere (which is opaque to these photons). Hard X rays (10 kev to ~500 kev) penetrate small depths of residual atmosphere and can be observed from balloons; but because they are more penetrating, more absorptive solid scintillation detectors must be used instead of gas-filled counters. Low-energy gamma-rays, photon energies from about 0.1 Mev to 10 Mev, can also be observed from balloons with scintillation detectors. Gamma rays with energies from a few Mev to several hundred Mev are typically observed with spark chambers, but the small flux of extraterrestrial photons at these energies makes observations from the upper atmosphere difficult. The relatively lower background environment of a low-inclination, circular satellite orbit is almost a requirement for observations in the high energy gamma-ray region.

The Rice University Gamma-Ray Astronomy Group (RUG-RAG) has been engaged in a program of observational astronomy for the past six years and had conducted a total of thirteen balloon flights prior to the two 1970 flights which are described in appendix A3. The observations of several regions of the sky have been reported in the literature: the Crab Nebula (Haymes and Craddock, 1966; Haymes, et al., 1968a), Virgo A (Haymes, et al., 1968c; Fishman, 1969), Sagittarius (Haymes, et al., 1969b), Centaurus A (Haymes, et al., 1969a), Cygnus X-1/X-3 (Haymes, et al., 1968b; Haymes and Harnden, 1970), and the Crab pulsar NP0532 (Fishman, et al., 1969).
Brief descriptions of the instruments and techniques employed by RUG-RAG are given in the above-cited articles, and more detailed discussions may be found in the theses of Craddock (1967), Ellis (1967), Fishman (1968; 1969), and Glenn (1969). The instrument, referred to as Gammascope II (see figure 20), used in nearly all of these investigations was a NaI(Tl) scintillation crystal surrounded by another well-type guard crystal of the same material. The electronics were configured to pulse height analyze photon energy losses in the 30 to ~600 kev range, a range which spans the hard X-ray and low-energy gamma-ray regions. This region is of considerable interest, not only because it contains many of the energies expected from radioisotope deexcitation and the 0.51 Mev positron annihilation energy, but also because it enables one to correlate the measurements made on a given object with the lower energy X-ray measurements of others; extrapolations are not necessary when a region of overlap exists.

While these studies have proved valuable, the upper limits placed on the supernova line emissions have been above the predicted flux levels. Also, the continuum spectra observed from several objects become too weak to be detectable beyond intermediate energies; the high end of the energy window has generally provided only upper limits. An increase of one or two orders of magnitude in the sensitivities of these observations might provide some real inputs to the theories of nucleosynthesis in stars and would undoubtedly reveal the existence of still further sources of gamma radiation.
III. ATMOSPHERIC GAMMA RAYS - A BACKGROUND FOR CELESTIAL OBSERVATIONS

For the purpose of this thesis, attention will be restricted to the photon energy range from 30 kev to about one Mev. Such radiation, which will be called gamma rays, may be conveniently detected through the use of scintillation crystals, such as NaI(Tl) or CsI(Na), by virtue of three basic interaction processes: the photoelectric effect, the Compton effect, and pair production. In the region of interest, photons are below the threshold energy for pair production ($2m_e c^2 = 1.02$ Mev), but this effect will occur in a detector due to the presence of higher energy photons. For CsI and NaI, the probability of Compton interaction dominates the cross sections for photon energies above about 100 kev (and below ~2 Mev). Once a $\gamma$ photon has interacted with a crystal by any of the three processes, it will have given up at least some of its energy to the excitation of atomic electrons within the crystal. In returning to the lowest available energy states, these electrons will emit optical quanta which may be detected through the use of photomultiplier tubes.

It will be seen below that the study of cosmic rays played a very important role in developing the current understanding of atmospheric gamma radiation. To be sure, nuclear physics itself, which has been largely responsible for the development of $\gamma$-ray astronomy, owes much of its achievements to information gleaned from the study of cosmic rays. It is more than a coincidence that the cosmic rays have turned out to be responsible for the production of the gamma rays in the atmosphere.

Before the empirical evidence concerning radiation in the atmosphere is presented, six major gamma-ray production processes will be described. Nuclear de-excitation (1) gives rise to a gamma photon when the atomic nucleus seeks a lower
energy state via electromagnetic radiation. Natural and induced radioactivity are the results of this process. Neutral pi mesons, π⁰, which are strongly interacting sub-nuclear particles, decay spontaneously (2) with a half life of ~10⁻¹⁵ seconds into two energetic photons. In the rest frame of the π⁰, the photons must carry off a total of 135 MeV, the rest mass energy of the π⁰, which appears to self-annihilate in the process. Positrons annihilate (3) with electrons to yield two gamma rays each of energy mₑc² or 511 kev. These first three processes are essentially results of nuclear physics. The remaining three can be obtained from semi-classical radiation theory. Bremsstrahlung (4) or braking radiation is emitted by charged particles when they are accelerated in the coulomb field of a nucleus. The functional dependence (upon mass) of the power emitted in such radiation is such that only electrons produce significant gamma radiation by this process; contributions from protons in most situations are entirely negligible. Synchrotron (5) radiation can produce a continuous spectrum of radiation which may include gamma rays. Charged particles spiralling about magnetic field lines emit photons as they are accelerated in their orbits. Again in most situations, only electrons produce significant quantities of radiation. Finally, the inverse compton effect (6) can produce gamma rays if low-energy photons are present in sufficient density in a region where a high density of energetic electrons also exists. In the rest frame of the electron, this interaction appears as a normal compton collision of the photon with the electron, but in the "lab frame" the photon is Doppler-shifted as a result of the collision. Hence low-energy photons may be transformed into gamma rays.

Observations in the atmosphere are hampered by the obvious problem of lack of accessibility. Even now that the
problem of getting measuring devices to the desired altitude has been fairly well solved, the design of instruments which can make definitive measurements remains a challenge. Early attempts involved the use of Geiger tubes in balloons and rockets and provided definitive counting rate versus altitude profiles. However, it was by no means clear what was being counted. Measurements now exist both for ionizing radiation (charged particles of several types) and for photons. General references on cosmic ray interactions with the atmosphere include: Perlow and Kissinger (1951), Puppi and Dallaporta (1952), and Ray (1961).

The electron-photon cascade has been singled out as the most important cosmic-ray process for gamma-ray production in the atmosphere and has been treated in depth by Nishimura (1967). A single neutral pi-meson which may result from the interaction of a primary particle with an atmospheric nucleus, then decays into two highly energetic gammas which in turn undergo pair production. Through positron annihilation with other electrons, more gammas are produced, and so on. The multiplication process continues creating more electrons and photons until the gammas fall below the pair production limit and losses via bremsstrahlung rob the electrons of their energy. The result is that the energy originally contained in the $\pi^0$ has been largely converted into gamma photons. Compton interactions of these will degrade their energy so that a large flux of low-energy $\gamma$-rays can be generated.

The investigations of a series of authors, including Jones (1961), Vette (1962), Peterson (1963), and Brini et al., (1967), have been utilized by Puskin (1969) in a detailed calculation of the gamma ray flux to be expected at balloon altitudes (about 4 mb. residual pressure). Puskin shows that in the low-energy region, bremsstrahlung is the most important
process, while annihilations account for a few percent. A key feature of his calculation is the utilization of a Monte Carlo technique to include the effects of Compton degradation of the gamma photons. Thus higher energy gammas are degraded into the low-energy region. The functional form of bremsstrahlung is able to account for the observed power-law gamma spectrum as being generated from the measured atmospheric electron spectra. The experimental findings of Haymes, et al., (1969c) can be generally explained by the analysis of Puskin, but a detailed treatment of the detector geometry and the effects of the large-mass shield would be required for a theoretical reproduction of the RUG-RAG measurements.

The work of many authors has developed a fairly consistent model of the atmospheric gamma radiation encountered at balloon altitudes. It should be possible to utilize this knowledge in the design of a gamma-ray detector which would make sensitive celestial observations, even in the presence of the atmospheric background. However, as many authors have pointed out (see e.g., Kreger and Mather [1967], p. 79, the shielding of gamma-ray detectors is not a simple matter and must be pursued with as full an awareness as possible of all radiations which may have a bearing on the problem. In many cases the elaborate steps taken to shut out unwanted radiations have only compounded the problem by the unanticipated generation of additional components of the background.
IV. OBSERVATIONAL PROBLEMS AND POSSIBLE SOLUTIONS

A. Current problems

The current "state of the art" in low-energy gamma-ray astronomy suffers from several drawbacks: (1) low "signal to noise" ratios (the extraterrestrial flux, or "signal", which is to be measured is quite small in comparison with the atmosphere background flux, or "noise"), (2) small collecting areas capable of γ-ray detection, (3) limited angular resolution, (4) limited energy resolution, and (5) short observing times. The first three problems are interrelated. The noise factor in the S to N ratio is contributed by the high level of atmospheric radiation which was discussed in section III. The fact that γ rays are difficult to collimate (because of their relatively great penetrating power) not only means poor angular resolution, but also means that it is difficult to prevent a "leakage" flux from entering a detector. For example, a beam of 500 kev photons can penetrate 1.2 inches of NaI before being reduced in intensity by $e^{-1}$. For the Gammascope II detector flown by RUG-RAG (see section II and appendix A4), the leakage flux is about 5 or 6 times that which enters through the acceptance angle, for 500 kev photons, or in other words, the effective solid angle at 500 kev is about 5 times that at 50 kev where the shielding is nearly 100% efficient.

The obvious solution to the problem of small area is to present a larger area to the "signal" flux. This is a matter of state of the art and economic feasibility. Total thin-crystal areas as large as 368 cm$^2$ (Clark, Lewin, and Smith [1968a]) and more recently single crystals as large as 13" diameter by 6" thick (area = 855 cm$^2$) (Kurfess [1971]) have been used, but large crystal volumes are difficult to shield from background radiation and consequently have rather large effective solid angles and high background counting rates.
Large crystals are also expensive (in the context of balloon astronomy which is a relatively inexpensive field of investigation), and a trade off must be made between the volume of crystal used for shielding and that used for actual detection.

The third drawback listed above is obviously related to the first two; increased active collimation can narrow the acceptance beam and possibly decrease the background level; but if a limited amount of crystal volume is available, the detection area will suffer. A possible solution to the latter difficulty is the use of passive shielding in addition to the scintillation material employed with anticoincidence techniques. There is a real need for vastly improved angular resolution, since identification of gamma emitters with X-ray and optical objects is not currently feasible in regions of the sky in which the density of such objects is high. While soft X-ray studies indicate many distinct objects in the general direction of the galactic center, current gamma ray observations must simultaneously view the entire region. While increased collimation and shielding may be expected to narrow the acceptance cone, the unavoidable exposure of the increased mass to the cosmic-ray beam may have undesirable side effects.

Solutions to the fourth problem, limited energy resolution, have been attempted (Jacobson, 1968; Chapman, 1968; Womack and Overbeck, 1970), but the use of solid state detectors, to gain the desired improvement in energy resolution, has thus far meant compromising the detection area. Larger active areas of lithium-drifted germanium are now available however, and the use of such detectors, with their associated cryogenics, is entirely feasible. The emission of gamma-ray lines from a celestial object, though not yet observed, would warrant the use of higher resolution techniques. If and when such emissions are detected, they will undoubtedly motivate a more concerted effort in the use of solid state
detectors.

Longer exposure times would certainly improve the observations. The use of a drift-scan technique cuts down the exposure to any particular direction considerably from that obtained with a tracking method. The result is that a large fraction of the time is essentially spent measuring the level of background radiation. However, in an experiment which tracks a celestial gamma-ray source in its diurnal motion across the sky, a useful observing time of eight to ten hours is obtained. This is certainly not a short time compared with a rocket flight, but is a factor of 100 shorter than that a satellite could provide, even if it only had a useful life of two months. For balloon observations, the usual flight outlook does not exceed ~40 hours, which for a given object, could double the time indicated above. However, half of the observing time must be spent in measuring the background radiation, since the determination of an extraterrestrial flux requires that the background be subtracted out. Satellites clearly offer longer observing times and have the additional advantage of being removed from the atmospheric background radiation. Yet the high cost and long "lead times" of spacecraft experiments have so far meant that only a few have been performed (see e.g., Metzger et. al., 1964; Clark, 1968; Vette, 1970), and those few have been omnidirectional rather than collimated measurements.
B. The Gammascope IV Solution

A project was begun by RUG-RAG in early 1969 to develop a new gamma-ray detector, called Gammascope IV-A (GS-IV), which would solve some of the problems outlined in part A of this section. A schematic drawing of the resulting telescope is shown in figure 1. The essential feature of the detector itself is its composite, active and inactive shield. Attributable to the entire balloon-borne system, which was developed in conjunction with the telescope (see appendices A1 and A2 for more details), is the fact that longer observations may be exploited through the use of longer times aloft (~40 hours) to view several celestial objects.

The GS IV scheme addressed itself to the five problems of part A as follows. It was believed that an "improvement" factor of about 25, over the performance of the previous RUG-RAG instrument, GS II, in the signal to noise ratio could be achieved, in spite of the fact that the exposed surface area of GS IV would be only one fourth that of GS II. The angular resolution would be improved by a factor of six to a $4^\circ$-FWHM acceptance beam. This was a primary design goal since such a resolution could, for instance, separate the source CYG X-1 from CYG X-3, or the radio galaxy M87 from the quasar 3C273. It was also believed that narrowing the opening aperture would help reduce the background counting rate, since the strength of a point source within the beam would be unaffected while the contribution from the diffuse radiation within the beam would go down in proportion to the solid angle. No attempt was made to improve the energy resolution over that of the previous instrument; the $13\%$ FWHM (at 511 kev) resolution of the CsI(Na) central crystal used was believed sufficient for the intended purposes.

A versatile new balloon-borne system was designed and constructed in an effort to improve the useful observing time
FIGURE 1 (see page 15)

Schematic diagram of the Gammascope IV-A Detector. The outer perimeter is an $\frac{1}{8}$-inch, pressure-tight, aluminum shell. Depths of shielding for the central crystal are (in units of gm cm$^{-2}$): NaI - 5, lead - 43, LiF - epoxy - 2, Pilot F plastic scintillator - 4, aluminum - 7, and miscellaneous - ~5.
gained from a single balloon flight. The system is capable of ~40 hours of continuous operation and can be controlled by radio command to acquire a new celestial object as the currently viewed object sinks below the "horizon" (usually defined as zenith angles, ZA, such that: sec ZA > 2.0). Thus as many as five separate candidate gamma-ray sources may be viewed in a single flight, for a potential improvement of five in useful observing time. Even for a more usual flight duration (~20 hours), a factor of over two can be gained.

The rationale behind the composite shield will now be described in more detail. One of the reasons for using active collimation material is that better shielding is provided when small weights of material are to be used. With GS IV it was decided not to include weight as a trade-off factor, hence the use of large amounts of very dense material, e.g., lead, was not excluded. A 1½-inch thickness of Pb will attenuate a 500 kev photon beam by a factor of over 600, while the 3-inch NaI thickness used in GS II has a corresponding factor of only about 13. Hence, on the basis of photon attenuation alone, GS IV was expected to be a much better collimator.

Such considerations are misleading; predictions based on partial analyses are at best inaccurate. As has been pointed out by many authors, (see e.g., Kreger and Mather, 1967) all aspects of the problem must be synthesized when a radiation detector is designed. Hence the lead shield should not be viewed just as an attenuator of γ-rays, but as a possible source of radiation as well. The cosmic rays will very predictably have just such an effect on lead.

It was realized that nuclear reactions in the lead would be initiated by the cosmic rays. Nuclear stars, spallation reactions, and nucleonic cascades could be expected to generate a wide range of particles and radiations. In an attempt
to remove these effects, an anticoincidence jacket of plastic scintillator was placed around the lead shield. Charged particles, in traversing 1 1/2 inches of plastic phosphor, will leave behind a detectable amount of their energy in the form of optical scintillations. GS IV would use the signal obtained from photomultiplier tubes viewing the Pilot F scintillator to reject simultaneously-occurring events within the central crystal.

With the use of large scintillator area, the count rate can be expected to be quite high. The geometric factor, $G_0$, which is a measure of the area presented to an isotropic flux, can be written $G_0 = \frac{1}{4} DH \left[ 1 + \frac{D}{2H} \right]$, for a cylinder of diameter $D$ and height $H$. If the flux of charged particles is taken to be one per cm$^2$, then the count rate in the plastic scintillator ($G_0 \sim 7 \times 10^4$ cm$^{-2}$) will be $\sim 7 \times 10^4$ sec$^{-1}$. If the "blanking time" (the period during which events occurring in the central crystal are rejected) could be made as short as half a microsecond, the "deadtime" (or fraction of actual time during which the central detector is turned off) would only be about 3%. Although events in the plastic itself decay in times on the order of 100 nanoseconds, as will be suggested later, a gating time of 500 nsec may be optimistically short; the effects of the detected particle may last considerably longer in the central crystal.

In the GS IV design, photons which escape the inner surface of the lead collimator must pass through a minimum thickness of one half inch of NaI. Pb K-X rays which might be expected to emerge in quantity as a result of interactions in the lead, are attenuated by four orders of magnitude in passing through the NaI shield. Photons of higher energies are, of course, less effectively rejected; more than half of those at 500 kev will escape undetected. However, only photons which emerge from the lead at times longer than 500 nsec after
the passage of the precipitating particle through the 
plastic can contribute to events measured in the central 
crystal. Most gammas emerging from the lead were expected 
to be "prompt", i.e., occurring at times shorter than ½μsec.

Another troublesome component of the balloon-altitude 
radiation environment is the neutron. RUG-RAG experience 
with GS II has demonstrated that inelastic neutron scatter can 
contribute significantly to the γ-ray count rate, through 
reactions like $^{127}$I(n,n'γ). The plastic shield of GS IV 
was expected to help thermalize neutrons so that they would 
be captured in the LiF epoxy layer of the detector, through 
the reaction: $^{6}$Li + n → $^{4}$He + $^{3}$H. Though $^{6}$Li is only 7.4% 
of the natural abundance of lithium, a half-inch thickness 
of the LiF-epoxy was expected to reduce a beam of thermal 
neutrons by a factor of ten.

This concludes the discussion of the design objectives 
which were set down in the preliminary design stage. Unfortu-
nately this phase of the work was done with a haste which 
precluded a more thorough analysis of the implications of 
the proposed design; it might have been possible to have 
avoided some of the problems, which in retrospect seem almost 
obvious, had more time been available.
V. THE PERFORMANCE OF GAMMASCOPE IV

Data on the performance of the new telescope were collected over a period of approximately 12 months. The completed balloon-borne system was flown twice (see appendix A3) and remained aloft for a total time of about 23 hours, most of which was spent at pressure altitudes of about 4 millibars. While the time available for observing the sea level response was ample, and that for observing the float-altitude characteristics, adequate, the time spent during ascent was not long enough to yield much useful information. For studies within the atmosphere, a rate of rise considerably slower than the 1000 ft sec\(^{-1}\) rate typically used would be needed. Appendix A1 describes the operation of the telescope in more detail, but the basic data obtained are count rates versus pulse height of events which occur in the central CsI(Na) crystal and are not accompanied by events in either the plastic or the NaI anticoincidence shields.

A. Sea Level Data

Extensive calibration is a necessary part of the development of a new detector. Some properties must actually be measured, while others may be estimated with the required precision from theoretical calculations. The relative angular response of the telescope to a source of gamma radiation as a function of the off-axis angle of the source position was determined in the laboratory using the radioisotopes indicated in Table I. The details of this calibration are given in appendix A1. Figure 2 shows the results for 60 keV photons, and the measured HWHM values at several other energies are indicated in Table I.

The energy resolution of the Harshaw integral-line assembly central detector was also measured in the laboratory. Table I also indicates the results of this determination.
<table>
<thead>
<tr>
<th>ISOTOPE</th>
<th>HALF-LIFE</th>
<th>GAMMA-RAY ENERGY</th>
<th>GS IV HWHM</th>
<th>GS IV FLIGHT 1970-2</th>
<th>CHANNEL NUMBER OF PHOTOPEAK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am²⁴¹</td>
<td>458 d</td>
<td>26 keV</td>
<td>1.8 ± 0.2</td>
<td>43 ± 3</td>
<td>9.9 ± 0.5</td>
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<tr>
<td>Ba¹³³</td>
<td>7.2 y</td>
<td>31</td>
<td>2.0 ± 0.1</td>
<td>20 ± 2</td>
<td>25.2 ± 0.5</td>
</tr>
<tr>
<td>Cs¹³⁷</td>
<td>30 y</td>
<td>32</td>
<td>2.0 ± 0.2</td>
<td>14.4 ± 0.6</td>
<td>82 ± 2</td>
</tr>
<tr>
<td>Am²⁴¹</td>
<td>458 d</td>
<td>80</td>
<td>2.2 ± 0.1</td>
<td>13.5 ± 0.5</td>
<td>106 ± 1</td>
</tr>
<tr>
<td>Cd¹⁰⁹</td>
<td>453 d</td>
<td>29 ± 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co⁵⁷</td>
<td>270 d</td>
<td>122</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Se⁷⁵</td>
<td>120 d</td>
<td>(121)136*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Se⁷⁵</td>
<td>120 d</td>
<td>265(280)*</td>
<td>2.1 ± 0.1</td>
<td>17 ± 1</td>
<td>54.0 ± 0.5</td>
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<tr>
<td>Ba¹³³</td>
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<td>359</td>
<td></td>
<td></td>
<td>72.5 ± 0.5</td>
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<tr>
<td>Sn¹¹³</td>
<td>118 d</td>
<td>393</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Se⁷⁵</td>
<td>120 d</td>
<td>401</td>
<td>2.0 ± 0.2</td>
<td>14.4 ± 0.6</td>
<td>82 ± 2</td>
</tr>
<tr>
<td>Na²²²</td>
<td>2.6 y</td>
<td>511</td>
<td>2.2 ± 0.1</td>
<td>13.5 ± 0.5</td>
<td>106 ± 1</td>
</tr>
<tr>
<td>Cs¹³⁷</td>
<td>30 y</td>
<td>662</td>
<td></td>
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<td>Mn⁵⁴</td>
<td>303 d</td>
<td>835</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* a peak at the parenthesized energy (at about 1/3 the intensity) causes the main peak to appear asymmetric

# Lederer, et al. (1967)
FIGURE 2 (see page 22)

Response of the Gammascope IV detector to a point source of monoenergetic gamma radiation. The data were taken in the laboratory using an Am$^{241}$ radioisotope placed at a distance 21 meters. The zero point of the abscissa is arbitrary; "on-axis" actually occurs at an abscissa value of \(-0.5\) degrees.
ANGULAR RESPONSE OF THE GAMMASCOPE IV DETECTOR TO 60-keV PHOTONS

FIGURE 2
Indicated with these results in figure 3 is the approximate inverse square root dependence of the resolution upon the energy. The $E^{-\frac{1}{2}}$ dependence comes about purely from counting statistics. The deposition of an energy $E$ in the crystal results in the production of $N$ photoelectrons. The uncertainty in the number of electrons is proportional to $\sqrt{N}$, while the number itself is approximately proportional to the energy. The finite resolution comes about as a result of the uncertainty in $N$. The percentage resolution, $R$, may be represented as $R \propto \frac{\Delta E}{E}$; and since $E \propto N$ and $\Delta E \propto \sqrt{N}$, then $R \propto \frac{\sqrt{N}}{N} = \frac{1}{\sqrt{N}} = \frac{1}{\sqrt{E}}$.

The diagram of the telescope (figure 1) shows that there is little material in the actual acceptance cone of the detector. Since the mass is uniform and had been measured, it was thought unnecessary to measure an instrumental absorption factor (e.g., after the fashion of Fishman, 1967). The correction was obtained using the measured thickness (0.119 cm, Al; 0.635 cm, NE 102 phosphor) in the well-verified exponential absorption law. Other corrections required to convert count rates to absolute fluxes, i.e., photofraction, efficiency, and X-ray escape, are available in the literature and need not be determined experimentally.

In order to determine the effectiveness of the composite shield, extensive "background" measurements were made. The gamma-radiation background is not a very well defined entity. The radiation environment at the surface of the earth varies greatly from place to place and may even show temporal variations at a given locality. Radioisotopes present in the earth's crust, in various building materials, and in the air have been shown to account for most of the variations. Radioactive fallout present in the air can influence the radiation measured by sensitive detectors. Gamma-ray counting rates,
Logarithmic plot of percent energy resolution versus energy for the CsI central detector. The data are given in column five of table I. Also indicated is the inverse square root dependence which is discussed in the text.
even at sea level, indicate a dependence upon geomagnetic latitude as a result of the variation in the cosmic-ray energy cut-off which is produced by the geomagnetic field.

Though absolute comparisons are difficult, relative measurements can be made. Figure 4 shows the effects of the anticoincidence circuitry on the background spectrum measured in the second-floor lab of the Rice Space Science Building. The lower curve was obtained with the entire anticoincidence system operative. The electronics for the anticoincidence circuitry were then disconnected from their power supplies, and another run was made with the physical components of the shield, as well as the orientation of the instrument, undisturbed. It is important, in conducting laboratory tests, to keep the detector orientation constant, since measurements have shown that the radiation field is typically not isotropic. Cosmic-ray interactions with uneven local mass concentrations, as well as the radioactive contaminants in the building materials, presumably account for the anisotropy.

In figure 5 another comparison is made. The spectra shown were taken in the Rice γ-ray spectrometer lab (see Adams [1964] for a description of the room), or "clean" room. The radiation in the clean room is more likely to remain stable as a result of the care taken in its construction. The top curve was obtained from the bare central crystal which had been physically removed from the composite shield. The middle curve shows the response of the central crystal to the radiation which emerges from the inner surface of the lead shield; the NaI guard crystals had been physically removed for this measurement which shows the lead K X ray at ~75 kev. Finally, the bottom curve is the spectrum obtained with the entire detector assembled and functioning in its normal mode. The turning up at the high energy end
Demonstration of the effects of the anticoincidence circuitry on the background spectrum measured in the laboratory. The upper curve was obtained with passive shielding only; the coincidence-rejection capability was disabled by turning off the anticoincidence circuitry. The lower curve resulted from a run made with the full circuitry operating. The effect of active shielding is to reduce the count rate.
Laboratory background spectra taken with different shield configurations. The upper curve was obtained from the central crystal while it was outside the shield and exposed directly to the ambient, room radiation. To obtain the middle curve, the NaI guard crystals were physically removed from the GS IV detector (see figure 1), and the central crystal was replaced in its normal position inside the shield. The lower curve resulted when the completely reassembled detector was operated in its normal mode. For a discussion of the upturn in the spectra at around channel 110 (not a real effect), see the text.
of these graphs is not a real effect. A slight non-linearity of the pulse height analysis was inadvertently introduced in an attempt to control the response of the analyser to very large pulses (energy losses much greater than 1 MeV). This effect was later removed and should not invalidate the present comparison particularly since it affected only the higher channels.
B. Ascent Data

Spectra taken during ascent suffer from the poor statistics inherent with short observing times, while the longer times needed to obtain smoother, more significant curves result in an average over a wide range of atmospheric depths.

Figure 6 shows several relevant count rates as a function of atmospheric depth. The Pfozter maximum is evident in all but one of the curves, which were obtained from the 1970-2 flight described in appendix A3. The various parameters shown are (from bottom to top of the graph):

1. "overflow counts" - isolated central crystal events which deposit more than the upper threshold energy,
2. "stored" (refers to treatment of this data by laboratory data analysis equipment) counts - all central crystal events which result in an energy loss between the upper and lower thresholds (34 to 622 kev for the flight shown) and are not rejected by the anti-coincidence circuitry,
3. "stored plus overflow counts" - all "bonafide" events detected in the central crystal (the sum of 1 and 2),
4. "reject counts" - all central crystal events rejected due to coincidence with guard crystal or plastic events,
5. "guard crystal counts" - derived from the ratemeter which monitored the NaI guard crystals,
6. "plastic counts" - derived from the ratemeter connected to the plastic shield electronics.

These data will be used in the next section to analyze the performance of the detector.
FIGURE 6 (see page 34)

Plot of several pertinent count rates versus atmospheric depth from the data of flight 1970-2. The various count rates are described in the text. The plastic scintillator threshold was changed (when the balloon was at an altitude of about 10 mb) in order to assess the effects of the plastic shield on the central detector count rate.
FIGURE 6

MEASURED COUNTING RATES VERSUS ATMOSPHERIC DEPTH FROM FLIGHT 1970-2
Shown in figure 7 are spectra obtained over 30 minute integration times. The altitudes at the median times are indicated.
Gamma radiation spectra taken at several atmospheric depths during the ascent phase of flight 1970-2. The accumulation times (hours, C.D.T.) and altitudes are indicated for each spectrum.
FIGURE 7

GS IV SPECTRA TAKEN AT SEVERAL ATMOSPHERIC DEPTHS

8:20 - 8:30  11 mb

7:50 - 8:00  33 mb

6:50 - 7:00  285 mb

6:20 - 6:30  805 mb

CHANNEL NUMBER

COUNTS PER 5 MINUTES

58 keV
135 keV
511 keV
C. Float Data

Figure 8 shows that the 1970-2 flight achieved float altitude at around 09:00 CDT. Shown with the pressure altitude (which was measured with a Metrophysics pressure transducer) are the stored count rate, overflow rate, reject rate, and plastic ratemeter. The changes in altitude which occurred at around 10:00 and 11:30 were the result of ballast-drop commands which were transmitted in an effort to make the balloon go higher. The balloon sank back down to depth of ~3.6 mb at about 12:30 and stayed there until termination.

The stored and overflow rates shown in the figure have been averaged over ~40 minute periods. This was done to achieve good statistical precision in the spectra so obtained. The spectra are shown in figure 9, which plots count rate against energy as determined from in-flight calibrations (see appendix A1 for a description of the calibrator and its use).

An extensive analysis of the float data was carried out to look for evidence of the detection of extraterrestrial gamma rays. Since only a slight dependence of count rate on pointing direction was found (see appendix A2), the data have been presented here without regard to actual orientation of the detector.

Spectral features are clearly evident in figure 9. There are pronounced peaks at 59 and 135 kev, as well as a more subdued one at around 510 kev. Structure is also evident at energies slightly above the 135 kev peak, in the range 140 to 200 kev. An explanation of these features will be sought in the next section.
FIGURE 8 (see page 40)

Count rates obtained during the float portion of flight 1970-2, shown as a function of time. Also indicated is the altitude of the balloon during the same time period.
Figure 8: Count rates and altitude versus time.

PLASTIC REJECT
OVFL STORED ALTIMETER

Counts per second

Time (hours, C.D.T.)

Altitude (m)
FIGURE 9 (see page 42)

Gamma-ray spectra obtained during flight 1970-2. The accumulation period (in C.D.T. hours) and altitude for each spectrum are indicated.
FIGURE 9

GAMMA-RAY SPECTRA OBTAINED DURING FLIGHT 1970-2

ENERGY (keV)

COUNTRIES PER HOUR

10:49 - 11:36 3.9 mb
0:30 - 9:16 3.9 mb
VI. INTERPRETATION OF THE PERFORMANCE

An analysis of the sea level performance of Gammascope IV reveals some unexpected departures from the design predictions. The composite shield is a very effective attenuator of gamma rays, better at lower energies than at higher ones. One might expect, therefore, that the background radiation measured with this instrument would exhibit a harder spectrum than the previous GS II detector. The apparent spectral hardening produced by lead shielding is graphically demonstrated by Kreger and Mather (1967) on page 91 in their article on "Background, Shielding, and Collimation". With such a hardening of the spectrum, a greater fraction of the total photons detected would fall above the "energy window" and be counted as overflows. Hence one would expect GS IV to measure a larger overflows-to-total-counts ratio than GS II. Such an effect is not observed; data taken at the NCAR Flight Station in Palestine, Texas, show overflows to be about 25% of the total count rate while a comparable figure for GS II was about 35%. A partial explanation for this effect may be found in Compton interactions. Photons which would otherwise have appeared as overflows may undergo Compton encounters, leaving an amount of energy which falls in the "energy window" of the analyser, and then escape through the guard crystal without being detected.

Another remarkable property of Gammascope IV may be attributed to Compton interactions. The most pronounced feature of all the GS IV background spectra (taken with the full anticoincidence circuitry working) is the low energy shelf which extends out to about 80 kev (see figures 4 and 5). The incident photons which cause this shelf cannot have energies equal to the energy losses represented in the shelf;
photons of such low energy could not penetrate the shield. Rather, the shelf may come about as follows. Higher energy photons undergo Compton collisions in the central crystal and lose between ~35 and ~80 kev of energy. (By the phrase "higher energy photons", photons of energies greater than ~115 kev are implied since photons less energetic than ~115 kev cannot deposit as much as 35 kev by a single Compton interaction.) After the initial encounter, they exit the central crystal without further interaction, either in the central crystal or in the guard crystals. The scattered photons can avoid interaction in the guard crystal either by passing through it or by being absorbed in the ~4 gm cm$^{-2}$ of radiationless material between the CsI and NaI crystals.

The mechanism described above could be checked with a theoretical calculation, but such a calculation would be difficult since it would involve not only the unknown incident photon spectrum, but also the kinematics of Compton collisions. Nelms (1953) has investigated the details of Compton interactions and has presented the results in graphical form, but the application of her results to the suggested calculation would probably require a Monte Carlo technique in order to provide an accurate representation of the physical processes involved.

The comparison of total counting rates between GS IV and GS II was disappointing. When allowance is made for the crystals' geometric factors, the GS IV rate of 1.5 sec$^{-1}$ is only down by 2½ from the GS II rate of 10 sec$^{-1}$. This is of course a very rough comparison; though the locality for both numbers quoted was Palestine, the GS II data were taken two years prior to the GS IV data.

The above considerations led to doubts about the flight performance even before the first trip through the Pfotzer
maximum. In reviewing the preliminary design arguments concerning the signal to noise ratio, it was realized that these arguments had been misleading.

In measurements of the type GS IV was intended to make, the statistical errors determine the sensitivity. The extraction of a net counting rate $S$ from two different rates, $B$ and $T = B + S$, results in an uncertainty or standard deviation of $\sigma = \sqrt{T + B}$. The sensitivity of such a measurement is proportional to chi, where $\chi = \frac{S}{\sigma}$. This ratio reduces to $\frac{S}{\sqrt{S + 2B}}$, where the symbols $S$ and $B$ are used to suggest source and background count rates. In astronomical observations, the source flux may usually be expected to be a constant parameter, but the source count rate may be varied by changing the area presented to the flux. The background counting rate obviously depends upon the instrument used. Applying this analysis to a comparison of GS IV with GS II yields a smaller improvement factor than was claimed in section IV. If $S$ is taken to be 2 and $B$, 10, in units of counts per second (typical GS II numbers for viewing the Crab Nebula) for Gammascope II, then improving the signal to noise ratio by 25 (while dividing the detection area and hence $S$ by four) will result in values of $B = 0.1$, $S = 0.5$, for GS IV. A calculation of the chi yields 0.43 and 0.60 for II and IV respectively. By this comparison, the improvement is a mere 1.4.

The ascent data of figure 6 show that all active components of the detector were functioning; the curves (with the exception of NaI ratemeter) exhibit the Pfotzer maximum and then fall off toward the top of the atmosphere. The fact that the reject rate exhibits this behavior is an indication that the anticoincidence circuitry functioned properly. The relative changes in the total count rate (stored plus overflows), up by a factor of about 25 from sea level to the
Pfotzer, and then down by a factor of about 10% from Pfotzer to float, reveal GS IV to be less effective than GS II. In going from sea level to the Pfotzer maximum, GS II experienced about a ten-fold increase which was followed by a factor-of-four decrease as float altitude was attained.

It was noted above that the guard crystal count rate did not show the expected behavior. While the plastic was responding to the ambient atmospheric radiation, i.e., it exhibited a Pfotzer maximum and then declined to a constant float value just as is observed for atmospheric radiation, the NaI apparently was not since it did not reach its greatest value until float altitude was attained. Figure 10 reproduces a portion of the data record for the NaI ratemeter. This ratemeter is monitored by a data-commutator for about 11 seconds every five minutes. The sporadic spikes in the record, which indicate the occurrence of very large events in the guard crystal, are suggestive of cascades (either photon-electron of nucleonic) in the 43 gm cm$^{-2}$ of lead. Such large events will undoubtedly be of longer duration than the ¼ - μsec blanking time of the reject circuitry and will consequently be assured of contributing at least one "bonafide" count in the central crystal. In fact, there is evidence for short periods of unusually high count rates; six counts occurred during one seven millisecond period, which gives an improbable 857 sec$^{-1}$ rate.

The guard crystal behavior suggests an interpretation based on interactions between the lead shield and the cosmic-ray beam, in particular, the nucleonic component, which is most intense at the top of the atmosphere, or the photon-electron component. A photon-electron cascade could be initiated in the lead by an energetic gamma ray which passed through the plastic scintillator undetected. Upon striking the lead, the photon would undergo pair production,
and a cascade would follow. The end effect could be a net production of low-energy gamma rays in the lead shield; a Monte Carlo calculation would answer the question of whether the lead is an absorber or a net source of gamma rays. Other experimenters (e.g., Kurfess [1971]) have had experiences with lead, but their results (when they are reported) are not conclusive on this question, and the different geometries and techniques employed prohibit fruitful comparisons with Gammascope IV. A treatment borrowed from the study of cosmic rays, however, does shed some light on the question of shielding versus production.

The concept of "radiation length" is a useful one for the study of cosmic-ray showers. This length is the depth of material an electron traverses before giving up $1 - e^{-1}$ of its initial energy as radiation. The number of shower particles, both electrons and photons, will increase from one (the initiating particle) to a maximum number at some depth within the material. The location of this maximum depends both upon the type of material in which the shower occurs and upon the energy of the incident particle. The same concept may be applied to photons, though a photon travels, on the average, slightly further than a radiation length before producing a positron-electron pair.

The GS IV lead shield has a depth of ~43 gm cm$^{-2}$, which is about 7 radiation lengths, since the radiation length for lead is about 6 (Rossi [1952]). A simplified shower model (see Galbraith [1958]) predicts the maximum number of shower particles to occur at $t_{\text{max}} \sim \ln \frac{E_0}{\epsilon_c}$, where $t_{\text{max}}$ is measured in radiation lengths, $E_0$ is the initial particle energy, and $\epsilon_c$ is the "critical energy" for the material (that energy at which ionization losses equal radiation losses for electrons). If one uses the observed $t_{\text{max}}$ in the atmosphere to infer the effective energy of the initiating particles responsible for
atmospheric showers, then $t_{\text{max}} \sim 3$ in air implies a $t_{\text{max}}$ of about 5 in lead. Hence the same particles which create the Pfotzer maximum in the atmosphere will create a shower maximum $5/7$ of the way through the GS IV shield. Though the remaining two radiation lengths of shielding will reduce the intensity somewhat from its maximum value, the net effect of the shield will probably be to multiply the particle flux by about an order of magnitude.

This development, however, is for large cascade events and is not a continuous process. That the rate of occurrence of such showers is low can be seen from figure 10. If the large spikes in the data record are interpreted as cascades, a rate of about $\frac{1}{2}$ cascade per second is indicated. (Taking a "spike" to be an instantaneous reading greater than 100,000 counts per second, 30 such events occur in the seven 11-second data segments shown.) Even if each shower contributed two or three "bonafide" counts, this effect would only amount to one or two counts per second, or less than seven percent of the total background count rate. Such electron-photon shower activity was probably not detrimental to the performance of GS IV, particularly since initiating charged particles were detected by the plastic anticoincidence jacket.

Another related effect can be treated through the use of an "energy build-up" factor. For experiments employing passive shielding, the presence of scattering within the shield will modify the usual exponential absorption behavior. The flux of particles detected will actually be greater, due to scattered photons, by a factor $B$ which may be defined as:

$$B = \frac{I_d}{I_o e^{-\tau l}}$$

where $I_d$ is detected or observed flux, $I_o$ is the flux incident on the shield, $\tau$ is the attenuation factor (units of inverse length) for the shield, and $l$ is the shield thickness. Once a $B$ factor has been determined for a given energy, material,
FIGURE 10 (see page 50)

A portion of the data record for the NaI guard crystals' ratemeter. Since this device measures the product of pulse height and pulse duration, the count rate scale is only accurate for $\frac{1}{2}$-μsecond guard crystal events (a pulse width of $\frac{1}{2}$-μsec was used in the calibration). Long-duration events will result in anomalously high count rate readings.
Figure 10

NaI GUARD CRYSTALS RATEMETER

C.D.T. TIME

10^3 COUNTS / SEC

ON BOARD VOLTS

8:38 8:43 8:48 8:53 8:58 9:03 9:08
and geometry, it can be used to predict the detected flux from a known flux of incident radiation, i.e., \( I_d = B I_0 e^{-\mu d} \). Lead shields of the thickness employed in GS IV have a B-factor of about 2 for 500 kev photons. Hence the flux which penetrates the shield will be twice what would be predicted from the simple exponential-absorption law.

Figure 11 shows an attempt to explain the spectral features observed in the data obtained at float altitude. The histogram curve is a reproduction of the uppermost curve presented in figure 9. If a simple power law is fit to the data beyond 200 kev, a reasonably good fit is obtained, except in the region around 510 kev where a peak appears to be superimposed on the continuum. However, if this same power law (of \( \gamma \sim 0.5 \)) is extended to the lower energies, it lies well above the "trough" which is evident in the data at around 100 kev. The motivation for using a power law to describe the high end of the spectrum is that it is a good description and that power-law photon spectra have been shown (Puskin [1970]) to exist in the atmosphere as a result of Compton degradation of bremsstrahlung photons.

Yet the count rate is about two orders of magnitude higher than that expected from atmospheric photons coming through the aperture, (based on a comparison with the fluxes observed by GS II or with the calculations of Puskin); and the power law of such a fit to the GS IV data is much harder (spectral index, \( \gamma \sim 0.5 \)) than that found by Glenn (1969) (\( \gamma \sim 1.9 \)) from the Gammascope II data. This comparison suggests an origin for the observed photons in the Gammascope IV shield itself. Electron bremsstrahlung, followed by multiple Compton degradations of the photons, could generate a quasi-power-law spectrum in the lead (though the presence of nuclear \( \gamma \) rays might alter or even dominate the spectrum).
An observed float-altitude spectrum from flight 1970-2 (also shown as the top curve of figure 9) is shown by the histogram; the smooth curve represents an attenuated, power-law spectrum of the form: \( N(E) = AE^{-\gamma} \exp\left(-L \tau(E)\right) \), where \( E \) is the energy, \( A \) and \( \gamma \) are the usual power-law coefficients, \( L \) is the thickness of the attenuating medium (NaI), and \( \tau(E) \) is the energy-dependent attenuation coefficient of NaI (see figure 13). The horizontal dashes are the resulting spectrum obtained by subtracting the smooth curve from the histogram.
Figure 11

Float-Altitude Spectrum

Counts per 300 Seconds

Energy (keV)
If such a shield-generated power law is assumed, and if the attenuation of these photons by the NaI guard crystal is folded in, then a spectral index of $\gamma \approx 1.5$ is obtained for the resulting spectrum which is indicated by the smooth curve in figure 11.

A description of the observed spectrum by this power law ($\gamma \approx 1.5$), attenuated by the NaI, removes the difficulty of the observed curve falling below the fit. If the smooth curve is subtracted from the histogram of the figure, the residual (shown with horizontal dashes) is very suggestive of an interpretation based upon positron annihilation and nuclear deexcitation lines. (Note that below energies of ~100 kev, in the figure, the residual curve and the histogram are indistinguishable.)

The 511 kev radiation presumably originates largely in the shield; atmospheric photons coming through the aperture of the telescope are expected to contribute less than one percent of the observed count rate in this energy region (based on Glenn's [1969] measurements of the absolute atmospheric gamma-ray flux.) The fact that this peak appears slightly broader than the instrumental resolution may be due to positrons not annihilating at rest. Glenn (1967) discusses a broad atmosphere feature at an energy of 490 kev, but the feature seen with GS IV is definitely centered on 511 and not 490 kev. (The energy calibrator flown on GS IV makes the conversion from channel number to energy more certain than that possible with GS II.) The results of Womack and Overbeck (1968) support the interpretation based on annihilation radiation and also suggest an interpretation of the other features in terms of neutron interactions.

In their search for spectral line emissions from the sun, Womack and Overbeck employed an actively-shielded
solid-state detector. Though they observed a rich spectrum of gamma-ray lines, almost all of these lines were attributed to neutron interactions with the Ge(Li) detector. Shafroth (1967) has treated the response of NaI crystals to both thermal and fast neutrons; and much of his findings is applicable to CsI as well, since the pulse height spectra observed in the crystals were largely attributable to iodine reactions.

Dyer and Morfill (1971) have considered spallation reactions induced in CsI detectors by incident protons in the 100 MeV region. While such reactions will undoubtedly occur in Gammascope IV, most spallations are expected to occur in the greater mass of the shielding material. Any effects generated within the central crystal itself would probably be obscured by the high background rate from other sources.

In the analysis which follows, candidate nuclei were restricted to $^{127}$I and $^{133}$Cs; and candidate reactions, to (n, n'γ) and (n,γ). Since the energy resolution of CsI(Na) limits the certainty with which gammas lines can be identified, and since a plausible explanation on this basis is obtained, no further sources or reactions were included in the analysis.

A knowledge of the nuclear level structure of the nuclei involved is essential for an understanding of the spectra produced. For $^{127}$I, the lowest levels (see figure 12) are at 58 kev and 203 kev; for $^{133}$Cs, 81 and 161 kev states lie lowest. These lowest lying levels will be important for the inelastic neutron scatter reactions in which the incident neutron loses energy to the excitation of the struck nucleus.

The level structure of $^{128}$I is not well known because the excited states decay to the ground state nearly instantaneously following the neutron capture and because there is
FIGURE 12 (see page 57)

Only the ground states and first two excited states for each isotope are indicated; see Lederer, et al. (1967) for complete level structure.
SIMPLIFIED NUCLEAR LEVELS DIAGRAM

FIGURE 12
apparently a rich density of low lying states. Studies of the lifetimes of these states (Korteling et al., 1969; DuToit and Bollinger, 1961) have shown a gamma line at 133 kev to be the most intense, probably because of the existence of a nuclear level of this energy above the ground state. This much is fairly well established: the most intense (by a factor of 5 or more) line emission from $^{127}$ (n,$\gamma$)$^{128}$ is at 133.3 ± 0.1 kev (Korteling et al., 1969).

Most of the gamma-ray emissions from the capture reaction on Cs$^{133}$ are near-instantaneous, making it difficult to deduce the level structure of Cs$^{134}$. Fairly intense lines at 116 and 176 kev have been observed (Korteling et al. [1969]) to have half-lives in the tens-of-nanosecond range, but so far no identification of the nuclear states involved has been possible. A relatively strong line at 130 kev also is observed but has a half-life too short to measure with current techniques. While these and the other lines listed in table II are prompt emissions, a metastable state with a very long half-life does give rise to delayed emissions from the capture reaction. Cs$^{134m}$ apparently owes its existence to the fact that electric dipole and quadrupole radiation, as well as the first three orders of magnetic multipole radiation, is "forbidden".

The nuclear levels of Cs$^{134m}$ are also shown in figure 12. The metastable state at 138 kev decays only very rarely in a direct M4 transition to the ground state. The predominant line is the 127 kev E3 transition to the first excited state, which is followed by an M1 transition to the ground state (resulting in a 10 kev photon). Hence the gamma spectrum expected from Cs$^{134m}$ (IT,$\gamma$)Cs$^{134}$ is composed of a single line, at 127 kev, which has an observable temporal behavior associated with it since the half-life of Cs$^{134m}$ is 2.9 hours.
The \((n,n'\gamma)\) reaction has the property that gamma lines above the energy of the incident neutrons are strictly prohibited. Thus the appearance of a peak at 59 kev and not at 203 kev from \(^{127}\text{I} (n,n'\gamma)\) implies a sharp "cutoff" or very soft neutron flux.

Capture reactions will compete for such a flux; the cross section for \(^{127}\text{I} (n,\gamma)\) is 0.43 barns \((E_n = 0.1 \text{ MeV})\) (Shafroth [1967]) while the inelastic scatter cross section is 0.30 barns. Hence what one would expect to see from the bombardment of \(^{127}\text{I}\) with 0.1 MeV neutrons would be approximately equal to 59 and 133 kev peaks, from the scatter and capture reactions respectively. (The 25-min \(\beta\)-activity of \(^{128}\text{I}\) would be superimposed on the line structure.)

Though measurements of inelastic neutrons scattering on \(^{133}\text{Cs}\) have apparently not been made, the well-known level structure of \(^{133}\text{Cs}\) leads one to expect 80 kev to be the first strong line observed from such a reaction. The absence of any pronounced 80 kev feature in the GS IV data leads to the conclusion that the \((n,n'\gamma)\) reaction on \(^{133}\text{Cs}\) does not contribute to the spectrum observed by GS IV, probably because of a low excitation cross section relative to iodine.

In this interpretation, a soft neutron flux (with a "cutoff" below \(-0.2 \text{ MeV}\)) incident on the central CsI crystal is responsible for the lines in the observed spectrum. The peak at 59 kev is due to the reaction \(^{127}\text{I} (n,n'\gamma)\). The feature at \(-135\) kev is due largely to the \(^{127}\text{I} (n,\gamma)\) reaction, possibly with some admixture of radiation from \(^{133}\text{Cs} (n,\gamma)\)\(^{134}\text{Cs}\). The broad feature in the 150-200 kev range is not sufficiently distinct to justify an interpretation, but both \(^{127}\text{I} (n,\gamma)\)\(^{128}\text{I}\) and \(^{133}\text{Cs} (n,\gamma)\)\(^{134}\text{Cs}\) have lines in this region (see table II).

It is interesting to compare the relative intensities predicted from the above interpretation with those actually
### Table II

**Gamma-ray Line Emissions from Cesium Iodide**

### Inelastic Neutron Scatter Reactions

<table>
<thead>
<tr>
<th>Energy</th>
<th>Relative Intensity</th>
<th>Cross Section</th>
<th>Energy</th>
<th>Relative Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>58 keV</td>
<td>strongest observed</td>
<td>0.3 ± 0.05 barns at $E_n = 0.4$ MeV</td>
<td>54 keV (should be strongest)</td>
<td></td>
</tr>
<tr>
<td>145</td>
<td></td>
<td></td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>172</td>
<td>2nd strongest</td>
<td>0.31 ± 0.08 barns at $E_n = 0.65$ MeV</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>203</td>
<td></td>
<td></td>
<td>276</td>
<td></td>
</tr>
<tr>
<td>214</td>
<td></td>
<td></td>
<td>303</td>
<td></td>
</tr>
<tr>
<td>360</td>
<td></td>
<td></td>
<td>356</td>
<td></td>
</tr>
<tr>
<td>375</td>
<td></td>
<td></td>
<td>382</td>
<td></td>
</tr>
<tr>
<td>417</td>
<td>3rd strongest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>441</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Neutron Capture Reactions

<table>
<thead>
<tr>
<th>Energy</th>
<th>Relative Intensity</th>
<th>Cross Section</th>
<th>Energy</th>
<th>Relative Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>124 keV</td>
<td>5</td>
<td>0.43 barns at $E_n = 0.1$ MeV</td>
<td>60 keV</td>
<td>5</td>
</tr>
<tr>
<td>133</td>
<td>42</td>
<td></td>
<td>116</td>
<td>156 (sum of 4 lines)</td>
</tr>
<tr>
<td>142</td>
<td>4</td>
<td></td>
<td>127</td>
<td>weak prompt - 2.9 hr half-life for</td>
</tr>
<tr>
<td>147</td>
<td>3</td>
<td></td>
<td>130</td>
<td>55</td>
</tr>
<tr>
<td>153</td>
<td>6</td>
<td>25</td>
<td>176</td>
<td>100</td>
</tr>
<tr>
<td>156</td>
<td>4</td>
<td></td>
<td>186</td>
<td>18</td>
</tr>
<tr>
<td>160</td>
<td>8</td>
<td></td>
<td>198</td>
<td>52</td>
</tr>
<tr>
<td>193</td>
<td>5</td>
<td></td>
<td>205</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>211</td>
<td>11</td>
</tr>
</tbody>
</table>

1. Shafroth (1967)
2. Van Leof and Lind (1956)
3. deduced from $^{133}$Ba decay
observed, for the two peaks at 59 and 135 kev. The intensity of a particular gamma-ray line which has its origin in the interactions of a neutron beam with some material may be represented as:

\[ I_\gamma(\chi) = \frac{I_n \alpha_\gamma \sigma_\gamma}{\sigma_T} \left[ 1 - \exp(-\sigma_T N \chi) \right], \]

where \( I_\gamma(\chi) \) is the intensity of the gamma line at a distance \( \chi \) within the material, \( I_n \) is the incident flux of neutrons, \( \sigma_\gamma \) is the cross section for the neutron reaction which produces the particular gamma-ray line, \( \alpha_\gamma \) is the number of gamma rays produced per neutron interaction, \( \sigma_T \) is the total reaction cross section for all neutron interactions, and \( N \) is the number density of target particles with which the neutrons can react. From the above expression it is clear that the ratio of two gamma lines' intensities is equal to the ratio of their respective products of \( \alpha_\gamma \) times \( \sigma_\gamma \). The cross sections given in table II yield a ratio:

\[ \frac{\sigma_{59}}{\sigma_{135}} = 0.14 \pm 0.04, \]

where the errors, both on the cross sections and in the computed ratio, are to be interpreted as estimated uncertainties, and the assumed values of the \( \alpha \)'s are indicated. The intensity in the 59 kev peak was estimated graphically by subtracting the contribution of the Compton shelf which was observed at low energies in the laboratory (the float spectra also indicate the existence of this shelf). The result for the ratio of the intensities of the peaks is:

\[ \frac{I_{59}}{I_{135}} = 0.89 \pm 0.05, \]

where again the error is an estimated uncertainty. While the two ratios disagree by more than the uncertainties, they are certainly of the same order of magni-
tude. Though this comparison doesn't add much weight to the argument, it does show that the interpretation of the gamma-ray lines as due to neutron reactions is at least reasonable.

The flux of fast neutrons (energies ≥ 58 kev) required to produce the observed count rate in the 59 kev peak can be estimated. If the GS IV shield is assumed to be about 70% effective in thermalizing and subsequently absorbing incident fast neutrons, and if neutron production within the shield is ignored, then a value of about 5 neutrons cm\(^{-2}\)sec\(^{-1}\) is obtained. This may be compared with the observed flux of about 1 neutron cm\(^{-2}\)sec\(^{-1}\) which was inferred from the measurements of Haymes (1964). Hence a neutron flux about 5 times that which has been observed would be required to explain the GS IV float spectrum on the basis of ambient atmospheric neutrons. Presumably neutron production within the GS IV shield contributes a large fraction of the neutrons responsible for the observed gamma-ray lines.

It is difficult to draw any firm conclusions from the temporal behavior of the float data, but it can be seen from figure 8 and table III that there is a statistically significant general increase of the count rates with time. The fact that segment 4 has higher count rates than segment 1 or 2 is a further indication that the major response of the instrument was not to atmosphere gamma radiation. Since the intensity of atmospheric gamma rays decreases toward smaller residual depths, segment 4 which was taken at an average depth of 3.5 mb should show a lower rate than segments 1 or 2 when the balloon was deeper than 4 mb; just the opposite is observed.

Table III shows the percentage increase of segment 4 over segment 1, and of 7 over 4, broken down into seven categories. All columns of the table show a positive increase with time, but the 135 peak (and the 100 "trough") seem to
**TABLE III**

FRACTIONAL INCREASE VERSUS TIME FOR 3 FLOA-ALTITUDE SPECTRA (see Fig. 9)

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Period of accumulation</th>
<th>Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOA-1</td>
<td>08:30 - 09:16</td>
<td>3.9 mb.</td>
</tr>
<tr>
<td>FLOA-4</td>
<td>10:49 - 11:36</td>
<td>3.9 mb.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spectral feature</th>
<th>Ratio of FLOA-4 to FLOA-1</th>
<th>Ratio of FLOA-7 to FLOA-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>59 kev peak</td>
<td>1.06 ± .02</td>
<td>1.04 ± .02</td>
</tr>
<tr>
<td>100 kev &quot;trough&quot;</td>
<td>1.23 ± .05 (4.5 σ)*</td>
<td>1.04 ± .05</td>
</tr>
<tr>
<td>135 kev peak</td>
<td>1.28 ± .05 (5.5 σ)</td>
<td>1.14 ± .04 (3.5 σ)</td>
</tr>
<tr>
<td>250 - 390 kev continuum</td>
<td>1.07 ± .02 (3.5 σ)</td>
<td>1.03 ± .02</td>
</tr>
<tr>
<td>511 kev peak</td>
<td>1.05 ± .03</td>
<td>0.99 ± .03</td>
</tr>
<tr>
<td>&quot;stored&quot;</td>
<td>1.06 ± .01 (6.0 σ)</td>
<td>1.03 ± .01</td>
</tr>
<tr>
<td>&quot;overflows&quot;</td>
<td>1.03 ± .01</td>
<td>1.00 ± .01</td>
</tr>
</tbody>
</table>

* attention is called to ratios which differ from 1.0 by a statistically significant amount (σ = standard deviation)
have a slightly enhanced increase which may be due to the build up of Cs\textsuperscript{134m} in the central crystal. The data are inconclusive.

It would have been interesting to monitor the sea level count rates and spectra as a function of time after the instrument had completed the flight to see if the detector had become activated. Such induced activity would exhibit a time behavior which might aid in the identification of the radio-nucleides responsible. Unfortunately, this was not possible for reasons mentioned in appendix A3.
VII. EVALUATION AND CONCLUSIONS

The analysis of the last section leads to the conclusion that the Gammascope IV detector did not fulfill its role as an astronomical telescope. The high background rate encountered at balloon altitudes together with the small surface area of the central detector made it difficult to extract a signal, even from one of the strongest objects in the sky, the Crab Nebula. Virtually all of the observed gamma radiation was produced by neutron and cosmic-ray interactions within the detector; less than 2% of the observed count rate was due to ambient atmospheric gamma rays.

The difficulty of the design seems to have been the large depth of material presented as a target for the cosmic ray beam. In fact, the 63 gm cm$^{-2}$ depth is not far from the atmospheric depth at which radiations in the atmosphere reach their maximum; i.e., Gammascope IV essentially had a built-in Pfotzer maximum. The ineffectiveness of the plastic anticoincidence circuitry at rejecting counts due to interactions in the shield is probably due to the short gating time used. Had an anticoincidence blanking time of considerably longer been used, the decrease in the number of central detector counts might have outweighed the increase in dead time. Yet in view of the presence in lead of such long-lived isomeric states as the 145 μsec level at 2.2 Mev (Alburger and Pryce [1954]), it may be the case that the dead time would increase to 100% before the longer-lived activities were eliminated by a longer blanking time. This question could feasibly be answered by the inclusion in the balloon-borne system of a command capability to change the gating time during a flight, but this has not been done and the question remains in doubt.

Another way of possibly improving the performance of the detector would have been to use iron instead of lead as the
principle component of the shield. This would have increased the linear dimensions somewhat (~15%) for the same depth of material, but the lower atomic number of Fe would have meant fewer neutrons produced by nucleonic cascades in the shield (Kreger and Mather [1967]). Also, the use of a considerably greater depth of dense material might have helped. Instead of the secondary production reaching a peak value near the inner surface of the shield, if the shield were two or three times as thick, the production would fall off considerably just as it does in the atmosphere at lower altitudes. The difficulty with this approach is that such a detector would probably be too heavy to be flown on currently reliable balloons; but with the perfection of 50 x 10^6 cu.ft. balloons (GS IV used a 15 x 10^6 cu.ft.) it is not entirely unreasonable to consider such an approach.

Although an effective thermal neutron shield was included in the GS IV design, it would probably have been more useful had it been inserted between the lead and the NaI guard crystals. A radiationless absorber like lithium, together with a layer of neutron thermalizer just outside it, would reduce the neutron problem considerably if located inside the lead, whereas it was probably of little help in the GS IV configuration.

As indicated early in section VI, the use of a small area central detector was not a good idea. For small signal to noise ratios, and other things being equal, the sensitivity varies directly as the surface area and only as the square root of the noise: hence the background would have to be decreased by 16 to achieve the same improvement as obtained with a detection area only four times larger.

Another weak point of the GS IV design was the use of such a thin NaI guard crystal. (The good Compton photon suppression achieved with the GS II design is the result of
the 2.5 mean-path-length [at 500 kev] guard crystal thickness.) The selection of guard crystal thickness might well be based on an extensive theoretical calculation of the expected properties of anticoincidence mantles of various thicknesses. Certainly the problem experienced at the low end of the GS IV energy window dictates the use of thicknesses considerably greater than one-half inch.

In view of the results obtained with Gammascope IV, it seems that the more popular designs employing exclusively active shielding remain the best alternative. The quest for more sensitive instruments should be directed toward increasing the effective detection areas as much as possible while still retaining some shielding from the ambient background. Extremes like the design of Kurfess (1971) are useful for unique objects like pulsar NP 0532, but probably will not be of general use for randomly-emitting sources. In the design of larger actively shielded detectors, it is important to recognize not only the contribution of neutrons to the background radiation, but also the effects of cosmic ray interactions both with the guard crystal and with the central detector. Experiments designed specifically to investigate these problems may be necessary to define unambiguously the relative contributions of the various effects.

While the Gammascope IV detector performance may have been a disappointment, the balloon-borne system was an unqualified success. All of the intended design goals were met in the implementation of this potentially valuable astronomical platform. The exploitation of this potential was indeed accomplished, by the plan described in appendix A4. The result was a highly successful, triple observation from a single southern hemisphere flight conducted in November 1970. The results of this experiment will be presented elsewhere.
A1. THE CONSTRUCTION OF GAMMASCOPE IV-A

The translation of the design shown in figure 1 into a physical reality was accomplished in about six months. With the exception of the scintillation crystals and the plastic phosphor sections, the entire detector was fabricated in the Rice University Space Science Facilities. A description of the instrument, from the inside outward, follows.

The central detector is a special integral-line assembly made by the Harshaw Chemical Company of Cleveland. It consists of a 2-inch diameter by 2-inch thick crystal of CsI(Na) which is viewed by an RCA 8053 photomultiplier tube (2-inch photocathode). CsI(Na) is quite similar to NaI(Tl) in its optical properties and has the added qualities of being physically more sturdy and non-deliquescent. Its detection efficiency is slightly better than that of NaI(Tl) as can be seen from figure 13 which shows the total attenuation coefficients for CsI and NaI. The CsI crystal is oriented in Gammascope IV with the phototube behind it so that the only material on the aperture side is a 0.010 inch sheet of aluminum and a \( \frac{1}{16} \) -inch layer of packed MgO powder.

The NaI(Tl) guard crystals were also fabricated by Harshaw. The forty-inch length of NaI called for in the design was built in two sections. The front guard crystal is a 17-inch long anulus of \( 2\frac{1}{16} \) -inch I.D. and 4-inch O.D. It is optically coupled at the front end to a 5-inch diameter by a \( \frac{3}{4} \)-inch thick piece of Ne 102 plastic scintillator which provides charged particle rejection in the forward direction. Six RCA 4516 phototubes (\( \frac{1}{2} \)-diameter photocathode) view the plastic and forward NaI section simultaneously through the six optical windows on the front face of the plastic.

The rear crystal has the same cross section as the front
Total attenuation coefficients for CsI (heavy, solid line) and NaI (dashed line) are plotted versus photon energy. The relative contributions of Compton, photoelectric, and pair production processes are indicated for CsI. The data for NaI are from National Bureau of Standards Circular No. 583; those for CsI, from *Gamma-ray absorption coefficients for elements 1 through 100* derived from theoretical values of the National Bureau of Standards, LASL-2237, by E. Storm, E. Gilbert, and H. Israel. Conversion of the coefficients to range (in units of gm cm\(^{-2}\)) can be accomplished using the densities: NaI - 3.67 gm cm\(^{-3}\) and CsI - 4.51 gm cm\(^{-3}\).
TOTAL ATTENUATION COEFFICIENTS
FOR CsI AND NaI

τ (cm⁻¹)

ENERGY - MEV

FIGURE 13
but is optically joined to a $\frac{3}{4}$-inch diameter by $\frac{1}{4}$-inch thick slab of NaI which closes the rear end of the shield. A pyrex glass optical window provides for the viewing of the entire 23-inch length and the end face with a single RCA 8054 phototube. A $\frac{3}{4}$-inch hole through the rear anulus provides a path for the high-voltage-in and signal-out cables to the central crystal. The entire Harshaw assembly slides into a $4\frac{1}{16}$-inch I.D. aluminum tube which lines the inner surface of the lead.

The lead shield was constructed in four sections which were machined and bored from cylindrical ingots cast by the Nelco Company of Houston. Through the use of ultrasonic techniques, the uniformity of the lead ingots was tested and verified. The completed shield (of $7\frac{1}{2}$-inch maximum diameter) was mounted inside the LiF-epoxy shell using $\frac{1}{4}$-inch thick phenalic spacers, with the interstitial spaces filled with polystyrene foam. Copper tubes were used to provide access paths for the electrical cables to the Harshaw assembly.

Concentric aluminum pipes of outer diameters, 9 and $8\frac{1}{2}$ inches, with $\frac{1}{8}$-inch thick walls, were used as a mold for the LiF-epoxy shell which was poured using the substance described in table IV. When cured, the LiF epoxy mixture can be machined to close tolerances and is quite strong. (Several hard hammer blows are required to crack a $\frac{1}{4}$-inch thick piece.) The recipe of table IV was arrived at after extensive testing which showed it to have the maximum LiF content consistent with good pouring qualities and good structural strength.

The Pilot F scintillator, manufactured by the Pilot Chemical Division of New England Nuclear, Boston, was cast in two similar pieces which form a right-cylindrical shell, of length 48 inches, O.D. 12 inches, and wall-thickness, $1\frac{1}{2}$ inches. The two well-shaped annuli are identical except
TABLE IV

RECIPE FOR LiF-EPOXY

Ingredients (All chemicals produced by Dow)

256 gm. D.E.R. 334 - Epoxy resin
25.6 gm. BUTYL GLYCIDYL ETHER - Reactive dilugent
37.2 gm. D.E.H. - Epoxy curing agent
486 gm. LiF powder

To make about one pint of LiF-epoxy:

Mix all ingredients thoroughly (e.g., in a paint bucket with an electric drill). Place* mixture in a vacuum chamber until all bubbles have disappeared. Pour mixture gently (to avoid introducing new air bubbles) into mold and allow to cure for several hours.

The finished product has a LiF content of ~1.1 gm cm\(^{-3}\) as compared with a density of ~1.2 gm cm\(^{-3}\) for tightly packed pure LiF powder. The product, which has a total density of ~1.8 gm cm\(^{-3}\), is fairly strong and can be machined to close tolerances.

*Non-vacuum-pumped samples were found to contain (when smashed open with a hammer) \(\frac{1}{16}\) to \(\frac{1}{8}\) inch air pockets. Diligently pumped samples had no visible bubbles.
for the 5-inch hole cut in the end face of the front section to provide the telescope aperture. Each section is viewed by four RCA 8054 phototubes which are optically coupled to viewing windows on the end face circumferences.

Completing the detector structure is the outer shell which was fabricated from a large aluminum pipe of 12-inch I.D. by \( \frac{3}{8} \)-inch wall thickness and length of 52 inches. The outside was turned down on a lathe to a \( \frac{3}{16} \)-inch thickness except for a \( \frac{1}{4} \)-inch long band at each end and four 4-inch bands near the center. The center bands provided reinforcement around the mounting brackets and the end bands provided for drilled and tapped holes with which to mount the end plates. After it had been turned down, the pipe was split in half longitudinally with a milling machine, and \( \frac{5}{8} \)-inch by \( \frac{5}{8} \)-inch cross-section flanges were welded to each of the four longitudinal edges. After the inner components of the shield had been assembled, the two halves of the outer shell were fitted around them and bolted together with the use of a \( \frac{1}{16} \)-inch thick, gum rubber, flat gasket to provide a pressure seal. The 14-inch diameter, \( \frac{1}{4} \)-inch thick end plates were then bolted (through flat gaskets) to the ends of the shell. Cylindrical end cans, 6\( \frac{1}{2} \) inches tall by 14 inch diameter, completed the pressure seal when they were bolted to the end plates with the use of "0"-rings. Hence the outer shell provided an air-tight enclosure (maintained at atmospheric pressure) which housed the entire detector, including all high-voltage power supplies and photomultiplier tubes, thereby eliminating any chances of high voltage arcing, or corona, in a low pressure atmosphere. The normal end can thickness of \( \frac{1}{8} \)-inch was reduced to 0.032 inches over that portion of the front end can which was within the field of view of the detector. This meant a total depth of material within the detector beam of 0.32 gm cm\(^{-2}\), Al, and 0.98 gm cm\(^{-2}\), NE 102
FIGURE 14 (see page 75)

Range of several types of particles in various materials as a function of particle energy. Sources of the data are indicated in the upper left corner of the figure.
RANGE IN GM/CM²

PHOTONS

In Pb
1 - 5000 Mev
0.3 - 1 Mev

In Cu
4 - 5000 Mev
1 - 4 Mev

In Al
1 - 1000 Mev
1 - 75 Mev

In air
15 - 1000 Mev
1.5 - 15 Mev

In paraffin
15 - 1000 Mev
0.0075 - 0.015 Mev

ALPHAS

In air
1 - 1000 Mev
0.1 - 1 Mev

ELECTRONS

In Al
Penetration Range
0.01 - 20 Mev Kats and Peacock, Rev. Modern Phys. 22, 28 (1950)
1 - 10 Mev J. R. Young, J. Appl. Phys. 22, 1 (1951)
Integrated Range
Arn T. Melan, Rev. Modern Phys. 37 (1950)

Compiled from data in Handbook of Chemistry and Physics, 22nd Edition, and
Gladys R. White, RMI Report No. 1003 (1952) as reproduced in
Radiological Health Handbook, A. Giamma, ed. (1953)

FIGURE 14
plastic phosphor, which is only a slight addition to the 3 to 4 gm cm\(^{-2}\) of residual atmosphere encountered at balloon altitudes.

The pulse height analyzer (PHA; described below) was contained in a separate pressure-tight box which was attached to the outer-shell near the rear end of the detector. A solenoid-activated energy calibrator was also attached to the outside of the front end can. When commanded on, the calibrator moved a Cd\(^{109}\) radioisotope into the field of view, and when an "off" command was received, a spring forced the source back to its stowed position from which virtually no photons could reach the central crystal.

The weight of the entire detector, as described above, is about 650 pounds.

The 128-channel PHA used to analyze the photon energy-loss spectrum in the central crystal was designed and built at Rice and is shown schematically in the block diagram of figure 15. As shown in the diagram, the signals from the guard crystals and plastic shield are input to the anticoincidence circuitry along with the central crystal signal. If a coincidence is not found between the central signal and any of the other signals, the anticoincidence circuitry sends a pulse to the linear gate, thereby enabling the A to D converter to analyze the pulse which has occurred in the central crystal. The memory and buffer registers are provided to allow for the occurrence of as many as two additional counts during the ~1 millisecond interval required to send each count to the telemetry. The occurrence of more than three counts in a single millisecond will result in the loss of those other than the first three, but the probability of such an event is very small (~10\(^{-8}\), from Poisson statistics) for average count rates on the order of 20 sec\(^{-1}\). When a coincidence between a count in the central crystal and a count in either
FIGURE 15 (see page 78)

Functional diagram of the GS IV pulse height analyzer. See figure 19 for the relationship of the analyzer to the remainder of the balloon-borne system.
BLOCK DIAGRAM OF THE GAMMASCOPE IV PULSE HEIGHT ANALYZER

FIGURE 15
the NaI or the plastic is found, the linear gate remains closed and the event is not analyzed, but in this case a reject pulse is generated and sent to the telemetry (counted down by two). Also sent to the telemetry are the output voltages of the NaI and plastic ratemeters which give an analog measure of the count rates in the guard crystals and plastic scintillators.

The angular response curve shown in figure 2 was derived from data taken with the sources indicated in table I. All sources were located ten feet from the detector with the exception of the Am$^{241}$ source which was 44 feet away.

Also indicated in table I are the radioactive isotopes used in measuring the energy resolution of the CsI crystal. Spectra such as those displayed in figure 16 were used not only to determine the FWHM energy width of the photo-peaks but also to establish a correspondence between PHA channel number and energy. The channel number of the center of each photopeak, as well as the full width at the half-intensity point, was estimated from the graphically displayed spectra. Channel numbers G and energies E were used in a linear regression determination of the coefficients m and b in the equation: $E = mC + b$. Such a determination was made shortly before each flight of the telescope system.

As mentioned previously, a Cd$^{109}$ gamma-ray reference source was flown with the system to provide an inflight check of the stability of the PHA electronics. Data from the second flight (1970-2) indicate no detectable change in the position of the 88 kev photopeak; the pre-flight and inflight peaks agree to within the electronic uncertainty of $\pm 1_2$ channel.

Figure 17 shows the relationship between energy and channel number for flight 1970-2.
Energy-reference spectra obtained in the laboratory. These spectra and those of the other isotopes indicated in table I were used to establish a correspondence between energy-loss and channel number and to measure the energy resolution of the central crystal.
FIGURE 17 (see page 83)

Plot of photopeak energy versus the channel number in which the photopeak fell for the isotopes indicated in table I. The energy-versus-channel-number relationship, determined by a least squares procedure, is indicated by the straight line. The data shown were obtained shortly before flight 1970-2.
FIGURE 17

ENERGY CHANNEL NUMBER
RELATIONSHIP FOR FLIGHT 1970-2

\[ E \text{(keV)} = 4.69 \times \text{ch.no.} + 15.4 \]
A2. THE INTEGRATED BALLOON-BORNE SYSTEM

The Gammascope IV detector placed constraints upon the telescope system which would point it skyward; pointing errors had to be minimized because of the small acceptance angle of the detector; and the supporting structure had to be strong enough to support the 650-lb. weight of the instrument. Furthermore, improvements (over the previous RUG-RAG system Gammascope II) such as a variable declination capability and the ability to take background measurements both east and west of the viewing direction were to be included in the new system.

In order to meet the structural requirements, "U"-shaped beams of 6061-aluminum alloy were bolted together to form the inner gondola and "cage" assembly. (Bolted construction was used because welding destroys the temper which imparts the high strength properties to the aluminum alloy). The cage assembly forms the polar axis of the equatorial telescope mount, provides mounting surfaces for the declination shaft bearings, and offers protection for the detector as the system is parachuted to earth and impacts the ground. (When the telescope is commanded to a declination of +90°, the detector is entirely contained within the cage.) A sketch of the balloon-borne system is shown in figure 18.

The magnetometer-controlled servo system employed previously by RUG-RAG (Craddock [1967]) was modified only slightly for use with the GS IV system; the servo system is capable of maintaining the inner gondola azimuth within ± ½ degree of magnetic north (or south). Since the magnetic variation (the difference between geographic and geomagnetic north) changes with longitude and since balloon flights typically span many degrees of longitude, a means of correcting for a changing magnetic variation was provided. A nylon sprocket gear was fixed to the lucite block which contains
FIGURE 18 (see page 86)

Sketch of the balloon-borne telescope system. See also figure 21.
the Shonstedt flux gate magnetometers and was driven (using a nylon chain) by a command-controlled DC motor. A potentiometer (also driven by the chain) was calibrated to give a real time readout of the magnetic variation value of the system, and this value was updated during each flight as the balloon drifted in longitude. (Correct magnetic variation values as a function of geographic position were obtained from U.S.A.F. Aeronautical Charts.)

Other telescope-pointing errors are introduced by balloon drift. An equatorial telescope must be aligned with its polar axis at an elevation angle equal to the geographic latitude of the observing place; hence compensation must be made for the latitude drifts of the balloon. A latitude drive assembly was fabricated using a chain-driven jack screw which was powered by a 10-watt, 60 hz motor. The bottom polar axis bearing was attached to a $\frac{1}{2}$-inch magnesium plate which moved on cam-followers that ran in curved tracks. The radii of the tracks were such that as the elevation angle of the cage was increased or decreased, the distance between the upper and lower bearings remained fixed and the polar axis (or cage) remained normal to the mounting plate. A potentiometer coupled to the jack screw was calibrated and used in real time to update the polar axis elevation angle to the latitude of the balloon's location.

A third effect due to balloon drift is a change in the apparent sidereal rate; as the balloon drifts east (west) the rate appears faster (slower) than the usual ~15 degrees per hour. The use of a DC stepping motor to drive the polar axis is a convenient solution to this problem. The driving logic for the motor includes a ten position mode selector which has, in addition to a double-rate mode and a stop mode, eight other pulse rates. The use of different driving oscillators (selected prior to the flight) for eastward and
westward drifting flights provides eight different drift modes in each direction. Each mode continuously corrects for a specific balloon drift speed ranging from no drift at all to a drift speed of over 100 miles per hour. Two potentiometers attached to the driving gears of the right ascension mechanism are calibrated to read out the hour angle setting of the telescope to an accuracy of a tenth of a degree. Together with the U.T. time and the longitude of the balloon (from tracking data), the hour angle values are used to determine the right ascension pointing error. If an error develops, a faster or slower drift mode is commanded in order to drive the error back through zero. With this system, the pointing error can be maintained at less than ¼ degree by giving mode-change commands every hour or so.

When a given celestial object reaches the "horizon", a command (separate from the mode change command) is issued to reverse the direction of rotation of the right ascension axis and increase the rate to -10.3 degrees per minute (the 10.3° figure includes 0.25° due to the fact that the earth continues to rotate during the finite time interval required to acquire the next object). After the hour angle has been adjusted to that of the new object, a declination command is sent to reset the declination to that of the new object. Calibrated potentiometers attached to the declination drive mechanism (also powered by a 10-watt, 60 hz. motor) provide a readout of the declination of the telescope. The source change operation can be carried out in less than 20 minutes.

During nighttime flights accurate pointing error information is supplied by a star sensor (Twieg [1970]) which is mounted to the polar axis. It supplies elevation and azimuth error values for the polar axis alignment. Unfortunately the sensor was intended only for nighttime use and was not able to perform on either of the daytime flights.
The outer gondola provides a stable platform against which the inner gondola can turn on its azimuth axis. The platform, as shown in figure 18, is a 12 foot square, of welded aluminum-tube construction, which is strengthened by a cable understructure. Cables run from the four corners to a 30-inch magnesium shaft which protrudes vertically downward from the center of the gondola. Braced in this fashion, the outer gondola easily supported the one-ton weight of telescope system plus ballast, but the inner gondola received severe shocks when the instrument impacted the ground. Fortunately the cage structure (which is easily rebuilt) was able to bend and absorb the shock so that the detector was undamaged.

Since the servo-system torque motor drives against the outer gondola in aligning the inner gondola with the geomagnetic field, the relative moments of inertia of the two structures are important. Though the outer gondola has a mass about \( \frac{1}{3} \) that of the inner one, larger dimensions give it a moment of inertia about four times that of the inner gondola (as determined from a measurement of the angular displacements of the two structures when subjected to equal torques for equal times). In spite of the fact that the semi-rigid coupling of the outer gondola to the balloon should enhance its relative moment of inertia, the experience of flight 1970-2 was that such a coupling was actually detrimental to the performance of the servo system. Slow, long-term (on the order of minutes) oscillations were observed in both the torque motor current and the inner gondola orientation. These are believed due to oscillations of the balloon flight train (see figure 21). As discussed in appendix A4, the use of a swivel joint to decouple the telescope system from such oscillations proved effective in eliminating this problem.

The presence of this oscillatory azimuthal pointing error
(estimated rms value as large as 2°) may have reduced even further the small excess flux of extraterrestrial gamma rays that was observed in the data from flight 1970-2. The first object viewed during that flight was the Crab Nebula which is known to be a strong emitter in the energy range observed on that flight. Due to the high instrumental background rate and the small central detector area, the flux from M1 was barely detectable, and only then because of the long (more than $10^4$ seconds) observation time. A spectral analysis of the 1970-2 data was limited by the poor statistics and does not warrant a detailed report. A search for the pulsation period of the Crab Nebula pulsar was not successful.

The remainder of the balloon-borne system will not be described in the text, but sub-systems are shown in the block diagram of figure 19. Listed in table V is pertinent information regarding the system.
FIGURE 19 (see page 92)

Block diagram of the Gammascope IV-A balloon-borne system. Some portions of the system are depicted in greater detail than others.
### TABLE V

**COMMUTATOR FORMATS**

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 GRND</td>
<td>1 -2.5 v REF</td>
</tr>
<tr>
<td>2 +5 v REF</td>
<td>2 GRND</td>
</tr>
<tr>
<td>3 SLOW HA POT</td>
<td>3 +2.5 v REF</td>
</tr>
<tr>
<td>4 FAST HA POT</td>
<td>4 HEL MAG</td>
</tr>
<tr>
<td>5 SLOW DEC POT</td>
<td>5 SUM: PRESSURE SWITCHES</td>
</tr>
<tr>
<td>6 FAST DEC POT</td>
<td>6 NS LEVEL</td>
</tr>
<tr>
<td>7 LAT POT</td>
<td>7 EW LEVEL</td>
</tr>
<tr>
<td>8 MAG DEV POT</td>
<td>8 MAIN AMPS</td>
</tr>
<tr>
<td>9 NaI RATEMETER</td>
<td>9 +12 v P S MONITOR</td>
</tr>
<tr>
<td>10 ALTIMETER</td>
<td>10 -12 v P S MONITOR</td>
</tr>
<tr>
<td>11 MAIN VOLTS</td>
<td>11 REJECT RATE</td>
</tr>
<tr>
<td>12 FRONT PLASTIC H V M</td>
<td>12 SUM: MOTOR THERMOSTATS</td>
</tr>
<tr>
<td>13 REAR PLASTIC H V M</td>
<td>13 THERMISTOR</td>
</tr>
<tr>
<td>14 FRONT NaI H V M</td>
<td>14 DEAD TIMER</td>
</tr>
<tr>
<td>15 REAR NaI H V M</td>
<td>15</td>
</tr>
<tr>
<td>16 ↓ MAG</td>
<td>16</td>
</tr>
<tr>
<td>17 PLASTIC RATEMETER</td>
<td>17 FEC &amp; FT THERMOSTATS</td>
</tr>
<tr>
<td>18 HEATER VOLTS</td>
<td>18 MT &amp; RT THERMOSTATS</td>
</tr>
<tr>
<td>19 +28 v REG MONITOR</td>
<td>19 PHA &amp; REC THERMOSTATS</td>
</tr>
<tr>
<td>20 +5 v REG MONITOR</td>
<td>20 HEATER AMPS</td>
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</table>

### RA MODE PERIODS

(mILLISECONDS)

<table>
<thead>
<tr>
<th>MODE</th>
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<th>WEST</th>
<th>DRIFT SPEED</th>
<th>OSCILLATOR FREQUENCIES</th>
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<td>184.284</td>
<td>-643</td>
<td>EAST 630.97</td>
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<tr>
<td>2</td>
<td>316.972</td>
<td>368.568</td>
<td>+123</td>
<td>WEST 542.64</td>
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<td>3</td>
<td>310.632</td>
<td>361.197</td>
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</tr>
<tr>
<td>4</td>
<td>304.293</td>
<td>353.825</td>
<td>+91</td>
<td>REVERSE 250.00</td>
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<td>6</td>
<td>291.614</td>
<td>339.083</td>
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<td>7</td>
<td>285.275</td>
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<td>8</td>
<td>278.935</td>
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<td>272.596</td>
<td>316.968</td>
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<td>10</td>
<td>STOP</td>
<td>STOP</td>
<td>+888</td>
<td></td>
</tr>
</tbody>
</table>

FAST REVERSE PERIOD: 8.000 ms

### VCO ASSIGNMENTS

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<th>TYPE</th>
<th>FUNCTION</th>
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</thead>
<tbody>
<tr>
<td>3.9</td>
<td>0-5v</td>
<td>TM CURRENT- 60 Hz COMMANDS</td>
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<tr>
<td>5.4</td>
<td>0-5v</td>
<td>STAR SENSOR</td>
</tr>
<tr>
<td>7.35</td>
<td>±2.5v</td>
<td>PARALLEL MAG</td>
</tr>
<tr>
<td>10.5</td>
<td>±2.5v</td>
<td>COMMUTATOR B</td>
</tr>
<tr>
<td>14.5</td>
<td>0-5v</td>
<td>COMMUTATOR A</td>
</tr>
<tr>
<td>22.0</td>
<td>0-5v</td>
<td>RA PULSES</td>
</tr>
<tr>
<td>30.0</td>
<td>±2.5v</td>
<td>REJECT RATE</td>
</tr>
<tr>
<td>165.0</td>
<td>±2.5v</td>
<td>PCM</td>
</tr>
</tbody>
</table>
A3. THE FLIGHT EXPERIENCE

Three major experiments using the Gammascope IV system were conducted in the spring and summer of 1970. The first was a flight simulation performed in an environmental test chamber at Holloman AFB, New Mexico, and was intended as an engineering "shake down". The other two were actual flights launched from the National Center for Atmospheric Research at Palestine, Texas. Excerpts from reports issued by the responsible agencies are reproduced below as a means of describing what actually took place.

The following was taken from the report issued by the Central Inertial Guidance Test Facility, Air Force Missile Development Center, Environmental Test Branch, Holloman Air Force Base, New Mexico:

Discussion: This test was run in the Stratosphere Chamber on April 16, 1970. Mr. Albert C. Heath, Electronic Engineer, is Project Manager for Rice University and made all test arrangements. He was assisted in the system set-up and operation by Mr. Neil Johnson and Mr. Rick Harnden, Space Science Instructors, and Mr. Edward Peterson, Mechanical Engineer. All operating and monitoring of the telescope system was done by the above named personnel. The system was subjected to a pressure and temperature environment which simulated a balloon flight. Temperature readings were taken from six points on the telescope system and recorded by the Data Logger along with readings of chamber conditions. Sixty-two MDSLE man-hours were required for the test for a total of thirteen specimen test hours. All system components operated properly throughout the test except the declination and latitude drive motors. These motors froze up during the test, but Mr. Heath did not feel that this affected the success of the test. The motors will be insulated prior to the first balloon flight.

As indicated in the report, the 60 Hz synchronous motors used to drive the declination and latitude assemblies failed to operate at the low temperatures encountered. On the subsequent flights, these motors were thermostatically maintained at a temperature of 60°F using heater strips and power taken from the heater battery pack (see figure 19), and they
functioned properly.

The description below was taken from the Balloon Flight Summary, Flight Number 556-P, issued by NCAR:

This summary will describe one balloon flight from the NCAR Scientific Balloon Flight Station at Palestine, Texas for Rice University located at Houston, Texas. The principal investigator was Dr. Robert C. Haymes. Funding for the balloon flight was provided by the Air Force Cambridge Research Laboratory (AFCRL).

The object of the flight was to measure the energy spectrum of the Crab Nebula [from 30 KeV to 560 KeV] utilizing a self-orienting gamma ray telescope.

The flight requirements were: Normal launch and ascent to approximately 125,000 feet, float at altitude approximately 15 hours, terminator, parachute descent and recovery.

The scientific electronic requirements were 30 PCM commands.

In order to meet load and altitude requirements, a Winzen 15.0 million cubic foot balloon, constructed of 0.7 mil polyethylene, was selected.

Dr. Haymes and his associates arrived at the Balloon Flight Station on 24 April 1970, and readied their gondola for flight. After a three day delay due to adverse weather conditions, NCAR Flight No. 556-P was launched into clear skies at 0812 CDT, 5 June 1970. At the time of launch, the surface winds were west-southwest at three knots, and the temperature was +14.5°C. The balloon system ascended at an average rate of 779 feet per minute to a float altitude of 124,000 feet. After a float at altitude of 7 hours and 48 minutes, the flight was terminated from the tracking aircraft. (The flight was terminated early due to a malfunction on the scientific gondola.) The gondola was safely parachuted and landed 11 miles west of Ballinger, Texas at 1804 CDT. A recovery crew, which was on hand, found the gondola in good condition and turned off all power. The instruments were loaded on a truck and returned to the Balloon Flight Station at Palestine, Texas.

The malfunction mentioned in the above report refers to the fact that the azimuth shaft bearings locked up, during or shortly after launch, and prevented the servo system from operating; hence no telescope pointing was achieved. The problem was determined to have been due to insufficient torque
applied in tightening the bolts which fix the bearings to the inner gondola. An improved procedure was implemented and this problem has not subsequently recurred.

Unexpectedly high counting rates were registered by the telescope during this flight, and steps were subsequently taken in an effort to improve the performance of the detector. The detection thresholds in the guard crystals and plastic scintillators were lowered in the hope that this would enhance the anticoincidence capabilities of the system. As indicated in the body of this thesis, these efforts accomplished little.

The second flight was described in the NCAR Flight Summary for Flight Number 565-P:

\[\ldots\] Dr. Haymes and his associates arrived at the Balloon Flight Station on 24 April 1970, and had flown one previous flight in this 1970 spring series (556-P). NCAR Flight No. 565-P was readied on the launch pad on 27 June 1970, after a one day delay due to adverse weather conditions. The balloon was released from the launch vehicle at 0619 CDT. At the time of launch, there were scattered clouds at 10,000 feet, the surface winds were south at four knots, and the temperature was +22°C. After a normal launch, the balloon system ascended at an average rate of 743 feet per minute to a float altitude of 123,500 feet. The balloon was allowed to float at altitude for 9 hours and 42 minutes and was terminated at that time to avoid the San Andres mountains range. Unpredictable winds during descent carried the parachute more northerly than anticipated and the gondola landed 150 yards from the shore in Elephant Butte Reservoir, Mexico. Four boats were in the immediate area of splash down and the gondola and parachute were towed in near to the shore and secured. A recovery of the instruments had to be delayed due to darkness. After first light on 28 June 1970, a salvage barge was leased to lift the gondola from the lake onto a truck for return to the Balloon Flight Station at Palestine, Texas.

This flight (referred to as flight 1970-2) was even more ill-fated than indicated in the report. A freak accident which occurred the evening before the flight narrowly missed killing one of the launch crew and possibly injuring several others.
As the inner gondola was being hoisted up to the outer gondola (which was resting 3 feet off the ground on wooden supports), one of the forks broke loose from the fork lift which was being used to hoist the gondola. The 400-lb. fork crushed one side of the outer gondola as it fell to the ground and came to rest leaning against the side of the 1200-lb. inner gondola which was left dangling in mid-air from the one remaining fork. Half a dozen men were standing in and around the gondola when the accident happened, but fortunately none was hurt seriously. The delicate equilibrium of the inner gondola was made more secure with the use of a second fork lift, and in a hour's time the gondola was safely anchored to its test fixture. Damage to the system was minor and superficial so that feverish repairs and a spare outer gondola enabled the flight to proceed the following morning.

The water landing caused extensive damage to wiring and exposed electrical components (motors, power amplifiers, thermostats, etc.), but the fact that all the electronics were contained in pressurized cans saved the system from even more extensive damage.
A4. AN INTERIM ONGOING EFFORT

The balloon-borne system described in this thesis proved itself to have a great potential for astronomical observations, though that potential was not realized due to the disappointing performance of the Gammascope IV-A detector. In order to realize that potential and in order to take advantage of an opportunity to make southern hemisphere observations, an interim scheme (pending the design and construction of a new detector) was devised.

The GS IV system was refurbished and modified to accommodate two detectors of the Gammascope II design (see figure 20 for a schematic diagram of the GS II detector). Since two such detectors were available, it was decided to fly both of them simultaneously. Not only would the presence of two detectors allow comparison between the two instruments to be made, but also it would increase the effective exposure to the observed objects. If the additional mass of a second detector does not increase the background counting rate (through cosmic-ray interactions in the local material), a factor of $\sqrt{2}$ in sensitivity can be gained by flying both instruments. This is equivalent to making two flights with a single detector. However, if the two-detector background rate were increased to twice what it would have been with only one, the increase in sensitivity would be a factor of 1.02 instead of 1.41 (the 1.02 factor was obtained by using a source strength like that of Cygnus X-1). The detectors were mounted side by side, with their axes parallel, on a new yoke-type polar axis. Since the GS II detectors were lighter (combined weight ~300 lb.) and considerably shorter than the GS IV-A detector, the inner gondola was modified to make it lighter and shorter too. A new outer gondola, using bolted construction, was also built for use with the modified system which is called Gammascope IV-B.
FIGURE 20 (see page 100)

Schematic diagram of the Gammascope II detector. This instrument was used in most of the previous RUG-RAG experiments and in the flight described in appendix A4.
In order to eliminate the servo system "hunting" problem, two changes were made. A swivel joint, substituted for the "U"-joint previously used in the balloon train (see figure 21), decouples the outer gondola from balloon motions. Also, a small, "tachometer", D.C. motor was introduced into the system. The emf induced in this motor (by relative rotations of the two gondolas) is amplified and used as a negative feedback in the servo loop. The performance of the system was thereby vastly improved; "overshoots" in acquiring a null were almost completely eliminated; and "hunting" was reduced considerably.

To accommodate the two detectors, the pulse height analyzer was extended from seven to eight bits, effectively making it a 256-channel analyzer. The eighth bit was an identifier bit which distinguished pulses from detector A from those of detector B (see Glenn [1969] for a description of the slight difference between detectors A and B).

RUG-RAG was a participant in an expedition known as Galaxia 70 which involved the launching of several balloon flights from Parana, Argentina. Flight 1970-4 was launched for RUG-RAG on 25 November 1970 and resulted in the acquisition of 17\frac{1}{2} hours of noise-free data from the Gammascope IV-B telescope system. Objects in the constellations of Vela, Scorpius, and Sagittarius were successively viewed, with only fifteen minutes of the flight time being used for making the two source changes. Though detector A malfunctioned and had to be turned off (by radio command), detector B functioned properly throughout the flight, and statistically significant gamma-ray fluxes were observed from each of the three regions. (These results are to be reported elsewhere: Johnson, et al. [1972]; Haymes, et al. [1972]; Harnden [1972].)
FIGURE 21 (see page 103)

Balloon flight train used by the NCAR Balloon Flight Station personnel who conducted the GS IV balloon flights. This diagram was taken from NCAR Balloon Flight Summary, Flight Number 565-P.
FIGURE 21

WINZEN 0.7 15.0 x 10^6 FT^3

79' CHUTE

RADAR TARGET

(4) 10'-3/16" CABLES

U-JOINT

(4) 20'-3/16" CABLE

SCIENTIFIC INST

CRUSHPAD

276' BEACON ANT.

(4) 7'-1/4" CABLE

BALLAST

BALLOON FLIGHT TRAIN
REFERENCES


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Peterson, L., The 0.5 MeV gamma-ray and the low-energy gamma-ray spectra to 6 gm/cm² over Minneapolis, J. Geophys. Res., 68, 979, 1963.


Puppi, G. and N. Dallaporta, The equilibrium of the cosmic ray beam in the atmosphere, Progress in Elementary Particles and Cosmic Ray Physics, 1, 315, 1952.


