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OPERATION

FIELD REPORT

September 1983

Los Alamos National Laboratory
Sandia National Laboratory
Air Force Technical Applications Center

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TAURUS FIELD REPORT

SEPTEMBER 1983

Compiled by W. D. Evans and R. A. Jeffries

Contributions by

J. R. Cessna

W. D. Feldman

T. E. Latta, SNLA

L. R. Rollstin, SNLA

W. R. Scarlett

S. R. Shaw

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TAURUS FIELD REPORT

CONTENTS

Contents (cont)

1.0 INTRODUCTION

Operation TAURUS was the first demonstration of a system capable of fully characterizing the nuclear signature of foreign reactors in space. The TAURUS system included a nuclear instrumentation payload carried by a small sounding rocket, the associated ground radar and computing systems needed to predict and monitor the positions of the rocket and the satellite target, and data analysis hardware and software which presents the payload data in real time. Although this first test was against a "virtual" target rather than an actual satellite, all components required for an actual deployment were successfully tested. This operation also measured the radiation background and gathered system performance data needed to assess the risks and benefits of an actual mission.

TAURUS is the first phase of a program addressing national requirements for the detection and characterization of nuclear materials in space. The total program, nicknamed DORADO at Los Alamos, is a joint cooperative effort involving the Los Alamos National Laboratory, Sandia National Laboratories, the Air Force Technical Applications Center (AFTAC), the Defense Advanced Research Projects Agency (DARPA), and others.

The goal of the TAURUS phase of the DORADO program was the demonstration of an early initial capability to detect and characterize foreign nuclear reactors in space. The payload flown in this operation utilized instrumentation that required a minimum of development. We have initiated conceptual design and development of an advanced payload capable of greatly improved sensitivity and spectral resolution.

The demonstration flight of this system was conducted from the Kauai Test Facility (KTF), a permanent sounding rocket range operated by Sandia National Laboratories at Barking Sands, Kauai, Hawaii. This facility is also ideal for operational deployment of TAURUS against "RORSAT-type" satellites. Analysis of many RORSAT trajectories indicates that the probability of the passage of RORSAT's through the accessible target area from KTF is high. Because the RORSAT's historically follow the same ground track, an intercept opportunity can be expected to occur about every seven days.

The payload was lofted by a Terrier Tomahawk unguided sounding rocket. A typical RORSAT ephemeris obtained from NORAD was used to define a "predicted" target orbit in time and space. Real-time radar was used to monitor the rocket track, and the closest approach distance to the "virtual" satellite was calculated during the flight. A retro-rocket provided a means of trajectory modification to increase the distance of closest approach. This retro-system was also successfully tested during Operation TAURUS.

Operation TAURUS was sponsored by the Department of Energy/Office of International Security Affairs, AFTAC, and Los Alamos National Laboratory Institutional Supporting Research funds. The instrumentation, rocketry, and data reduction elements of the TAURUS program were assembled using the technical resources and facilities of the National Laboratories of the Department of Energy. If a decision is made to deploy this system, then identification of target satellites, tasking of missions, and reporting of results will be the responsibility of the appropriate elements of the Department of Defense and the intelligence community. The rocket payload has been recovered and will now be refurbished and held ready for future deployment as required.

This field report is intended to provide a timely description of the program objectives, operational procedures and experimental results.

2.0 EXPERIMENT PHYSICS

2.1 Purpose

The TAURUS payload was designed to detect, positively identify, and determine the operating characteristics of an orbiting nuclear reactor by measurements of the γ-ray, neutron, and positron emissions. A secondary purpose was to develop and test modern instrumentation having future application for Los Alamos Treaty Verification Program.

2.2 Instrument Design

The TAURUS-I payload was designed to include two instruments and be lofted by a 9 inch Terrier-Tomahawk sounding rocket to approach (within approximately 10 km) an orbiting, lightly-shielded reactor operating in the power range between 30 and 100 kw. Power and telemetry allocated to the instrument payload were 87 lbs, 25 W, and 1 Mb/s, respectively. The Sandia facility at Barking Sands, Kauai was the launch site.

2.3 Expected Background Radiations

In order to predict background counting rates due to naturally occurring neutrons, charged particles and γ-rays, it was important to assess the intensity of these radiations. With a half-life to β^- decay of approximately 13 min, most background neutrons just above the Earth's atmosphere have been produced locally by nuclear interactions between galactic cosmic rays and constituents of the upper atmosphere. Since the payload's apogee of 250 km is well below the Earth's trapped ion radiation belt, no detectable neutron fluxes resulting from interactions between these particles and the rocket were expected. The spectrum of the atmospheric albedo neutron flux was calculated using the measured spectrum of galactic cosmic rays, the known atmospheric constituents, and all relevant nuclear cross sections. This spectrum, reproduced from Hess et al. (1961), is shown in Fig. 2.1. Although the shape of the spectrum has been confirmed only crudely for neutrons with energy below about 10 MeV, the total intensity has been determined experimentally to be approximately 0.15 cm^{-2} s^{-1} at the geomagnetic latitude of Hawaii (Lockwood, 1973).

Again, because the maximum altitude of the rocket was well below the base of the inner Van Allen radiation belt, only detection of very energetic galactic cosmic rays was expected. Their intensity ranges between about 0.3 and 0.6 particles/cm^2-s corresponding to solar maximum and minimum conditions, respectively.

Three contributions to the γ-ray background were expected: 1) the diffuse cosmic x-ray and γ-ray background, 2) the Earth albedo radiation or secondary radiation originating from the interaction of galactic cosmic rays with constituents of the Earth's atmosphere, and 3) rocket produced background caused by radioactive materials in the rocket and cosmic ray induced secondary radiation. A conservative estimate of these backgrounds for a spacecraft in equatorial orbit at 500 km altitude and invariant latitude $\lambda = 18°$ is shown in Fig. 2.2. Integration

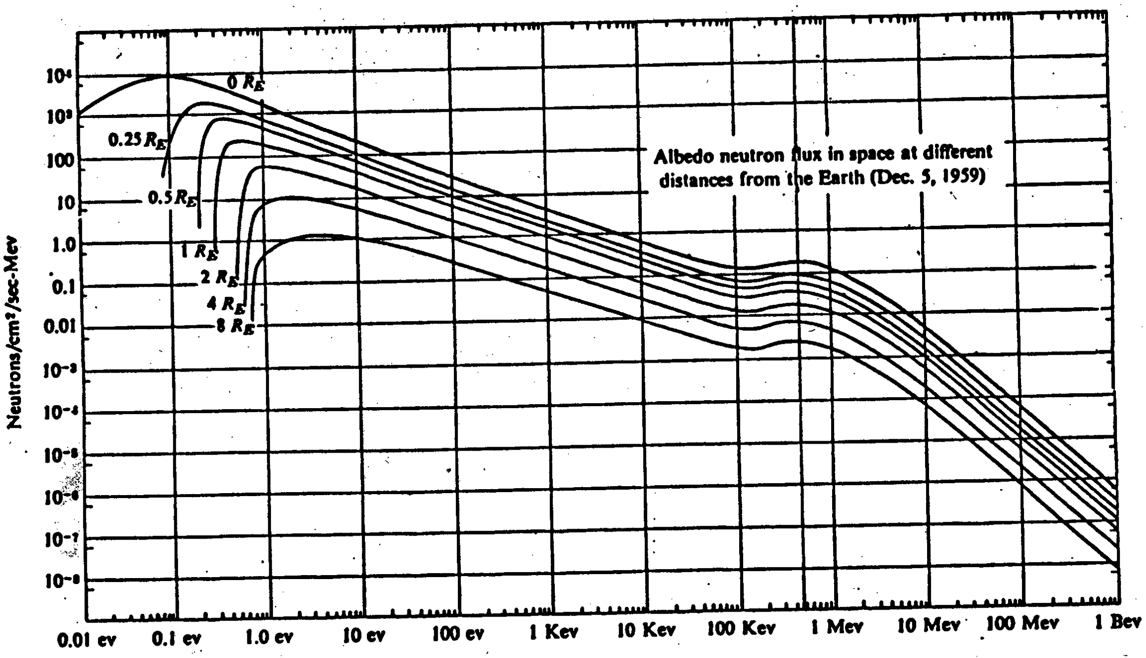


Fig. 2.1. The calculated neutron-energy spectrum in space at different distances from the earth above the geomagnetic equator. The OR_E is for the top of the atmosphere, which is roughly 100 km altitude.

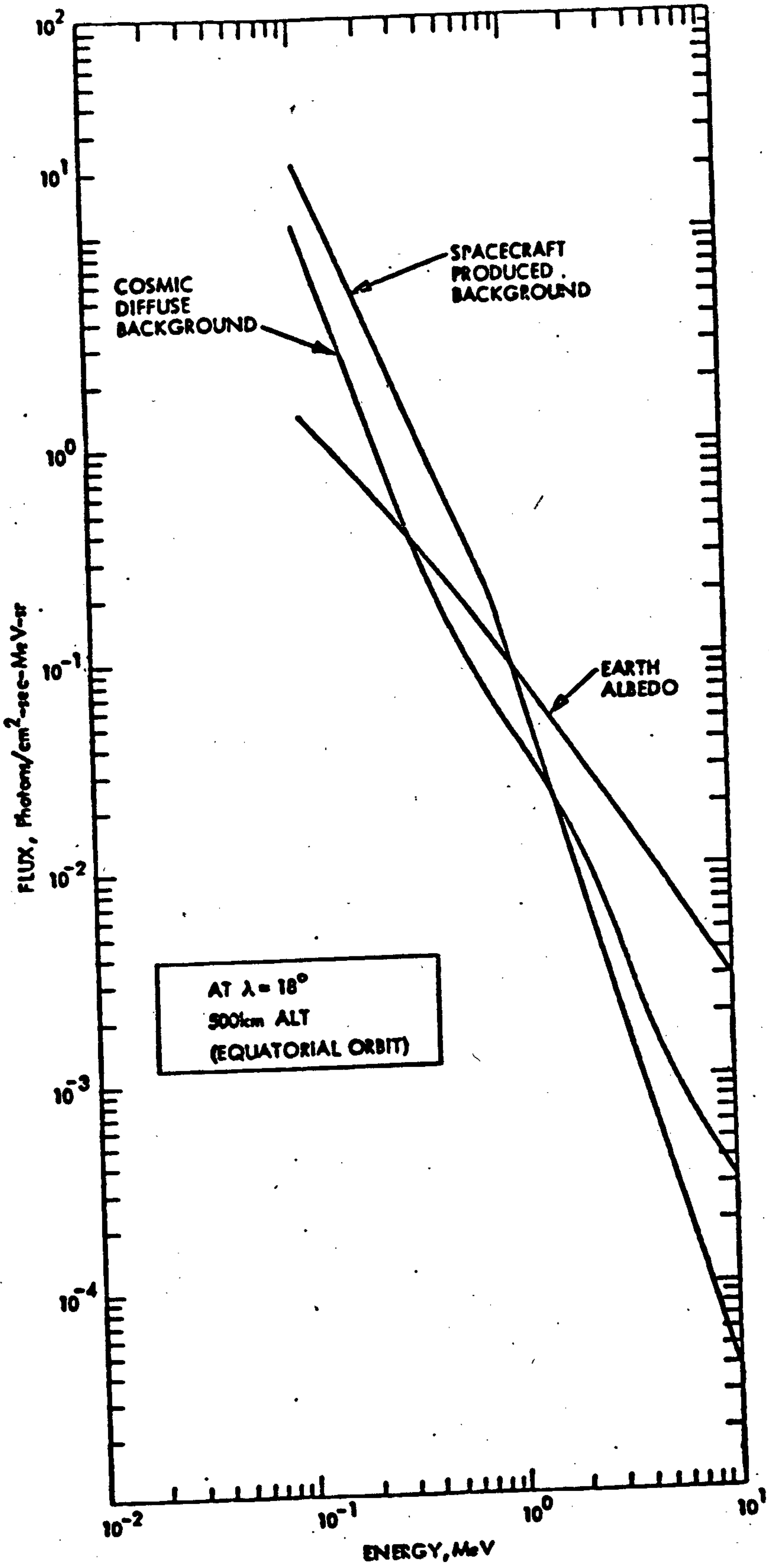


Fig. 2.2. Estimated gamma radiation background components.

of these curves for energies greater than 100 keV and assuming appropriate solid angles yields approximately 16.4 photons/(cm^2-s).

2.4 Expected Reactor Neutron Flux

Measurements from a lightly shielded nuclear reactor show a leakage of about 1 neutron of 2 MeV average energy per fission. For a reactor, 3.1×10^{10} fissions are needed per watt-s, so a 100 kilowatt reactor leaks $S = (3.1 \times 10^{10})$ fiss/W-s) $\times$ (1) (n/fis) $\times$ (10^5) (watts), or $S = 3.1 \times 10^{15}$ neutrons/s (R. E. Malenfant, private communication). If A_n is the detector area and ε_n is its collection efficiency then the yield at d = 10 km distance is

$$Y_{on} = \frac{S A_n \varepsilon_n}{4 \pi d^2} = 2.47 \times 10^2 A_n \varepsilon_n \text{ counts/s} \tag{1}$$

Since

$$Y_n(t) = \frac{Y_{on} d^2}{d^2 + U^2 t^2}$$

where U is the speed of the reactor past the rocket at t = 0, corresponding to closest approach, the total counts, Y_{Tn}, is given by

$$Y_{Tn} \int_{-\infty}^{\infty} = Y_n(t)dt = \frac{Y_{on} d}{U} \int_{-\infty}^{\infty} \frac{dz}{1 + z^2} = \frac{\pi Y_{on} d}{U}$$

where the substitution $z = Ut/d$ has been made. Since U is approximately 7 km/s and d = 10 km, then

$$Y_{Tn} = 4.49 \, Y_{on} \; . \tag{2}$$

2.5 Expected Reactor Gamma-Ray Flux

Lightly shielded reactors are also a source of γ-rays. A leakage of about 1 MeV/fission of photons having average energy of 0.9 MeV is expected. The resultant flux corresponds to a source strength of $S = 3.1 \times 10^{10}$ (fission/watt-s) × (2 MeV/fission) × (10^5 W)/(0.9 MeV/photon) = 3.4×10^{15} photons/s. This number is nearly identical to that estimated for the neutron flux. Making similar definitions we find a yield at 10 km of

$$Y_{0\gamma} = 2.74 \times 10^2 A_\gamma \varepsilon_\gamma \qquad (3)$$

and a total yield

$$Y_{T\gamma} = 4.49\ Y_{0\gamma} \qquad (4)$$

2.6 NAS-I Design and Calibration

The neutron sensor, NAS-I, consisted of a ^{3}He gas proportional counter placed within a cylindrical annulus of BC412 plastic scintillator as shown in Fig. 2.3. The proportional counter was 5.7 cm diameter by 20 cm long and was filled with 10 atmospheres of ^{3}He gas. The plastic scintillator had a 16 cm o.d., a 6 cm i.d., a 20 cm length, and was viewed by eight, 1.5 in. diameter photomultiplier tubes. Both the ^{3}He counter and the plastic scintillator responded to neutrons. Because the ^{3}He counter was insensitive to γ-rays but very sensitive to neutrons having energies less than about 10 eV it was used in a singles

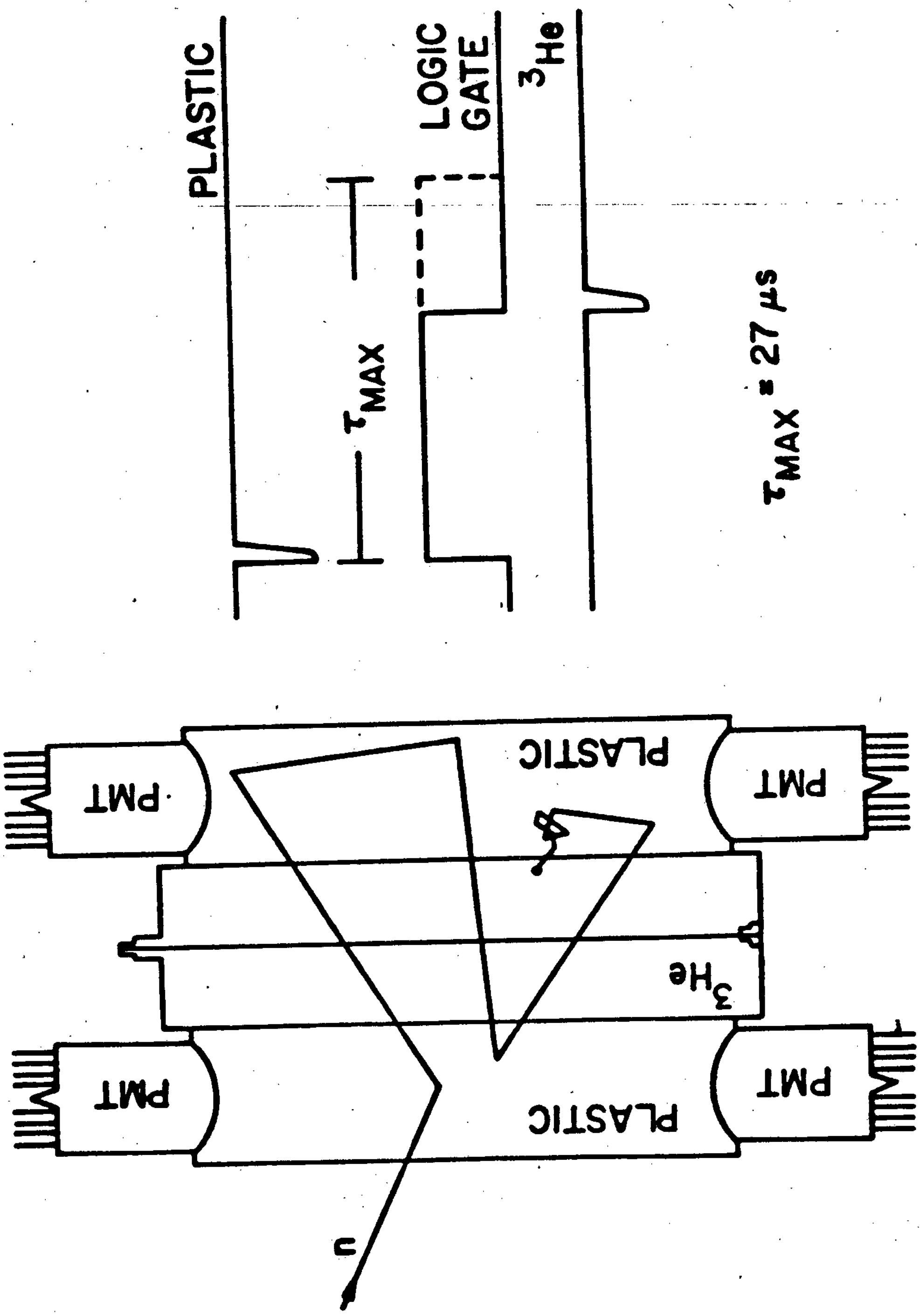


Fig. 2.3. Neutron sensor - NAS-I.

mode of operation as a moderated gas proportional-counter neutron detector. Calibration using monoenergetic neutron beams generated by the Los Alamos vertical Van de Graaff accelerator yielded detection efficiencies in the range between 5 and 6% for neutron energies less than about 5 MeV. These efficiencies assumed an area $A_n = 3.2 \times 10^2\ \text{cm}^2$, the projected area of the plastic scintillator. Inserting these quantities into Eqs. (1) and (2) gave a maximum counting rate of about 4350 counts/s at closest approach and a total of about 1.95×10^4 counts during the rocket flight. These numbers are to be compared with an albedo neutron count rate of 2.6 counts/s and a total over the entire rocket flight of about 1450 counts. This total does not include events corresponding to minimum ionizing galactic cosmic rays because they correspond to very large pulses in the plastic and therefore can be easily identified and neglected.

Information about the spectral shape of the source neutron distribution was obtained from a pulse-height analysis of the plastic scintillator output. The principle of operation is outlined in Fig. 2.3. Neutrons incident on the plastic deposit all their sensible energy (down to about 450 keV) to multiple proton recoils within about 30 ns. However, since the ^{3}He counter does not count 450 keV neutrons efficiently, many more proton-recoil collisions were needed before detection by this counter was possible. The associated slowing down time for this additional energy loss coupled with penetration of the ^{3}He tube, was in the range between 20 and 50 μs as shown in Fig. 2.4. This differential coincidence fraction versus slowing-down time was measured using an Am-B

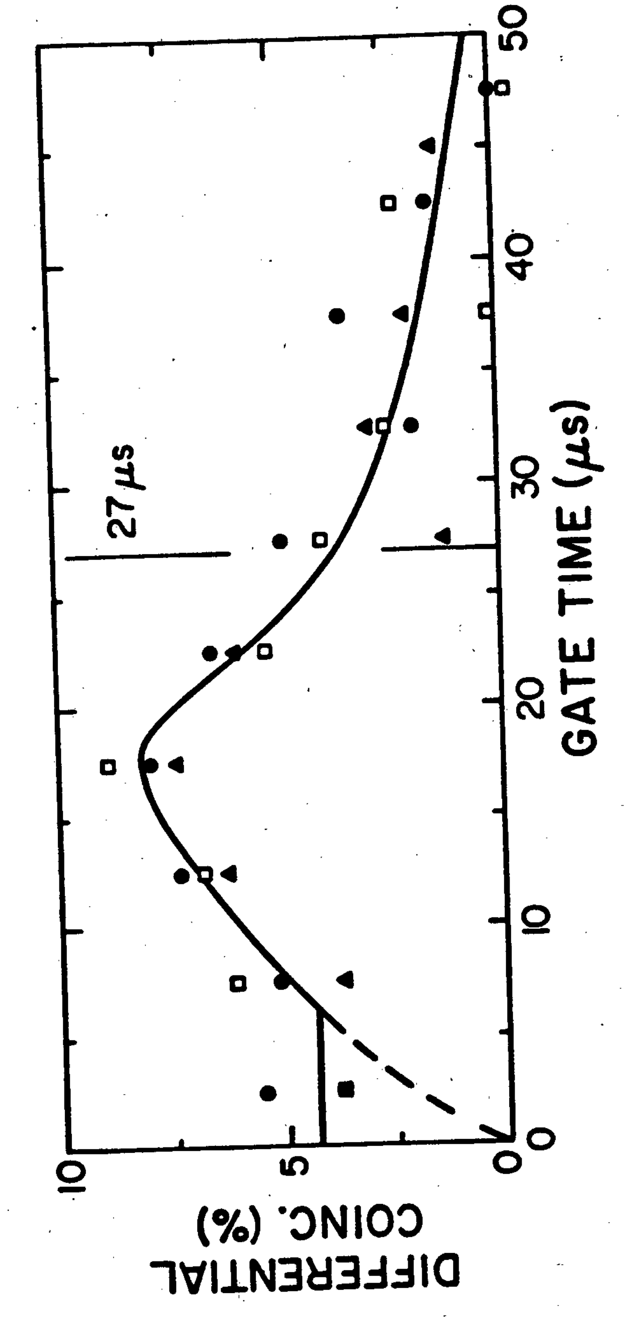


Fig. 2.4. NAS-I sensor calibration plastic - ^{3}He coincidence.

neutron source illuminating the NAS-I detector. A 27 μs maximum gate time for a coincidence between the plastic pulse and the ^{3}He tube pulse was chosen (see vertical line in Fig. 2.4) as a compromise between detection efficiency and an inordinately high chance coincidence counting rate at the distance of closest approach. A coincidence between the plastic and ^{3}He tube then signaled the occurrence of a nearly complete energy loss in the plastic. The associated plastic pulse height was then a true measure of the incident neutron energy. Spectral resolution was limited only by nonuniform light collection and nonlinearities of the light output of the plastic.

The spectral response of the NAS-I detector to monoenergetic neutrons between 0.6 MeV and 4 MeV was calibrated using the Los Alamos vertical Van de Graaff accelerator. Several typical pulse-height distributions are shown in Fig. 2.5. Two of these distributions are replotted in linear energy space in Fig. 2.6. The energy resolution for all the measured spectra are summarized in Fig. 2.7. Inspection shows that although the resolution degrades seriously for energies below approximately 1 MeV, it ranged between about 50 and 75% for energies above 1 MeV.

The energy-dependence of the detection efficiency is shown in two different formats in Figs. 2.8 and 2.9. Whereas the absolute efficiency for detecting coincidence events varied between about 2.5% and 2% for neutrons having energies in the range between about 450 keV and 4 MeV (Fig. 2.8), the coincidence to singles fraction was nearly constant at 40% over the same energy range (Fig. 2.9). It is not clearly known why

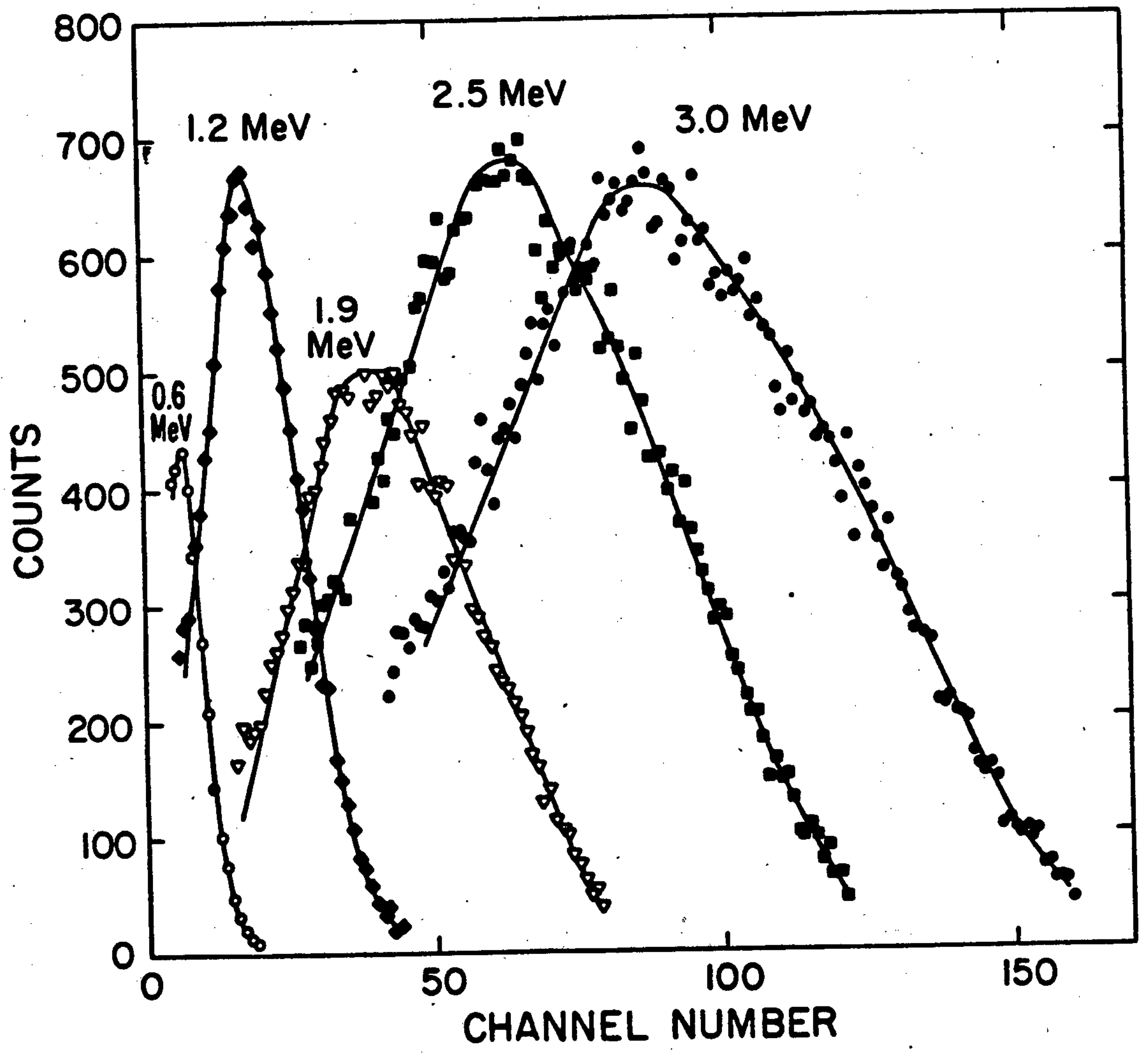


Fig. 2.5. NAS-I sensor spectral calibration monoenergetic neutrons.

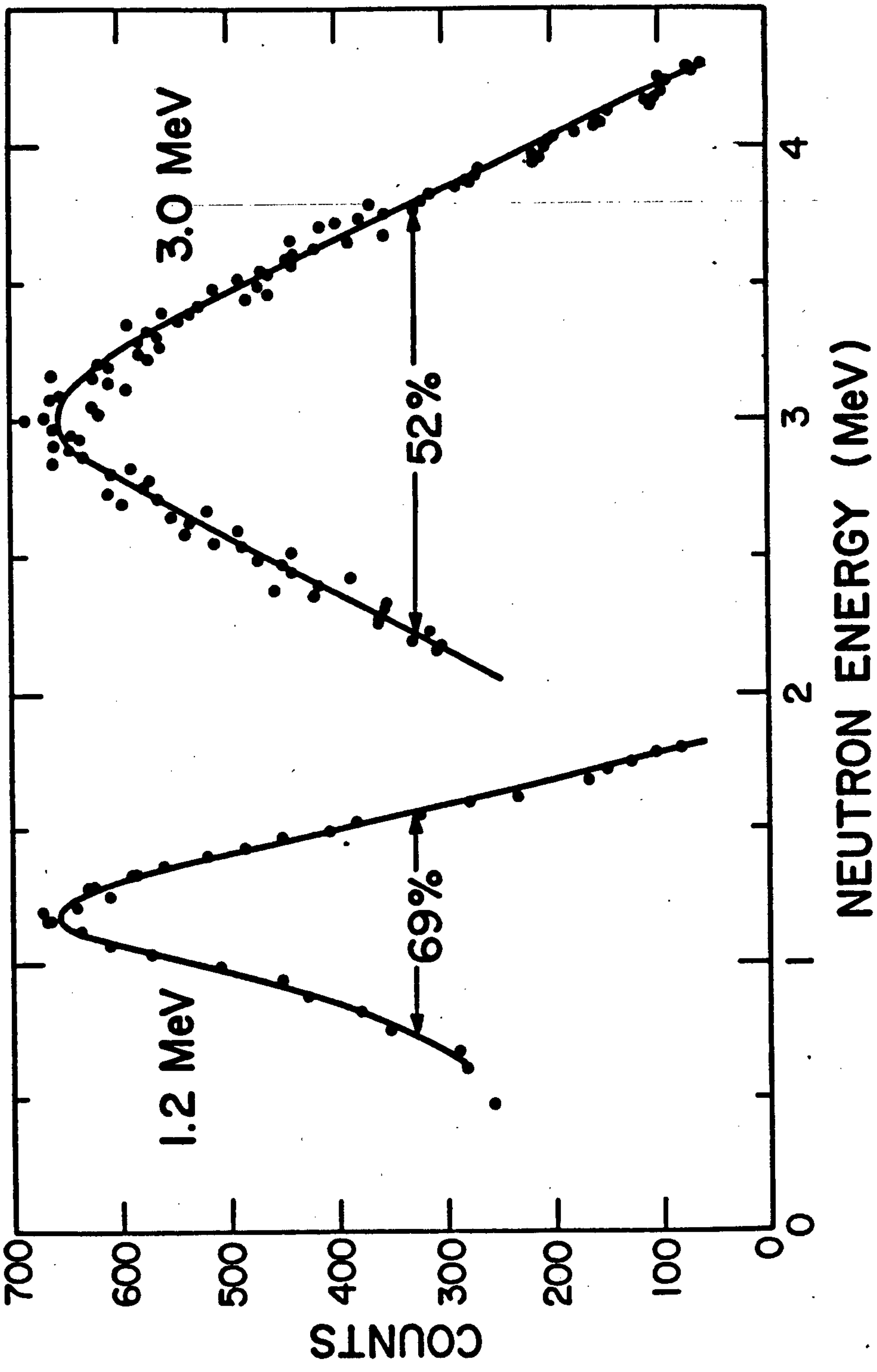


Fig. 2.6. NAS-I sensor calibration monoenergetic neutrons.

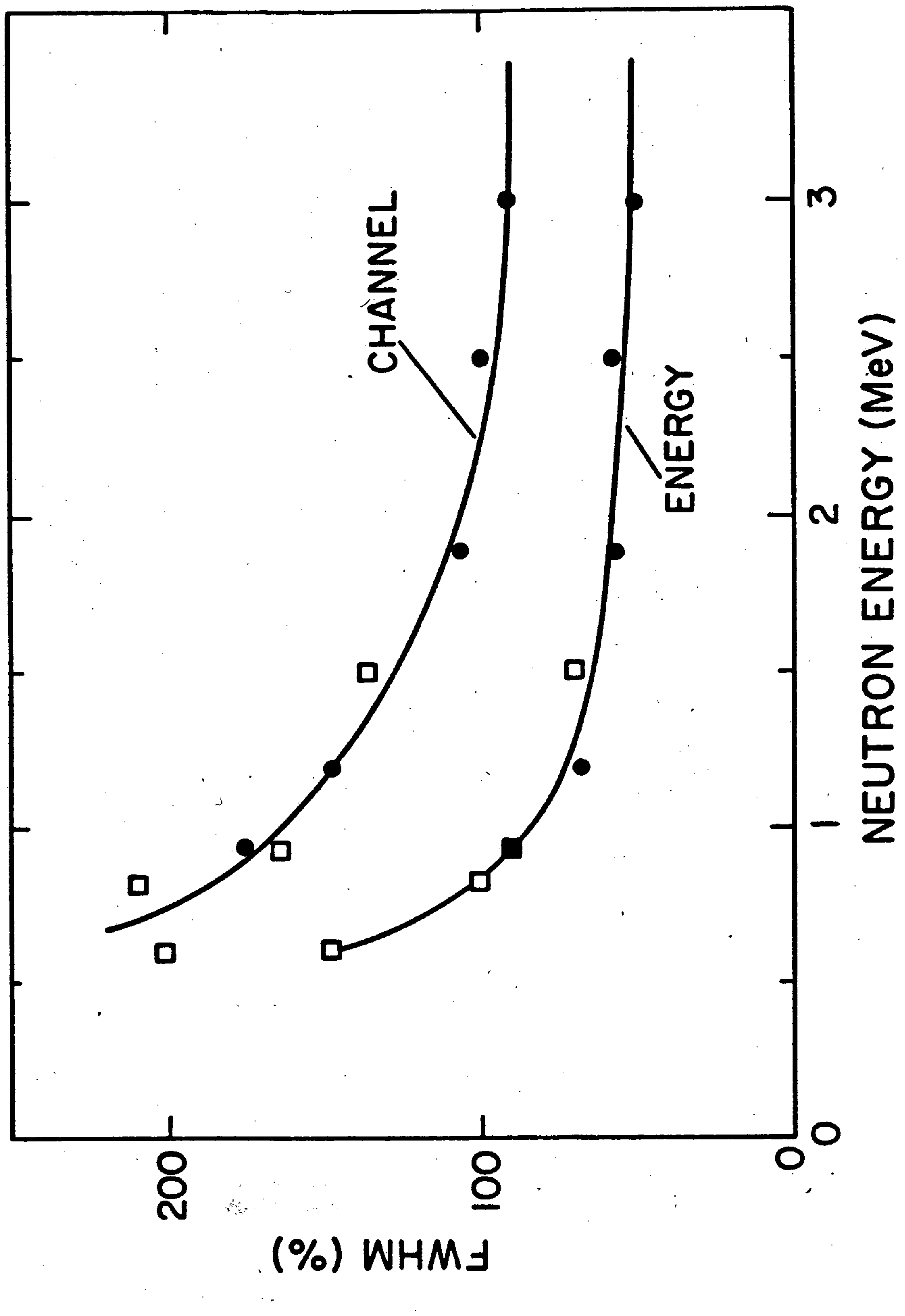


Fig. 2.7. NAS-I sensor calibration energy resolution.

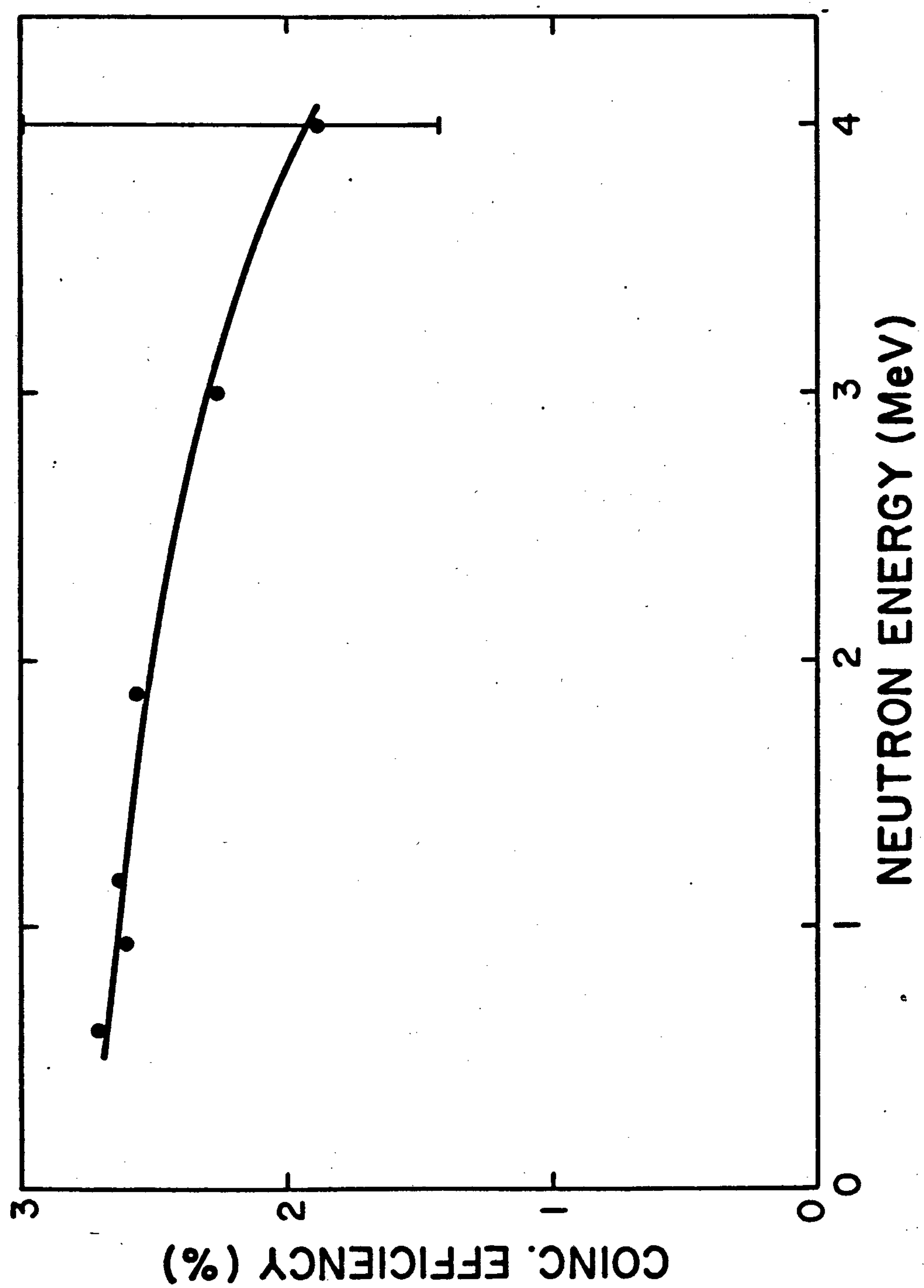


Fig. 2.8. NAS-I sensor calibration coincidence efficiency.

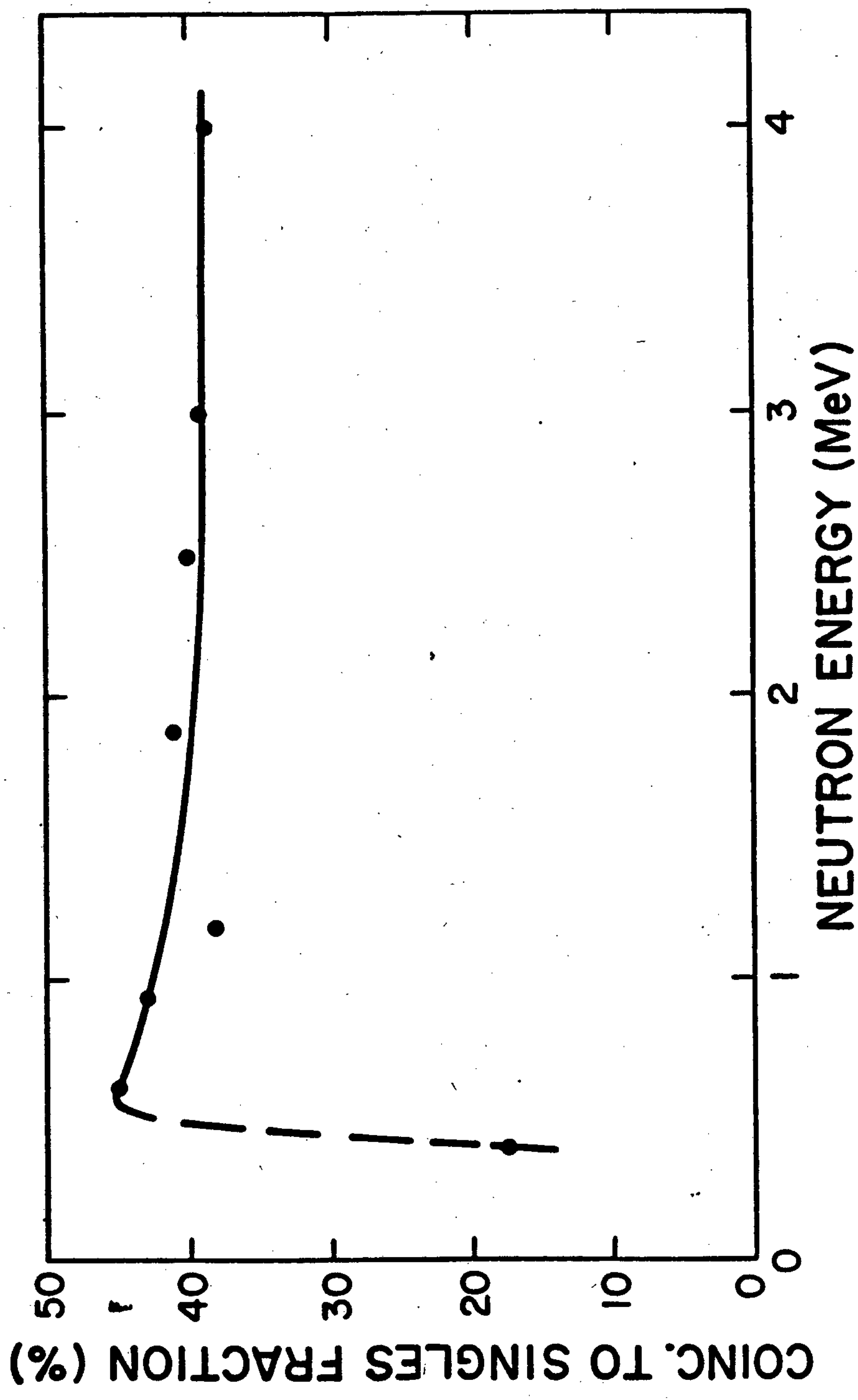


Fig. 2.9. NAS-I sensor calibration singles coincidence.

the coincidence efficiency drops off so sharply below approximately 450 keV but the reason may be related to the low light output for low energy proton recoils. This output is calibrated in Figs. 2.10 and 2.11 using a linear laboratory pulse height analyzer and the logarithmic pulse-height analyzer built into NAS-I, respectively.

2.7 Expected NAS-I Plastic Counting Rates

The plastic will respond to all incident ionizing fluxes very efficiently. Since the minimum plastic penetration thickness is 10 cm and the mean free paths to 1 MeV neutrons and γ-rays are approximately 4.5 cm and 10 cm, respectively, the probabilities for at least one detectable interaction should be greater than approximately 90% and 70%, respectively. Choosing 100% efficiency for the purpose of estimating maximum rates, a singles counting rate for neutrons is 7.9×10^4 s^{-1} and for γ-rays is 8.8×10^4 s^{-1}. Addition of 1/8-in. of Pb sheet surrounding the NAS-I for ballast should reduce the γ-ray background to below approximately 2.5×10^3 s^{-1} but not change the neutron albedo count rate.

Because of the high singles plastic count rate at closest approach and the 27 μs coincidence rate necessitated by the NAS-I design, the probability for a chance coincidence will be close to 100% at this point. However, outside of a ±6 s interval centered on closest approach, the singles count rate should be less than approximately 9.1×10^3 s^{-1} corresponding to a percentage dead time resulting from chance coincidences of less than approximately 22%. Since the resultant chance coincidence counting rate of 950 s^{-1} will be always less than the expected true coincidence rate (which at ±6 s is 1740 s^{-1}), measurement of

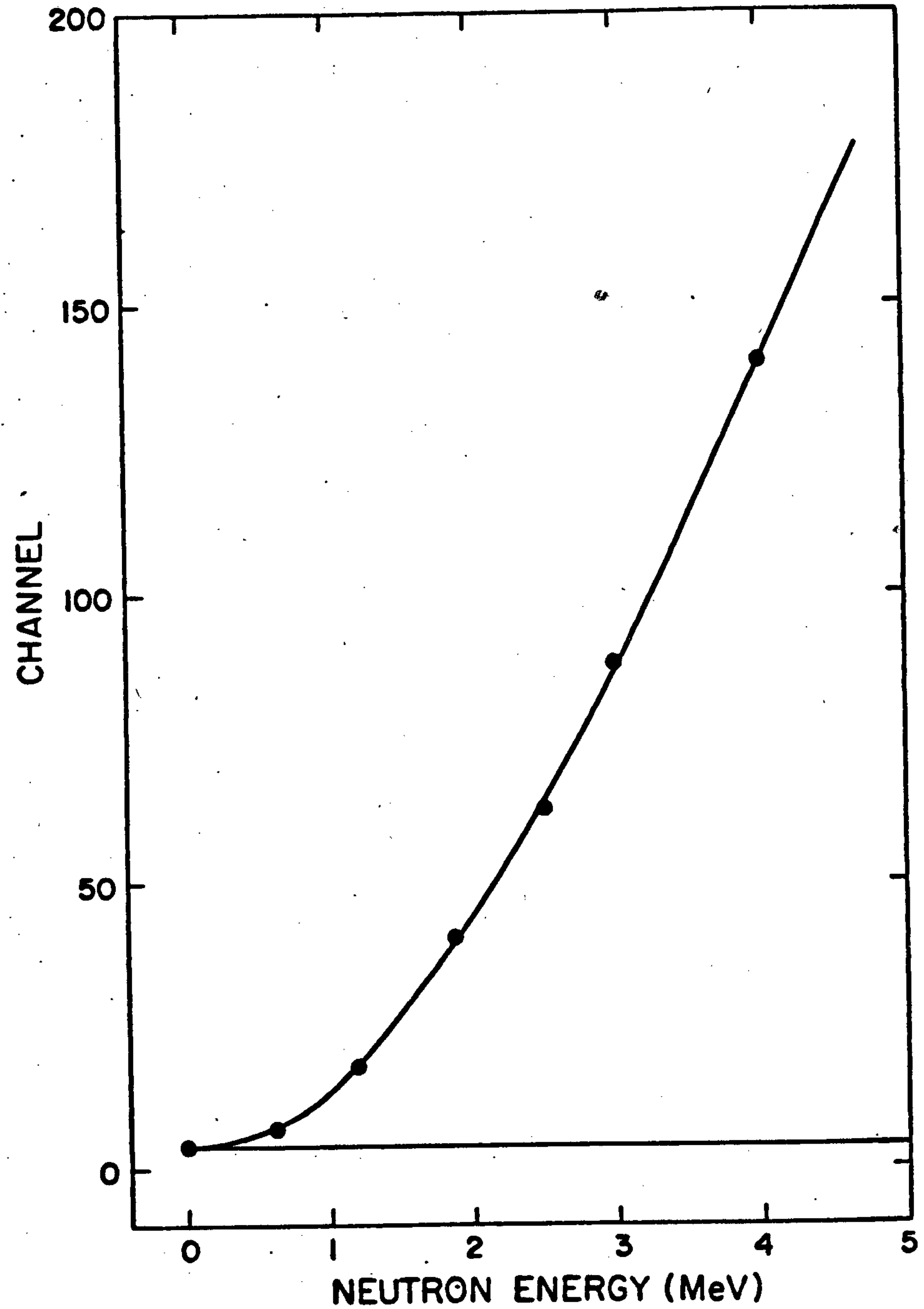


Fig. 2.10. NAS-I sensor calibration laboratory (linear) analyzer.

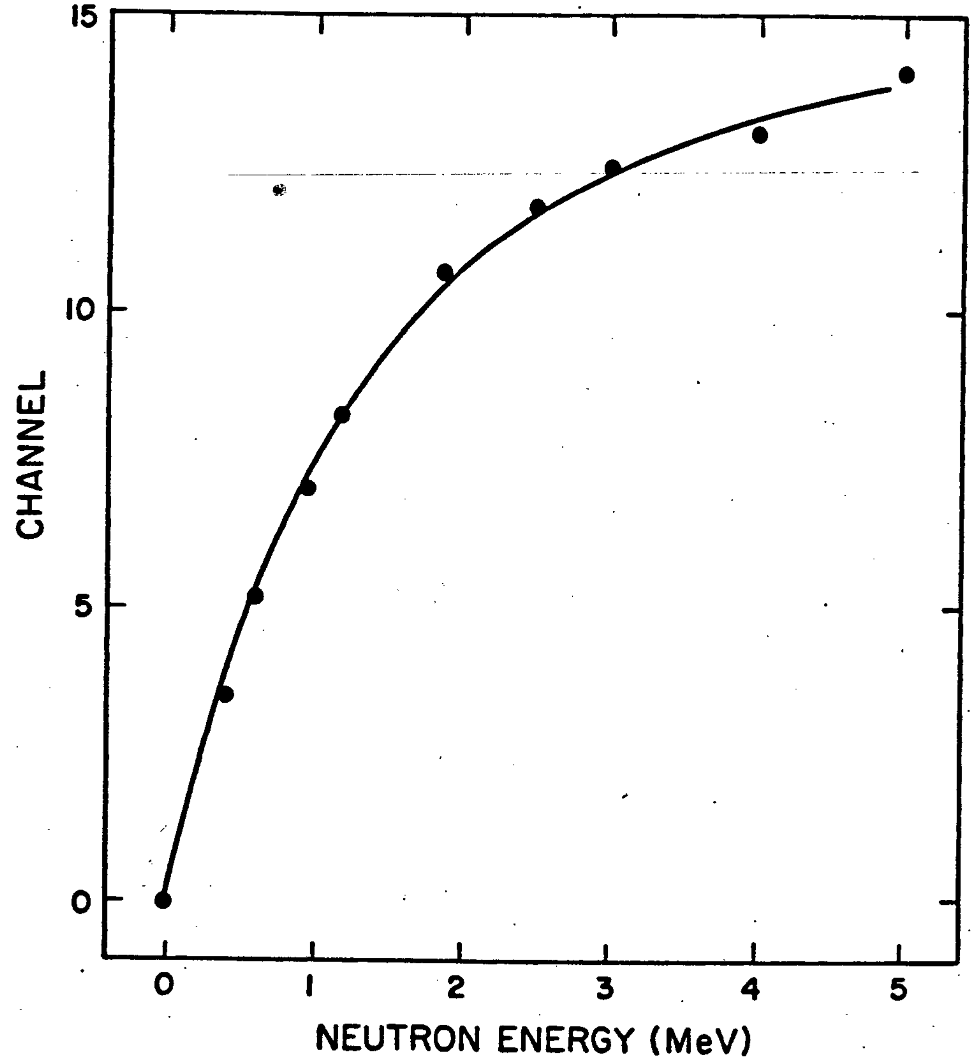


Fig. 2.11. NAS-I sensor calibration payload (logarithmic) analyzer.

energy spectra should be possible. Integrating the expression for $Y_n(t)$ from ±6 s to ± τ where $Y_n(\tau) = 1.1\ s^{-1}$ (the background neutron coincidence counting rate) gives

$$\tau = \frac{d}{V}\frac{Y_n(\tau)^{\frac{1}{2}}}{Y_n(\tau)} = 58\ s \text{ and } Y_{Tn} = 2\,\frac{Y_{on}d}{U}\int_{6}^{58}\frac{dz}{1+z} \simeq 1 \times 10^3$$

counts spread over 12 pulse-height channels.

2.8 Background/Gamma Design and Calibration.

The Background/Gamma (B/G) detector provided four functions: 1) it characterized the gamma-ray flux emitted by the reactor. 2) by measuring the gamma radiation, it also allowed correction for the gamma-induced background in the neutron detector; 3) it provided a measurement of the charged-particle environment in which the system was operating; and 4) it would detect positrons emitted by the reactor (when both the reactor and the detector are located on the same geomagnetic L-shell) and would determine their spectral distribution. The design of the instrument, shown schematically in Fig. 2.12, is based upon commercially available 3 × 3 in. scintillation gamma-ray spectrometers and custom organic (plastic) scintillation spectrometers for the detection of charged particles. The two charged-particle spectrometers were each positioned between a pair of gamma-ray spectrometers, providing an indication of the detection of a positron through the detection of the two 0.511 MeV coincident positron annihilation gamma-rays. This configuration provided the added advantage of a γ-ray shadow collimation arrangement which helped enhance the signal-to-noise ratio of gamma fluxes emitted by a point source (yielding a modulation synchronized to

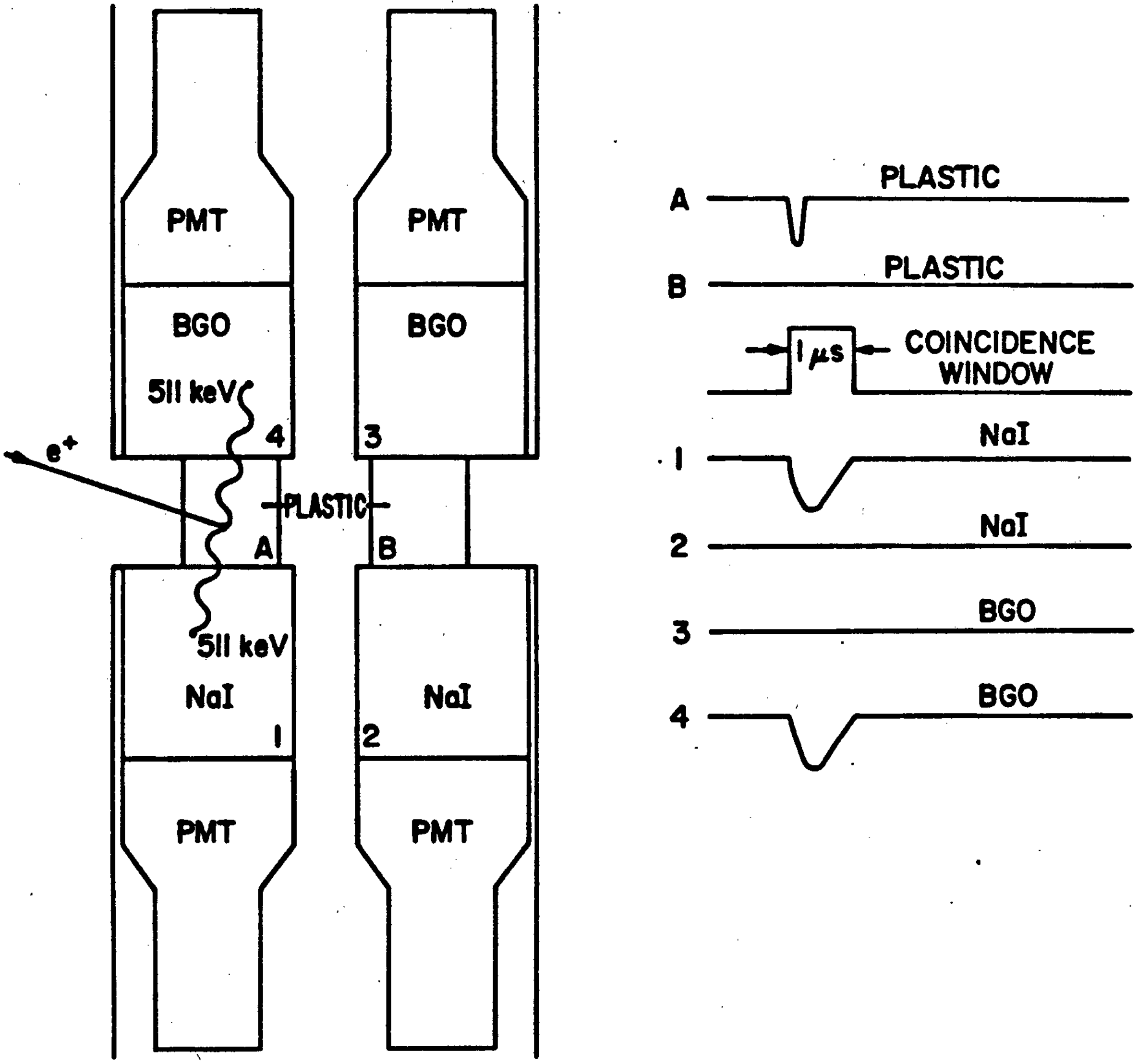


Fig. 2.12. B/G sensor.

the rocket spin rate) amidst a nearly isotropic background of ionizing radiation.

Two types of gamma-ray spectrometers were employed. Two sodium iodide (NaI) spectrometers were included in order to relate to data previously acquired by Solar Max Mission (SMM) gamma-ray spectrometers, and also to provide superior resolution at energies $\tilde{<}$ 2 MeV. Two bismuth germanate ($Bi_4Ge_3O_{12}$, or BGO) spectrometers were included to provide superior efficiency at higher energies where appreaciable fluxes are observed even in the SMM data. The gamma-ray spectrometers employed 3 in. diameter Hammamatsu type R 1307 photomultiplier tubes with resistive voltage dividers (bleeder strings). Each was contained within a housing which also served as a magnetic shield.

The charged particle detectors used plastic scintillators. The configuration of the scintillators was designed to optimize the detection and identification of positrons, within the constraints of the mission. The scintillators were coupled to 1-1/2 in. diameter RCA type C70132D photomultiplier tubes, allowing a very compact mechanical assembly. The plastic scintillators were exposed to the space environment after removal of the nose cone, and were shielded from incident light only by a thin film of aluminum deposited directly upon the scintillator and covered by an opaque layer of aerodag G. The plastic detectors will be replaced after recovery and before reuse, while the remainder of the package, within sealed containers, should require minimal refurbishment.

Calibrations of the gamma-ray spectrometer were performed utilizing menoenergetic gamma-ray sources. Total response functions were used to derive incident spectral functions from the observed response. Calibration of the particle detector was also accomplished using radioactive sources. Its efficiency in detecting positrons was measured using a ^{22}Na source and its energy resolution was determined using a ^{207}Bi conversion electron source.

3.0 PAYLOAD DESCRIPTION

3.1 General

Figure 3.1 shows a schematic representation of the overall rocket payload. From left to right, it consisted of 1) the Ogive nose containing ballast and the retro-rocket, 2) the charged-particle and gamma measurements section (G/B-Detector), 3) the neutron measurements section (N-Detector), 4) the telemetry section and 5) the payload recovery section. Without ballast, the payload weighed approximately 250 lbs. Forty pounds of ballast was added to reduce the nominal apogee altitude to the desired value.

A retro-rocket, included in the nose of the payload, was available to be fired on RF command in order to reduce the apogee altitude of both the payload and the second-stage motor. Clamshell doors forward of the retro-rocket nozzle open if retro fire is necessary. These doors were hinged to remain attached to the nose cone so that their apogee altitude would be reduced. The retro fire option was exercised in this flight.

The 42-in. long nose cone, containing the retro-rocket and ballast, was ejected from the payload after retro fire and before measurement

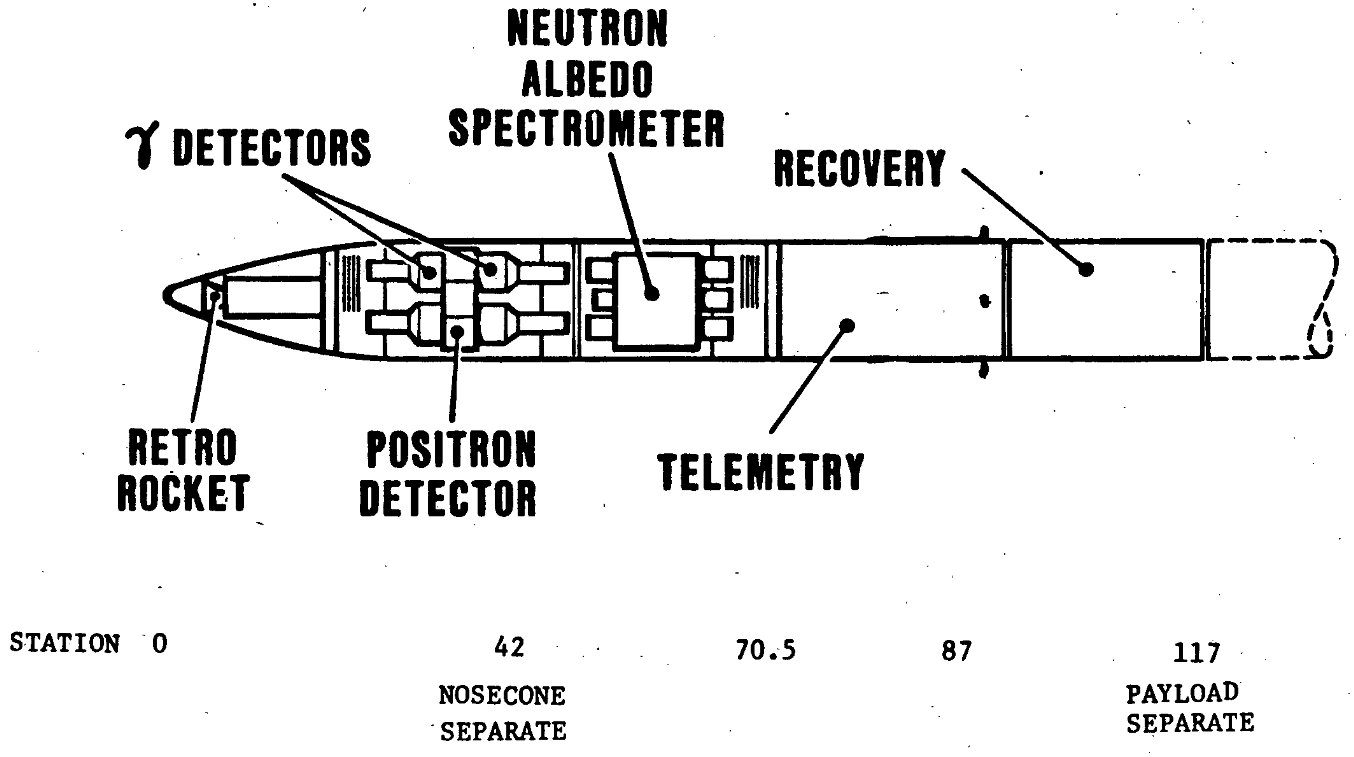


Fig. 3.1. SNL/LANL TAURUS I payload/152-236.

altitude was reached. This permitted the forward measurements section an unobstructed view.

The payload separated from the second-stage motor (Sta. 117) after the measurement period allowing the payload to tumble for reentry and recovery.

The "G" detector was mounted in two hermetically sealed cans containing detectors and related electronics. The "B" detector was mounted in an annulus between the two "G" detector cans. There was a sealed channel between the two "G" detector cans for cables. When the nose cone was jettisoned, the "B" detector was exposed to ambient pressure and temperature. The "G" detector was pressurized to 2 atm absolute with dry N_2 at T-180 minutes. The G/B package was 8 in. diamter, 24.56 in. long and weighed 36 lbs.

The "N" detector was mounted in a single hermetically sealed can containing detectors and related electronics. The can and end plates were laminated with 0.135 in. of lead and 0.05 in. conetic for additional magnetic shielding. The "N" detector was pressurized to 1.3 atm absolute with dry N_2 several days prior to launch. The "N" package was 7.5 in. in diameter, 18 in. long and weighed 51 lbs.

3.2 G-Detector Electronics

A block diagram of the G/B instrument electronics is shown in Fig. 3.2. The instruments consisted of four gamma-ray spectrometers and two plastic particle detectors. Two of the four gamma photo-multipliers viewed sodium iodide (NaI) scintillators whereas the remaining two

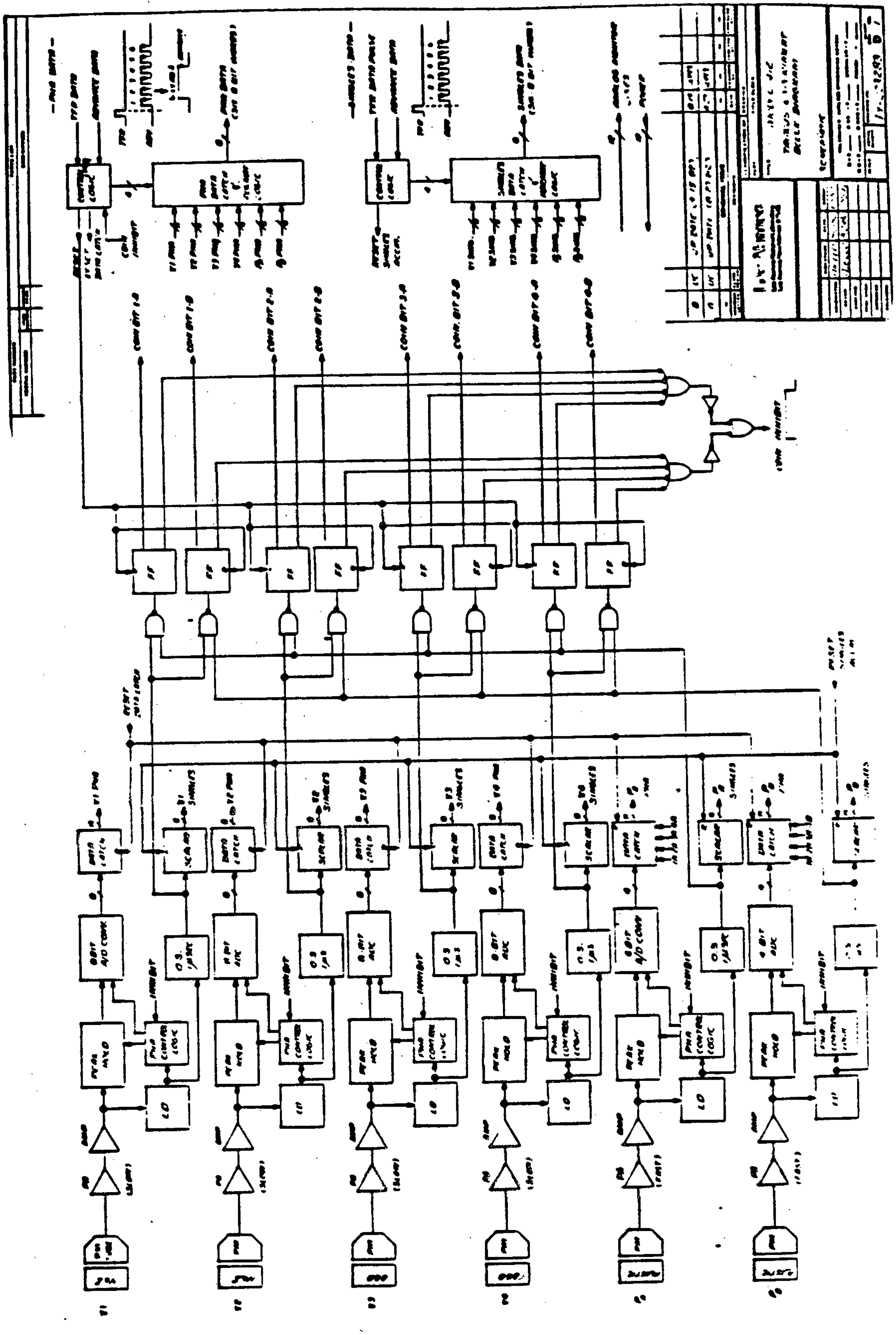


Fig. 3.2. G/B sensor electronics.

viewed bismuth germinate scintillators. Each of the six channels contained similar analog electronics for processing the signals of interest and each did so independently via its charge sensitive preamplifier, postamplifier, stretcher and analog-to-digital converter. The electrical signals from each of the gamma channels were digitized by individual 8-bit (256 levels) A/D converters and the digital data were stored two words deep in data latches and shift registers and presented as 8-bit PHA words to the PCM encoder. The main frame telemetry assignments for the four gamma PHA and the two plastic PHA words are found in Section 3.4. The response from the two plastic particle detectors was treated in a similar manner except that the A/D converter provided only 4-bit (16 level) pulse height resolution. The remaining four bits in the 8-bit PHA data word were required to identify which, if any, of the four gamma-ray spectrometers responded in coincidence (within 1 μs) with that particular pulse in the particle detector. When such a coincidence event was identified by the electronics, then further analysis was prevented and the PHA data in all channels for this event were held for readout by the PCM encoder. In addition to the six PHA data words, discrete pulses which exceed a predetermined threshold in each of the six channels were accumulated in individual 8-bit scalars and output to the telemetry as "singles" data words. These six words were commutated within the main frame as detailed in Section 3.4. The flow charts shown in Figs. 3.3 and 3.4 indicate the logic flow required for singles and PHA data readout. The logic required for handling the event (coincidence) data as opposed to the normal PHA data handling logic is indicated by the flow charts shown in Figs. 3.5 and 3.6.

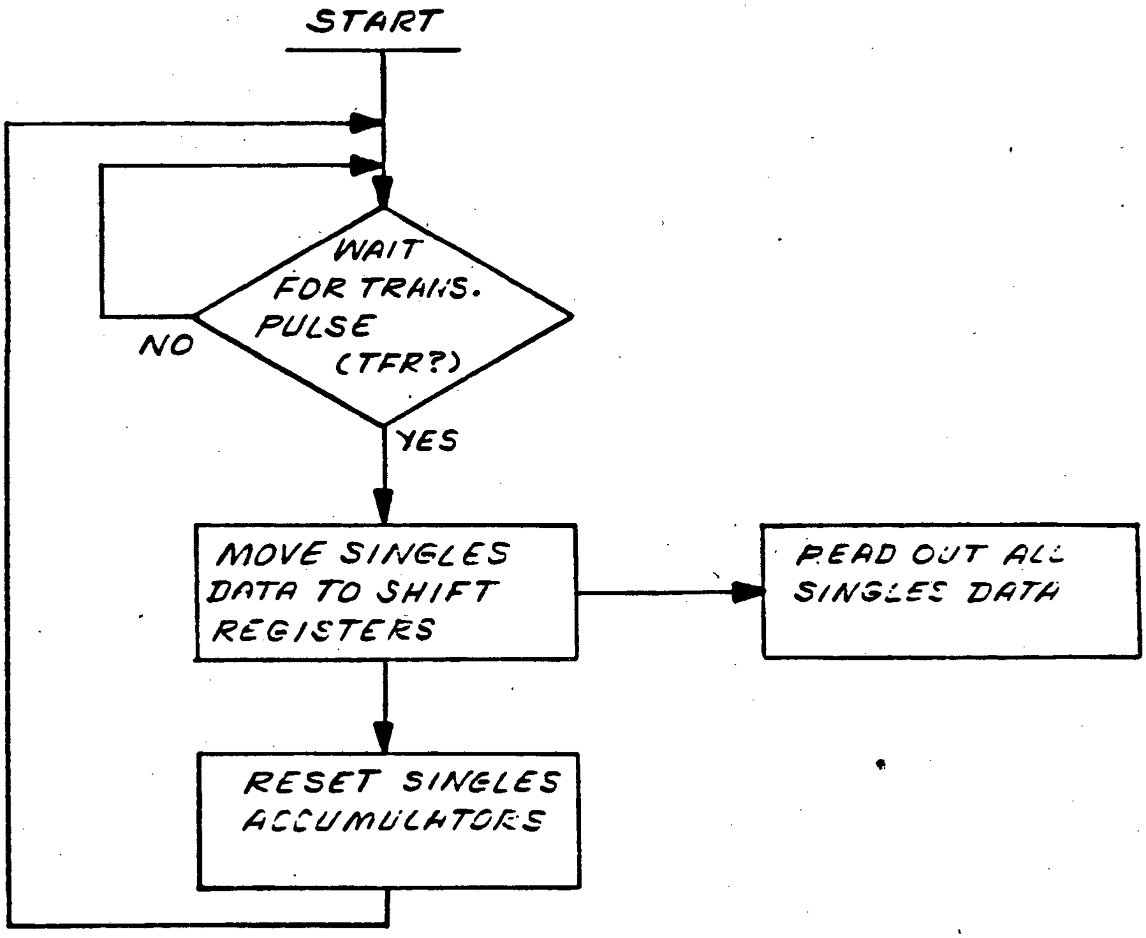


Fig. 3.3. Singles data readout.

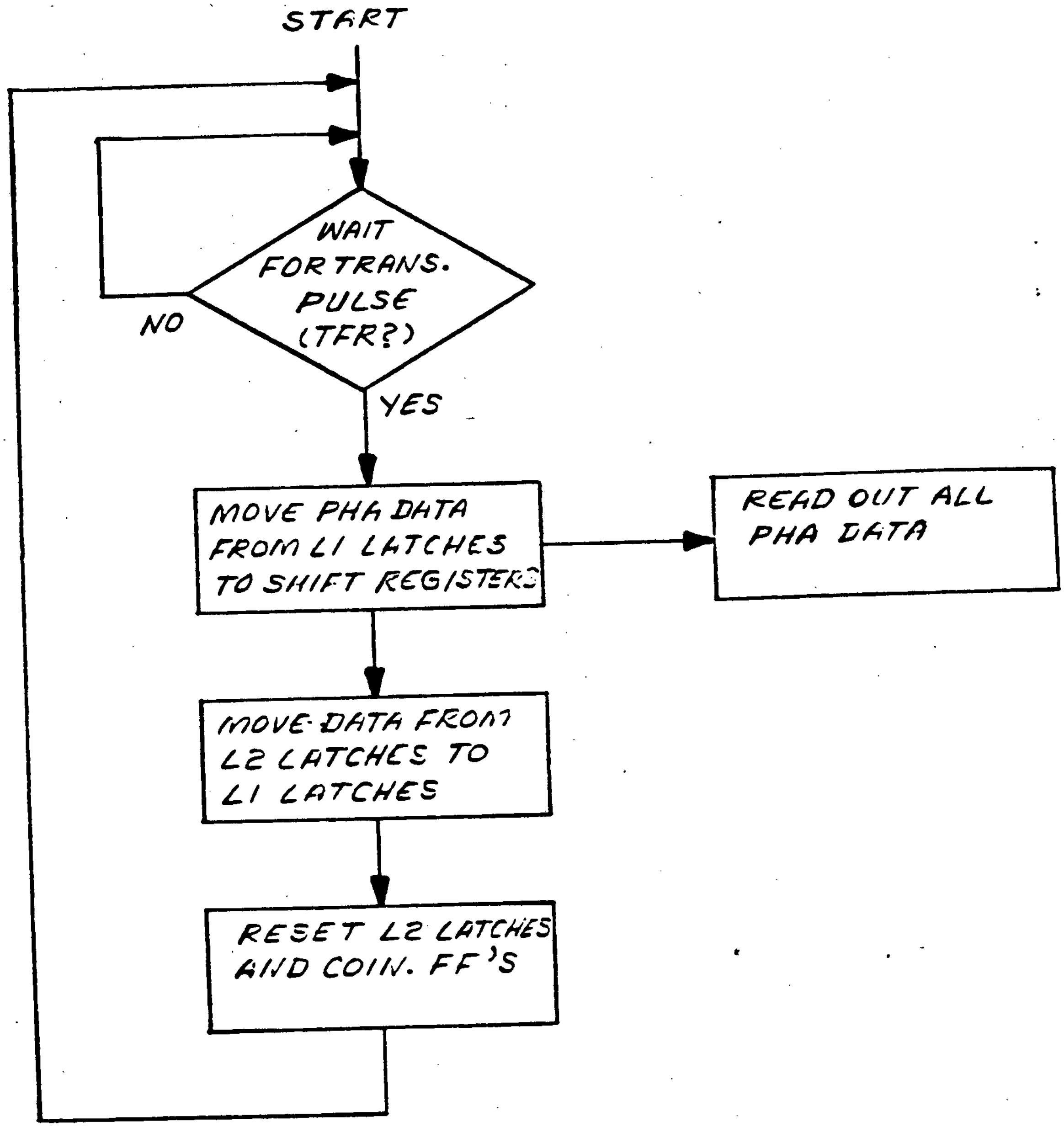


Fig. 3.4. PHA data readout.

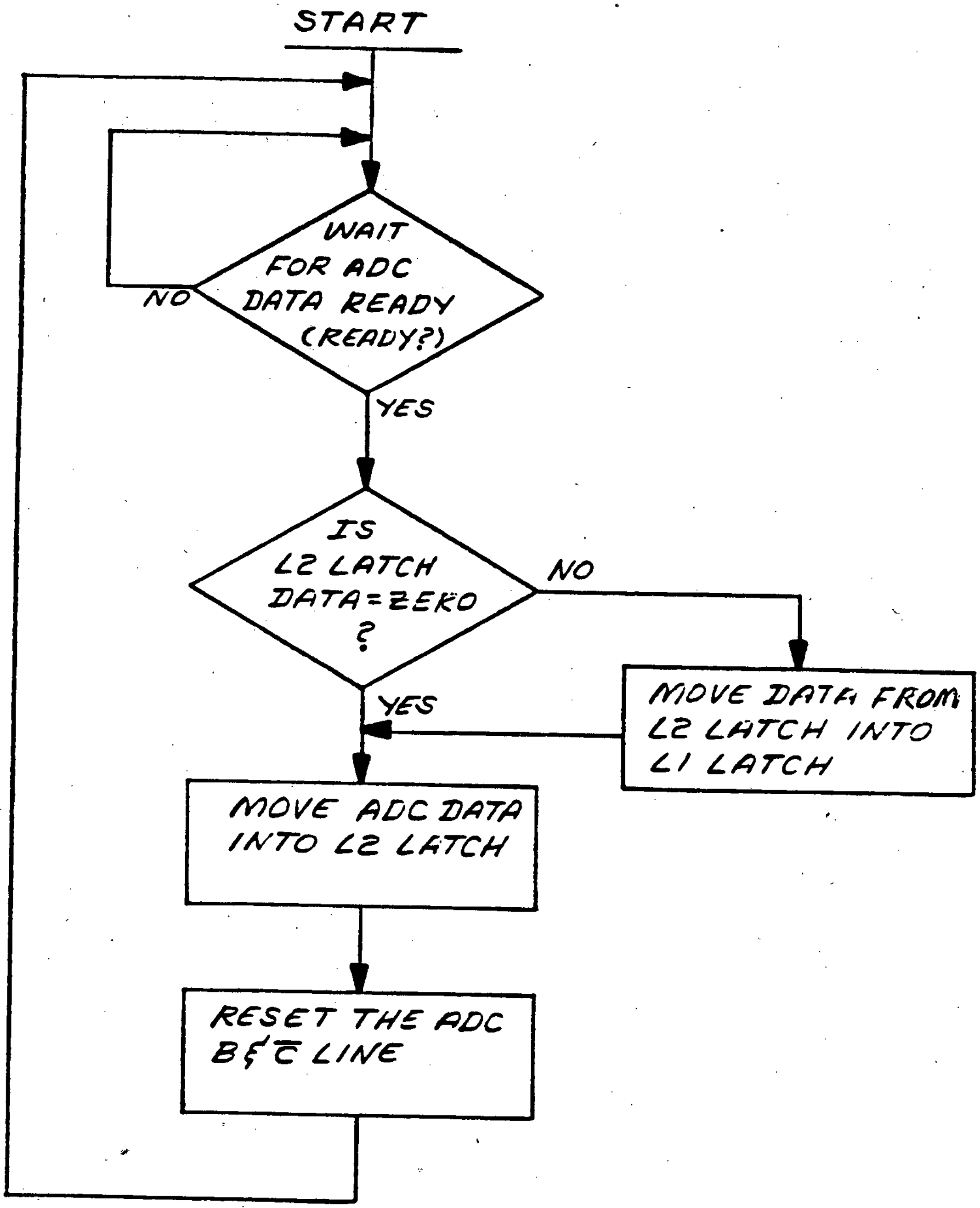


Fig. 3.5. ADC data handling.

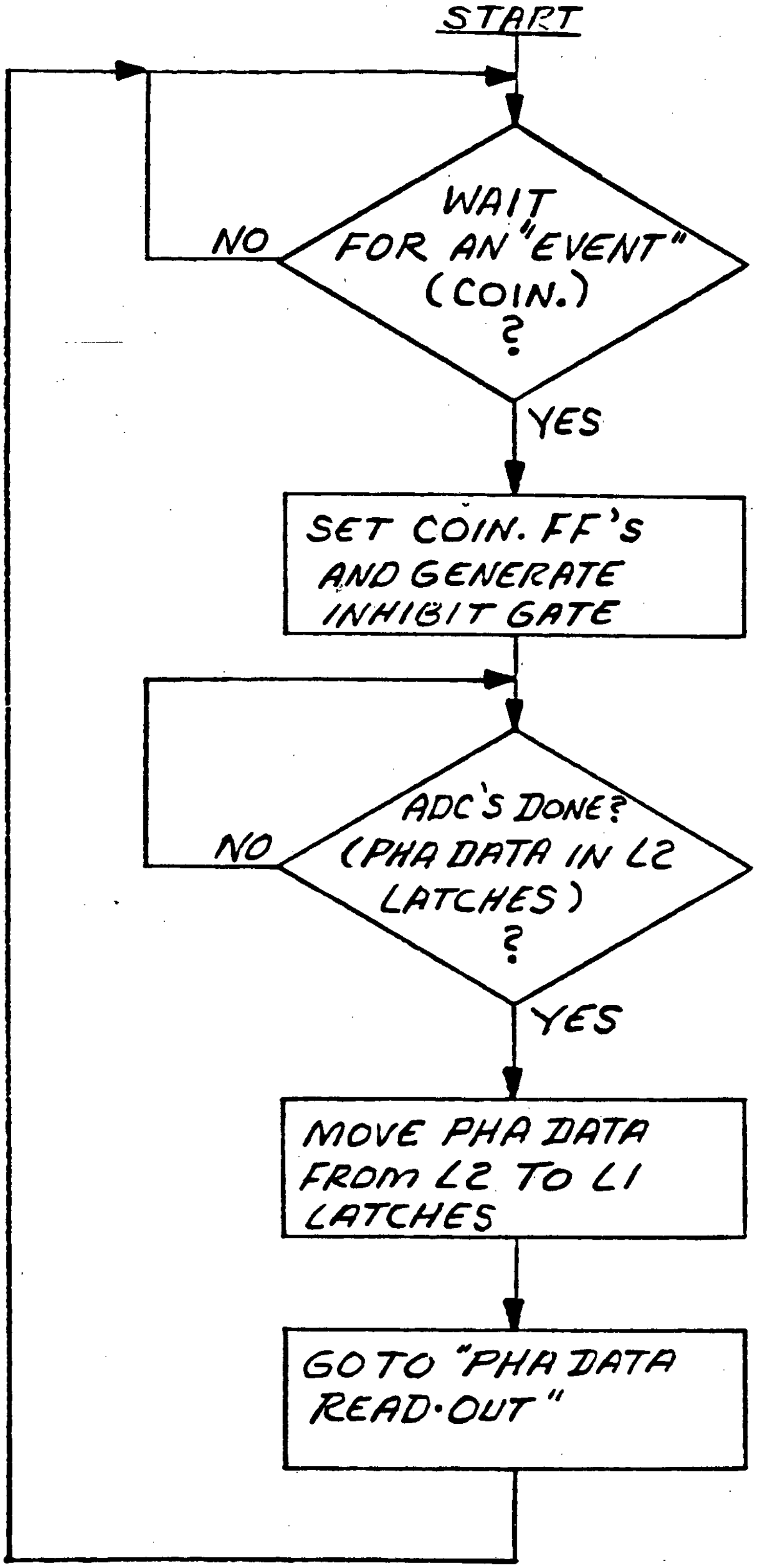


Fig. 3.6. Event data handling.

Nine G-detector performance monitors were telemetered once every 32 frames in word 74. Those are detailed in Table 3.1.

3.3 N-Detector Electronics

A block diagram of the N-Detector electronics is shown in Fig. 3.7. The signal current from all 8 photomultiplier tubes was summed together and fed into one very low noise charge sensitive preamplifier. The voltage tail-pulse from the preamp was amplified and shaped to a near Gaussian shape, monopolar response with a 5-pole filter. The leading edge to peak response time was 1.33 μs. An active baseline restorer was employed to allow count rates of 10^5/s or more to be tolerated with little distortion.

Once a pulse in this channel exceeded 40 mV in amplitude a discriminator set two time intervals in process. A 27 μs coincidence window was opened during which any ^{3}He response was detected as a "coincidence." A 3 μs delay occured after which the PMT pulse peak amplitude was strobed into a 4-bit RAM. The amplitude was converted via a 4-bit logarithmic flash A/D converter. The strobe delay cannot be retriggered during the 27 μs coincidence window and the "peak hold" circuit was reset to zero at the end of each 27 μs interval.

The singles counts from the 27 μs one-shot were accumulated in the 3-bit binary giving an indication of possible pile up in the PMT channel.

The current pulses from the ^{3}He chamber were coupled to a second charge sensitive amplifier and its voltage output amplified and shaped with a 5-pole filter to a near Gaussian, bipolar response with peak

TABLE 3.1

EXPERIMENT MONITORS, WORD 74

PARAMETER	FRAME NUMBER	NOMINAL ANALOG	NOMINAL DIGITAL	ENG. UNITS CONVERSION	ACTUAL NOM. VALUE	FUNCTION
HV-1	0	4.21	215	4.65 v/bit	1000 v.	(N) PMT 1-4 HV
HV-2	1	4.09	209	4.78 v/bit	1000 v.	(N) PMT 5-8 HV
HV-3	2	4.01	205	8.29 v/bit	1700 v.	(N) He^3 HV
T1	3	2.5	128	.196 C°/bit	variable (25°C)	(N) electronics temp
+3v	4	3.99	203	.0148 v/bit	3.00	(N) low v. mon.
+6v	5	4.05	207	.0290 v/bit	6.01	(N) low v. mon.
-6v	6	3.98	203	-.0296 v/bit	-6.01	(N) low v. mon.
HV-4	7	1.95	99	7.81 v/bit	773 v.	(G) NaI HV
HV-5	8	2.75	140	7.81 v/bit	1090v	(G) BGO HV
HV-6	9	4.25	217	4.90 v/bit	1060 v.	(G) P HV
+15	10	2.5	128	.117 v/bit	15 v	(G) low v. mon.
-15	11	2.5	128	-.117 v/bit	-15v	(G) low v. mon.
+5	12	2.5	128	.0392 v/bit	5.00 v	(G) low v. mon.
T2	13	2.5	128	.196 C°/bit	variable (25°C)	(G) NaI Temp.
T3	16	2.5	128	.196 C°/bit	variable (25°C)	(G) BGO Temp.
T4	17	3.75	191	.392 C°/bit-50°C	variable (25°C)	(G) Bkgnd, ext. temp.

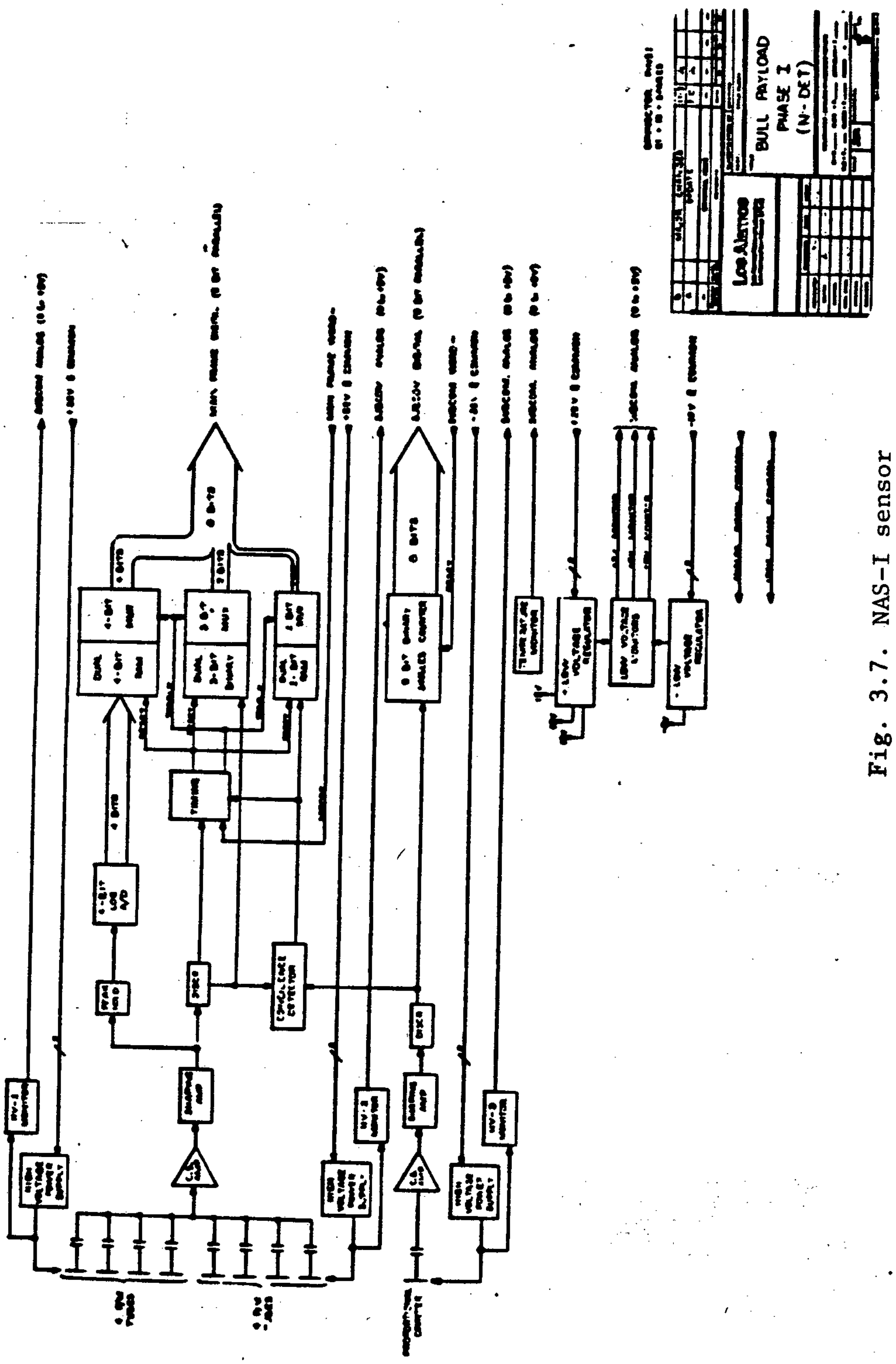


Fig. 3.7. NAS-I sensor electronics.

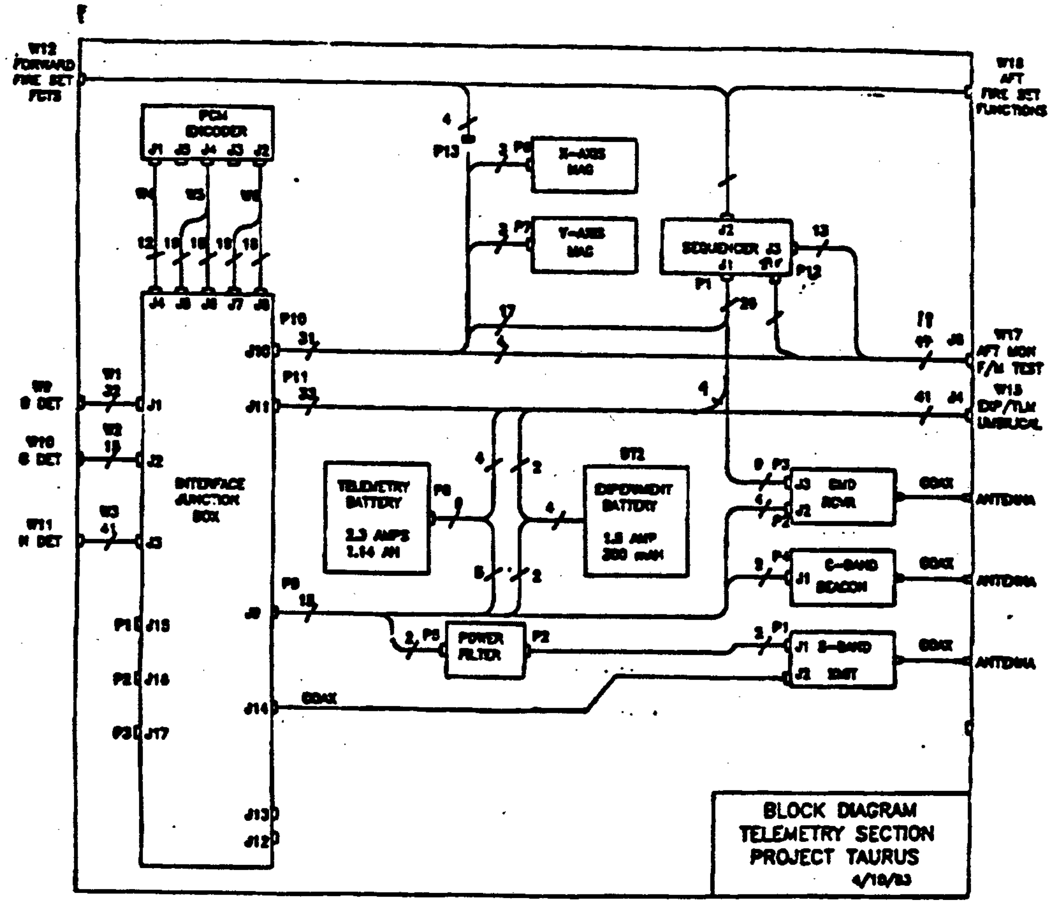


Fig. 3.8. Telemetry section electronics.

If multiple events occurred in that interval, the amplitude readout corresponded to the coincidence event. Otherwise, the amplitude readout corresponded to the last valid PMT event in the accumulation interval. Seven analog performance parameters were sampled once per 32 frames to provide experiment status data. Interpretation of these parameters is as shown in Table 3.1.

Two high-voltage power supplies delivered approximately +1000 V to each of two groups of 4 PM tubes. HV-1 monitored the high voltage for tubes 1-4 (forward group) and HV-2 monitored the high voltage for tubes 5-6 (aft group). A third high voltage supply provided +1700 volts to the ^{3}He chamber and was monitored by HV-3. A temperature monitor, T1 indicated the temperature from a sensor on the N-detector power conditioner board in the main electronics stack at the aft end of the instrument. The status of the low voltage regulation circuits was monitored by three channels looking at +3 V, +6 V, and -6 V regulated outputs.

3.4 Telemetry

Aft of the neutron detector package was the Telementry Section which provided the housekeeping functions for the payload. The principal parts of the TLM section are described below; a block diagram is shown in Fig. 3.8.

A Motorola, MCR 151 H-1, command receiver operating on 48.0 MHz received signals from the launch control center for the payload to execute specific functions. The functions and time of transmission were:

1.	Second Stage Ignition	T+18 s
2.	Nose Doors Open	T+70

amplitude at 2.2 μs. No baseline restorer was required in this channel due to the low pulse rate expected. A low level discriminator was set to respond to all valid chamber responses. An ^{3}He discriminator response was recorded in the 8-bit singles counter and set the "coincidence bit" if the 27 μs coincidence window was "open."

The main frame digital data were read out alternately approximately every 34 μs and 43 μs (see Section 3.4) in an 8-bit word made up of 4-bits log PMT amplitude (4-MSBs), 3 bits PMT singles, and 1-bit coincidence flag (LSB).

Since 27+ μs was required to process each PMT pulse, it should not often occur that more than one singles count was recorded in each readout. On the other hand, at extremely high count rates, the 27 μs window becomes shortened somewhat and it was possible under such conditions to record multiple counts (more than 2) within a sample period. Note also that once per frame, the sample interval was 60 μs.

Because the event processing time was long and event occurrences were not synchronous with TM samples, a dual set of storage elements was provided, which operated in a toggle mode with 8-bits of data always waiting to be read out while the other storage elements were waiting for storage of data. Priority logic allowed the toggle to occur asynchronously without losing data. When data were requested by the TM system, it was held constant during a sample window, after which a toggle occurred if no data were being processed, or at the end of the process whichever occurred last. The maximum wait to toggle was 27 μs.

Since coincidence data were of prime interest, whenever the coincidence bit was set, no further 4-bit log-amplitude latches were permitted.

3.	Retro-rocket Fire	T+85
4.	Nose Cone Separate	T+100
5.	"N" High Voltage ON	T+105
6.	"G" High Voltage ON	T+110
7.	Payload Separate	T+400
8.	Baro Arm	T+412

All signals received by the command receiver were routed to the SNLA designed sequencer for decoding, signal conditioning and delay as appropriate. The sequencer also contained the fire-set which generated output pulses with sufficient energy to fire the high-energy initiators used throughout the system.

A Motorola SST-171C, C-Band Radar Transponder, which received on 5750 MHz and transmitted on 5655 MHz, permitted tracking of the payload until loss of RF signal shortly before impact.

Separate batteries were included for the experiment and the TLM sections. The batteries were remotely activated, primary reserve silver-zinc, and were capable of powering the payload in excess of 60 minutes.

A Schonstedt, Model MND-5C-200/500, dual-axis magnetometer provided information on the payload pointing vector as a function of time.

A Loral Data Systems, Model PCM-460A-24 PCM, encoder converted the analog state-of-health and bi-level experiment data to a serial NRZ-L bit-stream for transmission. Telemetry frame assignments are listed in Table 3.2 below. Each frame consisted of 83 9-bit words, each with the last bit providing odd word parity. Word 74 in each frame was subcommutated to provide 32 analog performance parameters which are identified

TABLE 3.2

TAURUS MAIN FRAME TELEMETRY ASSIGNMENTS

DATA	WORD NUMBER								
FRAME SYNC	0								
FRAME SYNC	1								
FRAME SYNC + SFID	2								
NEUTRON PHA	3	12	21	30	39	48	57	66	75
GAMMA 1 PHA	4	13	22	31	40	49	58	67	76
GAMMA 2 PHA	5	14	23	32	41	50	59	68	77
GAMMA 3 PHA	6	15	24	33	42	51	60	69	78
NEUTRON PHA	7	16	25	34	43	52	61	70	79
GAMMA 4 PHA	8	17	26	35	44	53	62	71	80
P1 PHA	9	18	27	36	45	54	63	72	81
P2 PHA	10	19	28	37	46	55	64	73	82
NEUTRON SINGLES	11								
GAMMA 1 SINGLES	20								
GAMMA 2 SINGLES	29								
GAMMA 3 SINGLES	38								
GAMMA 4 SINGLES	47								
P1 SINGLES	56								
P2 SINGLES	65								
ANALOG SUBCOM	74								

in Table 3.3. The subcom frame number was identified in bits 5 through 9 of main frame word 3. Main frame sync was provided by the sync pattern, 111110101, 001100010, 0000, which occurred in words 0 1, and the first 4 bits of word 2 in every main frame. Various TM system sample rates and intervals are listed in Table 3.4.

The Interface Junction Box provided a method of interconnecting the TLM components. It also contained internal/external power relays and relays for turning experiment power on/off, as well as the ±15-V experiment power supply and circuits for interfacing the experiment data with the PCM encoder.

A Loral Data Systems, Model CTS-702 V, 3 W, S-band FM telemetry transmitter operating on 2263.5 MHz was used to transmit the payload data to the KTF receivers.

3.5 Rocket System Description

The Sandia developed Terrier-Tomahawk 9 (TT9) rocket system was used to carry the payload to measurement altitude. This system was a two-stage solid propellant, unguided vehicle that exhibits well characterized, low dispersion flight performance. It has been used to carry more than 30 9-inch diameter payloads weighing between 165 and 330 lbs for the purpose of scientific measurements. Figure 3.9 is a sketch of the TT9 system with the TAURUS payload attached.

The first- and second-stage motors were connected with a slip-fit, conical interstage adapter that was clamped to the Terrier motor and slides into the Tomahawk nozzle exit cone and throat. The first stage booster separated from the second-stage system as the Terrier motor

TABLE 3.3

TAURUS ANALOG SUBCOM ASSIGNMENTS

FRAME NUMBER	DATA
0	HV1
1	HV2
2	HV3
3	TEMP 1
4	+3 VOLT MON
5	+6 VOLT MON
6	−6 VOLT MON
7	HV4
8	HV5
9	HV6
10	+15 VOLT MON
11	−15 VOLT MON
12	+5 VOLT MON
13	TEMP 2
14	X-AXIS MAGNETOMETER
15	Y-AXIS MAGNETOMETER
16	TEMP 3
17	TEMP 4
18	GROUND
19	TIMER FLAG LINE
20	F/M BAT & SEP MON
21	F/M CAP & H/S MON
22	AXIAL ACCELERATION
23	G-SWITCH MONITOR
24	HV ON/OFF MON
25	CHUTE/NOSE MONITORS
26	CMD RECEIVER AGC
27	NOT USED
28	TLM BATT MON
29	EXP BATT MON
30	X-AXIS MAGNETOMETER
31	Y-AXIS MAGNETOMETER

TABLE 3.4

TAURUS DATA SAMPLE RATES

BIT RATE = 1,048,576 bps
BIT DURATION = 0.953674 E-6 sec

BITS/WORD = 9 WITH ODD PARITY

WORD RATE = 116,508 wps
WORD DURATION = 8.583 E-6 sec

WORDS/FRAME = 83

FRAME RATE = 1404 fps
FAME DURATION = 712.4 E-6 sec

NEUTRON EXP.

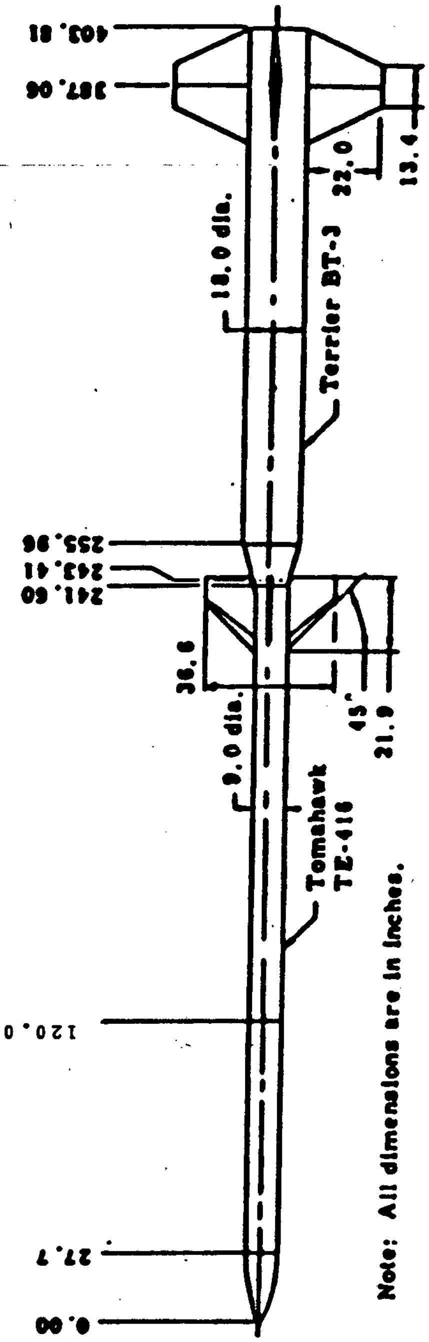
NORMAL DURATION BETWEEN SAMPLES ALTERNATES BETWEEN 4 WORDS = (34.33 E-6 sec) AND 5 WORDS (42.92 E-6 sec) AND ONCE/FRAME DURATION IS 7 WORDS = 60.08 E-6 sec

GAMMA EXP

NORMAL DURATION BETWEEN SAMPLES IS 9 WORDS = 77.25 E-6 sec
ONCE/FRAME DURATION IS 11 WORDS = 94.41 E-6 sec

ANALOG SUBCOM

DURATION BETWEEN SAMPLES IS ONCE PER 32 FRAMES
SAMPLE RATE = 43.8 Hz
SAMPLE INTERVAL = 22.8 E-3 sec



Note: All dimensions are in inches.

Fig. 3.9. Sketch of the Terrier-Tomahawk 9 rocket system.

burned out because of the aerodynamic drag/mass differential. The first-stage vehicle was aerodynamically stabilized with four trapezoidal-platform double-wedge section Terrier tail fins that have a plan area of 0.134 m^2 each.

The first-stage motor of the TT9 rocket system was the Mk 12, Mod 0 Advanced Terrier Booster developed by the Hercules Powder Company and the Naval Ordnance Station at Indian Head, Maryland. The Terrier had a principal diameter of 0.457 m (18.0 in.), a nominal total burn time of 4.60 s, and a sea-level impulse of 1.086 (10^6) N.s (244 100 lbf.s). The second-stage motor was the Tomahawk TE-416 developed by Thiokol Chemical Corporation. The Tomahawk had a principal diameter of 0.229 m (9.0 in.), a nominal total burn time of 9.91 s, and a sea-level total impulse of 421 700 N.s (94 790 lbf.s). The nominal sea-level thrust/time histories for the rocket motors are presented in Table 3.5.

TABLE 3.5

Nominal Sea-Level Thrust-Time Histories of the Advanced Terrier and Tomahawk Rocket Motors

Advanced Terrier		Tomahawk	
Time (s)	Thrust (N)	Time (s)	Thrust (N)
0.	0.	0.	0.
0.1	214140.	0.1	69530.
0.2	219690.	0.2	63830.
0.3	222498.	0.35	62920.
0.4	225510.	0.48	56060.
0.5	228560.	1.15	56960.
0.6	231260.	1.50	53100.
0.7	234490.	5.20	51550.
0.8	237950.	6.50	42060.
0.9	240850.	7.90	37080.
1.0	244420.	8.20	38620.
1.1	245900.	8.70	18670.
1.2	249700.	8.91	0.
1.3	252180.		
1.4	255880.		
1.5	259240.		
1.6	261320.		
1.8	268550.		
2.0	276240.		
2.2	283490.		
2.4	289030.		
2.6	292620.		
2.8	292940.		
3.0	294280.		
3.2	292770.		
3.4	286590.		
3.6	271170.		
3.8	242860.		
4.0	193150.		
4.1	159940.		
4.2	123240.		
4.3	84010.		
4.4	46320.		
4.5	21700.		
4.6	0.		

Advanced Terrier:

Nozzle Exit Area = $0.1596\ m^2$ ($1.7184\ ft^2$)

Total Impulse = $1.086\ (10^6)\ N \cdot s$ (244 100 lbf/s)

Tomahawk:

Nozzle Exit Area = $0.03749\ m^2$ ($0.4035\ ft^2$)

Total Impulse = 422 000 $N \cdot s$ (94 870 lbf/s)

4.0 GROUND SYSTEMS

4.1 Payload Real Time Data Acquisition

4.1.1 Purpose. The TAURUS Real Time Data Acquisition system's purposes were 1) to capture a high speed telemetry data stream and convert the data to digital form; 2) store the data in large buffers in a global section of a computer's memory; 3) add time stamps and control information to the data buffers; and 4) make the data buffers available to the real time archival and real time analysis systems.

4.1.2 Hardware and Data Flow. The hardware components of the system will be described in terms of the data flow from the point of entry into the system through arrival of the time-stamped buffers in computer memory. All the hardware described here was duplicated into two fully redundant systems, called System A and System B.

a. D/PAD One. The D/PAD One was a programmable combination bit and frame synchronizer which served as the point of entry to the data acquisition system for the serial telemetry data stream. The D/PAD converted the serial data stream into series of parallel 16-bit digital words. The telemetry data arrived at the rate of 1.048×10^6 bits/s, or one bit every 0.955 microseconds. The D/PAD took eight consecutive telemetry data bits and placed them in the eight low order bits of the 16-bit digital output word. The ninth bit was used for a parity check. If the parity indicated an error, the most significant bit (MSB) of the output word was set ON, otherwise it was set OFF. The current frame ID (0-31) was placed in bits 8 through 12 (LSB = bit zero) of the output word and bits 13 and 14 were always cleared. When the output word was assembled the D/PAD signaled via a word sync line that the information on the 16 parallel data lines then represented valid data. Since nine telemetry bits were used to compose the output word, the output rate was one 16-bit word every 8.6 microseconds or 1.86 mega-bits/s.

b. CAMAC Crate Controller. The controller was a Bi-Ra model 1302 type A-2.

c. Micro-Programmable Branch Driver (MBD). The MBD was a 300 ns programmable processor. Software for this unit was downline loaded from the host computer at startup time. The MBD's function was to readout the CAMAC memory module transferring the data via direct memory access (DMA) into a global data buffer area in the host computer's memory. At startup time the host computer gave the MBD the starting address of the global data buffers and control information. This data structure was composed of a 4-word (16-bit words) control area followed by five 6400 word data buffers. The first 6144 words of each buffer contained data transfers from the MBD (i.e., six of the 1024 word CAMAC memories). The last 256 words of each buffer contained the time stamp and buffer specific control information. The MBD was notified that a CAMAC memory bank was full by a LAM (look at me) interrupt signal. The MBD then read out and transferred the data to the host computer's memory. Each 1024 word transfer continued into successive location in the host's memory until 6144 words had been transferred. When one of the buffers had been filled the MBD notified the host via an I/O interrupt and then calculated a new starting transfer address by skipping over the 256-word time and control area or by returning to the first buffer if the fifth one was just filled. The interrupt rate to the host was about once every 52.5 milliseconds.

d. DATUM 9310 Time Code Generator/Translator. The time code translator took in an analog time signal and translated it to a digital form. In the TAURUS application we operated the DATUM in demand-response mode. When the acquisition software made a request for a time stamp it was returned three 16-bit words that contained the time to a tenth of a millisecond. The format of the words was:

Component	Word	Bits
Hundreds of Days	2	12-15
Tens of Days	2	8-11
Units of Days	2	4-7
Tens of Hours	2	2-3
Units of Hours	2	0-1
	1	14-15
Tens of Minutes	1	11-13
Units of Minutes	1	7-10
Tens of Seconds	1	4-6
Units of Seconds	1	0-3
Hundreds of Milliseconds	3	12-15
Tens of Milliseconds	3	8-11
Units of Milliseconds	3	4-7
Tenth of Milliseconds	3	0-3

e. Host Computer System. Each of the two host computers was a Digital Equipment Corp. VAX 11/750. Each VAX was equipped with 4 megabytes of memory, and floating point accelerator. Each machine had two UNIBUSes and a single MASSBUS. The MBD was attached to the host via one of the UNIBUSes while the other UNIBUS was used for a RA81 disk, the DATUM Time Code device, and real time display and control terminals. There was also a TU77 tape drive on each system attached via the MASSBUS.

4.1.3 Software. The software fell into three categories: 1) the code that was downline loaded into the MBD, 2) the device driver for the MBD; and 3) the host resident real time code.

a. MBD Code. The MBD was programmed in MBD assembly language. This was cross assembled using a MACRO library originally developed at the Los Alamos Meson Physics Facility (LAMPF) and later refined at the Tri University Nuclear Laboratory (TUNL) located at Duke University. The code was downline loaded by a FORTRAN program using facilities of the MBD driver (see below). The functions of the MBD, code called TARDAP (Taurus Data Acquisition Program), were described in the MBD hardware section above.

b. Device Driver. The VAX MBD device driver, called CXDRIVER, was obtained from TUNL. The TAURUS version was modified to support buffered data paths and multiple outstanding I/O requests. The driver functioned as the interface between CAMAC hardware and VAX software.

c. Host Resident Real Time Acquisition Code. The host resident acquisition code consisted of a control module and an acquisition module which communicated with the MBD via CXDRIVER.

c.1 Control. When the control program was invoked it created three subprocesses which it owned for the duration of the experiment. These were the data acquisition module (ACQUIRE), the Data Archival Module (ARCHIVE), and the Real Time Analysis Module (RTANL). When all processes were started Control presented a menu on the involking terminal. (See Operations section below for description of this menu.) This menu allowed the user to start, pause, and halt the experiment. In addition, it allowed the user to pass process modification requests to the archival and analysis modules.

c.2 ACQUIRE. When ACQUIRE was told by the user via Control to start the experiment (or resume following a pause) it first generated two I/O requests through CXDRIVER to the MBD. It then waited for an interrupt from the MBD. Upon receipt of a "buffer full" interrupt from the MBD, ACQUIRE took the following actions:

i. Generated another I/O request to the MBD. This was done to insure that the I/O queue was always at least one deep for the MBD. If this were not done, ACQUIRE would not be able to keep up with the MBD (recall that the MBD needs a new I/O request within 6 milliseconds and it took in excess of 10 milliseconds to generate another).

ii. ACQUIRE then requested a time stamp from the DATUM time code translator. This time code along with a count of the accumulated number of buffers processed and a logical buffer number

(1 to 5) were placed in the diagnostic portion (last 256 words) of the data buffer.

iii. ACQUIRE notified the data archiver and analysis codes as to the availability and location of the data. Note if the "W" switch was in the off position ARCHIVE was not notified. (See Operations section for details.)

iv. ACQUIRE then waited for another interrupt from the MBD.

When ACQUIRE received a pause command it purged all MBD I/O, told the user the current buffer processed counts and waited for a resume (G) command. When ACQUIRE received a halt command it waited for all I/O to complete, gave the user a buffer processed count, and then terminated.

4.1.4 Operations. To begin processing, the user logged onto the command terminal as CAMAC and typed the command SETUP. This caused the following actions.

1. The MBD was downline loaded.
2. The control task was started.
3. Control started the subprocesses: ACQUIRE, ARCHIVE, and Real Time Analysis.
4. Control displayed the following menu:

```
Enter G when ready to start or resume
Enter D to toggle display status, W to toggle write status
Graphics display is ON Archive is OFF MM:SS time
```

The last line of the menu reflected the status of process control switches and gave the minutes and seconds from the last time stamp. The display switch (D) told the analysis module whether to do graphic data display or not. Entering a D would change this switch. The write switch (W) told the ACQUIRE module whether it should inform ARCHIVE when data was available. Entering a W toggled this switch.

When the user was ready to start acquiring data, a G was entered. Control then told ACQUIRE to enable the data stream and then display the following menu:

```
Run started,
        Enter H to halt     P to pause     C to clear displays
        D to toggle display status        W to toggle write status
        Graphics display in ON ARCHIVE is OFF MM:SS time
```

The last line of this menu was identical to the first menu. At any time while the experiment was running the user could enter a C. This was passed to the analysis code as a request for a new page on the graphics outputs. Entering a P would cause ACQUIRE to stop the data stream, and then CONTROL would redisplay to the first menu. Entering an H would cause CONTROL to signal all subprocesses to terminate. Status information would then be displayed on the console by each of the modules as they terminated. When all subprocesses have terminated CONTROL would them terminate.

4.2 Payload Real Time Data Archiving

4.2.1 Purpose. The real time data ARCHIVE's purpose was to capture all the data given it by the real time acquisition code and transfer it to a disk file.

4.2.2 Environment. The ARCHIVE code operated as a subprocess of the real time acquisition control process described above. Its input came from global data buffers resident in the VAX memory. Its output was to a file resident on a RA81 disk.

4.2.3 Processing Method. When ARCHIVE was first started by CONTROL it tested to see if its output file existed. If it didn't, it would create and preformat the file. For processing speed, ARCHIVE insisted that the file be contiguous. The size of the file was dictated by the variable REC_NUM in ARCHIVE. For TAURUS, that value was 22,800 which allowed ARCHIVE to store approximately 20 minutes of data. If more than 20 minutes of data was presented to ARCHIVE, it simply "wrapped around" and continued from the beginning of the file again.

Once ARCHIVE had its output file open it signaled CONTROL that it was ready and then waited for ACQUIRE to signal that data was available. ACQUIRE signaled the availability of data by setting a common event flag which served as an "alarm clock" for ARCHIVE. The number (1 to 5) of the current buffer would have been placed in a variable, BUFF_POINT, by ACQUIRE prior to awakening ARCHIVE. ARCHIVE checked to see if the last I/O for this buffer had been completed. If it had not, ARCHIVE counted a disk overrun error and went back to "sleep."

If the last I/O was complete, a new asynchronous I/O was scheduled for this buffer. The I/O request specified that a block of ARCHIVE's code, called WRITE_AST, be invoked on I/O completion.

ARCHIVE then compared the accumulated buffer processed count to its prior value to determine if any data had been missed. If one or more buffers were skipped, the number was added to the "buffers missed" counter.

When an I/O operation completed, WRITE_AST was invoked. This routine checked the success of the write. If there was an error, a write error counter was incremented.

When the user requested shutdown via the Halt command to CONTROL, ARCHIVE waited until all its disk I/O was done and then displayed the following counts:

1. Number of buffers written
2. Number of wrap arounds
3. Number of I/O errors
4. Number of disk overruns
5. Number of buffers missed.

If no errors occur, Items 3, 4, and 5 would be zero. Item 1 should agree with the buffer write request count display by ACQUIRE. Item 2 tells how many times 20 minutes of data time was exceeded and the file was restarted.

4.3 Real Time Data Display

4.3.1 Purpose. The purpose of the real time data display was to provide a continuous graphic and printed summary of the data received during the rocket flight.

4.3.2 Environment. The real time analysis code, RTANL, operated as a subprocess of the real time acquisition control process described above. Its input came from the global data buffers in the VAX memory. The output was sent to two graphics terminals and a line printer.

4.3.3 Program Operation. Each time RTANL was started, the initialization section was run. The functioning of this section were:

1. Prompt the user for the plot scale factors. Default values (described in Sec. 4.3.4 below) appropriate for the anticipated data were provided, or alternative values might be supplied.
2. The user determined from which of the four gamma detectors data would be plotted.
3. The plot files were initialized; axes, grids, and label were drawn. The Los Alamos National Laboratory Common Graphics System Library (CGS) was used for the plotting. Plots appeared on the screens of the two auxiliary graphics terminals, one devoted to neutron data, the other to gamma data.
4. Counters and indices were initialized. Numerous constants were precomputed.
5. Headings for the analog displays were written to the line printer.

When initialization was complete, the program waited for a signal from ACQUIRE indicating that data were available in the VAX memory.

RTANL read the 6400-word buffers and processed all complete main-frames in them. (There were approximately 74 main-frames to a buffer, fractional frames at the ends are ignored). Some percentage of the buffers was always missed. Because of the high data acquisition rate there was no "dead-time" for calculations and plotting. The buffers were numbered internally, so the number of missed buffers could be determined.

Time was determined by counting buffers:

6144 words/buffer - 116508 words/s = 0.05273 s/buffer.

Some plots were made every 76 buffers (including missed buffers), (4.0078 s). Other plots and the printed output occurred at every tenth 4-second plot. The plot times were user selectable during RTAL initialization, 4 and 40 were defaults.

4.3.4 Data Analysis. The terminology below is that used in Table 3.2 (TAURUS Main Frame Telemetry Assignments) and Table 3.3 (TAURUS Analog Subcom Assignments). Each main frame word contained 16 bits. In the notation of RTANL bit 1 was the most significant, bit 16 was the least significant. Bit 1 was always the parity bit. When bit 1 = 1, the data were suspect and ignored. The frame number (0-31) was always in bits 4-8, data were in bits 9-16.

On all plots, the vertical axis represented time, increasing upwards. The plots were scaled for 600 s of data or a value selected by the user during initialization. Both graphics screens contained two plots. Singles and coincidences vs time were plotted in the left half, spectra in the right half. The beginning of each 83 words of the hexadecimal form nnFA and nn31. There were words 0 and 1 of the main frame.

The following data were displayed in real time.

1. Neutron Singles

The neutron ^{3}He singles counts were in bits 9-16 of main frame word 11. The counts were summed over the 4-s intervals (default) and at the end of each the average counts/frame was computed and scaled by the factor 0.5 × 1404 frames/s (default). These numbers (counts/s) were plotted against time (in seconds) on the "neutron screen."

2. Neutron Coincidences

When neutron coincidences occurred, bit 16 of the neutron PHA words was turned on. The number of coincidences in each 40-s plot interval was averaged over the total number of PHA words used and scaled by the factor 0.5 × 18 words/frame × 1404 frames/s. The resulting coincidences/s were plotted vs time on the "neutron screen."

3. Neutron 16-Channel Pulse Height Spectra

The energy channel numbers (0-15) were in bits 9-12 of the neutron PHA words. The occurrences of each channel number were tallied over each 40-s plot interval. The data were scaled by the default factor 30 s/count. The spectra (occurrences vs channel number) were plotted on the "neutron screen," using a linear scale at a vertical position displaced according to the plotting time. Thus, the spectra were stacked onto a single plot.

4. Gamma Singles

There were four detectors measuring gamma singles, which were all selected for plotting during the initialization phase of RTANL. The data were in bits 9-16 of main frame words 20, 29, 38, or 47. These data were treated in the same way as the neutron singles and were plotted on the "gamma screen" at 4-s intervals. The default scaling factor was 1404 frames/s.

5. Gamma 255-Channel Pulse Height Spectra

The energy channel numbers (1-255) were in bits 9-16 of the gamma PHA words of the main frame. The detector selected during the initialization phase of RTANL was used for the spectrum data. The occurrences of each channel number were tallied over each 40-s plot interval. The numbers of occurrences were plotted against channel number on the "gamma screen." The data were scaled by the default factor 1.00 and each spectrum was plotted using a linear scale at a vertical position displaced according to the time.

6. Particle Singles

Two plastic scintillators, P1 and P2, measured particles with energies in the range between 200 keV and 5 MeV. Single counts from P1 and P2 are in bits 9-16 of main frame words 56 and 65, respectively. These data are treated in the same way as the neutron singles and are plotted on the "gamma screen" using the symbols A and B at 4-s intervals.

7. P1 and P2 Coincidences

The P1 and P2 coincidences were indicated by bits 9-12 of the P1 PHA and P2 PHA words. If any of these 8 bits was on, a coincidence was tallied. The totals were accumulated for 40 s, averaged over the number of frames used, scaled by a default factor of 1404 frames/s and plotted on the "gamma screen" on a logarithmic scale.

8. Analog Subcom Data

The analog subcom data (main frame word 74) were printed every 4 s on the line printer. The data printed were the voltages and temperatures corresponding to the analog data for frames 0-13 and 16-17. The minimum and maximum values of each variable in each 4-s interval were printed.

9. Data Sync

In the large buffers we expected 74.02 frames on the average. A running ratio of frames/buffer actually observed to this expected valve was computed and printed every 4 s. The valve printed was actually 1.0 minus the ratio.

10. Quality of Data

In each frame 35 of the 83 words were looked at by RTANL. The total number of these words was tallied. The number of bad words (bit 1 = 1) was also tallied and 1 minus the ratio printed every 4 s.

4.3.5 Termination of RATANL. At the end of the experiment, when the Halt command was given to CONTROL, RTANL was stopped and there was displayed on the screen the number of buffers missed and the percentage of data lost.

4.4 Post Flight Data Analysis

4.4.1 AFTERSHOT Program - Overview. AFTERSHOT is an interactive Fortran program written for the VAX-11 to analyze and plot TAURUS data after the shot. The program is designed to permit the data to be analyzed in many different ways. The following files are used. All are on the directory (CAMAC.SOURCE).

AFTERSHOT.COM	Command file to run AFTERSHOT. To run AFTERSHOT type: AFTERSHOT The command file prompts for one of three options: a. Run only (no compile or link), b. Compile, link, and run, c. Compile and link in debug mode, run.
AFTERSHOT.FOR	AFTERSHOT Fortran program, required only if changes are to be made.

AFTERSHOT.FIX	A small file included in the executable program, required only if changes are made in the AFTERSHOT.FOR file.
AFTERSHOT.EXE	Executable version of AFTERSHOT. This file must be remade if changes are made in AFTERSHOT.FOR or AFTERSHOT.FIX.

The input data is on the disk file (CAMAC.DATA)/TAURUS.DAT. This is the raw data from the experiment and is an enormous file. All other input is entered from the terminal when requested by the program. Conventions used in entering input are given below.

Default values are almost always provided and can be obtained by typing "RETURN."

When there is a choice of letters (e.g., A, B, C = def) type "A" to get option A, type "B" to get option B. Any other character (or "RETURN") will get option C.

When there is a choice of numbers (e.g., 1, 2, 3 = def) a "RETURN" cannot usually be used--some number must by typed. Type "1" to get option 1, type "2" to get option 2. Any other number will get option 3.

When default numbers are integers, integers must be typed. When default numbers are real, real numbers (i.e., numbers with decimal points) must be typed.

Upper case letters must be typed.

When more than one item is selected, the items must be separated by commas or blanks. (e.g., A B C or A,B,C)

The program contains four main sections.

SET UP

In this section the time interval containing the data to be analyzed is selected.

READ DATA

In this section the raw data (for the time to be analyzed) is read from the disk. The types of data to be worked with are selected and extracted from the total data. Each type of data read is stored in a "data block."

PLOT PREPARATION

In this section the data blocks are prepared for plotting. Each prepared block (sometimes several from a single data block) is a "plot block."

PLOT

The plot blocks may be plotted as general plots (data vs time, channel number or energy). The plot blocks may be least squares fitted to a variety of functions and plotted. Some plot blocks may be plotted as histograms.

4.4.2 Set UP Section.

FATE OF PLOTS

Plots may be sent to the terminal (default), to a GGS metafile (which can be saved for film processing), or both.

EARLIEST TIME ON FILE

The data file contains only the last 20 minutes of data (22800 buffers). Because of the wrap-around feature, the latest data may be at the beginning of the file and the earlier data at the end. Somewhere on the file there will be an earliest record. (It is expected that there will be no wrap-around and that the earliest record will be record 1. The actual wrap-around features of the code have not been checked out).

It is necessary to provide the Julian day, hour, minutes, and seconds associated with the earliest record. When these are established they can be put into the program by changing the data statement values of BEGIN-DAY, BEGIN-HOUR, BEGIN-MINUTE, BEGIN-SECOND. These become default values.

START AND STOP TIMES OF ANALYSIS

The start and stop times of data to be analyzed must be entered in seconds. The times are determined as follows:

Find the time of interest during the experiment as recorded from the terminal. These times are in minutes and seconds corresponding to the time stamp on the data. Convert the values to seconds.

Find the hour during which the data was taken (i.e., BEGIN HOUR) and convert this to seconds.

Add the 2 numbers to get total seconds. This is the start time.

Add the number of seconds to be analyzed to get the stop time.

The plot time interval DELTAT, is the time (in seconds) over which data is to be accumulated. The accumulated data is plotted. For example, if the start and stop times are 4300 and 4500 seconDs, and DELTAT is 2 seconds, plot points containing 2 seconds of data will occur every 2 seconds, 100 points total.

4.4.3 Read Data Section.

DATA TO BE EXTRACTED FROM THE DISK FILE

There are 16 types of data avilable. As many as are desired may be selected, but all selected at one time should be compatible with the time interval and DELTAT. Typically, singles data requires a long interval and a small DELTAT, while PHA data uses a short time interval and DELTAT equal to the interval. The 16 types of data are:

Neutron Singles
Gamma-1 Singles
Gamma-2 Singles
Gamma-3 Singles
Gamma-4 Singles
P-1 Singles
P-2 Singles
Neutron PHA
Gamma-1 PHA
Famma-2 PHA
Gamma-3 PHA
Gamma-4 PHA
P-1 PHA
P-2 PHA
Gamma+P
Analog

Note: If "Neutron PHA" is selected, there will be an option of accumulating total counts (plastic singles) or channel data (spectral). Also, "Neutron Singles" data will be read. Note: If "Gamma+P PHA" is selected spectrum data from 1 of 6 detectors (4 Gamma, 2 P) will be accumulated, subject to 1 or more constraints in an event table, described below. The program prompts for both the detector and the event table constraints.

If an error is made, the opportunity to try again is provided. The actual data reading is done by Subroutine READALL.

RECORDS TO BE READ

The actual records to be read can be either entered directly or calculated from the start and stop times. The calculation is valid only if the data is continuous, that is, no gaps in time during the data acquisition. (There are approximately 19 records/s of data).

The program shows the record selected and the corresponding time.

The program will ask if the record is correct; if not another record may be chosen. If the record selected is correct, the program provides the opportunity to modify the times of the analysis. These opportunities constitute a little game to bring records and times together.

In addition, continuous and interruptable reading options are provided. The interruptable option permits ending the reading at the end of any 20 second time period. The times of each record read may be printed at the terminal.

Approximately 20 seconds of data may be read in one pass.

4.4.4 Plot Preparation Section. The available data blocks are displayed, each with a number. The blocks to be prepared for plotting are selected by number.

Note: If the "Neutron PHA" block is selected, the "Neutron (^{3}He) Singles" will also be selected and will be prepared first. One or more of several plot preparation subroutines will be called.

SINGLES

SINGLES prepares singles data and neutron PHA count data (plastic singles) for plotting.

Two plot blocks are produced for each data block.

a. Measured Counts (raw data) vs time,

b. True Counts vs time

where True Counts = Measured Counts corrected for measurement time, dead time, detector area and efficiency.

Printed output data of Measured Counts Dead Time Counts, True Counts and Statistical Weights is prepared.

NUPHA

NUPHA prepares neutron PHA channel data for plotting vs channel number or energy.

For each time interval (typically, there is only 1) 4 plot arrays are set up:

a. Coincidence counts spectrum

b. Total counts spectrum

c. Chance coincidence spectrum

d. True counts spectrum

A factor FUDGE may be calculated or entered to normalize (d) to (c).

GAMPHA

GAMPHA prepares Gamma PHA spectra for plotting. A plot block is prepared for each time (usually only one) in the data block.

PLASPHA

PLASPHA prepares P PHA spectra for plotting. A plot block is prepared for each time (usually only 1) in the data block.

GPALL

GPALL prepares the Gamma+P coincidence data for plotting. Two plots may be made--a spectrum for one of the detectors and a histogram to the event table for either of the P detectors. There are six detectors for spectra that may be plotted--4 gamma and 2 P.

The event table consists of 16 combinations of coincidences for each P-detector, and accumulates the number of events of each type.

ANALOG

ANALOG prepares analog subcom data for plotting and printing. The option of using either raw data or data converted to physical quantities (temperatures, voltages, etc) is provided. Minimum, maximum, and average values are printed and plotted as functions of time.

4.4.5 PLOTS.

Set up X-axis

The program provides for plots vs time, channel number, energy, or histogram plots. All or part of the available data may be plotted.

Plot blocks to plot

Any or all of the prepared plot blocks may be plotted on a single plot. The available plot blocks are displayed, along with the maximum value of the data in each, which is used for setting up the y-axis.

Subroutine BULLPLT is called to produce "general plots" of data vs time, channel number, or energy. Subroutine HISTOPLT is called to plot histograms of the Gamma+P Event Table. The data may be fit to any of 7 functions. This is done by Subroutine BULLFIT. A confusing number of options exist. The 7 functions are exponentials, Gaussian distributions, Lorentzian distribution and a parabola.

The data may be fit to a function in one or two sections. For example, the data on both sides of a peak may be fitted to a function, with the peak not included in the fit. A background function may be computed and subtracted from the data (and the difference fitted). The background function may be a previous fit, the sum of several previous fits, or 0. The actual fitting calculation is done by Subroutine REGRES. The plotting is done by Subroutine BPLOTID.

5.0 PRELAUNCH OPERATIONS

5.1 Schedule

Figure 5.1 shows the Field activity schedule used for the TAURUS operation. Activities concerning another payload (MAGSPACS) which was flown prior to TAURUS, are also included. Some deviations from the schedule occurred when it was necessary to work around the problems that occurred as a normal part of the operation. The only significant change was a 24-hour delay from the original planned launch time of 1600 hours (local time) September 22. This slip occurred because of a last minute open circuit in the rocket umbilical cord and probably resultant minor anomoly in the telemetry encoder, a commercial unit routinely used for rocket and satellite systems. This slip did not significantly detract from the success of the mission. In an operational scenario, launch would have been delayed until the next opportunity some seven days later.

5.2. Payload Tests. A large number of payload tests were performed during prelaunch field operation. These tests occurred in a hierarchical structure proceeding in general from the most fundamental level with the instruments connected to PIDAS units, to the most advanced levels with all flight and ground system integrated as time progressed.

The PIDAS tests accomplished checkout of the instruments independent of other system elements. The PIDAS units simulate the TM--instrument interface and log and display data from all instrument channels. These tests were performed with and without radioactive source stimulation of the instruments. Procedures and data recording occurred

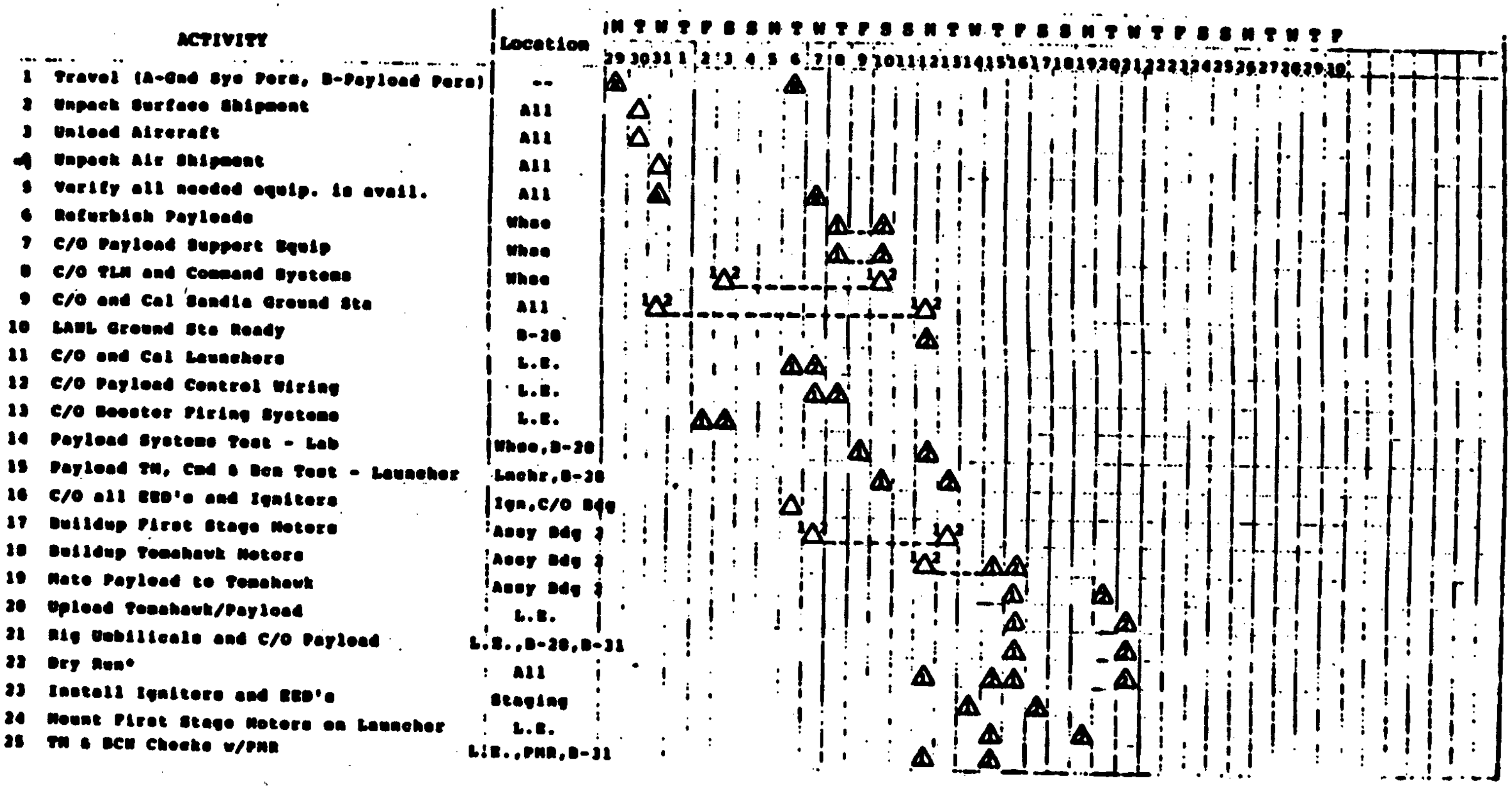


Fig. 5.1. TAURUS field activities schedule MAG SPACS (1) and TAURUS (2)

per a test plan written prior to field deployment. The objective of this level of test was to verify that instrument performance in the field was identical to that before shipment.

The next higher level of testing was a system test on a primitive level with no RF link. This test is designed to answer 4 fundamental questions:

1. Is the interface safe for the instruments?
2. Are the voltage levels correct?
3. Can the instrument be exercised correctly through the umbilical port?
4. Are the TM timing pulses correct?

This primitive level of system test was performed per a test plan written prior to field deployment.

A full range of higher level system tests was performed with varying parts of the flight and ground equipment included as time progressed. All of these tests included a RF link and either included data readout directly from a DEPAD CRT or full data recording through one of two computers as fit the needs of the test.

The highest level of testing was the "full-up" systems test. These tests evaluated all systems, including:

1. TM link from pad 19 through the 15 ft dish and 4 receivers.
2. Command RF link.
3. Power and payload control through umbilical.
4. Data acquisition through both computers.
5. Instrument stimulation from sources.

6. Fire bridge wires, simulate vehicle event sensors, instrument commands through command link.

Several dry runs were performed which were in effect full-up systems tests and countdown practices combined. These tests were designed to identify logistic flaws in the countdown script as well as to prove that all systems could perform according to the necessary sequence.

6.0 LAUNCH OPERATIONS

6.1 Countdown

The two terminal countdown procedures used for this launch are attached to this section. The first listing, Table 6.1, covers all range and vehicle operations. The second document Table 6.2 covers the payload in detail. The two countdowns were coordinated to provide a common set of milestones.

The actual countdown proceeded on schedule with no significant departures from the plan.

TAURUS participants are listed in Table 6.3.

TABLE 6.1

RANGE TERMINAL COUNTDOWN

-------------NOTES TO KAUAI TEST FACILITY COUNTDOWN CHECKLISTS----------------

1. TIMES SHOWN FOR LINE ITEMS ARE THE TIMES BY WHICH THESE ACTIVITIES SHOULD NORMALLY BE COMPLETED TO ALLOW THE ORDERLY PROGRESSION OF THE OPERATION. IF AN ACTIVITY CANNOT BE COMPLETED BY THE SPECIFIED TIME, THE TEST CONDUCTOR (TC) SHOULD BE INFORMED AS SOON AS THE SITUATION IS RECOGNIZED SO THAT CONTINGENCY PLANS MAY BE ADOPTED IF POSSIBLE.

2. THE CHECKLIST IS DISPLAYED ON VIDEO MONITORS AT KEY PLACES AROUND THE SITE. THE TIMES SHOWN ON THE DISPLAY REPRESENT THE TIME LEFT IN WHICH TO COMPLETE THE ITEM ON SCHEDULE.

   CURRENT WORLD TIME IS DISPLAYED IN THE UPPER RIGHT HAND CORNER, THE TIME TO GO IS DISPLAYED AFTER THE OPERATION NUMBER IN THE TOP CENTER OF THE SCREEN.

3. TIME INDICATIONS ARE TRUNCATED TO PROVIDE ADEQUATE RESOLUTION WITHOUT UNDUE DISPLAY CLUTTER AS FOLLOWS:

   TIMES OF MORE THAN THE ONE DAY ARE GIVEN IN DAYS AND WHOLE HOURS.

   TIMES OF LESS THAN ONE DAY BUT MORE THAN ONE HOUR AND THIRTY MINUTES ARE GIVEN IN HOURS AND WHOLE MINUTES.

   TIMES LESS THAN ONE HOUR AND THIRTY MINUTES AND GREATER THAN FIFTEEN MINUTES ARE GIVEN IN MINUTES AND SECONDS.

   TIMES OF FIFTEEN MINUTES OR LESS ARE GIVEN IN SECONDS.

4. CHECKLIST ITEMS INCLUDE, FROM LEFT TO RIGHT:

   A LINE NUMBER USED BY THE COMPUTER TO KEEP ITEMS IN ORDER.

   THE TIME LEFT TO ACCOMPLISH THE TASK.

   THE ITEM NUMBER TO BE USED WHEN REPORTING COMPLETION OF A TASK.

   IDENTIFICATION OF PERSON DIRECTING OR CLEARING INITIATION OF A TASK, USUALLY THE TEST CONDUCTOR.

   IDENTIFICATION OF THOSE WHO WILL ACCOMPLISH THE TASK.

   A BRIEF DESCRIPTION OF THE TASK.

5. WHEN A TASK IS FINISHED THE PERSON PERFORMING IT SHOULD REPORT TO THE TC AS FOLLOWS: "CHECK ITEM ___", (THE ITEM NUMBER IS GIVEN TO THE RIGHT OF THE TIME.)

OPERATIONAL ASSIGNMENTS, TAURUS I

COUNTDOWN DESIGNATOR	ASSIGNMENT	NAME
	OPERATIONS MANAGER	HOBAN
	SCIENTIFIC ADVISOR	EVANS
	OPERATIONS SUPERVISOR	ENO
	MISSION DIRECTOR	JEFFRIES
AERO	PROJECT AERODYNAMICIST	ROLLSTIN
ANTCO	ANTENNA SYSTEMS CONTROL	ANDERSON
AP	AREA PATROL	CANUTE
BC	BOOSTER CONTROL	SMELSER
BR	BALLOON RELEASE	AKIU
CMD	COMMAND TRANSMITTERS	GOEN
COMP	COMPUTER SYSTEMS CONTROL	FINNELL
EXCO	EXPERIMENT COORDINATOR	SCARLETT
FSC	FLIGHT SAFETY COORDINATOR	BARTON
GSE	GROUND SYSTEMS	MARTINEZ
LA	LAUNCHER CONTROL	WALKER
MAET	MISSILE ACCIDENT TEAM ADVISOR	WALKER
MD	MISSION DIRECTOR	JEFFRIES
PC	PAD CHIEF	CURTIS
PLAO	PAYLOAD CONTROL	MIKO
PPE	PAYLOAD PROJECT ENGINEER	LATTA
PRED	TARGET & PREDICTION COMPUTER	MILLARD
RADAR	WIND RADAR	GIPSON/MOORE
RECO	RECEIVING & RECORDING	STUCKERT
RECVY	RECOVERY SYSTEMS & OPERATIONS	JOHNSON/ BAHLMAN
TC	TEST CONDUCTOR	HAY
TD	TEST DIRECTOR	ENO

REVISION D

```
-00 05 01 00 000      TAURUS I LAUNCH
-00 05 00 00 000      --------TAURUS I TASK 1 - VEHICLE AND RANGE PREPS--------
-00 05 00 00 000      1-1         ALL     STATION TIME 1100 LOCAL
-00 05 00 30 000 VV05
-00 04 59 55 000 VV07
-00 04 59 50 000 VV08
-00 04 59 45 000      1-2  TC/  PPE     ADJUST P/L BALLAST
-00 04 30 00 000      1-3  TC/  PC      PERFORM NOSE DOOR INIT. RESIST MSMTS
-00 04 00 20 000 VV01
-00 04 00 15 000 VV02
-00 04 00 10 000 VV70
-00 04 00 00 050 VV04
-00 03 59 40 000 VV06
-00 03 59 35 000 VV07
-00 03 50 00 000      1-4         TC      PERFORM COUNTDOWN NET CHECKS
-00 03 50 00 000      1-5  TC/  ALL     VERIFY ALL STATIONS READY FOR CHECKOUT
-00 03 50 00 000      1-6                 TD
-00 03 50 00 000      1-7                 AERO
-00 03 50 00 000      1-8                 ANTENNA CONTROL
-00 03 50 00 000      1-9                 BOOSTER CONTROL
-00 03 50 00 000      1-10                COMMAND TRANSMITTERS
-00 03 50 00 000      1-11                COMPUTER
-00 03 50 00 000      1-12                EXPERIMENT COORDINATOR
-00 03 50 00 000      1-13                FLIGHT SAFETY COORDINATOR
-00 03 50 00 000      1-14                MISSION DIRECTOR
-00 03 50 00 000      1-15                PAD CHIEF
-00 03 50 00 000      1-16                PLAO
-00 03 50 00 000      1-17                PRED
-00 03 50 00 000      1-18                PPE
-00 03 50 00 000      1-19                RECO
-00 03 50 00 000      1-20 TC/BC,PLAO VERIFY ALL P/L SYSTEMS OFF
-00 03 45 00 000      1-21     PC     REMOVE P/L COVER, VERIFY UMBILICALS
-00 03 40 00 000      1-22     PC     CLEAR PAD, RETURN TO CONTROL TRLR.
-00 03 35 00 000      1-23 TC/ LA     ELEVATE LAUNCHER TO 79.5 DEGREES
-00 03 35 00 000      1-24     LA     SET LAUNCHER AZIMUTH TO 329.7 DEGREES
-00 03 05 00 000      1-25     PC     CLOSE TASK 1 (V1)
-00 03 01 00 000      ------------TAURUS I TASK 2 - PAYLOAD CHECKOUTS----------
-00 03 00 05 000 VV11
-00 03 00 00 050 VV04
-00 03 00 00 000 VV13
-00 02 56 00 000      2-1  TC/ PPE    VERIFY P/L SYSTEMS ARE ON
-00 02 55 00 000      2-2     TC,TD   INFORM PMRF THAT P/L IS ON
-00 02 53 00 000      2-3     TC,TD   VERIFY THAT PMRF IS RECEIVING SIGNALS
-00 02 50 00 000      2-4  TC/PPE,CMD PERFORM COMMAND SENSITIVITY CHECKS
-00 02 30 00 000      2-5     PPE     ADVISE P/L SYST OFF & C/O COMPLETE
-00 02 25 00 000      2-6     PPE     VERIFY P/L IS GO
-00 02 20 00 000      2-7     TC      CLEAR PC TO LAUNCH PAD
-00 02 20 00 000      2-8  TC/ ALL    COORDINATE ANY RGD ACTIVITIES
-00 02 19 00 000      2-9     AERO    OBTAIN FINAL DATA, CALCULATE PARAMETERS
-00 02 15 00 000      2-10 TC/ PC     LOWER LAUNCHER TO STOW POS'N
-00 02 10 00 000      2-11    PPE/PC  PRESSURIZE "G" SECTION
-00 02 05 00 000      2-12    PPE     REMOVE CAL SOURCES
-00 02 00 10 000 VV14
-00 02 00 00 050 VV04
-00 01 55 00 000      2-13    TC      CLOSE TASK 2 (VV16)
-00 01 50 00 000      ---------TAURUS I TASK 3 - COUNTDOWN STANDBY-------
-00 01 35 00 000      3-1     TC      CLOSE TASK 3
-00 01 31 00 000      ------TAURUS I TASK 4 - P/L PREPS & BOOSTER ARMING------
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-00 01 30 11 000 VV17                                                REVISION D
 00 01 30 05 000 VV18
 00 01 30 00 050 VV04
-00 01 30 00 000 VV20
-00 01 29 00 000      4-1  TC/ PPE      VERIFY F/M SAFE & P/L SYST OFF
-00 01 28 00 000      4-2      TD       VERIFY BOOSTER PANEL KEY SAFE
-00 01 27 00 000      4-3  TC/ MD,EXCO VERIFY EXPERIMENT NET
-00 01 25 00 000      4-4      PC       CLEAR PAD OF ALL UNNECESSARY PERSONNEL
-00 01 23 00 000      4-5  TC/ PC,BC    PERFORM FINAL FIRE MODULE ARMING
-00 01 20 00 000      4-6  TC/ PC,BC    CONNECT BOOSTER FIRE UMBILICAL
-00 01 15 00 000      4-7  TD/ MD       VERIFY STUTUS & AUTHORITY TO PROCEED
-00 01 15 00 000      4-8  TC/ PPE,PC   VERIFY READY TO MOVE LAUNCHER
-00 01 14 00 000      4-9  TC/ PC,LA    PLACE LAUNCHER IN REMOTE & VERIFY
-00 01 13 00 000      4-10 TC/ PC       CLEAR ALL PERSONNEL TO SAFE AREA
-00 01 10 00 000      4-11 TC/ LA       ELEVATE LAUNCHER TO 79.5 DEGREES
-00 01 05 00 000      4-12     TC       CLEAR PC & BC TO PAD
-00 01 02 00 000      4-13     PC       REMOVE LAUNCHER BOOM SUPPORTS
-00 01 00 03 000 VV21
-00 01 00 00 000 VV22
-00 01 00 00 000      4-14     PC       REMOVE P/L SUPPORT STRAP
-00 00 55 00 000      4-15 TC/ PC,BC    INSTALL BOOSTER FIRING KEY PLUG
-00 00 50 00 000      4-16     PC       VERIFY PAD AREA READY FOR LAUNCH
-00 00 49 00 000      4-17     PC       RETURN TO DOCK AREA
-00 00 45 00 000      4-18     AP       VERIFY LAUNCH AREA CLEAR & GATE LOCKED
-00 00 45 00 000      4-19     TC       CLOSE TASK IV (VV23 & VV24)
-00 00 45 00 000      ------------TAURUS TASK 5 - COUNTDOWN STANDBY------------
-00 00 36 00 000      5-1      TC       CLOSE TASK 5
-00 00 36 00 000 SS02
-00 00 35 59 800 EE01
```

REVISION D

```
-00 00 36 00 000       TAUR TRMNL COUNT
-00 00 36 00 000       -----------TASK 6 - TAURUS TERMINAL COUNTDOWN-----------
-00 00 35 55 000 VV27
-00 00 35 45 000 RR00
-00 00 35 06 000 VV25
-00 00 35 00 050 VV71
-00 00 35 00 000       6-1 TC/  ALL      VERIFY READINESS FOR TERMINAL COUNT
-00 00 35 00 000       *                   MISSION DIRECTOR
-00 00 35 00 000       *                   TEST DIRECTOR
-00 00 35 00 000       *                   AERO
-00 00 35 00 000       *                   ANTENNA CONTROL
-00 00 35 00 000       *                   AREA PATROL
-00 00 35 00 000       *                   BOOSTER CONTROL
-00 00 35 00 000       *                   COMMAND TRANSMITTERS
-00 00 35 00 000       *                   COMPUTER
-00 00 35 00 000       *                   EXPERIMENT COORDINATOR
-00 00 35 00 000       *                   FLIGHT SAFETY COORDINATOR
-00 00 35 00 000       *                   LAUNCHER CONTROL
-00 00 35 00 000       *                   PAYLOAD CONTROL
-00 00 35 00 000       *                   PAYLOAD PROJECT ENGINEER
-00 00 35 00 000       *                   TARGETING & PREDICTION
-00 00 35 00 000       *                   RECEIVING & RECORDING
-00 00 35 00 000       6-2  TC/ AP       VERIFY SITE INTEGRITY & SAFETY
-00 00 26 00 000       6-3      CMD      PRIME TX TO LOW POWER & INITIAL ANT POS
-00 00 25 01 000 VV28
-00 00 25 00 000       6-4  TC/ AERO     CONFIRM PRELIM LCHR SET & IMPACT DATA
-00 00 24 00 000       6-5      TD       PASS SETTING & IMPACT DATA TO PMRF
-00 00 23 00 000       6-6  TC/ BC       "PRELAUNCH ENABLE" & "REMOTE POWER ON"
-00 00 22 00 000       6-7      BC       VERIFY "BSTR CONNECT" & VISICORDER ON
-00 00 21 00 000       6-10     ANTCO    ORIENT ANTENNA TO PRESET #1 POSITION
-00 00 20 01 000 VV29
-00 00 20 00 000       6-11     TD       VERIFY AUTHORITY TO PROCEED WITH MD
-00 00 18 00 000       6-12     PPE      CONFIRM P/L SYSTEMS ON, RADAR BEACON ON
-00 00 17 30 000       6-13     RECO     CONFIRM RECEIVING TELEMETERING
-00 00 16 01 000 VV30
-00 00 15 00 000       6-14     TD       ADVISE PMRF THAT TM & BEACON ARE ON
-00 00 10 01 000 VV31
-00 00 07 01 000 VV74
-00 00 07 00 000       6-15 TC/ PPE      VERIFY ALL PAYLOAD SYSTEMS ARE GO
-00 00 06 01 000 VV73
-00 00 05 30 000       6-16     ANTCO    VERIFY AT PRESET #1 & #2 DATA SELECTED
-00 00 05 01 000 VV32
-00 00 05 00 000       6-17     AERO     CONFIRM FINAL LCHR SETS & IMPACT DATA
-00 00 04 45 000       6-18     TD       VERIFY RANGE STATUS
-00 00 04 30 000       6-19     PPE      VERIFY P/L IS GO
-00 00 04 01 000 VV33
-00 00 04 00 000       6-20 TC/ LA       SET LCHR TO FINAL SETTINGS & CONFIRM
-00 00 03 45 000       6-21     TD       PASS FINAL SETTING & IMPACT DATA TO PM
-00 00 03 30 000       6-22     TD       VERIFY PMRF TRKG & DATA RECEIVING
-00 00 03 15 000       6-23     TD       MD/PMRF FINAL CLEARANCE TO LAUNCH
-00 00 03 01 000 VV34
-00 00 03 00 000       6-24 PPE/PLAO     INITIATE P/L BATTERIES
-00 00 02 30 000       6-25     PPE      VERIFY P/L BATTERIES
-00 00 02 30 000       6-26 TD/ TC       CCMP KEY TO "READY"
-00 00 02 20 000 RR01
-00 00 02 01 000 VV35
-00 00 02 00 000       6-27     PPE      VERIFY P/L ON "INTERNAL"
-00 00 01 50 000 LL00
```

```
                                                           REVISION D
-00 00 01 45 000      6-28     PRED    VERIFY THAT PREDICTOR IS RUNNING
-00 00 01 35 000      6-29     AERO    VERIFY "MIN RANGE " IS RUNNING
-00 00 01 31 400 VV37
-00 00 01 30 000      6-30     BC      SET "LAUNCH ENABLE"; VERIFY GO STATUS
-00 00 01 15 000      6-32     TD      CONFIRM RANGE IS GO
-00 00 01 01 400 VV36
-00 00 01 00 000 AA03
-00 00 01 00 000      6-33     BC      VERIFY BOOSTER ARM (MANUAL BACKUP)
-00 00 00 46 400 VV75
-00 00 00 40 000      6-34     PPE     VERIFY P/L SYSTEMS GO
-00 00 00 31 400 VV38
-00 00 00 30 000      6-35 TC /RECO    START RECORDERS 1 & 3
-00 00 00 20 000      6-36 TC /PLAO    CONFIRM COMMUNICATION ON IC NET 5
-00 00 00 10 200 VV39
-00 00 00 09 200 VV40
-00 00 00 08 200 VV41
-00 00 00 07 200 VV42
-00 00 00 06 200 VV43
-00 00 00 05 200 VV44
-00 00 00 04 200 VV45
-00 00 00 03 200 VV46
-00 00 00 02 200 VV47
-00 00 00 01 200 VV48
-00 00 00 00 200 VV49
-00 00 00 00 000 FF03
-00 00 00 00 000 LL01
-00 00 00 00 000      6-37     BC      OBSERVE FIRE FUNCTION (MANUAL BACKUP)
+00 00 00 09 800 VV50
+00 00 00 10 000      6-38 TD/ PPE     ENABLE CMD #1, "2ND STG FIRE"
+00 00 00 14 800 VV51
+00 00 00 17 505 CC01 CMD #1 - 2ND STAGE
+00 00 00 18 000      6-39     PLAO    ANNOUNCE SECOND STAGE
+00 00 00 19 800 VV52
+00 00 00 20 000      6-40     ANTCO   GO TO SLAVE IF TRACK VALID
+00 00 01 00 000      6-41 TC/ PPE     ENABLE CMD #2, "NOSE OPEN"
+00 00 01 09 735 CC02 CMD #2 - NOSE OPEN
+00 00 01 12 000      6-42     PLAO    VERIFY NOSE OPEN
+00 00 01 20 000      6-43     TD(PPE) RETRO FIRE DECISION; SEND AS REQD
+00 00 01 25 000      6-44     PLAO    VERIFY RETRO FIRE
+00 00 01 30 000      6-45 TC/ PPE     ENABLE CMDS: 4-NOSE SEP; 5-N ON; 6-G ON
+00 00 01 39 735 CC04 CMD #4 - NOSE SEPN
+00 00 01 39 800 VV55
+00 00 01 40 000      6-46     PLAO    VERIFY NOSE SEP
+00 00 01 44 735 CC05 CMD #5 - "N" HV ON
+00 00 01 49 735 CC06 CMD #6 - "G" HV ON
+00 00 01 59 800 VV57
+00 00 02 00 000      6-47     PPE     VERIFY ALL HIGH VOLTAGES ON
+00 00 02 30 000      6-48     TC      AUTHORIZE REPOS CMD ANT FOR CMDS 7&8
+00 00 02 59 800 VV57
+00 00 03 00 000      6-49 TC /RECO    START RECORDERS 2 & 4
+00 00 03 59 800 VV58
+00 00 04 59 800 VV59
+00 00 05 00 000      6-50     AERO    ADVISE MEASUREMENT RANGE
+00 00 05 59 800 VV60
+00 00 06 30 000      6-51 TC/ PPE     ENABLE CMD #7-P/L SEP & #8-BARO ARM
+00 00 06 39 735 CC07 CMD #7 - P/L SEPN
+00 00 06 49 735 CC08 CMD #8 - BARO ARM
+00 00 06 59 800 VV61
+00 00 07 10 000      6-52     PLAO    VERIFY P/L SEPN & BARO ARM CMDS
+00 00 07 30 000      6-53     TC      CCMP KEY SWITCH TO "SAFE"
```

REVISION D

```
+00 00 07 30 000 PR00
+00 00 07 59 800 VV62
+00 00 08 59 800 VV63
+00 00 09 59 800 VV64
+00 00 10 59 800 VV65
+00 00 11 30 000      6-54    PLA0     VERIFY BARO CLOSE & HV OFF
+00 00 11 59 800 VV66
+00 00 12 59 800 VV67
+00 00 13 59 800 VV68
+00 00 15 00 000      6-55    RECO     CALL REENTRY AND L.O.S.
+00 00 15 00 000 EE02 END
```

TABLE 6.2

PAYLOAD TERMINAL COUNTDOWN

TAURUS EXPERIMENT TERMINAL COUNT 4.10 p.1 9/21/83

Time	NET 5			NET 6		
T - 36 min (-2160 sec)						
				1	PI	Ready for terminal count
				2	EE	Ready for terminal count
				3	DATA	Ready for terminal count
T - 35 min (-2100 sec) (On NET 5)						
	6-1	ALL	Ready for terminal count			
	*		EXPERIMENT COORDINATOR			
	*		PLAO			
		(Switch back to NET 6)				
T - 20 min (-1200 sec)						
	6-11	TD	Verify Authority to proceed with MD			
				4	DATA	Verify A & B write OFF
				5	DATA	A & B data programs GO
				6	PI	Verify A & B display ON
				7	PLAO	TLM ON
				8	PLAO	FM ON
				9	PLAO	Beacon ON
				10	PLAO	CMD FM ON
				11	PLAO	N LV ON
				12	PLAO	G LV ON
T - 18 min (-1080 sec)						
				13	EXCO	PPE: P/L Systems ON/Beacon ON
	6-12	PPE	Confirm P/L Systems ON, Radar Beacon ON			
T - 900 sec (-15 min)						
				14	EE	Verify TLM quality
				15	EE	Verify analogs nominal
T - 720 sec (-12 min)						
				16	DATA	Clear screens
				17	DATA	A & B write ON
				18	PLAO	Turn HV1,HV2,HV3 ON
				19	PLAO	Turn HV4,HV5,HV6 ON
				20	EE	Verify ALL HV ON & analogs GO
				21	PI	Verify G data nominal
				22	PI	Verify N data nominal
				23	PLAO	Turn HV OFF
				24	DATA	A & B write OFF
				25	EE	Verify ALL HV OFF & analogs GO
T - 420 sec (-7 min)						
				26	EXCO	PPE :Payload is GO
	6-15	PPE	Verify All Payload Systems are GO			
T - 360 sec (-6 min)						
				27	DATA	CLEAR screens
T - 330 sec (-5 min 30 sec)						
				28	DATA	Computer GO
				29	EE	Analogs GO
				30	PI	Data GO
				31	PLAO	GO
				32	EXCO	PPE: Payload is GO

TAURUS TERMINAL COUNT 4.10 p.2 9/21/83

T - 270 sec (-4 min 30 sec)
6-19 PPE Verify P/L is GO

T - 240 sec (-4 min)
33 PLAO Install battery key plug

T - 180 sec (-3 min)
6-24 PPE/PLAO Initiate P/L batteries
34 PLAO Initiate TLM BAT
35 PLAO Initiate EXP BAT
(call before -150 sec) 36 PLAO Verify P/L batteries
6-25 PPE Verify P/L batteries
37 DATA A & B write ON
38 PLAO TLM to INT
39 PLAO EXP to INT
40 PLAO TLM-INT-PWR
41 PLAO External PWR OFF
42 EXCO PPE: P/L to "INTERNAL"

T - 120 sec (-2 min)
6-27 PPE Verify P/L on "INTERNAL"

T - 60 sec
43 PLAO Ready to launch
44 PLAO SWITCH TO NET 5
45 DATA Ready to launch
46 PI Ready to launch
47 EE Ready to launch
48 EXCO PPE: Payload GO

T - 40 sec
6-34 PPE Verify payload systems GO

T + 69 sec
49 DATA CLEAR screens

T + 104 sec
Command 5 sent: N HV ON

T + 109 sec
Command 6 sent: G HV ON

T + 114 sec
50 EE Verify N HV ON

T + 119 sec
51 EE Verify G HV ON

T + 120 sec
52 EXCO PPE: Verify all HV ON
6-47 PPE Verify all HV ON

T + 672 sec (NOMINAL HV OFF TIME)

T + 690 sec (+11 min 30 sec)
53 EE Verify HV OFF
54 DATA HALT Data program

TABLE 6.3

Name	Organization	Name	Organization
Aiello, William P.	LANL	Kessel, D.	SNLA
Anderson, D. M.	SNLA	Langdon, J. B.	SNLA
Anderson, Richard C.	LANL	Latta, T. E.	SNLA
Baca, Louis R.	LANL	Longmire, Jerry L.	LANL
Bahlman, J. J.	SNLA	Martinez, A.	SNLA
Barnett, Charles R.	LANL	Maydew, R. C.	SNLA
Barton, W. R.	SNLA	McFarland, A. V.	SNLA
Cabral, Charles, LTC	USAF	Miko, D. W.	SNLA
Canute, Jack	SNLA	Millard, W. A.	SNLA
Cessna, James R.	LANL	Moore, Kurt	LANL
Curtis, C. J.	SNLA	Moore, W. R.	SNLA
Donham, Dorothy	LANL	Pacheco, John F.	LANL
Eno, R. L.	SNLA	Piotrowski, Michael	LANL
Evans, W. Doyle	LANL	Robertson, Cleo R.	LANL
Feldman, William C.	LANL	Rollstin, L. R.	SNLA
Finnell, R. T.	SNLA	Scarlett, Robert W.	LANL
Gardner, W. A.	SNLA	Shaw, Steven R.	LANL
Geck, W. R.	SNLA	Smelser, J. H.	SNLA
Gipson, H. E.	SNLA	Spencer, Kenneth M.	LANL
Goen, P. K.	SNLA	Stone, L. M.	SNLA
Hay, R. G.	SNLA	Stuckert, H. A.	SNLA
Hoban, T. J.	SNLA	Tech, Earl Ray	LANL
Jeffries, Robert A.	LANL	Walker, W. E.	SNLA
Johnson, D. W.	SNLA	Wright, Patricia	LANL

6.2 Intercept Calculations

The target is expected to be in a well behaved, nearly circular orbit inclined 65° with respect to the equator at an altitude near 260 km. It orbits the earth about 16 times per day (see Fig. 6.1 for a plot of the mean motion of a typical target) and repetitively covers the same ground track. The tracks are about 3.5° apart in longitude. One south-to-north and one north-to-south pass through the Kauai Test Facility intercept volume occurs about every seven days.

In an operational deployment, target tracking will be done by the worldwide tracking net of NORAD with headquarters at Cheyenne Mountain, Colorado Springs. Our principal contact there is Lt. Roger Hall (303-473-4010, ext. 3510). Lt. Hall routinely supplies Sandia with the satellite orbital elements from which the position can be calculated for any past or future time using the NORAD derived SGP-4 computer code. This code is operational on Sandia's HP-1000 computer at KTF.

NORAD will begin "enhanced tracking" of the target several days before launch to rapidly detect changes in its orbit. The orbital elements will be sent by priority TWX to the Navy facility at Barking Sands. Sandia's Aerodynamics Group will use the elements to generate a position-time plot of the target as it passes through the KTF intercept volume.

A specific point in space will be chosen for the intercept (IP), and the payload will be launched to arrive at that point where it will be stationary, relatively speaking, as the target passes above.

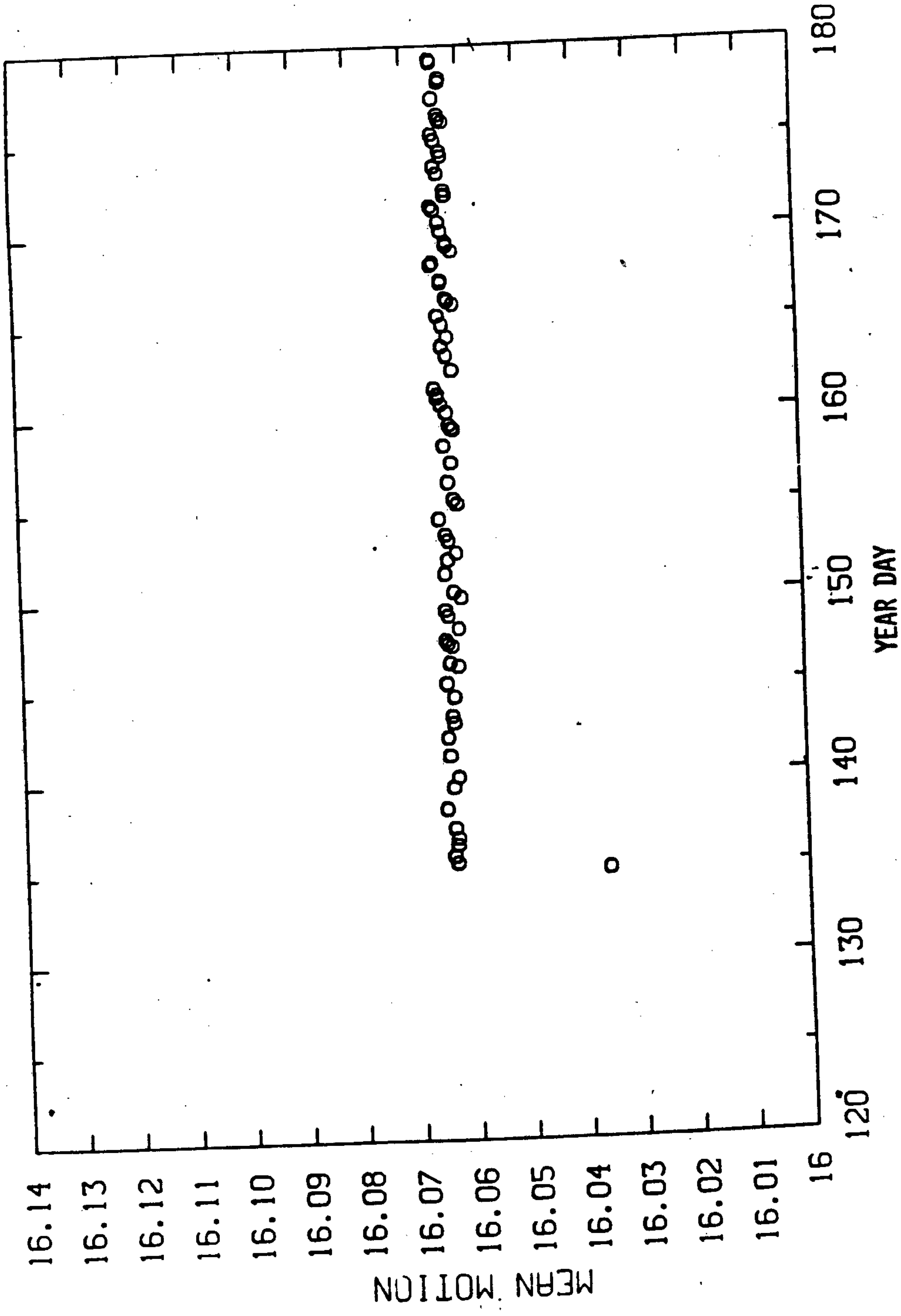


Fig. 6.1. Mean motion of typical rorsat satellite

NORAD analysis has shown that changes to the target orbit are made only at certain geographic locations and it is unlikely that changes will be made later than about nine hours before the KTF orbit. Sandia will contact NORAD two to three hours before launch to confirm the target is still on track to the IP.

For this demonstration launch, previously determined RORSAT orbital data were used to create a "virtual" satellite for targeting. All communications links that would be used operationally were exercised during this demonstration.

Intercept of the target at the planned IP requires that the rocket to fly a precise trajectory. This was accomplished by adjusting the payload weight and the launch azimuth and elevation angles. Since atmospheric winds also have a large effect on trajectory (2° elevation and 10° azimuth corrections are not uncommon), the wind profile was continuously updated. Anemometer readings from three elevations on a tower near the launcher gave near-surface winds. A continuous series of balloons were released and tracked to obtain wind data to high altitudes starting several hours before launch.

The wind balloon radar, anemometers and the minicomputer hardware and software for wind data processing were operated by the Sandia Aerodynamics Group. The computer continuously calculated launcher settings. The final setting was entered manually approximately five minutes before launch. Payload ballast was adjusted before launch, after confirmation of the IP.

The payload was tracked continuously from liftoff by four of the PMRF precision track, C-band radars (two at Barking Sands, one at the 1500-ft msl Makaha Ridge and one at 3500 msl Kokee). Digitized data were fed to the HP-1000 computer which continuously calculated the payload trajectory and predicted the x, y, z and time coordinates of apogee. These coordinates were compared with the coordinates of the IP. To demonstrate the "back-off" capability, the Test Director initiated an RF command to fire the retro-rocket and reduced apogee altitude.

If required during an actual mission, two other PMRF radars on Makaha Ridge and the 3500 ft msl Kokee radar are capable of tracking the satellite as it comes within range (about eight minutes before IP) to obtain position information on both the target and the payload from the same tracking sources.

6.3 Rocket Performance

The weight of the TAURUS payload could be incrementally adjusted between 250 and 320 lbs by adding ballast to the nose section. By adjusting the weight and the launch elevation angle (QE), any point in the sector shown in Fig. 6.2 could be reached at an apogee altitude of 250 km. Figure 6.3 shows the altitude/range capabilities of the TT9 system as a function of payload weight. TAURUS I was launched from launcher No. 19 with a payload weight of 290 lbs at a launch QE of 81.4 degrees. The trajectory and flight sequence is described below.

The Terrier motor was ignited (T-zero) at 0200Z, 24 September 1983 (1600 HST, 23 September 1983). The first-stage vehicle was rail-guided on the launcher for a distance of 26.7 ft (5.24 m) and then released (launched). The vehicle speed was approximately 162.7 m/s and the

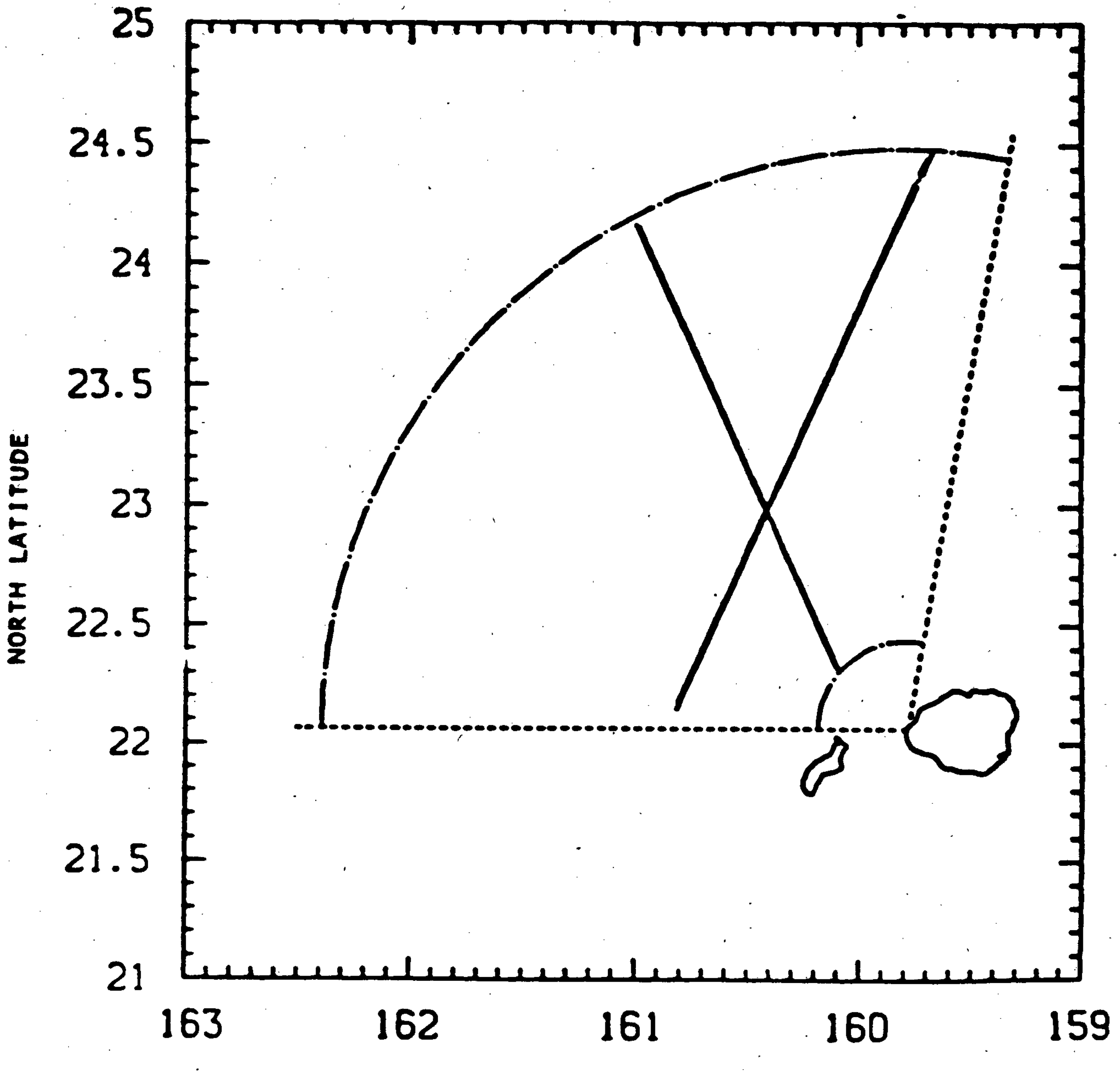


Fig. 6.2 TAURUS operational range with typical RORSAT orbits.

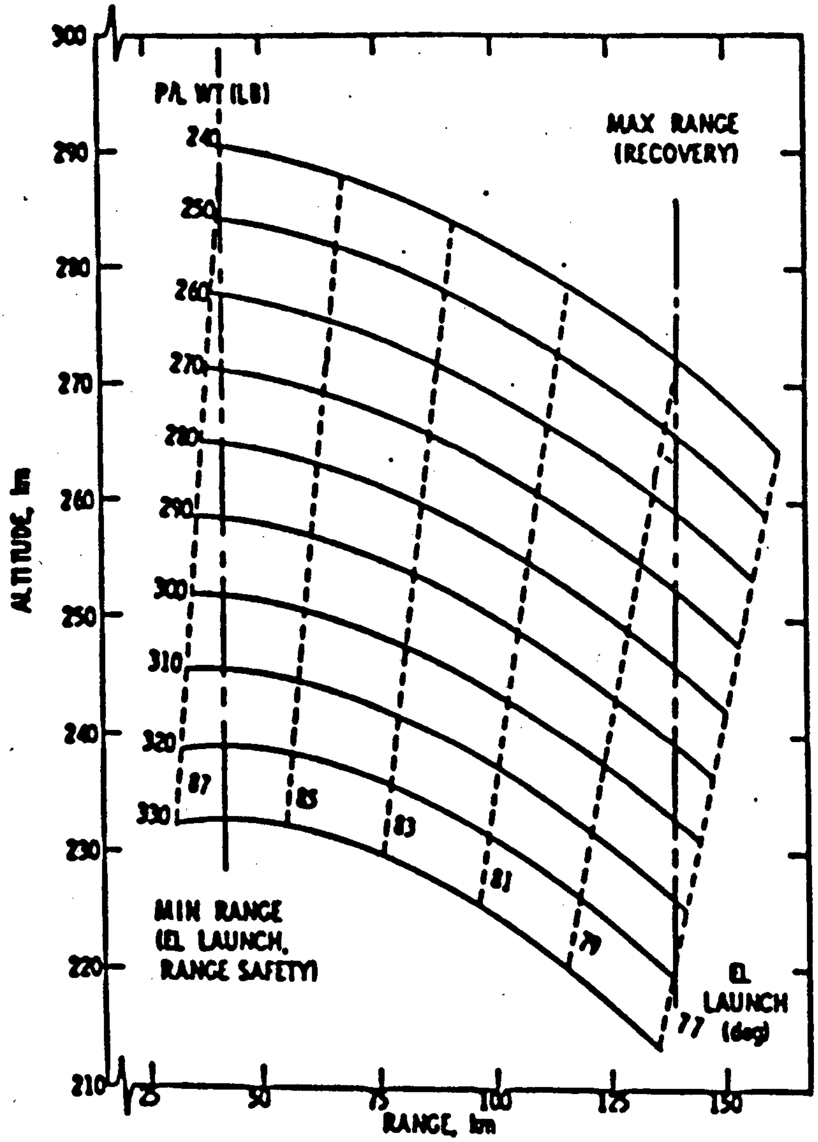


Fig. 6.3. Altitude/range capabilities of Terrier-Tomahawk system.

altitude of the system center of gravity was 22 m at launch which occurred at T+0.38s. The Terrier motor burned out and separated from the Tomahawk at T+5 s at a speed of 1.0 km/s and an altitude of 2.2 km. The second-stage vehicle coasted for approximately 13 s before the Tomahawk motor was ignited. The flight conditions at Tomahawk ignition were T+17.8 s, speed 0.68 km/s, altitude 12.8 km, elevation flight-path angle 75.7°. The Tomahawk motor burned for approximately 9 s. Flight conditions at Tomahawk burnout were T+26.5s, speed 2.1 km/s, altitude 24.0 km, elevation flight-path angle 74.5°, and Mach number 7.29. The vehicle left the atmosphere (altitude 90 km) at T+63.1s with an elevation flight-path angle near 72.0°. Uncorrected, the TAURUS I vehicle would have continued to an apogee altitude of 252 km, 125 km downrange at T+245 s and would have approached the "virtual" satellite to within 16.0 km at T+243 s.

Fifteen seconds of tracking after the vehicle left the atmosphere yielded good trajectory prediction information. At T+80s the retro-rocket was command initiated to provide a longitudinal impulse to the system of 1256 lbf.s, with a motor burn time of 2.4 s. This modified the apogee altitude to be 247 km 123 km downrange at T+245 s. Closest approach to the "virtual" satellite was 19.3 km which occurred at T+243 s. Coordinates of the satellite (object "one") and TAURUS payload (object "two") near the time of closest approach are presented in Table 6.4. Geocentric east is X, Y north, and Z up from the tangent plane through launcher No. 19, the origin. APPR is the separation of the two objects.

TABLE 6.4

TAURUS AND SATELLITE POSITIONS NEAR CLOSEST APPROACH

TIME(S)	X-ONE(KM) X-TWO(KM)	Y-ONE(KM) Y-TWO(KM)	Z-ONE(KM) Z-TWO(KM)	APPR(KM)
232.0	-99.824 -51.630	176.949 99.157	258.863 244.867	92.575
233.0	-96.745 -51.876	170.050 99.580	259.071 244.986	84.721
234.0	-93.666 -52.114	163.151 100.018	259.270 245.097	76.897
235.0	-90.587 -52.352	156.251 100.460	259.461 245.196	69.123
236.0	-87.509 -52.593	149.351 100.908	259.643 245.283	61.417
237.0	-84.430 -52.834	142.451 101.364	259.817 245.369	53.807
238.0	-81.353 -53.075	135.550 101.801	259.982 245.433	46.371
239.0	-78.275 -53.323	128.649 102.238	260.139 245.495	39.174
240.0	-75.198 -53.565	121.747 102.700	260.286 245.541	32.376
241.0	-72.121 -53.809	114.845 103.153	260.426 245.580	26.314
242.0	-69.044 -54.044	107.943 103.610	260.556 245.610	21.614
243.0	-65.968 -54.279	101.041 104.061	260.678 245.634	19.289
244.0	-62.891 -54.527	94.138 104.505	260.792 245.653	20.165
245.0	-59.816 -64.773	87.235 104.951	260.896 245.654	23.908
246.0	-56.740 -55.019	80.331 105.393	260.992 245.651	29.425
247.0	-53.565 -55.262	73.428 105.833	261.080 245.641	35.930
248.0	-50.590 -55.506	66.524 106.264	261.159 245.624	42.951
249.0	-47.516 -55.755	59.620 106.777	261.229 245.599	50.358
250.0	-44.441 -55.993	52.715 107.151	261.291 245.562	57.828
251.0	-41.367 -56.211	45.811 107.597	261.344 245.512	65.487
252.0	-38.294 -56.442	38.906 108.042	261.388 245.457	73.232

Commands were sent at T+100, T+105, T+110, and T+400 to initiate nose cone separation, "N" high-voltage turn-on, "G" high voltage turn-on, and payload separation, respectively. After separation of the booster which occurred at T+408 s, the payload, as expected, went into a flat spin until the heat shield and parachute were baro-deployed at 15 kft msl. Chute deployment occurred at T+670 s and the velocity was near 200 ft/s. A flotation bag, a strobe light and a 200 milliwatt RF beacon operating on 230.4 MHz were initiated with parachute deployment.

Payload impact was T+850 s at a velocity of around 70 ft/s, 230 km downrange. The payload trajectory was nominal and impact was within one-sigma dispersion for the Terrier-Tomahawk rocket system.

6.4 Payload Performance

Neutron and gamma-ray high voltages turned on as scheduled at 104 s and 109 s after liftoff, respectively. All neutrons and gamma-ray count rates rose immediately to their nominal values of about 35 s^{-1} for the single ^{3}He counter and ~150 s^{-1} for all the gamma-ray scintillators. This response can be seen in the on-line data plots shown in Fig. 7.1 in the following section. Although occasional times of poor data quality resulted in spurious values, and the temperature of all detectors rose with time, the data set as a whole remained solid.

6.5 Recovery Operations

A Sandia/Navy team recovered the payload using an 85 ft, all aluminum Weapon Recovery Boat stationed at PMRF, Port Allen. A Navy S2F aircraft, containing radio DF equipment, located the payload shortly after impact and vectored the recovery boat to its location. The boat, which was also outfitted with DF equipment, was deployed from Port Allen at T-9 hours and was standing by in the recovery area.

The payload, now minus the nose cone, weighed 175 lbs and displaced 140 lbs of sea water at impact. As expected, it sank, nose down, below the flotation bag that was designed to keep it suspended indefinitely. The payload was recovered at approximately 1730 local, 1-1/2 h after launch, without incident and returned to Port Allen, docking about 0530 local (9/24). After disassembly, the various payload sections were inspected and checked. All were found to be in excellent condition. Slight damage to the gamma instrument was observed, probably the result of structural damage to the sealed can (at impact) which allowed some moisture into the detector compartment.

7.0 EXPERIMENTAL DATA

7.1 Real-Time Data Processing

A. Summary. Both real-time data processing systems performed as expected with no hardware or software malfunctions. Details for each system (A and B) are given below.

B. System A Particulars (all times are Z time)

1. SETUP

   a. The system was readied at day 267, hour 1, min 15.

   b. The following RTANL initialization parameters were used:

4.0	second count rate time interval
4.0	second analog printer time interval

702.0	neutron singles scale factor
1404.0	gamma singles scale factor
1404.0	particle singles scale factor
12636.0	neutron coincidence scale factor
1404.0	particle coincidence scale factor
30.0	neutron spectrum scale factor (120.0/count rate time interval)
1.0	gamma spectrum scale factor (4.0/count rate time interval)
	gamma spectra were based on data from the number 1 detector.

2. The A system was given the G (go) command at 1:40:28. This was scheduled for T-20 minutes.
3. The C (screen clear) command scheduled for T-12 min was issued at 1:48:05.
4. The W (write on) command scheduled for T-150 s was issued at 1:48:12. The command commences a period of data recording to capture data at the high voltage on test.
5. The W (write off) command following the verification of HV and N and G nominal data was issued at 1:50:19. During this first write period, 2418 records were written to the file.
6. The W (write on) command scheduled between T-180 s and T-120 s was issued at 1:57:32. This commenced the main data recording period just prior to the payload going to internal.

7. The C (clear screen) command scheduled for t+69 s was issued at 01:14. The intent of the command is to have the last portion of the rocket's flight N and G display data on the screens following the experiment.

8. The H (halt command) was issued at 2:10:09. During the time the system was on 34155 records (6400 words buffers) were processed by ACQUIRE. Of these, 16,679 were processed by RTANL, which mean the real time displays resulted from processing 49.83% of the data. ARCHIVE wrote 16747 records to the disk file during its two recording periods.

9. During the experiment the data quality on System A was generally good. Data quality ranged from 0.0 to approximately 0.02 near loss of signal time.

   Recall that the quality number is 1.0 - (goodwords/totalwords), hence 0.0 represents perfect data quality while 1.0 indicates no valid data. See the System A analog print for details.

10. During the experiment the Data Sync on System A was generally on the order 10^{-5} to 10^{-3}.

    Recall that the sync number is defined as ((frames processed x the inverse of frames per buffer)/ buffers processed), and that the range of sync is from 0.0 to 1.0 with 0.0 being the ideal value. Since there is not an interger number of frames per buffer, small variations from zero are to be expected. See the System A analog print for details.

C. System B Particulars

1. SETUP
    a. The B System was readied at day 267 hour 1 min 15.
    b. The following RTANL initialization parameters were used:

4.0	second count rate time interval
4.0	second analog print rate
702.0	neutron singles scale factor
1404.0	gamma singles scale factor
1404.0	particle singles scale factor
12636.0	neutron coincidence scale factor
1404.0	particle coincidence scale factor
30.0	neutron spectrum scale factor (120.0/count rate time interval)
1.0	gamma spectrum scale factor (4.0/count rate time interval) gamma spectra were based on detector 4 data.

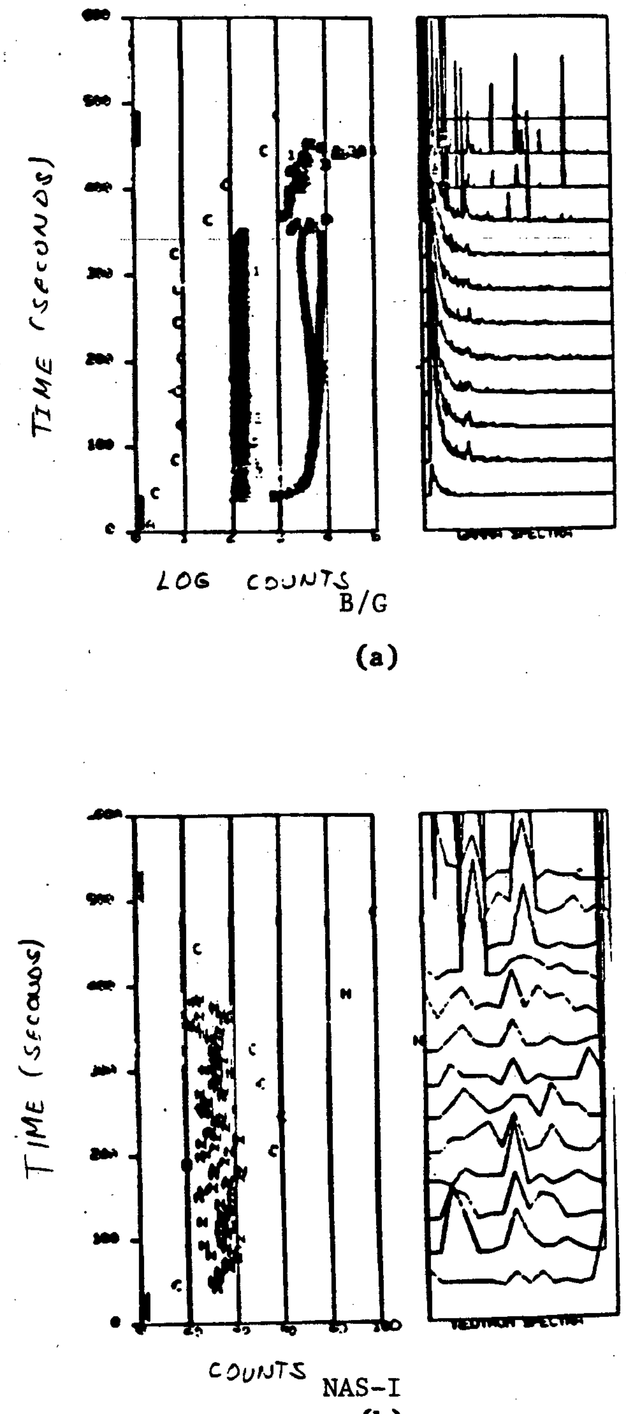
2. The B System was given the G (go) command at 1:40:25.
3. The C (screen clear) command scheduled for T-12 min was issued at 1:48:06.
4. The W (write on) command scheduled for T-150 s was issued at 1:48:15.

5. The W (write off) command following the verification of HV and N and G nominal data was issued at 1:50:19. The 2351 records were written to the file during this first write period.
6. The W (write on) command scheduled between T-180 s and T-120 s was issued at 1:57:31.
7. The C (clear screen) command scheduled for T+69 s was issued at 01:11.
8. The H (halt command) was issued at 2:10:09. During the time the system was ON 34129 records (6400 words buffers) were processed by ACQUIRE. Of these, 16772 were processed by RTANL, which means the real time displays resulted from processing 49.14% of the data. ARCHIVE wrote 16710 records to the disk file during its two recording periods.
9. During the experiment the data quality on System B degraded earlier than that on System A. The DPADs were "cross strapped" at that time. See the System B analog printout for details.

7.2 Summary of Flight Data

Plots of real time gamma ray and neutron data were displayed on-line according to the format described above. Copies of these displays for the time period following T+69 s are shown in Figs. 7.1a and 7.1b corresponding to the gamma-ray and neutron data, respectively. Inspection shows nearly all count rates rising at high voltage turn-on staying approximately steady until about T+460 s when the payload telemetry signal was lost. The exceptions are the plastic scintillator count rates which continued to rise steadily as apogee was approached. After apogee, the count rates of the two individual sensors diverged, with the count rate of Sensor B declining slightly and the count rate from Sensor A continuing to rise slightly. The reason for this behavior is not presently clear.

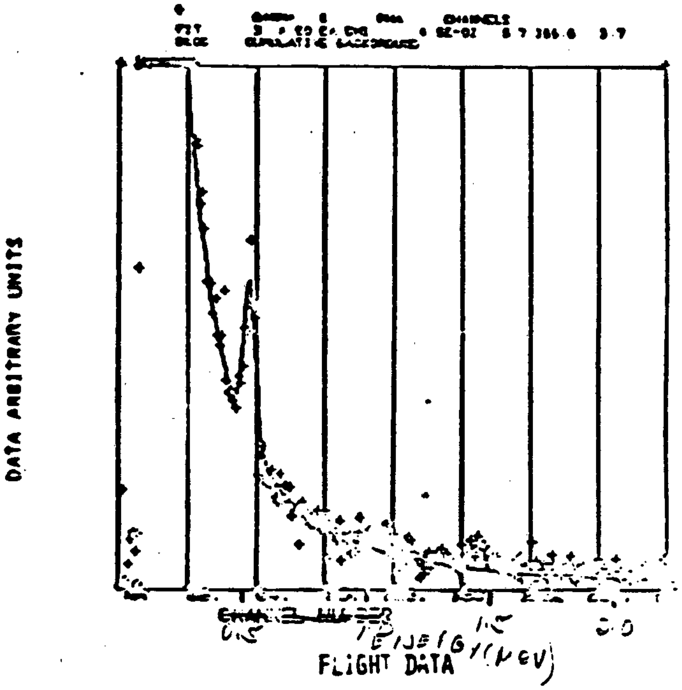
7.2.1 NaI and BGO Data. The gamma ray data returned by the NaI detectors showed a steady count rate of approximately 150 counts/s. The total gamma-ray count rates of all four 3 x 3 in. spectrometers corresponded to about 3 counts/cm^2-s. Thus, the anticipated background level of ~1000 counts/s per sensor was very conservative, and the sensitivity of the instrument in a programmatic mission would actually be somewhat greater than that quoted in the design calculations. The spectral distributions of the response observed from both sensor types were identical and consisted of a power-law background with index, α, $3.2 \lesssim \alpha \lesssim 4.0$ upon which two peaks were superimposed. The stronger peak was at 0.511 MeV and the weaker at approximately 1.45 MeV. This is shown in Fig. 7.2a. The energies of the peaks were determined from (and consistent with) a prelaunch calibration spectrum using ^{22}Na and ^{137}Cs sources as shown in Fig. 7.2b. Identical results were obtained by the BGO crystals as shown in Figs. 7.3a and 7.3b.



B/G
(a)

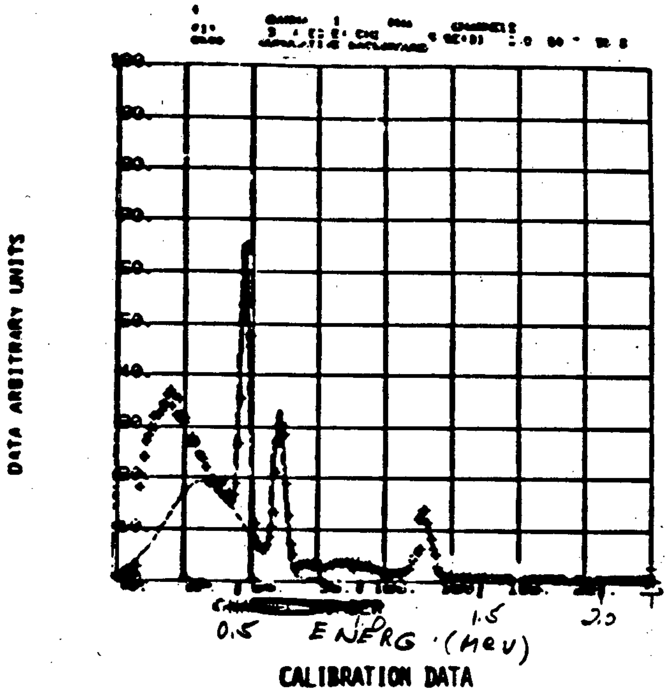
NAS-I
(b)

Fig. 7.1 Real time data display.



FLIGHT DATA

(a)



CALIBRATION DATA

(b)

Fig. 7.2. B/G NaI data.

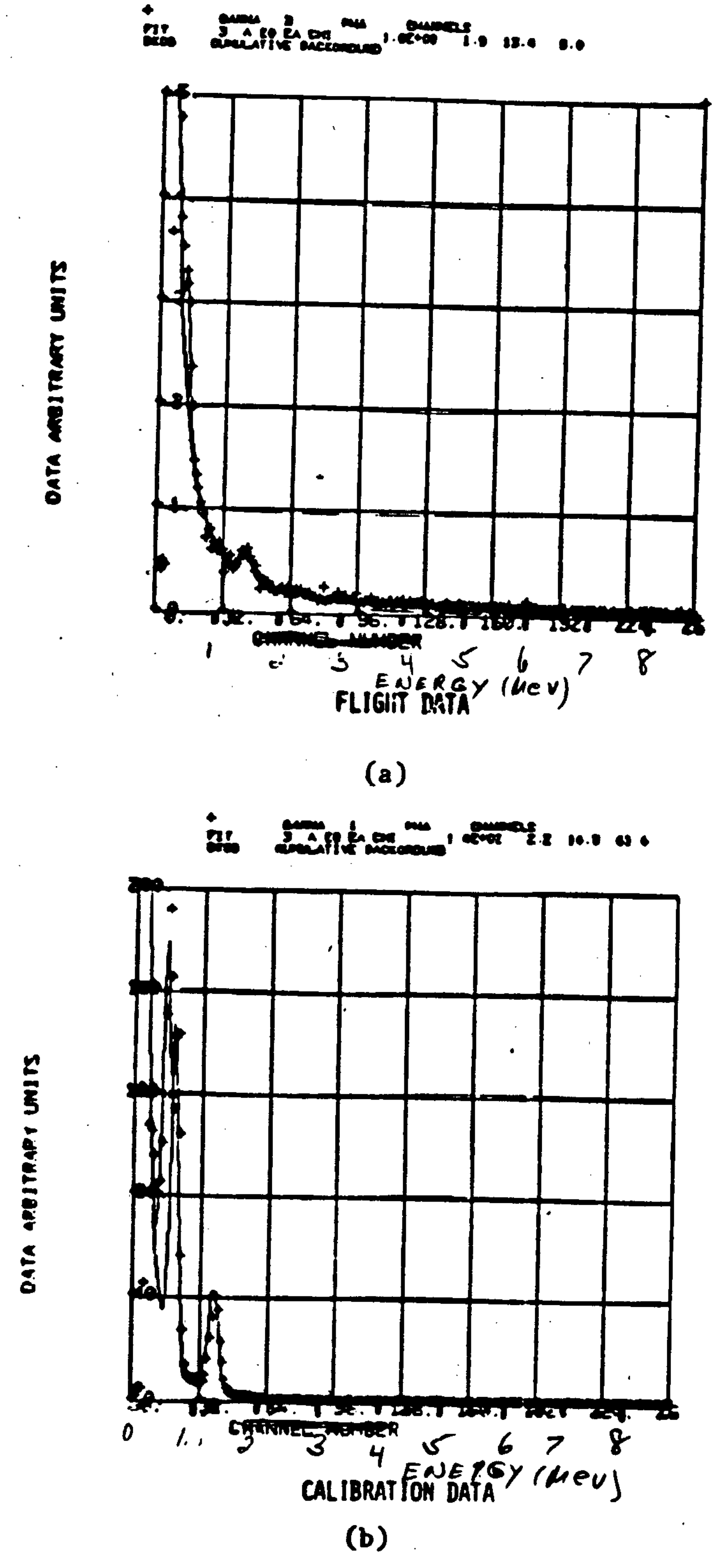


Fig. 7.3. B/G BGO data.

Whereas the 0.511 MeV line results from cosmic-ray induced positron annihilation radiation in the terrestrial atmosphere, the 1.45 MeV line resulted, most likely, from trace amounts of 40K in the glass envelopes of the photomultiplier tubes.

7.2.2 Neutron Data. Post-flight analyses of the neutron data yielded a singles count rate of the moderated ^{3}He gas proportional counts of about 35/s, a plastic scintillator singles count rate of about 750/s, and a plastic scintillator-^{3}He tube coincidence count rate for neutrons having energy, E_n, in the range between 0.45 and 5.3 MeV near 0.7/s.

The energy spectrum of singles plastics events occurring during the time interval between T+110 and T+455 s is shown in Fig. 7.4. Three peaks are evident. Whereas the lowest peak results from tube noise and gamma-rays and the peak in the highest channel results from directly-penetrating galactic cosmic rays, the very broad peak near 2 MeV results from the spectrum of terrestrial albedo neutrons folded into the energy-dependent detector efficiency and energy-level spacing.

The ^{3}He-plastic coincidence spectrum is shown in Fig. 7.5 superimposed on the spectrum expected from the separate ^{3}He tube and plastic scintillator measurements expected to occur by chance. Subtraction of the chance-coincidence spectrum correction for energy-dependent efficiencies and energy-level spacing yield the spectrum of the differential albedo-neutron flux, dJ/dE shown in Fig. 7.6. The solid line gives the best fit Gaussian function, $dJ/dE = A\exp - (E-E_a)^2/E_o$. The fit was made

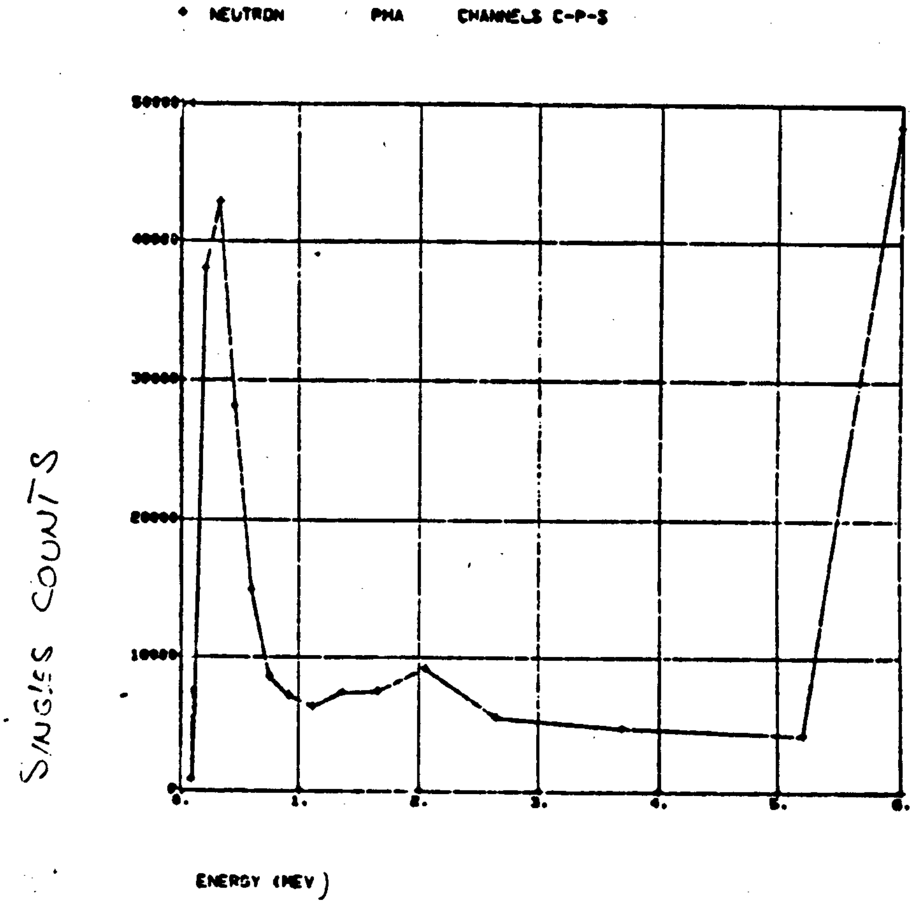


Fig. 7.4. NAS-I singles data.

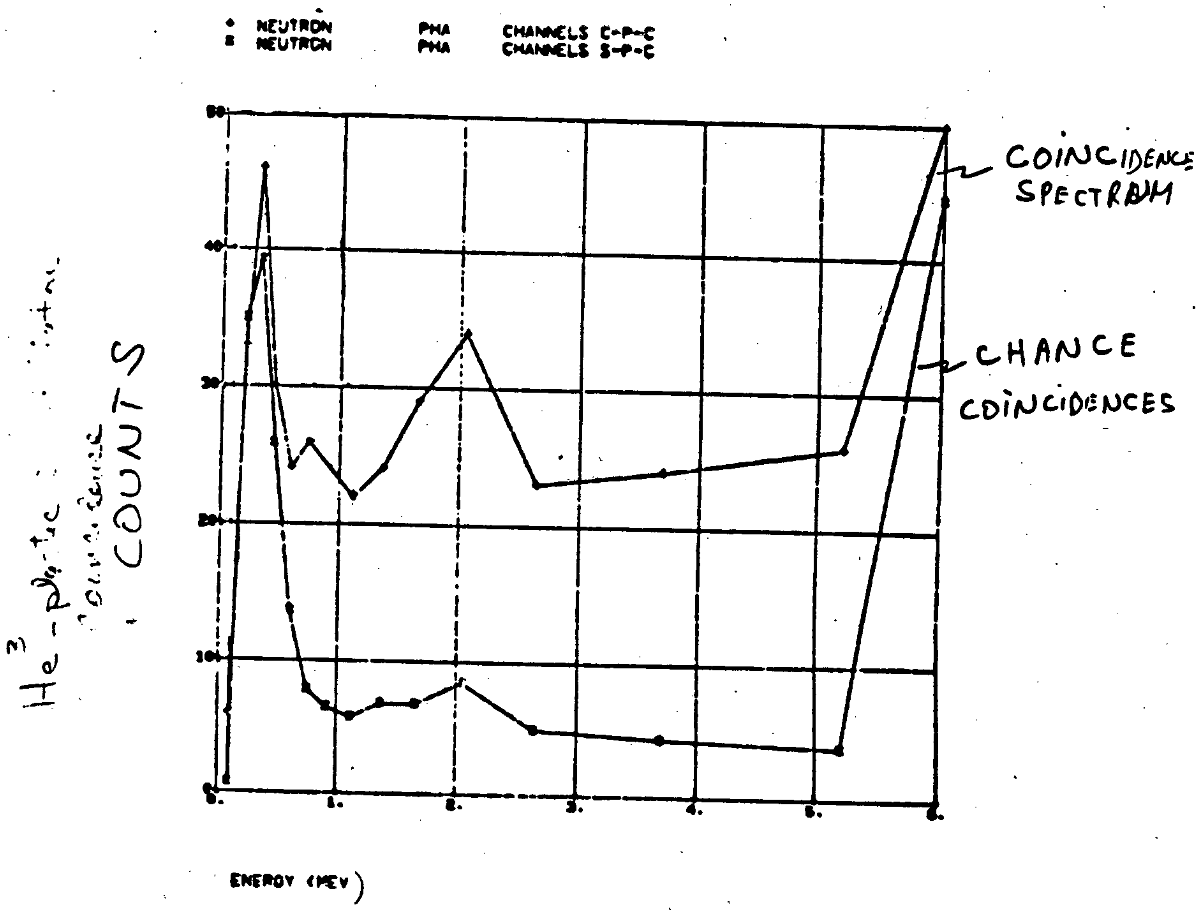


Fig. 7.5. NAS-I plastic-^{3}He coincidence data.

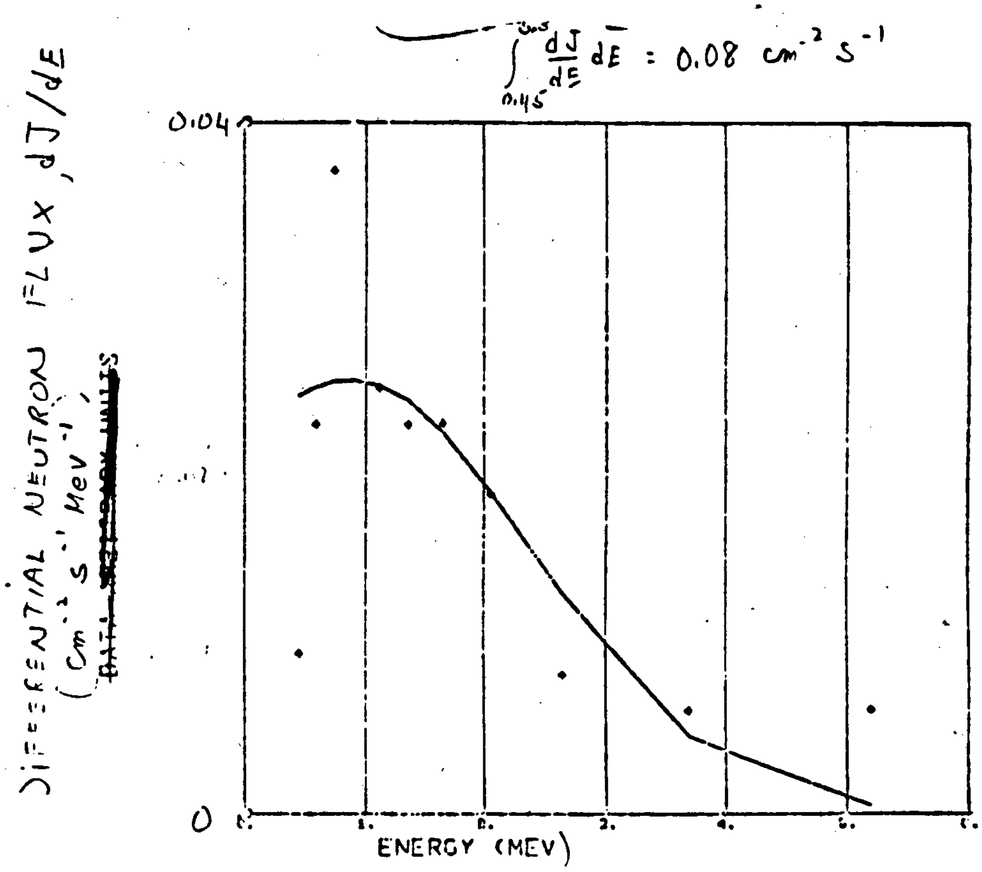


Fig. 7.6. NAS-I neutron differential flux data.

using all data points except the last at 5.3 MeV assuming statistical uncertainties only. The resulting best-fit parameters are A = $0.025/cm^2$ - s - MeV, E_a = 0.88 MeV, and E_o = 2.17 Mev with a reduced chisquare, $\chi^2 = 0.95$. Numerical integration of the data for energies between 0.45 MeV and 5.3 MeV yield a total flux of $0.08/cm^2$ - s. All results are in excellent agreement with previous measurements in this energy range near the geomagnetic latitude of Hawaii (see e.g., Lockwood, 1973).

A feature of the coincidence spectrum in Fig. 7.5 ignored in the foregoing analyses is the dominant peak in the highest energy channel. Since these events correspond to large energy deposition in the plastic scintillator, it is reasonable to presume that they result from directly penetrating galactic cosmic rays as mentioned in the discussion of Fig. 7.4 previously. Indeed, the interpretation is consistent with the measured He^3-tube singles count rate of about 35/s. Assuming an isotropic cosmic-ray spectrum, as measured by previous researchers, and using the effective area of the ^3He tube flown aboard TAURUS of about 100 cm^2, we estimate a cosmic-ray flux incident on the upper atmosphere above Hawaii of about $0.34/cm^2$ -s. This value is very close to the average flux measured near solar maximum of about $0.3/cm^2$ - s which verifies our presumption.

Comparison of the measured singles ^3He background of 35/s and our coincidence background of 0.7/s with the rate expected from a 20 km close approach to a 100 kw nuclear reactor of about 1090/s (see page 11 of this report) shows that the spectrometer flown aboard the TAURUS mission would have fulfilled the original objectives. Furthermore the present design which includes a spectral measurement capability, reduces the naturally-occurring background as measured using a simple moderated ^{3}He gas-proportional counter by a factor of 35/0.7 = 50. Such a low background enables detection and characterization of a 100 kw reactor from distances as much as 10 times larger than achieved in the simulation performed during this flight.

8.0 SUMMARY

The TAURUS I experiment conducted on September 23, 1983 demonstrated without question an initial operational capability to identify and characterize foreign nuclear reactors in low Earth orbit.

Instrumentation designed to measure γ-rays, neutrons, and positrons performed flawlessly and returned high-quality data. Background levels, and thereby signal-to-background ratios expected for reactor encounters, were established.

Operationally, the countdown-to-launch which included orbital prediction, timing, instrument check out, and launcher setting was practiced repeatedly and found to be adequate in scope and practical in execution.

The Terrier-Tomahawk 9 rocket system again delivered a predictable and nominal payload trajectory. Using PMRF radars to provide real-time payload location and newly installed Sandia computing resources, the distance of closest approach to the "virtual" satellite target was available to the Test Director early in the flight. Although this payload trajectory actually fulfilled the original criterion of equal to or greater than 10 km, the retro-rocket system was exercised to increase the encounter spacing to over 19 km.

Recovery hardware in the payload functioned as planned making the recovery operation itself routine. The TAURUS payload, damaged only slightly during reentry, will be refurbished and available for use as required.

Only one minor incident, discovery of an open circuit in a multi-conductor rocket umbilical cord, during terminal countdown prevented launch on the first planned opportunity and flawed an otherwise technically and operationally perfect demonstration.

Having demonstrated this IOC using "off-the-shelf" resources, efforts can be directed to a second-generation system. Some items identified at this early date for attention include:

1. replacement of the telemetry system with onboard recorders,
2. increased payload thermal insulation,
3. minor redesign of electrical circuitry, and
4. modification to include an externally accessible trouble shooting panel.

Other improvements, including more sensitive instrumentation, are under consideration.

Finally, during the execution of TAURUS I, it became evident that even a small operation cannot be executed on Kauai without notice. Radio traffic between experimenters was forbidden, and no public information was released. Never-the-less, the operation was discovered and reported in the Kauai newspaper, albeit with our cover story of ionospheric measurements, and repeated by the Oahu media. If an operational deployment is planned, it should probably include for diversion some more routine and visible experiment such as a barium release.

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