The launching of the Transit 4A satellite on June 29, 1961, marked the first attempt to orbit three satellites simultaneously. The middle member of the three, Injun, is a radiation research satellite developed by Professor James A. Van Allen and his associates at the State University of Iowa. This paper describes Injun in some detail, especially the low-energy proton detectors developed for it at APL, and some preliminary conclusions drawn from the data already received from Injun.

G. F. Pieper

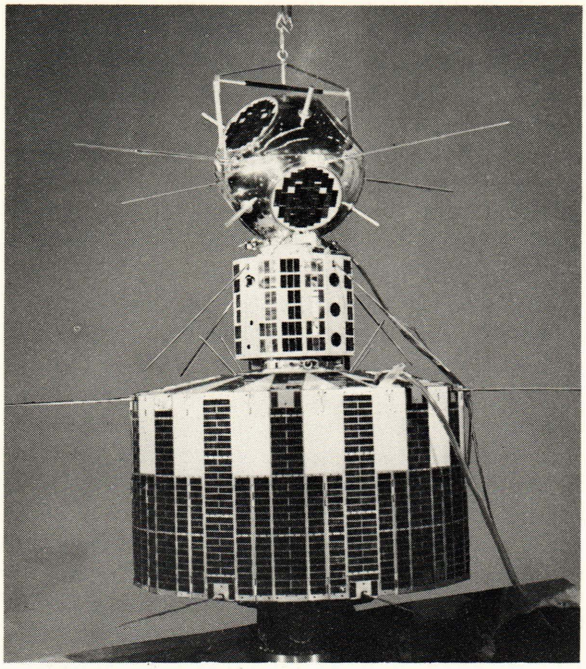
INJUN

A Radiation Research Satellite

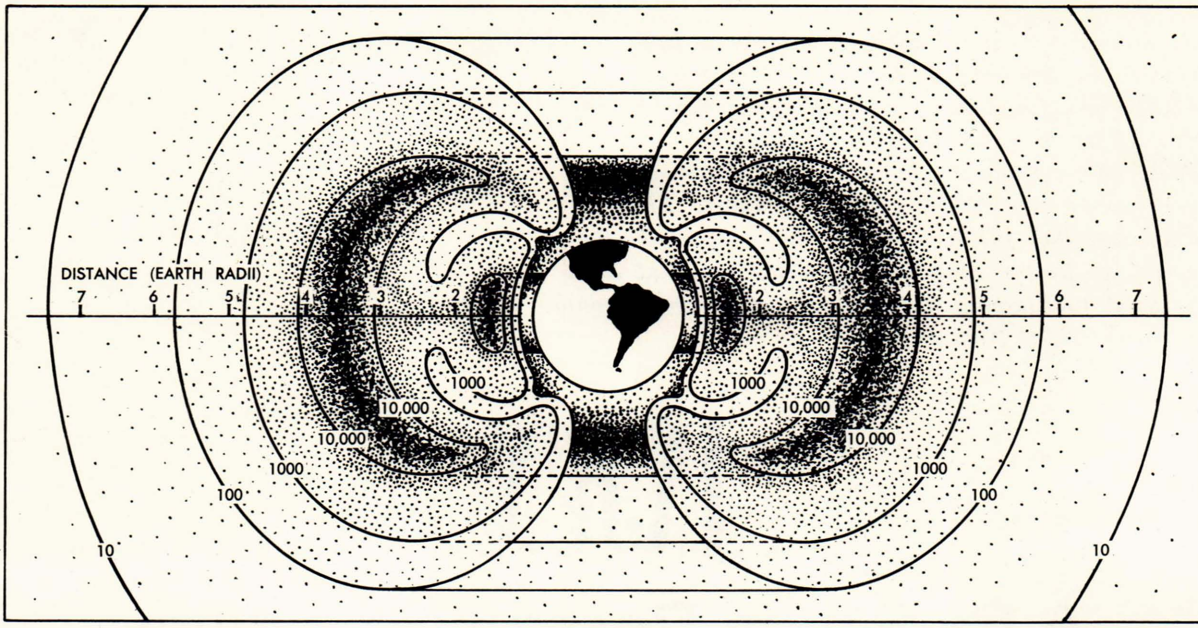
The discovery of the geomagnetically trapped radiation zones by Professor James A. Van Allen of the State University of Iowa (SUI), formerly Supervisor of Upper Air Exploration at APL, is one of the most exciting and far-reaching results of man's exploration of space. Since their discovery, much has been learned about the composition and extent of the Van Allen radiation zones; much, however, still remains to be learned.

At the present time, the locations of the radiation zones in space are reasonably well established. The motion of the particles in these regions is governed by the magnetic field; it consists of circular motion about a line of force, a longitudinal motion between mirror points, and an azimuthal drift around the earth. Further, it appears that the inner zone is quite stable in time, while the outer zone shows wide variations in extent and intensity—a phenomenon related to magnetic storm activity observed on earth. The energy spectra of the protons and electrons that make up the radiation zones, however, are known only approximately at this time.

To account in detail for the origin and behavior of the Van Allen radiation zones is one of the most interesting problems in contemporary geophysics. In addition to their scientific value *per se*, however, a more accurate description of the Van Allen zones than presently exists is of great importance to the Applied Physics Laboratory for one very practical reason: ionizing radiations have a damaging effect on the operation of solar cells, transistors, and various other satellite components. It is imperative that the environment in which the



Three satellites being prepared for simultaneous launching on June 29, 1961. The Transit 4A satellite (bottom) supports the Injun (center) and Greb satellites.



Geomagnetically trapped radiation zones discovered by J. A. Van Allen are shown in their relative positions in space, as determined by a recent space probe.

operational Transit satellites will exist be well understood so that the satellites may be designed to operate satisfactorily for the required five-year lifetime. The present understanding of the Transit environment is inadequate for this purpose; the Injun satellite marks the beginning of an attempt to rectify this situation.

Consideration of the possibility of using a part of the payload capability of the Thor-Ablestar vehicle for a radiation-measurements satellite began in October 1960. Preliminary plans led subsequently to inclusion of the Injun satellite in the Transit 4A launching which took place on June 29, 1961. This launching, in fact, marked the first attempt to orbit three satellites simultaneously. On the launch pad, Transit 4A (175 pounds) was the bottom member of the trio; next was Injun (40 pounds); and on top was an NRL satellite, Greb (Galactic Radiation Energy Balance) (55 pounds), designed to measure solar Lyman-alpha and X-radiation. It was intended that the three satellites separate from each other immediately after injection, each to orbit independently. The three-satellite orbit actually achieved was almost exactly as programmed—apogee of 620 statute miles, perigee of 550 statute miles, and orbital inclination of 66.8°. The orbit's inclination makes it a most interesting one for radiation measurements. The Injun passes through the auroral zones, the lower reaches of the outer Van Allen zone, and the inner zone; the detection devices carried by Injun are designed to make measurements in all three regions.

It was also intended that Injun, like Transit 4A, be magnetically oriented by the inclusion of a permanent magnet. Injun was thus to be the first magnetically oriented radiation-detection satellite, able to distinguish the direction of incident radiation fluxes relative to the direction of the local magnetic field. Several of its detectors are arranged in pairs to take advantage of this fact.

The scientific purposes of the Injun satellite include:

1. Measurement, with total energy and selective energy detectors, of particle fluxes moving parallel and perpendicular to the geomagnetic field over a wide range of magnetic latitudes, including both Van Allen radiation zones.

2. Measurement of the absolute particle flux trapped in both radiation zones, and a limited study of its energy dependence.

3. Monitoring of cosmic rays and solar protons over a wide range of magnetic latitudes.

4. Detailed plotting of the auroral zones by both photometric and particle-flux methods with high spatial and time resolution.

5. Study of the latitude variation of airglow and auroral emissions and subsequent correlation with phenomena measured at several ground stations in the United States and Canada.

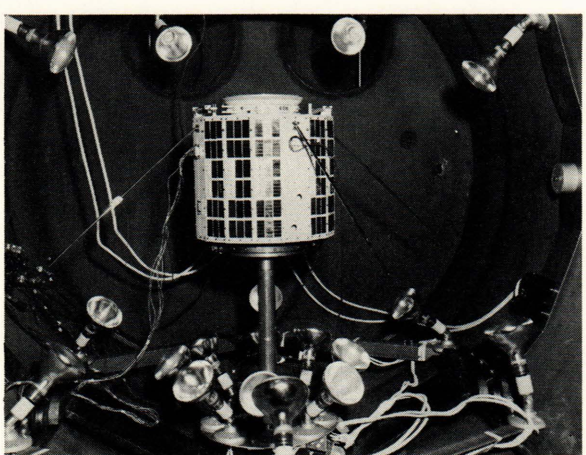
Instruments similar to many of those on Injun are due to be carried in other satellites and space probes in other projects in which SUI is participating. This will make comparisons of data obtained in different flights highly meaningful.

Mechanical and Electrical Design

The Injun satellite is designed to fit entirely within a right circular cylinder 16 inches in diameter and 13 inches high. Actually, the Injun cross section is that of a sexadecahedron 15.75 inches across corners and 15.45 inches across flats. Twelve of the sixteen panels are covered by solar cells. The remaining four panels, located at opposite ends of perpendicular diameters, provide ports for certain detectors and attachment points for the sections of the antenna.

In addition to its fourteen radiation detectors, Injun contains a data-handling system, a transmitter, an antenna, a power supply system, and a command receiver.

Data-Handling System—Sixty-four 4-bit binary shift register accumulators make up the data-handling system. Each detector is allotted a number of accumulators consistent with its expected counting rate. In addition, accumulators are used for a Barker synchronizing word, the satellite clock, various voltage and temperature measurements, and a magnetic aspect sensor. Data are read continuously from the accumulators at the rate of 256 bits per second. Thirteen of the detectors are read once per second, or to a spatial resolution of 10 kilometers, and one detector is, in effect, read four times per second, or to a spatial resolution of 2.5 kilometers, in order to investigate localized auroral phenomena.



The Injun satellite is shown in preparation for thermal-vacuum tests at the APL Environmental Test Laboratory.

Transmitter—A frequency-shift keying between 3072 and 4096 cps is used to indicate binary information readout of the accumulators. Amplitude modulation is used on an RF carrier at 136.5 mc. Radiated power is 200 milliwatts.

Antenna—The antenna consists of two linearly-polarized sweptback dipoles. It is made up of four separate elements, each 21.5 inches long by 0.25 inch in diameter.

The data encoding and telemetry system is designed to permit a direct output from simple ground receiving equipment into a digital computer. The predicted signal-to-noise ratio at a 3000-kilometer slant range is above 21 db, at least 9 db above the threshold for automatic data processing.

Power System—The total power required by Injun is 2.0 watts. The power system consists of solar cells and nickel-cadmium storage cells. The battery capability is 15 hours at full load, while the solar cells provide an average power of at least 0.4 watt even during the minimum sunlight orbit.

Command Receiver—The capability of the power system is not sufficient for all components of the satellite to operate continuously. It is launched and remains normally in a standby condition with only a command receiver and part of the data system operating. The command receiver can be interrogated from the ground stations at Iowa City, Iowa, and Lima, Peru, with three different commands so that the satellite turns fully on for a period of 8, 32, or 135 minutes. It is turned on as desired for data taking or tracking purposes, subject to the condition of the power system as indicated by various monitors.

Injun Detectors

Injun contains fourteen radiation detectors, listed in the Table, four of which are the APL proton detectors described in the next section. The remaining ten detectors, all developed at SUI, are primarily concerned with the detection of electrons and optical emissions from the auroral and subauroral atmosphere, and secondarily with the detection of low-energy protons (energy in the tens of kev).

Five of the ten SUI detectors employ small (approximately 2 by 2 by 0.3 mm) cadmium sulphide crystals as the sensitive element. These crystals show a change in their electrical conductivity when subjected to an energy flux in the form of charged particles or electromagnetic

INJUN RADIATION DETECTORS

Instrument	*Detection Feature*	*Orientation**
CdS total energy	Protons > 5 kev Electrons > 100 ev Light	$\theta = 180°$
CdS with magnetic broom	Protons > 5 kev Electrons > 250 kev Light	$\theta = 180°$
CdS total energy	Protons > 5 kev Electrons > 100 ev Light	$\theta = 90°$
CdS with magnetic broom	Protons > 5 kev Electrons > 250 kev Light	$\theta = 90°$
CdS optical monitor	Light	$\theta = 90°$
213 GM counter	Electrons > 30 kev Protons > 0.5 Mev	$\theta = 90°$
Photometer	Light of 5577 Å	$\theta = 0°$
Magnetic spectrometer		
GM a	Electrons 45-60 kev	
GM b	Electrons 80-100 kev	$\theta = 90°$
GM c	Background monitor	
APL proton detector	Trapped protons 1-17 Mev	$\theta = 90°$
APL proton detector	Trapped protons, background	$\theta = 90°$
APL proton detector	Solar protons 1-17 Mev	$\theta = 180°$
APL proton detector	Solar protons, background	$\theta = 180°$

* Orientation is referred to the magnetic field line, with $\theta = 0°$ being the downward direction in the Northern Hemisphere.

radiation. They are used to measure total incident energy, with a small sweeping magnet to measure total incident energy except for low-energy electrons, or with a transparent cover to measure total incident energy except for all low-energy particles.

The other SUI detectors in Injun consist of a Geiger counter, a photometer, and a two-channel magnetic electron spectrometer, whose characteristics are defined in the Table.

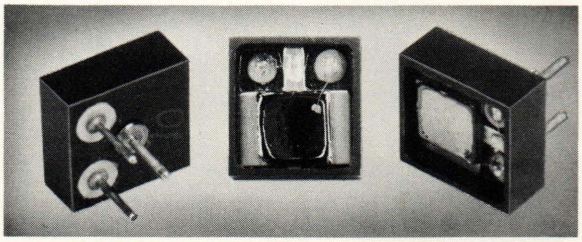
APL Proton Detectors

A recent development in nuclear physics has been the use of a *p-n* junction in silicon as a charged particle detector. When such a junction is reverse biased, a region is formed that is free of conducting electrons and holes. The passage of a charged particle through the depleted layer creates electron-hole pairs that are separated by the electric field, and the electrons and holes are collected at the junction surfaces. The collection of the charge can be observed and the passage of the incident particle thus noted exactly as is done with an ordinary gas-filled ionization chamber.

Junction detectors have several advantages for measurements of protons in space. They are very small and light; they can be operated on low voltages (e.g., 10 to 50 volts); and they consume essentially no power. The depletion layer is so thin, generally of the order of 100 microns, that the junctions are insensitive to X-rays and bremstrahlung; in addition, they can be made insensitive to electrons. The size of the output pulse of the detection unit is proportional to the energy deposited in the junction's depletion layer. By selecting an appropriate absorber to cover the entrance hole in a suitable shield and by adjusting the discrimination level, it is generally possible to select a desired energy range with a given detector.

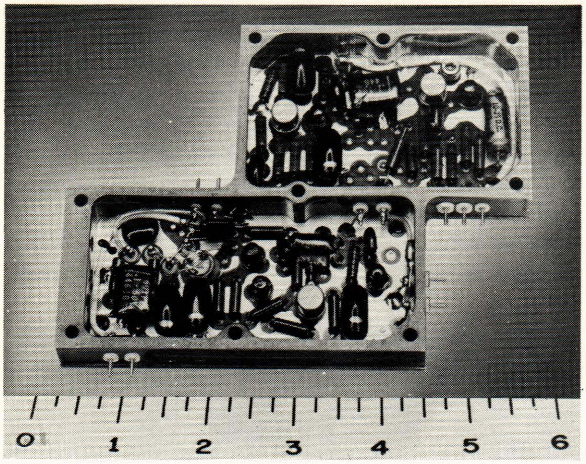
The APL proton-detection unit for Injun consists of two pairs of two detectors. One pair is mounted so that the two detectors "look out" at right angles to the axis of the satellite and thus at right angles to the earth's magnetic field. This pair is designed to measure trapped protons in the inner Van Allen radiation zone. The other pair is mounted so that the detectors "look out" parallel to the axis of the satellite and thus parallel to the magnetic field. These two detectors actually "look out" through the bottom of the satellite as it stands on the launch pad, and thus, because of the orientation of the satellite's permanent magnet, they "look upward" at high northern magnetic latitudes to measure solar protons.

All four detectors are symmetrically mounted in an aluminum housing so that they are essen-



***p-n* junction detectors for measurements of protons in space. Units shown were manufactured by Solid State Radiations, Inc., Los Angeles, California.**

tially identically shielded. Small Alnico V permanent magnets are mounted over the detectors to keep electrons of less than 250 kev from reaching the detectors. One detector of each pair has an opening of 0.18 steradian through the magnet; the other detector of the pair has its opening filled by an aluminum plug so as to serve as a background monitor for the active detector. Each detector is 4 by 4 mm in area. All four detectors are made from the same resistivity silicon and are similarly biased to assure as nearly identical operation of the detectors as possible and thus to facilitate intercomparisons. Since the detectors are light-sensitive, the active member of each pair is covered by an aluminized Mylar foil. The response range for the active detectors is from 1 to 15 Mev.



One of four electronic packages used with the proton detectors in the Injun satellite. Each package contains a charge-sensitive preamplifier, two stages of voltage amplification, and a discriminator-pulse shaper.

The electronic circuits used with each of the four detectors are packaged as shown in the accompanying photograph. They consist of four parts: a charge-sensitive preamplifier followed by two stages of voltage amplification and a discriminator-pulse shaper. The preamplifier and amplifier are adaptations of circuits designed at Oak Ridge by T. L. Emmer. The discrimination level set at the output of the second voltage amplifier is adjusted to correspond to 900-kev energy deposition in the detector. Pulses large enough to pass the discrimination threshold fire a univibrator whose output is tailored to the input requirements of the SUI data-handling system. The proton-detector package weighs 1060 grams and requires 250 milliwatts at +18 volts DC.

The proton-detection unit was designed by the writer in collaboration with C. O. Bostrom. Important contributions to the mechanical design were made by F. H. Swaim and to the electrical design by D. A. Davids.

Results

The launch of Transit 4A, Injun, and Greb was a complete success except for the failure of the separation mechanism between Injun and Greb. These two satellites are doomed to a somewhat unhappy marriage for their predicted life in space of more than 50 years. Only two features of Injun are seriously affected: (a) the photometer is shielded by Greb and thus is useless; and (b) the increased size and moments of inertia of the combined payload will prevent the achievement of the accurate magnetic orientation that was desired for Injun; however, a partial orientation should occur. The failure to orient accurately greatly complicates data analysis on the ground. One month after launching Injun, all components of the satellite were working completely satisfactorily.

Preliminary results from the reduction of data taken in the first two weeks after launch have already shown two new pieces of information concerning the Van Allen radiation zones and magnetic storm phenomena, the results coming largely from the APL proton detectors.

In passes of the satellite through the lower reaches of the outer Van Allen zone no counts are shown by the active detectors, indicating an absence of protons in the range of 1 to 15 Mev. Previously it was known that the zone contained no protons of energy greater than 30 Mev. It is now reasonably certain that the zone contains no protons of energy greater than 1 Mev.

On July 14, 1961, a solar flare occurred on the sun. During the ensuing magnetic storm, Injun passed over Northern Canada, and large numbers of counts were observed in the active proton detectors as well as some increase in the background counting rates. This marks the first time that protons in the range of 1 to 15 Mev have been unambiguously associated with such magnetic storms.

The Injun satellite represents APL's first attempt to assess the environment in which the operational Transit system must function. The success of the experiments, particularly the operation of the proton detectors, has led to an expanded research program at APL concerning particle measurements in space and their effects on satellite components.