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An experiment to detect energetic neutrons and gamma rays from the sun

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Abstract: A payload for the detection and measurement of high energy neutrons and gamma rays from the sun was flown onboard the first Indian satellite *Aryabhata*. The payload system for this neutron-gamma experiment was designed for detecting energetic neutrons in the energy range 10–500 MeV and gamma rays in the energy range 0·2–20 MeV. The details of the design of the payload, various tests carried out on it as well as the preliminary in-orbit performance are presented.

Keywords. Satellite instrumentation, solar neutron experiment.

1. Introduction

The emission at times of solar flares of a variety of combinations of electromagnetic radiations from radio through gamma rays, and of energetic charged particles, is now well established. In addition, it is certainly to be expected that nuclear reactions induced by energetic charged flare particles on the solar surface could take place, giving rise to neutrons and gamma rays. Indeed, during the August 1972 flare, Chupp *et al* (1973) from instruments on OSO-7, have observed intense nuclear gamma ray line emission in addition to the continuum. However, so far there is no well-established evidence for high energy neutron emission during times of intense solar activity. While the emitted charged particles would be affected by the interplanetary magnetic field, the neutral radiation viz., neutrons and gamma rays, can directly reach the earth; thus observations on them could provide a new method of studying the solar flare phenomenon. Though most of the low energy neutrons (<10 MeV) would decay during the sun-earth journey, the energetic ones have a reasonable chance of reaching the earth. Also, the simultaneous observations of neutrons and gamma rays in a single event would be able to establish reliably the generic relation between them. With this primary objective we designed an experiment in which the technique of pulse shape discrimination in a scintillator crystal was employed to separate neutron events from gamma ray events. This technique proven by us in balloon experiments (Daniel *et al* 1970; Joseph 1970) was used in the design of an experiment in the first Indian scientific satellite *Aryabhata*. In this paper we describe the scientific objectives of this experiment and the various technical aspects including the performance of the payload during the environmental qualifying tests, and during tests carried out after the integration of the payload with the satellite—namely, the autonomous and complex tests carried out at Bangalore, India, and at the USSR Cosmodrome. The performance of the payload in orbit, based on preliminary analysis of the limited data obtained during the first few orbits, is also described.

2. Scientific objectives

The experiment was designed with the following scientific objectives.

(i) To detect simultaneously the possible impulsive emission of energetic neutrons (10–500 MeV) and gamma rays (0·2–20 MeV) at times of intense solar activity. The possibility of observing the delayed signal from neutrons with respect to gamma rays is an important capability of the experiment.
(ii) To detect any steady or quasi-steady solar emission of energetic neutrons and gamma rays.
(iii) To measure the splash albedo flux of neutrons and gamma rays as a function of latitude.
(iv) To detect gamma ray bursts of the type first discovered by Vela satellites and any other type so far not discovered.

3. Design of the experiment and fabrication of the payload

3.1. *Design of the experiment*

The principle of the detection and separation of neutrons and gamma rays is based on the fact that in an inorganic crystal scintillator like CsI(Tl), the high rate of ionisation (dE/dx) due to the low energy protons and helium nuclei released in nuclear interactions caused by neutrons, gives rise to a pulse shape different from the low (dE/dx) due to the fast electrons originating from gamma ray interactions in the crystal (Mathe and Schlenk 1964). Specifically, the derivative of these two pulse shapes would cross the zero axis at different points—earlier for neutrons and a little later for gamma rays. This cross-over time (T) is characteristic of the rate of energy loss and is independent of the amplitude of the pulse. Taking advantage of this property, we can separate the two types of events and measure the energy deposited in the crystal, event by event. This unique capability is potentially useful for detecting even small increases in the neutron flux.

In order to ensure that the relatively over-abundant low energy gamma ray flux is recorded with a minimal efficiency without appreciably reducing that of neutron detection, a large area small thickness disc of CsI(Tl) crystal of 12·5 cm diameter and 1 27 cm thickness, was chosen as the basic detector. The pulse shape discrimination (PSD) technique separates neutron and gamma ray events which deposit more than 4 MeV in the crystal. However, for gamma rays with $E < 4$ MeV, the PSD technique is not required and the detector samples them purely on the basis of energy release in three suitable energy bins between 0·2 and 4 MeV. The experiment makes a two-dimensional analysis, for E (>4 MeV) and T, each analysed in 64 channels.

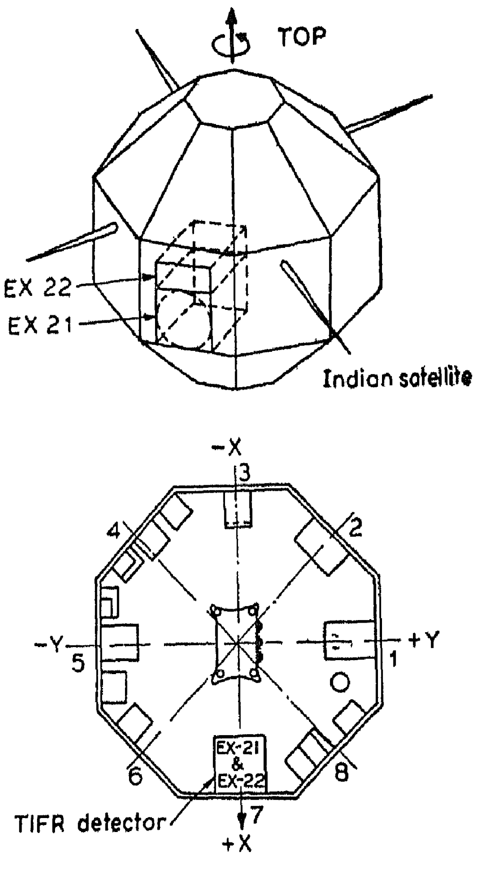
The minimum detectable solar flux for neutrons is estimated to be $\approx 5\times10^{-3}$

neutrons/cm^2 s, while the minimum detectable flux of gamma rays is $\approx 10^{-2}$ photons/cm^2 s. However, in order to arrive at reliable absolute fluxes, it will be advisable to calibrate the instrument using neutron and gamma ray beams of known energy from accelerators. Mention may also be made that charged particles which cause a coincidence between the 4π anticoincidence shield and the main detector (COIN) were also continuously monitored.

3.2. *Payload construction details*

The experimental payload consisted of two boxes, hereafter referred to as Ex-21 and Ex-22. The physical dimensions for Ex-21 and Ex-22 were 278 mm × 245 mm × 245 mm, and 278 mm × 245 mm × 140 mm respectively. The weights were 15·2 kg and 4·7 kg respectively. The two packages were placed one above the other, with Ex-21 near the deck plate, in bay No. 7 of the belly-band of the satellite as shown in figure 1.

The main detector crystal housed in Ex-21 was viewed by a 12·5 cm diameter photomultiplier tube and completely surrounded by a 1 cm thick NE-102 plastic scintillator viewed by four 3·81 cm diameter photomultiplier tubes; the latter served as the charged particle anticoincidence shield for the main detector. The pulse amplifiers for the CsI(Tl) and plastic scintillator, the PSD logic electronics and the high voltage supply for the photomultipliers were housed at the back of Ex-21. At the front end



TIFR equipment lay-out on deck plate
approx. scale 1:15

Figure 1. A schematic diagram showing the position of the experiment in the satellite.

of Ex-21, a special arrangement was provided to introduce a ^{241}Am radioactive source during laboratory calibration. The rest of the electronics, wired on eight printed circuit boards was placed inside Ex-22.

4. Tests and evaluation of the payload

4.1. *General*

The flow chart of the neutron-gamma event selection procedure is shown in figure 2. Briefly, the low energy gamma rays (LEG) of energy 0·2–4 MeV were analysed in

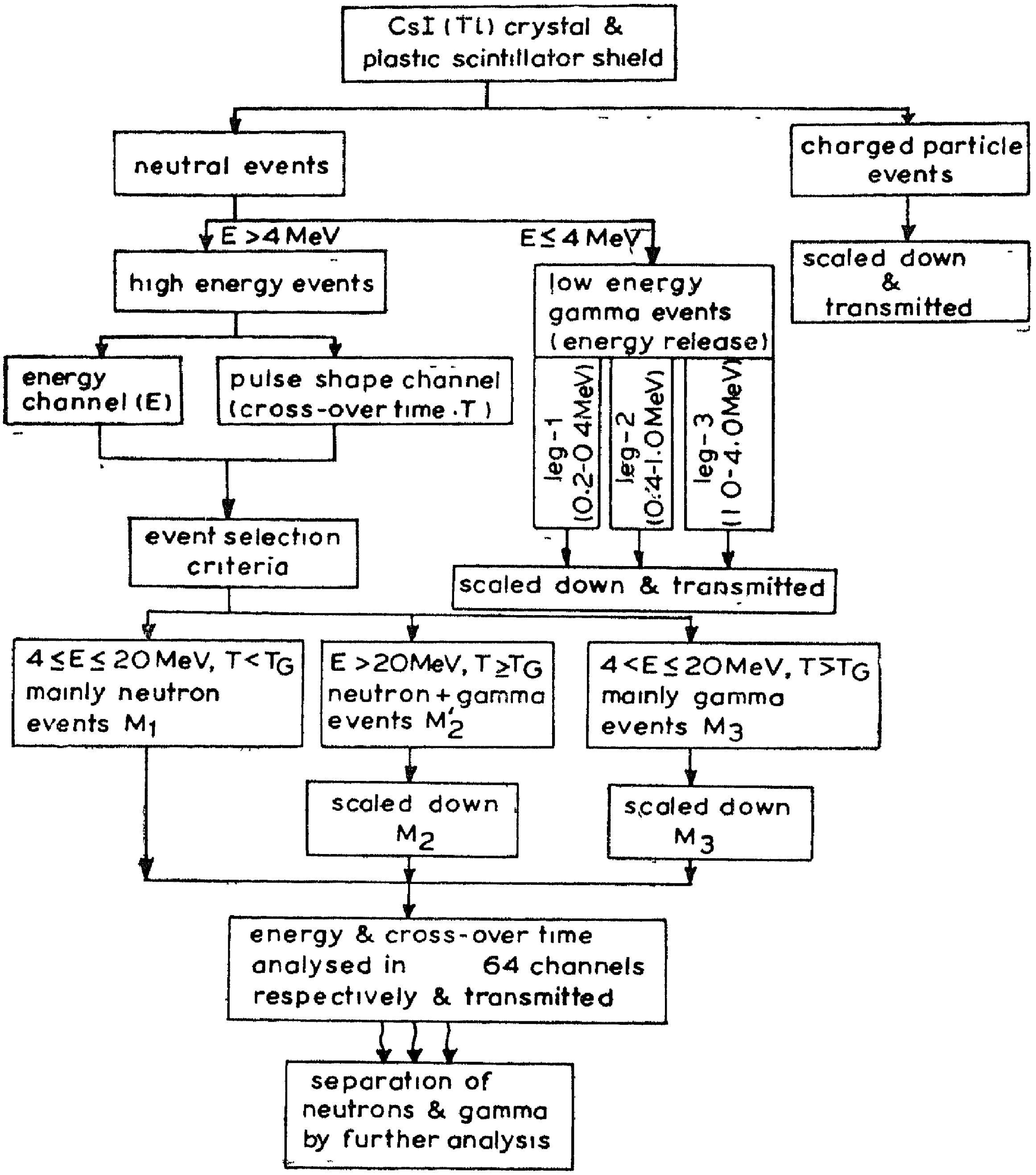


Figure 2. The flow chart for the selection of different types of events.

three energy bins without recourse to PSD, while the events giving energy loss > 4 MeV were analysed on the basis of their pulse shape, using the PSD technique. Since the telemetry readout is made every second, the various types of events were sampled suitably depending on the calculated counting rates in orbit and shown in table 1. To set various thresholds in terms of energy released in the CsI(Tl) crystal, 5·49 MeV alpha particles from the ^{241}Am radioactive source were used.

For the plastic scintillator, the threshold was set using the observed pulse height for 279 keV gamma rays from the radioactive source ^{203}Hg. Further, the rejection efficiency of the anticoincidence shield was checked using cosmic ray mu-mesons

4.2. *Bench tests*

After setting various thresholds as described in § 4·1 above, the electronic logic was thoroughly checked, and the boxes Ex-21 and Ex-22 were integrated to carry out further tests. All the information on the eight parameters of the experiment, namely, LEG-1, LEG-2, LEG-3, COIN, E, T and indicators $M2$ and $M3$, were available as 35 parallel bits when the telemetry interrogation pulse entered the experiment. For the bench test, a special test unit—the digital data interface unit (DDIU)—was built. This unit scans the experiment every one second, accepts 35 parallel bits, decodes the information and prints the data for the eight experimental parameters on a HP5050B printer.

First, 5·49 MeV alpha particles from the ^{241}Am radioactive source were used to simulate neutron-like events Next, the background gamma ray data which provides information on LEG-1, LEG-2, LEG-3, COIN and the E, T plot for $M2$ and $M3$ type events were taken. This gave very good separation between neutron-like and gamma ray events After thoroughly testing the experiment on the bench it was

Table 1 Expected and observed counting rates for the neutron-gamma experiment

	Types of events		Expected		Observed in orbit 2 from SHAR (Preliminary) (counts/s)
			Minimum (counts/s)	Maximum (counts/s)	
1	Low energy gamma ray events (energy release)	LEG-1 (0·2–0·4 MeV)	15	90	17
		LEG-2 (0·4–1·0 MeV)	12	72	14
		LEG-3 (1–4 MeV)	7	42	8
2	High energy gamma ray events (energy release)	4–20 MeV	2	12	not determined yet
		> 20 MeV	0·5	3	
3	High energy gamma ray events (energy release)	neutron events	0·01	0·2	0·05
4	Charged particles	coincidence events	30	200	31

integrated with the satellite and the environmental, autonomous and complex tests described below were carried out.

4.3. *Environmental tests*

After thoroughly testing the experiment in the laboratory, the payload was subjected to the following environmental tests:

temperature cycling (—10°C to +55°C),
thermovac tests (temperature cycling in the range —10°C to +55°C and vacuum level of 10^{-6} mm of mercury),
shock and vibration tests at specified levels.

The intercomparison of the data obtained during these tests and the bench tests showed that the variation of parameters was within the acceptable limits.

After full qualification of the payload in the environmental tests, it was again thoroughly checked in the laboratory before integrating it with the satellite.

4.4. *Autonomous test*

After integration of all the experiments with the satellite, the autonomous test in which only the neutron-gamma experiment was powered, was performed in two stages. In the first stage, the experimental packages were placed in the satellite and the experiment was powered through the satellite power system. Using the DDIU, ^{241}Am calibration data and the background data were taken. In the second stage, with experimental packages in the same position, the data were taken through the satellite telemetry system and the data decoded and printed out using an on-line PDP-11 computer. The data compared very well with the bench test data.

4.5. *The complex test*

In this test all the subsystems of the satellite were integrated and the data taken through satellite telemetry when all the subsystems were powered. The data were taken in similar fashion as in the second stage of the autonomous tests. The data compared well with autonomous test results indicating that there was minimum of interference from other subsystems, and that the experiment was working satisfactorily in this mode. Further, complex tests were performed with the solar panels in position. Again, the data showed that the experiment was working satisfactorily.

4.6. *Autonomous and complex tests at the Cosmodrome*

After thoroughly testing the experiment as described above, the integrated satellite was taken to the Cosmodrome in the USSR. Autonomous and complex tests in various modes were carried out. The data showed that the experiment was working satisfactorily.

, Performance in the orbit

he satellite *Aryabhata* launched on 19 April 1975 started giving data from orbit 2. he quick-look data obtained at Bears Lake tracking station provided the first ɜsult of the experiment in orbit. Preliminary analysis of the data showed that ıe experiment was working satisfactorily in orbit. The electric power supply to the ıree experiments onboard was available upto orbit 41. The data obtained ave been analysed and the results are published elsewhere (Damle *et al* 1976).

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