The Russian-US INTREPID Project

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Abstract

INTREPID (Ionization-Neutron Transition-Radiation Electron-Proton-nucleus Investigation Detector) is a potential joint Russian-US balloon project. INTREPID is meant (1) to integrate and cross-calibrate the transition radiation detection and ionization-neutron calorimetry techniques and (2) to study the spectra of primary cosmic-ray (PCR) electrons from $\sim 2 \times 10^9$ to $\sim 10^{12}$ eV and of the nuclear component at energies up to 10^{14} eV. The potential capabilities of the instrument are discussed.

1. Introduction

The study of the spectra of PCR electrons at $\sim 2 \times 10^9 - 10^{13}$ eV and protons and nuclei below and in the "knee" range can potentially provide information on local nearby sources of high-energy PCRs and their propagation in the Galaxy. Experimental techniques applied so far have been unable to provide a final solution of these problems. As regards the electron spectrum, there is significant scatter among the data obtained by various experiments, and no case where a single instrument has obtained results across the entire energy range. An additional problem is that the high energies of particles intiating cascades in standard calorimeters can be only be estimated with the use of model-based simulations. So it would be very useful to measure energies with two independent methods.

The technique of Compton Scatter Transition-Radiation Detectors (CSTRD) [1,2] provides the possibility of extending the range of measured values of particle Lorentz factors γ (and thus energy) independently of the cascade development up to $\gamma \sim 10^5$. The INCA project has developed the technique of the ionization-neutron calorimeter (INCA) to (1) determine the cascade energy by measuring both the ionization and the yield of thermalized neutrons, (2) select electrons against the proton-produced background, and (3) enlarge significantly the acceptance of potential space instrument designs [3-6]. The integration of

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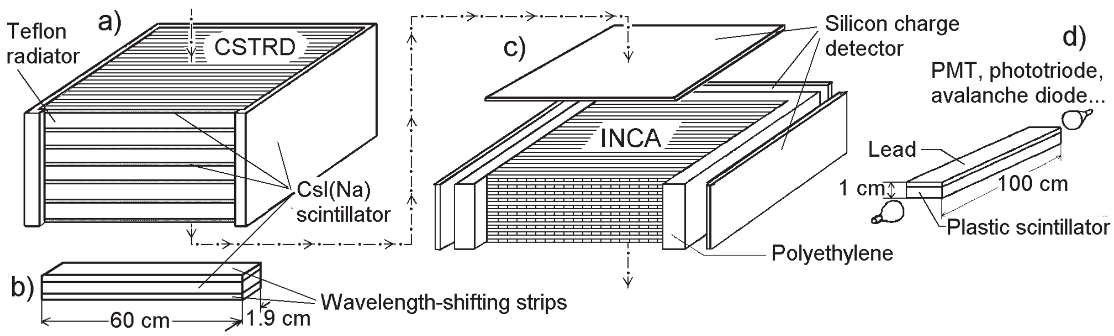

Fig. 1. Schematic of the INTREPID instrument. Certain of the elements are not shown for simplicity.

these two techniques allows us to construct an instrument with unique properties including the capability of cross-calibration and the ability initially to measure the electron spectrum over the energy range from $\sim 2 \times 10^9$ to $\sim 10^{12}$ eV.

The main problem in measuring the spectrum of primary electrons is the suppression of proton-produced background. To resolve this problem, we will use the fact that TR depends on Lorentz factor but not mass and that the neutron yield in a cascade (at the same energy) depends on the primary particle nature. Combined calorimeter-transition radiation detectors have been used to measure the high energy electron spectrum previously [7,8], but the INCA calorimeter‘s neutron capability provides additional and unique e-p discrimination.

2. The instrument

A preliminary schematic view of the instrument consisting of CSTRD, charge detectors, and INCA is given in Fig. 1. Its total weight is $\sim$ 1800 kg, compatible with the maximum launch weight of a long duration balloon.

2.1. Compton Scatter Transition-Radiation Detector

The CSTRD (Fig. 1*a*) is used to measure the Lorentz factor and charge of the primary particles. Although Compton Scatter TRDs have been used previously [9], the INTREPID CSTRD is based on the design for the ACCESS experiment [1,10]. It utilizes teflon radiators and thin inorganic CsI(Na) scintillators to provide a response up to $\gamma \sim 10^5$. Standard TRD designs have also been developed with energy response at high γ [11], but the INTREPID CSTRD‘s use of scintillator rather than Xe-filled proportional tubes eliminates the need for a gas system and is well suited for potential 16-30 day circumpolar balloon flights.

The instrument consists of six layers of teflon radiator, each followed by a thin CsI(Na) scintillator. The lateral dimensions are 0.6 m $\times$ 0.6 m. The scintillator is divided into strips 1.9 cm wide × 0.6 m long so that transition radiation X-rays scattered out of the incident particle beam can be identified (Fig. 1*b*). Each CsI strip is encapsulated between two wavelength-shifting acrylic strips which transport the light to photomultiplier tubes at the end of the strips. The detector is surrounded on six sides by a set of 1 cm thick CsI scintillator layers. The presence of both horizontal and vertical scintillator layers on all six sides of the detector reflects the broad angular distribution of the scattered radiation and provides a wide field of view for the incoming particles. The choice of detector parameters involves a number of trade-offs. The efficiency decreases above 200 keV, even though the energy dependence is greatest above 200 keV [1]. Thicker scintillators would increase the detected signal, but then the detector weight and thickness along the particle beam (which translates into interaction or shower probability) would increase unacceptably. To measure the nucleus charge with $Z \gg 1$, additional information is derived from the dependence of the pulse shape on Z for CsI scintillators [12].

2.2. Ionization-Neutron Calorimeter

The INCA calorimeter is used to measure primary particle energy and charge. It takes the form of a parallelepiped of 1200 kg weight and $1 \times 1 \times 0.2$ m^3 dimensions (Fig. 1*c*). The inside absorber is composed of 20 layers, each consisting of 40 logs, with each log 10 mm thick (3.5 mm lead and 6.5 mm plastic scintillator strips with optical fiber or plastic strip waveshifters) (Fig. 1*d*). Logs in alternate layers are mounted at right angles. Newly developed plastic scintillators enriched by orthocarborane [13] are used as position-sensitive detectors of both the neutron and ionization signals. PMTs or avalanche diodes are mounted at the ends of the upper scintillator strips (about 10% of total number) to record single neutron-produced light pulses during time gates of $\sim 300\,\mu$s after the origin of an interesting cascade. Vacuum phototriodes or plastic photosensitive plates are mounted at the ends of the other scintillator strips. The difference in analog pulse height read out at the two ends of a strip determines the shower axis position. The total number of channels is 400. The total thickness of INCA is $\sim 0.6\lambda^p_{int}$ or ~ 13 radiation lengths, and the geometric factor is ~ 1 m^{2}sr.

Currently, a new, functionally integrated, silicon pixel structure is under design [6] for use as side detectors of particle charge (c.f. Fig.1). The first samples of such detectors have been manufactured and test results correspond to the expected features. Preliminary analysis shows that high-sensitivity photodetectors could be designed on this basis and used instead of PMTs.

3. Scientific Objectives

INTREPID is designed first of all to study PCR electrons at $\sim 2\times10^9 - 10^{12}$ eV, and, in particular, near $E_e \sim 2 \times 10^9$ eV (the range of the spectrum bend related to the CR life time in the Galaxy). The second goal is the study of primary protons and nuclei at $E_0 \sim 10^{11} - 10^{14}$ eV. Energies up to $E_0 \sim Z \times 10^{14}$ eV are assumed to be studied with both the detectors: The CSTRD measures Lorentz factor γ as well as the charge of particles traversing the detector, while INCA measures the energy as well as the charge of particles entering the calorimeter from one side. In the latter case, the cascade energy is determined by measuring both the charged and neutron components which are rather weakly correlated at the initial cascade stage. This could provide an accuracy of $\delta E_p/E_p \sim 30 - 40\%$ (and less for nuclei) in spite of the small calorimeter thickness.

4. Conclusion

INTREPID (Ionization-Neutron Transition-Radiation Electron-Proton-nucleus Investigation Detector) – a potential joint US-Russian balloon project – is considered. The instrument is meant (1) to integrate the promising TRD and INCA techniques, (2) to improve and cross-calibrate both the approaches, and (3) to study the spectrum of primary electrons from ~ 2 GeV to ~ 1 TeV as well as the PCR nuclear spectrum and mass composition at energies up to $\sim 10^{14}$ eV.

5. References

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