SEARCH FOR ACOUSTIC SIGNALS FROM HIGH ENERGY CASCADES

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Introduction.   High energy cosmic ray secondaries can be detected by means of the cascades they produce when they pass through matter. When the charged particles of these cascades ionize the matter they are traveling through, the heat produced and resulting thermal expansion causes a thermoacoustic wave. These sound waves travel at about 10^{-5} the speed of light, and should allow an array of acoustic transducers to resolve structure in the cascade to about 1 cm without high speed electronics or segmentation of the detector.

Experimental System.   The University of Arizona cosmic ray group operates an observatory at 747 g/cm^2 atop Mt. Lemmon, 72 km from the campus in Tucson, Arizona. The system, whose layout is shown in Fig. 1, consists of an experimental stack offset to the side of the building, and four airshower detectors located near the four corners of the building. The shower detectors are liquid scintillation tanks 1.8 m x 1.8 m in size. The experimental stack, shown in Fig. 2, consists of a cascade generator of Fe and Pb followed by a tank of trichloroethylene located at a depth corresponding to the maximum of a cascade generated by a 0.7 TeV gamma ray. This trichloroethylene tank acts as the acoustic detector and has four acoustic transducers located within the tank. The Pb above and Fe below the tank are in contact with the tank walls and provide an acoustic mirror. Beneath the acoustic detector is a hodoscope to provide some positioning information for the cascade core, and a three section calorimeter consisting of liquid scintillation detectors sandwiched between layers of Fe. The acoustic signals are continuously digitized by a multichannel waveform digitizer. When a large signal is found in the calorimeter, a trigger pulse is generated. The trigger pulse stops the digitizer after an appropriate delay to allow the acoustic wave to arrive at the transducers. Also, pulse heights from the shower detectors, calorimeter, and hodoscope are recorded, and the arrival times of the shower detector pulses are recorded to provide azimuth and zenith information.
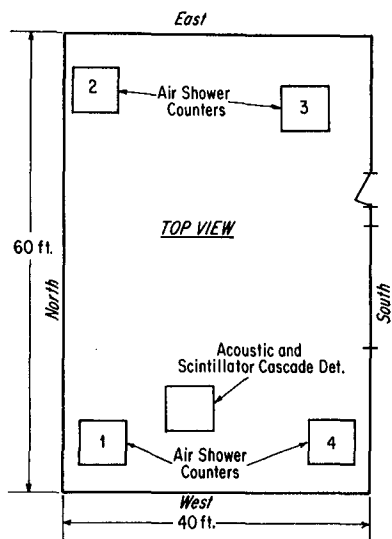

Fig. 1. Observatory layout, showing position of airshower counters and experimental stack.

<u>Acoustic Detector.</u> The acoustic detector first used in this experiment was a tank of mineral oil instead of the tricholoroethylene currently used. The expected signal-to-noise (S/N) ratio in the near field of a cascade-produced thermoacoustic wave in mixed units is given by[1]
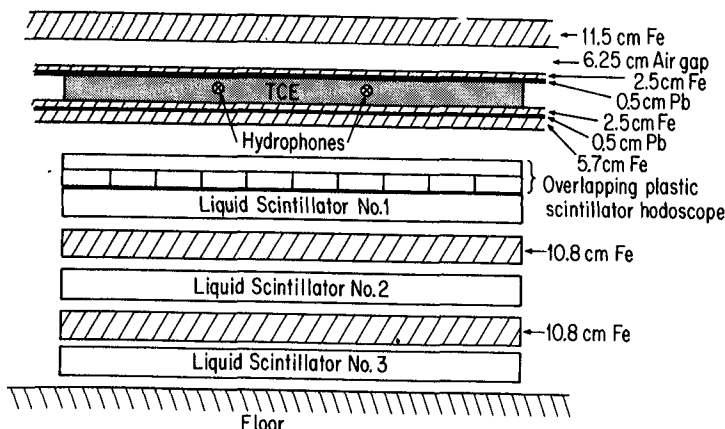

Fig. 2. Side view of acoustic and scintillator cascade detector.

$$\left(\frac{S}{N}\right)_{near\ field} = (2.2 \times 10^{-9})\ L\ n^2/R_0(m),$$

where

$$L \equiv [\beta(°C^{-1})c(m/s)/C_p(cal\text{-}g^{-1}\text{-}°C^{-1})]^2\ [dE/d\xi(MeV\text{-}g^{-1}\text{-}cm^2)]^2_{min}\ \rho(g\text{-}cm^{-3})/T(°K).$$

n is the number of charged particles in the cascade and $R_0(m)$ is the distance to the observation point. A gamma ray of 50 TeV with a Pb shower generator is expected to achieve a S/N ratio of 7, for which the thermoacoustic wave should be clearly visible relative to the thermal noise. With trichloroethylene, it is calculated that a gamma ray of 15 TeV is necessary to achieve a S/N ratio of 7. The transducer amplifier system used in the detector can be characterized by the constant k in the equation

$$\left(\frac{N}{S}\right)_f = k\left(\frac{N}{S}\right)_i\ ,$$

where $(N/S)_i$ is the acoustical noise-to-signal ratio, $(N/S)_f$ is the electrical noise-to-signal ratio at the amplifier output, and k is a degradation constant. For the system used, k has a value of 1.2, so that the expected S/N ratios in the recorded data are about 80% of those in the detector itself. In the fall of 1984, simulations of this process were conducted at the University of Arizona Health Sciences Center with an 18 MeV electron linac. One of the results indicates that a minimum density of 5×10^5 electrons/cm^2 is needed in mineral oil to produce a detectable acoustic wave. When this condition is applied to cosmic ray cascades, $\pi \lambdabar^2$ gives the size of the cascade core over which n must exceed 5×10^5, where $\lambdabar = \lambda/2\pi$ and λ is the wavelength determined by the transducer center-frequency. For the 50 kHz center frequency of the transducers in this experiment, $\pi \lambdabar^2 = 0.35$ cm^2.

<u>Present Results.</u> At the time of writing of this paper, no strong candidates for acoustic signal events have been recorded by this experiment. The reason for this is intimately connected to the gamma ray family phenomena. The density of charged particles in the acoustic detector produced by a cascade depends on the lateral distribution of energy among the gamma rays when they enter the shower generator. For example, a 100 TeV gamma ray will produce a higher particle density than if that same 100 TeV is spread out laterally among many gamma rays.

Event rates for this detector were expected to be low. However, the gamma ray family phenomena has made the rate less than initially expected. The integral spectrum of individual gamma rays[2] observed at 650 g/cm^2 can be used to calculate the worst-case event rate. In this case, a rate of 1 event per 11,000 hours for mineral oil and 1 event per 1,100 hours for trichloroethylene is found. However, these individual gammas are members of families. If, instead, we employ the integral spectrum of gamma ray families[3] and assume the lateral spread of the members of the families is small, we obtain an optimisic rate of 1 event per 736 hours for mineral oil and 1 event per 110 hours for trichloroethylene.

The integral spectrum of events which occurred during 829.7 hours of exposure with the mineral oil detector has $\gamma=-2.2\pm0.3$, in agreement with gamma-family results for $\Sigma'E_\gamma$. During the mineral oil run, 4 events were observed with energy >50 TeV; it is believed that these events did not produce a sufficient particle density because each cascade did not result from a single gamma ray. The integral spectrum calculated from particle densities observed at the shower detectors gives a spectral index of -1.42±0.1. The differential flux of events as a function of $\cos\theta$ can be expressed as

$$f(\cos\theta)d\Omega = f_0[\exp(-x/\Lambda\cos\theta)]d\Omega \quad ,$$

where x is the atmospheric depth and Λ is the mean-free path. We obtain a value of $\Lambda=78\pm8$ g/cm^2.

At this time, the trichloroethylene detector has been exposed for 155 hours, and one weak candidate for an acoustic signal has been seen. It is hoped that this detector will provide interesting results in the months to come.

References

1.   T. Bowen, Proc. 16th ICRC, Tokyo, <u>11</u>, 184 (1979).

2.   M. Akashi et al., ibid, <u>7</u>, 68 (1979).

3.   M. Akashi et al., ibid, <u>13</u>, 98 (1979).