

# APPLICATIONS OF GIANT SCINTILLATION DETECTORS\*

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## INTRODUCTION

In this talk, I will describe some developments of the past few years relative to the use in physical research of the very large scintillation detectors. If I may remind you, the large detector -- except for size -- operates in much the same way as a small one. The effect of size is to increase the sensitive mass and hence absorption of the system, be it for neutrons, gamma rays, charged particles, or neutrinos. Along with size come increased demands on transparency to the scintillation light, reflective coatings, the use of many photomultiplier tubes, and the trappings associated with sheer mass. I will not dwell on these design problems, but consideration of them is the day to day concern of the experimentalist and any advance, such as the discovery of a cheaper or more efficient scintillator, has an important effect on the research that can reasonably be contemplated.

## PLANNED USES

### Conservation of Heavy Particles

The principle of heavy particle conservation, called conservation of baryons, which implies that the number of nucleons

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(reckoned algebraically) is constant, is one of the fundamental assumptions of physics. According to this principle, for example, free protons should not be expected to exhibit any radioactivity. Ordinary decay of the neutron is consistent with the principle because the products include a heavy particle, i.e., a proton. As reported in the 1957 Liquid Scintillation Counting Conference, the stability of nucleons had been checked by a Los Alamos group using large liquid scintillators with the resultant lower limit of  $10^{22}$  years. This limit was raised by Los Alamos to  $4 \times 10^{23}$  years in 1958 and to  $10^{26}$  years by a group at CERN in 1959 (1).

Equipment is now being constructed at Case Institute by C. Giamati and myself, which should enable this limit to be raised significantly. The idea of the Case experiment is to shield a relatively small (200 liter) detector from cosmic rays by going into a deep salt mine and using a large anti-coincidence detector. Figure 1 shows a schematic of the experiment. Any proton decay (either bound or unbound proton) will give rise to energetic charged lighter particles, e.g., mesons, electrons. A decay in the scintillator will, therefore, produce a pulse. To prevent such an event from also triggering the cosmic ray anticoincidence, an iron isolation shield is placed between the two detectors. It is estimated from cosmic ray measurements made in the Morton Company salt mine, which will be used for this experiment, that the anti-coincidence will be required to reduce the cosmic rays by a factor of only  $10^3$  to enable a lifetime of  $\sim 10^{27}$  years to be detected.

### Further Reactor Antineutrino Studies (2)

Thus far we have seen the interaction of free antineutrino with matter via the reaction



As described in the 1957 conference, this series of investigations was intimately related to the Los Alamos development of large scintillation systems. In those experiments we succeeded in measuring the interaction cross section to within + 23 per cent  $[\sigma = (1.10 \pm 0.25) \times 10^{-43} \text{ cm}^2/\text{fission } \bar{\nu}]$ , and in obtaining a very crude but reasonably direct measure of the fission antineutrino spectrum. It is a matter of some interest to measure this fundamental interaction cross section and the antineutrino spectrum with better precision, and this is one of the

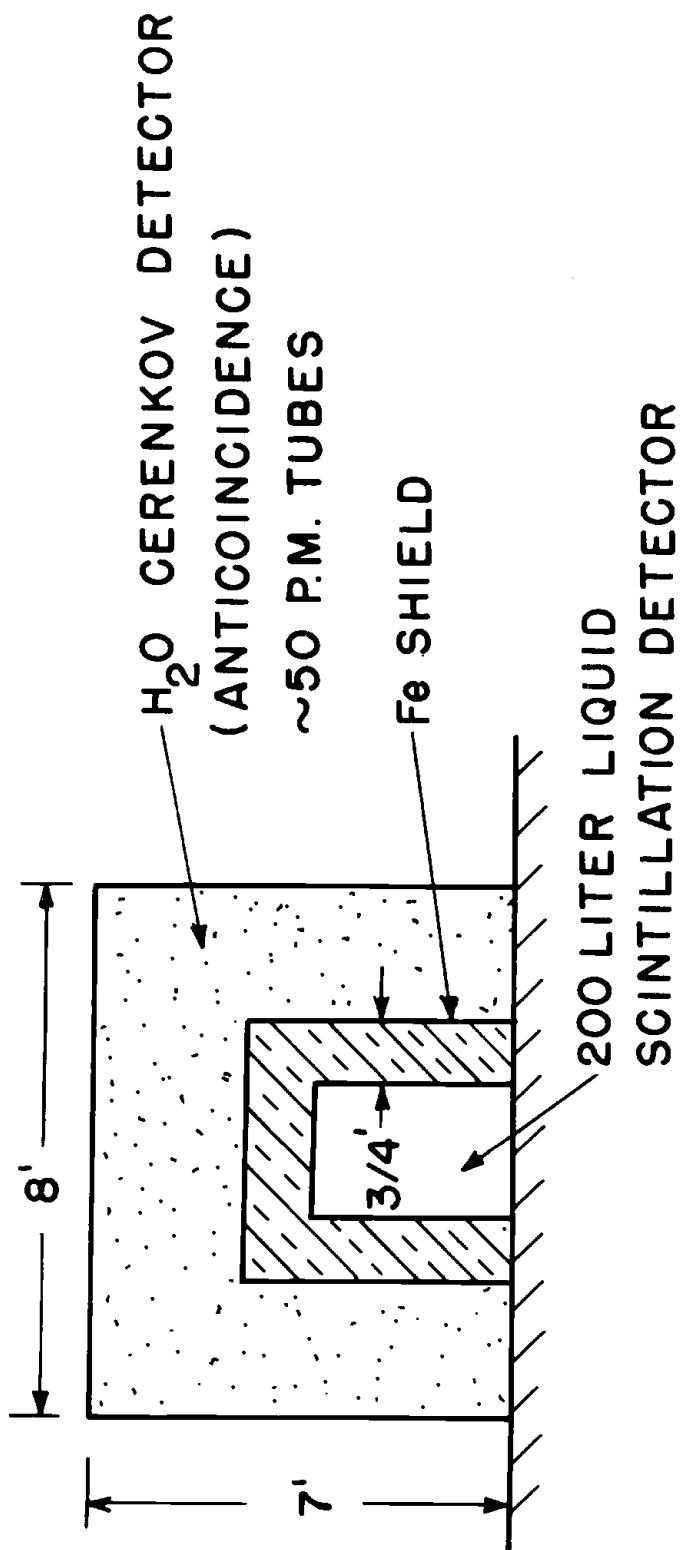
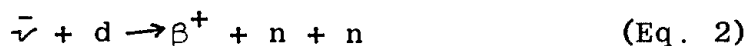


Fig. 1. Schematic of nucleon stability experiment.

objects which has led to the design of the equipment shown schematically in Fig. 2. Figure 3 is a picture of the detector shell prior to the addition of the tubes, circuitry, etc. When it is outfitted, this 2000 liter vessel will have a complement of 132 5-in. photomultipliers. The sequence of events is as follows: an antineutrino transmutes a proton in the inner sphere producing a neutron and positron, which are captured and annihilate within the sphere. The essential features of this detector are that it makes a well defined target with minimal edge effects and a much higher cadmium concentration than in the past. Consideration of the characteristics of such a detector indicates significant reduction in backgrounds, both accidental and those associated with cosmic rays, a high and well determined efficiency for antineutrino-induced events, and improved energy resolution. A signal rate of  $30 \text{ hr}^{-1}$  is anticipated.

The same detector, except for a change in the contents of the inner sphere, is being considered for use in observing the reaction



The change will consist of substituting a mixture of deuterated and regular scintillator for the regular scintillation with which reaction (1) will be studied. The deuteron reaction has a cross section which is an order of magnitude smaller than the proton reaction. However, it is hoped that the more distinctive nature of the event which is marked by two neutrons will aid in discriminating further against the background.

### High Energy Neutrinos

Within the past year Pontecorvo, Schwartz, Lee, and Yang have suggested that high energy machines capable of producing observable quantities of neutrinos were now a real possibility. In the same period, two such machines -- the colossal CERN and Brookhaven AGS accelerators -- have been brought into operation. Interest in this possibility is due to the fact that the weak interaction has thus far been studied at low energies which do not reveal its structure. High energies, on the other hand, are in principle capable of asking such detailed questions. By way of orientation, it will be recalled that the wavelength of a particle,  $\lambda$ , which measures its size, decreases with increasing particle energy and that such reasoning led to the electron scattering experiments of

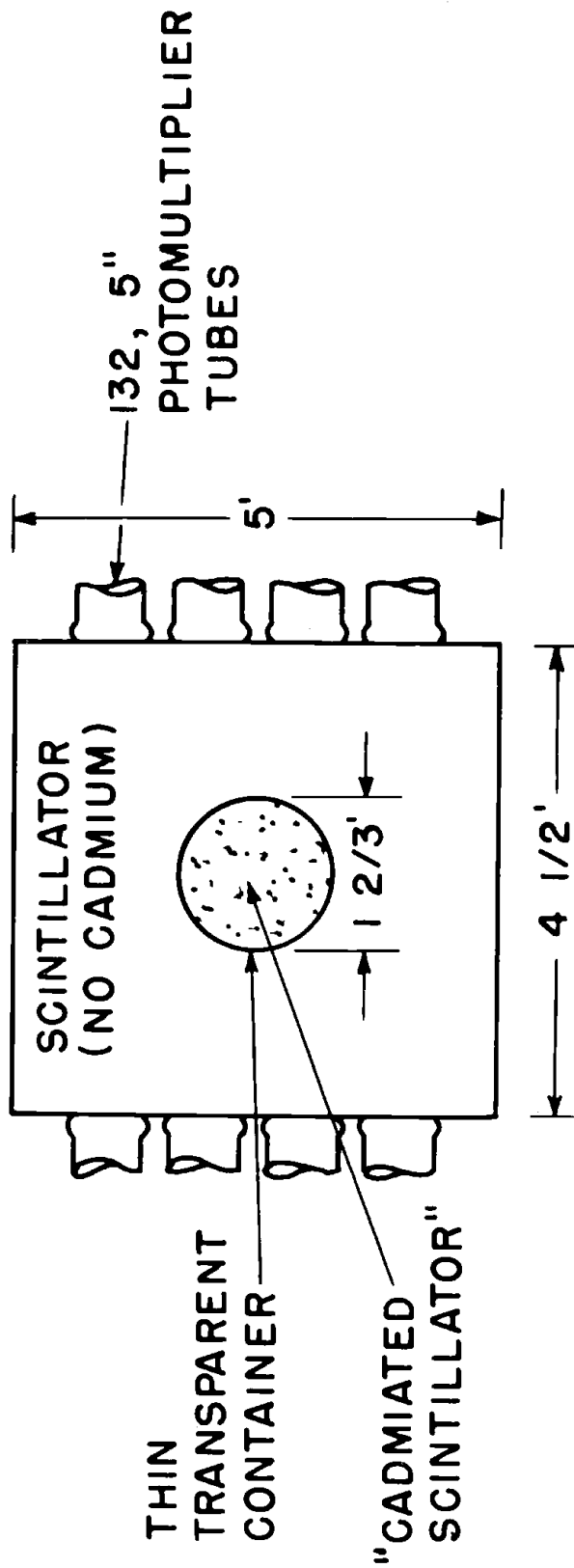


Fig. 2. Schematic of antineutrino detector.

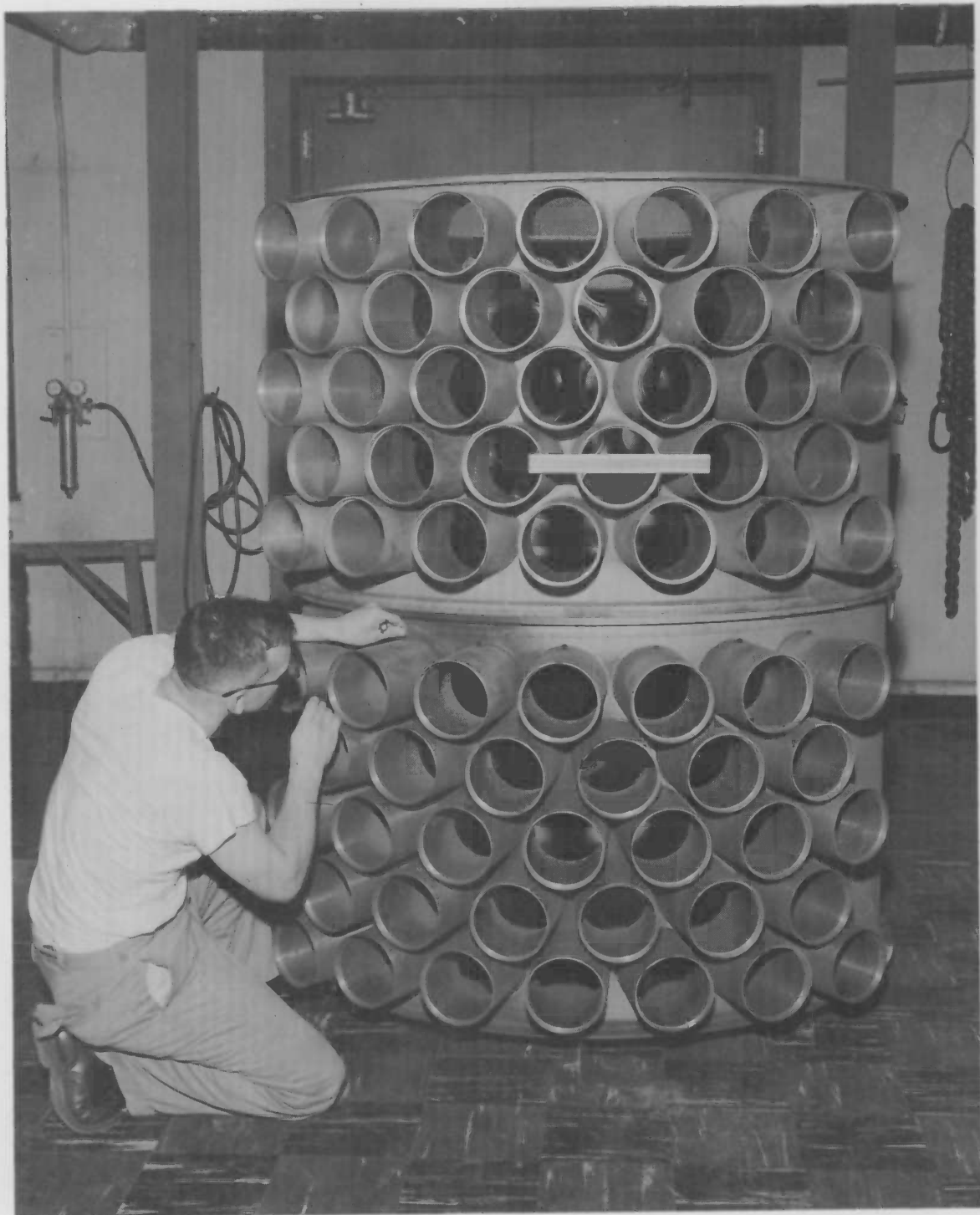


Fig. 3. Shell of antineutrino detector.

Hofstadter and collaborators at Stanford in which the structures of the proton and deuteron were studied. Other questions which may now be subject to experimental check include: Is the  $\beta^-$  decay  $\nu$  the same as the  $\nu$  associated with meson decay?

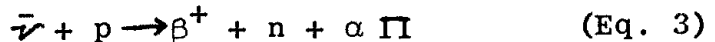
A schematic of a high energy  $\nu$  facility is shown in Fig. 4. Protons strike a target producing, among other particles,  $\Pi$  mesons which decay in flight giving  $\nu$ 's. The high energy of the parent proton is reflected in a generally forward motion of the decay products. A massive shield removes all particles but the  $\nu$  (and  $\bar{\nu}$ ), which then enter the experimental area.

Analysis of the details shows that for ten 25 beV protons per pulse and  $10^3$  pulses/hr (as at CERN), we can expect to obtain 1 event/hr in a 50-metric ton mass of  $H_2O$ . This is a conservative estimate.  $\}_1 \sim \}_2 \sim \}_3 \sim 20$  meters, which indicates the need for large detectors. Consideration of the cosmic ray background during the machine pulses shows that anticoincidence detectors are required for counting experiments.

The anticoincidence requirements are truly impressive, and measures contemplated at the ZGS machine under construction at the Argonne National Laboratory stagger the imagination -- the entire experimental set-up may be enclosed in an anticoincidence detector. This would require at least several tens of square meters of detector! There is, however, no technical reason why such a jumbo-sized anticoincidence shield cannot be constructed.

(This large area detector calls to mind the extensive cosmic ray shower detector array set up by Rossi's M. I. T. group at Volcano Ranch, near here.)

Let us consider for a moment the nature of the  $\nu$  event so as to understand the  $\nu$  detector needs. Reaction (1) for high energies might be generalized to read,



where  $\alpha$  is the multiplicity of pions produced. If  $\bar{\nu}$  has an energy of 500 MeV,  $\alpha \lesssim 2$  and the  $\beta^+$  and  $n$  have energies  $\gtrsim 100$  MeV. The occurrence of this reaction would prove the identity of neutrinos from  $\Pi$ ,  $\mu$ , and  $\beta$  decay. Such high energies make possible the use of Cerenkov detectors, but the cost in photomultiplier tubes and the insensitivity of

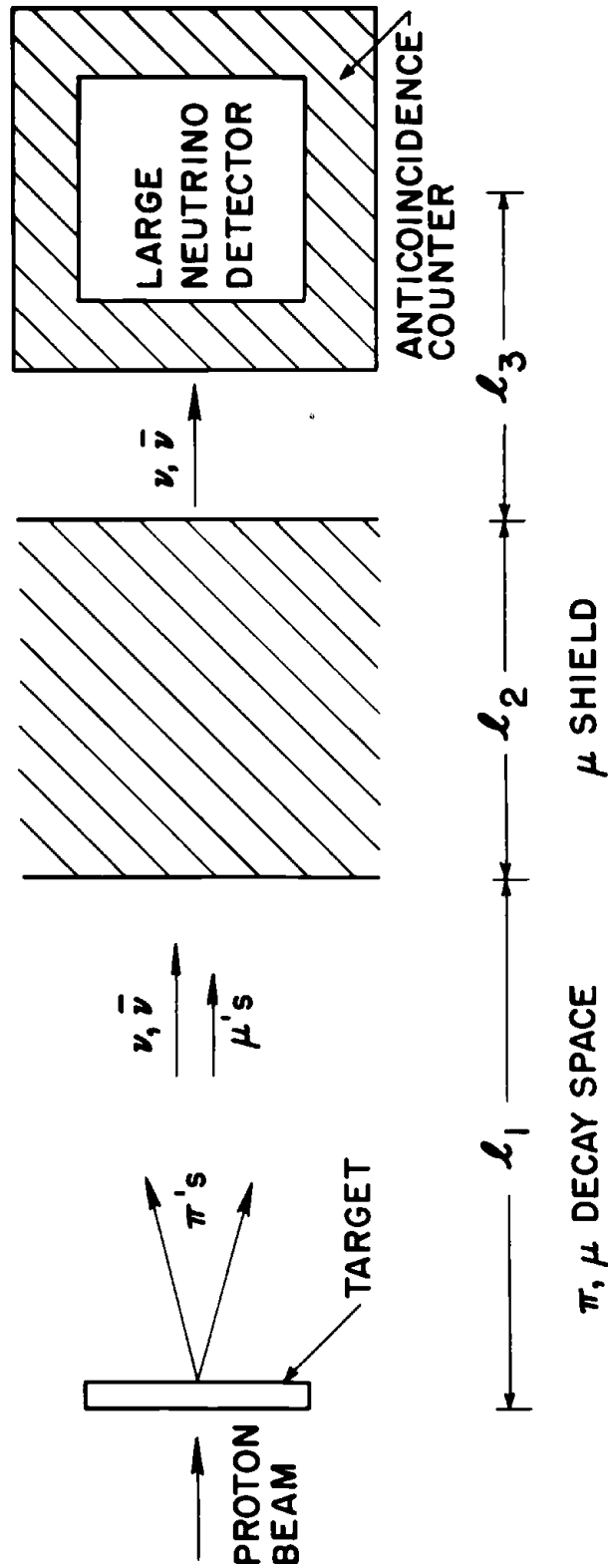


Fig. 4. Schematic of an experimental arrangement for high energy neutrino experiments.

Cerenkov effect to lower energies favor scintillation detectors, especially since the recent Los Alamos find of a low cost scintillator solvent.

### Cosmic and Cosmic Ray Neutrinos - High Energy

In concluding, I would like to pose the question: Is there any hope of seeing high energy neutrinos from the cosmos (cosmic) or in a less ambitious vein, neutrinos secondary to cosmic ray primaries which strike the earth's atmosphere (cosmic ray)?

Because of the high energies involved, natural radioactivity poses no problem, and we must contend only with the other particles in the cosmic radiation -- specifically, muons and their secondaries. Since the best way to contend with muons is to avoid them, a deep underground (or water) location is indicated. However, we cannot hope to go deeply enough and so an anticoincidence is necessary. A reduction of  $\sim 10^6$  can be achieved by using existing salt mines; an anticoincidence could give another  $10^3$  or so.

The signal rate from the cosmic ray  $\nu$ 's is very dependent on the theoretical assumptions but conservatively estimated might be  $\sim 1 \text{ day}^{-1}$  in  $5000 \text{ m}^3$ .

Assuming such a behemoth could be built, one might hope to achieve a signal to background of  $10^{-3}$ . Some additional discrimination can be achieved on an energy basis, since the cosmic rays are mostly of very high energy.

It is just becoming possible to speak of these experiments. At Case we are beginning to study these questions in some relatively small-scale experiments underground.

### CONCLUSION

In this talk I have touched on some of the more exotic uses and possibilities of very large scintillating systems. I have mentioned low energy  $\nu$  studies, high energy physics, further cosmic ray questions, and anticoincidence applications on a large scale.

In the past few years, experimentalists have grown

accustomed to the complexities associated with high energy physics in particular, so that thoughts of hundreds of photomultipliers and thousands of gallons of scintillator are not quite as frightening as they once were. Meanwhile, it appears that the unique characteristics of large scintillation detectors will continue to make interesting new applications possible.

#### REFERENCES

- (1) H. Frauenfelder, private communication (1960).
- (2) F. Reines, Ann. Rev. Nucl. Sci., in press (1960).