promotion of integrated farming systems in developing countries to alleviate malnutrition should not create potential health hazards. However, we believe that the inferred link between fish farming development in the Third World and human influenza pandemics is grossly overstated.

Pigs and poultry have been brought together without fish on traditional mixed farms in Asia and Europe for centuries, although more recent trends in livestock development in both East and West are towards monocultures because of management and marketing considerations. Most integrated livestock–fish farms raise a single species of terrestrial animal with fish. In the examples cited by the authors, only 16 per cent of the freshwater fish farms in Hong Kong with livestock have more than one species of livestock. Similarly pig–hen–fish culture is not widespread in Thailand and the example discussed in the Commentary (hens in cages above pigs which consume hen faeces) is based on a single farm which has since discontinued the practice in favour of pig-fish integration (the original article implied, but did not actually state, that the practice is widespread — another example of the danger in making a generalization from a very limited data base).

Poultry manure has little nutritional value for intensively fed monogastric animals such as pigs because most of the nitrogen is in a non-proteinaceous form. In short, the co-location of pigs and poultry to supply manure for fish culture is neither prevalent nor likely to become so.

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NAYLOR AND SCHOLTISSEK REPLY — In Pullin and Shehadeh (1980), cited in our article, M.N. Delmendo (Food and Agriculture Organization, Bangkok) states "Thailand practices integrated poultry-pig–fish farming, particularly in the central plain where the water supply is abundant". We claimed no more than that pig-poultry–fish systems do occur and pointed out a potential health hazard of expanding the practice of co-locating pigs and poultry around fish ponds, both points which Edwards *et al.* appear to concede.

It would be encouraging if pig–fish systems could be kept separate from poultry–fish systems but to achieve that seems likely to require qualification of a published proposal submitted in February 1988 to the Consultative Group on International Agricultural Research (CGIAR). The proposal being considered by CGIAR argues forcefully for "fully

integrated crop/livestock/fish farming with maximal efficiency of use of on-farm resources" and emphasizes the need for a "whole farm" approach to the development of tropical freshwater aquaculture.

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Massless particles from a perfect fluid

SIR—Your report[1] on the experiments of Danzmann, Meyerhoff *et al.*[2] on heavy-ion collisions encourages me to draw attention (even if hesitatingly) to a phenomenon which Basilis Xanthopoulos and I[3-5] have encountered in the context of the collision of plane impulsive gravitational waves in general relativity.

Briefly, the phenomenon is this: a perfect fluid, in which the energy-density (ε) equals the pressure (p) and the velocity of sound equals the velocity of light, can be transformed into massless particles, or 'null dust'. More precisely, we showed that the presence of an ($\varepsilon = p$)-fluid in the region of the space-time, after the instant of collision of two impulsive gravitational waves, implies that it is the result of a transformation of null dust following the leading edge of the impulsive waves. This transformation, first encountered in the framework of general relativity, is, as Roger Penrose pointed out to us, equally possible in the framework of special relativity (see ref. 6 and ref. 5 Fig. 1). There can be no doubt that the transformation described does and will take place under the circumstances considered. Indeed, as we wrote, "If the reality of this ultimate state of matter i.e. a fluid with $\varepsilon = p$ is accepted, then the fact that such matter can be converted into null dust, both in the frameworks of general and special relativity, gives credence to the possibility that null dust, as classically defined, may have an equal reality." The principal question concerns the reality of an ($\varepsilon = p$)-fluid.

It was pointed out by Zel'dovich[6] in 1962 that the ultimate equation of state of electrically neutral matter consisting of charged constituents of opposite signs, is one in which equality between the energy-density and the pressure is attained and the velocity of sound equals the velocity of light. (For a simple account of Zel'dovich's arguments see ref. 7.) Zel'dovich estimates that the density at which the ultimate equation of state may be attained is 3×10^{16} g cm^{-3}, that is, ~ 100 times the nuclear density, 3×10^{14} g cm^{-3}. However, already at densities of 3×10^{15} g cm^{-3}, we may expect $p \sim \frac{1}{3}\varepsilon$—the

conventional limiting form of the equation of state for a fully relativistic gas.

If we accept the attainability of the equation of state $p = \varepsilon$ as reasonable, how is the null dust described, in the context in which it is transformed into an ($\varepsilon = p$)-fluid? In the framework of general relativity, the Ricci tensor, R^{ij}, is related to the energy-momentum tensor, T^{ij}, by Einstein's equation

$$R^{ij} = -2(T^{ij} - \tfrac{1}{2}g^{lm}T_{lm}g^{ij})$$

with the conventional relativistic units. For an ($\varepsilon = p$)-fluid this relation gives

$$R^{ij} = -4\varepsilon u^i u^j,$$

where u^i denotes the time-like four-velocity of the fluid. Null dust is now described by the relation

$$R^{ij} = \text{constant } k^i k^j$$

where k^i is a null vector. In other words, an ($\varepsilon - p$)-fluid becomes null dust when $u^i \to k^i$, as it does at the shock fronts.

We now turn to the possible relevance of the foregoing remarks to the experiments on the heavy-ion (uranium-thorium) collisions. If we describe the collision as being between two fluids with a density $\rho \sim 3 \times 10^{14}$ g cm^{-3}, then we may expect that at the instant of collision a reflected shock wave results. It is known that the compression following such a reflection can be quite high if the effective 'ratio of specific heats' γ is close to 1. Thus the compression can be as high as 23 even for $\gamma = 1.2$. Because $\gamma \to 1$ even at densities as 'low' as 3×10^{15} g cm^{-3}, it would not appear unreasonable to suppose that a compression exceeding 50 is possible under the conditions of the experiments and that a state of matter approaching Zel'dovich's ultimate state occurs. And if it does, why should we not suppose that conversion to null dust, having the characteristics we have described, takes place?

It does not seem likely that the phenomenon described is relevant to the experiments of Danzmann *et al.*[2] because in their experiments, the energy of the collisions was so arranged that the nuclei just grazed one another. But it may be relevant to experiments of more energetic collisions (apparently now being planned) in which the nuclei will strike one another with such strength that a shock wave of the kind described may indeed result, with the attendant phenomena.

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