ments and roots at a cost considerably below that of concrete barriers¹ probably afford the technique a wide application.

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¹ Goode, J. E., and Marchant, W. T. B., *Nature*, **195**, 410 (1962).

Plutonium and americium in fish

PENTREATH and Lovett¹ have presented data on $^{239+240}\text{Pu}/^{238}\text{Pu}$ ratios in plaice which cause us some concern in the light of what we have recently reported on the probability of biological discrimination between different plutonium isotopes². Although not discussed in their report the ratios in different fish tissues from any one composite sample seem to show approximately two- to threefold differences in the uptake behaviour of ^{238}Pu and $^{239+240}\text{Pu}$, depending on the time of year. As no consistent trends among the ratios in the various tissues seem evident, we question the significance of these differences. Counting errors associated with the $^{239+240}\text{Pu}$ measurements run typically about 20% (range 4–47%). The errors for the ^{238}Pu measurements are not reported but undoubtedly are higher due to the lower levels of ^{238}Pu in the samples. Furthermore, where counting error for $^{239+240}\text{Pu}$ is the least (for example, gut contents), the ratios are more consistent and tend to approach a mean value of 4.4, which is in good agreement with the ratio (4.3) measured in surface sediment² collected from the same general area in July 1975. In fact, if the same relative counting errors reported for the $^{239+240}\text{Pu}$ measurements are assigned to the corresponding computed ^{238}Pu values, comparison of the mean values of the ratios for all tissues from each collection do not indicate differential behaviour between the isotopes. We propose that if the counting errors associated with both the ^{238}Pu and $^{239+240}\text{Pu}$ measurements were propagated, the resultant errors about the ratios would indicate that the apparent differences in plutonium isotope behaviour in certain tissues suggested by their data are not, in fact, significant.

Furthermore, we question the advisability of computing concentration factors for plutonium and americium in plaice in which only filtered seawater concentrations of the actinides are used. In this case the impression given is that ^{241}Am accumulates in plaice muscle fivefold over that of $^{239+240}\text{Pu}$. In another study³, concentration factors in worms based on total

plutonium and ^{241}Am in Windscale sediments indicate that the accumulation of plutonium is favoured over that of ^{241}Am by a factor of two. The discrepancy could be due to a 'species effect'; however, it also may be simply an artefact of the different way in which the concentration factors were computed.

Summation of the monthly discharge data reported by Pentreath and Lovett gives an estimated integrated annual discharge ^{241}Am /plutonium ratio of about 1.4, which is not too unlike either that measured in the sediments³ (1.7) sampled in July 1975 or those that can be computed from their data for the various fish tissues (especially November 1975) and gut contents. These similarities suggest to us the possibility of a real ^{241}Am /plutonium ratio in water somewhat higher than 0.2 reported for ^{241}Am and $^{239+240}\text{Pu}$ in their filtered sample. One recent report⁵ states that 30% of the $^{239+240}\text{Pu}$ in their filtered samples. One recent report⁴ states that 30% of the $^{239+240}\text{Pu}$ in Windscale waters is associated with filterable particulates ($>0.22\text{ }\mu\text{m}$). While apparently no comparable published data for ^{241}Am exist, there are indications^{5,6} that ^{241}Am may be strongly particulate in seawater. We recognise the limitations involved in determining concentration factors; however, until more information is at hand concerning the bioavailability of both soluble and particulate forms of these elements, we believe that concentration factors based only on one fraction of the total element in water may be artificially high.

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¹ Pentreath, R. J., and Lovett, M. B., *Nature*, **262**, 814–816 (1976).

² Beasley, T. M., and Fowler, S. W., *Nature*, **262**, 813–814 (1976).

³ Beasley, T. M., and Fowler, S. W., *Mar. Biol.*, **38**, 95–100 (1976).

⁴ Hetherington, J. A., et al., in *Impacts of Nuclear Releases into the Aquatic Environment: IAEA-SM 198*, 193–212 (International Atomic Energy Agency, Vienna, 1975).

⁵ Volchok, H. L., et al., in *Assessing Potential Ocean Pollutants*, 27–63 (National Academy of Sciences, Washington, DC, 1975).

⁶ Murray, C. N., and Fukai, R., in *Impacts of Nuclear Releases into the Aquatic Environment: IAEA-SM 198*, 179–191 (International Atomic Energy Agency, Vienna, 1975).

PENTREATH AND LOVETT REPLY The errors associated with the ratios of $^{239+240}\text{Pu}/^{238}\text{Pu}$ were omitted in order to avoid a discussion on them. Fowler and Beasley are correct in assuming that most of them are not significantly different, as deduced from errors associated with counting. But there were one or two samples which did seem to be different and these are being investigated further. By and large, however, we are generally impressed as to their lack of variance in view of the widely

differing ratios which obtain in the Windscale area. Fowler and Beasley argue from the axiom of a constant ratio, assumed to be $\approx 4.3:1$. In fact the ratio in the Windscale discharge is not accurately known but seems to have declined from $\approx 20:1$ to $\approx 4:1$ in the last 10 years as deduced from measurements made on surface sediments¹. The ratio thus also varies with depth in the sediment, and this variance with depth differs from one area to another. The fish may therefore have been exposed to slightly different seawater ratios and to largely different ratios in ingested material. Because each organ may have a different biological half-time for plutonium, different ratios could be expected in the organs of some fish. This is rather speculative, however, and it would be very difficult to demonstrate in individual fish and could only explain large ratios.

With regard to the comments concerning the calculation of concentration factors, these calculations were made using the only data available at the time—filtrate sea water samples taken from the same area and at the same time as the August fish samples. These data were kindly proffered by a colleague and we thought the calculations made with them would be of interest; we still do. In doing so, however, we wished neither to commend nor condemn the use of filtrate seawater values for the general calculation of concentration factors. There are as many arguments against using total seawater values—such as the variability in particulate matter in shoreline areas—as there are for their use. The views on this subject of one of us (R.J.P.) are discussed at length elsewhere². For the Windscale area the greatest sources of error for plaice are likely to be, as stated in our paper, the variable discharge rate and the movements of the fish into and out of the area close to the discharge pipe.

Finally, with regard to the amounts of ^{241}Am relative to those of plutonium, we remarked that the concentrations of the former may well have been influenced by a large release at the end of 1974. It is of interest that in samples taken in February 1976 the ratio was $>2:1$ in the majority of organs whereas that of the discharge during the previous six months has been $<0.5:1$.

In short, therefore, the principal objective of the paper was to give some indication of the concentrations of plutonium and americium in plaice in comparison with the amounts of these radionuclides discharged. The points raised by Fowler and Beasley were not discussed as we considered it more advisable to obtain further data rather than attempt to over-interpret those few data which we had already obtained.

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¹ Hetherington, J. A., in *Environmental Toxicity of Aquatic Radionuclides: Models and Mechanisms*, 81–106 (Ann Arbor Science, Michigan, 1976).

² Pentreath, R. J., in *Oceanogr. mar. Biol. A. Rev.*, **15** (in the press).