SO_2 concentration of 0.03 ppm. In the United States there are 200 million people and the death rate is approximately 2 million per year; this leads to 10,000 deaths per million man-concentrations.

A source of uncertainty in evaluating the effect of SO_2 is the belief that pure SO_2, by itself, does not cause a hazard to health. In the presence of particulates, sulfuric acid is formed, which is hazardous. Ferris (*6*) has proposed that the air quality standards should be products of SO_2 and particulate concentrations. Since the pollution tax is based inherently on emissions, I do not see how to take account of such refinements, but suggest that we instead assume a high concentration of particulates—which is not unusual.

How hard should we try to stop these deaths? That depends on the value of human life—or rather, the last 10 years or so of human life, since it is the sick people who die a little earlier. Many people would assume a figure of $30,000 here, which is a typical value of a life insurance policy. But the exposure is involuntary; Farmer (*7*) and Starr (*8*) have pointed out that when the exposure is involuntary people are, and should be, willing to accept only 1/100 of the risk. I therefore assign a value of $3 million, so that an integrated exposure of 6 million man-concentrations costs 6 million × 10,000 per million × $3 million = $180 billion or $30,000 per man-concentration.

In matters of radiation exposure, this type of calculation has been suggested before. The product of radiation dose and population leads to the unit of a man-rem. From a calculation similar to the above, I obtain $500 per man-rem. Lederberg (*9*) finds the same, and Sagan (*10*) finds $30 per man-rem. Clearly, the numbers are not precise. On the basis of my value, for example, the "cost" of medical x-rays averages $45 per person per year, which is about what the patient pays the hospital to administer the x-rays. A nuclear power station would be taxed between $100 and $100,000 a year on the same basis.

We are now in a position to specify a procedure for calculating a pollution tax. For any proposed emission, the winds around the site must be measured over a year, or else a conservative figure taken. Then, for a measured or calculated rate of emission of SO_2, a concentration averaged over a year can be calculated at any point. This calculation has already been done for radiation around nuclear power plants. Unless the polluter can justify using another figure, the winds should be taken as specified in the Atomic Energy Commission's safety guides (*4, 11*). The concentration is then multiplied by the population to arrive at the integrated exposure in man-concentrations, and hence the tax.

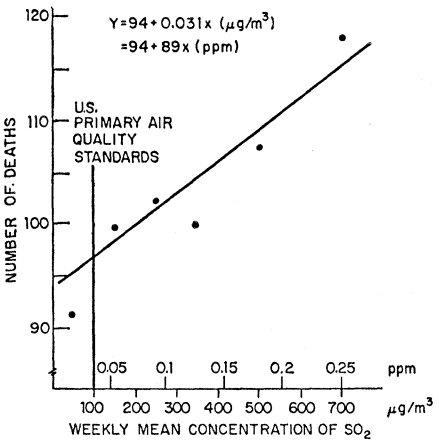

Fig. 1. Total number of deaths in 156 winter weeks in Oslo, from 1958–1959 to 1964–1965, as a function of weekly mean SO_2 concentrations (*1*).

By this means we can take into account the pollution caused by domestic oil heaters; these do not have high chimneys, and they cause local high concentrations of SO_2 over densely populated areas. Of course, we do not expect a million householders to measure the wind speed. But a "standard" conservative calculation can be performed for "typical" domestic homes with "stacks" 15 m high, situated in neighborhoods with "typical" populations. We should evaluate this separately for the categories town, suburbia, and country. The large polluters—industry and power stations—are able to perform a complete calculation, and the tax should encourage them to disperse the SO_2 by using tall stacks, or to locate in relatively unpopulated areas.

Without performing the calculations in detail it is difficult to tell exactly how such a tax would be distributed among polluters. We can, however, calculate the total tax from concentration measurements. I estimate that in 1972 the integrated exposure in the Boston metropolitan area will be 10,000 man-concentrations. The total pollution tax would then be about $300 million. Of this, perhaps one-fourth (about $25 per person) will be and should be paid by many individuals as they pay their bills for heating oil. This is big enough to be a significant, and proper, incentive for people to consider carefully their burning of oil. Perhaps this tax is too large overall; it could be changed by any desired factor, by changing the value assigned to a human life.

The same principle could be applied to other pollutants; in the case of NO_x we are concerned with a threshold for smog formation. In this case the sum over concentrations can be cut off at the lower level, but the averaging is not so good. Again the tax should be related to people because smog where there are no people is unimportant. For example, there are mountain valleys filled with smog from natural NO_x, but no one is worried about this natural smog.

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9. J. Lederberg, *Bull. At. Sci.* **27** (No. 8) (October 1970).
10. L. Sagan, *Science*, **177**, 487 (1972).
11. L. Rogers and C. C. Gamertsfelder, in *Environmental Effects of Nuclear Power Stations* (International Atomic Energy Agency, Vienna, 1971), p. 127. See also appendex A in (*4*).

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Survival of Rana pipiens in Deionized Water

Kalckar's statement that frogs die within a few hours if placed in distilled water (*1*) expresses a view that is apparently generally accepted (*2*). His statement is based on the premise that frogs lose sodium chloride rapidly through permeable skin and inefficient salt reabsorptive mechanisms (via the kidney) to aqueous environments. Only the presence of an inwardly directed active transport mechanism for Na+ allows a fasting frog to effect a net gain of sodium chloride if some salt is present in its bathing medium. In apparent support of his statement that frogs cannot survive a distilled water environment Kalckar makes reference to Ussing (*1*) and to the lectures of Krogh given around 1935. Ussing's publication does not mention the frog's inability to survive a distilled water environment. I cannot speak for the content of Krogh's lectures; however, in a publication dated 1936, Krogh reports that he continuously sprayed *Rana esculenta* with distilled water and that these frogs survived for more than 3 to 12 weeks at room temperature (*3*). Krogh sprayed the frogs with 12 liters of distilled water per 24 hours, the results being taken as a demonstration that frogs can take up chloride ion from tap water. For example, a frog kept in tap water was reported to have a blood Cl^- of 2.48 mg/g and a frog sprayed for 5 weeks, a blood Cl^- of 2.0 mg/g. The latter frog would then take up Cl^- from tap water.

Krogh made two points. First, he observed that the frog possessed a remarkable power to retain salts. The second observation was that the frog also possessed a mechanism for absorbing Cl^- through its skin from dilute solutions of sodium chloride. The ability of a frog to conserve salt is often overlooked, but its ability to take up salt from dilute solutions has formed the basis of many studies of active ion transport. I now report confirmation of Krogh's first statement and attempt to provide some clue to the origin of the false idea that frogs cannot survive immersion in distilled water. I also show how erroneous ideas are introduced into a body of knowledge; as such, it is an example of Hans Elias's perpetuated error hypothesis (*4*).

In experiments designed to test the limits of tolerance of *Rana pipiens* to deionized water, I and my colleagues have placed frogs in 5-gallon polyethylene jars with a wire screen closing the top. They were not fed and were maintained at a temperature of about 24°C. A syphon was attached to the bottom edge of the container. The height of the syphon was such that the polyethylene jar filled to a depth of 10 cm and to a volume of 4 liters with deionized water before emptying completely to a drain every 40 minutes. Deionized water was obtained by means of two deionizers (Continental Water Company) placed in series. According to the company, these deionizers deliver water whose Na^+ content is less than 2 parts per billion. We found that the ion content was less than 0.1 part per million, as determined by Barnsted purity meter (model PM-2), an instrument which does not display lower values accurately. A syphon to remove the water bathing the frogs was used to prevent the frogs from reabsorbing any Na^+ that they might lose to the water, for any reason, including Na^+ derived from catabolized tissue. After this treatment, the frogs were killed, and Na^+ was determined by means of an AutoAnalyzer (Technicon Instruments).

In order to ascertain whether the syphoning procedure leached Na^+ from frogs as they were supplied, we compared the Na^+ content of ashed whole frogs after the syphoning procedure with similar measurements of total body Na^+ taken from frogs received in the same shipment and killed before the start of the experiment. These values provided a baseline for comparison. In other experiments, blood was taken from frogs kept in periodically syphoning deionized water. The serum Na^+ concentration was determined for these frogs and also compared with the serum Na^+ of frogs, from the same shipment, which had been killed at the beginning of the experiment. Twelve frogs were placed in the syphoning containers at the beginning of each experiment. At most four died (cause unknown) before the end of the experiment. However, frogs often jump violently in an apparent attempt to escape and may fall unconscious into the water and drown. The dead frogs were removed within 8 hours. The living frogs molted during the experiment, and the discarded tissue was removed through the syphon. Since the depth of the water in the polyethylene container reached 5 cm midway in the filling cycle, the frogs were forced to move about for at least 20 minutes during each cycle in order to breathe. Their movement and the rise and fall of the water level assured mixing, doubtlessly washing off any salt that might have been lost by the skin.

In one experiment the Na^+ in the serums of frogs that had been killed upon arrival was 89.5 ± 7.0 meq/liter (mean ± S.D.; $n = 8$), whereas the Na^+ in the serums of frogs from the same shipment living in syphoning deionized water for 30 days was 75.7 ± 8.4 meq/liter ($n = 8$). In a second experiment the serum Na^+ of untreated frogs yielded 79.5 ± 3.5 meq/liter ($n = 8$) and that of frogs from the same shipment living in syphoning deionized water for 45 days was 81.7 ± 7.9 ($n = 11$).

It was probably not significant that in the second experiment the serum Na^+ levels of the treated frogs was higher than in the untreated animals. In separate experiments we found that the total body Na^+ of frogs living in syphoning deionized water also appears to remain unchanged. Thus, serum Na^+ is not maintained at the expense of total body Na^+. Untreated frogs killed and ashed upon arrival yielded 0.0415 ± 0.008 mg of Na^+ per milligram of the ash weight (mean ± S.D.; $n = 8$), whereas those from the same shipment kept 30 days in syphoning deionized water yielded 0.0483 ± 0.003 mg of Na^+ per milligram of the ash weight ($n = 8$), and those living in deionized water for 60 days yielded 0.0404 ± 0.002 mg of Na^+ per milligram of the ash weight ($n = 8$). Again, one of the experimental values was higher than that of the untreated control. Thus, initial and final values of serum or total body Na^+ depends more on random selection of frogs for Na^+ analysis than upon the time spent living in deionized water.

Since the serum Na^+ and total body Na^+ of the frogs were not significantly depleted, questions may be raised with respect to the previous environment of these frogs. Our experiments indicate that regardless of the prior history of the frog, maintenance for 30 to 60 days in deionized water does not alter the Na^+ content.

Frogs have been kept for special purposes in distilled or deionized water (*5, 6*). In some cases these frogs are used in experiments with isolated frog skin, such as those described by Ussing and Zerhan (*7*). We have found that frogs kept in stainless steel pans in running deionized water for 2 to 3 months before use have potential differences which range from 20 to 40 mv and short-circuit currents from 30 to 50 $\mu a/cm^2$, and provide excellent material (isolated skins) for Na^+ transport studies. It is also true that frogs withstand starvation rather well. The weight loss (in grams) of 14 frogs kept in syphoning deionized water was found to be 4 ± 1 (S.D.) per 30 days for a 50-g frog.

Our observations confirm the report of Krogh's regarding the frog's control of Na^+ permeability by skin and kidney. Why then is the opposite conclusion generally accepted? First, frogs injected with labeled (radioactive) Na^+ rapidly lose the "label" to bathing medium containing Na^+ (*6*). Thus, it appears that frogs lose Na^+ readily through their skins. However, if the radioactive frogs are placed in Na^+-free water, the outflux of label almost entirely stops (*6*, *8*). When the frogs are returned to water containing minute amounts of Na^+, the loss of radioactive Na^+ again increases, as is characteristic of an exchange reaction (*9*). No net loss of Na^+ occurs. A one-for-one exchange of $^{22}Na^+$ for $^{23}Na^+$ takes place across the skin, free of energy requirements other than that of the kinetic energy of motion produced by the ambient temperature. The exchange cannot occur if Na^+ is unavailable in the bathing medium. It is, therefore, possible that isotope experiments of Na^+ outflux in living frogs are at least partly measurements of an exchange reaction rather than of net Na^+ loss. Consequently, tracer experiments on living frogs may give the impression that the skin is permeable to Na^+ when it is not.

Perhaps a second reason for thinking that frog skin is permeable to Na^+ may arise from experiments with the isolated frog skin preparation by Ussing (*10*). In this preparation, radioisotope experiments indicate the presence of an outflux of Na^+ which would soon deplete a living frog of Na^+ if it occurred in vivo. Some of the outflux of radioactive Na^+ may be the result of "exchange diffusion," a special case of an exchange reaction proposed by Ussing (*10*). It is also possible that "edge-damage" at the circumference of the plastic chambers between which the frog skin is clamped results in a local increase in frog skin permeability to Na^+ (*11*). Because of the leak produced by edge-damage Na^+ outflux measured radioisotopically may mislead one to think that the living frog is highly permeable to Na^+. Thus the effect of an exchange reaction and edge-damage on Na^+ outflux may have produced the false impression that living frogs lose Na^+ from their skins at rates that do not permit their survival unless they are kept in water containing traces of Na^+ which they actively transport inward. Likewise that frogs can concentrate Na^+ from dilute solutions of NaCl is not necessarily an indication that they must do so if they are to survive. Whatever the reason for the misconception about a frog's ability to survive salt-free water, it is clear that frogs do not lose appreciable amounts of Na^+ to distilled or deionized water and are able to survive such environments for many weeks.

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References and Notes

1. H. M. Kalckar, *Science* **174**, 557 (1971); H. H. Ussing, *Harvey Lect.* **59**, 1 (1963–64).
2. It is difficult to document the prevalence of a scientific belief, whether true or false. In this case Kalckar's article was processed at least three times: (i) as a text presented (*1*) as the first Jean Weigle Memorial Lecture, sponsored by the division of biology at the California Institute of Technology in 1970, and I assume that he made the same introductory statement to this audience as was published in *Science*; (ii) the editorial review procedures of *Science* overlooked the error; and (iii) how many readers of *Science* have corresponded concerning this matter? Surely many individuals interested in transport phenomena would have read the introduction to Kalckar's article.
3. A. Krogh, *Scand. Arch. Physiol.* **76**, 60 (1937).
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6. C. B. Jorgensen, *Acta Physiol. Scand.* **19**, 171 (1949); L. Greenwald, *Physiol. Zool.* **44**, 149 (1971).
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12. Supported wholly by funds from the Veterans Administration.

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I am thankful to McAfee for putting an important record straight concerning the diary of the hardy frogs in Krogh's laboratory in 1935 to 1936.

In my introduction to the topic on a general membrane problem, transport, I should have confined myself to Krogh's demonstration of active transport of sodium chloride by frogs and left out the separate and more specific problem, how long frogs can survive in distilled water. As emphasized by McAfee (*1*), Krogh did indeed demonstrate clearly that frogs placed in running distilled water were able to survive not only a few hours but several weeks (*2*). McAfee's own experiments also underline that we are dealing with a separate problem of osmoregulation which is of basic importance. The outcome of these frog experiments from Krogh's 1937 publication was quite surprising. How is it that my recollection 38 years back is that poor? Krogh's lectures were exciting and lucid. My only reasonable guess is that the lecture series which I followed in the semester 1934 to 1935 just preceded the experiments or took place when the experiments were in the planning stage, when problems and questions were being posed. My belated account should therefore rather have tried to portray the situation at that time and simply stated the problems under discussion, one of those being the question of the length of time (in days or hours) a frog would be able to survive in running pure distilled water. I note now from Krogh's article of 1937 that the first frog experiment in distilled water started sometime in February 1935 and that after 1 day of exposure to running distilled water a 52-g frog had lost 2.63 mg of Cl; subsequently the losses went down. In tap water no loss occurred.

My reference to Ussing's work was prompted from Krogh's quantitative observations of active uptake of NaCl from very dilute NaCl solutions to which the frog was exposed (this is the title of the 1937 publication by Krogh; see also page 65 and table 5 in Krogh's article) and to his discussion of uptake of Na^+ as compared to Ca^{2+} (*2*, pp. 70–71).

The results of Krogh's experiments on the effect of distilled water on frogs (the power to retain salt) and the experiments by McAfee (*1*) raise additional basic problems of great interest. As McAfee states in his closing remarks the fact that frogs can concentrate Na^+ from dilute solutions of NaCl "is not necessarily an indication that they must do so if they are to survive." I fully subscribe to his conclusions, thank him for his fight against misconceptions, and hope that by this reply I have been of some assistance, and we can avoid contributing to the type of complacency which Elias (*3*) calls perpetuating errors, so common in biology.

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