actions do or do not occur in the atmosphere.

In summary, on the basis of a conservative analysis of emissions data, the anthropogenic sources of atmospheric CCl_4 appear consistent with the present biospheric loading. However, there is considerable uncertainty about CCl_4 background concentrations, as well as the production-emission data and the atmospheric lifetimes of halocarbons. Therefore, although one cannot exclude the existence of small natural sources, it is clear that atmospheric CCl_4 is predominantly anthropogenic. According to our calculations, we would also predict that, at its current rate of emissions, CCl_4 atmospheric loading will increase at the rate of about 2.4 ppt per year in the troposphere. This rate suggests a uniform CCl_4 concentration of about 76 ppt for the year 1975. This value is in fair agreement with the 1975 Northern Hemisphere CCl_4 concentration of 80 to 90 ppt reported by Hanst *et al.* (*17*), recognizing that a CCl_4 hemispheric gradient of about 10 to 15 ppt probably exists (*2*).

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References and Notes

1. M. J. Molina and F. S. Rowland, *Nature (London)* **249**, 810 (1974).
2. J. E. Lovelock, R. J. Maggs, R. J. Wade, *ibid.* **241**, 194 (1973).
3. P. E. Wilkniss, R. A. Lamontagne, R. E. Larson, J. W. Swinnerton, C. R. Dickson, T. Thompson, *Nature (London) Phys. Sci.* **245**, 45 (1973).
4. J. E. Lovelock and S. A. Penkett, *Nature (London)* **249**, 434 (1974).
5. H. B. Singh, L. Salas, L. Cavanagh, paper No. 76-15.2, to be presented at the 69th annual meeting of the Air Pollution Control Association, Portland, Ore., June 1976.
6. D. Lillian *et al.*, *Environ. Sci. Technol.* **9**, 1042 (1975).
7. M. J. Molina and F. S. Rowland, *Geophys. Res. Lett.* **1**, 309 (1974).
8. J. R. Skeen, *Chem. Eng. (N.Y.)* **57**, 361 (1950); Chemical Information Service, Stanford Research Institute; J. C. Soviero, paper presented at the 12th annual Federal Statistics User's Conference, Washington, D.C., 17–18 October 1968.
9. *IARC Monograph on the Evaluation of Carcinogenic Risk of Chemicals to Man* (International Agency for Research on Cancer, World Health Organization, Lyon, France, 1972), vol. 1, p. 54.
10. *Jpn. Chem. Week*, 22 May 1969; 1 March 1974; 1 August 1974.
11. *Kirk-Othmer Encyclopedia of Chemical Technology* (Wiley-Interscience, New York, ed. 2, 1964), vol. 5, p. 135.
12. *Chemscope*, 12 October 1973.
13. "Fluorocarbons and the Environment, Report of Federal Task Force on Inadvertent Modification of the Stratosphere (IMOS)" (Council on Environmental Quality–Federal Council for Science and Technology, Washington, D. C., June 1975).
14. D. P. Fowler and T. O. Peyton, Stanford Research Institute, prototype report for the National Cancer Institute (contract NO1-CN-55176), SRI Project 4418, 1976.
15. A. J. Murray and J. P. Riley, *Nature (London)* **242**, 37 (1973).
16. "Preliminary Economic Impact Assessment of Possible Regulatory Action to Control Atmospheric Emissions of Chlorofluorocarbons and Chlorocarbons" [prepared by A. D. Little, Inc., Cambridge, Mass., for the Environmental Protection Agency, Research Triangle Park, N.C. (contract 68-02-1349), 1975].
17. P. L. Hanst, L. L. Spiller, D. M. Watts, J. W. Spence, M. F. Miller, *J. Air Pollut. Control Assoc.* **25**, 1220 (1975).
18. "Oil and Hazardous Materials Technical Assistance Data System" [Division of Oil and Special Materials Control, Environmental Protection Agency (WH-448), Washington, D.C., 1975].
19. G. McConnell, D. M. Ferguson, C. R. Pearson, *Endeavour* **34**, 13 (1975).
20. *Chem. Eng. News* **53**, 15 (1975).
21. H. B. Singh, D. Lillian, A. Appleby, L. Lobban, *Environ. Lett.* **10**, 253 (1975).
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Carbon-Nitrogen Cycling Through Microbial Formamide Metabolism

Abstract. *A microbially mediated carbon-nitrogen cycle involving a newly isolated facultatively methylotrophic pseudomonad is described. The new isolate utilizes formamide as its sole carbon, nitrogen, and energy source. Other organisms involved in the proposed cycle are cyanogenic plants; phytopathogenic fungi, which convert cyanogenic glycosides to formamide; and nitrifying microorganisms. This cycle may be quantitatively important in view of the large variety of cyanogenic plants known to exist.*

The cycling of carbon and nitrogen in the environment has been widely investigated, but with the exception of urea and *N*-methylated amines, cycling involving microbial growth on nitrogen containing one-carbon compounds has not been demonstrated.

We have isolated a bacterium which is capable of growth on formamide ($HCONH_2$) as the sole carbon, nitrogen, and energy source, producing CO_2 and NH_3 from formamide during the course of growth. This organism, which has been designated *Pseudomonas SL-4*, was isolated from a lesion on the leaf of a cyanogenic plant, *Sorghum*, which was infected with the pathogenic fungus *Gloeocercospora sorghi*. This fungus has been shown to convert the cyanide present in *Sorghum* to formamide, possibly as a means of cyanide resistance (*1*).

Pseudomonas SL-4 is a gram-negative pink-pigmented rod which is catalase-positive, oxidase-positive, and motile by a single polar flagellum. It is capable of rapid growth (heavy turbidity after 24 hours) on a variety of one-carbon compounds, such as formamide, formate, methanol, and methylamine.

Pseudomonas SL-4 represents one component of a proposed carbon-nitrogen cycle (Fig. 1) which also involves *Sorghum* and the plant-pathogenic fungus *G. sorghi*. The CO_2 produced by *P. SL-4* during the metabolism of formamide is available for utilization by plants in photosynthesis. Incorporation of CO_2 into cell material by cyanogenic plants such as *Sorghum* yields cyanide in the form of cyanogenic glycosides (*2*). Conversion of cyanide to formamide by the enzyme formamide hydro-lyase in *G. sorghi* (*1*) converts carbon and nitrogen into a form metabolizable by *P. SL-4*. In

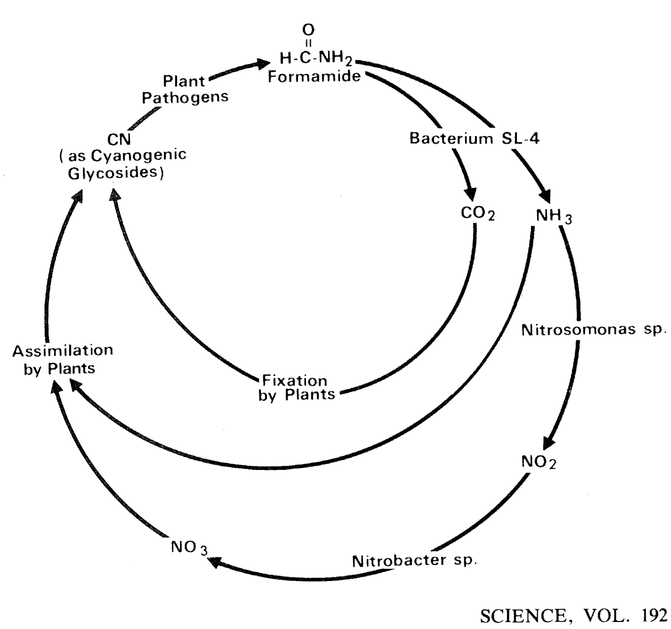

Fig. 1. Carbon-nitrogen cycling through formamide.

contrast to the direct incorporation of CO_2, the NH_3 produced by *P. SL-4* may first be converted, by way of a variety of nitrifying microorganisms, to nitrate. Nitrate may then be incorporated by plants, or the NH_3 may be incorporated directly without oxidation. *Pseudomonas SL-4* possesses the enzyme formamide amidohydrolase (E.C. 3.5.1.4), which performs reaction 1, and formate dehydrogenase (E.C. 1.2.1.2), which performs reaction 2. Since the nitrogen/carbon ratio is high in formamide, nitrogen is in excess. We have observed that formate does not accumulate and CO_2 and NH_3 are the major products.

$$\mathrm{HC(O){-}NH_2 + H_2O \xrightarrow{\substack{\text{formamide}\\ \text{amidohydrolase}}} HCOOH + NH_3} \tag{1}$$

$$\mathrm{HCOOH + NAD^+ \xrightarrow{\substack{\text{formate}\\ \text{dehydrogenase}}} CO_2 + NADH + H^+} \tag{2}$$

where NAD is nicotinamide adenine dinucleotide and NADH is its reduced form.

Pseudomonas SL-4 growing on formamide therefore occupies a position similar to that of organisms which hydrolyze urea (reaction 3) in that the same products are produced.

$$\mathrm{H_2N{-}C(O){-}NH_2 + H_2O \xrightarrow{\text{urease}} 2NH_3 + CO_2} \tag{3}$$

While *P. SL-4* also possesses urease activity, it is incapable of growth on urea as the sole carbon, nitrogen, and energy source.

Sorghum has been shown to contain up to 1.6 m*M* cyanide as cyanogenic glycosides (*4*). Since fungal infection of *Sorghum* converts up to 90 percent of the cyanide present to formamide (*1*), significant quantities of formamide (1.4 m*M*) are available for utilization by *P. SL-4*. In addition to *Sorghum*, other cyanogenic plants have been shown to be infected by pathogenic fungi which convert cyanide to formamide (*3*). Since over 1000 species of cyanogenic plants have been demonstrated (*2*), significant quantities of carbon and nitrogen may be cycled in this manner.

The two major sources of nitrogen for mineralization are the proteins and nucleic acids of living organisms and the excretion of simple nitrogenous compounds (urea and uric acid) by animals (*5*). The nitrogen content of the first sources is liberated upon the death of the cells; proteins are hydrolyzed to amino acids and nucleic acids to purines and pyrimidines. These hydrolysis products are then further degraded to yield NH_3. In the cycle shown in Fig. 1, however, NH_3 is released by initial conversion of a plant product (cyanide) to formamide, followed by hydrolysis to yield the NH_3. In addition to the utilization of a product from a living plant, this cycle differs from that involving proteins and nucleic acids in that the compound involved in mineralization (formamide) is a single-carbon compound, as opposed to the multicarbon amino acids and nitrogenous bases involved above. Furthermore, the carbon-nitrogen compound is a microbial product, as compared with urea and uric acid, which are produced by higher organisms.

While quantitatively not as important as cycles involving urea, the formamide-mediated carbon-nitrogen cycle could be significant because of the large numbers of plants that produce cyanogenic glycosides.

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References and Notes

1. W. Fry and D. Munch, *Proc. Am. Phytopathol. Soc.* 1, 34 (1974).
2. E. Conn, *J. Agric. Food Chem.* **17**, 519 (1969).
3. W. Fry and R. Millar, *Arch. Biochem. Biophys.* **151**, 468 (1972).
4. R. Loyd and E. Gray, *Agron. J.* **62**, 394 (1970).
5. M. Alexander, *Microbial Ecology* (Wiley, New York, 1971).
6. This study was supported in part by federal funds received under the Hatch Act.

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Xenon-133: Ambient Activity from Nuclear Power Stations

Abstract. *The average activity of xenon-133 within and at approximately 100 kilometers from Albany, New York, from April to July 1975 was 2.6 picocuries per cubic meter of air. The source was gaseous effluents from boiling water reactors located in the northeastern United States. Its 5.29-day half-life makes xenon-133 an appropriate isotope to observe for the study of regional and hemispheric dispersion of pollutants.*

Although ^{133}Xe is an important gaseous radioactive fission product released in nuclear weapons tests and in the normal operation of the nuclear fuel cycle, it has usually been considered a local problem. With few exceptions, measurements of ^{133}Xe have been attempted primarily at the site boundaries of nuclear facilities. During 1964 and 1965, however, Scholch *et al.* (*1*) measured the activity of ^{133}Xe in atmospheric air samples taken from a location in West Germany. They observed an average activity of about 0.1 pc/m^3. The source for this activity was not evident. However, a maximum was obtained in June 1965, possibly attributable to a Chinese nuclear bomb test.

In 1975 we undertook to measure the average ambient background of ^{133}Xe in northeastern New York State and to determine the source of this activity. From April to July we collected samples at various locations within and at approximately 100 km from Albany (Fig. 1). The pattern was designed to ensure that the activity we were measuring was not from a local source, such as a hospital or laboratory using ^{133}Xe, but was an ambient activity for this section of the state. Most of the sampling locations were 100 km or more from the nearest nuclear power reactor releasing ^{133}Xe. Whereas samples in the West German study were obtained from an air liquefaction plant, our system permitted collection of grab samples at any desired location.

Air samples of 1 m^3 were collected with a portable air compressor and 15-liter stainless steel vessels containing 1 to 5 cm^3 of stable xenon carrier. The krypton and xenon fractions were separated from the samples by cryogenic adsorption and gas chromatography, as follows. The air sample in the high-pressure vessel was leaked at a reduced pressure of approximately 300 torr through a system containing three traps in series. The first trap, empty and at Dry Ice temperature, removed water vapor. The second trap, filled with glass beads and held at liquid nitrogen temperature, removed CO_2. The third trap, a column 1.5 m long and 1.25 cm in diameter filled with activated charcoal and maintained at liquid nitrogen temperature, retained the xenon and krypton. After the sample had been passed through, the charcoal-filled trap was warmed to 15°C, under vacuum, to remove most of the adsorbed nitrogen, oxygen, and argon. It was then heated to 200°C to drive off xenon and krypton, which were collected on a small molecular-sieve trap at liquid nitrogen temperature.

The krypton and xenon fractions are chromatographically separated and purified by using a column 4.6 m long and 0.63 cm in diameter filled with 94 percent type-5A molecular sieve and 6 percent