

Selenium: A Review

by L. E. COLES

*(County Public Health Laboratory, The Institute of Preventive Medicine,
The Parade, Cardiff)*

Selenium was identified 150 years ago by Berzelius in the residue from sulphuric acid production—the name coming from the Greek word “selene” meaning the moon because of its resemblance to tellurium, an element which had been discovered earlier and was named from the Latin word “tellus”, meaning the earth.

It is a rather rare element, there being no large deposits anywhere and it is mainly obtained commercially as a by-product of the electrolytic refining of copper. Compounds of selenium are used in photo-electric cells, *e.g.* in photographic exposure meters, photometers, counting devices and light controlled switches; as orange and maroon pigments, when calcined with cadmium sulphide, for plastics and ceramics; as decolorisers of glass and for the manufacture of ruby glass; to increase the resistance of rubber to heat, oxidation and abrasion; and as lubricants to increase the machinability of stainless steel.

As a therapeutic agent selenium sulphide is used as a shampoo for certain scalp conditions and isotopic labelled selenium compounds have been used to evaluate pancreatic morphology¹.

In most farming areas, the virgin soils contain so little available selenium that cultivated crops cannot absorb more than traces. However, the quantities absorbed vary from 0.1 to 30 p.p.m. depending on the solubility in water of available selenium compounds¹. Chronic poisoning from selenium in animals occurs in the form of “blind staggers” which is characterised by loss of hair, hooves, nails and teeth and a particular kind of paralysis. Grain containing 10 p.p.m. of selenium causes the typical “alkali disease” in pigs which produces emaciation and lack of vitality².

A survey has been carried out in over a hundred families in a seleniferous area. The manifestations of the disease were bad teeth, yellowish discolouration of the skin, skin eruptions, chronic arthritis in some, diseased nails and subcutaneous oedema¹. There is some evidence from human epidemiological studies that selenium may be a factor contributing toward increased susceptibility to dental caries¹.

In industries where selenium compounds are used the atmospheric concentration should be below 1.0 mg/m³ of air. The threshold limit given by the American Conference of Government Industrial Hygienists for hydrogen selenide is 0.2 mg/m³ of air¹.

Under ordinary conditions the threshold of toxicity to animals and probably also for man is placed at 3 to 4 p.p.m. in the diet and more recently it has been stated that a concentration of 5 p.p.m. in common foods or one tenth of this concentration in milk or water is potentially dangerous¹. The presence of

methyl selenide in the breath, making it smell of garlic, is one of the early symptoms of selenium poisoning and this may occur with a daily ingestion of only a few milligrammes. It is probable that continued ingestion of 5–10 mg/day would lead to nervous symptoms and gastro-intestinal disorders. It is claimed that the more refined and processed foods usually contain less selenium, that protein diminishes the toxicity of selenium and that it is not so poisonous in high protein foods as in high carbohydrate foods^{3,4}. It is also claimed that some of the ingested selenium is stored as a protein compound in the tissues.

TABLE I
SELENIUM CONTENT OF FOODS^{5,6}

Most fruits and vegetables	less than 0.01 p.p.m.
except garlic, mushrooms and radish which contain 0.25, 0.13 and 0.04 p.p.m. respectively	
Grain products vary widely, e.g.	
Corn flakes	0.025 p.p.m.
Barley cereal	0.67 p.p.m.
Whole wheat flour, whole wheat bread and brown sugar contain 2–4 times more selenium than white flour, white bread and white sugar.	
Milk products	
Table cream	lowest 0.005 p.p.m.
Skim milk	highest 0.05 p.p.m.
Dried skim milk powder	0.10–0.25 p.p.m.
Meat products	
Chicken muscle	0.1 p.p.m.
Pork kidney	0.2–0.5 p.p.m.
Sea foods	0.4–0.7 p.p.m.

All these values suggest that a diet well balanced in other nutrients is probably also nutritionally adequate with regard to selenium.

In livestock, selenium deficiency results in white muscle disease in calves and liver malfunctioning and muscle degeneration in pigs¹. In 1957, the role of selenium in nutrition became important when it was demonstrated that a diet, to which selenium had been added at a level of 0.5 p.p.m., prevented dietary liver necrosis in rats⁷. There is also a relationship between selenium and vitamin E in reducing the incidence of retained placentae in dairy cows receiving a diet deficient in selenium⁸. A number of papers have been published on the protective action of selenium against the toxic effects of cadmium and mercury,^{9,10} and it appears that there may be some nutritional adaptation of the organism to selenium¹¹. Preliminary work in Jamaica also suggests that protein malnutrition disease may also be associated with selenium deficiency¹.

Apparently selenium deficiency is more widespread than has been suspected in the past and Scott, in an editorial article in the journal *Nutrition* which is called "The Selenium Dilemma"¹², attempts to balance the problem of dealing with selenium deficiency and cancer with the evidence that in certain circumstances the element and its compounds are carcinogenic.

METHODS FOR THE DETERMINATION OF SELENIUM IN BIOLOGICAL SUBSTRATES

The first reliable analysis of biological material appeared in 1964¹³, when an oxygen flask technique was applied and 5-litre flasks were used with one gramme samples.

The general method of A.O.A.C.¹⁴ may be sufficiently accurate for high concentrations of selenium, for example, from 1–5 p.p.m. using a five-gramme sample, but for microgramme amounts it is not sufficiently sensitive, *e.g.* 1 ml 0.001 N $\text{Na}_2\text{S}_2\text{O}_3 = 19.8 \mu\text{g}$ of Se. Further practical experience shows that mercuric oxide is not a good fixative if one is trying to recover very small amounts.

A colorimetric method giving a blue colour with codeine in concentrated sulphuric acid does not seem to have gained popularity¹⁵ but possibly could be used as a screening test after wet oxidation.

The method chosen as a standard method in the analysis of raw, potable and waste waters¹⁶ consists of isolation of the selenium from interfering substances by ion-exchange and subsequent determination as the colloidal element produced by reduction with either ascorbic acid or hydrazine sulphate. This method has been chosen because of its simplicity and the avoidance of distillation and use of known carcinogens (*e.g.* di-aminobenzidine). Selenium is conveniently absorbed on to an anionic resin and separated from many other compounds, for example mercury, by passing through a cationic resin. The reactions with mercaptobenzoic acid¹⁷ or mercaptobenzothiazole¹⁸ give fine absorptiometric linear graphs but anyone who has tried it will find that it does not work in the presence of many other ions such as are found after wet oxidation. A limit of detection of selenium in the range of 50–100 picogrammes has been claimed for waste waters using atomic absorption carbon rod technique¹⁹, but this has been done by using large samples and preconcentration techniques. Matrix interferences have not yet been overcome. Similarly gas/liquid chromatography using an electron-capture detector has been used to detect 0.002 μg in a 1-ml organic extract of sea water²⁰. A recently published spectrophotometric method involves oxidation of hydroxylamine hydrochloride to nitrous acid by selenious acid followed by a diazotisation and coupling reaction. However, although there do not appear to be any common interferences, the range is only from 0.01 mg to 0.20 mg of selenium which is not sensitive enough²¹. A sensitivity down to 0.1 μg has been claimed in water analysis by taking advantage of the specific reaction of the catalytic effect of selenium on the sulphide reduction of methylene blue, which can be measured photoelectrically and the reduction time documented on a recorder²².

The main problem is to destroy the organic matter without losing selenium. It can be done in the absence of fatty material, for example in plant material, although it is very necessary to maintain oxidising conditions at all stages of wet oxidation and this requirement explains the efficiency of oxidising mixtures containing perchloric acid. However, if the biological substrate is particularly difficult to destroy, *e.g.* fatty material, and the digestion procedure has to be modified by raising the temperature to complete the wet oxidation, there is the

likelihood that selenium will be lost. Controlled experiments have shown that some selenates are volatile above 200°C and, therefore, during the nitric acid/peroxide/perchloric acid digestion the temperature has to be carefully watched²³. There is no completely satisfactory standard that can be used in checking recoveries of selenium from biological materials unless good oxidising conditions are maintained throughout because the organic forms of selenium can be converted to volatile selenides during decomposition of the sample^{24,25}.

Workers who have carried out surveys on selenium in biological materials have usually concluded that the best approach has been the fluorescent method which is based on the piaszelenol formed between selenium and diamino-naphthalene. The limit of sensitivity is extremely low, in the region of 0.05 microgramme and for this reason there are difficulties^{23,26}. The fluorescence is not absolutely specific for selenium; substances likely to give false positives are direct light, oxygen and certain solvents and it is, therefore, not easy to get a satisfactory blank value. Mercury interferes with the development of fluorescence.

The immediate problem that agricultural analysts have to face is to be able to rely on a method for the determination of selenium at a level of 0.5 p.p.m. in a feeding stuff and, if possible, to develop a screening or limit test for routine work. The draft directives of the E.E.C. in relation to colours, preservatives and antioxidants include in their general purity criteria that they should not contain, amongst other things, selenium in detectable quantities. A calibration curve can easily be obtained between the range 0.1–0.5 of a microgramme of selenium using the fluorimetric procedure.

The advice of the author on the analysis of the ordinary compound feeding stuff is to extract the oil in the usual way by soxhlet extraction. Wet oxidise the defatted material with nitric acid, hydrogen peroxide and perchloric acid and determine the selenium by fluorimetry after the formation and extraction of the 4,5-benzopiazselenol.

SUMMARY

- (a) Selenium is an essential element for nutritional reasons.
- (b) The nutritional requirement lies in the range of 0.1 to 0.3 p.p.m. of selenium.
- (c) Selenium can be an extremely toxic element in moderately excessive quantities.
- (d) Levels in the region of 2–10 p.p.m. produce chronic toxic symptoms.
- (e) Studies suggest that in some way or other it has an effect in the action of various carcinogens and may itself be carcinogenic.
- (f) Wet oxidation of defatted material followed by fluorimetric determination using diaminonaphthalene is the method of choice for selenium.

References

1. Rosenfeld, I., and Beath, A., "Selenium—Geobotany, Biochemistry, Toxicity and Nutrition," Academic Press, London, 1964.
2. Thompson, J. N., and Scott, M. L., *J. Nutrit.*, 1969, **97**, 335.
3. Morris, V. C., and Levander, O. A., *J. Nutrit.*, 1970, **100**, 1383.
4. Smith, M. I., U.S. Publ. Health Repts., 1939, **54**, 1441.
5. Morris, V. C., and Levander, O. A., "Selenium Content of Foods," *Nutrit.*, 1970, **100**, 1383-1388.
6. Amer, M. A., and Brisson, G. J., "Selenium in Human Food Stuffs," *J. Inst. Can. Sci. Technol. Aliment.*, 1973, **6**, No. 3, 184-187.
7. Schwartz, K., and Foltz, C. M., *J. Amer. Chem. Soc.*, 1957, **79**, 3292-3293.
8. Trinder, N., Hall, R. J., and Renton, C. P., *Vet. Rec.*, 1973, **93**, 641.
9. Paitzek, J., Astadalova, I., Benes, I., and Babicky, A., *J. Reprod. Fert.*, 1968.
10. Koesman, J. H., Peeters, W. H. M., Keudstaal-Hol., C. H. M., Tjioe, P. S., and De Goeiz, J. J. M., *Nature*, 1973, 245, 385.
11. Jaffe, W. G., and Mondragon, M. C., *J. Nutrit.*, 1969, **97**, 431.
12. Scott, M. L., *Nutrit.*, 1973, **103** (6), 803.
13. Allaway, W. H., and Cary, E. E., *Analyt. Chem.*, 1964, **36**, 1359.
14. "Official Methods of Analysis," 1945 and 1965, The Association of Official Analytical Chemists, Washington, D.C.
15. Horn, M. J., *Ind. and Eng. Chem. (Anal.)*, 1934, **6**, 34.
16. "Analysis of Raw, Potable and Waste Waters," H.M.S.O., London, 1972.
17. Cresser, M. S., and West, T. S., *Analyst*, 1968, **93**, 595-600.
18. Bera, B. C., and Chakpabartty, M. M., *Analyst*, 1968, **93**, 50.
19. Reichel, W., *Analyt. Chem.*, 1971, **43**, 1501-1503.
20. Yasuaki Shimoishi, *Analyt. Chim. Acta*, 1973, **64**, 465-468.
21. Osburn, R. L., Shendriker, A. D., and West, P. W., *Analyt. Chem.*, 1971, **43** (4), 594-597.
22. West, P. W., and Rawakrishna, T. V., *Analyt. Chem.*, 1968, **40**, 966.
23. Hall, R. J., and Gupta, P. L., *Analyst*, 1969, **94**, 292.
24. Gorsuch, T. T., *Analyst*, 1959, **84**, 151.
25. Down, J. L., and Gorsuch, T. T., *Analyst*, 1967, **92**, 398.
26. Olson, J. *Assoc. Offic. Analyt. Chemists*, 1969, **52**, 627.