The uptake of both forms of thallium increased as expected with both time and applied concentration, but a significant difference was noted in the overall levels of accumulation with Tl^+ concentrations in the root tissue reaching ten times those found for Tl^{3+} under similar conditions.

The uptake of Tl^+ was found to be affected by temperature, with the uptake increasing with temperature over the range 0–30 °C, but showed inhibition thereafter. The uptake of Tl^{3+} was unaffected by changes in temperature. Figure 1.

The uptake of Tl^+ was severely diminished by several common metabolic inhibitors, particularly by vanadate which is recognised as an inhibitor of the Na^+/K^+ ATPases. Tl^{3+} uptake was unaffected.

Desorption studies showed that Tl^+ could not be removed from the root tissue, suggesting that it had entered the cell, but Tl^{3+} was easily removed by cation exchange, suggesting that it was confined to the extracellular space.

Overall the results suggest a process of active uptake for Tl^+ but passive uptake for Te^{3+}.

1 F. A. Cotton and G. Wilkinson, 'Advanced Inorganic Chemistry', Wiley-Interscience, New York, 4th edn., 1980, pp. 326–351.
2 I. C. Smith and B. L. Carson, 'Trace Metals in the Environment', Volume 1, Thallium. Ann Arbor Science.
3 E. Epstein, *Plant Physiol.*, *27*, 457–474 (1952).

S11

Aluminum-Induced Inhibition of Calmodulin-Regulated Phosphodiesterase Activity: Enzymatic and Optical Studies

NEAL SIEGEL and ALFRED HAUG

Pesticide Research Center and Department of Microbiology, Michigan State University, East Lansing, Mich. 48824, U.S.A.

Calmodulin, a highly conserved, endogenous calcium-binding protein, plays a major role in coordinating the effects of second messengers in response to cellular stimulation. Calcium is bound to four specific sites on calmodulin which has a molecular weight of about 17000 [1]. Calmodulin also seems to participate in regulating the polymerization of brain microtubules whose assembly depends in part on the local level of cyclic 3′:5′-nucleotide phosphodiesterase [2]. Results presented in this communication show that aluminum binds stoichiometrically to calmodulin thereby changing its conformation which, in turn, leads to an inhibition of the calmodulin- and calcium-dependent phosphodiesterase activity.

Calmodulin was prepared from bovine brain acetone powder by affinity chromatography [3] with 500 mM NaCl in the elution buffers to enhance the purity of the material. All buffers and assay solutions were free from contaminating metals as analyzed on a Varian atomic absorption spectrophotometer, model 1475. Calcium binding was measured under equilibrium dialysis conditions. The enzymatic activity was assayed as described [4].

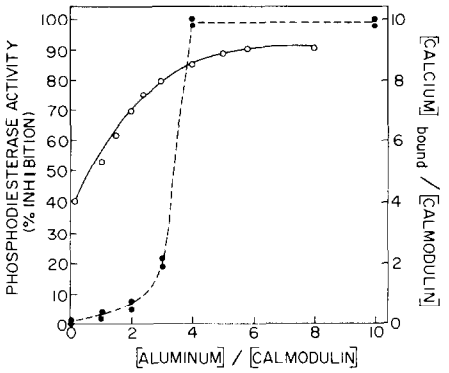


Fig. 1. Effects of aluminum ions on bovine brain calmodulin as monitored by calcium binding (o) and inhibition of calcium–calmodulin stimulated cyclic 3′:5′-nucleotide phosphodiesterase activity (•). The enzymatic assay was conducted in the presence of 25 μM $CaCl_2$ and 5 μM calmodulin, at pH 6.5, Tris buffer 10 mM, with reaction times varying between 15 and 30 min.

The addition of increasing aluminum concentrations to calmodulin- and calcium-dependent phosphodiesterase produces a distinctive inhibition of the enzymatic activity (Fig. 1). In the absence of aluminum, 0 percent inhibition corresponds to 0.6 nmol/ml·min cyclic GMP hydrolyzed. 50 percent inhibition of the enzymatic activity occurs at a molar ratio of 3:1 [aluminum]/[calmodulin]. The metal-induced inhibition does not appear to result simply from a displacement of calcium from its specific sites on calmodulin, as demonstrated by measuring the calcium content with atomic absorption (Fig. 1). Rather, application of aluminum causes a larger hydrophobic surface exposure of the protein as compared to that generated by calcium, as evidenced by fluorescent, hydrophobic probes. These results are in accord with those from circular dichroism experiments indicating that aluminum induces helix-coil transitions in calmodulin at stoichiometric ratios [5]. These kinds of changes in the protein may explain why the aluminum–calmodulin complex cannot interface properly with the enzymatic protein and lost at least part of its regulatory character; formation of this complex may thus be a key lesion in aluminum toxicity.

Acknowledgement. This work was supported by the U.S. Department of Energy contract No. DE-AC02-76ER01338.

1 C. B. Klee, T. H. Crouch and P. G. Richman, *Annu. Rev. Biochem.*, *49*, 489 (1980).
2 K. Watanabe and W. L. West, *Fed. Proc.*, *41*, 2292 (1982).

3 C. R. Caldwell and A. Haug, *Anal. Biochem., 116*, 325 (1981).
4 D. J. Wolff, P. G. Poirier, C. O. Brostrom and M. A. Brostrom, *J. Biol. Chem., 252*, 4108 (1977).
5 N. Siegel and A. Haug, *Biochim. Biophys. Acta*, in press (1983).

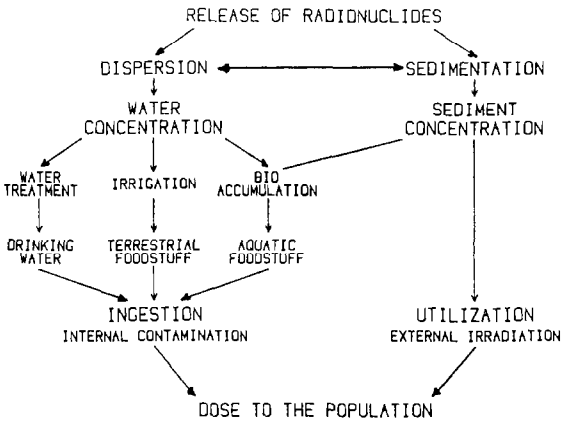
S12

Accumulation of Radionuclides in Aquatic Organisms

P. SCOPPA

Commission of the European Communities c/o ENEA Centro Ricerche Energia Ambiente, La Spezia, Italy

A good knowledge of the physico-chemical and biological processes involved in the transfer of radionuclides in the environment is essential for evaluating the radiological consequences of radioactive effluents released in the various phases of the nuclear fuel cycle [1]. As far as radionuclide releases to aquatic environments are concerned, the main transfer pathways may be represented schematically as follows:



Radioecological studies provided a considerable amount of information on the environmental behaviour of many radionuclides. Since critical pathways to man are generally food chains, particular emphasis was given to research on radionuclide transport and accumulation in living organisms. Bioaccumulation factors for a given radionuclide may differ by several orders of magnitude in freshwater and marine biota (plants, invertebrates, fish, waterfowl or shorebirds).

The acquired knowledge allowed the application of mathematical models for describing the transfer of the most important radionuclides through food chains and for evaluating the radiological impact of radionuclides released in normal operations [2]. Steady-state concentrations in the aquatic environment can be easily converted to equilibrium concentrations in biota and potential doses to man calculated considering the more important ingestion pathways [3].

The critical pathways are generally consumption of fish and ingestion of water when radionuclides are released to freshwater ecosystems, consumption of molluscs or crustaceans when radioactive effluents are released to marine ecosystems. Therefore, bioaccumulation factors are very important parameters in determining the dose to man.

In the case of light water nuclear power reactors discharges, most of the dose is caused by a relatively few radionuclides, such as:

– tritium (pressurized water reactors), phosphorus-32, cobalt-60, niobium-95, iodine-131, cesium-134 and cesium-137, for freshwater environments;

– manganese-54, cobalt-58, cobalt-60, zinc-65, iodine-131, and cesium-137 for marine environments.

The information collected from research on the environmental behaviour of radionuclides may be very useful for a better understanding of the processes responsible for accumulation of stable metal ions in aquatic organisms and biomagnification through food chains.

Acknowledgement. Contribution No. 1906 of the Programme Radiation Protection of the Commission of the European Communities.

1 F. W. Whicker and V. Schultz, 'Radioecology: Nuclear Energy and the Environment, CRC Press Inc., Boca Raton, USA (1982).
2 Commission of the European Communities, Methodology for evaluating the radiological consequences of radioactive effluents released in normal operations – Joint Report by the National Radiological Protection Board and the Commissariat à l'Energie Atomique – Document No. V/3865/79 (1979).
3 R. S. Booth, S. V. Kaye and P. S. Rohwer, A Radiological Assessment of Radionuclides in Liquid Effluents of Light Water Nuclear Power Stations. Report ORNL-TM-4762; Env. Sci. Div. Publication No. 716, Oak Ridge National Laboratory, USA (1975).

S13

New Aspects of the Interaction between Polysaccharides and Metal Ions in Relation to the Mineral Nutrition of Plant Roots

S. DEIANA, A. DESSI, G. MICERA*

Istituto di Chimica Generale ed Inorganica dell'Università, 07100 Sassari, Italy

C. GESSA and M. L. DE CHERCHI

Istituto di Chimica Agraria dell'Università, 07100 Sassari, Italy

Recent discoveries emphasize the newly emerging concept that an extracellular apparatus, rich in