

to that in which protons are accelerated, it is seen that, in this case, the biologically most important fraction of the heavy beam which produces the thin-down hits would be subjected to an especially large increase of intensity. It might be mentioned in this connection that the optical emission lines of all heavy components, particularly those of calcium and iron, have been identified in the flare spectrum.

Other parameters on which no data are available are the intensities of flare-produced beta, x-, and gamma rays. It thus appears that, while the extra-atmospheric ionization dosages plotted in Fig. 1 certainly represent the lower limit, they might possibly do so by a large margin. On the other hand, flares of the size under discussion are rare events that occur only a few times during the entire peak of one 11-year cycle.

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Concentration of Cesium-137 by Algae

The ab-adsorption of Cs^{137} by algae is of interest because Cs^{137} is one of the critical fission products in power reactor wastes and atomic weapon fallout, because it has an estimated half-life of 26.6 years, because it is water-soluble, and because it may be expected to increase in the environment as more and more use is made of nuclear energy as a source of electric power. It is well known that plankton take up radioactivity in fairly high concentrations (1). The purpose of this investigation was to study the accumulation of Cs^{137} by fresh-water algae (2).

Unialgal cultures of nine species, collected from the vicinity of Oak Ridge National Laboratory, were dosed with Cs^{137} chloride so that the initial activity of the nutrient media ranged from 1556 to 4056 disintegrations per minute, per milliliter. Results from these nine species are given in Table 1. The concentrations (in parts per million) of potassium present in the nutrient media were determined by flame photometry. The concentration factor given in Table 1 is the ratio of the activity of wet weight of washed algal cells (disintegrations per minute, per gram) to the activity of the nutrient medium (disintegrations per

minute, per milliliter). The remainder of this report deals with the accumulation of cesium by *Euglena intermedia* and *Chlorella pyrenoidosa*. Dense populations were produced repeatedly in a putrified "Euglena" nutrient medium (3); white fluorescent lamps, delivering about 380 ft-ca, controlled by automatic clocks to give a 20-hour day and a 4-hour night, were used. The extent to which these algae decontaminate their nutrient medium was investigated. In 6 days *Euglena* decontaminated the medium by 69 percent; in 11 days, by 82 percent; in 18 days, by 86 percent; and in 34 days, by 96 percent. *Chlorella* decontaminated the medium by about 47 percent at each concentration of Cs^{137} in 13 days. The rate of decontamination appeared to vary directly with the number of cells in *Chlorella*, but in *Euglena* there was an increase in uptake per cell from the time cells ceased dividing, as the population became maximum.

Unialgal cultures of *Euglena* and *Chlorella*, grown in three concentrations of Cs^{137} , demonstrated repeatedly that the uptake of this radionuclide is linear with concentrations of 1, 5, and 10 $\mu\text{C}/\text{lit}$ or of 1, 5, and 10 $\times 10^{-7}$ mmole/lit. Knauss and Porter (4) have found this to be true for calcium, iron, manganese, zinc, copper, and strontium at varied concentrations in *Chlorella*. However, at concentrations of 0.04 mmole/lit or more, in the present study, the concentration factor for cesium was reduced.

Morgan and Myers (5) have reported that uptake of cesium by *Chlorella* is significantly depressed by traces of potassium ion in the exchange solution. Also, cesium has been reported by MacLeod and Snell (6) to behave similarly to sodium, potassium, and rubidium in the nutrition of lactic acid bacteria. The relative influence of potassium and stable cesium on the uptake of tracer cesium by *Euglena* was determined experimentally, and the results are shown in Fig. 1. In the range of concentrations from 0.5 to 4.0 mmole/lit, potassium had a slight depressant effect on the uptake of Cs^{137} at tracer levels. When 1 mmole of potassium was present, increasing the concentrations of cesium carrier from 0 to 0.15 mmole/lit depressed the uptake of tracer cesium. The further increase of cesium content to 0.75 mmole/lit caused little additional depression of Cs^{137} uptake. It should be noted that an addition of an equimolar amount of potassium resulted in very little additional depression of the cesium uptake. The effect of potassium in the medium is presumed to be slight, because a concentration factor of 100 was found for *Chlorella* grown in media with potassium concentration as high as 1 mmole/lit.

In experiments during which *Chlorella* was grown in varying concentrations of stable cesium, the concentration factor

Table 1. Uptake of cesium-137 by species of algae.

Species	Potassium (parts per million)	Days after dosing	Concentration factor
<i>Rhizoclonium hieroglyphicum</i>	1	5	1530
<i>Oedogonium vulgare</i>	1	3	790
<i>Spirogyra ellipsoidea</i>	1	2	341
<i>Spirogyra communis</i>	13	5	220
<i>Gonium pectorale</i>	10	2	138
<i>Oocystis elliptica</i>	10	10	670
<i>Chlamydomonas</i> sp.	8	5	52
<i>Euglena intermedia</i>	8	14	706
<i>Chlorella pyrenoidosa</i>	8	11	154

for Cs^{137} was 46 to 59 in the absence of cesium, 15 to 18 with 0.5 mmole of stable cesium per liter, and 8 to 12 for other concentrations of stable cesium up to 2.5 mmoles per liter.

Since it has been shown that dead organic material can have a high affinity for cesium (7), *Chlorella* and *Euglena* cells which had been grown in a medium containing 15 parts of potassium per million were washed, killed in formalin, and dosed with Cs^{137} . After 8 days the concentration factor was 16 for *Euglena* and 418 for *Chlorella*. Because dead *Chlorella* showed a high concentration factor for cesium, an experiment was performed to test the uptake of cesium from varying levels of cesium, potassium, and cesium-potassium by these dead cells. Healthy living cells of *Chlorella* were washed and centrifuged in demineralized water. These cells were then killed with formalin, equally distributed into 33 large centrifuge tubes, and resuspended in demineralized water. To the 33 tubes were added stable salts to make three classes of 11 each, as follows: (i) 0 to 5 mmoles of potassium per liter; (ii) 0 to 5 mmoles of cesium per liter; and (iii) potassium and cesium in varying ratios but always totaling 2.5 mmole/lit. Each tube was dosed to give an activity of about 1 μC of Cs^{137} per liter and left standing for 72 hours. Thereupon, the cells in each tube were

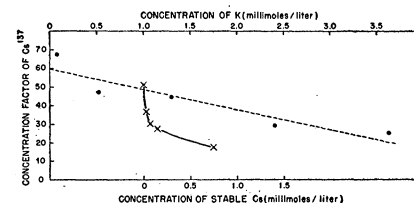


Fig. 1. Influence of potassium and cesium ions in the nutrient medium on the concentration of Cs^{137} by *Euglena intermedia*. The broken line represents the influence of potassium (regression line determined by least squares). The solid line represents the influence of cesium (curve fitted by eye), with potassium constant at 1.0 mmole/lit.

centrifuged, washed, dried, weighed, and analyzed for radioactivity. The dead cells of *Chlorella*, with no added salts and at all levels of potassium (i), were found to concentrate Cs¹³⁷ by a factor varying from 35 to 68; the variations appeared to be random. In mixtures containing stable cesium, (ii) and (iii), the concentration factor varied around 1—that is, the algal cell bodies contained the same amount of Cs¹³⁷ as did an equal amount of the medium.

These results suggest that structural components persist in dead *Chlorella* which adsorb cesium from very dilute solutions and that this adsorption is not affected by the concentration of potassium in the medium. From these data it may be inferred that, in killed cells of *Chlorella*, potassium and cesium behave independently, but that in live cells of *Chlorella* and *Euglena*, particularly at tracer levels of potassium, ions of potassium and cesium form a metabolic pool.

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Bronchodilator Action of the Anticoagulant Warfarin Sodium

During the administration of warfarin (Coumadin) sodium, or 3-(α -acetylbenzyl)-4-hydroxycoumarin sodium, to patients with coronary thrombosis and other forms of thromboembolic disease, Livesay (1) noticed improvement in the asthmatic condition of several patients who had bronchial asthma in addition to the thromboembolic involvement. This observation prompted us to look for a direct bronchodilator action of warfarin sodium. For this purpose we employed the isolated guinea pig tracheal chain

(2), a method which has been used extensively in pharmacological studies and which has been found to correlate well with clinical bronchodilator activity.

The results are shown in Table 1. Aminophylline, a well-established clinical bronchodilator, was used as a reference standard for the kymographic recording of relaxation or dilatation of the uncontracted tracheal chain. The lever system was adjusted so that 5 mg of aminophylline in the 100-ml bath, or a bath concentration of 0.05 mg per milliliter, produced a fall of about 2 cm on the kymograph tracing. Warfarin sodium was indeed found to possess some tracheodilator activity, being about 50 percent as active as aminophylline. By comparison, two different commercial samples of heparin sodium were found to be very weak, only about 5 percent as active as aminophylline. Since warfarin sodium and heparin sodium are sometimes injected simultaneously to secure the immediate anticoagulant effect of heparin and to initiate the slower but more prolonged effect of warfarin, a combination of equal amounts of the two drugs was tested on the tracheal chain. The tracheal dilatation was again approximately 50 percent that of aminophylline, demonstrating that the dilator effect of warfarin sodium was not influenced by the simultaneous presence of the heparin.

It has been pointed out (3) that some of the beneficial action of anticoagulants in myocardial infarction may be due to properties other than that affecting coagulation. The initial dose of warfarin sodium is usually 75 mg by intravenous, intramuscular, or oral administration, as compared with an aminophylline dosage of 250 to 500 mg intravenously or intramuscularly for emergency bronchodilatation and 100 to 250 mg orally for nonemergency use. If the dilator effect demonstrated on the tracheal chain is reflected in a corresponding bronchodilatation in man, it seems possible that the initial injection of warfarin sodium may produce some immediate bronchodilatation as well as initiating the slower anticoagulant action. Perhaps prolonged administration of small oral maintenance doses might also account for a bronchodilator effect by the same mechanism.

It is interesting to note, in this connection, that a coronary dilator action has been reported in dogs following intravenous injection of the disodium salt of bishydroxycoumarin (Dicumarol) (4) and of solubilized ethyl biscoumarate (Tromexan) (5). Owren (6) has noted an improved effort tolerance from long-term anticoagulant therapy in patients with angina pectoris. The coronary dilator activity of warfarin sodium is yet to be investigated.

Studies will be extended to other anti-

Table 1. Tracheodilator potency of anticoagulants, as compared with that of aminophylline.

Source	Bath concn. for 2-cm lever fall (mg/ml)	Approximate tracheodilator potency
<i>Aminophylline</i>		
10-ml ampule	0.05	100
<i>Warfarin sodium</i>		
Powder	0.1	50
<i>Warfarin sodium</i>		
3-ml vial	0.1	50
<i>Heparin sodium-A</i>		
10-ml vial	1.0	5
<i>Heparin sodium-U</i>		
10-ml vial	1.0	5
<i>Warfarin sodium plus heparin sodium-U</i>		
Vials—equal wts.	0.1 plus 0.1	50

coagulants to determine whether the observed warfarin sodium tracheodilatation or bronchodilatation is a general property of 4-hydroxycoumarin anticoagulants.

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Action of Selected Redox Substances on Bacterial Bioluminescence

Bioluminescence in *Achromobacter fischeri* and other luminous bacteria (1) depends upon a series of electron transfer reactions. The demonstration by Strehler (2) of bioluminescence in cell-free extracts of *A. fischeri*, and subsequent studies on the properties of this system, reviewed by McElroy and Strehler (3), showed that its essential components are reduced flavin mononucleotide (FMNH₂), a higher fatty aldehyde, from C₆ to C₁₆, atmospheric oxygen, and an extract of bacterial enzymes. Substrate and phosphopyridine nucleotide-specific dehydrogenase, reduced di- or triphosphopyridine nucle-