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ACCUMULATION AND RETENTION OF CHROMIUM-51 BY FRESHWATER ZOOPLANKTON

by

M.F. BAUDOUIN and P. SCOPPA

1974

Joint Nuclear Research Centre
Ispra Establishment - Italy

Biology

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It was concluded that the transfer of ^{51}Cr from water to zooplankton should not play an important role in the radioactive contamination of aquatic food chains.

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ABSTRACT

The importance of direct absorption on ^{51}Cr accumulation by three representative species of freshwater zooplankton has been studied. Net uptake of trivalent ^{51}Cr was rapid, but accumulation did not occur to a considerable extent. Most of the ^{51}Cr accumulated by **Cyclops abyssorum** and **Eudiaptotomus padanus** had a half-life of only a few hours. These copepods when exposed to chromate did not accumulate hexavalent ^{51}Cr. The cladoceran **Daphnia hyalina,** which is veri sensitive to the toxic action of chromate, accumulated only small amounts of ^{51}Cr.

It was concluded that the transfer of ^{51}Cr from water to zooplankton should not play an important role in the radioactive contamination of aquatic food chains.

ACCUMULATION AND RETENTION OF CHROMIUM-51 BY FRESHWATER ZOOPLANKTON(°)

M.F. Baudouin and P. Scoppa

Biology Group Ispra
G.D. Research, Science and Education, E.E.C.

Corrosion of the cooling circuits of atomic reactors results in the presence of ^{51}Cr in effluent coolant waters of nuclear plants (1). Therefore, aquatic environments may receive relatively large quantities of ^{51}Cr (2). Very little is known of the physico-chemical forms of ^{51}Cr in terrestrial waters (3-5). The radionuclide is present in marine organisms (6-8) and may be concentrated to some extent by the biota (9-12). The nature and the importance of the biological uptake of chromium in the freshwater environment has not been adequately investigated.

It was therefore of interest to acquire better information on the accumulation of ^{51}Cr by a number of different species of freshwater organisms. This knowledge is very useful to evaluate the relative importance of ^{51}Cr on the radioactive contamination of aquatic food chains and to establish whether accumulation from heterotrophic nutrition or direct uptake from water is the principal pathway for accumulation of ^{51}Cr.

The present report is the contribution concerning direct absorption from water, accumulation and retention by some representative species of freshwater zooplankton.

(°) Contribution N° 988 of the Biology Programme, Directorate General XII of the Commission of the European Communities.

MATERIALS AND METHODS

All experiments were carried out using water from Lake Monate (Lago di Monate), a lake of Northern Italy which has been extensively studied for its ecological aspects (13).
Some physico-chemical characteristics of Lake Monate water are the following: pH 7.0 - 7.1, conductivity 75 µS, alkalinity 0.58 meq/l, calcium 0.46 meq/l, magnesium 0.20 meq/l, sodium + potassium 0.16 meq/l, sulphate 0.18 meq/l, chloride 0.06 meq/l .

Three of the most representative species of freshwater zooplankton were used: Eudiaptomus padanus padanus (Burkhard), Cyclops abyssorum prealpinus (Einsle), and Daphnia hyalina (Leydig).
Plankton was collected from Lake Monate with a conical net having a mesh width of 88 µm and transported to the laboratory within 1 hour. Single zooplanktonic species were isolated as described elsewhere (14). Experimental animals were adult individuals acclimated to test conditions for 48 hours.
The average size of copepods, i.e. the length of cephalothorax, was 0.43 mm for Eudiaptomus and 0.62 mm for Cyclops. Mean size of Daphnia, i.e. the distance between the top of the head and the base of the shell spine, was 1.27 mm .
In experiments in which dead animals were used, zooplankters had been killed by a rapid exposure to the temperature of 50°C .

Chromium-51 labelled chromic chloride and sodium chromate were purchased from Amersham Radiochemical Center. Specific activities in the range 246-276 mCi/mg Cr .

In aqueous solutions with high specific activity ^{51}Cr-chromate undergoes significant reduction upon storage (15). Therefore, trivalent chromium impurity was removed (16) immediately before the use of sodium chromate.

Observations on the behavior of trivalent chromic chloride and hexavalent sodium chromate when added to Lake Monate water were made using methods originally developed in studies of chromium in seawater (10).

Accumulation of ^{51}Cr by zooplanktonic organisms was followed in parallel experiments in which 100-300 animals of each species were exposed to the radionuclide added to Lake Monate water prefiltered through 0.5 µm cellulose acetate. The volume of water employed was sufficiently large that changes in ^{51}Cr content of the water from uptake by the animals were negligible and therefore could not affect the apparent uptake rate. The radioactivity of water was measured at intervals throughout the exposure period. At the same times, a known number of living animals were collected, blotted on adsorbent paper and counted for ^{51}Cr radioactivity. The amount of ^{51}Cr per gram wet weight of each zooplanktonic species was calculated from the number of animals using previously established relationships between length and weight (17-18).

The retention of ^{51}Cr by copepods following uptake of the radionuclide was observed by maintaining the animals in Lake Monate water. At short time intervals, the water was changed and a known number of zooplanktonic organisms were counted for their ^{51}Cr radioactivity.

Uptake and release experiments were carried out in containers immersed in water baths thermostated at the required temperature within 0.5°C .

To avoid chromium adsorption or chemical interactions with food, the animals were fasted during the experiments.

There was no artificial aeration because air bubbling makes Daphnia come to the water's surface (14) and favours the oxidation of trivalent chromium (5).

Wide spectrum fluorescent tubes provided light of approximately 70 lux. Light was automatically controlled and the daily photoperiod was of 12 hours.

The use of a large volume of water in relation to the number of animals prevented oxygen depletion and minimized alterations of water quality caused by metabolic activities of zooplanktonic organisms. Dissolved oxygen, pH and conductivity did not show any significant change at the end of the test periods.

All ^{51}Cr determinations were made using a NaI-Tl activated well scintillation detector coupled with an Intertechnique gamma spectrometer. When needed, the data were corrected for the low counting efficiency of the scintillation detector and for the physical decay of the isotope.

RESULTS AND DISCUSSION

Although chromium can exist in a number of valence states, only trivalent and hexavalent forms can be considered as important, because they are the most stable under environmental conditions.

In natural waters, ^{51}Cr is represented by several chemical species (3-5).

It could be partially removed from Columbia River water using membrane filters, chelating resins and both cation and anion exchange resins: the most part of chromium was present in anionic forms (3).
Therefore, both trivalent and hexavalent chromium were taken into consideration in our studies which consisted of different experiments directed to investigate: the behavior of chromium solutions when added to the test water, the uptake, accumulation and release by zooplanktonic organisms.

Before adding solutions of trivalent chromium salts to natural waters it should be taken into consideration the very low solubility product of chromic hydroxide, which is in the range of 10^{-30}. Therefore, in pure water at pH 7.0, the highest theoretical concentration of chromic ions is 10^{-9} M , i.e. approximately 0.05 ug Cr/l . Despite trivalent chromium can form a large number of soluble hexacoordinate complexes with various ions and molecules, including water, in experiments with natural waters having neutral or subalkaline pH values, a particular care should be exerted to use chromium concentrations which are compatible with the solubility product of chromic hydroxide.
In our studies, chromic chloride was added to Lake Monate water, where $Cr^{3+}(aq.)$ and $Cr(OH)_2^+$ are among the chemical species likely to exist.
Preliminary observations were made on the behavior of $^{51}CrCl_3$ when added to the test water. When Lake Monate water had been prefiltered through an eterlon net having a mesh width of 88 um, the addition of a chromic chloride solution resulted in a rapid change and a loss of radioactivity from the lake water, probably from the formation of colloidal chromic hydroxide and its adsorption to the walls of the container. There appeared to be also formation of filterable

radioactive particles, due to precipitation and/or adsorption on suspended materials (Table I). The amount of filterable radioactivity increased with time and at 22 hrs about 90% of the ^{51}Cr radioactivity remaining in the water was in this form. No significant change occurred after that time.

The rapid disappearence of trivalent chromium from water indicated that adsorption to glass walls was responsible for the loss of approximately 30% of the initial radioactivity. However, the remaining ^{51}Cr was not in solution but for the most part in filterable forms. Further experiments carried out on Lake Monate water prefiltered through a 0.5 µm cellulose acetate filter provided further information on the behavior of trivalent chromium when added to the test water. In the absence of suspended material, the loss of radioactivity from water was higher and increased continuously with time (Table II). Approximately 40% of the initial radioactivity remained in the water after 22 hrs. Filterable radioactive particles accounted for a small percentage of ^{51}Cr. However, their contribution increased progressively with time, reaching 10% after 48 hrs. A comparison with the results obtained on lake water prefiltered through 88 µm shows that the formation of radioactive filterable particles is mainly due to adsorption of ^{51}Cr on suspended materials. However, when trivalent chromium is added to lake water free of suspended matter, a relevant fraction of the radionuclide is lost by adsorption to the glass walls of the container.

These results showed the shortcomings encountered in the evaluation of experimental data obtained in studies in which radioactive solutions of trivalent chromium salts are added to natural waters having approximately neutral pH values.

Several series of experiments were made to observe the accumulation of ^{51}Cr by three species of zooplanktonic organisms when the radionuclide was added to Lake Monate water in the form of a solution of chromic chloride. Some representative results are shown in Table III. It can be seen that the radioactivity of water decreased progressively with time. Since the volume of water was sufficiently large that changes in the ^{51}Cr content of the water from uptake by zooplanktonic organisms should be considered as negligible, these losses of water radioactivity were due to adsorption of ^{51}Cr, probably as colloidal chromic hydroxide, to the glass walls of the containers. If we take the ratio of radioactivities as an apparent index of the accumulation process, it can be argued that the accumulation of trivalent ^{51}Cr occurs rapidly, the concentration of the radionuclide in the animals exceeding that in the test water in less than 30 minutes. Accumulation took place initially at a fast rate and there was a remarkable reduction in the accumulation rate after approximately 8 hours. At the end of the 16 hours of observation, accumulation occurred at a very slow rate showing that under the conditions of the laboratory tests a great length of time would be required to reach isotopic equilibrium conditions. Since temperature may have a considerable influence on the uptake of radionuclides, other series of experiments were carried out increasing water temperature to 15°C. The results, presented in the lower part of Table III, show that both apparent uptake rate and accumulation were higher than those observed at 10°C. It was impossible to ascertain whether biological, chemical or physical factors have the main influence on these changes.

Accumulation of trivalent ^{51}Cr by dead zooplanktonic organisms was very low, the radioactivity ratios being less than 5. Therefore, it could be deduced that accumulation of ^{51}Cr was dependent on the biological activity of the animals. However, taking into account the

small amounts of ^{51}Cr accumulated by some species of zooplankton, surface adsorption may be responsible for a significant percentage of the total radioactivity of the animals. This is the case of Cyclops, in which dead animals accumulated up to 30% of the trivalent chromium radioactivity taken up by living organisms. This percentage falls to less than 10% in Daphnia and to 3% in Eudiaptomus. If the observed uptake of ^{51}Cr was mainly a passive process, variations of chromium concentration in the test water should result in a marked influence on the accumulation of chromium by zooplanktonic organisms. To clarify this important point, accumulation should have been studied increasing by at least one order of magnitude the concentration of chromium in the water. As mentioned earlier, such an increase in the concentration of trivalent chromium in our test water would result in the formation of chromic hydroxide in colloidal and precipitated forms. Therefore, a comparison between experiments carried out with largely different amounts of chromic chloride added to Lake Monate water could be misleading. In fact, the amounts of chromium added to one liter of water do not represent the actual concentrations of chromium in solution. Taking into account this fundamental limitation, labelled chromium chloride and stable chromium chloride carrier solutions were added to the test water and experiments on the accumulation of ^{51}Cr by zooplanktonic organisms were performed. In the three species examined the calculated amounts of total chromium taken up by the animals increased almost proportionally to the apparent chromium concentration in the water, also when chromic chloride was added in amounts corresponding to 400 ug Cr/l . This means that chromium uptake is a passive process, independent of the ionic concentration of trivalent chromium in water, but related to other physico-chemical forms of chromium, such as colloidal chromic hydroxide which can be bound with or within the organism.

Two series of observations were made of the release of ^{51}Cr by copepods following uptake of the radionuclide in the trivalent form. Similar experiments were not performed on Daphnia because of its superficial characteristics.

The percentage of ^{51}Cr radioactivity remaining at different periods of time after exposure to non-radioactive Lake Monate water are shown in Figure 1 for Eudiaptomus and in Figure 2 for Cyclops. It can be seen that in both zooplanktonic species the release of ^{51}Cr occurred at a very rapid rate, but a certain amount accounting for approximately 10% of the initial radioactivity was retained more firmly.

These results showed that in copepods ^{51}Cr was present in at least two different compartments each having a different type of binding with or within the organism. The most part of ^{51}Cr radioactivity was released very rapidly, suggesting a weak binding to the body surfaces.

In natural waters well oxygenated and having alkaline pH values, the thermodynamically stable form of chromium is the chromate ion. However, when the redox potential is decreased and the pH goes below 8, the formation of trivalent chromium is favoured.

A purified solution of hexavalent ^{51}Cr, in the form of sodium chromate, was added to Lake Monate water in the same conditions used in the case of trivalent chromic chloride. A true solution was obtained and there was practically neither adsorption to the walls of the container nor formation of radioactive filterable particles, even after 144 hours (Tables I and II).

Therefore, in the case of hexavalent chromium, studies on the uptake and accumulation by zooplankton will not be affected by the serious limitations encountered in the experiments with trivalent chromium.

However, when radioactive sodium chromate was added to Lake Monate water containing zooplanktonic organisms, water radioactivity decreased to approximately 90% of its initial value at the end of the observation period (Table IV). Probably hexavalent chromium had been partially reduced as a consequence of the chemical environment and/or of the metabolic activities of zooplanktonic organisms.

In contrast to the results obtained with trivalent chromium, both copepods did not accumulate ^{51}Cr-chromate to a considerable extent. The uptake of hexavalent chromium by the cladoceran Daphnia was very rapid, more than 80% of the ^{51}Cr accumulated at the end of the observation period being already in the animals after a 4-hour exposure.

An increase of water temperature to 15°C resulted in minimal changes in the cases of Eudiaptomus and Cyclops, whereas uptake rate and accumulation were strongly increased in Daphnia.

Other experiments were carried out on zooplanktonic organisms which had been killed by a rapid exposure to the temperature of 50°C. Accumulation of hexavalent chromium was negligible and no significant difference was observed between the three planktonic species taken into consideration.

Increasing the concentration of sodium chromate in the test water resulted in higher accumulation of ^{51}Cr by the animals. A passive uptake and an accumulation from a binding of the chromium within the organism, probably after reduction to the trivalent form, could have been expected in view of the results obtained from acute toxicity studies (19).

Median lethal concentrations of hexavalent chromium for a 48-hour exposure are: 0.022 mg Cr/l for Daphnia, 10.1 mg Cr/l for Eudiaptomus, and 10.0 mg Cr/l for Cyclops. The shape of the toxicity curves (Figure 3) suggests that a passive uptake is involved. Furthermore, the high sensitivity of Daphnia to chromate is in good agreement with the observation that only this species accumulated hexavalent chromium to an appreciable extent.

Further studies on the release of the ^{51}Cr accumulated from test water containing sodium chromate were not possible. In the case of copepods, the amounts accumulated were too small. For Daphnia, as already mentioned before, this type of experiments requiring frequent water changes cannot be easily performed because of the superficial characteristics of this cladoceran.

CONCLUSIONS

1) The addition to Lake Monate water of ^{51}Cr in the form of a solution of chromic chloride results in the formation of radioactive particles and adsorption of ^{51}Cr to the walls of the container (Figure 4). When ^{51}Cr was added as sodium chromate, a true solution was obtained: neither formation of radioactive particles nor adsorption occurred.

2) Accumulation of trivalent ^{51}Cr by zooplanktonic organisms occurs rapidly, but a great length of time is required to reach equilibrium conditions (Figure 5). The amounts of ^{51}Cr accumulated are not relevant: radioactivity ratios being approximately 80 for Eudiaptomus, 40 for Daphnia, and 15 for Cyclops. From measurements of the rate of loss of ^{51}Cr accumulated by copepods, it is apparent that the radionuclide was present in at least two compartments, each having a different type of binding with or within the animal (Tables V and VI). The most part of ^{51}Cr is very weakly bound and therefore has a rapid

turnover rate. Only minor differences in the retention of trivalent ^{51}Cr were observed between the two species taken into consideration for such experiments.

3) Hexavalent ^{51}Cr is accumulated to a very limited extent by copepods: radioactivity ratios are approximately 4 for Eudiaptomus and 6 for Cyclops. Uptake by the cladoceran Daphnia is higher, the radioactivity ratio being 20 at 10°C and 35 at 15°C (Figure 6). In good agreement with these results, Daphnia is very sensitive to the toxic action of chromate, whereas cladocerans are rather resistant. The regular shape of toxicity curves suggests that a passive process is involved in the uptake. A similar type of uptake of chromate has been observed for fish (20).

4) Too little is known of the physico-chemical forms of chromium in the aquatic environment and therefore at present it is impossible to obtain reliable numerical values indicating the extent of biological concentration processes. However, the small amounts of chromium accumulated by zooplankton and present mainly in a compartment with a very short half-life indicate that the transfer of this radionuclide from water to zooplankton should not play an important role in the radioactive contamination of aquatic food chains.

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LEGENDS TO FIGURES

Figure 1 - Retention of chromium-51 by Eudiaptomus padanus following a 48-hour exposure to chromic chloride in Lake Monate water.

Figure 2 - Retention of chromium-51 by Cyclops abyssorum following a 48-hour exposure to chromic chloride in Lake Monate water.

Figure 3 - Toxicity curves for chromate in Lake Monate water.

Figure 4 - Distribution of radioactivity following the addition of chromium-51 in the form of chromic chloride to Lake Monate water.

Figure 5 - Accumulation of chromium-51 by zooplankton following addition of chromic chloride to Lake Monate water.

Figure 6 - Accumulation of chromium-51 by zooplankton following addition of sodium chromate to Lake Monate water.

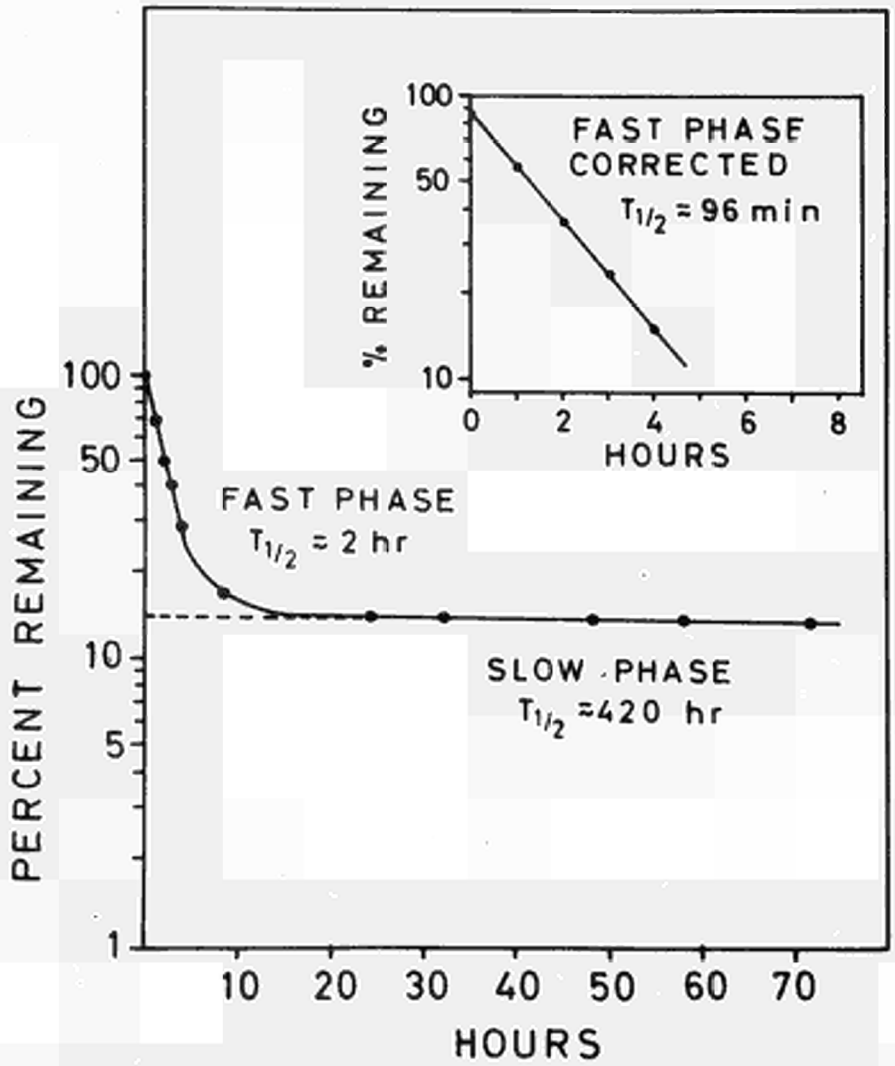

Figure 1 - Retention of chromium-51 by Eudiaptomus padanus following a 48-hour exposure to chromic chloride in Lake Monate water.

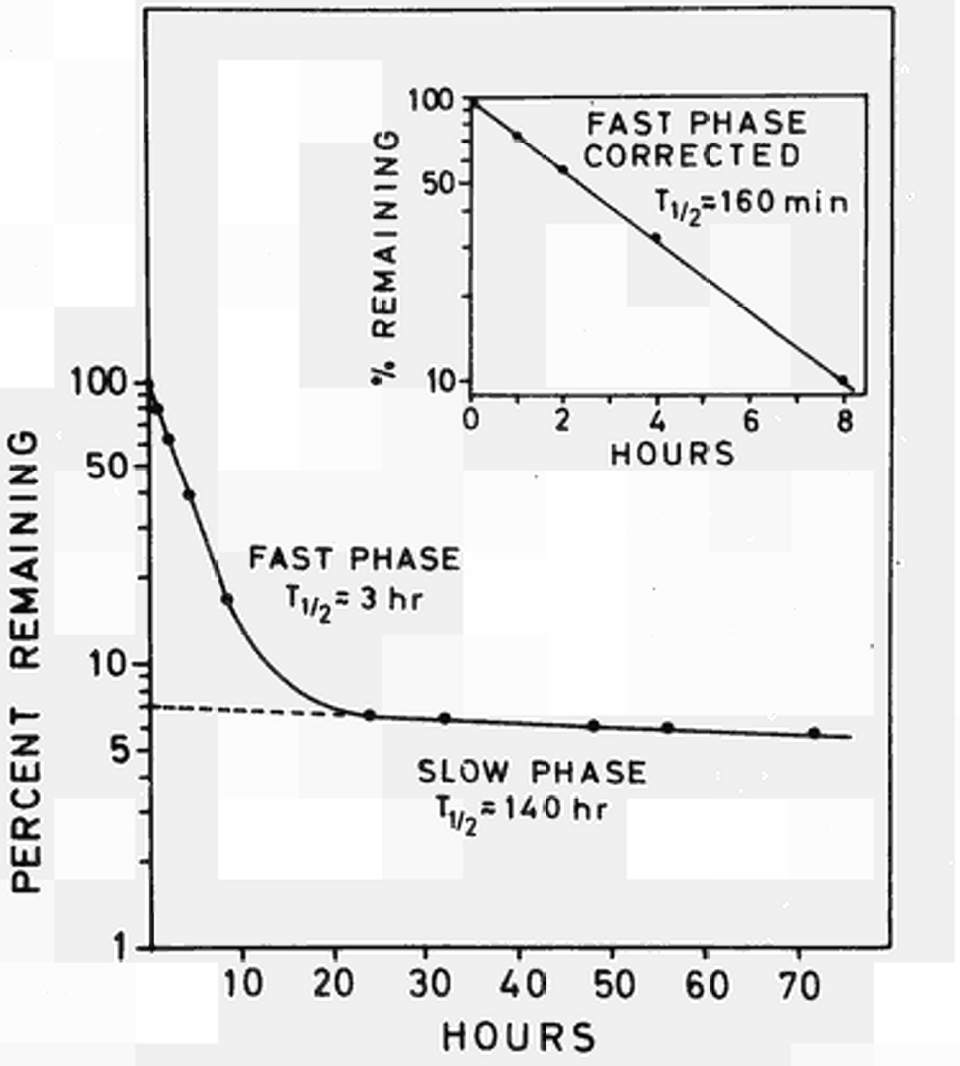

Figure 2 - Retention of chromium-51 by Cyclops abyssorum following a 48-hour exposure to chromic chloride in Lake Monate water.

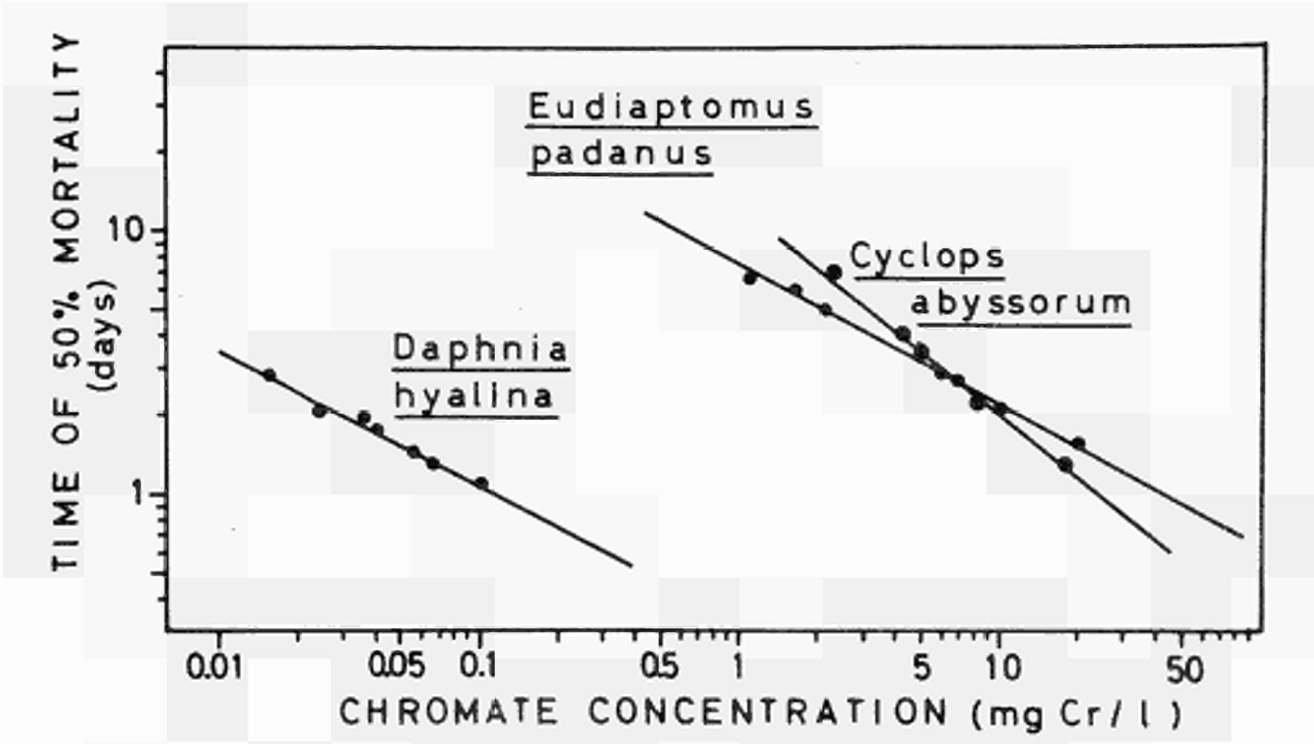

Figure 3 - Toxicity curves for chromate in Lake Monate water.

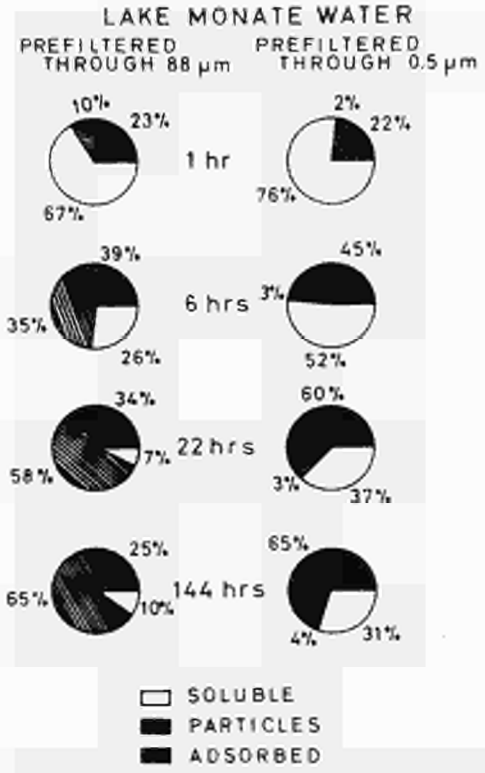

Figure 4 - Distribution of radioactivity following the addition of chromium-51 in the form of chromic chloride to Lake Monate water.

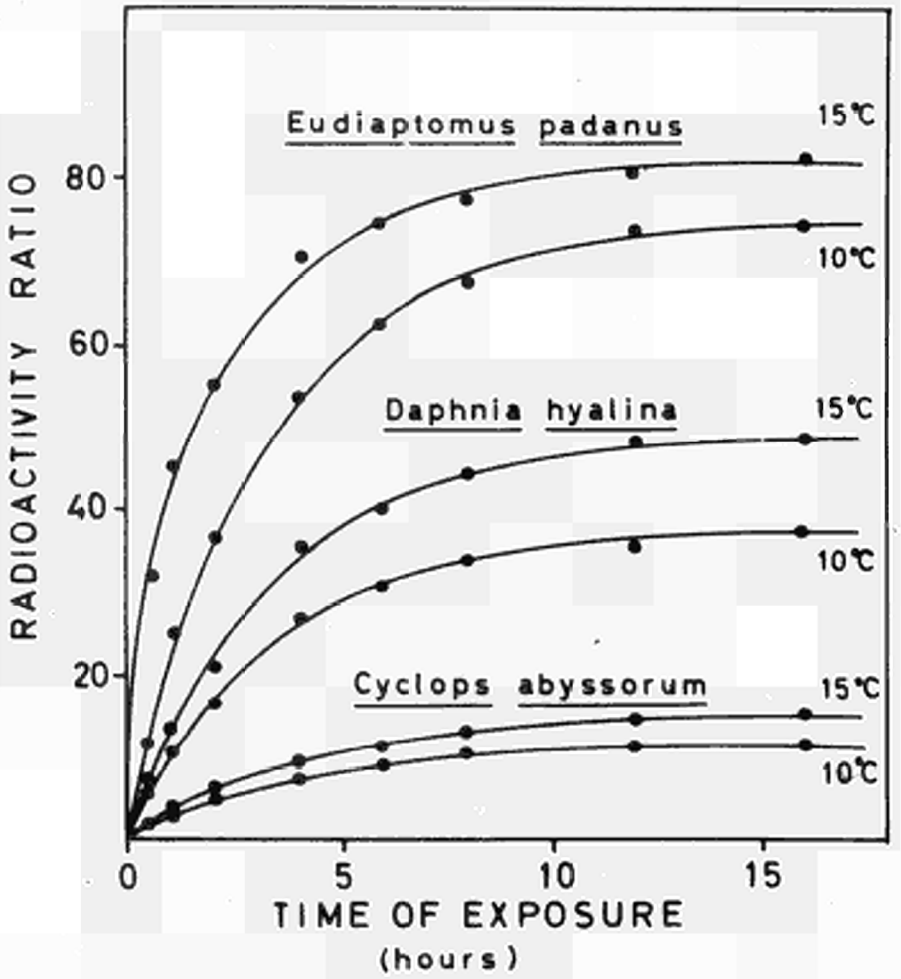

Figure 5 - Accumulation of chromium-51 by zooplankton following addition of chromic chloride to Lake Monate water.

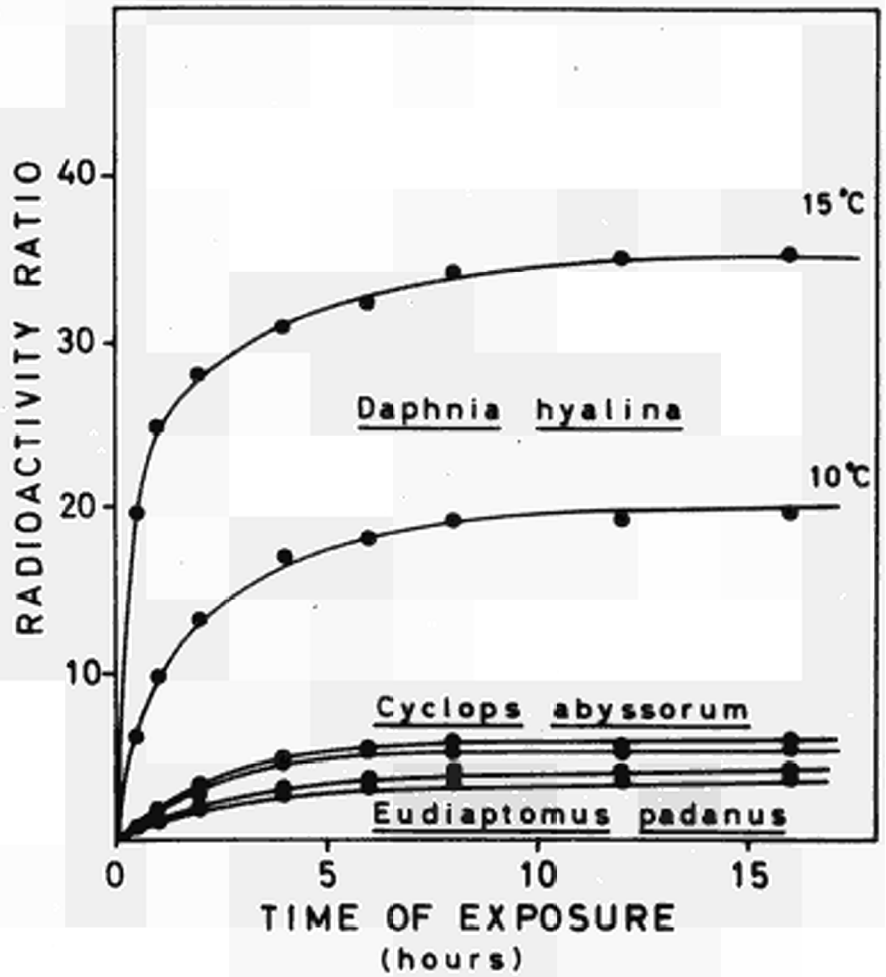

Figure 6 - Accumulation of chromium-51 by zooplankton following addition of sodium chromate to Lake Monate water.

TABLE I

CHANGES IN WATER RADIOACTIVITY AND FORMATION OF FILTERABLE PARTICLES FOLLOWING THE ADDITION OF CHROMIUM-51 IN THE FORM OF CHROMIC CHLORIDE OR SODIUM CHROMATE TO LAKE MONATE WATER PREFILTERED THROUGH 88/um

TIME OF OBSERVATION (hr)	CHROMIC CHLORIDE		SODIUM CHROMATE	
	Percentage of initial 51-Cr remaining in the water	Percentage of the remaining 51-Cr in particulate form	Percentage of initial 51-Cr remaining in the water	Percentage of the remaining 51-Cr in particulate form
0	100.0	------	100.0	------
1	77.2	13.4	99.9	0.13
4	63.2	38.2	100.2	0.20
6	61.3	57.5	99.0	0.44
8	63.0	69.4	99.1	0.43
10	63.8	77.4	100.5	0.25
22	66.0	88.5	98.7	0.21
28	68.6	87.6	96.8	0.22
48	71.9	88.6	97.3	0.33
54	70.2	88.5	95.2	0.27
144	74.8	86.5	97.3	0.48

TABLE II

CHANGES IN WATER RADIOACTIVITY AND FORMATION OF FILTERABLE PARTICLES FOLLOWING THE ADDITION OF CHROMIUM-51 IN THE FORM OF CHROMIC CHLORIDE OR SODIUM CHROMATE TO LAKE MONATE WATER PREFILTERED THROUGH 0.5/um

TIME OF OBSERVATION (hr)	CHROMIC CHLORIDE		SODIUM CHROMATE	
	Percentage of initial 51-Cr remaining in the water	Percentage of the remaining 51-Cr in particulate form	Percentage of initial 51-Cr remaining in the water	Percentage of the remaining 51-Cr in particulate form
0	100.0	------	100.0	------
1	78.1	2.2	99.5	0.29
4	58.5	4.1	99.3	0.22
6	54.6	5.0	100.5	0.36
8	49.5	6.1	99.7	0.26
10	48.4	7.2	100.1	0.31
22	40.2	8.2	99.3	0.36
28	38.0	9.6	99.8	0.34
48	37.4	9.8	100.0	0.39
54	35.3	11.2	98.3	0.41
144	34.9	12.4	97.9	0.36

TABLE III

CHROMIUM-51 RADIOACTIVITY OF ZOOPLANKTERS MAINTAINED IN LAKE MONATE WATER CONTAINING THE RADIONUCLIDE ADDED AS CHROMIC CHLORIDE (0.05 µg/l)

	Time of exposure (hours)	Eudiaptomus padanus			Daphnia hyalina			Cyclops abyssorum		
		Radioactivity of water (cpm/g)	Radioactivity of animals (cpm/g wet weight)	Ratio of radioactivity (animals/water)	Radioactivity of water (cpm/g)	Radioactivity of animals (cpm/g wet weight)	Ratio of radioactivity (animals/water)	Radioactivity of water (cpm/g)	Radioactivity of animals (cpm/g wet weight)	Ratio of radioactivity (animals/water)
Temperature 10°C	0	1724	------	----	1826	------	----	1785	------	----
	½	1517	17900	11.8	1593	9399	5.9	1590	3339	2.1
	1	1414	27714	19.6	1478	15815	10.7	1513	4993	3.3
	2	1276	46957	36.8	1403	30866	22.0	1474	7517	5.1
	4	1155	61215	53.0	1232	33018	26.8	1312	9709	7.4
	6	1086	67658	62.3	1163	35472	30.5	1257	11816	9.4
	8	1034	69278	67.0	1096	36606	33.4	1273	13239	10.4
	12	982	71784	73.1	1075	37733	35.1	1124	13151	11.7
	16	1017	75156	73.9	1123	41326	36.8	1068	12186	12.0
Temperature 15°C	0	1559	------	----	1684	------	----	1613	------	----
	½	1419	45976	32.4	1465	10988	7.5	1436	3303	2.3
	1	1279	54357	42.5	1415	19385	13.7	1323	5424	4.1
	2	1107	60664	54.8	1280	26752	20.9	1194	7642	6.4
	4	982	69035	70.3	1111	39329	35.4	1065	10118	9.5
	6	904	67348	74.5	986	39243	39.8	968	11422	11.8
	8	887	68122	76.8	973	42909	44.1	984	12792	13.0
	12	871	69941	80.3	965	46031	47.7	936	13759	14.7
	16	846	69372	82.0	951	45648	48.0	919	14520	15.8

TABLE IV

CHROMIUM-51 RADIOACTIVITY OF ZOOPLANKTERS MAINTAINED IN LAKE MONATE WATER CONTAINING THE RADIONUCLIDE ADDED AS SODIUM CHROMATE (0.05 µg/l)

	Time of exposure (hours)	Eudiaptomus padanus			Daphnia hyalina			Cyclops abyssorum		
		Radioactivity of water (cpm/g)	Radioactivity of animals (cpm/g wet weight)	Ratio of radioactivity (animals/water)	Radioactivity of water (cpm/g)	Radioactivity of animals (cpm/g wet weight)	Ratio of radioactivity (animals/water)	Radioactivity of water (cpm/g)	Radioactivity of animals (cpm/g wet weight)	Ratio of radioactivity (animals/water)
Temperature 10°C	0	1865	------	----	1794	------	----	1925	------	----
	½	1793	1076	0.6	1731	10559	6.1	1832	2015	1.1
	1	1818	1820	1.0	1713	16787	9.8	1847	2770	1.5
	2	1756	3336	1.9	1683	22384	13.3	1793	4841	2.7
	4	1730	4325	2.5	1695	28815	17.0	1765	7766	4.4
	6	1694	4913	2.9	1657	29660	17.9	1803	9015	5.0
	8	1710	5643	3.3	1621	30961	19.1	1742	8884	5.1
	12	1671	6016	3.6	1583	30077	19.0	1756	9131	5.2
	16	1634	6209	3.8	1568	30733	19.6	1698	9002	5.3
Temperature 15°C	0	2103	------	----	1985	------	----	2073	------	----
	½	2074	1244	0.6	1743	33989	19.5	2013	2214	1.1
	1	2120	2332	1.1	1811	45094	24.9	1973	3749	1.9
	2	2063	4332	2.1	1784	49952	28.0	2035	6716	3.3
	4	2035	6105	3.0	1752	53962	30.8	1927	9442	4.9
	6	1983	6941	3.5	1791	58208	32.5	1895	10423	5.5
	8	2007	7627	3.8	1732	58715	33.9	1871	10478	5.6
	12	1936	7744	4.0	1715	60196	35.1	1846	10153	5.5
	16	1873	7679	4.1	1653	58351	35.3	1892	10784	5.7

TABLE V

MULTIPLE COMPONENT RETENTION OF CHROMIUM-51 BY EUDIAPTOMUS PADANUS FOLLOWING A 48-HOUR EXPOSURE TO CHROMIC CHLORIDE (0.05 µg/l) IN LAKE MONATE WATER

FAST COMPONENT				SLOW COMPONENT			
Initial amount (%)	Rate constant (k)	Biological half-life (days)	Effective half-life (days)	Initial amount (%)	Rate constant (k)	Biological half-life (days)	Effective half-life (days)
86	10.343	0.0667	0.0665	14	0.0396	17.5	10.8

TABLE VI

MULTIPLE COMPONENT RETENTION OF CHROMIUM-51 BY CYCLOPS ABYSSORUM FOLLOWING A 48-HOUR EXPOSURE TO CHROMIC CHLORIDE (0.05 µg/l) IN LAKE MONATE WATER

FAST COMPONENT				SLOW COMPONENT			
Initial amount (%)	Rate constant (k)	Biological half-life (days)	Effective half-life (days)	Initial amount (%)	Rate constant (k)	Biological half-life (days)	Effective half-life (days)
93	6.243	0.1111	0.1106	7	0.1189	5.8	4.8

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