INSTITUTE FOR FISHERIES RESEARCH
UNIVERSITY MUSEUMS
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

April 28, 1933

Report 207

THE TOXICITY TO FISH LIFE OF CYANIDE SOLUTIONS, AND OF THE PRODUCTS DERIVED FROM CERTAIN CHEMICAL TREATMENTS OF CYANIDE SOLUTIONS

In July and August, 1931, Dr. Wendell H. Krull of the Institute for Fisheries Research ran a series of experiments to determine the toxicity of cyanide solutions to fish life. This work was done at the request of the Stream Control Commission, but only a preliminary statement of the results obtained was reported at the time.

In April, 1933, Dr. Carl L. Hubbs of the Institute ran a further series of experiments, also at the request of the Stream Control Commission. These experiments were made to determine not only the toxicity of cyanide solutions, but more particularly the toxicity of the products derived from certain chemical treatments of cyanide solutions. These treatments are the ones being experimented upon by Mr. E. F. Eldridge of Michigan State College, in an effort to develop a practicable means for the destruction of the toxicity in large measure of cyanide wastes, which now constitute an important element in the pollution of Michigan streams and in the killing of fish life.

Such information as we have been able to obtain, from a cursory examination of published reports and from an unpublished report issued by the U. S. Bureau of Fisheries, indicates that the toxicity of cyanide to fish life has not been accurately determined. The toxicity as determined by us is considerably greater than would be expected from the previous experiments we have seen reported.

TOXICITY THRESHHOLD OF SODIUM CYANIDE FOR VARIOUS FISHES

At the concentration given some of the fishes were killed while others lived; stronger concentrations were lethal, weaker ones were not. Details of the experiments, which were run by Dr. Krull in 1931, are given in Appendix I.

Species of fish	Age of fish	Toxicity threshhold p.p.m.	1 part in:
Rainbow trout	fingerlings	0.25	4,000,000
Hornyhead chub	half-grown	0.25 (?)	4,000,000
Large-mouth bass	fingerlings	0.29	3,500,000
Rock Bass	fingerlings	0.33	3,000,000
Bluegills	half-grown	0.33	3,000,000
Mud pickerel	half-grown	0.33	3,000,000
Rainbow darter	adults	0.33	3,000,000
Creek chub	half-grown	0.40	2,500,000
Pumpkinseed sunfish	half-grown	0.50	2,000,000
Yellow bullhead	fingerlings	0.50	2,000,000
Muddler (C. bairdii)	adults	0.73	1,500,000
Carp	large young	1.00 or less	1,000,000 or more
Black-chinned and black-nosed shiner	adults	1.00 or less	1,000,000 or more
Mud-minnow	adults	1.00	1,000,000

It seems clear that most small species of fish and that the young of game fishes are killed in sodium cyanide solutions much weaker than one part per million. This extremely high toxicity explains the death of fishes in streams below plating plants or other industries discharging cyanide wastes into streams.

Clearly some treatment, to remove or greatly lessen the toxicity of these cyanide wastes, is desirable. Mr. E. F. Eldridge, who is experimenting on treatment methods likely to prove practicable, has recently prepared a series of samples representative of cyanide wastes as they are or would be discharged into Michigan streams, before treatment and after three different treatments. These samples have been tested in our laboratory, to determine their toxicity to fish life.

In this experiment a uniform procedure was followed. The test fish used were all common shiners, Notropis cornutus, all of yearling age, caught in one seine haul four days before the experiment in the Saline River. These were gradually warmed to 24°C, with a very slight loss after the unavoidable initial deaths. During the first three days of the experiment, not a single fish of the dozens in the stock supply died. This proves that they were in good condition for the experiment. These experiments were run at temperatures varying from 25° to 27.5°C, representing summer conditions. No food was given the fish while being acclimated to aquarium conditions, or while in the experiments.

Two fish were used in each trial, being kept in 1 liter of the solution (approximately 1 quart), in a two-quart wide-mouth fruit jar, without top. Air was kept moving over the jars by electric fans. In the first series run, each experiment was run in duplicate: one jar was aerated by bubbling compressed air, while the other was not aerated.

The water used in diluting the samples was the filtered water used in the Museum Aquarium. This is known to be very satisfactory for fish life, and was considered more representative of stream water than distilled water. The supply was found to be alkaline, pH 8.1, with strong enough buffer action to neutralize the acid product obtained from treating the cyanide solution with sulphuric acid. The original product of this experimental treatment had at first a pH of about 5.0, and remained below 5.2 during the experiment. But on the second day of an experiment, a 50% solution of this product (equivalent to 100 p.p.m. of cyanide before treatment), as well as a 2.5% solution (5 p.p.m.), showed a pH of 7.8. The control jar with fish at the same time had a pH of between 7.9 and 8.0.

The solutions were received April 19, 1933, at A.M., having been brought to Ann Arbor by Mr. Tom Powers of the Stream Control Commission. Except for the sludge sample, all were clear. Some white precipitate was noticed in the carboy containing the cyanide solution, indicating some hydrolysis or other chemical action.

EXPERIMENTS WITH UNTREATED CYANIDE SOLUTION

"This solution was prepared by dissolving exactly 3.6 grams of potassium cyanide (KCN) in 18 liters of water. The solution would then contain 200 parts per million KCN. I feel that this is as near representative of the cyanide content of cyanide waste as is practical for our purpose. The cyanide content of a cyanide waste would, of course, vary over quite a wide range." (Eldridge)

Results of tests

Experiments started at 3:00 P.M., April 19

p.p.m. in terms of KCN	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
10	100,000	Yes	0:01	0:02	
"	"	"	0:01	0:06	
"	"	"	0:02	0:12	Run in same solution after first two fish died.
"	"	"	0:02	0:12	" "
"	"	No	0:01	0:02	
"	"	"	0:01	0:10	
"	"	"	0:02	0:10	Run in same solution after first two fish died.
"	"	"	0:02	0:11	" "
5	200,000	Yes	0:04	0:12	
"	"	"	0:04	0:12	
"	"	"	0:04	0:16	Run in same solution after first two fish died.
"	"	"	0:04	0:20	" "
"	"	No	0:02	0:08	
"	"	"	0:04	0:14	
"	"	"	0:03	0:17	Run in same solution after first two fish died.
"	"	"	0:03	0:13	" "
2	500,000	Yes	0:05	0:17	
"	"	"	0:05	0:17	
"	"	"	0:11	0:58	Run in same solution after first two fish died.
"	"	"	0:17	1:22	" "
"	"	No	0:05	0:21	
"	"	"	0:05	0:22	
"	"	"	0:10	0:29	Run in same solution after first two fish died.
"	"	"	0:10	0:34	" "
1	1,000,000	Yes	0:42	138:00	Equilibrium recovered later
"	"	"	—	163:30	
"	"	No	0:15	0:24	
"	"	"	0:15	0:51	
"	"	"	0:15	1:21	Run with other two.
"	"	"	0:18	1:53	Run in same solution after first two fish died.
"	"	"	0:25	1:53	" "
0.5	2,000,000	Yes	—	138:00	
"	"	"	—	—	Last seen alive at 163:30
"	"	No	—	18:08	Last seen alive at 17:05
"	"	"	—	"	" " "
0.2	5,000,000	Yes	—	102:45	Aeration was stopped at 68:00
"	"	"	—	102:45	" " "
"	"	No	—	17:05	Last seen alive at 11:15

P.p.m. in terms of KCN	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
0.2	5,000,000	No	-	-	Fish alive at 163:30
0.1	10,000,000	Yes	47:40	47:50	
"	"	"	48:10	48:15	
"	"	No	-	17:05	Last seen alive at 11:15
"	"	"	-	31:40	
0.0	(Control)	Yes	-	163:30	Air was shut off at 68:00
"	"	"	-	-	Do.; one still alive at 163:30
"	"	No	-	16:45	Last seen alive at 10:55
"	"	"	-	16:45	" "

<u>Interpretation of the data given above</u>: It is clear that the solutions of potassium cyanide made up to 10, 5 and 2 p.p.m. (1 part to 100 000, 1 part to 200 000 and 1 part to 500,000) were quickly lethal. The solutions at 1 p.p.m. were lethal when not aerated but were not lethal when aerated. Judging from the experiments by Krull, we would expect either that other fish would have died in this solution or that the strength of the original solution (200 p.p.m.) had been materially weakened, perhaps by the hydrolysis of the cyanide. Weaker solutions 0.5 to 0.1 p.p.m. (from 1 part to 2,000,000 to 1 part per 10,000,000) showed no apparent ill effects on the fish, which could not be attributed to bacterial action. In fact all the fish in the weaker solutions, whether with or without aeration, lived longer than in the unaerated control. This was probably due to the partial sterilization of the water. In conclusion, we can regard 1.0 p.p.m. as approximately the toxicity threshhold for the KCN solution used.

EXPERIMENTS WITH THE PRODUCT OF PERMANGANATE TREATMENT OF 200 P.P.M. CYANIDE SOLUTION

"A similar solution to No. 1 was made up in a tank connected to an air line. The exact amount of potassium permanganate to complete the following reaction was added.

$$3KCN + 2\,KMnO_4 + 5\,H_2O = 2\,Mn(OH)_4 + 3\,KOCN + 2\,KOH$$

The solution was then well mixed and allowed to stand over night. In the morning the sludge was drawn through a valve in the bottom of the tank and the supernatent drawn into the 5 gallon bottle. The sludge is contained in bottle No. 4. In this reaction the $Mn(OH)_4$ is almost quantitatively removed in the form of a sludge. There remains in solution the KOCN, the toxicity of which we apparently know very little. The KOH formed as a result of the reaction is neutralized by the bicarbonates in the water precipitating $CaCO_3$ which would be contained in the sludge. We have therefore, only the KOCN to worry about. The quantity of KOCN produced by 200 p.p.m. KCN would be 250 p.p.m. I am not particularly interested in the toxicity of the sludge in bottle No. 4." (Eldridge)

Results of tests

First series, started 4:00 P.M., April 19

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
200	5000	Yes	0:50	–	Recovered later; alive and normal at 167:45
"	"	"	0:50	–	" " "
"	"	No	0:50	1:30	
"	"	"	0:50	1:30	
100	10,000	Yes	–	137:00	Died during previous night; air turned off at 67:00
"	"	"	–	137:00	" "
"	"	No	–	21:15	
"	"	"	–	101:45	
50	20,000	Yes	–	101:45	
"	"	"	–	101:45	
"	"	No	–	19:45	
"	"	"	–	21:15	
10	100,000	Yes	–	101:45	
"	"	"	–	101:45	
"	"	No	–	19:45	
"	"	"	–	–	Still alive and normal at 167:45
5	200,000	Yes	–	137:00	Air was turned off at 67:00
"	"	"	–	–	Do; still alive at 167:45
"	"	No	–	16:15	Last seen alive at 10:15
"	"	"	–	17:12	Last seen alive at 16:15
2	500,000	Yes	–	137:00	Died during previous night
"	"	"	–	137:00	" " "
"	"	No	–	16:15	Last seen alive at 10:15
"	"	"	–	23:30	
1	1,000,000	Yes	4:20	5:00	Death apparently due to some other cause.
"	"	"	–	137:00	
"	"	"	–	137:00	Added on death of first fish.
"	"	"	–	137:00	
"	"	No	–	16:20	Last seen alive at 16:20
"	"	"	–	32:00	

Second series, starting 12:40 A.M., April 20.

Using supernatant liquid after standing over all the sludge until 11:30 P.M., April 19.

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
200	5000	No	0:18	0:26	
"	"	"	0:40	1:02	

Third series, started 2:59 P.M., April 20

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
200	5,000	No	0:15	0:30	
"	"	"	0:29	1:21	
100	10,000	"	–	9:46	
"	"	"	–	9:46	
50	20,000	"	–	15:16	
"	"	"	–	24:24	
20	50,000	"	–	22:09	
"	"	"	–	–	Still alive at 144:15.
10	100,000	"	–	78:46	
"	"	"	–	114:00	Died during previous night.
5	200,000	"	15:54	15:59	
"	"	"	–	114:00	Died during previous ngith.
2	500,000	"	–	23:31	
"	"	"	–	–	Still alive at 144:15
1	1,000,000	"	–	18:51	
"	"	"	–	144:15	
0	(Control)	"	"	17:02	
"	"	"	–	27:50	

<u>Interpretation of data given above</u>: It is very clear from these data that the toxicity of a weak cyanide solution is very greatly reduced by the permanganate treatment. Whereas the toxicity threshhold was about 1 p.p.m., for the cyanide solution, it was about 100 p.p.m. for the treated product, expressing the concentration in terms of the original cyanide content. In those terms the 200 p.p.m. solutions were definitely fatal when unaerated, but apparently not fatal when aerated (only on test with two fish made), the 100 p.p.m. solutions (approximately 125 p.p.m. of potassium cyanate) when aerated did not kill, and when not aerated

kill slowly in one experiment but failed to kill in another experiment. All weaker solutions appeared non-toxic, for the fish lived about as long as, or longer than in the control. Conclusion: permanganate treatment of cyanide wastes can be expected to decrease the toxicity to about 1% of the original value.

The circumstance that some of the fish lived longer in the weaker solutions than in the controls may be due to the partial disinfecting of the water. The control solution and the weaker concentrations soon became very cloudy, probably from bacterial action. This apparently resulted in a total consumption of the dissolved oxygen, as in the next following series of experiments, for the fish swam nervously around lapping the surface. The solution corresponding to an original potassium cyanide content of 100 p.p.m. remained clear until the third day of the experiment, and the fish showed until then no symptoms of oxygen starvation. In the aerated solutions the "bacterial cloud" also appeared in time, even though the dissolved oxygen remained high. Thus the solution corresponding to 2 p.p.m. of cyanide had become very turbid on the third day of the experiment, though the oxygen then tested high (6.3 p.p.m.) and the fish were not at the surface.

EXPERIMENTS WITH THE SLUDGE PRODUCED BY THE PERMANGANATE TREATMENT OF A 200 P.P.M. CYANIDE SOLUTION

In the treatment of cyanide wastes with $KMnO_4$ the brown precipitate of $Mn(OH)_4$ would be deposited as a sludge, which would supposedly be removed and not discharged into a stream. However, accidents or carlessness might occur, allowing the sludge to enter a stream. It is therefore of some importance that the toxicity of the sludge be also known.

The sludge as received was derived as stated above from the complete treatment of 18 liters of 200 p.p.m. cyanide solution. According to the formula and data given by Eldridge approximately 4.53 grams of the sludge was present. The sludge as brought to us was in 1710 cc of the cyanate solution. From this, after settling, we pored off another 1000 cc of the clear supernatant (used in "second series" of tests reported on above). We thus started with 710 cc of the cyanate solution containing 4.53 g of the sludge. This was divided into five parts, of respectively 20, 50, 100, 200 and 340 cc, each of which was then diluted with our aquarium water to 1000 cc for the experiments, which were run in two quart jars, all aerated through the experiments, which were begun about midnight of April 19.

cc of sludge suspension	g of $Mn(OH)_4$ per 1000 cc	Approximate p.p.m. of $Mn(OH)_4$	Dead hr.:min.	Remarks
20	.13	130	105:25	Died during previous night
"	"	"	105:25	" "
50	.32	320	105:25	" "
"	"	"	—	Alive and normal at 161:00
100	.64	640	105:25	Died during previous night
"	"	"	105:25	" " "
200	1.28	1280	2:25	
"	"	"	2:25	
340	2.17	2170	1:05	
"	"	"	2:10	

<u>Interpretation of data given above</u>: The toxicity of the $Mn(OH)_4$ sludge must be very low, the threshhold being somewhere in the neighborhood of 1000 p.p.m. A moderate amount of the sludge would not likely harm a stream, though any considerable quantity would produce an unsightly appearance and a large amount in a small stream might produce a dangerous sludge bed in time.

EXPERIMENTS WITH THE PRODUCT OF SULPHURIC ACID TREATMENT OF 200 P.P.M. CYANIDE SOLUTION, FOLLOWED BY AIR-BUBBLING

"A solution of KCN similar to No. 1 was made up in the tank before mentioned. The quantity of sulphuric acid necessary to neutralize the natural alkalinity of the water and complete the following reaction was added.

$$2\ KCN + H_2SO_4 = 2\ HCN + K_2SO_4$$

The air was turned on and the solution aerated for over night. In the morning the solution gave no test for cyanides. It was then drawn into the 5 gallon bottle. The HCN produced as a result of this reaction is a gas and very volatile. The aeration for a considerable length of time (10 to 15 hours) carries it off to the extent that our chemical tests do not show the presence of the cyanide."

Results of tests

First series, started 5:00 P.M., April 19

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
200	5000	Yes	4:00	4:10	
"	"	"	4:10	4:20	
"	"	"	–	58:00	Run in same solution after first two fish died.
"	"	"	–	100:45	" " " ; air off at 68:00
"	"	No	0:02	1:20	
"	"	"	never	2:05	
"	"	"	1:03	1:09	Run in same solution after first two fish died.
"	"	"	–	24:15	" " "
100	10,000	Yes	–	–	Air off at 68:00; alive and normal at 168:30
"	"	"	–	–	" " "
"	"	No	–	45:20	
"	"	"	–	49:50	
50	20,000	Yes	–	–	Air taken off at 66:00; alive at 168:30
"	"	"	–	–	" " "
"	"	No	–	25:00	
"	"	"	–	–	Alive at 168:30
10	100,000	Yes	–	–	Air taken off at 66:00; alive at 168:30
"	"	"	–	–	" " "
"	"	No	–	16:05	Last seen alive at 15:25
"	"	"	–	18:47	
5	200,000	Yes	–	163:30	Air taken off at 68:00
"	"	"	–	–	Do.; alive at 168:30
"	"	No	–	15:25	Last seen alive at 9:15
"	"	"	–	15:25	" " "
2	"	Yes	–	100:45	Air taken off at 66:00
"	"	"	–	100:45	" " " "
"	"	No	–	15:25	Last seen alive at 9:15
"	"	"	–	15:25	" " "
1	"	Yes	–	163:30	Air taken off at 68:00
"	"	"	–	100:45	
"	"	No	–	17:00	
"	"	"	–	–	Alive at 168:30

Second series, started 2:53 to 2:58 P.M., April 20

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
200	5000	No	0:14	1:30	
"	"	"	0:48	1:43	

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
100	10000	No	-	114:02	Died during previous night.
"	"	"	-	-	Still alive at 162:30
50	20,000	"	-	17:47	
"	"	"	-	-	Still alive at 162:30
20	50,000	"	-	22:33	
"	"	"	-	-	Still alive at 162:30
10	100,000	"	-	17:03	
"	"	"	-	-	Still alive at 162:30
5	200,000	"	22:31	22:34	
"	"	"	22:31	22:34	
2	500,000	"	-	22:10	
2	"	"	-	-	Still alive at 162:30
1	1,000,000	"	-	18:31	
"	"	"	-	-	Still alive at 162:30
0	(Control)	"	-	23:08	
"	"	"	-	-	Still alive at 162:30

Interpretation of data given above: The full strength cyanide solution (200 p.p.m.) representative of cyanide wastes, after the acid + aeration treatment was found to be definitely toxic to fish life. This of course represents an undiluted treated waste. A 1:1 dilution of this treated waste, corresponding to an original cyanide content of 100 p.p.m., was found to be essentially non-toxic, as were all the weaker concentrations. The toxicity of the treated solution was therefore only .5% to 1% that of the untreated solution.

The toxicity of the full strength treated waste was apparently not very great, and most of it was apparently destroyed in the process of killing the first pair of fish, because a subsequent trial in the same jar indicated a great reduction or elimination of the toxicity. As in the previous experiments, the fish generally lived longer in the aerated than in the unaerated wastes.

A curious circumstance was that the fish appeared to live longer and to be less distressed in the strongest non-lethal solution than in the weaker solutions. This difference we ascribe to the sterilization of the solution by the residual cyanide or whatever toxic substance was involved. The weaker unaerated solutions (corresponding to an original cyanide content of 0 to 10 p.p.m.) became cloudy the first day, and the fish showed the usual signs of oxygen starvation. The 20 p.p.m. sample in about 19 hours, the 50 p.p.m. sample in 23 hours, the 100 p.p.m. sample in about 3 days. So long as the solution remains clear, the fish seemed normal. Tests showed that the dissolved oxygen content disappeared as these un-aerated solutions became cloudy and the fish began to lap the surface, some dying soon.

<u>Relation of cloudiness of solutions to dissolved oxygen content.</u>

P.p.m. (original) KCN content	Time hr.:min.	Clearness of solution	Dissolved oxygen, p.p.m.
2	24:24	cloudy for hours	0.0
50	25:52	becoming cloudy	2.0
100	24:18	entirely clear	4.8
100	72:05	becoming cloudy for 3 hours	0.0

These facts seem to indicate that toxic pollutions like cyanide wastes, if added to streams highly charged with organic pollution, might actually be beneficial through a partial sterilization of the water. Especially when the polluted stream runs later into a larger river or lake with large diluting power, such sterilization might actually make an otherwise hopeless stream suitable for fish life. This point is mentioned not as a recommendation for administrative action, because of the danger in overdoing the job, but more as a further indication of the complexity of the pollution control problem.

EXPERIMENTS WITH THE PRODUCT OF LIME TREATMENT OF 200 P.P.M. CYANIDE SOLUTION

"The same waste containing 200 p.p.m. KCN was treated with an excess (slight) of lime in order to make an alkaline solution. The total mixture was then aerated for about 20 hours. After aeration the sludge of calcium carbonate was allowed to settle. The clear liquor showed a slight trace of cyanide with our chemical tests.

"This is supposedly a reaction involving hydrolysis and perhaps oxidation of the cyanide, I have not had time to follow this reaction very closely and am not sure as to the end products. Hydrolysis alone would proceed as follows:

$$KCN - 2\ H_2O\ =\ KOOOH = NH_3$$

The end products in this case would be ammonia and potassium formate. If oxidation takes place also we would have the following reaction:

$$KCN = 2\ H_2O - O_2\ =\ KHCO_3 - NH_3$$

The products in this case would be a bicarbonate of potassium and ammonia. I also would expect to find some excess lime present and a rather high pH. When this solution is mixed with other water a precipitate of calcium carbonate can be expected from the excess lime [such precipitate was not obtained.]"Eldridge.

<u>Results of tests</u>

Experiments started 5:40 P.M., April 19 to 12:48 A.M., April 20

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
200	5000	Yes	0:07	0:15	
"	"	"	0:07	0:15	
"	"	"	0:06	0:19	Run in same solution, after first
"	"	"	0:07	0:22	" " two fish died
"	"	No	0:05	0:11	
"	"	"	0:06	0:15	
"	"	"	0:04	0:10	Run in same solution, after first two fish died.
"	"	"	0:05	0:12	" "
100	10,000	Yes	0:09	0:26	
"	"	"	0:12	0:26	
"	"	"	0:10	0:40	Run in same solution, after first two fish died.
"	"	"	0:14	0:86	" " "
"	"	No	0:06	0:16	
"	"	"	0:08	0:19	
"	"	"	0:07	0:10	Run in same solution, after first two fish died.
"	"	"	0:08	0:15	" " "
50	20,000	Yes	0:07	0:28	
"	"	"	0:16	0:45	
"	"	"	0:20	2:30	Run in same solution, fater first two fish died.
"	"	"	0:22	4:05	" " "
"	"	No	0:07	0:29	
"	"	"	0:07	0:40	
"	"	"	0:08	0:45	Run in same solution, after first two fish died.
"	"	"	0:08	0:51	" " "
20	50,000	Yes	—	—	Alive at 175:00
"	"	"	—	—	" "
"	"	No	0:21	1:45	
"	"	"	0:30	2:30	

P.p.m. in terms of original KCN content	Equivalent to one part in:	Aerated?	Equilibrium definitely lost hr.:min.	Dead hr.:min.	Remarks
20	50,000	No	0:30	1:48	Run in same solution, after first two fish died.
"	"	"	0:30	3:10	" " "
15	75,000	"	0:17	1:34	
"	"	"	0:18	7:56	Was almost dead at 2:02.
10	100,000	Yes	—	100:05	Perhaps dead a few hours
"	"	"	—	100:05	" "
"	"	No	—	19:32	
"	"	"	—	19:32	
"	"	"	—	19:47	Run in same solution, after first two fish died.
"	"	"	—	—	Do.: alive at 168:00
5	200,000	Yes	—	—	Alive at 175:00
"	"	"	—	—	" "
"	"	No	—	About 163:00	
"	"	"	—	"	
2	500,000	Yes	—	148:20	Died during previous night
"	"	"	—	148:20	" " "
"	"	No	—	About 163:00	
"	"	"	—	"	
1	1,000,000	Yes	—	—	Alive at 175:00
"	"	"	—	—	" "
"	"	No	—	About 163:00	
"	"	"	—	"	

Interpretation of data given above: It is clear that the toxicity of the 200 p.p.m. cyanide solution was not nearly as thoroughly destroyed by the lime treatment as it was by the permanganate or the acid + aeration treatment. The treated solutions corresponding to an original cyanide content of only 15 p.p.m. retained evident toxicity when not aerated by bubbling air; the solution of 50 p.p.m. (in same terms) was quickly lethal even when aerated, whereas the 20 p.p.m. aerated solution did not kill the fish. The air bubbling seemed to decrease the toxicity of the 50 p.p.m. solution.