Chemical Control of Australorbis glabratus

WILLIAM R. JOBIN, S.B., S.M., and GLADWIN O. UNRAU, S.B.

CONTROL of the snail intermediate host involved in transmission of schistosomiasis is being attempted in many countries. In the Western Hemisphere copper sulfate and sodium pentachlorophenate (NaPCP) have been used in attempts to control *Australorbis glabratus* (*1, 2*), but to date schistosomiasis continues to persist in many parts of tropical America. In recent years the pesticide industry has developed numerous chemicals, certain of which possess molluscicidal properties. The studies reported here consisted of laboratory evaluation of 28 candidate compounds and field appraisal of the effectiveness of promising candidates against *A. glabratus*. The compounds tested are listed below by trade name and chemical name; the letters in parentheses are supply references.

The authors were assigned to the Tropical Disease Section, Investigations Branch, Communicable Disease Center, U.S. Public Health Service, in San Juan, Puerto Rico, at the time the project was undertaken. Mr. Unrau is now with the Rockefeller Foundation, Castries, St. Lucia, West Indies.

The studies were conducted under the supervision of Dr. Herbert F. Schoof and Dr. Frederick F. Ferguson. Other staff members from the Tropical Disease Section who assisted with the work were Eduardo Kildare De León, who performed many of the laboratory tests; Anibal Carrion García, who assisted with the snail surveys; and Tomás Ocasio Abril, who assisted in development and maintenance of equipment. Juan R. Palmer of the Bureau of Environmental Sanitation, Puerto Rico Department of Health, gave general counsel on field studies, and Luis Vázquez, of the same organization, assisted with field tests in the Aibonito Valley.

acrolein (*A*) : acrylaldehyde
Bayer 73 (*B*) : 2-Aminoethanol salt of 2′,5-dichloro-4′-nitrosalicylanilide
carbaryl (*C*) : 1-naphthyl *N*-methylcarbamate
copper sulfate: copper sulfate
dichlorvos (*D*) : 0-2,2-dichlorovinyl 0,0-dimethyl phosphate
disodium endothal (*E*) : disodium salt of 3,6-endohexahydrophthalic acid
DN-1 (*F*) : dinitro-0-cyclohexylphenol
Dybar (*G*) : phenyldimethylurea
Eelicide-TFM (*H*) : sodium salt of 3-trifluoromethyl-4-nitrophenol
FD-75 (*I*) : alkenyl dimethyl ethyl ammonium bromide
GC-1283 (*J*) : dodecachlorooctahydro-1,3,4-metheno-2*H*-cyclobuta (*cd*) pentalene
HRS-230 (*K*) : hexachloro-2-cyclopentenone
HRS-1243 (*K*) : decachloropentacyclodecanone glycerol adduct
HRS-1362 (*K*) : decachloropentacyclodecanone acetamide adduct
HRS-1603 (*K*) : 2,3,6-trichlorobenzyl-oxypropanol and 2,4-D
ICI-24223 (*L*) : isobutyltriphenyl methylamine
Kepone (*J*) : decachlorooctahydro-1,3,4-metheno-2*H*-cyclobuta (cd) pentalen-2-one
Kuron (*F*) : 2-(2,4,5-trichlorophenoxy) propionic acid
NaPCP : sodium pentachlorophenate
Pentac (*K*) : bis (pentachlorocyclopentadienyl)
TD-47 (*E*) : di N,N dimethylcocoamine salt of 3,6 endoxohexahydrophthalic acid
TD-191 (*E*) : mono, N,N dimethylcocoamine salt of 3,6 endoxohexahydrophthalic acid
Tritac (*K*) : 2,3,6-trichlorobenzyloxypropanol
Win 4257-2 (*M*) : monosodium salt of 2,2-dihydroxy-3,3′,5,5′ tetrachloro diphenyl sulfide
Win-4257-17 (*M*) : disodium salt of Win 4257-2
Zectran (*F*) : methyl-4-dimethylamino-3,5-xylyl carbamate
Ziram (*G*) : zinc dimethyldithiocarbamate
Zytron (*F*) : 0-(2,4-dichlorophenyl) 0-methyl isopropylphosphoramidothioate

After the chemicals were processed through the laboratory phase, the compounds showing

237-827—67——5

promise were tested in preliminary field trials. The compounds showing the greatest potential were evaluated further in large-scale field tests, in which an evaluation was made of the most economical combinations of application times and concentrations. In addition to toxicity studies on adults and eggs of *A. glabratus*, effective compounds were tested for toxicity to the ampullarid snail *Marisa cornuarietis* which is used in biological control of *A. glabratus* in Puerto Rico. The guppy *Lebistes reticulatus* was exposed to the chemicals because of general interest in the toxicity of molluscicides to fish. Photodecomposition of the compounds was also studied for indications of toxic stability under field conditions.

Materials and Methods

Laboratory Tests

Snails (*A. glabratus* and *M. cornuarietis*) and guppies were collected weekly from representative field sites throughout Puerto Rico (fig. 1). They were stored in concrete tanks, such as the one to the left of the channel in figure 2, with ample vegetation and water. As many as 1,000 snails were used per week for the laboratory tests, and more than 12,000 snails were tested in all.

Tapwater controls were used with all the tests to check natural mortality. A chemical standard (NaPCP at 2.5 and 5.0 mg. per liter) was used with all 6-hour tests to check homogeneity of the snail populations' response to chemicals.

The chemicals were stored in a dark cabinet which had an average temperature of 25° C., and the stock solutions, prepared with distilled water, were kept in a refrigerator at 5° to 10° C. in dark bottles. Care was taken to avoid exposing the concentrates to direct sunlight in order to prevent photodecomposition. The concentrates were never kept longer than 3 months—usually a much shorter time.

The test concentrations were made up with tapwater, which is essentially filtered river water from the Río Grande de Loíza. This water was considered representative of Puerto Rican surface waters, although there are some harder and more alkaline waters on the south coast. The water quality was monitored daily for a full month and also at irregular intervals during the test program to show average and maximum-minimum values of chlorides, dissolved oxygen, hardness, alkalinity, pH, and chlorine residual.

In the standard laboratory procedure, the snails were placed in glass jars with 10 specimens per jar in 2 liters of solution (fig. 3). *A. glabratus* snails were exposed to the chemical for 1, 6, or 24 hours; *M. cornuarietis* for 6 hours. Three jars were used for each type of solution, with a tapwater control, a NaPCP control, and

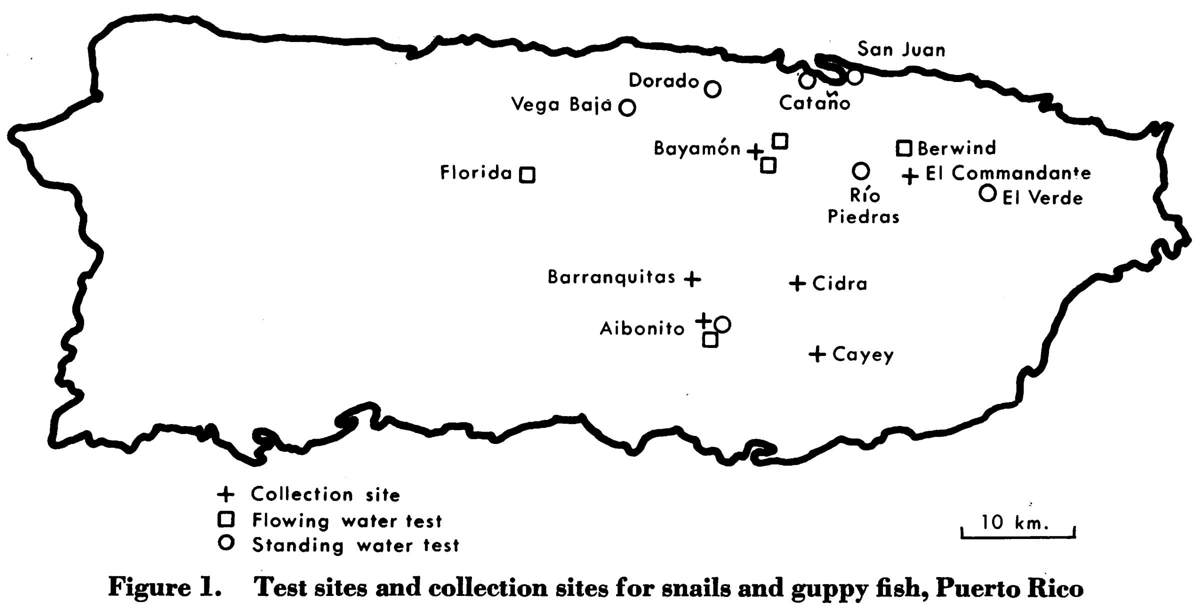


Figure 1. Test sites and collection sites for snails and guppy fish, Puerto Rico

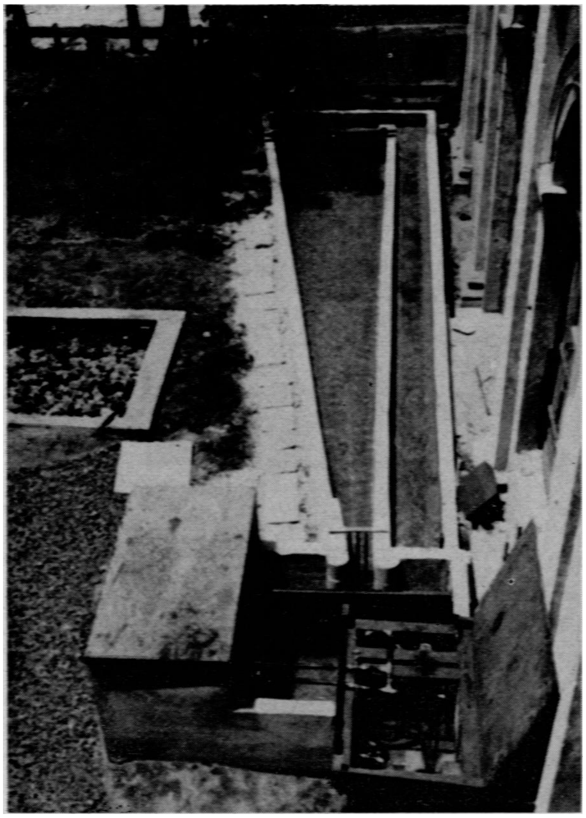


Figure 2. Concrete channel and tank for snail studies

three different concentrations of the test chemical. The test consisted of three steps: (*a*) applying the chemical, (*b*) rinsing the containers and the snails three times, and (*c*) placing the snails in 2 liters of tapwater with lettuce or snail food for 4 days of observation. Death was defined as continuous, submerged retraction from the third day to the fourth day. Shell diameters were recorded, and general observations on irritation, bleeding, and retraction were noted during the exposure period.

In the ovicidal tests, eggs were obtained on thin polyethylene strips placed in glass aquariums containing field-collected snails. After they were counted, masses of eggs (containing motile larval stages or prehatching forms) were placed in 100-ml. containers. Four containers were used for each of three different concentrations of the test chemical, with about 100 eggs per concentration. The eggs were checked microscopically for motility during exposure to the chemical, rinsed three times, and placed in tapwater for 2 weeks of observation. Nonmotile disintegrating embryonic forms were assumed to be dead.

The piscicidal tests were conducted with field-collected guppies which were temporarily maintained in large concrete holding tanks. The test procedure was identical to that for the adult snails, except that death was defined as lack of movement and size measurements were not made.

To summarize the laboratory data, the method of probit analysis (*3*) was used in most cases. This analytical method has been developed and refined for use with data pertaining to many types of biological phenomena, especially those involving the response of organisms to graduated concentrations of chemicals. With probit analysis it is possible to calculate the concentration which is lethal to 50 percent of the organisms (LC_{50}), if applied for a specified time. The precision or confidence limits of the LC_{50} can also be calculated, as well as concentrations producing other mortality of less than 100 percent (LC_{90}, LC_{99}, and so forth).

As a supplement to the probit analysis, the concentration which gave complete or 100 percent mortality (CM) in all laboratory tests was reported. This value can be determined by a simple inspection of the data, but it lacks the precision of the values obtained through probit analysis (*4*), and it is not possible to calculate confidence limits for the CM values. To give some indication of the precision involved, the CM value was usually reported as a pair of concentrations; the higher value gave complete

Figure 3. Laboratory test equipment

mortality while the other value indicated the next lower concentration tested, giving less than complete mortality.

Field Tests

Still water. Swamps and ponds from 1 to 3,000 cubic meters in volume were measured, and the water volume was calculated to a precision of 10 percent. Usually the natural snail population was sampled before treatment with a standard 500-cm.[2] dipper and a specified number of scoops, although caged snails were used in one test. A water sample of 250 ml. was analyzed for hardness, alkalinity, pH, chlorides, and dissolved oxygen.

The test chemical was formulated as an aqueous solution, suspension, or emulsion. It was then sprayed, as shown in figure 4, or mixed manually into the water body. At the time of treatment, the water temperature, sunlight, vegetation, bottom material, and frog, toad, or fish population were noted.

Post-treatment snail surveys were conducted in the same manner as the pre-treatment surveys at 1 and 4 days after treatment. Effects on vegetation, fish, toads, and frogs were observed.

Flowing water. Streams containing dense, natural populations of *A. glabratus*, with flow discharges between 7 and 35 liters per second were sampled for snails by scooping a specified number of dips at each section. Water depth, water surface width, vegetation type and intensity, bottom material, and average stream velocity were noted at representative sections along the stream. Water quality was analyzed in a

Figure 4. Spraying for field test of Eelicide-TFM against Australorbis glabratus

Table 1. Data for 8 compounds eliminated because of a 6-hour complete mortality of 10 mg. per liter or more or ineffectiveness in field tests against Australorbis glabratus

Chemical	6-hour LC_{50} (mg./l.)	6-hour complete mortality (mg./l.)	Still water field tests	
			Concentration (mg./l.)	Mortality (percent)
DN-1	5	[1] 54	11	83
Kepone	2	20		
SD-1581	2	[1] 15	9	5
TD-47	2	5		
TD-191	4	10		
Win 4257-2	1	10	30	98
Do			75	88
Win 4257-17	0.2	5	5	96
Do			5	59
Ziram	2	10	8	100

[1] $LC_{99.5}$—approximately the concentration which gave complete mortality.

manner similar to that for still water. Stream discharge was measured with weirs or current meters or by a simple, timed-float method and corrected for vertical velocity distribution.

At the time of application of the test chemical, incident sunlight, water temperature, and cloud cover were noted. Post-treatment samples of snail populations, identical to the pre-treatment samples, were made at 1- and 4-day intervals after treatment. The post-treatment snail samples were summarized in terms of the distance from the application point to the first live snail. This distance is termed the "distance controlled."

For 1-hour applications, a simple 200-liter barrel with an adjustable outlet was used as a dispenser, corrected every 15 minutes to give the desired average flow. For 6- and 24-hour applications an automatic dispenser was used. In most applications, constant head valves were attached to the chemical reservoirs to give the desired discharge. Discharge was calibrated directly with a graduated cylinder and stopwatch, and also by the drop in the level of the solution. When necessary, the solution was agitated to maintain a uniform concentration.

Natural half-life tests. These tests were conducted in the concrete snail study channel (fig. 2), which is equipped with a recirculating

Table 2. Laboratory data for 5 compounds

Test subject	Exposure (hours)	S[1]	$LC_{99.5}$ (mg./l.)[2]	Complete mortality (mg./l.)[3]
		NaPCP		
A. glabratus				
Adults	1	2.27	170±46	40–50
	6	2.06	36±14	15–18
	24	3.06	4.5±1.2	2.0–2.5
Eggs	6	------	5.6	--------
	24	------	1.4	--------
L. reticulatus	6	------	3	--------
	24	------	5	--------
M. cornuarietis	24	------	4	--------
		Bayer 73		
A. glabratus				
Adults	1	4.57	3.0±0.4	3–4
	6	4.31	1.0±0.1	0.8–1.0
	24	8.00	0.26±0.02	.2–.3
Eggs	1	------	3.0	--------
	6	------	1.0	--------
L. reticulatus	6	------	28	--------
M. cornuarietis	24	------	.5	--------
		ICI–24223		
A. glabratus				
Adults	1	1.60	22±9	10–20
	6	2.73	4.3±0.6	5–10
	24	4.90	0.44±0.03	.25–.50
Eggs	6	------	210	--------
L. reticulatus	6	------	2	--------
M. cornuarietis	6	------	6	--------
		Cu SO_4		
A. glabratus				
Adults	1	5.51	2.5±0.9	2–5
	6	4.80	1.1±0.3	.7–1.0
	24	5.21	0.25±0.08	.1–.2
Eggs	6	------	10	--------
L. reticulatus	6	------	15	--------
M. cornuarietis	6	------	----------	1.0
		Eelicide-TFM		
A. glabratus				
Adults	6	6.80	15.6±1.4	
	24	7	4.7±0.4	2–5
Eggs	24	------	----------	1–5
L. reticulatus	24	------	----------	50–100

[1] Slope of the probit of mortality versus log of the concentration plot, expressed as a ratio.

[2] Concentration which killed 99.5 percent of the snails and the 95 percent confidence limits.

[3] Concentration which gave complete mortality of the snails in the laboratory tests. The value is reported as a pair of concentrations; the upper value gave complete mortality and the other value was the next lower concentration tested.

pump. The channel was filled with 3,000 liters of the dilute solution of test chemical (in tapwater), and detoxification was measured by bioassay. At regular intervals 6- to 12-liter samples were taken from the flowing water, and 30 snails were exposed to the sample according to the standard procedure for laboratory evaluation. The toxic concentration of the solution in the channel during the test period was calculated from these data.

The channel was completely exposed to the April and May sunlight of San Juan, P.R., 18° N. latitude, a close approximation of the average annual intensity of sunlight in Puerto Rico. The canal supported a heavy growth of algae, making conditions similar to those in natural streams. The water was classified as soft. Hourly measurements of light intensity and water temperature were made. After each test the channel was flushed, rinsed, and then filled with fresh tapwater for the next test.

Results

The preliminary laboratory tests consisted of 6-hour applications of the test chemicals to adult *A. glabratus*. The results indicated the concentration which would kill 50 percent of the snails (6-hour LC_{50}). From past experience, it was determined that a chemical with a 6-hour LC_{50} of 15 mg. per liter or more did not merit further study, and 15 of the 28 candidate molluscicides were eliminated by this criterion. These chemicals and their 6-hour LC_{50} values, in milligrams per liter, were: dichlorvos, 20; disodium endothal, 20; Dybar, more than 100; FD–75, more than 65; GC–1283, more than 50; HRS–230, more than 20; HRS–1243, 15; HRS–1362, 25; HRS–1603, 25; Kuron, more than 60; Pentac, more than 20; carbaryl, more than 45; Tritac, more than 20; Zectran, 80; and Zytron, more than 100.

Additional laboratory study of the 13 remaining chemicals was conducted to determine the concentration of chemical which killed 99.5 percent of the snails with a 6-hour application (6-hour $LC_{99.5}$), or the concentration which killed all of the snails (6-hour CM). These parameters give an approximation of the concentration needed to achieve complete mortality in field testing, and they are more useful than the 6-hour LC_{50} for the evaluation of the compounds. Some of the compounds were also field tested for general indications of toxicity under field conditions. Eight of the 13 remaining compounds were eliminated at this stage, using a 6-hour CM of 10 or more mg. per liter or ineffectiveness in field tests as the criteria for elimination (table 1). The field tests in still water generally verified the low effectiveness indicated by the laboratory data. However, two of the eight compounds met the laboratory criterion but were relatively ineffective in field tests in flowing water. With a 6-hour application of 24 mg. per liter, TD–47 killed all of the *A. glabratus* for only 300 meters below the application point. Win 4257–17, applied at 6 mg. per liter, killed snails for only 70 meters downstream.

Through the process of elimination, 5 of the original 28 compounds (NaPCP, Bayer 73, $CuSO_4$, ICI–24223, and Eelicide–TFM) reached the final testing stage. Applications of these chemicals at 1, 6, and 24 hours were made in the laboratory with adult *A. glabratus* and eggs of *A. glabratus*. Adult *M. cornuarietis* and guppy fish were also exposed to the compounds (table 2). Because of the many factors involved, it is difficult to rank the chemicals in order of toxicity. Generally, Bayer 73 and $CuSO_4$ were more toxic than the other chemicals, based on the laboratory results with adult *A. glabratus*. Bayer 73 is clearly the most

Table 3. Field tests of Bayer 73

Still water test No.	Concentration (mg./l.)	Live *A. glabratus*		Percent kill	Water body	Vegetation
		Pre-treatment	Post-treatment			
1	4	400 in 10 scoops	0 in 10 scoops	100	pond	sparse.
2	1	10 per cage	0 per cage	100	do	Do.

Flowing water test No.	Concentration (mg./l.)	Application time (hours)	Stream velocity (cm./s.)	Distance controlled (km.) [1]	Discharge (l./s.)	Water quality
3	1	4	10	0. 2	14	soft.
4	1	6	180	1. 4	14	unknown.
5	22	1	1	4. 1	35	soft.

[1] Distance from point of chemical application to first live snail downstream.

Table 4. Field tests of ICI–24223

Still water test No.	Concentration (mg./l.)	Live *A. glabratus* in 60 scoops		Percent kill	Water body	Vegetation
		Pre-treatment	Post-treatment			
1	3	43	30	30	swamp	Heavy.
2	1	27	22	18	do	Do.
3	1	25	0	100	pond	medium.
4	2	45	1	98	pool	sparse.
5	3	19	0	100	swamp	heavy.

Flowing water test No.	Concentration (mg./l.)	Application time (hours)	Stream velocity (cm./s.)	Distance controlled (km.)	Discharge (l./s.)	Water quality
6	1	6	6	0. 02	10	soft.

Table 5. Field tests of $CuSO_4$

Still water test No.	Concentration (mg./l.)	Live *A. glabratus* in 60 scoops		Percent kill	Water body	Vegetation
		Pre-treatment	Post-treatment			
1	1.0	200	0	100	pool	sparse.
2	1.0	153	102	32	do	medium.

Flowing water test No.	Concentration (mg./l.)	Application time (hours)	Stream velocity (cm./s.)	Distance controlled (km.)	Discharge (l./s.)	Water quality
3	3.5	6	10	0.01	8	soft.
4	36	6	10	.20	7	Do.

Table 6. Field tests of Eelicide-TFM

Still water test No.	Applied concentration (mg./l.)	Post-treatment mortality (percent)			Vegetation
		A. glabratus	Guppy fish	Other fish	
1	9	100	0	0	light.
2	10	96	11	(1)	Do.
3	15	100	5	(1)	Do.

[1] None present.

toxic compound with regard to eggs of *A. glabratus*.

The tests in the outdoor canal gave a reliable means of comparing stability of the compounds under field conditions. With the bioassay technique, it was possible to observe the gradual loss in toxicity of the chemicals over several days. Two tests each were run with Bayer 73, NaPCP, and $CuSO_4$. The tests with Bayer 73 ran 4 days, those with the NaPCP and $CuSO_4$, 2 days each. In general, the toxicity decreased in a pattern similar to the decay pattern of radioactive materials, making it possible to estimate a "half-life" of the compound. Results of these canal tests indicated the following half-life values for natural conditions: NaPCP, 5 hours; Bayer 73, 50 hours; and $CuSO_4$, 5 hours.

The final field tests, summarized in tables 3–6, generally confirmed the laboratory data, with two exceptions: ICI–24223 and Eelicide–TFM were not as effective as had been assumed from the laboratory results. Bayer 73 was quite toxic at low concentrations in still water tests.

More interesting were the results from test 5 (table 3), which was conducted in a very slow stream. A high concentration was applied to give effective control for a great distance downstream. The 1-hour wave remained lethal for a distance of 4.1 km., or 114 hours after application. Since the toxic concentration for a 1-hour application is 3.0 mg. per liter, it can be calculated that Bayer 73 decayed with a half-life of 40 to 60 hours, agreeing well with the 50 hours obtained from the canal tests.

Still water tests of ICI–24223 (table 4) gave as low as 30 percent mortality with concentrations of 3 mg. per liter, and the flowing water application was completely unsuccessful. Since ICI–24223 is virtually nontoxic to eggs, the field performance suggests that it would not be an effective molluscicide.

The $CuSO_4$ performance in still water was fair (table 5), and the flowing water test verified that this chemical has a relatively short half-life. Tests with Eelicide-TFM (tables 2 and 6), indicated that 15 mg. per liter would be better for field use than the 5 mg. per liter indicated by the laboratory data. The nontoxicity of this compound to fish (*5*) was verified in test 1 (table 6) conducted in a pond containing guppies and other small fish.

The diameters of the snail shells were measured in all laboratory tests. The mean diameter for all the snails tested was 17 mm. with a total range of diameters from 6 mm. to 30 mm.

The NaPCP chemical controls which were run with the 6-hour test of all the chemicals showed little variation from one test to another. A chi-square test on the amount of variation showed that it was well within normal limits.

The results of the tapwater analyses indicated that the water quality was uniform throughout the test program, with an average hardness of 15 mg. per liter as $CaCO_3$, a pH of 7.5, an alkalinity of 86 mg. per liter as $CaCO_3$, and chlorides of 6 mg. per liter. Chlorine was never present.

Discussion

The NaPCP controls, the snail size measurements, the tapwater analysis, and the standardized techniques gave reasonable proof that all chemicals were evaluated under similar conditions. Furthermore, the use of a field strain of *A. glabratus* plus the use of river water as a test medium provided reliable data which can be used as a base for pilot field programs in Puerto Rico.

Since *M. cornuarietis* is widely used in experimental biological control in Puerto Rico and as an adjunct to chemical control in a few small watersheds, it was hoped that a compound would be discovered that was selectively toxic, killing *A. glabratus* but not harming *M. cornuarietis*. However, *M. cornuarietis* was generally more susceptible to chemicals than was *A. glabratus*.

Based on the laboratory data alone, NaPCP is clearly less toxic to adult *A. glabratus* than is Bayer 73, $CuSO_4$, or ICI–24223 for any application time. For 6-hour application to snail eggs, however, only Bayer 73 exceeds NaPCP in toxicity. The natural half-life tests indicate that NaPCP, along with $CuSO_4$, is rather unstable.

Summary

In laboratory and field evaluation of 28 chemicals for potential use against the snail *Australorbis glabratus*, intermediate host of *Schistosoma mansoni* in the Americas, 5 of the compounds (Bayer 73, ICI–24223, $CuSO_4$, NaPCP, and Eelicide-TFM) were toxic enough to warrant extensive testing.

In the laboratory, Bayer 73 was the most toxic of the five compounds to adults and eggs of *A. glabratus*. The concentrations of Bayer 73 which resulted in 99.5 percent mortality ($LC_{99.5}$) among adult snails were 3.0 mg. per liter for 1-hour applications, 1.0 mg. per liter for 6-hour applications, and 0.26 mg. per liter for 24-hour applications. Bayer 73 was far more stable than the other compounds in outdoor tests; it required 50 hours to decay to one-half the applied concentration. Five field tests with Bayer 73 further supported its superiority to the other compounds.

$CuSO_4$ had a 6-hour $LC_{99.5}$ of 1.1 mg. per liter for adult snails and 10 mg. per liter for eggs. It was highly unstable under field conditions, compared to Bayer 73.

ICI–24223 and NaPCP were less toxic than Bayer 73 and $CuSO_4$, and ICI–24223 gave poor results when tested in the field. Eelicide-TFM had a 6-hour $LC_{99.5}$ of 15 mg. per liter, but it was nontoxic to fish and it may be the best compound for use where fish are of value.

REFERENCES

(*1*) Jove, J. A.: Use of molluscicides in the control of bilharziasis in Venezuela. Bull WHO 14: 617–638 (1956).

(*2*) Klock, J. W., Gerhardt, C. E., Ildefonso, V., and Mateo Serrano, J.: Characteristics of sodium pentachlorophenate used against *Australorbis glabratus* in Puerto Rico. Bull WHO 16: 1189–1201 (1957).

(*3*) Finney, D. J.: Probit analysis. Cambridge University Press, Cambridge, England, 1962.

(*4*) Hopf, H. S., and Muller, R. L.: Laboratory breeding and testing of *Australorbis glabratus* for molluscicidal screening. Bull WHO 27: 783–789 (1962).

(*5*) Applegate, V. C., and King, E. L.: Comparative toxicity of 3–trifluoromethyl–4–nitrophenol (TFM) to larval lampreys and eleven species of fish. Trans Amer Fisheries Soc 91: 342–345 (1962).

SUPPLY REFERENCES

(*A*) Shell Chemical Co., New York City.

(*B*) Farbenfabriken Bayer AG, Wuppertal-Elberfield, Germany.

(*C*) Union Carbide Corp., New York City.

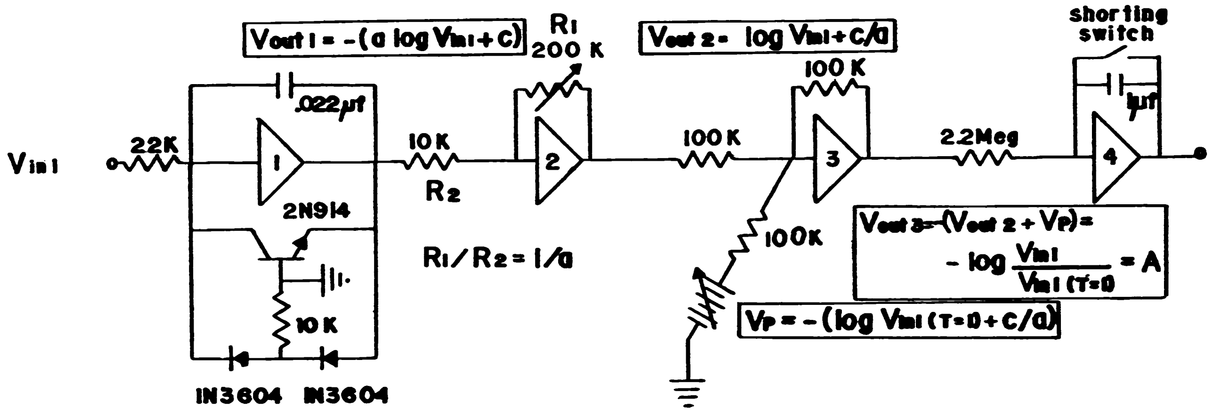
(*D*) Montrose Chemical Co., Newark, N.J.
(*E*) Pennsalt Chemicals Corp., Montgomery, Ala.
(*F*) Dow Chemical Co., Midland, Mich.
(*G*) E.I. DuPont de Nemours & Co., Inc., Wilmington, Del.
(*H*) Maumee Chemical Co., Toledo, Ohio.
(*I*) Fairbank Corp., Santurce, Puerto Rico.
(*J*) General Chemical Division, Allied Chemical Corp., Morriston, N.J.
(*K*) Hooker Chemical Corp., Niagara Falls, N.Y.
(*L*) Imperial Chemical Industries Limited, Alderely Park, Mosclesfield, Cheshire, England.
(*M*) Sterling-Winthrop Research Institute, Rensselaer, N.Y.

Analog Transmittance to Absorbance Converting and Integrating System

GRANTEE INVENTION

An inexpensive analog computer system, converting optical transmittance to absorbance, can be constructed by programing the Heath operational amplifier EUW–19A (Heath Co., Benton Harbor, Mich.) with a module built from the Heath adapter chassis EUA–19–1. This possibility has been demonstrated theoretically and by experience with the type of logarithmic convertor circuit that embodies a diffused-base transistor, as described by William L. Paterson (*Review of Scientific Instruments*, Vol. 34, page 1311, figure 2b, 1963). The system can economically equip a spectrophotometer to make rapid, linear measurements of absorbance over at least four decades.

An open ended voltage, V in 1, (see figure) corresponding to transmittance T enters operational amplifier OA1 and leaves as −(a log V in 1+c). A and c are constants characteristic of the system. OA1, stabilized by a condenser across the emitter and collector of its transistor, gives linear output for input voltages from a few millivolts through at least 40 volts (more than a 10,000-fold range). With a gain adjusted to equal 1/a, OA2 gives an output of log V in 1+c/a. By combining this output with an adjustable voltage, $V_P = -$(log V in 1 (T=1)+c/a) and reaching the summing point from a Heath voltage reference source, EUW–16, OA3 gives an output of −log [V in 1/V in 1(T=1)], which is numerically equal to absorbance. OA4 is an integrator including a shorting switch for resetting to zero.—Paul T. Clark, B.S., *Saint John's Hospital, Santa Monica, Calif. This invention was developed in part under Public Health Service grant No. CA06730.*



Analog transmittance to absorbance converting and integrating module