REVIEW OF CURRENT VERTEBRATE PESTICIDES

D. Glen Crabtree

Bureau of Sport Fisheries and Wildlife, Wildlife Research Center, Bldg. 45, Denver Federal Center, Denver 25, Colorado.

For the purpose of this brief review, emphasis will be placed on development, physical properties, physiological action, experience and limitations of vertebrate pesticides primarily of current operational importance in the control of field rodents and predatory animals.

INGESTED LETHAL AGENTS

STRYCHNINE ($C_{21}H_{22}N_2O_2$)

This alkaloid was discovered by Pelletier and Caventou[1] in 1817 as a constituent in the seeds of Strychnos Nux-vomica or Strychnos Ignatii, which were used for killing dogs, cats and birds in Europe at least as early as 1640. Strychnine (probably the sulfate) appears to have been introduced as a pesticide in the United States about 1847 and became the principal tool of the professional "wolfer" during the years 1860-1885.[2]

PHYSICAL PROPERTIES:

The alkaloid of commerce is a white or greyish white powder prepared from seeds grown in Southern Asia. It is quite stable, almost insoluble in water, but soluble in many organic solvents and to varying degrees in dilute acids with which it forms salts having limited solubility in water. Strychnine and its salts have an exceedingly bitter taste and are not absorbed through the normal intact skin.

Both the alkaloid and strychnine sulfate are widely used today as vertebrate pesticides. In the case of the latter, allowance must be made in preparing lethal baits since it contains only 78.04% strychnine.

PHYSIOLOGICAL ACTION:

Ingested strychnine is promptly absorbed, mainly, from the intestinal tract. When sublethal amounts are administered, part of the strychnine appears unchanged in the urine shortly after absorption begins and continues to be slowly excreted for several hours and part is probably detoxified in the liver.[3/] When injected intravenously 30% of the strychnine leaves the blood-stream in 2 minutes and only traces remain after 40 minutes. In fatal cases, strychnine is found principally in the liver and kidneys of the victim. The principal symptoms of strychnine poisoning, which may appear in from 5-30 minutes after ingestion, are due principally to increased reflex excitability of the spinal cord. The motor reflexes are modified so that smaller stimuli are effective and the response to slight stimulation is maximal, tetanic and tends to spread to all the muscles. Ordinary reflexes are increased but tetanus depends on an enormous exaggeration of the "startle" reflex from a sudden stimulus or fright. This involves contraction of all muscles which brings about several secondary results such as pain, asphyxia, increased metabolism, disturbance of temperature, rise in blood pressure, increased heart rate and early post-mortem rigor. Convulsive seizures may be interspersed by periods of quiescence. Death usually occurs from the tetanic arrest of respiration in the course of a major convulsion.

Evacuation and chemical antidotes are seldom effective in the treatment of strychnine poisoning since this substance is quite rapidly absorbed. The danger of giving an emetic lies in the possibility that emesis may initiate a convulsion which might lead to the aspiration of vomitus. Sedative treatment should be started as soon as possible by the intravenous injection of a barbiturate such as sodium pentobarbital to allay or prevent convulsions and the accompanying asphyxia, pain and anxiety. Following narcosis, the stomach may be washed if proper precautions are taken to prevent aspiration. Narcosis should be maintained until sufficient time has elapsed to allow for the detoxification of the absorbed strychnine, probably by the liver, and its excretion in the urine. The patient must be kept under observation for several hours and artificial respiration applied if respiratory spasm appears imminent.

EXPERIENCE AND LIMITATIONS:

Strychnine rapidly became the primary weapon of the old Biological Survey and its successor agency, the Bureau of Sport Fisheries and Wildlife in the cooperative control of noxious animals and birds. The alkaloid was mixed into a quantity of starch paste-soda-corn syrup mixture and poured over steam-crushed whole oats for field rodent control, such as ground squirrels, prairie dogs, kangaroo rats and field mice.

A typical formula for the preparation of lethal bait for field rodents is as follows:

1 oz. strychnine alkaloid
8 to 24 qts. of steam-crushed oats or maize (according to species)
2 qts. water (amounts adjusted according to qts of grain used)
1 oz. baking soda (amounts listed for 12 qt. batch)
2 oz. salt
1 oz. cornstarch
1 cup syrup

Dissolve starch in cup of cold water. Add salt and syrup to water and bring to boil. Add starch and stir until clear paste is formed. Dry mix soda and strychnine, add to paste and stir. Pour over grain and mix thoroughly. Spread to dry.

Strychnine alkaloid diluted with an inert powder such as magnesium oxide can be sprinkled over the surface of cubed carrots, sweet potatoes and apple slices for the control of pocket gophers. Strychnine-common salt cakes have been used for porcupine control. A strychnine alkaloid-glycerinated gelatin tablet containing approximately 2.18 grains of strychnine was devised for use in controlling predatory animals such as coyotes and wolves. A tablet is placed in a small ball of lard-sugar mixture or into a slit in a small piece of meat. Many such baits are exposed around the carcass of a bait animal which serves as the attractant.

The alkaloid is sometimes mixed with a simple starch paste and poured over small kernel wheat for sparrow control.

In general, the concentrations of strychnine used varied from 1 oz. of strychnine spread over 8 lbs. of steam-crushed oats to 1 oz. per 24 lbs., respectively.

Success with strychnine baits for rodent control in the field often varied from time to time, depending largely upon the rapidity with which the animals consumed the bait since the ingestion of a lethal dose in a short period of time is necessary to produce a lethal effect.

Strychnine alkaloid appears to have two marked characteristics - taste and toxic effect - which may interfere with the acceptance of a lethal dose by rodents. Taste appears to present little problem when bait containing strychnine is first exposed to rodents. Apparently, however, they quickly learn to associate the taste of strychnine with its effect and reject such baits on repeated exposure. The same holds true for the toxic effect of the strychnine. This situation led to considerable research by the Bureau in the early days in attempts to circumvent these two warning factors.

A third problem may occur if the carrier used to apply the strychnine to grain interferes with absorption of strychnine. In instances where "free-running grain" is required and the strychnine is applied in carriers which cause protracted absorption, increased amounts of strychnine must be used to supply the needed minimal quantity necessary for lethal effects.

Its use as a vertebrate pest control material embodies many advantages which other materials lack. One of these is the fact that strychnine is less toxic to many desirable forms of wildlife such as gallinaceous game birds and domestic poultry, etc., than for the rodents which it is used to combat. Because of its extremely bitter taste, materials containing strychnine are readily detected by humans, a fact which must be considered as an important safety element. On the other hand, it is very difficult to discolor a grain containing strychnine - a modern technique for the protection of birds. Some measure of protection in this area, of course, accrues from the use of steam-crushed whole oats which some birds do not readily accept.

To insure the ingestion of a lethal dose of strychnine-treated grain at a single feeding, it is sometimes necessary to pre-bait a rodent population to insure maximum control. This greatly increases the cost of a control application.

SODIUM MONOFLUOROACETATE ($FCH_2-C^{=O}-ONa$)

Monofluoroacetic acid ($FCH_2-C^{=O}-OH$) was first prepared in Belgium by Swartz in 1896, at which time he recorded some of its physical properties but made no mention of its toxicity.[4/]

Monofluoroacetic acid and its homologs then escaped the attention of biochemists and pharmacologists for some 40 years, until about 1935 when Gryskiewicz-Trochimowski and colleagues carried out extensive researches into the preparation and properties of fluoroacetates. This group recorded the toxic effects of fluoroacetate and its homologs but due to the war, this work was not published until 1947.

In the course of these pharmacological studies, it became apparent that the fluoroacetates were highly toxic to a large variety of animals through all the common routes of administration. The symptoms listed in the order of their appearance were - apathy, excitability and inability to see obstacles, enragement and convulsions. Death was attributed to asphyxiation with convulsive symptoms. No post-mortem lesions were observed. Of all the animals tested, monkeys were found to be significantly more resistant than most other mammals.

Other work in Europe with toxic fluorine compounds was apparently started in 1934 by Schrader in Germany. Little of this was recorded in the open literature at that time and was brought to light after the war through investigation of records by the British Intelligence Service.

Although the primary purpose of Schrader's work was to develop new insecticides, Schrader prepared 2-fluoroethanol in 1935 which was shown to be toxic to many animals. He also demonstrated that fluoroacetic acid itself was toxic to warm-blooded animals. From available records it appears that salts of fluoroacetic acid may have been patented for use as rodenticides in Germany before the war. Thus, the major advances in the preparation and study of the fluoroacetates up to 1939 appear to have bee made in Belgium, Poland and Germany.

Early in World War II, Sporzynski, one of Gryskiewicz-Trochimowski's colleagues escaped to England from Poland and directed the attention of the British to the compound methyl-fluoroacetate as an extremely toxic substance. McCombie and Saunders at Cambridge accordingly undertook a systematic study of the fluoroacetates and related compounds as potential chemical warfare agents. A large number of homologs of fluoroacetates were synthesized and toxicological studies performed with them.

While the work on the fluoroacetates was proceeding in Cambridge, Kharsach and colleagues at the University of Chicago were working on related programs in which many fluoro compounds were synthesized. An exceedingly interesting fact was uncovered in toxicological studies with aliphatic homologs of monofluoroacetates which is that only compounds having an even number of carbon atoms were toxic and those containing an odd number of carbon atoms were relatively non-toxic. Toward the end of the war, Marias reported that fluoroacetic acid was a toxic constituent of the poisonous plant "gifblaar" (Dichapetalum cymosum) which had long been recognized as a serious hazard to cattle in South Africa. This led to a renewed investigation of this series of compounds in an attempt to produce an antidote which might be useful in cases of stock poisoning. In 1957 Peters isolated and tentatively identified as monofluoro-oleic acid, the toxic principal of seeds from Dichapetalum toxicarium "ratsbane" a west African plant, seeds of which had long been used to poison rats and as a chemical warfare material by natives of this region. These constitute the only known instances of monofluorinated aliphatic acids occuring in nature.

In about 1944, the U.S. Chemical Warfare Service suggested to the U.S. Fish and Wildlife Service the possibility of employing sodium-monofluoroacetate as a rodenticide. This compound was subsequently developed by the Denver Wildlife Research Laboratory of the Fish and Wildlife Service as a mammalian pest control material. Although initially utilized by the Armed Services for operational rodent control it has since become a lethal material of major importance for the control of field rodents and mammalian predators in programs conducted by governmental agencies.

PHYSICAL PROPERTIES:

Sodium monofluoroacetate (1080) is a chemically stable compound which is not particularly corrosive to metals. It is relatively insoluble in many organic solvents and in vegetable fats and oils, but extremely soluble in water. This compound is hygroscopic and will absorb water vapor from the atmosphere if not kept in a hermetically sealed container. It decomposes at approximately 200°C., which allows the destruction of unused baits by burning.

PHYSIOLOGICAL ACTION:

Perhaps the outstanding characteristic of the toxicology of "1080" is the extremely wide variation in susceptibility between different species of animals and the divergence of symptoms elicited.[5] For instance, dogs have been killed with a dosage of "1080" as small as 0.06 mg/kg. whereas the Norway rat requires about 5.0 mg/kg.

Variations in the amount necessary to produce lethal effects often occur in different strains of the same animal species.

The major manifestations of "1080" poisoning are the involvement of either the central nervous system or the heart, or a mixture of both. In general, the effect on herbivorous animals is usually one of cardiac involvement in which the heart is thrown into fibrillation. Generally with this group, respiration may cease before heart action has completely stopped. Convulsions are mild and usually limited to terminal phases of "1080" poisoning. This is the picture usually found in rabbits and cattle poisoned with "1080".

Carnivorous animals, on the other hand, react to "1080" poisoning primarily through effects on the central nervous system. The dog exhibits typical symptoms of this character. The onset of symptoms is usually preceded by a few minutes of barking and howling together with non-recognition of human presence and actions suggestive of fearful hallucinations or hysteria. If the dose is sufficiently large, emesis occurs but as the amount ingested approaches minimum lethal levels, vomiting may not occur. The terminal phases of "1080" poisoning in a dog involves a tonic spasm followed by running movements executed in a prone position. The course of tonic spasms may subside at times and the dog may appear normal, but ultimately repeated convulsive anoxic assaults on the respiratory center lead to death through respiratory paralysis. Seldom can death be attributed primarily to action on the heart.

As with most omnivores, in man and monkey a mixture of central nervous system and cardiac involvement is usually the case.

"1080" is rapidly absorbed from the gastro-intestinal tract and by the time symptoms are observed, sufficient material has been absorbed to cause death. "1080" does not seem to be excreted to any significant extent nor does it appear to be detoxified in the body. One of the most characteristic features of "1080" poisoning is the invariable occurrence of a latent period prior to the onset of symptoms and it is perhaps this latent period which contributes most to its effectiveness as a rodenticide. In other words, a lethal dose may be ingested by an animal long before warning is given by the development of symptoms. Although repeated doses of Sodium monofluoroacetate has been demonstrated to increase the resistance of rats to subsequent doses, this effect appears to be short-lived and of little practical significance in its use as a rodenticide. Likewise, "1080" is not accumulative to any practical degree.

No effective antidote to "1080" poisoning has yet been found and treatment consists of alleviation of symptoms as they occur. The mode of action of "1080" apparently is to block citric acid oxidation, leading to the accumulation of citric acid in the body cells.

EXPERIENCE AND LIMITATIONS:

The use of grain baits containing 2 oz. 1080/100 lbs. of steam-crushed oats (0.125%) has led to phenomenal control of field rodents.

The high water solubility of "1080" soon led to the development of a poisoned water technique for the control of commensal rats and mice, in which approximately $\frac{1}{2}$ oz. sodium monofluoroacetate containing 0.5% nigrosine black dye is dissolved in a gallon of water. The dye is present as a warning against consumption by humans. This solution is then exposed in locked and firmly fastened-down bait boxes in commercial establishments for rat and mouse control.

In the case of predatory animals, particularly the coyote, large chunks of horse and sheep meat, etc. are injected with a water solution of "1080" at the rate of 1 mg. per ounce of meat. These stations are exposed in thinly populated country during winter months when access by the public is minimal.

Outstanding success was also encountered with the use of "1080" for the control of predatory animals.

Although "1080" has been perhaps the most successful all-around lethal agent ever employed for predator and rodent control, there are certain inherent disadvantages in its use as a control agent. Due to its persistence in the carcasses of animals killed with it and their subsequent availability for consumption by other animals, particularly canines, the problem of secondary poisoning may prohibit its use in some situations. In this regard, dogs have been killed by chewing on the dried carcass of a rat or mouse killed with "1080" several months prior to being found by the dog.

Of all the currently available control drugs and chemicals, ingestion of a sublethal dose of "1080" appears to produce the strongest aversion to subsequent feedings on baits containing it. For this reason other pesticides are usually required for "clean-up" treatment, where needed, following a "1080" rodent control program. When large doses are ingested by canines, vomiting usually occurs and the vomitus remains toxic to other canines which may lick or consume it. Due to its bland taste, it can be ingested by humans without realizing that a toxic material was contained in the food or drink involved. Although some partially useful compounds have been found for combating "1080" toxicosis, it must be remembered that if a lethal dose is absorbed into the blood-stream, the outcome will doubtless be fatal.

Under certain conditions "1080" may possibly be absorbed through the unbroken skin. It is, of course, easily absorbed through cuts and abrasions and is poisonous if it should enter the body in this manner. Proper protective measures should always be observed in handling "1080" as such, or poison baits containing it.

Sodium monofluoroacetate is registered for use only by professional pest control personnel including those employed by Federal, State or local government agencies.

THALLIUM (Thallous-Sulfate Tl_2SO_4)

Thallium was discovered by Crookes in 1861 through its characteristic green line in the spectrum when examined in an emission spectroscope.

It is obtained as a by-product in the purification of cadmium and has also been recovered from sludge occurring in the synthesis of sulphuric acid from iron pyrites.

The use of Thallium as a lethal agent for rodent control apparently originated about 1920 when a German company introduced a proprietory rat poison containing Thallium as a toxic principle.6/ In July 1924, samples of poison grain and rat baits were obtained by the Bureau of Biological Survey from the original German producer for study in this country. Preliminary examination showed that these products were toxic to wild and white rats and stimulated investigation of the toxicological properties of Thallium salts when administered to laboratory rats and rabbits. Following these laboratory investigations, Thallium compounds were introduced for control of rodents, particularly prairie dogs and ground squirrels that refused to take strychnine baits. Arrangements were made at this time for domestic supplies from American sources, and operational control programs with this material developed from this point.

PHYSICAL PROPERTIES:

Thallium is related to Gallium and Indium and forms monovalent and trivalent salts. Only the thallous compounds have been extensively studied, principally the acetate and sulfate, chiefly because they are more stable than thallic compounds.

Thallous sulfate is a stable compound having limited solubility in water and slight odor and taste, and this form has been the principal compound used as a lethal agent for vertebrate pest control.

PHYSIOLOGICAL ACTION:

The physiological action of Thallium salts somewhat resembles those of lead, although Thallium is a more treacherous material from several standpoints since lower doses are required to produce acute toxicity and antidotal procedures have not been demonstrated to be of value in preventing death after the ingestion of lethal quantities.

Thallous salts are excreted slowly in the urine with an initial appearance occurring about 2 hours after oral ingestion. It is retained in all organs of the body with the highest concentration occurring in the liver. As with "1080" there is a considerable latent period between the time of ingestion and the appearance of symptoms, which probably accounts for its excellent rodenticidal properties.

Allopecia (loss of hair) is a distinctive symptom of chronic Thallium poisoning but since considerable time is necessary for this to take place, it is not seen in acute cases where the victim may die in a period extending from a few hours to several days.

Symptoms of Thallium poisoning develop slowly in rodents which have ingested baits containing it and death usually occurs the second to fourth day after ingestion. Thallium salts are readily absorbed from the gastro-intentinal tract as well as from the intact skin.

With continued administration of small amounts, Thallium compound symptoms may appear in about a week and death may occur as long as 3 or 4 weeks later. In cases of chronic poisoning a thin, blue line "lead line" may appear on the margins of the gums. In cases of human thallicosis, symptoms appearing in the first 24 hours consist of tingling and pain in the hands and feet, severe seizures of abdominal pain and vomiting. This is followed by weakness of the extremities, stomatitis and convulsions. Marked delirium usually precedes coma and death by respiratory failure. Often there is a rise in body temperature, 24 to 48 hours prior to death, together with signs of pulmonary edema and bronchial pneumonia. If the course of the poisoning extends over a considerable period, degenerative changes take place in most of the endocrine glands and calcium metabolism is markedly altered, producing rickets.

EXPERIENCE AND LIMITATIONS:

Thallium Sulfate has proven to be an excellent rodent and predatory animal poison, due primarily to its ready acceptability to most species. For field rodent control, a concentration of Thallium Sulfate of 1½% is usually employed. It is ordinarily applied in water solution to steam-crushed whole oats which are then air dried and exposed for field rodent control.

Thallium has also proved to be an excellent commensal rodent poison under certain conditions. Thallous sulfate has been used to prepare lethal stations for coyote control by dusting the powdered chemical into slits cut about one inch apart over the surface of a freshly butchered horse, sheep or burro. The chemical is then massaged into the meat with a pointed stick, at the rate of about 1 ounce per 100 lbs. of meat. Uneaten portions of such stations are disposed of by deep burial at the time of their removal.

Although Thallium baits have been very successful in controlling rodents and predator infestations, its almost universal toxicity to all birds and animals may give rise to troublesome primary and secondary poisoning of desirable species.

Because of its absorption through the intact skin, precautions must constantly be observed by personnel preparing or exposing Thallium-containing baits, since it constitutes probably the most hazardous lethal agent that is employed in vertebrate control programs.

ZINC PHOSPHIDE (Zn_3P_2)

Zinc phosphide appears to have been first synthesized by Marggraf in 1740.[7] The product commercially available today is a finely divided, dense powder, having a black or grayish-black metallic appearance which possesses a definite phosphorus odor and is of about 94% purity. The pure compound contains 75.99% zinc and 24.01% phosphorus.

PHYSICAL PROPERTIES:

This chemical is quite stable when dry but should be kept in hermetically sealed containers to avoid slow hydrolysis brought about by contact with atmospheric moisture. It is insoluble in water and alcohol. It is soluble in dilute hydrochloric acid and sulfuric acid with the evolution of highly flammable phosphine. Zinc phosphide reacts violently in concentrated sulfuric or nitric acid and when mixed with other oxidizing agents.

PHYSIOLOGICAL ACTION:

The toxicity of this compound was examined from time to time with a view to substituting it for phosphorus in clinical experimentation. When zinc phosphide comes into contact with dilute acids such as occurs in the stomach, phosphine (Ph_3) is released and this substance probably dominates the toxicological picture from that point. In the main, rats usually succumb overnight from the ingestion of lethal baits with terminal symptoms of convulsions, paralysis, coma and death from asphyxia. Occasionally, death may be prolonged for several days, in which case, the course of intoxication follows that observed in poisonings with yellow phosphorus in which the liver is heavily damaged.

Prolonged exposure to phosphine as sometimes occurs in industrial operations can also produce the ordinary phenomena of chronic phosphorus poisoning. To this extent, zinc phosphide may be considered to possess some characteristics of accumulative toxic materials.

Although some experimentation was conducted with samples of zinc phosphide of varying purity in the early 1930's, extensive use of this material for vertebrate pest control in the United States did not occur until about 1942-1943 when, due to the war, strychnine supplies became uncertain and it was necessary to develop an alternate control material which was available in this country for field rodent control.

Since zinc phosphide decomposes in the presence of moisture, it was applied suspended in mineral oil or petroleum jelly to steam-crushed whole oats. The concentration employed for field rodent control varies from 1-2% with the lower concentration usually being employed.

Zinc phosphide coated grains deteriorate very little over considerable periods if they are kept dry. In the field when exposed to rains, baits will lose approximately one-half their toxicity in 12-24 hours and most of their lethal characteristics in two or three days. Field rodent baits containing this compound have been reasonably successful and can be prepared at a minimum cost, since the chemical itself is relatively inexpensive.

EXPERIENCE AND LIMITATIONS:

Zinc phosphide baits at a concentration of about 1% have been successfully employed for commensal rodent control by incorporating it into materials such as fresh ground beef, ground bacon, canned dog food, dried dog food and fresh ground or canned fish. Sometimes the powdered chemical is merely sprinkled over lettuce, cubed vegetables or fruits and exposed for rat control.

Although zinc phosphide baits have a strong, pungent, phosphorus-like odor, this characteristic seems to attract rodents, particularly rats, and apparently makes the bait unattractive to some of the other animals. However, carelessly exposed grain baits have proven to be lethal to domestic poultry. Since this compound is highly toxic to all forms, appropriate care must be employed in its use for the control of commensal and other rodents.

CYANIDE (Compounds Yielding HCN on Hydrolysis)

The glycoside amygdalin found in many plants, particularly in the seeds of cherry, almond and peach releases hydrocyanic acid when ingested. One gram of cherry kernels has been estimated to yield 1.7 mg. of HCN. The Ancient Egyptians are said to have prepared extracts from peach seed for use as a poison and the Romans employed such extracts for suicidal purposes.[3/] Although HCN is often used for rodent control as a fumigant, the compounds employed as ingested lethal agents are sodium or potassium cyanide (NaCN and KCN) which releases HCN in the presence of water. Thus the toxicology of the poisonous cyanides is largely that of hydrocyanic acid.

PHYSICAL PROPERTIES:

Sodium cyanide is commercially available as a coarse white powder of 95-98% purity. It is somewhat deliquescent in damp air and emits a slight odor of HCN. It is odorless when perfectly dry. It melts at 563°C. and decomposes in aqueous solution yielding HCN. Potassium cyanide has physical properties similar to that of the sodium compound but is sometimes employed when a finer powder is desired for certain purposes.

PHYSIOLOGICAL ACTION:

Hydrocyanic (prussic) acid is the most rapidly acting lethal agent used for rodent or predator control. It produces death with asphyxial symptoms by hindering the oxidative processes of the tissues, and since it also interferes with most catalytic reactions, HCN is classed as a general protoplasmic poison. In general, compounds containing the CN radical are toxic only if they can liberate HCN. When large doses are administered, the animal may fall within 10 seconds and die in convulsions in from 2-5 minutes. With smaller doses, in the human, the symptoms are mental dimness, headache, palpitation, labored breathing, unconsciousness, violent convulsions and death as late as 10 hours after ingestion. Treatment depends upon prompt diagnosis and the administration of a nitrite such as the inhalation of amylnitrite to change a portion of the hemoglobin to methemoglobin, which combines with the HCN in the blood-stream to form cyanhemoglobin, a non-toxic compound.

EXPERIENCE AND LIMITATIONS:

Use of sodium or potassium cyanide as an ingested poison in vertebrate control is largely limited to the propulsion of sodium cyanide into the mouth of a predatory animal by means of the coyote getter.

Initial experimentation two years ago, with 5 grain capsules of potassium cyanide imbedded in small squares of seal blubber or lard-sugar bait balls for wolf control in Alaska were promising but no further work has been done. The cyanide capsule baits were prepared and frozen and kept in this state by exposing them in the low winter temperatures prevailing in the interior of Alaska. Baits remaining uneaten were self-destroying, in that the spring thaw allowed moisture to destroy the gelatin capsule and react with the KCN leaving an innocuous residue.

The inorganic cyanides have been very successful in taking coyotes, as the active ingredients of the coyote-getter device, but their use in baits except under constant frozen conditions is prevented by their lability in the presence of moisture.

RED SQUILL (Urginea maritima)

Red Squill, often referred to as the sea onion, is a plant belonging to the lily family and is a native to countries bordering on the Mediterranean Sea. The dried and ground bulbs, as well as extracts of this plant, have been employed since ancient times in the Mediterranean area to combat rats.[8/] It is still used today where available for this purpose.

PHYSICAL PROPERTIES:

Red Squill powders and extracts are employed for rat control, primarily the Norway rat, as the powdered crude drug or resins obtained through the process of ethyl alcoholic extraction of dried and ground red squill bulbs.[9/]

The active "rat killing" principals are glycosides of which one "Scilliroside" ($C_{32}H_{46}O_{12}$) has been obtained in crystalline form. This material has a toxicity, LD-50%, for male rats of 0.7 mg/kg.[10/]

Red Squill bulbs, powders and extracts deteriorate in rat killing ability when subjected to temperatures in excess of 80°C. or if this temperature is maintained longer than 24 hours. The powder slowly loses toxicity when it remains in contact with the air and exhibits only about one-half of its original potency when stored for 4 years under ordinary warehouse conditions. The toxicity is retained when kept in hermetically sealed containers.

PHYSIOLOGICAL ACTION:

In addition to rat killing properties, brought about by its action on the central nervous system, red squill and its extractive products have an action on the heart similar to that of digitalis. Red Squill baits are highly emetic and distasteful to most animals except the rat, which shows little aversion to them. After having consumed the red squill bait, the rat is unable to get rid of it through emesis since this animal is unable to vomit. Post-mortem examination shows pronounced irritation of the upper digestive tract, but not extensive enough to prove fatal.

EXPERIENCE AND LIMITATIONS:

Red Squill, when presented in attractive baits, usually those containing 50% fresh meat, has given excellent control of Norway rats. Squill baits are not taken sufficiently well by house mice or roof rats to be of value for control of these species. If a sub-lethal dose is taken, red squill creates an aversion to further feeding on baits containing it, which persists for a period of four to six weeks.

Because of the troubled situation in Algeria, the principal source of satisfactorily toxic red squill, supplies have been meager and this product has not been generally available for use. Owing to the necessity for standardizing red squill products and extracts by bio-assay techniques, which are slow and expensive, the list of processors has dwindled to only one in this country. If and when the situation normalized in Algeria, processing of red squill on a large scale may again become attractive, as the demand for this product has materially increased during the past five years.

ANTU Alphanaphtylthiourea (1-(1-Napthyl)-2-thiourea) ($C_{11}H_{10}N_2S$)

ANTU is the code designation for the chemical alphanaphthylthiourea. This substance was discovered to be a useful Norway rat poison by Dr. Curt P. Richter, Johns Hopkins Hospital, Baltimore, Maryland, in 1942 while he was working under a grant of funds from the Committee on Medical Research of the Office of Scientific Research and Development, during World War II.[11/]

PHYSICAL PROPERTIES:

ANTU is a light gray powder, quite insoluble in water and in many organic solvents. It is stable to ordinary heat but will melt at about 180°C. It has no odor, but its taste varies with individuals - many people claim that it is entirely tasteless, while others find it intensely bitter. There is no known antidote for this poison, and treatment is limited to the use of emetics to remove the toxic agent and cathartics to eliminate it.

PHYSIOLOGICAL ACTION:

In Norway rats, ANTU causes death by changing the permeability of the blood vessels in the thoracic area, and the animal dies from drowning in its own body fluids, which accumulate in the pleural cavity around the lungs.

It is much more toxic to Norway rats than to the black, Alexandrine, or frugivorus forms. Even young Norway rats are more resistant to it than are adults. A small sub-lethal dose will cause the development of a tolerance to future quantities. This tolerance is very marked for several days but is lost after about two weeks. Rats that have survived this poison will refuse for several weeks to eat baits containing it.

This poison is dangerous to dogs as well as to rats, and must be used cautiously when pets are roaming freely in the areas where treated baits are to be exposed. It is not highly toxic to monkeys, and presumably that would hold true of man. Diet has a great deal to do with the susceptibility of an animal to the poison - carnivores, as a group, seem to be more susceptible than are herbivorous species.

EXPERIENCE AND LIMITATIONS:

ANTU has been fairly successful in controlling Norway rats when mixed with attractive food baits at a concentration of 1%, or dusted over the surface of water upon which it forms a floating film.

The disadvantages consist chiefly of the hazard of ANTU baits to dogs and the fact that an initial sub-lethal dose quickly produces a tolerance in rats, with the result that increased amounts of this compound are necessary for lethal results.

ANTICOAGULANTS

At present there are five anticoagulant compounds available for commensal rodent control. Two of these are 3-substituted-4-hydroxy-coumarin derivatives and three are 2-substituted-1, 3-indandiones. Only one compound in each group has a common name; these are warfarin, a 4-hydroxycoumarin derivative and diphacinone, a 1, 3-indandione derivative.

All five are listed below in the order of their development.

	Common Name	Composition	Chemical Name
1.	Warfarin	($C_{19}H_{16}O_4$)	3-(alpha-acetonylbenzyl)-4-hydroxycoumarin
2.	None	($C_{14}H_{14}O_3$)	2-pivalyl-1,3-indandione
3.	None	($C_{17}H_{14}O_5$)	3-(alpha-acetonylfurfuryl)-4-hydroxycoumarin
4.	Diphacinone	($C_{23}H_{16}O_3$)	2-diphenylacetyl-1,3-indandione
5.	None	$(C_{14}H_{14}O_3)_2$ Ca	2-isovaleryl-1,3-indandione calcium salt

In April 1948, J. A. O'Connor described the first successful use of an anticoagulant compound, dicoumarin, for controlling rats under field conditions. The use of anticoagulant chemicals as rodenticides introduced a new principle into control procedures - the ingestion of successive doses by multiple feeding on baits containing such low concentrations of the active ingredient that from a practical standpoint, "bait shyness" does not develop in rodent populations. These types of rodenticides produce their effects slowly so that the result appears to be in the nature of a fatal hemorrhagic disease rather than one of an acute poisoning.

Warfarin was introduced in the United States in 1950 and established the multiple feeding technique as a practical commensal rodent control measure.[12/]

PHYSICAL PROPERTIES:

All of the anticoagulants listed above are quite stable compounds and their sodium salts are soluble enough in water to allow their use as lethal water baits.

PHYSIOLOGICAL ACTION:

The principal action of these anticoagulant compounds in the body is to prevent the formation in the liver of prothrombin, which is a necessary element in the complicated process of blood clotting. Since the disappearance of prothrombin from normal blood takes place slowly, it is usually necessary to maintain the anticoagulant block for a period of days in order to increase the clotting time of the blood sufficiently to sustain prolonged internal or external hemorrhage. The hypoprothrombinemic action of the anticoagulants is counteracted by massive doses of Vitamin K_1 and by transfusion with whole blood.

EXPERIENCE AND LIMITATIONS:

The anticoagulants have been extremely successful in controlling commensal rodents when applied by professional pest control operators and by the public. Only minor secondary poisoning instances have been encountered and most of these involved cats. Primary poisoning of pets and domestic animals is a rare occurrence, since birds and poultry are quite resistant to the action of these chemicals and the cereal baits employed are not attractive to dogs and cats. The anticoagulant rodenticides differ with respect to activity and for this reason the cereal bait concentration used varies from 0.005% to 0.05% depending upon the compound selected. When each anticoagulant was field tested at the recommended concentration, satisfactory control resulted.

TRACKING POWDERS

The use of "tracking powders" containing highly toxic substances as a means of commensal rodent control is not new. Powders or dusts containing various toxicants, irritants, or other chemicals through which rats and mice traveled, have been observed in the past to elicit various biological responses. Only recently, however, has it become apparent that the tracking powder technique can be used to introduce, through ingestion as a result of the act of grooming, materials that are refused in foods or which produce "bait shyness" when present in baits that are consumed in sub-lethal quantities.

The urge of the commensal, and some of the other rodents to groom themselves, i.e., the licking of foreign substances from the pelage, tail and feet, is apparently not discouraged by the taste or effects of materials encountered. This has been clearly demonstrated in experiments where rats and mice have continued to groom themselves after repeated exposure to powders containing drugs or chemicals that are not acceptable to them when offered in a bait. Thus, it seems that many animals are not able to relate the biological responses that are produced by the ingestion of toxic compounds with the act of grooming through which they were acquired.

ARSENIC TRIOXIDE (AS_2O_3)

Arsenic compounds have been used since it was first recognized as an entity in the 13th Century as an instrument of criminal poisoning and to combat vermin. For the latter purpose, it is sometimes employed in food baits at a concentration of 1-3% and as a poisoned water bait but with much less efficiency than when exposed in the form of a "tracking powder". Arsenic can cause both acute and chronic poisoning. Acute intoxication brings on vomiting, abdominal pain, shock, convulsions, coma and death. The chronic effects are fatigue, dermatitis, paralysis, visual disturbances, degeneration of the liver and kidneys, and "garlic breath".

Arsenic "tracking powders" have given excellent commensal rodent control in situations where its exposure did not constitute a hazard to other life. Its use in general is limited to placement in burrows.

ENDRIN (1,2,3,4,-10, 10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo,endo-5, 8-dimethanonaphthalene)

This highly toxic chlorinated compound is widely used as an insecticide. During recent years orchardists have used it to remove field mice by applying directly on the orchard floor at about 2 lbs. per acre.

Endrin appears to be extremely toxic to most vertebrates, causing death through effects on the central nervous system. Thus, an orchard treated with this amount of endrin is a hazard to domestic pets, livestock and desirable wildlife, as well as to the personnel making the application.

MISCELLANEOUS COMPOUNDS

ANTU, anticoagulants and red squill have been successfully incorporated into "tracking dusts". The anticoagulants and red squill present little hazard when properly used as lethal tracking agents and have removed infestations of rats and mice that resisted other measures. The amount of labor involved in applying "tracking powders" materially increases the cost of a control operation, and because of this, "tracking powders" are used principally as a "clean-up" procedure.

FUMIGANTS

Fumigants are used in field rodent control as "clean-up" measures to remove the few individuals remaining after the application of lethal baits. Its utility is confined to burrowing rodents such as prairie dogs, ground squirrels, rats, etc., and the material is applied directly into a burrow system by blocking all exits with plugs of earth. Effectiveness of fumigants employed in this manner depends upon the ability of the substance used to produce a toxic concentration in the atmosphere within the tunnels occupied by the rodents. Many factors influence the functioning of fumigants, such as soil composition which may enhance adsorption of the toxicant and lower its effective concentration in the atmosphere of the burrow; variation in moisture content of the soils may exert a similar adverse effect, and cracks in the soil may allow the lethal gas to escape. Application of fumigants to individual burrows involves considerable labor and time which limit the feasibility of the method to "clean-up" problems.

CALCIUM CYANIDE ($CaCN_2$)

Calcium cyanide flakes or dust have been used for many years as a fumigant for the control of burrowing rodents. The flakes are inserted into the burrow entrance with a large spoon, using 1 to 2 ounces per placement. The dust is pumped into the burrow with a dust foot pump.

Both physical forms of this compound are stable compounds when kept dry and in hermetically sealed containers. In the presence of moisture HCN is released into the atmosphere of the burrow system and is subsequently inhaled by the rodents.

This procedure is generally successful and owing to the distinct odor of cyanide presents little hazard to the operator. The fact that calcium cyanide decomposes in the presence of moisture, as well as its placement underground, renders it relatively non-hazardous to domestic animals and desirable wildlife.

CARBON DISULFIDE (CS_2)

This compound has been used as a burrow fumigant for many years by soaking a waste ball in CS_2, rolling it down the burrow and igniting it by throwing a lighted match into the hole. Another and usually more effective method of application is to insert it into the burrow by means of a hose attached to a pump. In both cases, the burrow is plugged with earth to contain the gas.

PHYSICAL PROPERTIES:

Carbon disulfide is a volatile and flammable liquid boiling at 46°C., has a flash point of -25°C. and an ignition point under 200°C.

PHYSIOLOGICAL ACTION:

Carbon disulfide resembles the chlorinated methanes in its effects. It has about the same acute toxicity as chloroform and produces similar symptoms, including vomiting, weakness, convulsions and unconsciousness. Poisoning usually occurs from inhalation, and daily exposure should not exceed 20 ppm. in the inspired air. Chronic poisoning occurs in industry; and the symptoms include psychic disturbances from irritability to mania; tremors; and auditory and visual disturbances. The latter may result in blindness.

EXPERIENCE AND LIMITATIONS:

This compound is usually successful in controlling burrowing rodents but is rather expensive for extensive use. Precautions must be observed by the operator to avoid injury from the health and fire hazard which is inherent in this fumigant.

PYROTECHNIC (GAS) CARTRIDGES

This item was developed by the Bureau of Biological Survey and is currently produced by the Pocatello Supply Depot of the Fish and Wildlife Service, Pocatello, Idaho. It consists of a cardboard cylinder packed with charcoal and an oxidizing agent in such proportion that combustion is not complete, with the result that carbon monoxide is produced.

Ignition is by means of a fuse, and ease of application is one of its outstanding characteristics. These cartridges keep well under ordinary warehouse conditions and are easily transported. The effects of carbon monoxide poisoning are well known, and when convenient this material can be used by merely extending a hose from an automobile exhaust into a rodent burrow.

PHYSIOLOGICAL ACTION:

Carbon monoxide (CO) is a poisonous gas producing headache, dizziness, nausea, collapse, unconsciousness and death. Two hundred ppm. in inspired air may produce symptoms of poisoning in a few hours, and 1000 ppm. can cause unconsciousness in one hour and death in four hours.

EXPERIENCE AND LIMITATIONS:

These "gas cartridges" have given fairly satisfactory results in the control of burrowing rodents but are used mostly for the control of woodchucks in the eastern United States. They present little in the way of hazards to operating personnel or domestic animals and wildlife.

LITERATURE CITED

1. Henry, T. A. 1913. The plant alkaloids. J. and A. Churchill, London.
2. Young, S. P., and E. A. Goldman. 1944. The wolves of North America. The American Wildlife Institute, Washington, D.C.
3. Sollmann, T. S. 1948. A manual of pharmacology. W. B. Saunders Company, Philadelphia, Pa.
4. Pattison, F. L. M., 1959. Toxic aliphatic fluorine compounds. Elsevier Publishing Company. Distributed in the U.S.A. by D. Van Nostrand Company, Inc., New York, N.Y.
5. Chenoweth, M. B. 1950. Monofluoroacetic acid and related compounds. National Research Council, Washington, D.C.
6. Munch, J. C. 1931. The pharmacology of thallium and its use in rodent control. Technical Bulletin No. 238, U.S. Department of Agriculture, Washington, D.C.
7. Wood, G. B., and C. H. LaWall. 1926. United States Dispensatory, Twenty-first Edition. J. B. Lippincott Co. Philadelphia, Pa.
8. Stoll, A. 1937. The cardiac glycosides. The Pharmaceutical Press. London.
9. Crabtree, D. G., J. C. Ward and F. E. Garlaugh. 1942. The fortification of red squill (Urginea maritima) by means of an extract of red squill. Jour. Am. Pharm. Assoc. 31:142.

10. Stoll, A. and J. Renz. 1942. Cardiac glucosides. XXIII. Scilliroside, an active specific rodent poison of red squill. Journ. Am. Pharm. Assoc. 31, 142.

11. Ward, J. C. 1946. Rodent control with 1080, ANTU and other war-developed toxic agents. Am. Jour. Pub. Health. 36 (12) 1427.

12. Crabtree, D. G. 1951. Raticidal potentialities of WARF-42. Soap and Sanitary Chemicals. Feb. 1950.