Aspects of Pesticidal Uses of Carbaryl on Man and the Environment

Environmental Protection Agency

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Preface

Because of the Environmental Protection Agency's statutory mandate to protect the public health and well-being of its citizenry through control of economic poisons, a comprehensive effort intended to insure intensive and regular review of all economic poisons was initiated March 18, 1971 to identify those pesticides which could represent potential unreasonable adverse effects on man and his environment. Since that date, comprehensive "internal reviews" have been conducted by staff of the Office of Pesticide Programs on a number of pesticides. The initial direction for this program was in a memorandum from the Administrator of the Environmental Protection Agency.

This report summarizes data reviewed in a literature search on carbaryl. This report is not intended to correlate data from different sources, nor present opinions on contradictory findings.

The review of carbaryl covers all uses of the pesticide in the United States and should be applicable to future needs in the Agency. The review was researched and prepared by the Criteria and Evaluation Division, Office of Pesticide Programs, EPA.

ACKNOWLEDGMENTS

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SUMMARY

Carbaryl is the common name for the chemical, 1-naphthyl methylcarbamate. It is the active ingredient in insecticides marketed as Sevin®, the registered trademark of Union Carbide Corporation. Union Carbide Corporation is the inventor and sole U.S. producer of carbaryl. The manufacturing plant is located at Institute, West Virginia.

Carbaryl is a synthetic organic chemical belonging to the carbamate group. It is a white crystalline solid, essentially odorless, soluble in polar organic solvents, and of low solubility in water. Carbaryl is formulated for commercial use as wettable powders, dusts, granulars, baits, and liquid suspensions.

The first U.S. registration of carbaryl was issued in 1958 for use on cotton; the first full year of commercial use was 1959. Since that time major uses have developed for insect pest control on forage, vegetables, fruit and nut crops, forests, homes and gardens, poultry, and pets.

The major products containing carbaryl and produced by Union Carbide are Sevin 50W Carbaryl® Insecticide (EPA Reg. No. 1016-41), Sevin Sprayable Carbaryl® Insecticide (EPA Reg. No. 1016-43), Sevimol 4 Carbaryl® Insecticide (EPA Reg. No. 1016-68) and Sevin 4 Oil® Carbaryl Insecticide (EPA Reg. No. 1016-70). Manufacturing concentrates are also available for use by formulators in preparing their own products. By 1973, the U.S. Environmental Protection Agency (EPA) had accepted over 1250 products containing carbaryl, produced by over 240 registrants.

Carbaryl is considered to be the first successful carbamate insecticide to be used on a large scale. It is effective against a large number of common insect pests, including lepidopterous larvae and various species of beetles, grasshoppers, ants, leafhoppers, plant bugs, and scales. It is not effective against phytophagous mites, but it does control certain parasitic arachnids.

In the 1959 - 1963 period, tolerances and registrations were obtained for carbaryl in the U.S. for use on over 80 raw agricultural commodities, and these registrations represent proven effectiveness against approximately 200 pests. In addition to its pesticidal properties, carbaryl is registered for apple thinning. It has not been observed to thin crops other than apples.

The action of carbaryl, similar to the organophosphates, is against acetylcholinesterase enzymes. It exerts mild to moderate cholinesterase inhibition in mammals, but unlike organophosphates, the inhibition caused by carbaryl is spontaneously reversible. The product is a contact and stomach poison but not a fumigant or vapor toxicant. Atropine is antidotal and use of 2-PAM is contraindicated.

Carbaryl displays an acute toxicity less severe than that of DDT or most organophosphates. It is slightly more toxic than malathion as determined by tests with laboratory animals. The acute oral LD_{50} is 500-850 mg/kg for the rat; it is slightly higher for dogs and rabbits. Carbaryl does not readily penetrate mammalian skin as indicated by an acute dermal LD_{50} > 4000 mg/kg for the rat. The inhalation 4 h LC_{50} is > 390 mg/m^3 for the guinea pig, and > 814 mg/m^3 for the dog.

The Advisory Panel on Carcinogenesis in the *Report of the Secretary's Commission on Pesticides and their Relationship to Environmental Health*, DHEW, 1969, using as a basis all published literature on carcinogenicity determined in scientific experiments, assigned carbaryl to a group of chemicals judged "not positive for tumorigenicity."

Reproductive and teratogenic effects in experimental animals have been investigated extensively. High dosages of carbaryl in continuous exposure throughout the critical periods of gestation sometimes resulted in teratogenic response. Results under manufacturing conditions, as well as ingestion of residues on food, suggested little potential hazard to humans.

Available information indicates that carbaryl is a mild cholinesterase inhibitor in man. In laboratory trials, humans ingested carbaryl in daily oral doses of 0.06 and 0.13 mg/kg. Extensive blood chemistry, urinalysis, stool examination, and EEG studies showed no substantive changes clearly attributable to carbaryl.

The health of Union Carbide employees working in production, handling, and shipping areas of the carbaryl manufacturing plant has been monitored since 1960. In the 15 years of commercial production, three employees with typical symptoms of carbamate poisoning were treated as patients' by the Union Carbide Medical Department.

The intoxications were reported as mild by the attending physician and the men recovered promptly and returned to work. Cumulative chemical laboratory profiles taken from the health records of eight men from 1961 to 1973 show no significant changes in observed body chemistry and results of laboratory tests were considered to be within normal ranges. No occupationally related abnormalities have been found in any carbaryl process employees.

A few cases of acute human poisoning from carbaryl use have been reported. A record of cases held by Union Carbide Medical Department indicates that over 12 years only 18 probable poisonings and 52 alleged poisonings.

Data have been collected on the impact of carbaryl on the environment. Applications of carbaryl according to label directions generally were indicated to have minimal and short-lived effects on other nontarget species and the environment. However, carbaryl is selectively toxic to certain organisms such as bees. Temporary population declines of certain of these susceptible nontarget species have been noted. Carbaryl residues, with a half-life of 3 or 4 d, decompose to less toxic products. Carbaryl is not persistent and does not bioaccumulate.

Tests were performed to determine the toxicity of carbaryl to certain wild animals, birds, and fish. The typical acute oral LD_{50} was: mule deer 200-400 mg/kg; mallards > 2129 mg/kg; pheasants > 200 mg/kg; and Canada geese 1700 mg/kg. LC_{50} values for certain freshwater and saltwater fish species at 24 and 96 h generally range from 1-20 ppm.

The toxicological and environmental hazards reviewed in this summary suggest that carbaryl has relatively low environmental hazard.

Chapter I

THE MANUFACTURE AND FORMULATION OF CARBARYL INSECTICIDE

Sevin® is the registered trademark of Union Carbide Corporation under which various formulations of Sevin carbaryl insecticide are marketed. Carbaryl is the common name for the active ingredient 1-naphthyl methylcarbamate.

I.A. Synthesis

Carbaryl is manufactured by the two processes described in I.A.1. and I.A.2.

I.A.1. Tetralin oxidation process: Carbaryl is produced domestically by Union Carbide at one site, Institute, West Virginia. The pesticide is produced by a multistep process employing naphthalene, phosgene, and methylamine as the major raw materials (Lambrech, 1959; 1961). High purity 1-naphthol is produced from naphthalene by the tetralin oxidation route. Phosgene is prepared from chlorine and carbon monoxide. The naphthol and phosgene are reacted in toluene solution to produce naphthyl chloroformate which is then reacted with methylamine to yield 1-naphthyl methylcarbamate which crystallizes and is separated by centrifugation. The synthesis is illustrated by the reaction steps in Figure I.A.

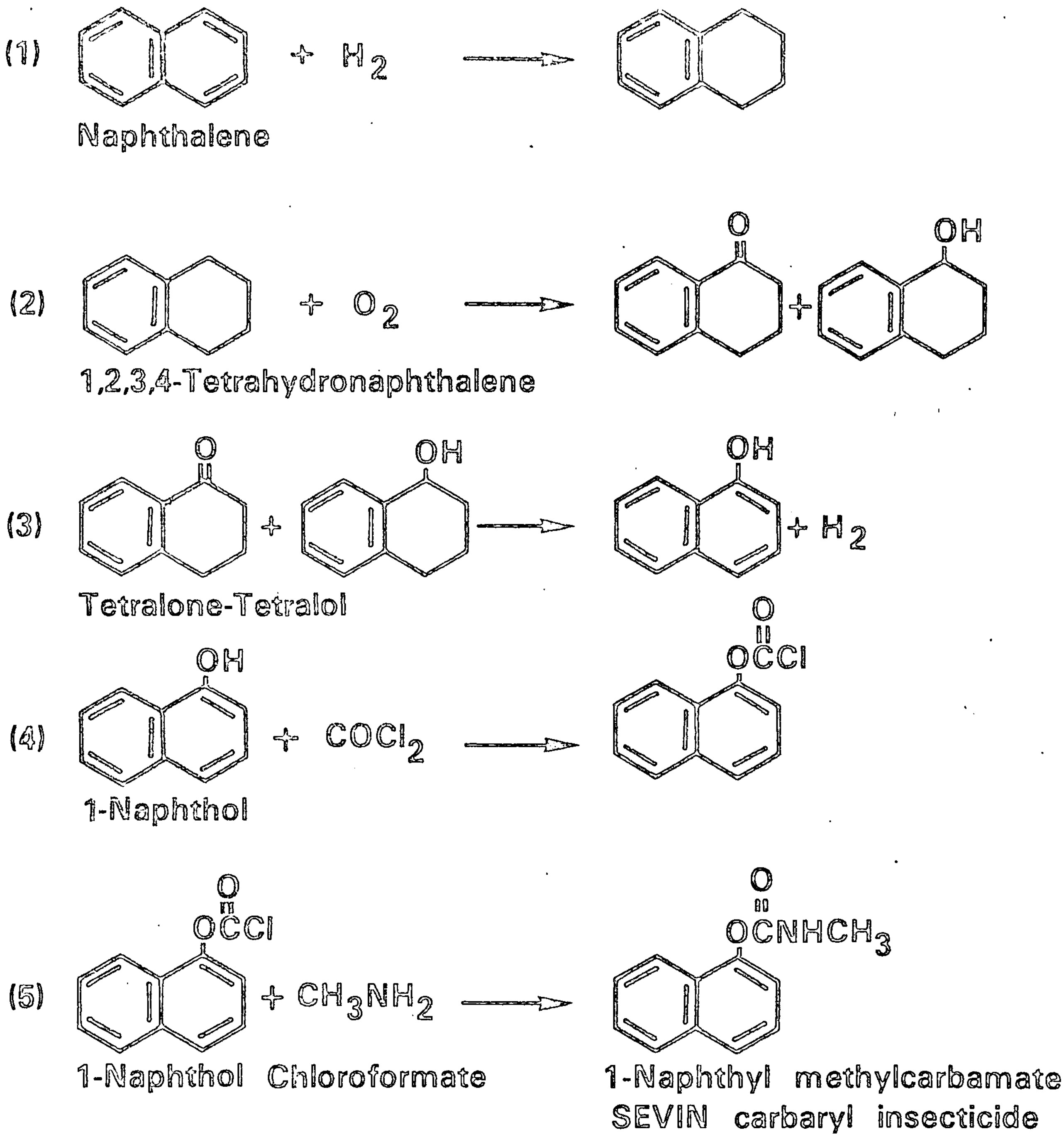

Figure I.A. Reaction steps in Sevin® carbaryl insecticide manufacture
Source: Union Carbide Corporation

The purity of the carbaryl produced by this process is described in Table I.A. American Standards Association Fact Sheet K62.38 (1962) provides properties based on Sevin carbaryl insecticide. The United Nations Food and Agriculture Organization (FAO) Provisional Specification 26/1(S)/6 (1973) established a maximum tolerance of 0.05% for 2-naphthol and 2-naphthyl methylcarbamate.

Table I.A. Typical analysis of technical Sevin® carbaryl insecticide

	Percent by Weight	
Components	Analysis	UCC Specification
Carbaryl	99.4	99.5 + 0.5
1-Naphthol	0.15	0.4 max
Methylamine + methylamine HCl	0.07	0.1 max
Water and other volatiles	0.21	0.5 max
2-Carbaryl	0.01	0.05 max
2-Naphthol	0.01	-
Bis-1-naphthyl carbonate	0.01	-
1-naphthyl 4-dimethylaminobenzoate	0.01	-

Source: Union Carbide Corporation.

Chemical and physical properties of technical Sevin carbaryl insecticide are:

Appearance	White or off-white crystalline solid
Odor	Essentially odorless

Melting point	142°C
Vapor pressure	0.002 mm Hg at 40°C
Crystal density	1.232 g/ml at 20/20°C
Bulk density	35+3 lb/ft^3
Flammability	Cleveland open cup 193°C
Corrosive action	None

Stability:

Stable to heat and light at 70°C

Slowly decomposes at its melting point at 142°C

Hydrolyzes to 1-naphthol rapidly in alkaline solutions

Hydrolyzes slowly in neutral or acidic solutions

Explosiveness of dust: equivalent to or greater than coal dust

Solubility in water: 40 ppm at 30°C

Solubility in organic solvents at 25°C:

N-methyl-2-pyrrolidone:	45 to 50%
Dimethyl formamide:	40 to 45%
Dimethyl sulfoxide:	40 to 45%
Acetone:	20 to 25%
Cyclohexanone:	20 to 25%
Isophorone:	20 to 25%
Dioxane:	15 to 20%
Methyl ethyl ketone:	15 to 20%
Chloroform:	10 to 15%

Methylene:	10 to 15%
Butyl CELLOSOLVE:	5 to 10%
Ethanol:	5 to 10%
Ethyl acetate:	5 to 10%
Nitrobenzene:	5 to 10%
Cyclohexanol:	5 to 10%
ESPESOL-1 (mixed aromatic solvent):	1 to 3%
Toluene:	1 to 3%
Xylene:	1 to 3%
Deodorized kerosene:	< 1%

I.A.2. Sulfonation of naphthalene: An alternate process used by other manufacturers may employ 1-naphthol produced via sulfonation of naphthalene. Examples are Badische Anilin & Soda-Fabrik AG in West Germany (Dicarbam carbaryl) and Makhteshim-Agan in Israel (Ravyon carbaryl). This process is shown in Figure 1.B. Since sulfonation of naphthalene leads to the formation of significant amounts of beta isomer, the final carbaryl product may contain amounts of 2-naphthyl methylcarbamate in excess of 0.05%.

2-Naphthyl methylcarbamate is an undesired impurity in the pesticide chemical. Toxicological concern has been expressed over adverse crop flavor effects allegedly due to its presence in carbaryl. Concern has also been expressed because of the reported cataractogenic property of 2-naphthol (Fitzhugh and Buschke, 1949).

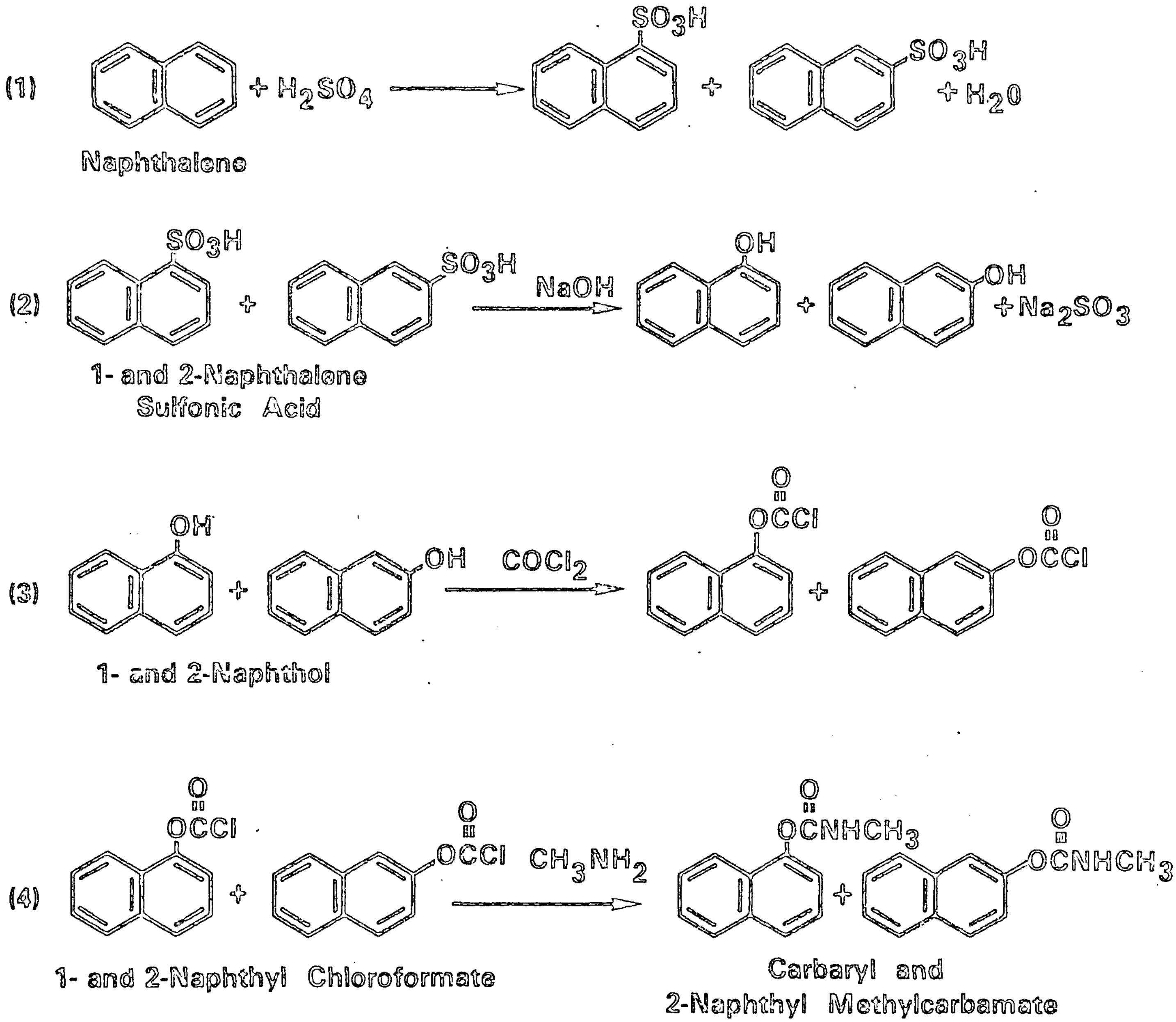

Figure I.B. Alternate carbaryl manufacturing process
Source: Union Carbide Corporation.

Low levels of 2-naphthol formed by the tetralin oxidation process allow production of carbaryl containing a maximum of 0.05% 2-naphthyl methylcarbamate. This contamination level meets the provisional FAO specification permitting a maximum impurity level of 0.05% 2-naphthol and 2-naphthyl methylcarbamate in technical carbaryl.

I.B. Formulations of Sevin carbaryl insecticide

Carbaryl is a hard crystalline solid only slightly soluble in solvents commonly used in pesticide formulation. For this reason, most registered formulations are wettable powders, dusts, baits, and granulars. Liquid suspensions of micronized Sevin carbaryl insecticide are also available. True solutions and emulsions are not common and comprise only a small fraction of available commercial products.

The first testing and early sales of Sevin carbaryl were made with a 50% wettable powder and field-strength dusts formulated from a 50% dust concentrate. These formulations were prepared by hammermilling to a particle size range of 10 - 50 μ and were registered in 1958 and marketed for insect control on vegetables and fruits.

The trend toward low-gallonage sprays in equipment without mechanical agitation created a need for the first Sevin "sprayable" formulations. Some experimental prototypes were wettable powders and oil- or water-based liquid suspensions which contained 30 - 45% carbaryl by weight. All contained technical carbaryl which had been air-milled to a particle size principally in the range of 3 - 10 μ. Through combination of small particle size with appropriate thixotropic and dispersing agents, formulations with satisfactory shelf life, suspension, and resuspension properties were developed.

Sevin sprayable insecticide is an 80% active wettable powder (EPA Reg. No. 1016-43) compatible with most commonly used pesticides and is the carbaryl formulation most widely used in the United States.

Further refinement of air-milled carbaryl formulations has resulted in pourable liquids for low-volume and ultra-low volume (ULV) spraying, which prevent spray droplet evaporation and improve deposit retention.

Research on tank-mix and ready-mix formulations of molasses and carbaryl was initiated in 1967 after discovery (Lincoln et al, 1966) of improved insect control resulting from this combination. The trade name, Sevimol®, was registered for this line of products, the most successful being Sevimol-4 (EPA Reg. No. 1016-68). Sevimol-4 may be used as a ULV spray. When diluted with water, it is compatible with most other pesticide formulations.

Sevin 4 Oil was developed to prevent droplet evaporation under the hot, dry application conditions encountered in grasshopper control. It is a suspension of 4 lb micronized carbaryl/gal in nonphytotoxic oils of low volatility. Sevin 4 Oil was registered (Reg. No. 1016-70) in 1971. It may be applied undiluted or diluted up to 1:1 with oil. It is not compatible with aromatic solvents, water, or other pesticides.

During the 1960's many products containing Sevin carbaryl were developed. These included combinations with other pesticides in dusts, wettable powders, emulsifiable concentrates, liquid suspensions, baits, granulars, and aerosol products. A formulation review was published by Entley et al (1965).

I.B.1. Manufacturing concentrates: Manufacturing concentrates are prepared for formulators and processors who often do not have milling facilities but who need milled formulations for processing and packaging specialty products containing carbaryl. The concentrates are preground to specific particle size with varying inert ingredients to provide flowability for mixing and in some instances, wettability. The manufacturing concentrates are registered for use in manufacturing, formulating, and repackaging only, not for application or resale. Concentrates containing 97.5, 95, 85, 80, and 50% Sevin carbaryl insecticide are registered (EPA Registration No. 1016-73, -77, -74, -76, and -75, respectively). A wide variety of specialty products made from these concentrates includes granulars, baits, wettables, suspensions, solutions, emulsifiable concentrates, and pressurized sprays for agricultural, home and garden, and other specialty uses.

I.B.2. Dusts: Field strength dusts of 1.75 - 20% carbaryl are made by blending a dust base with an appropriate diluent of equivalent particle size to insure product uniformity. The active ingredient is stable in acidic diluents with a water content of less than 5%. Sevin carbaryl dusts made with diluents of pH 8 or greater or a moisture content over 5% are subject to a color change to pink or violet and a subsequent loss of carbaryl. A wide range of acceptable diluents with a product shelf life of more than a year is available. Representative examples are shown in Table I.B. A dust particle size range of 20 - 50 μ provides good crop coverage.

EPA Registration Nos. 1016-40 and 1016-76, respectively, have been assigned to 50 and 80% dust base Sevin carbaryl insecticides. Specifications and specific methods for preparation are considered trade secrets.

Table I.B. Typical diluents used in Sevin carbaryl dust formulations

Trade Name	Type	pH	Producer
Barden Clay	Kaolinite	4.0-5.0	J.M. Huber Corp.
Cab-O-Sil	Synthetic	4.5-6.0	Godfrey L. Cabot, Inc.
Frianite	Diatomite	5.5-6.5	California Industrial Minerals Co.
Glendon Pyrophyllite	Pyrophyllite	6.0-7.0	General Minterals Co.
Hi-Sil 233	Synthetic	6.5-7.5	Pittsburgh Plate Glass
Narvon 1F2	Kaolinite	5.0-5.5	Narvon Mines, Ltd.
Pikes Peak Clay	Montmorillinite	4.5-5.5	General Reduction Co.
Pyrax ABB	Pyrophyllite	6.5-7.0	R.T. Vanderbilt Co.
#29 Pyrophyllite	Pyrophyllite	5.5-6.0	Whittaker, Clark, & Daniels, Inc.
Zeosyl	Synthetic	6.5-7.5	J.M. Huber Corp.

I.B.3. Wettable powders: Sevin carbaryl wettable powders are prepared by blending technical carbaryl with appropriate diluents and surfactants. For wettable powders ranging from 5 - 50% carbaryl and intended for use at high dilution in spray equipment, hammermilling of the ingredient blend and reblending are sufficient. A particle size of 10 - 50 μ is an acceptable standard for such products. For sprayable products containing 75 - 85% carbaryl intended for use in concentrate spray equipment, airmilling is used to achieve a particle size of 3 - 10 μ. Where tank-mix compatibility with other pesticides is desired, a compatibility agent is also required. Dust diluents are selected with the same precautions mentioned for dust formulations in order to provide for adequate shelf life.

Sevin 50W carbaryl insecticide (EPA Registration No. 1016-41) by microscopic count contains, at most, 5% particles smaller than 5 μ, a minimum of 80% particles 10 - 30 μ, and a maximum of 5% particles larger than 30 μ.

Sevin sprayable 85% carbaryl insecticide (EPA Registration No. 1016-42) was developed for use as a wettable powder in equipment designed to handle only emulsifiable concentrates. It is a free-flowing, microfine powder, readily wettable and dispersible in a wide range of hard and soft waters. It can be used in spray equipment varying from knapsack sprayers to high-concentrate, low-volume sprayers. This product is produced by airmilling. The particle size specifications require a minimum number of particles less than 2 μ; 70% in the range of 3 - 10 μ; 25% in the range of 10 - 15 μ; and no particles over 20 μ. This formulation is presently for export sale only. It has exceptionally good shelf life stability and should not be used in combination with most emulsifiable concentrates of other pesticides.

Sevin sprayable carbaryl insecticide (EPA Registration No. 1016-43) is Union Carbide's 80% product, ground in airmills to the same particle size specifications as for Sevin sprayable 85% insecticide. It is compatible with most commonly used emulsifiable concentrates. This formulation performs well in waters of varying degrees of hardness, and will withstand at least 18 months of tropical storage.

I.B.4. Granulars: Granular formulations of carbaryl are made from manufacturing concentrates and a wide variety of inerts. Combinations with fertilizers, other pesticides, and bait attractants are common. Most granulars contain 5 - 10% carbaryl but formulations of up to 20% have been registered.

Most granulars are made by the adhesion technique. A tumbler-type blender, charged with the granular carrier, is sprayed with mineral oil or an equivalent sticker so that in blending all particles become coated. A Sevin carbaryl manufacturing concentrate is added, which upon blending, adheres to the granules. The product is then screened to break up any agglomerates. If water or a solvent-diluted sticker has been used, the granules are dried.

I.B.5. Liquid formulations: Sevimol 4 carbaryl insecticide (EPA Registration No. 1016-68) is a homogenous suspension of airmilled carbaryl in feed-grade molasses and appropriate adjuvants. The light tan liquid has a distinct molasses odor. Carbaryl is present at 40% by weight, or 4 lb active in the 10 lb US gal. Sevimol 4 is nonflammable, noncorrosive, and stable for 2 years at 38°C. When diluted 1:1 with water, Sevimol 4 is compatible with other pesticides; it is not compatible with spray oils such as kerosene.

Sevin 4 Oil carbaryl insecticide (EPA Registration No. 1016-70) is a suspension of airmilled carbaryl in nonphytoxic, low-volatile oil with appropriate thixotropic and surfactant agents. It is an off-white liquid containing 49% by weight carbaryl, or 4 lb/US gal. The product is stable for at least a year. Sevin 4 Oil may be used as a ULV spray by aircraft only. Dilution to 1:1 with kerosene, diesel oil, or No. 2 fuel oil only may be made. Further dilution is not recommended. Other pesticides, aromatic solvents, and water are not compatible with Sevin 4 Oil.

More than 1200 products containing Sevin carbaryl insecticide have been registered by EPA. A product survey shows most are dust formulations, followed by wettables, pressurized sprays, granulars, and suspensions. Most pressurized sprays, over half of the dusts, and about one-half the wettables are formulated with one or more other pesticides. Combinations of Sevin carbaryl with other insecticides, fungicides, and acaricides rank in that order. A total of 34 other pesticides have been combined with Sevin carbaryl according to this survey. The list of other pesticides includes captan, copper, dichlorophen, folpet, malathion, pyrethrins, sulfur and zineb.

I.C. Packaging

Most Union Carbide Sevin carbaryl insecticide products are packed in paper bags, corrugated box-board cartons, and plastic bottles which, according to the label, may be disposed of by burning or burying. Changes of packaging may occur at times depending on available supply.

Sevin 99% technical carbaryl is shipped in 3 - 5 ply, Kraft, 25 kg or 50 lb bags, palletized, and shrink-wrapped as needed. The manufacturing concentrates are shipped in 30 - 50 lb bags or cartons. Sevin 80% dust base carbaryl insecticide is supplied in 50 lb bags. All these products will be reformulated or repackaged and are not intended for application or resale as shipped.

Sevin sprayable carbaryl is packed for consumer use in 50 lb bulk cartons with polyethylene liners or in 10 lb, sift-proof, 2 ply Kraft bags, packed 4 to a 21" x 14" x 13" carton. Sevin 50W is packed in

30 lb bulk bags and in 50 lb baler bags. Each baler bag contains 10, 5 lb bags or 25, 2 lb bags of Sevin 50W.

Sevimol 4 is provided in 1 gal plastic jugs packed 6 per carton, 5 gal plastic jugs packed one per carton, in 53 gal drums, and in bulk. Sevin 4 Oil is packed in 55 gal drums and in bulk.

I.D. Disposal practices

The quick decomposition of Sevin carbaryl insecticide under alkaline conditions facilitates waste disposal. Dilute suspensions of carbaryl are amenable to treatment by biologic disposal systems. Suspensions containing up to 100 mg carbaryl/l, fed to laboratory activated sludge units, were oxidized efficiently without adverse effects on the biologic populations. Similar results have been obtained in a simulated sewage oxidation pond.

For disposing of small amounts of carbaryl suspended in water, caustic treatment in settling tanks is sufficient. For each 5 lb of carbaryl carried into the tank, addition of 2 lb of flake caustic will accomplish complete decomposition. A 24 h treatment will insure a complete reaction. Solid wastes may be buried by landfill. Hydrated lime should be mixed with the carbaryl waste in the fill in the ratio of 1:5.

Empty bags may be burned where open fires are permissible. Exposure to smoke or fumes should be avoided. Incinerators operating at higher temperatures will oxidize carbaryl more completely. Where burning or controlled combustion cannot be safely accomplished, burial of empty bags is preferred.

Literature Cited

American Standards Association, Inc. (ASA). Common name for the pest control chemical 1-naphthyl methylcarbamate carbaryl. American Standards Association, New York. 1962. 2 pp. [Fact Sheet K62.38]

Entley, W.J., D.C. Blue, and H.A. Stansbury, Jr. Techniques used in formulating Sevin. Farm Chem, June 1965. pp. 52-53, 56, 58, 60.

Fitzhugh, O.G., and W.H. Buschke. Production of cataract in rats by beta-tetralol and other derivatives of naphthalene. Arch. Ophthalmol. 41:572-582. 1949.

Food and Agriculture Organization (FAO). Carbaryl technical. FAO Provisional Specification 26/1/(S)7. United Nations, Food and Agriculture Organization, New York. March 8, 1973.

Lambrech, J.A. α-Naphthol bicyclic aryl esters of N-substituted carbamic acids. US Patent No. 2,903,478 (composition). September 8, 1959.

Lambrech, J.A. Method and composition of destroying insects employing 1-naphthyl N-methyl carbamate. US Patent No. 3,009,855 (use). November 21, 1961.

Lincoln, C., G. Dean, J.R. Phillips, E.J. Matthews, and G.S. Nelson. Molasses-insecticide sprays for control of bollworm. Ark. Farm Res. 15(1):4. 1966.

Bibliography

Aly, O.M., and M.A. El-Dib. Chapter 20. Photodecomposition of some carbamate insecticides in aquatic environments. In: S.J. Faust and J.V. Hunter, eds. Organic Compounds in Aquatic Environments (5th Rudolfs Research Conference, Rutgers State University, New Brunswick, New Jersey, July 1969). Marcel Dekker, Inc., New York. 1971. pp. 469-493.

Lamberton, J.G., and R.R. Claeys. Degradation of 1-naphthol in sea water. J. Agric. Food Chem. 18(1):92-99. 1970.

Okada, K., K. Nomura, and S. Yamamoto. Studies on the chemistry of stability of pesticides. Part I. The deterioration of formulated 1-naphthyl-N-methylcarbamate by ultra violet irradiation. Nippon Nogei Kagaku Kaishi (J. Agric. Chem. Soc. Jpn.) 35:739-742. 1961.

CHAPTER II. PHARMACOLOGY, METABOLISM, AND TOXICOLOGY OF CARBARYL

Pharmacologically, carbaryl unlike organophosphate insecticides is a competitive and reversible inhibitor of acetyl cholinesterase. This chapter will discuss animal and plant metabolism; metabolic pathways are described which are similar in plants and animals. Hydrolytic and oxidative reactions which lead to less toxic metabolites and their conjugation and excretion are the dominant metabolic routes.

Toxicologically, carbaryl is both a contact and stomach poison without fumigant action. Insecticidal properties were first described by Haynes et al (1957). Carbaryl has been tested in many insects, other arthropods and species of warm-blooded animals; the degree of toxicity varies widely among different species. In mammals, carbaryl is of moderate peroral toxicity. It penetrates the skin poorly unless formulated with certain solvents or surfactants. Special studies have not indicated involvement in cataract formation, demyelination potential, or potentiation in combination with other pesticides. Carbaryl is a compound of low chronicity in lifetime dietary feeding studies. It has not exhibited carcinogenic or mutagenic properties. High dosages of carbaryl in continuous exposure throughout critical periods of gestation sometimes resulted in teratogenic response. These findings are discussed in further detail in this chapter.

II.A. Pharmacology

The principal pharmacologic effect of carbaryl insecticide in the mammalian system is the reversible inhibition of cholinesterase, specifically acetylcholinesterase. The reversibility of inhibition is so rapid that unless special precautions are taken, measurements of blood cholinesterase of humans and animals exposed to carbaryl are likely to be inaccurate and always in the direction of appearing to be normal. Signs of poisoning include constriction of the pupils, salivation, profuse sweating, epigastric pain and muscular incoordination. Depending on the severity of the case, all methods treating poisoning by organic phosphorous compounds are useful with the exception of 2-PAM and other oximes which are not recommended. Animal studies indicate that use of 2-PAM might be harmful. Administration of antidotes should be restricted to atropine (Hayes, 1963). Considerable detail comparing cholinesterase inhibition by parathion and carbaryl, and the control of symptoms by atropine, is provided by Carpenter et al (1961).

II.B. Metabolism

Metabolism of carbaryl has been thoroughly investigated in both plants and animals. A presentation of the metabolic pathways of carbaryl in plants and animals and the toxicity of metabolites helps explain the toxicologic hazards associated with its use as a pesticide.

II.B.1. Plant metabolism: The dissipation of carbaryl residues from plant surfaces is dependent on the cumulative effects of washing by rainfall, physical abrasion, dilution by plant growth, volatility and by penetration into plant tissues.

Loss from treated surfaces has been found to be accelerated by high relative humidity in laboratory tests (Lyon and Davidson, 1965).

The volatilization half-life of radiolabeled carbaryl on a glass surface at 25°C was reported to be 14 h; however, in a study on leaf surface under outdoor conditions, the half-life was 3 d (Abdel-Wahab et al, 1966). By contrast, in field usage where all the factors regulating dissipation are present, the half-life of carbaryl averages from 3 to 7 d. The washing effect of rain is particularly dramatic in reducing residues and has been measured by bioassay (Wiggins et al, 1970), by residue analysis (Polizu et al, 1971; Williams and Batjer, 1964), and by radiotracer experiments (Wiggins et al, 1970).

Of the insecticide deposited on the plant surface, only a small fraction penetrates into plant tissues, as shown by studies on rice, (Andrawes et al, 1972b; Fukuda and Masuda, 1962; Masuda and Fukuda, 1961), cocoa (Sundaram and Sundaram, 1967), apple (Williams and Batjer, 1964), corn (Andrawes et al, 1972b), bean (Wiggins et al, 1970), wheat (Andrawes et al, 1972b), tomato and potato (Andrawes et al, 1972b), and peanut and alfalfa (Andrawes et al, 1972b). These experiments have demonstrated that small amounts of carbaryl are slowly absorbed by plants. The highest penetration resulted from applications of the insecticide in acetone solutions (Wiggins et al, 1970; Andrawes et al, 1972b). This greater-than-normal absorption is probably a consequence of the dissolution of natural plant waxes which normally inhibit penetration of aqueous formulations of carbaryl. Extensive washoff associated with rain or sprinkler irrigation and the increased phytotoxicity of emulsion concentrates compared with that of wettable powder and dust formulations are further evidence of the low absorption of carbaryl under normal use.

II.B.1.a. Movement of residues within the plant: Inside plant tissues, carbaryl is subjected to complex biochemical reactions which ultimately yield water-soluble metabolites. These residues are relatively immobile, as shown by radiolabeled carbaryl applied to the leaves of cocoa (Sundaram and Sundaram, 1967), tomatoes and wheat (Andrawes et al, 1972b). Translocation within the plant is primarily in an upward direction moving by xylem transport to the site of transpiration. Radiolabeled carbaryl residues have been known to move into the leaves when roots are suspended in an aqueous preparation of carbaryl (Fedorova and Karchik, 1971; Fukuda and Masuda, 1962; Mostafa et al, 1966), or when carbaryl is injected into the stem (Dorough and Wiggins, 1969; Wiggins et al, 1970). Stem injection of bean seedlings resulted in an accumulation of the radioactivity in the epicotyledonous leaves with little movement thereafter to the new leaves. Similarly, injection of carbaryl into the stem of mature plants resulted in localization of the residues in the foliage with only minor quantities translocated to wheat seeds, potato tubers, peanuts, and tomato fruit (Table II.A.).

II.B.1.b. Plant metabolites: The metabolism of carbaryl has been defined in a wide variety of plants by investigators utilizing injection techniques (Abdel-Wahab et al, 1966; Andrawes et al, 1972b; Dorough and Casida, 1964; Dorough and Wiggins, 1969; Kuhr, 1968; Kuhr and Casida, 1967; Mostafa et al, 1966), root uptake (Mostafa et al, 1966); cut stem (Wiggins et al, 1970), and surface application to the leaf (Abdel-Wahab et al, 1966; Andrawes et al, 1972b; Wiggins et al, 1970). Plant species studied have included the foliage of apples (Williams and Batjer, 1964), cocoa (Sundaram and Sundaram, 1967), cotton (Mostafa et al, 1966), peas, corn, pepper, pinto beans (Mumma et al, 1971), tomatoes, potatoes (Andrawes et al, 1972b), rice (Andrawes et al, 1972b; Fukuda and Masuda, 1962), snap beans and wheat (Abdel-Wahab et al, 1966; Andrawes et al, 1972b; Dorough and Wiggins, 1969; Kuhr and Casida, 1967; Wiggins et al, 1970). Metabolism in fruit is defined for apples, beans, tomatoes, and wheat. These studies have shown that only after penetration into the plant does carbaryl undergo biotransformation to its primary metabolites (Figure II.A.), and that the parent compound has a half-life of 1 - 7 d regardless of the method of application.

The first definitive work toward identification of the water-soluble plant metabolites of carbaryl was accomplished by Kuhr and Casida (1967). Bean seedlings were stem-injected with radiolabeled carbaryl, and water extracts of the macerated tissue were subjected to thin-layer chromatography. A series of glycoside conjugates was separated into zones on the chromatograms, then scraped off and enzymatically hydrolyzed with β-glucosidase or gluculase. The primary carbaryl metabolites were released from plant sugars, and it was shown that a single metabolite could be conjugated with different sugar moieties.

Generally only minor amounts of nonconjugated organosoluble compounds are detected in plants and in these studies unchanged carbaryl is the principal compound in the solvent fraction.

From the water layer, the derived aglycone metabolites formed through oxidative or hydrolytic reactions have been shown to uniformly consist of 4-hydroxycarbaryl, 5-hydroxycarbaryl, and 1-naphthyl (hydroxymethyl) carbaryl (also called methylol carbaryl) as major constituents, with 1-naphthol and 5,6-dihydro-5,6-dihydroxycarbaryl present in lesser quantities. More recently, 7-hydroxycarbaryl has been found in bean and alfalfa foliage (Wiggins et al, 1970; Williams, 1961). When the carbaryl is labeled in the carbonly or N-methyl functions, radioactive carbon dioxide or methylamine may be expired from the plant (Kuhr and Casida, 1967).

Table II.A. Translocation of 1-naphthyl-^{14}C carbaryl from foliage to fruit

Plant	Holding conditions	Method of application	Time (d)	Percent of applied dose in fruit
Tomato	Greenhouse	Seven surface treatments	50	0.4
Wheat	Greenhouse	Leaf blade surface	21	0.1
	Greenhouse	Stem injection	21	2.5
Potato	Field	Stem injection	21	0.6
			42	1.4
Peanut	Field	Stem injection	21	0.5

Source: Andrawes et al (1972b).

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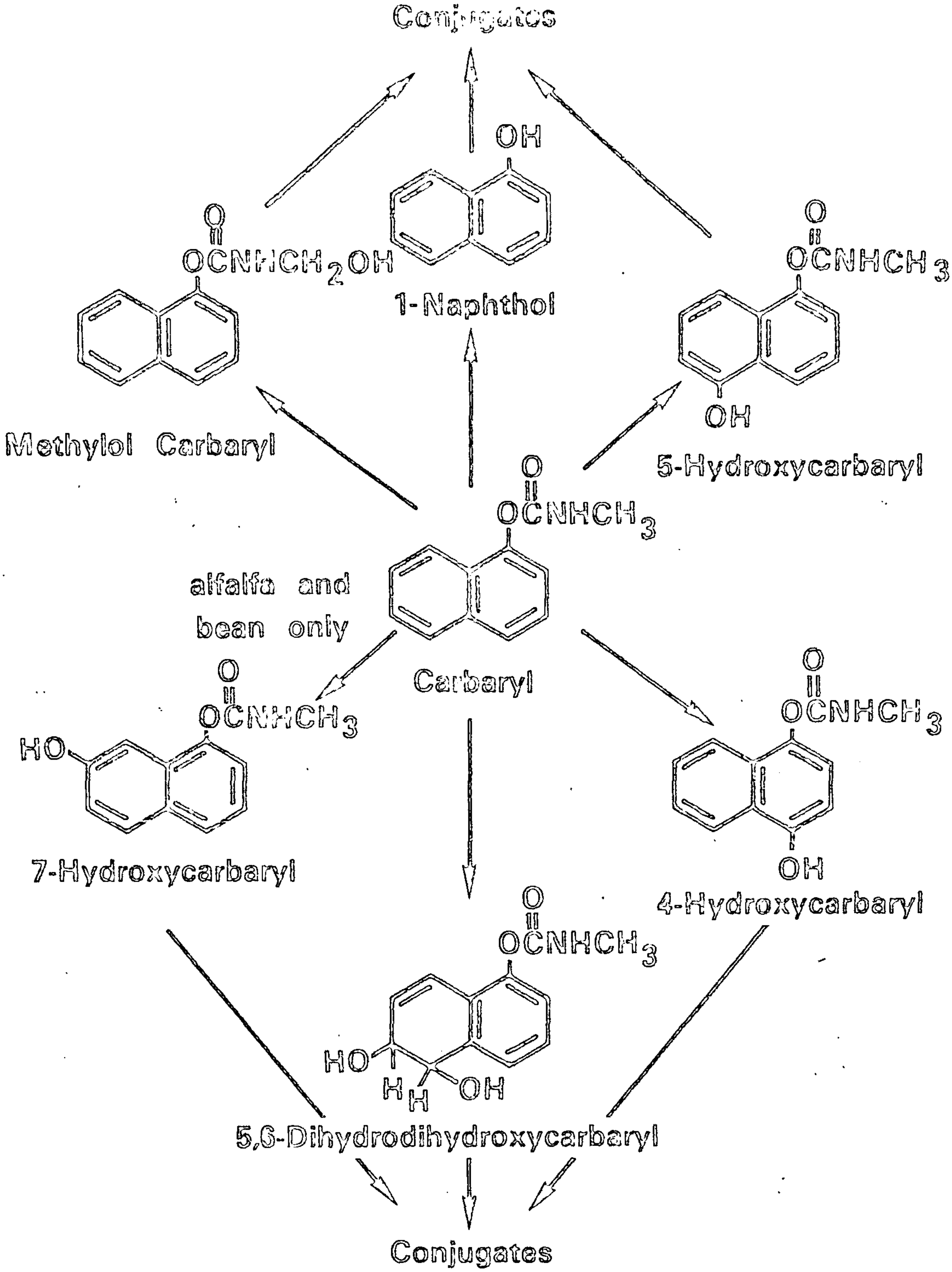

Figure II.A. Metabolism of carbaryl in plants

Source: ANDRAWES et al 1972b.
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II.B.2. Animal metabolism: Metabolism of carbaryl has been studied in animals by in vitro and in vivo techniques.

II.B.2.a. In vitro studies: The metabolism of carbaryl has been demonstrated in preparations from mouse, rabbit, and rat liver (Lucier et al, 1972). Homogenates, microsomes and soluble fractions were compared for activity with and without various cofactors. Optimum activity for carbaryl detoxication was found to reside in the presence of microsomes fortified with $NADPH_2$. Mouse, rabbit, and rat liver fractions metabolized carbaryl in the same manner. Lucier et al (1972) concluded that the in vitro metabolism proceeded as follows.

(1) Hydroxylation of the N-methyl group to yield 1-naphthyl (hydroxymethyl)-carbamate.

(2) Hydroxylation of the 4- and 5-positions of the naphthyl ring to yield 4-hydroxy-1-naphthyl methylcarbamate and 5-hydroxy-1-naphthyl methylcarbamate.

(3) A proposed epoxidation of the 5,6-position of the naphthyl ring with subsequent epoxide opening and proton migration to yield 5,6-dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate.

(4) Hydrolysis of the latter compound to yield 1-hydroxy-5,6-dihydro-5,6-dihydroxynaphthalene.

(5) Hydrolysis of carbaryl and/or the hydroxymethyl-carbaryl to yield 1-naphthol (hydrolytic reactions involved in the metabolism of carbaryl and its carbamate metabolites yield methylcarbamic acid and 1-naphthol).

The in vitro hydroxylated metabolites of carbaryl form conjugates (water-soluble metabolites) consisting of sulfates, glucuronides (Knaak et al, 1967; Leeling and Casida, 1966; Mehendale and Dorough, 1971), and premercapturic acids (Bend et al, 1971). This primary metabolic pathway has been confirmed by other investigators utilizing subcellular enzyme systems from livers of rat (Dorough et al, 1963; Lucier et al, 1972; Matsumura and Ward, 1966; Oonnithan and Casida, 1966, 1968; Palut et al, 1970; Strother, 1970, 1972), chick (Abou-Donia and Menzel, 1968), guinea pig (Knaak et al, 1967), and human (Matsumura and Ward, 1966; Strother, 1970, 1972).

An organ maintenance technique has been developed which, in turn, has provided in vitro metabolic data on livers from different species paralleling those obtained in vivo (Chin et al, 1973; Chin and Sullivan, 1971; Strother, 1972). The metabolic pathway of carbaryl in the liver maintenance techniques has been qualitatively similar to that reported for homogenized liver enzyme systems. In the species tested by the liver maintenance test, the similarity to man was described in descending order as cow, guinea pig, hamster, and mouse; the monkey and dog were dissimilar (Sullivan et al, 1972b). This technique has also been employed with livers from bluegill, catfish, perch, goldfish and kissing gourami (Sullivan et al, 1973), and rat lungs and kidneys (Chin and Sullivan, 1971).

The major site of detoxication of carbaryl is the liver, primarily through hydroxylation, but some metabolism is accomplished extrahepatically by hydrolysis. At least two esterases isolated from human brain have the capacity to hydrolyze carbaryl (Sakai and Matsumura, 1971). Plasma albumins of man, monkey, mouse, horse, guinea pig, goat, rabbit, rat, sheep and swine have shown esterase activity, distinct from that of aliphatic and aromatic esterases and cholinesterase, capable of hydrolyzing carbaryl (Casida and Augustinsson, 1959). Intestinal metabolism of insecticides is also involved in the total detoxication process. In a comparative study with isolated midgut preparations of two insect species and the white mouse, there was appreciable metabolism of carbonyl-^{14}C carbaryl during penetration. Free 1-naphthol and water-soluble metabolites were the principal degradation products found at this site in all three species. After incubation of 1-naphthyl-^{14}C carbaryl or 1-(1-^{14}C) naphthol with everted sacs of rat small intestine, the metabolite 1-(1-^{14}C)-naphthyl glucuronide was isolated from the mucosal and serosal fluids. Water-soluble ^{14}C-metabolites were synthesized more rapidly in the caranial intestine than in mid- or caudal-portions (Pekas, 1971). Radioactive carbaryl, introduced into a culture of human embryonic lung cells, was completely metabolized within 3 d to water-soluble conjugates and organoextractable metabolites (Baron and Locke, 1970). The former consisted of glucuronides of 4-hydroxycarbaryl and 5,6-dihydro-5,6-dihydroxycarbaryl and the latter contained 4-hydroxycarbaryl and 1,4-naphthalenediol.

Insect microsomes form the same metabolites as described for mammalian microsomes (Kuhr, 1969).

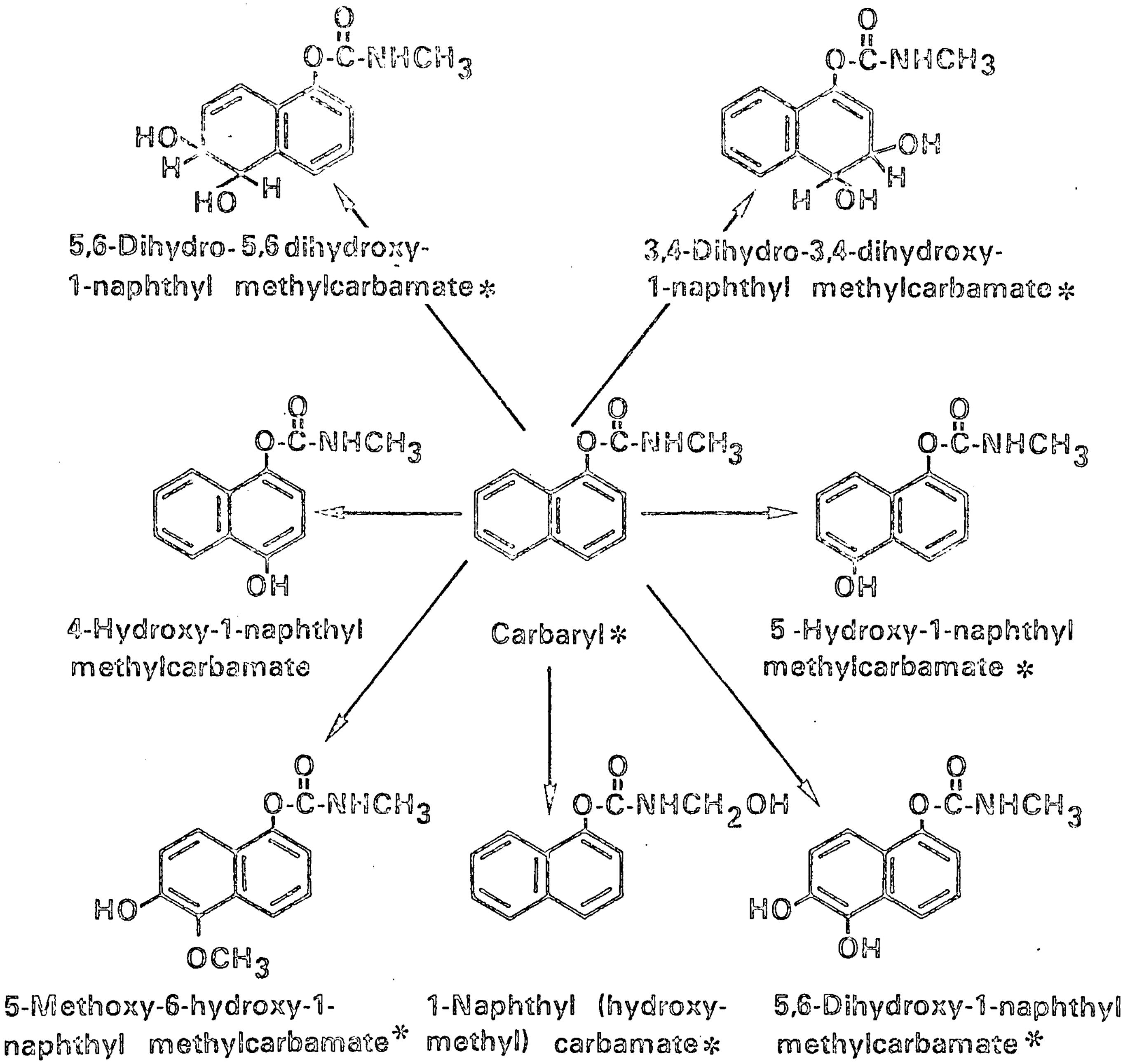
II.B.2.b. In vivo studies: The metabolism of carbaryl has been examined in a variety of mammalian species, including rat and rabbit (Bend et al, 1971; Casper and Pekas, 1971; Chin et al, 1973; Chin and Sullivan, 1971; Dorough et al, 1972; Dorough and Wiggins, 1969; Hassan et al, 1966; Krishna and Casida, 1966; Lucier et al, 1972; Sullivan et al, 1972a), guinea pig (Knaak et al, 1965), dog (Knaak and Sullivan, 1967, Sedov, 1971), goat (Dorough and Casida, 1964; Dorough et al, 1963), pig, monkey (Knaak et al, 1968), cow (Baron, 1968, Baron et al, 1968; Baron et al, 1969; Dorough, 1967, 1970, 1971; Whitehurst et al, 1963) and man (Best and Murray, 1962; Knaak et al, 1965, 1968; Sullivan et al, 1972b). It has also been studied in chicken (Andrawes et al, 1972a; Paulson and Feil, 1969; Paulson et al, 1970), and fish (Ishii and Hashimoto, 1970).

Radiotracer studies have shown that carbaryl is rapidly metabolized to more soluble products and is excreted almost entirely within 24 - 96 h after consumption (Dorough, 1967; Hassan et al, 1966; Knaak and Sullivan, 1967; Knaak et al, 1965, 1968; Krishna and Casida, 1966; Lucier et al, 1972; Paulson and Feil, 1969; Sullivan et al, 1972b). Elimination takes place mainly through the urine, feces and respiratory gas. The only animal examined that excreted < 70% of the dose of naphthyl-^{14}C label in the urine was the dog (Knaak and Sullivan, 1967). Fecal elimination of carbaryl by-products is significant in the dog and appears minor in other species (< 10%).

These results were compared with a published report for the rat. Thirty-five and 11%, respectively, of the naphthyl and N-methyl labels were excreted by the dogs in feces, while 40 and 23%, respectively, of the same two labels were excreted in urine over a 7-d period.

Small amounts of carbaryl and its metabolites are deposited in poultry eggs (Andrawes et al, 1972a; Paulson and Feil, 1969) and in the milk of dairy animals (Baron, 1968; Baron et al, 1968, 1969; Dorough, 1967, 1970, 1971; Dorough and Casida, 1964; Whitehurst et al, 1963). Long-term feeding of 1-naphthyl-^{14}C carbaryl to laying chickens and lactating cows showed only 0.15% and 0.22% of the administered dose appearing in eggs (Andrawes et al, 1972a) and milk (Dorough, 1971), respectively.

A composite metabolic pathway of carbaryl in intact animals (Figure II.B.) has been drawn from the spectrum of metabolites identified in the urine (Table II.B.), milk (Dorough, 1971) and eggs (Andrawes et al, 1972a).



* Hydrolysis products of these carbamates were also formed by certain species.

Figure II.B. Primary metabolites of Carbaryl in animals

Table II.B. Metabolites of carbaryl in various species

Metabolites	Rat[a,b]	Guinea Pig[a]	Dog[a]	Cow Urine	Cow Milk	Chicken Urine	Chicken Eggs	Monkey[a]	Pig[a]	Man[a]
Carbaryl	F			F,C	F,C	C	F			
1-Naphthol	F,G,S	G,S	G	F,C	S	F,G,S	F,G,S	G	S	G,S
1-Naphthyl (hydroxymethyl) carbamate	G			F			F			
1,5-Naphthalenediol						C				
4-Hydroxy-1-naphthyl methylcarbamate	G,S	G,S	G	F		C,S		G	G	G
5-Hydroxy-1-naphthyl methylcarbamate	G,S			F	C	C,S				
5,6-Dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate	G	G	G	F	F			G	G	G
5,6-Dihydro-5,6-dihydroxy-1-naphthol				F,C	F					
3,4-Dihydro-3,4-dihydroxy-1-naphthyl methylcarbamate				F	F					
3,4-Dihydro-3,4-dihydroxy-1-naphthol				F,C						
5,6-Dihydroxy-1-naphthyl methyl-carbamate						C				
5,6-Dihydroxy-1-naphthol						C				
5-Methoxy-6-hydroxy-1-naphthyl methylcarbamate					S					
5-Methoxy-6-hydroxy-1-naphthol					C					

a Neutral metabolites were not characterized; identification was based on chromatographic elution pattern.
b Glutathion conjugates were reported, reference No. 9.
Note: F - free, G - glucuronide, S - sulfate, C - conjugate; the conjugating function was not characterized.
Source: Union Carbide Corporation.

The metabolites shown in Figure II.B. were not formed by all the species studied. Unconjugated metabolites of carbaryl constitute only a small portion of the total radiolabeled metabolites in the urine of animals given 1-naphthyl-^{14}C carbaryl. Free carbaryl, 1-naphthol, 4-hydroxy-1-naphthyl methylcarbamate, 5-hydroxy-1-naphthyl methylcarbamate, 1-naphthyl (hydroxymethyl) carbamate, 5,6-dihydro-5,6-dihydroxy-1-naphthol, 3,4-dihydro-3,4-dihydroxy-1-naphthol, 5,6,-dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate and 3,4-dihydro-3,4-dihydroxy-1-naphthyl methylcarbamate have been detected in unconjugated form.

The major portion of the urinary metabolites consists of the water-soluble sulfate and glucuronide conjugates of the primary transformation products. Some intact conjugates have been separated and identified as such (Knaak et al, 1967; Paulson et al, 1970) after acid hydrolysis (Bend et al, 1971) or after enzyme hydrolysis (Dorough, 1970; Knaak et al, 1967; Leeling and Casida, 1966). Water-soluble metabolites have been routinely subjected to enzyme and acid hydrolysis and the released aglycone identified by comparison with authentic standards. Under such conditions the conjugating function is not characterized. These metabolites have been identified from chicken urine: 1-naphthyl sulfate, 1-naphthyl glucuronide, 4-(methylcarbamoyloxy)-1-naphthyl sulfate, 5-(methylcarbamoyloxy)-1-naphthyl glucuronide and 5-(methylcarbamoyloxy)-1-naphthyl sulfate (Paulson et al, 1970). The authors also used a unique trapping system that permitted detection of a conjugate of 5,6-dihydroxy-1-naphthyl methylcarbamate, a metabolite otherwise unreported. In a study of rat metabolism, the premercapturic acid conjugates S-(3,4-dihydro-3-hydroxy-1-naphthyl methylcarbamate) glutathion and/or S-(5,6-dihydro-6-hydroxy-1-naphthyl methylcarbamate) glutathion were postulated (Bend et al, 1971). This was based on the isolation of S-(4-hydroxy-1-naphthyl)cysteine and/or S-(5-hydroxy-1-naphthyl)cysteine after acid hydrolysis of the original conjugate; in a series of studies (Knaak and Sullivan, 1967; Knaak et al, 1965, 1968), a metabolite was originally identified as 1-naphthyl methyl-imidocarbonate O-glucuronide. Further chemical characterization assigned the structure of 5,6-dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate glucuronide to this metabolite (Sullivan et al, 1972b). The metabolites 1-methoxy-6-hydroxy-1-naphthyl methylcarbamate sulfate and a conjugate of 5-methoxy-1,6-naphthalenediol have been reported only from milk of cows treated with 1-naphthyl-^{14}C carbaryl (Dorough, 1971).

Hydrolytic reactions involved in the metabolism of carbaryl and its carbamate metabolites yield methylcarbamic acid which is further degraded to carbon dioxide and methylamine (Casida, 1963). The major portion of the liberated carbon dioxide is eliminated as a respiratory gas; the remainder is incorporated into normal body products and cycled in natural physiological processes (Baron, 1968; Baron et al, 1969; Paulson and Feil, 1969). Methylamine has been shown to be metabolized in animals to formaldehyde, formic acid and carbon dioxide (Schievelbein and Werle, 1957).

The basic in vivo metabolic reactions (oxidation, hydrolysis and conjugation) have all been verified by in vitro isolated enzyme preparations. The enzymes engaged in the metabolism of carbaryl are widely distributed in animal tissues and fluids. Oxidative mechanisms have been demonstrated in liver preparations (Bend et al, 1971; Chin et al, 1973; Chin and Sullivan, 1971; Dorough and Casida, 1964; Dorough et al, 1963; Leeling and Casida, 1966; Matsumura and Ward, 1966; Oonnithan and Casida, 1966; Palut et al, 1970; Strother, 1972; Sullivan et al, 1973), and hydrolytic reactions have been shown to be operative in the plasma (Casida and Augustinsson, 1959), the intestine (Pekas, 1971, 1972; Pekas and Paulson, 1970), the brain (Sakai and Matsumura, 1971), lung and kidney (Chin and Sullivan, 1971).

Ingested carbaryl readily crosses the gastrointestinal barriers (Casper et al, 1973). Once inside the mammalian body, it is metabolized rapidly and efficiently to compounds of lower toxicity and greater water solubility, which are quickly eliminated.

Results from biochemical studies performed with oxidative microsomal enzymes of various species have shown that interaction of pesticides and drugs or other foreign compounds can occur at this site and level and that carbaryl can participate in such interactions (Cress and Strother, 1972; Puyear and Paulson, 1972; Stevens et al, 1972; and Stitzel et al, 1972). Although the presence of carbaryl can stimulate increased enzyme induction, an insufficiency in enzyme production may still exist and the competition of different xenobiotics for simultaneous chemical alteration by the same enzymes can be demonstrated experimentally. Competitive hydroxylation reactions by mixed pesticide and drug substrates can be produced in vitro with microsomal preparations. The consequences of such "overloading" are reflected if the inactivation system is saturated by an excess of drug, whereby increased toxicity of the pesticides may become apparent (Weiss and Orzel, 1967). If the system is dampened by an unusual quantity of the pesticide, the drug action may be extended (Stevens et al, 1972; Stitzel et al, 1972).

Manifestations of carbaryl interaction with pharmaceuticals have been demonstrated in behavioral experiments. With measurements in activity wheels, rats which received subchronic levels of carbaryl for 14 d showed no effect on their activity but reflected a significant decrease in such activity as measured by wheel revolutions when they were atropinized (Singh, 1973). Rat behavior that had been stimulated by caffeine showed an antagonism with carbaryl treatment and the antagonism was in turn negated with atropine sulfate. Rats trained to exhibit discrete behavior in avoiding electrical shock through food rewards showed alterations in behavior patterns after receiving treatments of carbaryl with pentobarbital, chlorodiozepoxide or impramine (Goldberg and Johnson, 1964). Results from similar studies with carbaryl and other cholinesterase inhibitors suggested that all rats pretreated with atropine sulfate showed changes in behavior (Goldberg et al, 1965). The responses observed from the various drugs on the avoidance reactions were not related to cholinesterase inhibition (Goldberg et al, 1964, 1965). Doses of a known drug extender, SKF525-A, altered both brain cholinesterase levels and behavior responses of rats treated with eserine, but in combination with carbaryl, only slight behavioral effects were noted with no potentiation of cholinesterase inhibition. These interactions are probably related to competition for detoxification mechanisms.

Measurement of the relative barbiturate-induced sleeping times of pesticide-treated and untreated animals offers a means of quantitating interactions of pesticides and drugs. Three such studies with carbaryl have been reported. In the first, mice were orally dosed with 75, 150 or 300 mg/kg of carbaryl, followed 1 h later with an intraperitoneal dose of 100 mg/kg of hexabarbital. Prolonged sleeping times were obtained with all three levels of pesticide, and they were directly correlated with the dose (Stevens et al, 1972; Stitzel et al, 1972). In the second set of experiments, white leghorn cockerels were given capsules containing 0-400 mg/kg of carbaryl daily for 3 - 6 d, and sleeping times were determined 24 h after the last dose by injecting 75 mg/kg of pentobarbital into the breast muscle. The effect was shown to be a decreased sleeping time with doses over 100 mg/kg (Puyear and Paulson, 1972). The third study was performed with Japanese quail. Single oral doses of 100 and 200 mg/kg carbaryl were followed 5 to 48 h later with intramuscular injections of 50 mg/kg sodium pentobarbital. There were no effects on the sleeping times with this regimen (Cecil et al, 1973). The seeming discrepancy of results in these studies was considered by the authors to probably be a reflection of the time differences between the carbaryl and drug treatments during which the increased time intervals permitted detoxification of carbaryl with a nullification of the competitive interaction. The role of carbaryl in the increased metabolism of serotonin and catecholamines is presently one of unknown toxicologic significance. In rats, oral doses of 50 mg/kg and greater caused higher levels of urinary excretion of 3-methoxy-4-hydroxymandelic acid (and its corresponding alcohol) with an augmented turnover of heart norepinephrine (Hassan, 1971). The author proposed that certain imbalances were related to the stress mechanisms, which in turn provoked enhanced amine synthesis or its release from natural storage sites rather than resulting from decreased utilization of the amines (Hassan and Cueto, 1970; Hassan and Santolucito, 1971). The urinary amine composition returned to normal following cessation of dietary carbaryl. Researchers at MIT and Roche Institute of Molecular Biology have found that the brain serotonin level changes in experimental animals following each meal. They demonstrated that the dietary composition alone can radically affect the serotonin content.

Protein-deficient diets of experimental animals result in increased susceptibility to carbaryl (Boyd and Boulanger, 1968; Boyd and Krijnen, 1969). This is a general phenomenon and is more pronounced with certain other pesticides (Krijnen and Boyd, 1970).

The involvement of the anticholinesterase action of carbaryl at the neuromuscular junction has been confirmed in two studies with muscle preparations. An oral dose of carbaryl, 56 mg/kg to rats, affected the electrically stimulated responses of the in situ soleus muscle by increasing tensions during tetanus and decreasing the time of tension development (Santolucito and Whitcomb, 1971).

Santolucito et al (1972) suggested that carbaryl also possibly exerted peripheral sympathomimetic effects on muscles because in vitro duodenal, illial and uteral muscle preparations elicited responses in combination with norepinephrine.

Two pigs from a litter of 13-week-old specific pathogen-free pigs were fed a ration containing the cholinesterase-inhibiting insecticide carbaryl at 150 mg/kg (live weight) daily for 72 and 83 d, respectively. Three pigs from the same litter were fed 150 mg/kg of carbaryl daily for 4 wk and then 300 mg/kg per d, the total feeding period being 46 and 85 d, respectively. Two pigs were maintained on the same basal ration as controls. The clinical syndrome of chronic intoxication was characterized by progressive myasthenia, incoordination, ataxia, intention tremor, and clonic muscular contractions terminating in paraplegia and prostration. The females in each group required a larger total dose of carbaryl to induce paralysis and death than did the males. Lesions were confined to the central nervous system and skeletal muscle. Moderate to severe edema of the myelinated tracts of the cerebellum, brain stem, and upper spinal cord was associated with vascular degenerative changes. The pattern was consistent with a vasogenic type of edema (Smalley et al, 1969).

Swine given single oral doses (1.0 to 2.0 g/kg body weight) of carbaryl developed signs of intense parasympathetic stimulation;

doses > 1.5 gm/kg body weight also were lethal. Signs of intoxication included salivation, muscular tremors, vomiting, central nervous system depression, anorexia, dypsnea, and cyanosis. These signs of poisoning were brought under control by atropine injections; treated swine recovered after a few days of muscular weakness and anorexia.

In swine given carbaryl at dosages of from 150 to 300 mg/kg of body weight daily for 8 to 12 wk, signs of intoxication were a functional neuromuscular dissociation starting with relaxation of suspensory ligaments in the rear legs and incoordination. Soon other manifestations of toxicosis became apparent, primarily progressive ataxia, a string-halt gait in the rear legs, and partial paralysis. Death inevitably occurred if carbaryl feeding was continued. When carbaryl feeding was stopped and drug-induced diuresis was instituted, paresis disappeared and the pigs recovered. When carbaryl was fed during diuretic therapy, paresis disappeared, but reappeared on cessation of drug-induced diuresis, and the pigs died (Smalley, 1970).

Electroencephalograms were determined on rhesus monkeys that had received a daily dose of carbaryl equal to 1000 times the estimated human intake (as determined in the Market Basket Survey) for a continuous period of 18 mo (0.01 to 1.0 mg/kg/day). Although no behavior changes were noted, a reduction of amplitude of certain brain wave forms and an increase of bilateral synchrony between the brain hemispheres were recorded (Santolucito and Morrison, 1971).

II.B.3. Comparison of plant and animal metabolism: Carbaryl is degraded by similar basic metabolic pathways in plants and animals. The principal differences observed are:

1. Conjugation in plants is achieved through the formation of glycosides (Casida and Lykken, 1969; Fukuto, 1972; Kuhr, 1968) whereas in animals, glucuronides, sulfates and premercapturic acids are formed (Dorough, 1970; Fukuto, 1972; Ryan, 1971).
2. The metabolite 7-hydroxycarbaryl has been detected exclusively in certain plants (Wiggins et al, 1970).
3. Animal metabolites that have been described from animals only include: 3,4-dihydro-3,4-dihydroxy-1-naphthyl methylcarbamate; 3,4-hydro-3,4-dihydroxy-1-naphthol; 5,6-dihydroxy-1-naphthyl methylcarbamate; 5,6-dihydroxy-1-naphthyl; 1-methoxy-5-(methylcarbamoyloxy)-2-naphthol; and 5-methoxy-1,6-naphthalenediol (Casida and Lykken, 1969).

Some cross-over experiments have been carried out in which plant metabolites have been fed to rodents. A mixture of radiolabeled water-soluble plant metabolites was orally introduced to rats and the radioactivity was totally eliminated from the body within 96 h (Dorough and Wiggins, 1969). No change in the metabolic profile was found in the excretion products.

Synthesis of β-glucosides of the 4- and 5-hydroxycarbaryls has been accomplished (Cardona and Dorough, 1973). When injected intraperitoneally into mice, it was determined that 4-hydroxycarbaryl was 28 times more toxic than its conjugate, and the toxicity of 5-hydroxycarbaryl was 19 times greater than its corresponding glycoside. Thus, conjugation per se is another step in reducing the inherent toxicity of the carbaryl aglycones.

II.C. Human studies

At least seven studies have been performed with humans exposed to carbaryl. Two studies were performed among industrial workers exposed for prolonged periods, two were performed under laboratory conditions, and three with agricultural workers.

II.C.1. Industrial plant workers: Before construction of the present Union Carbide manufacturing plant, Sevin carbaryl was made in interim facilities. Fifty-nine employees operated these facilities, and during 1959-1960, observations and clinical tests were performed on them (Best and Murray, 1962). These employees worked in production, handling and shipping areas and during the 19 months period, relationships were studied between air concentrations of carbaryl, blood cholinesterase levels, and urinary excretion of 1-naphthol. The most heavily exposed employees excreted the largest quantities of 1-naphthol and occasionally exhibited slightly depressed blood cholinesterase. No secondary anticholinesterase symptoms were detected by the medical personnel in attendance or were reported by the employees at any time.

The present Sevin carbaryl insecticide manufacturing plant located at Institute, West Virginia, began production in 1960. In the 13-year period of nearly continuous production, three employees with typical symptoms of carbamate poisoning were treated as patients by the Union Carbide Medical Department. All three individuals received excessive respiratory exposure to carbaryl dust. The intoxications were reported as mild by the attending physician, and the men recovered promptly and returned to work. Five of the original production operators and three of the Shipping Department employees who have bagged technical carbaryl for a number of years are still working at these jobs. Bagging is an area of high potential exposure. Cumulative clinical laboratory profiles taken from these eight men's Multiphasic Health Screening Records during the period 1961 to 1973 show no significant changes in body chemistry, and the results of the laboratory tests are considered to be within normal ranges. Relative constancy in levels of bilirubin, blood urea nigrogen, and urine specific gravity indicate no harmful changes have occurred in liver and kidney functions and that carbaryl has acted, at most, as a mildly toxic, readily reversible cholinesterase inhibitor. All plant workers receive periodic medical examinations, and no occupation-related abnormalities have been found in any of the Sevin carbaryl process employees.

II.C.2. Controlled experiments: In a controlled experiment, groups of male volunteers ingested Sevin carbaryl insecticide by mouth in daily doses of 0.06 and 0.13 mg/kg for a period of 6 wk (Wills et al, 1968). Extensive blood chemistry, urinalysis, stool examination and EEG studies showed that no substantive changes occurred that were clearly attributable to carbaryl. A slight decrease in the ability of the proximal convoluted tubules to reabsorb amino acids was noted in the group receiving the higher dose but those on the lower dose level displayed an increased resorption compared to the control group. These slight deviations were reversible physiologic changes; they returned to normal values after the exposure to carbaryl was terminated.

Penetration of the skin on various body sites of human volunteers has been tested with a series of pesticides (Feldman and Maibach, 1970; Maibach et al, 1971). Small doses of ^{14}C labeled technical products were dissolved in acetone and applied and ^{14}C was determined in the urine for 5 d after application. There was significant absorption of all compounds tested including carbaryl; the rate and amount varied greatly with the different areas of the body treated. The role of the acetone solvent in modifying penetration is unknown and was an uncontrolled factor in these tests.

II.C.3. Field studies with humans: Two monitoring studies of health hazards resulting from field applications of carbaryl have been independently conducted in both hemispheres. Farmers in Quebec, Canada, applying 0.5 - 8.0 lb of Sevin 50W per 100 gal of water to orchards with air blast sprayers wore respirators and absorbent pads on wrists and foreheads (Hayes, 1971; Jegier, 1964; Wolfe et al, 1967). The residues accumulated on the pads were analyzed and calculated as containing only 0.025% of the total toxic dose (respiratory plus dermal). It was concluded that a very low order of hazard was encountered. A similar experiment performed in orchards of Sydney, Australia, with respirators and pads affixed to seven different body areas indicated that respiratory exposure was "infinitesimal" and dermal exposure was less than 0.1% of an estimated fatal dose (Hayes, 1971; Simpson, 1965; Wolfe et al., 1967).

The California State Department of Agriculture established an arbitrary 2-day period as a safe interval between application of carbaryl and the time of reentry of field workers (California Department of Agriculture Title 3, 1971). The 2-day time interval for carbaryl applied to citrus, grapes, peaches, and nectarines. The 2-day re-entry interval has since been dropped in the California pesticide worker safety regulations. This was done because the California Department of Food and Agriculture decided that any residues that might be present did not represent sufficient hazard to require the interval.

Vandekar (1965) measured the α-naphthol in urine of inhabitants of huts that had been treated with carbaryl. Maximum amounts extracted within 24 h were equivalent to 70% of the amount found to be the oral no-effect level in dogs. In this group, blood cholinesterases of some subjects were depressed 15% after 1-wk exposure.

II.C.4. Human poisonings: The total carbaryl poisonings that have been brought to the attention of the Union Carbide Corporation are as follows:

Year	Probable Poisonings(a)	Alleged Poisonings(b)
1960	2	13
1961	6	5
1962	2	4
1963	1	19
1964	0	6
1965	0	0
1966	2	0
1967	0	5
1968	1	0
1969	1(c)	3
1970	0	2
1971	3	5

(a) Cases in which there was exposure to carbaryl and symptoms of illness were compatible with those expected from a cholinesterase inhibitor.

(b) Cases in which there was possible exposure to carbaryl but symptomatology was not compatible.

(c) Of the 18 probable poisonings over the 12-yr record period, one case confirmed as due to carbaryl was fatal and was a suicide.

II.C.5. Medical uses: A Product marketed as Carbacide containing 5% carbaryl in an inert carrier has been used directly on humans as a treatment for ectoparasitic infestations (Sussman et al, 1969a, 1969b). Effective human louse, crab louse and scabies control has been achieved within three days following dusting, and the patients were declared asymptomatic.

II.D. Toxicology

Sevin carbaryl insecticide is of moderate peroral toxicity in mammals. As a technical or commercially formulated product, it penetrates the skin poorly. In special studies, carbaryl has been evaluated for cataract formation, neuromuscular degenerative potential and interaction with other pesticides. No reasons for undue concern over hazards in these areas were discovered. A low degree of chronicity was observed in lifetime feeding studies in rats and other species; carbaryl residues do not persist or accumulate in animal tissues. Teratogenic and reproductive effects have been extensively investigated. Responses are observed occasionally in some species at high dosages or by nondietary routes of administration. Using test protocols generally accepted by the scientific community, no adverse reproductive or teratogenic responses are observed. These include dietary inclusion studies in several species, such as rats, mice, guinea pigs, hamsters, and monkeys. In tests for carcinogenesis and mutagenesis, no evidence of potential for hazard in product use has been discerned.

The majority of the basic supporting data on the toxicology of Sevin carbaryl insecticide has been developed by the Chemical Hygiene Fellowship established at Carnegie-Mellon University, Pittsburgh. This work has proceeded continuously since 1954. Because of the widespread public acceptance of carbaryl in the United States, many other laboratories have contributed to the toxicologic knowledge on carbaryl.

Foreign studies employing samples of carbaryl from sources other than U.S. manufacture have been reported. References to these are not included here for the following reasons:

(1) The source or purity of the carbaryl used has not been established and there is evidence that this varies significantly from carbaryl of U.S. origin.

(2) Translations of the complete studies are often not available.

(3) In instances where translations are available essential test details are often obscure or absent.

II.D.1. Acute studies: All but the work reported for 1953 was performed with technical grade Sevin carbaryl insecticide, which is > 99% 1-naphthyl methylcarbamate.

II.D.1.a. Single dose by peroral intubation: Table II.C. lists results of acute toxicity tests of unformulated Sevin carbaryl obtained by peroral intubation. The vehicles used suspend finely ground carbaryl with almost no dissolution. The vehicle least likely to influence toxicity by its own presence is 0.25% agar. The average LD_{50} from 8 tests made over a period of 10 yr with technical carbaryl samples intubated into 90-120 g male rats as a suspension in 0.25% agar is 0.5 g/kg. In two instances the same sample was tested as a suspension in corn oil and in 0.25% agar. The comparative results show the corn oil suspension to be 108 - 125% more toxic than the agar suspension. In one instance the same sample was intubated as a suspension in 10% Tween 80® and in agar. The suspension in Tween was 152% more toxic than the agar suspension. Tests on formulations, discussed below, suggest that this increase will be caused by any surfactant, not uniquely by Tween.

Table II.C. Acute oral LD_{50} values for Sevin carbaryl in different laboratory species

Species	Weight (g)	Sex	Year made	Concentration intubated	Vehicle	LD_{50} in g/kg
Rat	90-120	M	1953	1%	10% Tween 80	0.19(0.13-0.26)
	90-120	M	1956	5%	0.25% agar	0.68(0.49-0.95)
	90-120	M	1956	5%	0.25% agar	0.51(0.38-0.67)
	340-550	M	1956	5%	0.25% agar	0.50(0.37-0.68)
	90-120	M	1956	5%	0.25% agar	0.48
	90-120	M	1956	1%	10% Tween 80	0.31(0.25-0.38)
	90-120	F	1956	5%	0.25% agar	0.61(0.49-0.75)
	90-120	F	1956	5%	Corn oil	0.56(0.29-1.07)
	90-120	M	1956	5%	Corn oil	0.31(0.20-0.47)
	90-120	M	1959	5%	0.25% agar	0.376(0.319-0.442)
	90-120	M	1960	5%	0.25% agar	0.537(0.49-0.588)
	90-120	M	1961	5%	Corn oil	0.429(0.307-0.598)
	90-120	M	1961	5%	0.25% agar	0.43 (0.31-0.60)
	90-120	F	1964	5%	Corn oil	0.31(0.25-0.38)
	90-120	M	1965	5%	0.25% agar	0.41(0.31-0.53)
	90-120	M	1966	5%	0.25% agar	0.54(0.35-0.79)
Mouse			1961	5%	0.25% agar	0.50(0.32-0.78)
Guinea pig	450-500		1956	5%	Corn oil	0.20(0.11-0.44)
	600-900		1956	5%	0.25% agar	0.28
	400-480	F	1970	3%	Corn oil	0.30(0.21-0.44)
Rabbit	2400-3200		1956	5%	0.25% agar	0.71
Cat	1800-3000		1957	2%	0.25% agar	0.25-2/2, 0.125-0/1
Dog	6750-9800		1956	100%	Powder	0.5-0/1, 0.325-0/4

Note: The sample tested in 1953 was considerably more toxic than any later sample. This was partly attributable to its having been tested as a suspension in Tween 80, but may also reflect that it was a product of research laboratory synthesis before the quality controls of pilot plant and commercial production had been perfected.

Source: Union Carbide Corporation.

In two instances animals of widely different weights, hence ages, were tested. Insignificant differences were found with both rats and guinea pigs.

In only one instance was the same sample administered separately to the two sexes. In this case it was 127% more toxic to male than to female rats.

From the data in the table, the species tested can be arranged in the order of their sensitivity to single gastric intubation of carbaryl, with the most sensitive first: cat, guinea pig, rat, mouse, rabbit, dog. The range between these species is about fourfold.

The sublethal effects from LD_{50} or higher dose levels were fairly uniform regardless of species: fine tremors, increased respiration, salivation, secretions from nose and mouth, porphyrin Harderian gland secretion, bulging of the eyeballs, and greatly increased sensitivity to stimuli such as noise or body contact.

II.D.1.b. Percutaneous absorption: The maximum volumes which could be retained were held on the clipped abdomens of albino rabbits for 24 h, and the animals were observed for 14-d. A dose of 2.5 g/kg applied as a 40% paste of a 50% wettable powder (containing a surfactant) in water killed 1 of 4 rabbits. A 1.25 g/kg dose, as a 25% suspension of a 25% wettable powder in water, did not kill 4 experimental rabbits. There were also no mortalities following exposure of 4 rabbits to 2 g/kg as a 10% suspension in dimethyl phthalate. According to the authors, it can be inferred that the LD_{50} of carbaryl in a wettable powder for rabbits is above 2.5 g/kg (Carpenter et al, 1961).

II.D.1.c. Subcutaneous injection: Subcutaneously in 90 - 120 g male rats, given as 25% active ingredient in lard at body temperature, the LD_{50} of carbaryl was 1.41 (1.02-1.95) g/kg; in 450 - 600 g male rats at 2 g/kg, it killed none of 5; and in 1600 - 3300 g female chickens the average lethal dose was 2.0 g/kg (Carpenter et al, 1961).

II.D.1.d. Intraperitoneal administration: Intraperitoneally in male rats as 4 or 5% active carbaryl in polyethylene glycol 400, the LD_{50} of various samples ranged from 0.057 (0.035-0.09) to 0.18 (0.14 - 0.22) g/kg, and as a 7.5% active ethyl alcohol solution one sample had an LD_{50} of 0.19 (0.13-0.26) g/kg. Intraperitoneally, in 2600 - 3600 g male albino rabbits, as 5% active carbaryl in 0.25% agar, the LD_{50} was 0.22 (0.12 to 0.41) g/kg. These and other acute toxicity studies have been reported (Carpenter et al, 1961).

II.D.1.e. Inhalation studies: Six guinea pigs inhaled 50% carbaryl wettable powder of 15 μ average particle size, for 4 h at a concentration of 390 (344 - 722) mg/m^3 and gained weight normally during the subsequent 2-wk observation period. There was evidence of nasal and ocular irritation and autopsies performed after 14 days disclosed healed hemmorrhagic areas in the lungs. This concentration is a dense dust cloud visible to the naked eye.

A group of six guinea pigs inhaled a mean of 230 mg/m^3 of Sevin 85 S, average particle size 5 μ, range 1 - 10 μ, during a 4-h period. In the ensuing 14-d observation period, the animals showed a slight weight decrease but regained their pretreatment weight by the end of this interval. Another group of five survived after 4 h in a mean concentration of 332 mg/m^3 of the same dust.

Because of the enormously increased surface area presented by micronized Sevin 85 S, dogs were placed in a dust concentration on the order of 75 mg/m^3. Within 5 h, typical symptoms attendant upon cholinesterase inhibition were seen. Attention is called to this phenomenon even though this microfine material is not marketed for crop dusting. A much coarser material diluted with 90% of inerts is available for dusting purposes.

Repeated inhalation of Sevin 85 S by rats results in no mortality nor grossly visible injury among rats that inhaled 10 (5 to 20) mg/m^3, 7 h/d, 5 d/wk, for a total of 90 inhalation periods (Carpenter et al, 1961).

II.D.1.f. Eye injury: a test with four albino rabbit eyes treated with 0.5 ml of 10% technical carbaryl in propylene glycol, resulted in no irritation to a trace of irritation at 24 h. One eye had a very small area of fluorescein staining necrosis and 3 were completely normal. An application of 0.05 g powdered technical Sevin carbaryl to the rabbit cornea resulted in a small area of necrosis in one of three eyes (Carpenter et al, 1961).

II.D.2. Special studies

II.D.2.a. Cataract formation has been reported in rats fed on diets containing 2-naphthol (Fitzhugh and Buschke, 1949). Because metabolism of carbaryl could form 1-naphthol, the eyes of rats were examined at intervals during a 2-year dietary feeding study of carbaryl (Carpenter et al, 1961). No lens abnormalities were found in 142 rats at 419 d. After 719 days, no eye pathology was observed at the highest or lowest dosage levels, 0.04 and 0.005%. One rat at 0.02% had eye inflammation; one at 0.01% had a cataract. This single cataract was judged to be of no significance.

II.d.2.b. Neuromuscular degenerated potential in chickens: Subcutaneous injection of solutions of carbaryl and triorthocresyl phosphate in lard at 37°C in 2-year-old hens produced similar gross symptoms of demyelination. The criteria of mortality, leg paralysis and microscopic evidence of demyelination indicated triorthocresyl phosphate to be at least eight times more active than carbaryl (Carpenter et al, 1961).

II.D.2.c. Potentiation by other pesticides: The possibility of a synergistic (more than additive) relationship between the toxicity of carbaryl and cholinesterase-inhibiting organophophorous insecticides, and between carbaryl and pesticides injuring by other mechanisms was investigated by determining the rat oral LD_{50} from gastric intubation of the pairs determined separately and together. The materials tested in combination with carbaryl, and the ratios of the LD_{50} predicted by the harmonic mean formula compared with that observed are as follows:

Organophosphorous compounds		Other compounds	
EPN	1.4	chlordane	0.5
diazinon	0.7	sesone	0.5
azinphosmethyl	1.3	DDT	1.2
malathion	0.9	dieldrin	0.4
methyl parathion	0.8	ferbam	0.5
parathion	1.3	lindane	0.8
mevinphos	1.5	lime-sulfur	0.4
demeton	1.0	Thanite	0.8
carbophenothion	1.1	toxaphene	0.7

None of the pairs deviated sufficiently from the prediction of the harmonic mean formula to indicate either synergism or antagonism (Carpenter et al, 1961). Similar results were obtained in 1967 by Keplinger and Deichmann of the University of Miami School of Medicine.

II.D.3. Subacute feeding studies: Prior to starting lifetime feeding of carbaryl to rats, groups of 10 were fed diets containing 2250 or 1500 ppm carbaryl for 96 days. The higher level produced a decrease in female body weight, increased liver weight in males, and increased kidney weight in females. While these changes were significant, appetite was not affected and only minor pathology was noted. At the lower level of 1500 ppm in the diet, only kidney weights in females were significantly increased (Carpenter et al, 1961).

II.D.4. Chronic feeding studies: A lifetime feeding study in rats employed groups of 20 males and 20 females each on diets containing carbaryl in concentrations of 0.04, 0.02, 0.01, 0.005, and 0.00%. During the test period, records were maintained on individual weights and other observations were made. Upon conclusion, a statistical evaluation included mortality or life span, appetite as measured by diet eaten, body weight gain, liver and kidney weights, incidence of neoplasms, examination for cataract, hematocrits at 3- and 6-month intervals, and micropathology of lung, liver, kidney, heart, spleen, pancreas, stomach, duodenum, descending colon, testis or ovary, urinary bladder, and adrenal gland. In the dietary concentrations ranging from 0.005 through 0.02% carbaryl, no deleterious effects in any of these criteria were found which could be charged to the toxicity of the insecticide (Carpenter et al, 1961).

At the 0.04% level equivalent to 18 mg/kg/d, growth rate was reduced, a transient cloudy swelling of kidney tubules was noted, and a cloudy swelling of control hepatic cords was noted. Thus, 0.02% (200 ppm) in the diet equivalent to 8.2 mg/kg/d can be taken as the "no effect" level in rats.

Dogs received capsules 5 days a week at levels equivalent to 400, 100, 25 and 0 ppm in their dry diet. The tissues from the 14 dogs killed after 1 year at doses of 400 ppm or less of carbaryl showed no permanent degenerative changes. No significant deviation from controls was noted in body weight, organ weights, hematologic studies, biochemical tests, cholinesterase levels, or in mortality (Carpenter et al, 1961).

II.D.5. Reproductive and teratogenic effects: Carbaryl, a reversible cholinesterase-inhibiting insecticide, was incorporated into the feed of pregnant beagle dogs and fed throughout the gestation period at levels of 50, 25, 12.5, 6.25 and 3.125 mg/kg body weight/day. Effects included number of animals with dystocia (difficult births) due to atonic uterine musculature, an apparent contraceptive effect at the highest dose level, and a teratogenic action at all but the lowest dose level. The teratism occurred in 21 of the 181 pups born, or 11.6%. It was concluded that carbaryl produces teratogenic and toxic effects in the pregnant beagle dog (Smalley et al, 1968).

Three successive generations of rats were maintained on diets with a daily intake of 0.01 g carbaryl or less. There was no effect found on reproduction or on growth rate and micropathology of pups (Weil et al, 1972).

In a teratogenic study, rats were fed carbaryl in the diet to provide daily doses up to 500 mg/kg, with no increase in teratogenic anomalies, and no effects on fertility or gestation. Only at the highest dose was weight gain reduced; many pups in this group died before weaning from mothers fed this level of carbaryl (Weil et al, 1972). The dosage was approximately one acute oral LD_{50} dosage per day.

A three-generation rat reproduction study in which gastric intubation and dietary feeding were compared has been reported (Weil et al, 1973). At the maximum daily feeding rate of 200 mg/kg, there were no reproductive effects noted in any group of rats; only minor reproductive effects were associated with 100 but no reproductive effects at 25 mg/kg by intubation. These contrasting oral route experiments produced neither teratogenic effects which were statistically different from controls nor mutagenic results. Cholinesterase inhibition and differential mortalities resulted from intubation of 100 mg/kg/d, although these deviations were not present at twice this level of carbaryl incorporated into the diet. These data reinforce the importance of the method of administration in toxicologic experimentation.

Pregnant guinea pigs were treated with carbaryl by gastric intubation or by carbaryl in the diet in 64-dose schedules (on 1, II.D.9. Toxicity of formulations: Sevin carbaryl insecticide formulations present human exposure mainly by dermal or inhalation routes. Skin penetration toxicity is low, as indicated by an LD_{50} greater than 4000 mg/kg active ingredient basis to rabbits (Union Carbide Corporation, 1974). Guinea pigs inhaled dust and wettable powder formulations with no visible effects except lacrymation from exposure to dense dust clouds. In actual use, cases of overexposure to Sevin carbaryl formulations have been very minimal.

Chapter III

IMPACT OF CARBARYL INSECTICIDE ON THE ENVIRONMENT

Since worldwide use began in 1958, much published data has accumulated on the impact of Sevin carbaryl insecticide on the environment. Although selectively toxic to certain organisms, applications of carbaryl generally have minimal and shortlived effects on nontarget species.

Carbaryl appears to have a relatively low order of toxicity to both aquatic and terrestrial vertebrates. The recommended use rates of carbaryl rarely cause any adverse effects on large or small mammals, birds, reptiles, amphibians, or fish. The latter have been extensively studied, as this chapter will show.

Among the invertebrate animals, earthworm populations may be temporarily reduced by heavy applications of carbaryl. Mollusks are generally unaffected; crabs and shrimp are highly susceptible. In practical use, open waters are unlikely to become contaminated with carbaryl because of precautionary labeling and the fact that carbaryl degrades fairly rapidly to less toxic metabolites.

Spraying large areas for forest insect pest control has not usually resulted in food depletion for insectivorous birds, although temporary loss of invertebrate fish food organisms has been observed in some treated streams.

Carbaryl is considered highly toxic to honeybees and has some adverse effects on certain beneficial insect parasites and predators.

It is metabolized by soil microorganisms and is relatively non-persistent in soil.

Spray residues of carbaryl are not persistent, having a half-life of only 3 or 4 days. No adverse effects were recorded on plant growth or crop production at normal use rates of the insecticide.

In summary, there have been few adverse effects on either wild or domestic vertebrates when carbaryl has been used as directed. Temporary population declines of certain susceptible nontarget species have been noted. Carbaryl is readily decomposed to less toxic products in soil, air, and water, does not persist in the environment, or accumulate in plant or animal tissues. Biomagnification of residues in animal food chains has not been demonstrated.

III.A. Effects on aquatic organisms

The effects of carbaryl on both vertebrate and invertebrate animals have been extensively studied. The results of laboratory and field experiments will be discussed under appropriate headings.

III.A.1.a. Acute toxicity to fish: Henderson et al (1960), using 95% technical Sevin carbaryl dissolved in acetone before dilution in water, reported a 96 h TLm to fathead minnows of 6.7 - 7.0 ppm in hard water and 12 - 13 ppm in soft water. Figures for bluegills were 5.3 - 5.6 ppm in soft water, while 50% wettable powder used under the same conditions produced a 96 h TLm of 5.5 ppm. Cope (1963) reported a 24 h TLm of 3.5 ppm and a 48 h

TLm of 2.0 ppm for rainbow trout, based upon work by Bridges and Andrews.

Burdick et al (1960) indicated no apparent losses of trout stream fishes when carbaryl was applied for forest insect control at 1.25 lb/acre as an 85% micronized powder suspended in fuel oil with paraffin sticker. Laboratory studies later conducted by Burdick et al (1965) on the toxicity of carbaryl to fingerling brown trout revealed that toxicity would probably not be a factor at the usual application rate of 1 - 1.25 lb/acre. The toxic level of 1.5 ppm would not be reached in application to water averaging over 4 in deep. Haynes et al (1958) reported that 28 ppm of technical carbaryl would produce an LD_{50} in goldfish in 48 h.

Table III.A.1. provides LC_{50} values for various other species.

Table III.A.1. The LC_{50} for various fish to carbaryl.

Fish Species	Exposure Time (h)	LC_{50} (ppm)	Source
Longnose killifish	24	1.75	Stewart, Millemann and Breese, 1967
Harlequin fish	24	3.4	Alabaster, 1969
Shiner perch	24	3.9	Stewart, Millemann and Breese, 1967
English sole	24	4.1	"
White mullet	24	4.25	"
Three-spine stickleback	24	6.7	"
Brown trout	48	1.5	FWPCA, 1968
Yellow perch	96	0.745	Macek and McAllister, 1970
Coho salmon	96	0.764	"
Brown trout	96	1.95	"
Rainbow trout	96	4.38	"
Carp	96	5.28	"
Largemouth bass	96	6.4	"
Bluegill	96	6.76	"
Redear sunfish	96	11.2	"
Fathead minnow	96	13.0	Stewart, Millemann and Breese, 1967
Goldfish	96	13.2	Macek and McAllister, 1970
Fathead minnow	96	14.6	"
Channel catfish	96	15.8	"
Black bullhead	96	20.0	"

Source: Pimentel (1971).

Katz (1961) tested 95% carbaryl and reported the 48 h LC_{50} in rainbow trout, coho salmon, bluegill, and threespine stickleback to be 1.3, 0.99, 5.3, and 10.45 ppm, respectively. The toxicity of carbaryl to four salmonid species was reported by Post and Schroeder (1971). Their data are given in Table III.A.2.

Table III.A.2. TLm values in ppb of carbaryl and TLm value confidence limits for four salmonids

Species	Fish body weight (g)	Time (h)	TLm (ppb)	Confidence limits
Brook trout	1.15	24	1,830	1,441 - 2,324
	1.15	48	1,500	1,176 - 1,913
	1.15	72	1,150	927 - 1,426
	1.15	96	1,070	905 - 1,263
	2.04	72	1,640	1,247 - 2,157
	2.04	96	1,450	1,047 - 2,008
Cutthroat trout	0.37	72	2,000	1,399 - 2,870
	0.37	96	1,500	1,176 - 1,913
	1.30	96	2,169	2,067 - 2,276
Rainbow trout	1.24	96	1,470	980 - 2,205
Coho salmon	1.50	24	2,950	2,201 - 3,953
	1.50	48	2,700	1,929 - 3,780
	1.50	72	1,690	1,341 - 2,129
	1.50	96	1,300	1,074 - 1,573

Source: Post and Schroeder (1971).

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Carbaryl was generally the least toxic of four insecticides tested. It was twice as toxic to Soda Lake brook trout, 1.7 times more toxic to the Oregon strain of Coho salmon, and 1.5 times more toxic to Wigwam (Drew) rainbow trout than to Snake River cutthroat trout of comparable body weight.

The toxicities of carbaryl (50%) to the Indian catfish, *Heteropneustes fossilis*, were reported. At 50 ppm, carbaryl was fatal within 4 h. At 40 ppm, 50% of the fish survived. Fish size and minor fluctuations in temperature did not influence mortalities. Death was preceded by irritability, wild swimming, loss of equilibrium, excretion of mucus and blackening of the skin (Saxena and Aggarwal, 1970).

III.A.1.b. Effects of chronic toxicity to fish: The effects on fish of carbaryl used in California rice culture were reported by the California Fish and Game Department employees (1963). The compound is used at 2 lb active ingredient/acre for control of tadpole shrimp. Highest concentration of carbaryl in water and samples was 0.86 ppm. Among 20 carp and 20 green sunfish placed in live boxes, no losses occurred the first 2 days. Two carp died on the third day, and one sunfish and one carp on day 4. No other mortality was observed. Live and apparently unaffected mosquitofish were observed daily in the rice field.

Lowe (1967) studied the effects of prolonged exposure to carbaryl on juvenile spot, *Leistomus xanthurus*, an estuarine fish. This species survived 5 months of continuous exposure to 0.1 ppm carbaryl in flowing seawater.

The uptake and persistence of carbaryl in channel catfish was investigated by Korn (1973) under laboratory conditions. Duplicate groups of fish were exposed to one of the following treatments of ring-labeled ^{14}C carbaryl and nonlabeled carbaryl mixtures for 56 d: 0.05 mg/l or 0.25 mg/l continuously in the water, and 0.28 or 2.8 mg/kg/wk in the diet. No fish mortality occurred during the experiment. Mean total residues of ^{14}C-labeled carbaryl and its metabolites and degradation products during exposure to 2.8 mg/kg/wk in the feed accumulated to 9 ng/g. The mean of total residues accumulated from bath exposure to 0.25 mg/l was 11 ng/g. The low treatment groups (dietary and bath) accumulated 1 and 2 ng/g, respectively. Total residues were dose dependent for both methods of exposure. Fish exposed to a dietary level of 2.8 mg/kg/wk eliminated residues rapidly after being placed on a carbaryl-free diet for 28 d, retaining a mean of only 2 ng/g. Residues remained constant for 28 d in fish previously exposed to 0.25 mg/l carbaryl in their bath for 56 d. Assuming a maximum application rate of 4.6 kg/ha to be administered to a body of water (0.34 mg/l in a 1-m deep pond), appreciable residue accumulation in channel catfish appeared to the authors to be unlikely (Union Carbide Corporation, 1968). This appears to be due to their ability to metabolize and/or excrete carbaryl. Probably little carbaryl should reach aquatic environments because the compound is unstable.

When fathead minnows, *Pimephales promelas*, were exposed to five concentrations (0.008-0.68 mg/l) of carbaryl insecticide 9 months and throughout a life cycle, the highest concentration prevented reproduction and decreased survival. At the high concentration, testes contained motile sperm and ovaries were in a flaccid condition and appeared to be in a resorptive state. At the 0.68 mg/l concentration, carbaryl contributed to mortality of larvae (produced by unexposed parents) within 30 d of hatching. The 96 h median tolerance concentration (TL 50) and the lethal threshold concentration (LTC) for 2-month-old fathead minnows were 9.0 mg/l. The maximum acceptable toxicant concentration (MATC) for fathead minnows exposed to carbaryl in water with a hardness of 45.2 mg/l and a pH of 7.5 lies between

0.21 and 0.68 mg/1. The application factors (MATC/96 h TL50 and MATC/LTD) both lie between 0.023 and 0.075 (Carlson, 1972).

The capacity of sheepshead minnows, *Cyprinodon variegatus*, to avoid several pesticides, including carbaryl, was investigated. Sheepshead minnows varying from 20 to 40 mm in length were maintained for at least 10 d in a 20% saline solution at 20°C to elminate weak or injured animals and fed fish flesh daily until 24 h before the experiment. Chemicals were tested to determine the 24 h LC_{50}s to sheepshead minnows. Whenever avoidance was observed, other concentrations were studied to determine the upper and lower limits inducing a response in the minnow. The first experiment evaluated the capacity of the test fish to choose between water treated with the pesticides (0.00001 - 10.0 ppm) and pesticide-free water and the second study gauged the ability of the minnow to differentiate between high and low concentrations of individual pesticides. Minnows avoided the test concentrations of DDT, endrin, Dursban, and 2,4-D, but not those of malathion and carbaryl. The 24 h LC_{50} of sheepshead minnows to 98% active ingredient carbaryl was 2.8 ppm (Hansen, 1969).

There have been no reports of fish kills when carbaryl has been used as directed in the field.

III.A.1.c. Effect on crustaceans and other arthropods: The toxicities of carbaryl to the red crawfish, *Procambarus clarkii*, were 24, 48, and 72 h TLm's of 5.0, 3.0, and 2.0 ppm, technical grade, respectively (Muncy and Oliver, 1963). Field use of carbaryl spray applied to rice heading at 0.8 lb/acre showed no measurable effect on the survival, growth, and reproduction of *P. clarkii* in Louisiana (Hendrick et al, 1966).

The California Department of Fish and Game (1963) also conducted tests on carbaryl toxicity to nontarget species when used to control tadpole shrimp in ricefields. Carbaryl applied at 2 lb active ingredient/acre gave maximum residues in ricefield water of 0.86 ppm. This was well below the toxic level found in 96 h laboratory bioassays for crayfish where mortality began at 1.8 ppm and the TLm was 2.8 ppm.

The levels of pesticide resistance in freshwater shrimp, *Palaemonetes kadiakensis*, from areas of both intensive and nonuse of pesticides were checked in Mississippi by Naqvi and Ferguson (1970). Comparative 24 h LD_{50} values (ppb) were 42.5 for a nonuse area contrasted with 271.8, 152.5, and 64.0 ppb for populations from sites adjacent to or subject to runoff from treated cottonfields. When caged in a canal near cottonfields, susceptible shrimp suffered 66% greater mortality than did native, resistant shrimp. The 48 h TLm of carbaryl for brown shrimp was 27.0 ppb, whereas the tolerance for white shrimp was only 13.0 ppb. It required 1.0 ppm of carbaryl to cause paralysis in small, 25 mm stone crabs within 24 h (Butler, 1962). The highest concentration of carbaryl tolerated by five kinds of phytoplankton utilized by molluscan larvae as food was 100 ppb.

Of the life-history stages of the Dungeness crab, *Cancer magister*, early larvae were more sensitive to carbaryl than the juveniles and adults. A concentration of 1.0 mg/l did not affect egg hatching but prevented molting of all prezoeae to zoeae. The concentration that killed 50% of the first-stage zoeae during a 96 h exposure was estimated to be 0.01 mg/l. Few zoeae were killed in 24 h by 82.0 mg/l, but the 24 h EC_{50} for death within 15 d after exposure was estimated to be 0.015 mg/l. The 24 h EC_{50} for cessation of swimming, which was not always permanent, was 0.0065 mg/l. Survival of zoeae after 25 d exposure to concentrations of 0.0001, 0.00032, 0.001, 0.0032, and 0.01 mg/l was 83, 60, 69, 21 and 0%, respectively, and control survival was 79%. Molting was delayed at a concentration as low as 0.0001 mg/l.

Young juvenile crabs are more sensitive to carbaryl than the older juveniles or adults. The 24 h EC_{50} for death or irreversible paralysis was estimated to be 0.76, and 0.35 - 0.62 mg/l for second- and ninth-stage juveniles, respectively. The behavior, growth, and survival of juvenile crabs were not affected when the animals were exposed to 0.032 mg/l of carbaryl for 24 h and then held in clean seawater for 44 days. The 24 h and 96 h EC_{50}'s for death or irreversible paralysis were 0.49 and 0.26 mg/l, respectively, for adult crabs. After eating cockle clams that had been exposed for 24 h to 1.0, 3.2, and 10.0 mg/l of carbaryl, 22, 77, and 100% of adult crabs, respectively, were irreversibly paralyzed within 6 h (Buchanan et al, 1970).

Stewart et al (1967) studied the toxic effects of carbaryl and its hydrolytic product, 1-naphthol, on marine organisms. Carbaryl was 30 - 300 times more toxic than 1-naphthol to crustaceans but less toxic than 1-naphthol to mollusks and fishes. Acute toxicity of these compounds to crustaceans and other arthropods is given in Tables III.A.3. and III.A.4.

Table III.A.3. Acute toxicity of carbaryl and 1-naphthol to estuarine crustaceans[1/]

Species	Temp.	Carbaryl EC_{50} (mg/l) 24 h Mean	Mean	1-naphthol EC_{50} (mg/l) 24 h Mean	48 h Mean
Mud shrimp	16°C	0.13	0.09	2.7	4.4
(Upogebia pugettensis)	20°C	0.04	0.04	7.6	4.5
Ghost shrimp**	17°C	0.47	0.08	15.0	3.5
(Callinassa californiensis)	20°C	17-5.6*	0.03	20.1	3.3
Shore crab		0.71	-	74.2	-
(Hemigrapsus oregonensis)		0.27	-	80.1	-
Dungeness crab		0.60	-	40.0	-
(Cancer magister)		0.63	-	55.5	-

1/ Adapted from Stewart et al (1967).
* Range
** Larvae

The 48 h EC_{50} (immobilization value at 60°F) for waterfleas, *Simocephalus serrulatus* and *Daphnia pulex*, to carbaryl was 7.6 and 6.4 ppb, respectively (Sanders and Cope, 1966).

Table III.A.4. The LC_{50} for various arthropods to carbaryl*

Arthropod Species	Exposure time (h)	LC_{50} (ppm)	Source
Stonefly *(Pteronarcella badia)*	24	0.005	Sanders and Cope, 1966
" *(Claassenia sabulosa)*	24	0.012	"
" *(Pteronarcys californica)*	24	0.030	"
Amphipod *(Gammarus lacustris)*	24	0.040	Sanders, 1969
Mud shrimp	24	0.04-0.13	Stewart, Millemann, and Breese, 1967
Ghost shrimp	24	0.13	"
Shore crab	24	0.27-0.71	"
Dungeness crab	24	0.60-0.63	"
Stonefly *(P. californica)*	48	0.0013	FWPCA, 1968
Waterflea *(Daphnia pulex)*	48	0.006	Cope, 1966
" *(D. pulex)*	48	0.0064	FWPCA, 1968
" *(Simocephalus serrulatus)*	48	0.008	Cope, 1966
Stonefly *(P. californica)*	48	0.0015	"
Amphipod *(G. lacustris)*	48	0.022	FWPCA, 1968
Ghost shrimp	48	0.03-0.08	Stewart, Millemann, and Breese, 1967
Red crawfish	48	3.0	Muncy and Oliver, 1963

*As reported by Pimentel (1971).

Sevin carbaryl was sprayed by airplane at 1.25 lb/acre in fuel oil with a paraffin oil sticker on an area near Onconta, New York. Its effect upon the aquatic fauna of two streams was studied. Square-foot samples collected before and shortly after spraying showed reductions of from 48.9 to 97.2% in weight of invertebrate fish food. Little recovery could be observed on one stream nearly a month later. The extreme reduction in available food would greatly reduce the productivity of the stream during the same year, if it did not result in migration or starvation of some of the fishes present (Burdick,et al, 1960).

There was a rise in the rate of drift of aquatic insects in a Pennsylvania stream contained within an area of woodland sprayed with carbaryl for control of the gypsy moth. It appeared from the pattern of drift that there was a drastic reduction of the standing crop of stream insects as a result of spraying. The insecticide was applied at 1.1 kg carbaryl/4.2 l water/ha. No rain fell in the region during the sampling period. Table III.A.5. presents the volume of aquatic insects per one foot (0.3 m) of stream width (exclusive of those emerging) collected in each stream for both 24 h periods.

Data for Slateford Creek showed a drastic increase in drift at the time of spraying. The average biomass of the two collections from the first day of spraying was over six times that of the average biomass for the preceding 6 d, and the peak of drift, reached 2 d after spraying had begun, was over 160 times the normal average. Thereafter the drop to near-normal levels was rapid. This drop probably resulted from a depletion of the standing crop due to mortality of drifters rather than to reattachment of recovered insects, and a return to truly normal conditions, since few bottom stones examined after the morning of 22 May revealed any living immature insects clinging to them. The data indicate that aerial spraying with carbaryl had a pronounced effect upon the aquatic insect community of Slateford Creek in spite of precautions against direct spraying of open water, washing of spray equipment in the stream, and other "misuses" often blamed for kills.

Table III.A.5. Biomass (number of milliliters of liquid displacement) of drifting aquatic insects per 1 foot (0.3 m) of stream. Collections were from approximately 7 a.m. on the first date to 7 a.m. on the second. AC, Allegheny Creek; SC, Slateford Creek.

Date (May)	SC (sprayed)	AC (unsprayed)
11-12	0.68, (0.25)*	0.08
12-13	0.20, (0.10)	0.02
13-14	0.20, (0.20)	0.08
14-15	0.10, (0.25)	0.10
15-16	0.16, (0.15)	0.36
18-19	0.30	0.42
19-20	1.78, (1.05)[a]	0.40
20-21	6.08	0.40
21-22	37.16[a]	0.48
22-23	1.25[a]	0.60
23-24	0.55[a]	0.58
24-25	0.30, (0.15)	0.38
25-26	0.20, (12)	0.46

*Figures in parentheses indicate the volume of insects in the second of the two nets placed at each station. Close agreement of each of these values with its mate indicated that complete analysis of one sample per date would be sufficient at other times.
[a] Spray.
Source: Coutant (1964).
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It was concluded that this increase in drift represented a considerable reduction of the standing crop of stream insects. While the full ecological significance of this reduction is not yet understood, it can hardly have a beneficial effect upon the food-chain relationships of the stream and surrounding woodland (Coutant, 1964).

Stream sampling for evidence of pesticide effects on aquatic arthropods was conducted by Butcher et al (1964) in Michigan. An 80 acre tract traversed by a stream was treated by aerial application of 80%

carbaryl at 1 lb active ingredient/acre on May 16. Intermittent sampling thereafter did not permit documentation of normal seasonal population changes such as reinfestation by multiple generation forms (e.g., chironomids) or population changes due to seasonal changes in the physical environment. There were some dissimilarities in rate of flow and temperature, along with a discontinuity in dytiscid, simuliid, tabanid, and tipulid recovery in quantitative samples, and limnephilids in qualitative samples after the spray application. Chironomids and amphipods (*Gammarus* sp.) were numerous both before and 3 d after spraying. However, the amphipod population was low a month later. Although the level of sampling intensity employed had limitations, the method would have demonstrated catastrophic decline. No such decline was evident in the two most numerous taxa, Amphipoda and Chironomidae.

III.A.1.d. Effects on mollusks: Current study of the comparative functional morphology of boring mechanisms in muricid gastropods disclosed lack of a method for thorough relaxation of these marine snails. Of the many chemicals employed in narcotization of gastropods, cocaine was reported to provide maximal relaxation, but in the muricid, *Urosalpinx cinerea*, it affected only partial expansion of the soft parts. A method was recommended for full relaxation and killing in an expanded condition of *Urosalpinx cinerea*, *Eupleura caudata etterae*, *Thais haemastoma floridana*, *Ocenebra erinacea*, *Nucella lapillus*, and *Polinices duplicatus*. Gastropods were made partially insensible in a solution of 10 ppm of Sevin carbaryl in one atmosphere of CO_2 and then frozen quickly on dry ice (Carriker and Blake, 1959).

Carbaryl significantly reduced numbers of juvenile clams in plots treated with 2.3 and 4.6 kg/acre. Pooling of samples taken at 1, 2, 4, 15, and 30 d after treatment showed that mean clam numbers per m^2 in untreated and treated plots were 364, 283, and 224, respectively, the reductions from the controls being 22 and 38%. Clam species differed in susceptibility to carbaryl; for example, numbers of the gaper clam, *Tresus capax*, were reduced by 58 and 69% at the low and high application rates in relation to those from the control plots, and the bent-nosed clam, *Macoma nasuta*, by 9 and 28%. There was no reduction in numbers of polychaete and nemertean worms. A carbaryl application of 2.3 kg/acre was as effective in controlling ghost shrimp, *Callianassa californiensis*, an oyster pest, at 4.6 kg/acre. Signs of stress and numbers affected were given for other mudflat animals (Armstrong and Millemann, 1974).

Experiments were reported on the effects of carbaryl and its hydrolytic product, 1-naphthol, on the survival, growth, and food consumption of larval and juvenile cockle clams, *Clinocardium nuttalli*. Clams were tested in standing seawater at a salinity of 25% and a temperature of 19 $\pm$ 2.0°C, and were fed cultures of the unicellular alga, *Monochryis lutheri*. Toxicant concentration ranged from 0.1 to 10.1 mg/l.

Larvae exposed to carbaryl concentrations of 0.8 mg/l were dead by day 7 of the test, and growth of those exposed to 0.4 mg/l was reduced by 15%. Carbaryl was less toxic than 1-naphthol to juvenile clams, the respective 96 h TLm's (median tolerance limits) being 3.75 and 2.7 mg/l. The growth of juvenile clams was reduced more by 1-naphthol than by carbaryl. The food consumption of juvenile clams exposed to 1.6 mg/l of carbaryl was markedly reduced and food conversion efficiency was impaired. Adult clams exposed to carbaryl concentrated the toxicant in their tissues; maximum concentrations were reached after 12 h exposure. Clams exposed at 11°C concentrated more toxicant than those exposed to 20°C. Tissue concentrations of toxicant decreased sharply after clams had been in clean sea water for 12 h. Carbaryl plus free 1-naphthol residues in tissues of adult cockle clams reached 6.85 ppm at 11°C and 6.63 ppm at 20°C after 12 h exposure to 2.0 mg/l carbaryl in seawater of 25% salinity. However, a 12 h flushing period, after 96 h exposure, reduced residues to only 0.17 and 0.18 ppm for the temperatures listed (Butler et al, 1968).

The acute toxicity of carbaryl and its hydrolytic product, 1-naphthol, to 10 species of marine animals was determined. Carbaryl was more toxic to larval and adult crustaceans than to larval and adult mollusks, *Mytilus edulis*, *Crassostrea gigas*, *Clinocardium nuttalli*, and juvenile fishes. Carbaryl was 30 - 300 times more toxic than 1-naphthol to the crustaceans but less toxic than 1-naphthol to the mollusks and fishes. The mean 48 h EC_{50} for the bay mussel, *Mytilus edulis*, was 2.3 mg/l for carbaryl and 1.3 mg/l for 1-naphthol. For the Pacific oyster, *Crassostrea gigas*, 48 h EC_{50}'s for carbaryl and 1-naphthol were 2.2 and 0.8 mg/l, respectively. Data on the cockle clam, *Clinocardium nuttalli*, were a mean of 7.3 mg/l for a 24 h EC_{50} on carbaryl and 6.4 mg/l for 1-naphthol for similar exposure (Stewart et al, 1967).

Preliminary data on the effects of 1.0 ppm carbaryl on growth showed 95% development of clam eggs and 60% development of oyster eggs as compared with untreated control cultures (Butler, 1962).

Effects of oysterbed treatment with polystream and carbaryl were evaluated by Haven et al (1966). Field tests conducted near Wachapreague, Virginia used 10 lb of carbaryl and 55 gal of polystream mixed with sand to treat a 1 acre test plot to control oyster drills, *Urosalpinx cinerea*. Application to planted oysterbeds did not reduce drill populations or drill egg cases deposited. Oyster production was not increased and treatment had an adverse effect upon most benthic macroinvertebrates. Oyster mortality from drills reached 65% on treated area, but only 9% on the control. However, drills were more abundant on the test area. Oystershell growth increment was 4.3 times greater on the control area 4 wk after treatment. Drill mortality was 10.5% in the treated area and 3.6% on the control plot. Clam mortality was 8% for treated and 1% for control areas. Mean growth increment was 0.2 mm for treated clams and 0.7 mm for controls. Caged mud crabs showed 28% loss in treated and 17% loss in control plots 4 d after application. A similar test with blue crabs showed 41% loss in the treated area but only 15% in the controls. During the 3 d following treatment, divers observed heavy mortality of polychaetes and amphipods, mantis shrimp *(Squilla empusa)*, sand shrimp *(Crangon septemspinosa)*, mud shrimp

(Upogebia affinis), and short razor clams *(Tagelus divisus)*. Many blue and mud crabs were affected, as shown by a "tumbling" activity. This chemical treatment did not reduce drill predation on oysters and had a deleterious effect on other components of the natural community.

III.A.1.e. Residues in aquatic organisms: Tompkins (1966) reported upon a surveillance program on Cape Cod, Massachusetts, concerned with an application of carbaryl for gypsy moth control. Residue levels found were not considered to be of environmental concern among the biota sampled. Residue data are given in Table III.A.6.

Table III.A.6. Parts per million of carbaryl insecticide residues in fish and molluscs

Species	Whole Body Analysis (No. Specimens) Prespray	Postspray
Alewife *Alosa pseudoharengus*	0.11(1)	0.18(1)
	0.16(1)	0.20(1)
	0.09(1)	0.16(1)
Calm, soft-shell *Mya arenaria*	0.13(1)	0.05(1)
	0.13(1)	0.10(1)
	0.10(1)	- - - -
	0.17(2)	0.10(2)
	0.09(3)	0.05(3)
	0.12(1)	0.13(2)
	0.12(1)	0.08(2)
Eel, American *Anguilla rostrata*	0.06(6)	0.14(2)
Flounder, winter *Pseudopleuronectes americanus*	0.13(7)	0.38(1)
	0.22(1)	0.06(1)
	0.18(2)	0.06(2)
	0.12(1)	0.13(1)
	0.11(6)	0.74(1)
	0.16(1)	- - - -
Mummichog *Fundulus heteroclitus*	0.15(4)	0.19(20)
	0.20(3)	0.19(2)
	0.13(2)	0.11(4)
	0.13(3)	0.17(3)
	0.06(6)	0.10(2)
	0.14(4)	0.11(4)
	0.11(4)	0.34(3)
Mussel, blue *Mytilus edulis*	0.17(3)	0.23(2)
Oyster, eastern *Crassostrea virginica*	0.09(2)	0.10(3)
	0.14(4)	0.05(3)
Perch, yellow *Perca flavescens*	0.11(10)	0.13(2)
	0.15(5)	0.12(1)

Table III.A.6. (continued)

Species	Prespray	Postspray
Quahog *Mercenaria mercenaria*	0.17(1)	0.04(1)
	0.07(1)	0.04(1)
	0.13(2)	0.08(3)
	- - - -	0.08(1)
	0.09(2)	0.24(1)
	0.12(3)	0.13(2)
	0.09(1)	0.08(2)
Scallop, bay *Aequipecten irradians*	0.13(6)	0.09(5)
Silverside Sp. not given	0.16(50)	0.21(35)
Stickleback Sp. not given	0.19(50)	0.06(62)
	0.19(27)	0.20(20)
	0.23(15)	0.19(22)
Sucker, white *Catostomus commersoni*	0.09(5)	0.11(1)
Sunfish *Lepomis gibbosus*	0.10(3)	0.10(2)
	0.13(3)	0.10(2)
Trout, brook *Salvelinus fontinalis*	0.08(1)	- - - -

figure within ( ) = No. of specimens
Source: Tompkins (1966).

III.B. Effects on terrestrial vertebrates

Carbaryl appears to have a relatively low order of acute oral toxicity to terrestrial vertebrates. Long-term exposure through feeding tests at high levels seems to depress reproduction and check survival in birds. Field test applications sometimes result in decreased reproduction among small rodents. Other studies of field use at application rates of 1.0 - 1.25 lb active ingredients/acre demonstrated little or no adverse effects except to temporarily deplete the food supply of insectivorous birds when large areas were sprayed.

III.B.1. Toxicity to wildlife: The LD_{50} for young mallards was > 2179 mg/kg; for young pheasants, > 2000 mg/kg; for young coturnix, 2290 mg/kg; for pigeons (*Columba livia*), 1000 to 3000 mg/kg; for sharptail grouse, 780 to 1700 mg/kg; and for Canada geese, 1790 mg/kg to carbaryl when the birds were fed the stated dosages orally in capsules (Tucker and Crabtree, 1970). The LC_{50} for mallards pheasants, bobwhites, and coturnix was > 5000 ppm of carbaryl in diets of 2-week-old birds, when fed treated feed for 5 d followed by untreated feed for 3 d (Heath et al, 1972). The LD_{50} for mule deer was 200 to 400 mg/kg (Tucker and Crabtree, 1970) to carbaryl when the mammals were given the stated dosages orally in a capsule.

Effects of carbaryl on quail and pheasants were studied by DeWitt and Menzie (1961). Carbaryl has a relatively low order of toxicity to young quail. Chronic poisoning resulted from feeding of diets containing 2500 ppm, or from the ingestion of 370 mg/kg/d during an 84 d test period. The average lethal dose was approximately 9250 mg/kg but some birds survived after ingesting more than 30,000 mg/kg. Body weights of young quail fed diets containing 250 ppm (or more) of carbaryl were below those of birds reared on insecticide-free diets. Pheasants appeared to be more resistant than quail to carbaryl. More than 40% of young birds survived after ingesting more than 100,000 mg/kg during a test period of 100 d. Growth appeared to be depressed by feeding diets containing 1000 ppm, or by ingestion of 100 mg/kg/d. Percentage depression was roughly proportional to the daily intake of toxicant. Quail which ingested 12,000 or more mg/kg of carbaryl during growth, winter, and reproduction periods produced fewer chicks than birds which had never been exposed to this compound, or which received it only during the breeding season. Reproduction of pheasants, as measured by the number of chicks surviving for 12 wk, was inhibited or reduced approximately 50% by inclusion of 500 or more ppm of carbaryl in diets fed prior to or during the breeding season.

Acute oral toxicities of carbaryl were determined in adult male sharp-tailed grouse and greater prairie chickens live-trapped in North Dakota and Nebraska. Tissues of the birds were analyzed for carbaryl residues after administration of measured dosages in gelatin capsules. The limited results indicate a relatively low acute toxicity to prairie grouse since two sharptails and three prairie chickens survived single oral doses of carbaryl ranging from 1020 to 1860 mg/kg. All but two sharptails died within 24 h. Droppings were collected for analysis from the two sharptails surviving large doses of carbaryl. The curve in Figure III.B.1. illustrates the rapid rate of elimination of carbaryl in the feces of sharptails. However, the two prairie chickens survived 2-3 d before death.

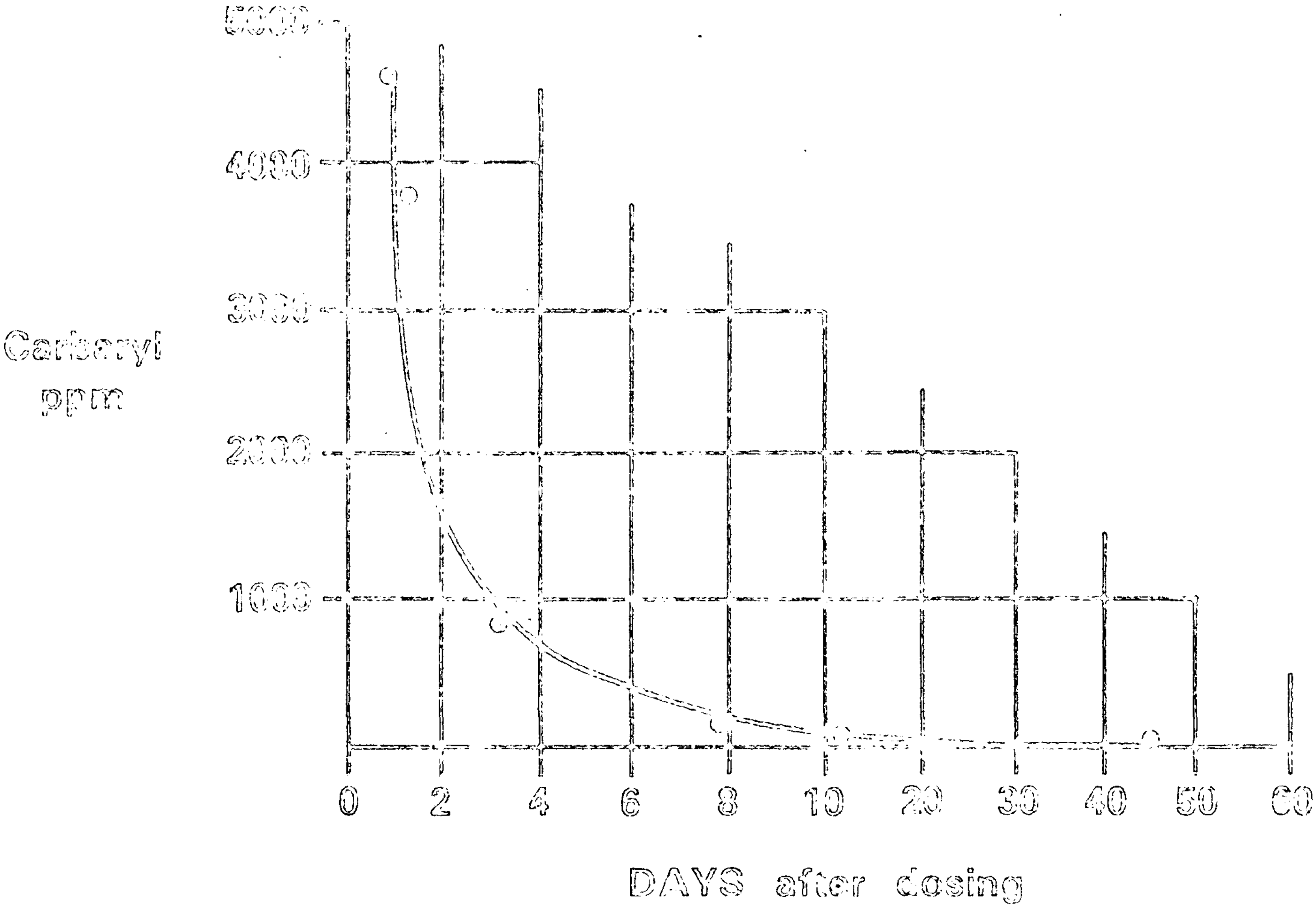

Figure III.B. Carbaryl concentration in droppings of two sharp-tailed grouse dosed at 1021 and 1500 mg/kg, respectively

From McEWEN et al 1964

Tissue residues of carbaryl ranging from 0.1 to 21 ppm were relatively low in five birds that died after large dosages. No carbaryl was recovered in the brain, kidneys, or liver of one surviving bird that was sacrificed in good condition 169 d after pesticide administration (McEwen et al, 1964).

Toxicity and residue data from these studies are given in Table III.B.1.

Table III.B.1. Acute oral toxicity of carbaryl and resulting tissue residues in adult male sharptails and prairie chickens

Species and number		Carbaryl dose[1/] mg/kg	Result	Carbaryl residues in tissues [2/] ppm ("wet basis")
Sharptail	# 6	2000	Death	9.0
"	#10	1750	"	17.0
"	#79	1650	"	0.1
"	#38	1500	Survival	Not analyzed
"	#18	1020	"	" "
"	#15	0	"	" "
Prairie chicken	#59	2750	Death	0.2
"	#65	2000	"	21.0
"	#57	1860	Survival[3/]	0.0
"	#61	1730	Survival	Not analyzed
"	#58	1390	"	" "
"	#34	0	"	" "

1/ Acute oral administration via gelatin capsule.
2/ Composite of brain, heart, kidney, liver, and muscle.
3/ Sacrificed 169 d after dosage.
Source: McEwen et al (1964).

III.B.2. Secondary effects: Recently ecologists have broadened their areas of experimentation from gross toxicities of pesticides to such secondary effects as altering the in vitro metabolism of rumen microflora and decreasing the efficiency of in vitro total digestibility. Determination of the in vitro effects of carbaryl on the rumen microflora of mule deer, *Odocoileus hemionus*, was reported by Barber and Nagy (1971). Rumen fluid for inoculum and as an additive to media was obtained from wild deer collected near Kremmling, Colorado on their winter range. Pure cultures of *Ruminococcus albus*, *Bacteriodes succinogenes*, *Streptococcus bovis*, and *Butyrivibrio fibriosolvens* were isolated from the collected rumen fluid. Cellulolysis by mixed cultures of these bacteria proved the most sensitive parameter of rumen bacterial function. Influence of carbaryl on percentage cellulose decomposition in vitro (as percent of digestion in control) was: 99.3, 72.6, 74.3, and 47.1% for carbaryl concentrates of 1, 10, 100, and 1000 ppm, respectively.

Volatile fatty acid (VFA) production in a broth medium containing a mixed carbohydrate substrate was affected adversely (See Table III.B.2.) The most obvious effect on the molar percentages of VFA was found to be the increase in acetic acid production at the expense of other components.

Table III.B.2. Effect of carbaryl inhibitory at 10 ppm on VFA production in vitro

Treatment	Molar percent VFA: Acetic	Molar percent VFA: Propionic & isobutyric	Molar percent VFA: Butyric	Total VFA (M moles/liter)
No pesticide	46.2	42.3	11.5	33.4
Carbaryl	55.1	37.6	7.3	26.0

Source: Barber and Nagy (1971).

These experimental results indicate that high levels of field application as compared to registered application rates would probably be necessary to affect in vivo rumen function. In some cases (12 other pesticides also were studied), a rumen inhibitory dose, as shown by in vitro results, exceeded an acute oral dose for deer (Barber and Nagy, 1971).

III.B.3. Effects of field applications: The effect of carbaryl on small mammals, birds, and other wildlife was studied in an Otsego County, New York area, being sprayed at 1.25 lb/acre for gypsy moth control. Records before and after spraying were obtained by trapping for small mammals and by observation for other species. The abundance of small mammals, as well as their condition and reproduction, seemed unaffected. Observations on 49 bird species failed to reveal any effect on their behavior, condition, or reproduction. Toads, frogs, salamanders, and snakes appeared to have been unaffected. A single application of carbaryl at this rate is probably not harmful to terrestrial wildlife (Connor, 1960).

Aerial spraying of carbaryl at 1 lb active ingredient/acre produced no discernible effects on bird or mammal life at Lostwood Refuge, North Dakota in the 3-month period following spray application. Total kill of insects on the sprayed area was estimated at 60%. Decline in insects and aquatic invertebrates, if any, did not result in any detectable movement of game species or song birds because of reduced food supply during the 6-wk period following spraying. Highest postspray residue found was 5.2 ppm in a sharptail grouse chick. Snowberry leaves contained 52 ppm carbaryl. Other environmental samples contained little or no carbaryl (McEwen et al, 1962).

The influence of spraying with carbaryl on nesting success in a sample of bird boxes on Cape Cod was reported by Bednarck and Davidson (1967). Approximately 1 lb/acre of carbaryl was applied, but measured deposits on glass plates indicated that 0.45 lb/acre was actually deposited on the ground. Data from 71 nests, mostly of tree swallows, collected over 6 years were studied to determine whether carbaryl sprayed during the last year (1965) affected clutch size, fertility, or mortality. The only evidence of a pesticide effect was on the only nest of birds hatched close to the time of spraying. These five young tree swallows were found dead in the nest and contained 0.4, 0.7, 1.8, 2.0, and 2.0 ppm of "apparent" carbaryl.

Gardona, trichlorfon, and carbaryl were tested in Connecticut for their effects on gypsy moths. All three formulations applied at 1 lb/acre reduced gypsy moth density to low levels. Leaf-feeding lepidopterans seemed equally susceptible to these insecticides. Sarcophagid and tachinid flies were not affected by carbaryl, but were reduced by the other two pesticides. One control area and three treated plots were monitored for any change in bird activity. Two 1 h counts were made on 8 d in each of the four plots monitored, the two parameters recorded being sighting and hearing (of a song or call). Notes also were made on all nests discovered in the test plots, as well as in three additional spray plots. Little apparent difference was reflected in the data involving sighting; an analysis of the different species heard shows that the species complex changed between pre- and posttreatment and that bird activity was decreased after insecticide treatment.

The application of the insecticides caused a depletion in the available food for the birds. *Calosoma* beetle species were susceptible to carbaryl residues. The overall effect was an increased concentration of bird activity in areas outside the sprayed plots. With nearly 40 species of birds known to feed on *P. dispar* caterpillars and with bird activity altered by the loss of these insects as available bird food, the effect of systematic insecticide coverage on large townships appears detrimental to some birds, particularly to nestlings requiring considerable amounts of food at a time when the insect biomass has been decimated. This bird-nest control relationship should be studied in depth (Doane and Schaefer, 1971).

Deviations in reproduction of the natural population of common redback voles were observed after treatment of forest territories with domestically produced carbaryl in the form of 35% moistened powder used at the rate of 0.5 g/m^2 for control of Ixodid ticks. Among adult rodents inhabiting treated areas, a significant number of males and females did not take part in the reproduction process (12% against 4% in the control area). Reduction of fertility and pathology of pregnancy in females were noted (Shilova et al, 1968).

Cotton rat reproduction was delayed by carbaryl application (2 lb/acre) to a grassland, resulting in a reduced population (Barrett, 1968). In laboratory tests, carbaryl was fed to cotton rats orally at a 1.1 mg/d/individual for 10 d. In these rats weighing from 140 to 150 g, both the number of litters born and number of females giving birth were reduced by more than 50%. There appeared to be, however, no effect on either the house mouse or the old-field mouse populations by the carbaryl (2 lb/acre) application.

III.C. Effects on domestic animals

Most research on carbaryl in relation to livestock and poultry has concerned residue accumulation in tissues, milk, or eggs. Feeding trials, even at heavy dosage levels, have rarely shown acute toxicity or any prolonged buildup of residues in tissues. Animals readily convert carbaryl into 1-naphthol or other metabolites. The principal route of elimination appears to be through the urine. Residues in eggs or milk are transitory and seldom exceed 1 - 2% of the administered dosage (see Chapter IV). The literature gives some evidence of teratogenic effects among progeny of exposed mammals or from injection into eggs (see Chapter II). However, these tests were run at exposure rates much in excess of those likely to be encountered in practical use.

III.D. Effects on bees and other beneficial insects

Bee poisoning from pesticides has increased significantly over the past 25 years with greater use of insecticides. Problems in orchard areas were reduced somewhat at the end of the "lead arsenate" era soon after World War II. New problems arose and many honeybee colonies were destroyed by insecticides. In more recent years, regulatory and extension efforts have included pesticide user and beekeeper cooperation. Such efforts have effectively reduced losses of bees to pesticides in certain states where the regulations have been followed.

III.D.1. Toxicity to bees: Contact poisoning studies in the laboratory were conducted by Atkins et al (1970) who recorded an LD_{50} of 1.336 μg/bee for carbaryl and listed it in their "most highly toxic" group. Field studies in California by the same workers (Anderson et al, 1971) again showed carbaryl in the highly toxic category which had LD_{50} contact toxic values of less than 2 μg of toxicant per bee.

Anderson and Atkins (1968) published an extensive review paper on pesticide usage in relation to beekeeping in which they mentioned their pioneering work in 1958 on the bee vs. pesticide problem. At that time they found carbaryl to be twice as toxic as DDT to bees in the laboratory. Carbaryl was also found to be highly toxic in field tests, with a residual effect for bees of at least 5 d on alfalfa.

Martin (1970) of Michigan listed carbaryl in a similar category with residual effect of spray persistent for 3 d or less. Likewise, the Agricultural Research Service (USDA, 1972) placed carbaryl in the hazardous group relative to effects on honeybees.

Laboratory tests made to determine the oral toxicity of carbaryl to adult bees fed by microapplicator gave a 24 h LD_{50} of 0.178 μg/bee at 32°C (Alvarez et al, 1970). Shaw (1959) reported that residues of carbaryl applied at 1.0 lb active ingredient/100 gal water were highly toxic for 24 h after application. Argauer et al (1972) gave the 24 h posttreatment oral toxicity of carbaryl to honeybees as 50% at 0.2 μg/bee and 100% at 0.4 μg/bee.

Carbaryl applied to the thorax of honeybees had a 24 h LD_{50} of 1.0 - 0.2 μg/bee (Barker, 1970). The toxicity of carbaryl to worker honeybees was investigated at 70°, 80°, and 90°F [16°, 27°, 32°C]. Carbaryl exhibited a negative coefficient of toxicity in that it was 3.81 times as toxic at 60° as at 80°F (Georghiou and Atkins, 1964). The toxicity of 2 d field-weathered residues of carbaryl 80% WP applied at 1.0 lb active ingredient/acre showed a 24 h percent mortality of 82 to the alfalfa leafcutter bee, *Megachile rotundata*; 78 to the alkali bee, *Nomia melanderi*; and 69 to the honeybee, *Apis mellifera* (Johansen, 1972). Similar application rates produced 93% loss from 3-h old residues and 85% loss from 8-h old residues in honeybees.

Honeybees frequently work sweet corn tassels to obtain pollen. In some years, honeybee losses may be devastating when corn has been recently treated with carbaryl to control the corn earworm, *Heliothus zea*, or the European corn borer, *Ostrinia nubilalis*. The threat to honeybees of carbaryl used in this manner is controlled to a major degree by plant competition. Tests in Wisconsin when weather favored growth of volunteer white Dutch clover showed bee preference for this species. Corn pollen pellets (from carbaryl-treated fields) comprised only about 9% of the samples taken at two colonies (Moeller, 1971).

Pollen samples contaminated with 5% carbaryl dust at levels of 100 and 10 ppm were found to kill 49 and 7 times as many adult honeybees, respectively, as uncontaminated pollen. More than 10 wk after preparation, contaminated pollens were still toxic to bees that foraged on them (Moffett et al, 1970).

Analyses were made of corn pollen stored in beehive frames for 8 months and its subsequent effects on caged honeybees fed in sugar syrup. Three samples of corn pollen from poisoned colonies gave 72 h mortalities of 36, 38, and 39%. One sample contained 0.6 ppm carbaryl. This represented the first successful bioassay for carbaryl in pollen stores during the spring following applications made to corn the previous August (Johansen and Brown, 1972).

Feeding pollen in the hive during the tasseling period of corn virtually eliminated pollen collection from this source and greatly reduced the total collection of pollen by field honeybees. Colonies fed pollen collected only 4.3% corn pollen as compared to 53.4% for colonies without such feeding (Moeller, 1972)

Morse et al (1963) described a method for carbaryl analysis in bees and pollen. The following data show ppm of carbaryl recovered from trap-collected pollen pellets on hives in treated areas.

Year	Hours after application						
	12	36	60	84	108	156	204
1962	28.7	7.41	3.38	4.74	0.10	0.22	1.25
1960	7.20	5.02	0.52	1.32	0.88	0.76	1.06

Laboratory caged bees, as well as bee colonies under field conditions, were fed carbaryl-containing food solutions. A short 10 h study revealed that the amount of the pesticide chemical residue found in bees compared quite closely with the amount consumed, even though the amount of carbaryl found is less than 3% of the total amount of carbaryl consumed after the first 3 h of feeding. The 10 h study also showed that several hours can elapse before bees succumb to the contaminant in their food supply. In a long-term feeding study, bees were fed carbaryl-fortified solutions. Carbaryl residue in honey appears to be quite stable and its level even increases with time; however, the primary cause for the increase is believed to be evaporation of the water from the honey stored in the colony. The carbaryl residue content of bee bread correlates well with the amount of residue found in the bees and occurs in more concentrated levels than in honey throughout the 56 d period. The amount of carbaryl in bees decreases following the termination of the carbaryl fortification but detectable amounts of carbaryl residue are found at low levels, even up to 64 d later. The minimum detectable level of carbaryl residue in bee bread and honey was 0.001 ppm and in bees, 0.0005 ppm (Winterlin et al, 1973).

Aerial applications of 1.25 lb/carbaryl/acre were made on 73,610 acres in two counties in New York State. Twenty-one colonies of honeybees were placed in five locations within the treated area. Five check colonies were placed 3 1/4 miles outside the treated area. During the spray and postspray period of 47 d, treated colonies lost a mean of 19,917 bees while check colonies lost a mean of 2936 bees. Mortalities were above normal for up to 3 wk following the insecticide applications. Colony recovery was rapid (Morse, 1961).

Colonies of *Apis mellifera* placed in a poor forage area, 3.25 miles from an area being air-sprayed with carbaryl at the rate of 1 lb actual material/acre, suffered a minor loss of adult field bees; this was the greatest distance (by 1.25 miles) that had been observed by a loss of this nature (Morse and Gunnison, 1967).

The leafcutting bee, *Megachile rotundata*, is more susceptible than the honeybee to many compounds commonly used in pest control on alfalfa (Johansen et al, 1963). Carbaryl was listed in the highly toxic category although leafcutting bees were less susceptible to its effects in laboratory tests than honeybees. At low concentrations of carbaryl, honeybees were readily affected (LD_{50} of 1.27 μg/bee), but the dosage necessary to produce an LD_{50} to leafcutter bee females was 30.5 μg/bee in tests at Logan, Utah. This was later confirmed in greenhouse tests.

The success of alfalfa leafcutting bees as pollinators of alfalfa grown for seed in the western United States depends on the solution of two problems. One is the fact that this species is a frequent host for a large number of parasitic, predaceous, and scavenging insects. The other problem is insecticides. Much work has been done to determine the relative toxicity of insecticides to honeybees, *Apis mellifera*, but comparatively little is known of effects of insecticides on wild bees.

Alfalfa leafcutting bees were exposed to leaves of alfalfa, (used in nest building) that had been treated with carbaryl in field and greenhouse cages. The treated alfalfa leaves were the only nest-building material, and fiddle-neck, *Phacelia tanacetifolia*, was the only source of pollen and nectar. Only one of the two plant species was sprayed in each test.

Both adult females and larvae died when the alfalfa leaves were the only source of exposure to the insecticides. Larval mortality was at least as great when the contaminated alfalfa leaves were used to build cells as when the contaminated pollen and nectar were used to provision the cell. Adult mortality was greater when the insecticide was applied to the fiddle-neck flowers than to the alfalfa leaves. Azinphosmethyl was highly and DDT moderately toxic. Carbaryl was relatively nontoxic (Waller, 1969). There was 82% survival of larvae exposed solely to contaminated pollen and nectar; 74% larval survival when exposed to treated alfalfa foliage for nest material; 71% adult survival in field cages exposed to prebloom spray of carbaryl; and 87% survival of larvae under the latter conditions.

III.D.2. Effects on other beneficial insects. Sixty-one pesticides were tested in the laboratory against five parasitic hymenopterans and six predatory coccinellids; the data served as guides for selecting the best materials for destroying pests without undue harm to natural enemies. Test species were exposed in replicated tests to day-old residues of the pesticides under standardized conditions of dosage, temperature, and humidity. The single dosages applied were those most commonly used upon orchard crops. The contact toxicity of carbaryl, using 50% WP at 0.5 lb/100 gal deposited 6.44 $\mu g/cm^2$. Persistence was rated medium high and toxicity high to all 11 species (Bartlett, 1963).

The toxicity of 16 pesticides to all life stages of the predatory coccinellid, *Stethorus punctum*, resulted in a high number of survivors from all treatments except 0.05 lb active ingredient/100 gal carbaryl WP 50%, and 0.1875 lb active ingredient/100 gal carbofuran WP 75% when tested in an insectary. This ladybird beetle is one of the most important predators of the European red mite in south central Pennsylvania (Colburn and Asquith, 1971). There was no 48 h exposure survival of adults, eggs, or larvae, and only 60% survival of pupae at this dosage of carbaryl.

The toxicity of one-half and full-recommended orchard dosages of eight pesticides to the convergent lady beetle, *Hippodamia convergens*, was assessed in the laboratory and the field. Diazinon, carbaryl, parathion, and azinphosmethyl were highly toxic, allowing no survival after 6 h. Essentially 100% mortality of nondiapausing adults resulted after 48 h exposure in the laboratory to the residues of all eight pesticides. Both the high and low dosages of diazinon and carbaryl were highly toxic through 7 d exposure, but some beetles survived after exposure to 8 - 14-day-old residues. Percent survival of nondiapausing adults (2 d exposure to 2-day-old residues) was 88 and 67% for dosage rates of 0.125 and 0.25 lb active ingredient/100 gal, respectively (Moffitt et al, 1972).

The purpose of another study was to determine if *Bracon mellitor*, an ectoparasite of the boll weevil, *Anthonomus grandis*, possessed the physiological mechanism for developing a tolerance to the insecticides used to control the boll weevil. The potential resistance to insecticides of *Bracon mellitor* was determined by treating each of five test groups for five or more generations with an organic insecticide commonly used for the control of cotton insects. Fourfold increases in tolerance were noted in groups treated with carbaryl.

The results demonstrated that the parasite has a mechanism for developing resistance to insecticides (Adams and Cross, 1967).

The effects of the residues of 62 commercial pesticides upon the predatory phytoseiid mite, *Amblyseius hibisci*, were examined in the laboratory to obtain information on how this species may be protected in integrated chemical and biological control programs and how the effectiveness of this predator may be measured with pesticidal check procedures, i.e., by the host increase arising from the predator's elimination by pesticides. Almost all the organic phosphate and carbamate insecticides tested were moderately to highly toxic. Carbaryl used as the 50% WP formulation applied at a 0.5 lb/100 gal dosage rate gave a residue deposit of 6.44 $\mu g/cm^2$. Toxicity rating for *A. hibisci* was designated as high (=LT_{50} < 1 day) (Bartlett, 1964).

The toxicity of recommended and selective field rates of 23 commonly used pesticides was evaluated for several populations of *Amblysecius fallacis* from Michigan apple orchards. *Amblysecius fallacis* is a common phytoseiid mite found in regularly sprayed apple orchards in the central and eastern United States and Canada. In commercial apple orchards in Michigan, *A. fallacis* is the commonest predator associated with the European red mite, *Panonychus ulmi*; the two-spotted spider mite, *Tegranychus urticae*; and the apple rust mite, *Aculus schlechtendali*.

Carbaryl, when used as the 50% WP formulation and applied at 1.0 lb active ingredient/100 gal caused 100% mortality when tested against both azinphosmethyl susceptible and resistant strains (Croft and Nelson, 1972).

Typhlodromus occidentalis and *Amblyseclus fallacis* are important predators of spider mites on deciduous fruit crops in the U.S. and Canada. In addition to their potential as biological control agents, both predators have acquired resistance to insecticides, particularly the organophosphates. Carbaryl proved to be highly toxic to both species, the LC_{50} values of a 50% W formulation being 0.13 and 0.08 lb/100 gal water for *T. occidentalis* and *A. fallacis*, respectively (Croft and Stewart, 1973).

After collection from an apple orchard sprayed nine consecutive years with carbaryl and when evaluated by a slide-dip residue treatment, an *Amblyseclus fallacis* population exhibited a 24- to 77-fold resistance level to carbaryl. Following both independent and simultaneous selections with azinphosmethyl and carbaryl in the laboratory and hybridization with a similarly treated organophosphorus-resistant strain, a strain resistant to both chemicals was obtained and maintained for 10-25 generations in the laboratory. Possibilities for establishing this population in the field and its useful role in providing for biological control of spider mites in an integrated pest management program were suggested. Also, additional chemical selection trials with *A. fallacis* are reported (Croft and Meyer, 1973).

Chemical exclusion of the phytoseiid mite from apple foliage with carbaryl or DDT resulted in the occurrence of significantly higher densities of the European red mite, *Penonychus ulmi*, than were observed on trees treated with azinphosmethyl, dieldrin, or the control, when the predator was allowed to survive. Lack of significant differences among the population means of either predator or prey in the three last mentioned plots indicated that no other insect or mite predator was involved. A major factor responsible for the decline of *P. ulmi* populations in the control, azinphosmethyl, and dieldrin plots was predation by *T. fallacis*. Low populations of *Tetranychus urticae* responded in a different manner, a significantly greater number occurring only in the carbaryl plot (Swift, 1970).

Plants deficient in nitrogen and phosphorus were less favorable than normal plants for the twospotted spider mite, *Tetranychus urticae*, but were more severly damaged by the mite increases. Added amounts of nitrogen, phosphorus, and potassium in the soil, and various foliar nutrients did not appreciably affect the mites. Also, various fungicidal sprays and heavy residues of insecticides and fungicides in the soil had no marked effects on egg laying or mortality of the mites on peach seedlings. Carbaryl did not stimulate egg laying; therefore, such applications do not account for increases in mite populations observed to follow orchard treatments with this material. Carbaryl had no appreciable effect on mortality of the twospotted spider mite, but was very toxic to its important predator, *Typhlodromus* sp. (Harries, 1966).

Numerous pesticides are known to provoke outbreaks of a variety of mites and aphids. Some conditions surrounding these upsets were reviewed and the capabilities of 59 different pesticides to induce increases of mites and/or aphids were examined in relation to their individual effects on some major natural enemies of mites and aphids. When critical examination was made of the arguments for either of the two suspected causes of such pesticide-induced outbreaks, i.e., (a) natural enemy destruction and (b) pest fecundity stimulation, it appears that neither by itself offers a completely adequate explanation. Since one method now commonly used for evaluating natural enemy effectiveness relies on measurement of host increases in insecticidal check plots, this technique may credit the natural enemies with undeserved efficiency if the insecticide stimulates the pest's fecundity. Fifty-nine different materials were examined for their effect on the reproductivity of the twospotted spider mite, *Tetranychus urticae*. Among the materials showing some initial suppression of mites, carbaryl in three of four trials produced abnormal fold increases of mites about 4-6 wk after treatment. When applied at 0.5 lb active ingredient/100 gal water, carbaryl was highly toxic to all natural enemies of mites and aphids tested. The maximum period of toxicity retention was 1 wk for the twospotted spider mite and 3 wk for the cotton aphid (Bartlett, 1968).

Four strains of *Typhlodromus occidentalis* from different geographical areas were exposed to 10 compounds common to the control of apple pests in the western United States. The Washington strain of *T. occidentalis* when contrasted with strains from Utah and California, exhibited tolerance differences for four compounds including carbaryl.

Carbaryl applications, when compared with reports of field evaluation in the published literature, were less toxic in the laboratory test than expected. Toxicity differences among strains appeared to be due to selection arising from previous chemical treatments and to have resulted in cross-tolerant, tolerant, and resistant strains of *T. occidentalis*. Relative susceptibility of four strains of *T. occidentalis* expressed as LC_{50} values of mg/ml of technical carbaryl were: Oak Glen, Calif. - 0.31; Provo, Utah - 0.21; Riverside, Calif. - 0.35; and Wenatchee, Wash. - 0.52 (Croft and Jeppson, 1970).

The susceptibility of the predatory mite, *Agistemus exsertus*, to carbaryl was determined using the Potter tower technique. The following concentrations of formulation were tested against the egg, protonymph, and adult stages: 0.06 g, 0.17 g, 0.5 g, 1.5 g, and 4.5 g of pesticide in 100 ml water. Carbaryl had no toxic effect on the egg stage at any concentration rate. Protonymphs were more susceptible than eggs. Carbaryl was lethal to nymphs of *A. exsertus* but only at high doses which are not practical for use in the field. Carbaryl caused no mortality of adults at any concentration (Abo Elghar et al, 1971).

Technical and commercial preparations of carbaryl were tested against larvae of the lacewing, *Chryosopa rufilabris*, two days after they molted to the third instar. The third larval stadium was signigicantly lengthened in individuals surviving topical treatment with carbaryl. The pupal stage was significantly prolonged by topical applications of the technical pesticide. Emergence was lowest among individuals topically treated with azinphosmethyl and carbaryl. In decreasing order, residues of commercial azinphosmethyl, carbaryl, ethion + oil, ethion, carbophenothion, and chlorbenzilate reduce the numbers of individuals surviving to adulthood (Lawrence et al, 1973).

Two days after moulting to the third instar, larvae of the green lacewing, *Chrysopa rufilabris*, were exposed to technical and commercial formulations of five pesticides. Technical pesticides in decreasing order of toxicity to *C. rufilabris* larvae were: azinphosmethyl, carbaryl, ethion, carbophenothion, and chlorbenzilate. Residues of commercial azinphosmethyl 2 EC and carbaryl 50% WP had high and medium toxicity, respectively. Exposure to 1 d residues of 7.19 ml/l (wt. vol - g/l) gave 65% mortality for 48 - 168 h (Lawrence, 1974).

Laboratory studies were made on the effect of several insecticides on the spider, *Tarentula kochi* (Hagstrum, 1970).

Zectran® and parathion were very toxic, malathion and carbaryl less toxic, and methoxychlor nontoxic when applied topically to *Tarentula kochi* in the laboratory. The penetration, metabolism, and excretion of a 4 µl/spider dosage of carbaryl were studied and found to be about 1-5%, 0.10-0.7% and 0.01-0.01% of the applied dosage, respectively, for the N-^{14}C methyl label, and 7%, 2% and 0.8%, respectively, of the applied dosage for the 1-^{14}C naphthyl label. The percent penetration was increased to a range of 11-82% when only 0.2 µg/spider were applied. With all dosages, the internal recovery ranged from 0.017 to 0.239 µg/spider, of which 1-30% were conjugated metabolites. About 1-20% of the conjugated metabolites were excreted. When the spiders were fed flies treated with 0.5 µg carbaryl, mortality occurred in 15 min to 10 h, and 0.04-0.08 μg was recovered internally. These feeding studies showed that carbaryl was as toxic as Zectran and parathion, but that penetration had limited its toxicity with topical application.

Aerial application of insecticides for control of the gypsy moth was studied in relation to effects on nontarget insects and birds (Doane and Schaefer, 1971). A carbaryl formulation was applied at 1 lb/acre in a total volume of 1 qt oil/acre. Based on drop net collections indicating an average prespray larval density of 75 x 10^4 larvae/acre there was at least 99% kill of gypsy moth larvae in the plots. Reduction in the number of egg masses per acre was excellent.

Many different species of nontarget insects were affected by the insecticides. Leaf-feeding lepidopterans seemed equally susceptible to all three formulations. Sarcophagid and tachinid flies were not affected by carbaryl. Residues of Sevin 4 oil were tenacious and highly toxic to gypsy moth larvae for at least 8 wk. At 20 d after treatment residues of Sevin 4 oil were highly toxic to *Calosoma* beetle adults.

A P-generation of female *Tetranychus urticae* kept on residues of a 200 ppm spray of carbaryl, 100 ppm DDT, and 25 ppm dioxacarb showed significantly (carbaryl and DDT) higher egg totals than their untreated controls. With dioxacarb the increase of egg production was marginal in the statistical analysis. The ratio females/males in the F_1 was shifted in favor of the females in the broods reared on carbaryl and DDT residues, but not in the case of dioxacarb. This increase in the female proportion is highly significant, with the strongest shift for carbaryl and a lesser one for DDT. Adult females of the F_1 also had a significantly higher egg production on carbaryl and DDT than their untreated counterparts. Hormoligosis (stimulation by small quantities of a stressor) was assumed responsible for observed effects. There was no evidence of improved nutritional basis through the altered physiology of the host plant (Dittrich et al, 1974).

The effect of various insecticides on the egg parasite, *Trichogrammar semifumation*, and certain predators in Southern California was studied by Stern (1963). Three field tests were conducted to determine the effect of carbaryl on the egg parasite. The materials were applied at dosages commonly used for control of various pests of field and vegetable crops in California. Carbaryl was extremely toxic to the adult parasites, and to the parasites developing within *Colias eurytheme* eggs or to those attempting to emerge from the host egg. Demeton, trichlorfon, and mevinphos were nearly as toxic as carbaryl. Mevinphos and carbaryl were moderately toxic to *Geocoris* spp.

Carbaryl applied at 24 oz/acre was highly toxic to the developing host larvae in nonparasitized eggs and also to the parasites within the parasitized eggs. Those white or black eggs from which neither parasites nor host larvae emerged were dissected 30 days after they were collected. All eggs in the black egg sample, taken from both treated and untreated plots and from which nothing emerged, were found to contain dead parasites.

In the plots treated with carbaryl, a large number of eggs contained parasites which had chewed an emergence hole in the egg and then died inside the egg. Apparently, a sufficient amount of carbaryl residue persisted on the egg to kill the emerging parasites.

Levels of resistance to organophosphorus and carbamate insecticides in larvae of *Anopheles albimanus* within the cotton-growing area of El Salvador were studied over a 2-year period, 1970-72. Sampling was done in June and February of each year, i.e., at the beginning and end of the cotton-spraying season. Resistance to parathion, methyl parathion, fenitrothion, carbaryl, and propoxur was found to rise during the spray period and to decline somewhat during the nonspray period, revealing an escalatory pattern which attained remarkably high levels by February 1972. Organophosphorus resistance manifested a lower degree of decline than carbamate resistance under both laboratory and field conditions during the nonspraying season. This decline was attributed to unequal integration of the respective resistance genes with fitness factors (Georghiou et al, 1973).

The inactivation rate constants and the reactivation rate constants of insect cholinesterases inhibited by the carbamate insecticide carbaryl were measured. The inactivation rate constant of honeybee cholinesterase, inhibited by carbaryl, was five times larger than that of housefly cholinesterase. This difference in rate constants may explain the difference between bee and fly sensitivities to carbaryl. The reactivation rate constants of the inhibited enzymes were about the same for both insects (Kunkee and Zweig, 1965).

An investigation of the toxic effects from single concentrated doses of two carbamate degradation products, 1-naphthyl (hydroxymethyl) carbamate, and 1,5-dihydroxynaphthalene demonstrated a marked increase in death of embryos in eggs deposited from the 7th to 14th days after treatment of *Bracon hebetor* virgin females. Hatchability returned to normal levels about the 15th day after administration of the carbamates. Poor hatchability from the 7th to the 14th day was due to an increase in the proportion of embryos dying during cleavage (Stage 1 Death). This indicated the vulnerable cells of the ovariole sequence to be those undergoing mitosis, a finding consistent with the reports of damage to the mitotic apparatus by related compounds in other organisms. Egg production was decreased only slightly. The results were similar whether the females were injected with one of the agents or exposed to a residual deposit of it. The female wasps were derived from a wild strain originally collected in Raleigh, North Carolina (Grosch and Hoffman, 1973).

Applications of carbaryl and cryolite (sodium hexafluoroaluminate) altered the basic structure of the arthropod community associated with collards at Ithaca, New York. Population outbreaks of aphids occurred when carbaryl was applied at weekly intervals throughout the season. Aphid populations declined early on plots in which carbaryl applications were stopped in midseason. Extensive leaf injury caused by flea beetles was associated with low and declining aphid densities. The density of aphid predators increased after carbaryl was withdrawn. However, predators were relatively rare in all treatments. The percent of the aphids parasitized did not differ significantly on treated and untreated plots in the late season when the aphid outbreaks occurred. The authors suggested that reduced interspecific competition may have been an important factor in the complex chain of events that led to the aphid outbreaks (Root and Skelsey, 1969).

Several species of entomophthoraceous fungi have been reported infecting potato-infesting aphids in Maine, but their impact on the populations has been variable. Because these fungi have been recorded as causing dramatic reductions in aphid populations, they are potential biological control agents in an integrated pest management system. Their utilization must take into consideration their compatibility with pesticides, for instance, on potatoes in Maine it would be unreasonable to abandon the use of fungicides against early and late blight and *Phytophthora infestans*. It would be especially important to select a fungicide that would control blights without inhibiting the spread of insect-attacking fungi. Carbaryl effect at 1 pt/acre on media containing pathogens, expressed as percent of growth of the control, was 0, 27.7, 0, and 33.7 for four insect pathogens, and 42.7% for the potato pathogen, *Alternaria solani* (Soper et al, 1974).

The effect of carbaryl upon forest soil mites and Collembola was reported by Stegeman (1964). Test plots were established in a red pine plantation and in a mixed hardwood stand in the Tully Forest, situated about 25 miles south of Syracuse, New York. Dosage rates varied from 0 to 50 lb/acre, and one treatment was the carbaryl and malathion combined. Neither mites nor Collembola were totally exterminated by any treatment used. The reduction in population was roughly proportional to the severity of the treatment up to a dosage of 10 lb/acre. The 50 lb/acre treatment had little additional effect. The rate of population increase of the mites 4-5 months after treatment was directly proportional to the dosage applied; i.e., greatest where treatment was heaviest. The population of mites was far greater on treated plots than on the controls at the close of this experiment. Collembola are more sensitive to treatment than mites and do not recover so rapidly.

Effects of soil insecticides in southwestern Ontario on non-target invertebrates (earthworms in pasture) were reported by Thompson and Sans (1974). One year after treatment of pasture plots with nine insecticides, there were no statistically significant differences (P=0.05) between numbers of earthworms in treated and untreated plots. Chemical analyses of earthworms obtained 3 wk after application of the insecticides showed that carbaryl residues were negligible. After one year, residues of only DDT and its metabolites were detected in appreciable amounts. Carbaryl was not apparent above the levels of detection. Both biomass and numbers of arthropods within a grain crop-grassland ecosystem were reduced by more than 95% in a carbaryl-treated (2 lb/acre) area (Barrett, 1968). Arthropod numbers remained well below numbers in the untreated area for 5 wk, but after 7 wk the total biomass had returned to normal. Phytophagous insects (both Homoptera and Hemiptera), dominant at the time of spraying, were more severely affected than predaceous insects and spiders. The spiders were back to normal density within 3 wk after treatment. Long-term side effects on litter decomposition, and arthropod density and diversity were demonstrated.

Increased populations of tetranychid mites, following application of carbaryl for the control of other pests, are common occurrences (Pielou, 1962). These increases are often so great as to cause speculation that carbaryl, besides destroying predators, has a direct stimulatory effect on reproduction in mites. However, females of *Tetranychus telarius* exposed to carbaryl, either in the young stages, or as adults, did not show significant increases in the rate of egg production. Nor did carbaryl have any significant repellent effect. Increases noted in the field evidently were caused solely by elimination of predators.

In a study of the effect of carbaryl on the leafcutter bee's ability to synchronize its activity rhythm to the environment, there was no evidence of the clock being affected. Of the 24 bees studied, five showed a marked reduction in locomotor activity for up to 48 h. Web spinning behavior in the female spider was not affected by single applications of carbaryl, but the amount of silk available was reduced (Stephen, 1972).

III.E. Effects on soils and soil microorganisms

The effect of carbaryl on populations of bacteria, actinomycetes, fungi, and *Azotobacter* in an alluvial soil were investigated. Soil samples were incubated up to 60 d with various concentrations of the pesticide before microbial analyses were made. Normal field doses (1 ppm) did not adversely affect any microbial population. Higher doses (100, 1000, and 5000 ppm) reduced the bacterial population at various intervals. Actinomycetes were markedly reduced by carbaryl during the entire incubation. The highest dose of carbaryl (5000 ppm) mildly affected the fungal population. *Azotabacter* was adversely affected by carbaryl on the first day of incubation. Carbaryl at 1000 and 5000 ppm reduced nitrogen fixation by *Azotobacter chrococcum*. In general, the addition of organic matter to the soil reduced the deleterious effects of the pesticide (Gaur and Misra, 1970).

The decomposition of carbaryl by a bacterial strain was investigated. Two hundred ml of mineral salts medium containing 0.5% potassium (monoacid) phosphate, 0.02% magnesium sulfate (heptahydrate), 0.02% calcium chloride and 0.001% ferrous sulfate (heptahydrate) were incubated within 10 g of fertile soil and 0.02% carbaryl on a rotary shaker for 15 d. Culture samples were streaked on a mineral salts-agar medium containing 0.2% carbaryl and incubated for 5 d. One colony designated as S-1 was further streaked on the carbaryl-agar medium. Two 100 ml aliquots of carbaryl contained mineral salts media, one nitrogen-free and the other contained 0.05% ammonium sulfate; these were inoculated with a plant culture of the S-1 strain. Samples were obtained from the rotary-shaker cultures at 24 h intervals and analyzed to determine the concentration of carbaryl. One ml of the growing culture containing 200 ppm carbaryl or less was mixed with 2 ml of absolute ethanol and treated with 1 ml p-nitroaniline solution and 1 ml of sodium nitrate solution (5% in water). In the medium containing the culture with nitrogen, the concentration of carbaryl decreased from 350 to 256 ppm after 5 d incubation. In the medium without nitrogen, the carbaryl level decreased from 350 to 8 ppm. The acid-ether extract of the 10-day-old culture was chromatographed in a 100:5:10 (v/v) mixture of isopropanol, ammonia, and water. In addition to carbaryl, four spots with Rf's of 0.04, 0.15, 0.49, and 0.61 were observed. It is believed that the S-1 strain had a pathway similar to that known for the metabolism of naphthalene by a *Pseudomonas* sp. through salicylate. The unknown with an Rf of 0.61 ran in a similar way to that of salicylic acid and like salicylic acid gave a pink color with diazotized p-nitroaniline reagent (Tewfik and Hamdi, 1970).

A comparison of the effects of spraying with DDT, carbaryl or water on litter decomposition and litter fauna was made, using a litter bag method. During the 13-wk experimental period, no significant differences were found between the rate of decomposition in the litter receiving the three different treatments. Twenty-four hours after spraying, the number of Collembola was greatly reduced in the carbaryl plots. At the end of the experimental period, the reduction of fauna, other than mites or Collembola, was significant at the 0.01 level compared to the effects of carbaryl or water. A resurgence of litter organisms after insecticide treatment did not occur. However, the great reduction in fauna other than mites and Collembola suggests that such a flare-up could have occurred due to decreased predator pressure. The "other fauna" contains many important mite and Collembola predators. An increased number of mites and Collembola would probably cause an increased rate of litter decomposition due to their important role in breakdown of dead material (Bodtker and Kingsbury, 1970).

The fungus, *Gliocladum roseum*, isolated from soil, metabolized carbaryl to three metabolites which were isolated by thin-layer chromatography. They were identified as 1-naphthyl n-hydroxymethylcarbamate, 4-hydroxy-1-naphthyl methylcarbamate, and 5-hydroxyl-1-naphthyl methylcarbamate by ultraviolet, infrared, and mass spectroscopy. This proves that N-alkyl-and aromatic ring-hydroxylation of carbaryl are important detoxication reactions of the fungus. The decrease of radioactivity from the growth medium containing side-chain labeled carbaryl indicated also that a further degradation of the formed metabolites occurs, or that an additional pathway is involved in carbaryl metabolism (Liu and Bollag, 1971a).

Carbaryl was degraded in the laboratory by two common soil microorganisms, *Pseudomonas phaseolicola* and *Aspergillus niger*. When *P. phaseolicola* was exposed to 100 mg of the carbamate, 1-naphthol equivalent to 2 μg of carbaryl was found after 1 h. The values were 4.5 μg at 2 h, 10.5 μg at 6 h, 270 μg at 24 h, and 310 μg at 48 h. An intermediate was observed which had an Rf between those of carbaryl and 1-naphthol on TLC. In studies involving *A. niger*, 1-naphthol production was evident. However, because of interfering materials, the components could not be separated (Zuberi and Zubairi, 1971).

The metabolism of carbaryl by the soil fungus, *Aspergillus terrus*, was investigated. Of the four degradation products isolated, two found only in minute amounts were tentatively identified as 4-hydroxy-and 5-hydroxy-1-naphthyl methyl carbamate. The two predominant metabolites, each accounting for about 20% of the added radioactive label, were identified as 1-naphthyl N-hydroxymethyl carbamate and 1-naphthyl carbamate. The metabolites began to appear at 2 d and peak accumulations were observed at 6 d. Each compound was decomposed to 1-naphthol, but it was not determined whether chemical or biological degradation was responsible. *A. terrus* further metabolized 1-naphthol (Liu and Bollag, 1971b).

The biological degradation of 1-naphthol was studied during growth, with replacement cultures and cell extracts of the fungus, *Fusarium solani*. Radioactivity of 1-naphthol-1-^{14}C disappeared partially during growth, but was completely dissipated by cell-extract activity. More than 80% of $^{14}CO_2$ evolved was collected after 60 min incubation in a cell-extract experiment. The active enzymes seem to be constitutive inasmuch as 1-naphthol was metabolized with cells not cultured on an inducing substrate. No difference in activity could be observed between cell-free extracts prepared from spores or mycelium of the fungus (Bollag and Liu, 1972).

The persistence and metabolism of ^{14}C-carbonyl-labeled carbaryl and 3,5-xylyl methylcarbamate were studied in five different soil types at two concentrations. Persistence was influenced by soil type, and $^{14}CO_2$ evolution varied from 2.2 to 37.4% of initial radioactivity during 32 d of incubation. Hydrolysis was the main pathway of degradation since very low concentrations of ^{14}C-carbonyl metabolites were detected. $^{14}CO_2$ evolution from ^{14}C-1,4,5,8-ring-labeled naphthol in soil was only 8.2% after 60 d. More than 70% of radioactivity was found to be linked to humic substances. Four metabolites, one of which was coumarin, were produced from ring-labeled naphthol by a soil pseudomonad (Kazano et al, 1972).

The effects of pesticides on the growth and survival of 16 different strains of bacteria were studied. The minimum effective inhibitory concentrations were high, ranging from 100 to 1600 ppm for carbaryl. A considerable increase was observed with increasing contact time in the bacteriostatic and bactericidal power, even with initially ineffective pesticide concentrations. The minimum effective inhibitory concentration decreased sharply during a second exposure. Carbaryl in concentrations of 1 and 0.1 ppm reduced the percentage of surviving bacteria to 50%. None of the pesticides in 0.1 ppm concentration affected survival of bacteria (Allegrini et al, 1972).

Thin-layered chromatography and identification of radiolabeled spots were used to investigate the metabolism of carbaryl by a number of soil fungi. The uninoculated control medium was found to contain 1-naphthol after 5 d, indicating chemical decomposition. Most culture filtrates contained hydroxylated derivatives. 1-Naphthyl N-hydroxymethylcarbamate was the major metabolic product found although *Penicillium* sp., *Mucor* sp., and *Rhizopus* sp. tended to hydroxylate in the ring position. In all the cultures, a decrease of radioactivity from carbaryl corresponded with the amount of metabolites formed (Bollag and Liu, 1972).

Seventeen fungal species from Wisconsin prairie soils were grown on nutrient media treated with aldrin, lindane, parathion, phorate, or carbaryl. All five insecticides inhibited to some extent the growth of most fungal species; this inhibition was a result of a particular insecticide-fungus combination. Threshold concentrations of insecticides, at which no decrease in growth of *Aspergillus fumigatus* or *Fusarium oxysporum* occurred, differed for each insecticide and also for each of the two fungi. Since most insecticides had some fungicidal effect, it was not surprising that none of the 17 fungi was able to utilize any of the insecticides as a carbon or phosphorus source. Carbaryl at 20 μg/ml inhibited growth of *F. oxysporum* by 37 - 44%. However, the addition of yeast extract, asparagine, ammonium sulphate, ammonium nitrate, or ammonium sulphamate to the culture media resulted in a complete suppression of the growth-inhibitory effect of carbaryl. Replacement of yeast extract with a vitamin mixture had no effect; fungal growth was still inhibited. These data, given by Cowley and Lichtenstein (1970), are shown in Table III.E.

Table III.E. Effect of carbaryl (at 40 μg/ml in basic culture medium) on the growth and sporulation of various soil microfungi

Dry weight as % of control (culture medium + 0.2% ethanol)

Fungus	Carbaryl
Acrostalagmus sp.	79 ± 7.0[a]
Aspergillus fumigatus	52 ± 10.6[a]
A. terreus	35 ± 3.8[a]
Emericellopsis sp.	25 ± 2.7[a]
Fusarium oxysporum	27 ± 3.6[b]
Myrothecium strigtosporum	32 ± 4.8[a]
Thielaviopsis sulphurellum	27 ± 3.1[a]
Penicillium janthinellum	43 ± 3.9[a]
P. javanicum	- - - - -
P. lilacinum	44 ± 3.2[a]
P. nigricans	8 ± 3.5[ab]
P. restrictum	72 ± 6.5 [a]
P. roseo-purpureum	61 ± 3.1 [a]
P. simplicissimum	77 ± 4.1 [a]
P. thomii	6 ± 0.3 [ab]
P. variabile	51 ± 5.4 [a]
Paecilomyces marquandii	98 ± 3.9

a = inhibition significant at 1% level.
b = decreased sporulation as compared to control.
Source: Cowley and Lichtenstein (1970).
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A suspension of 0.1% carbaryl was found to be extremely toxic to earthworms (An der Lan and Aspöck, 1962). The same authors later reported that carbaryl was highly toxic to fish (*Lebistes reticulatus*), earthworms, Helicidae, oligochetes, and *Turbellaria*, while only slightly toxic to some mollusks (Aspöck and An der Lan, 1963).

III.F. Fate in water

The fate of Sevin carbaryl insecticide in farm pond waters was studies under laboratory conditions. Carbaryl was found to chemically hydrolyze to 1-naphthol very rapidly in pond water. This hydrolysis was catalyzed by organic and inorganic constituents in the pond water with substantial enhancement of the hydrolysis reaction resulting from shaking. Loss of 1-naphthol after hydrolysis in sterile controls suggested volatilization or chemical degradation.

After enrichment procedures, a bacterial isolate, possibly a *Flavobacterium*, was found to rapidly degrade the hydrolysis product, 1-naphthol. With small numbers of the bacterium added to the pond water, 20 ppm of 1-naphthol were degraded within 12 d. The addition of higher numbers of the bacterium increased the rate of decomposition of 1-naphthol. Addition of a readily available carbon source, glucose, also increased the rate of insecticide decomposition. In pond water containing native bacteria in addition to the insecticide-decomposing bacterium, only the latter proliferated with most other bacteria disappearing, indicating lack of tolerance to the insecticide. Thin layer chromatography showed three intermediate degradative products of carbaryl in addition to 1-naphthol. Two compounds, o-hydroxycinnamic acid and salicylic acid were identified. One compound was not identified. No large accumulation of any product indicated further decomposition of the intermediates probably via the TCA cycle (Hughes, 1971).

The monoalkyl carbamate insecticide, carbaryl and propoxcur, and the dialkyl carbamates, pyrolan and dimetilan, were analyzed in aqueous media. Rates of hydrolysis were measured with different hydroxyl ion concentrations. The dialkyl carbamates were more stable to hydrolysis than the monoalkyl carbamates. The rates of hydrolysis at different pH values were also studied. Within the acidic pH range, all compounds were stable to hydrolysis. However, at pH 7.0 and 8.0 measureable hydrolysis was observed for carbaryl and with rise of pH, the rates of hydrolysis increased. About 99% of carbaryl was hydrolyzed in 9 d at pH 8.0. The temperature effect on hydrolysis was also investigated. The persistence of the carbamate pesticides in natural waters is greatly influenced by pH value and temperature of aquatic environment (Aly and El-Dib, 1971).

A three-year study (June 1966 - November 1968) was conducted to determine the extent of residues caused by spraying carbaryl for gypsy moth, *Porthetria dispar*, control in the Shackham Brook forest preserve, Tully, New York. The rate of application was 1.0 lb/acre and covered 365 acres of the 1966-acre study area. The study consisted of laboratory analysis of water, insect, and soil samples for the presence of carbaryl or its major breakdown product, 1-naphthol. Also, field samples of aquatic insect larval and naiad forms were taken to establish population levels before, during, and after the spray operation. Seven orders of aquatic insects were sampled.

The first year of the study was devoted to establishing prespray population levels and analyzing field samples for carbaryl and

1-naphthol. Soil and insect samples for laboratory analysis were taken once a year during the first and third years and twice during the second year. On June 9 of the second year, insecticide application was made and sampling continued. During the third year, sampling was continued as in the first year. LC_{50} studies were conducted on Odonata to determine a general level of carbaryl in the water needed to cause mortalities.

Analysis of population levels during the study period showed no fluctuations associated with insecticide runoff. Fluctuations that did occur seemed to be the result of water levels and temperature as influenced by seasonal changes. Laboratory analyses of field samples were negative and showed no residues above the 0.1 level. The results of the dosage-mortality studies on Odonata revealed LC_{50}'s of 1.9 in 18 h and 1.7 in 24 h. Levels of this magnitude would have been detected in field samples. In the Shackham Brook forest preserve, neither carbaryl nor its prime metabolite appeared to be present in the watershed (Felley, 1971).

Colorimetric and radiometric analyses were used to study the persistence of carbaryl in estuarine water and mud in laboratory aquaria held at two temperatures. In the absence of mud, the carbaryl concentration decreased approximately 50% in 38 d at 8°C. Most of this decrease was accounted for by the production of 1-naphthol. At 20°C, after 17 d, the carbaryl had almost completely disappeared, with 43% converting the 1-naphthol. When mud was present, both carbaryl and 1-naphthol declined to less than 10% in seawater in 10 d.

Both compounds were adsorbed by mud, where decomposition continued at a slower rate. Radioactive carbon dioxide was produced in the aquaria containing ^{14}C carbonyl-labeled and ^{14}C ring-labeled carbaryl, indicating decomposition by hydrolysis of the carbamate and oxidation of the naphthyl ring. The total recovery of the ^{14}C activity was only 40%. It is postulated that much of the remainder was evolved as methane. In a preliminary field experiment which treated a portion of a mudflat with carbaryl at rates similar to those used in the control of oysterbed pests, carbaryl could be detected in the mud for 42 d. 1-Naphthol persisted in significant quantities for only one day. Results presented here permit the drawing of certain conclusions. At low temperatures and under conditions where adsorption by mud is prevented, carbaryl will be degraded slowly, persisting for several weeks. One product of decomposition under these conditions is 1-naphthol, which is converted to unknown products by the action of light. The above processes are accelerated at higher temperatures.

When carbaryl is applied experimentally to shallow mudflats for oyster pest control, the pesticide is likely to be rapidly removed from water by adsorption on bottom mud. Degradation proceeds in this medium, ultimately to the rupture of the naphthyl ring to produce carbon dioxide and, possibly methane. Intermediate products in the degradation process are polar compounds arising from modifications of the naphthyl portion of the carbaryl molecule. Even with such processes, however, carbaryl and 1-naphthol are likely to persist in mud for 2 - 6 wk (Karinen et al, 1967). These data are given in Table III.F.

Table III.F. Carbaryl and 1-naphthol concentrations in mud from mudflats treated with 80 wettable carbaryl at 10 pounds of active ingredient per acre

	Concentrations of carbaryl				
	Top 1 inch		2-3 inch level		4-6 inch level
Days after treatment	Total,[a] ppm	As carbaryl, ppm	Total,[a] ppm	As carbaryl, ppm	Total,[a]
0	10.7	5.4	0.34	0.32	b
1	3.8	3.3	0.46	0.46	b
2	4.1	5.2	0.35	0.27	0.06
4	1.5	1.5	0.18	0.18	b
8	2.1	2.2	0.54	0.38	0.04
16	0.5	0.3	0.13	0.10	0.12
42	0.1	0.1	0.20	0.20	0.08

a Includes carbaryl and 1-naphthol calculated as carbaryl.
b Sample not analyzed.
Source: Karinen et al (1967).

Stewart et al (1967) reported that carbaryl dissolved in seawater was hydrolyzed to 1-naphthol at approximately 20% per day at 20°C and a pH of about 8. Hydrolysis was accelerated by temperature increases between 4 and 28°C and by exposure of the solutions to sunlight. Breakdown of 1-naphthol dissolved in seawater also was influenced by temperature and sunlight. However, 1-naphthol solutions not exposed to sunlight remained unchanged for 24 h or more at 20°C. The instability of carbaryl in a marine situation makes it important to compare its toxicity with that of 1-naphthol.

III.G. Fate in air

Irradiation of crystalline carbaryl of 50% wettable powder with sunlight or even with prolonged exposure to intense ultraviolet light produced no decomposition of the insecticide. Sunlight or weak ultraviolet irradiation of the compound in hexane or alcohol solutions for 1-3 h generated one minor cholinesterase-inhibiting decomposition product and a small amount of 1-naphthol (Crosby et al, 1965).

III.H. Fate in plants

At normal insecticidal doses, carbaryl has no adverse effect on plants. Elevated dosages do not normally cause phytotoxicity but in combination with organophosphates occasional phytotoxicity has occurred. Spray deposits are eroded primarily by rainfall. Surface residues are also lost by wind, volatilization, and absorption. The small percentage of carbaryl absorbed is metabolized to products less toxic than the parent carbaryl. The major residues of carbaryl remain on the plant surface and degrade with a half-life of 3 or 4 d. One interesting exception is the utilization of carbaryl as a fruit thinner for apples, an observation not repeated on any other crops for which its use is registered.

III.H.1. Movement, metabolism, and persistence in plants: Combined colorimetric analyses and bioassays (green rice leafhopper) clearly demonstrated that carbaryl added to the soil of pots containing growing rice plants was translocated into the aerial plant parts. Leaf blades accumulated maxima of 11 and 25 ppm from doses of 50 and 100 mg of carbaryl per pot, respectively. Biological activity was evident for 4 wk after transplanting into fresh soil. Results from field experiments closely paralleled those of laboratory studies (Masuda and Fukuda, 1961).

Distribution of C^{14}-labeled carbaryl in rice plants indicated primary movement from roots into leaf blades with little downward translocation. Root-dipping experiments resulted in greater uptake of carbaryl than through direct application to leaf blades or sheaths. Studies involving incorporation of carbaryl into various soil types suggested differential uptake which was dependent on soil composition, water content, degradation by microorganisms, and volatilization of the compound (Fukuda and Masuda, 1962).

Injection of C^{14}-labeled carbaryl into bean and cotton plants resulted in first-order degradation curves with a 3 - 7 d half-life value for the administered compound. The rate of loss varied with the plant species, and the C^{14} fragments released remained in the plant in an uncharacterized form (Casida, 1963a).

Carbaryl applied only to spur leaves of apple (var. Red Delicious) resulted in slight thinning response; applied to fruit only, heavy thinning occurred. Radioactive carbaryl applied to leaf or fruit surface moved into the vascular tissue of fruit with little detectable activity in seeds even after extended holding periods. Extraction of fruit and leaves followed by paper chromatography revealed unaltered carbaryl and an uncharacterized water-soluble compound containing both the naphthyl ring and carbonyl tagged moiety. It was postulated that carbaryl interfered with growth fractions in the vascular tissue of the fruit causing fruit abscission (Williams and Batjer, 1964).

Bean and cotton plants injected with carbaryl-C^{14} rapidly converted the insecticide to unidentified water-soluble products. The organosoluble fraction, which contained only unchanged carbaryl, comprised 59% and 6% of the applied radioactivity at 7 and 28 d, respectively. Total recovered radioactivity in the plant at these same time intervals was 87% and 55%, respectively (Dorough and Casida, 1964).

No evidence of free carbaryl metabolites characterized from animal studies was detected in the water-soluble fraction derived from homogenized cotton or bean plants injected with C^{14}-labeled carbaryl (Casida, 1963b).

Colorimetric analysis of carbaryl residues was accomplished by hydrolysis of the carbamate to 1-naphthol, and coupling this product with p-nitrobenzenediazonium fluoborate for color development. Accumulated analytical data showed the normal half-life of carbaryl on growing crops to be 2-4 d, and in soil approximately 8 d under normal conditions (Johnson and Stansbury, 1965).

Rates of loss of carbaryl varied from different substrates. At ambient temperatures, a half-life of 14 h was determined on glass plates; under normal sunlight, the half-life from bean leaves was 68 h. The loss curves were linear for the first 80-90% of loss indicating a direct escape of carbaryl rather than conversion to a more volatile species. From 0.5-1% of the dose on the leaf surface was converted to an unidentified compound that dissipated with time. Irradiation of carbaryl on a silica gel-coated plate with long-wavelength ultraviolet light produced no decomposition. Irradiation with short wavelength ultraviolet gave a ninhydrin positive spot which did not move from the origin on TLC analysis.

In a series of experiments carbonyl-labeled carbaryl was injected into the stems of 10-day-old (2 primary leaves), growing snap bean plants, and periodic harvests, homogenizations, and extractions were made. The following data were obtained: at 20 min after injection, 99% of the radioactivity was recovered as carbaryl; this declined with time to 5% at 6 d (half-life was 34 h). The remaining activity was divided approximately equally between the water-soluble extractives and the unextracted residues; less than 1% of each was present at 20 min, more than 38% of each at 6 d. An increasing loss of radioactivity was sustained over the period of the experiment and totaled 21% at 6 d (Abdel-Wahab et al, 1966).

Carbaryl labeled with C^{14} in the carbonyl and N-methyl positions was introduced into cotton in an aqueous solution through the roots and 40-47% of the total dose was readily distributed throughout the leaves, stems, and roots. Fifty percent of the insecticide entering the plant in 3 d was altered. Forty-seven percent of the alteration involved hydrolysis of carbaryl as evidenced by the evolution of $C^{14}O_2$ and the detection of free 1-naphthol (colorimetrically with 4-aminoantipyrine). Investigation of the liberated methylamine indicated 3% of the absorbed carbaryl was eliminated as a basic volatile substance (probably methylamine), 20% was changed into a water-soluble compound, and 40% was oxidatively degraded to CO_2. The 53% of the total metabolism was achieved nonhydrolytically as evidenced by recovery of the intact carbamate carbon skeleton labeled in both the ring and chain sites. This alteration was proposed to be the result of ring hydroxylation (Mostafa et al, 1966).

In a study by Kuhr and Casida (1967), carbaryl-C^{14}, labeled in the ring in the carbonyl position, and in the N-methyl group, was injected into growing bean plants and harvested serially in relation to time. Balances of unchanged carbaryl, the radioactivity distributed in the aqueous phase, insoluble residue, and loss were determined at 0, 1, 3, and 6 d postinjection. The figures were similar to those reported earlier and the position of the radiocarbon had only minor effects in the distribution of the radioactivity among the plant fractions after injection.

The water-soluble conjugates were characterized by concentrating the extracts and incubating with β-glucosidase or with glusulase. The aglycones were compared (TLC) with authentic samples of known carbaryl metabolites: identified aglycones included the 1-naphthyl (hydroxymethyl) carbamate, the 4-hydroxy-, the 5-hydroxy-, and the 5,6-dihydro-5, 6-dihydroxy- (tentative) carbaryls, all previously shown to be involved in the mammalian metabolism of carbaryl. Glycosides of 1-naphthol were also present, indicating that some hydrolysis of carbaryl had occurred. The presence of different sugars complexed with each of the various aglycones precluded good resolution on TLC plates (each chromatographic zone yielded most of the same metabolites after reaction with β-glucosidase). None of the sugar residues was specifically identified. The rate-limiting reaction in the plant must be the hydroxylation of the carbamates rather than the glycoside formation because unconjugated aglycones were present only in small amounts, if at all, in the plant (Kuhr and Casida, 1967). The relative distribution of C^{14}-labeled aglycones released from a water-soluble extract of growing bean plants 6 d after injection with carbonyl-labeled carbaryl is shown in Table III.H.1..

Table III.H.1. Distribution of C^{14}-labeled aglycones from water-soluble extract of bean plants

Compound	Rf value	% Recovered radioactivity
Unknown	0.00	4.9
Dihydrodiol[a]	0.18	15.6
Unknown	0.38	1.5
Methylol[b]	0.52	18.1
4-hydroxycarbaryl	0.55	33.0
5-hydroxycarbaryl	0.60	25.4
Unknown	0.71	0.5
Carbaryl	0.76	1.0
1-naphthol	0.95	c

[a] 5,6-dihydro-5, 6-hydroxycarbaryl.
[b] 1-naphthyl (hydroxymethyl) carbamate.
[c] detected only in experiments with naphtyl-labeled carbaryl.
Source: Kuhr and Casida (1967).
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Carbonyl-labeled carbaryl was applied by brushing both leaf surfaces and by spraying cocoa seedlings in three different seasons (dry, wet, and intermediate). The plants were harvested, homogenized, and assayed at various intervals. An average of 1.75% of the applied dose was found to be translocated from the treated area to other parts of the plant. Distribution of radioactivity from roots through the stem increased exponentially. Maximum translocation occurred in apical regions and areas of active growth; flush leaves were more radioactive than young leaves which in turn were more radioactive than mature leaves, indicating a continual redistribution of insecticide or metabolites toward growing and tip regions. Carbaryl uptake in cocoa was slow and the highest levels of radioactivity were observed 35-45 d after treatment. This was followed by a rapid loss of C^{14} between 45-70 d; the 1-2% radioactivity remaining beyond 70 d suggested that persistent metabolites were present in low concentrations. There were no significant differences in the amounts of carbaryl translocated in the dry, wet, or intermediate seasonal conditions (Sundaram and Sundaram, 1967).

Bean seedlings were treated by stem-injection with naphthyl-1-C^{14}-carbaryl followed by serial harvests at preselected intervals. The metabolites were extracted from the plants with acetone, and then partitioned into organo-and water-soluble fractions. Carbaryl was found to metabolize most efficiently at dose levels at or below 50 μg/plant, and had a half-life of about 3 d under these conditions. The disappearance of carbaryl was attended by a simultaneous increase in water-soluble conjugates and unextracted products. Without exception, the organosoluble metabolites were found to consist solely of unaltered carbaryl. Treatment of the water-soluble conjugate mixture with hot, dilute hydrochloric acid liberated 87% of the radioactivity as organosoluble aglycones. These aglycones were reported as carbaryl (6.2%); 1-naphthol (11.7%); 5-hydroxy-carbaryl (13.0%); 4-hydroxycarbaryl (24.5%); 1-naphthyl (hydroxymethyl) carbamate (21.8%); and water-solubles (22.8%) (Dorough and Wiggins, 1969).

Carbaryl-1-naphthyl-C^{14} was applied uniformly over the surface of bean leaves and fruit by dipping them in a preparation containing the insecticide in 15-20% aqueous acetone. Surface residues found to be almost entirely unchanged carbaryl dissipated with a half-life of about 1 wk. Extraction of internal radioactivity was followed by partitioning the residues into organosoluble and water-soluble fractions. The former, consisting entirely of unchanged carbaryl, was never greater than 5% of the applied at any period after application, and decreased rapidly with time. The water-soluble metabolites, consisting of glycoside conjugates, liberated their organosoluble aglycones after treatment with glycosidase and cellulose enzymes followed by hot, dilute hydrochloric acid. Aglycones formed in bean leaves are reported in Table III.H.2.

Table III.H.2. Residues in ppm on indicated days after application of carbaryl (exaggerated rate)

Aglycone	1	3	7	12	16
1-naphthol	0.64	3.9	5.6	6.8	4.4
Carbaryl	0.52	2.2	2.5	2.6	1.4
5-hydroxycarbaryl	0.30	1.7	3.2	3.7	2.7
4-hydroxycarbaryl	0.32	3.2	6.3	9.3	5.6
7-hydroxycarbaryl	1.00	6.8	10.5	13.5	11.2
Methylol[a]	1.30	7.6	11.3	14.8	10.9
Dihydrodiol[b]	0.20	0.7	1.1	1.6	0.7
Origin	0.30	2.1	3.4	5.4	4.0

[a] 1-naphthyl (hydroxymethyl) carbamate.
[b] 5,6-dihydro-5, 6-dihydroxycarbaryl.
Source: Wiggins et al (1970).

In mature fruit, 1-naphthyl (hydroxymethyl) carbamate was again the dominant aglycone, followed by 1-naphthol. The 7-hydroxy-carbaryl derivative, which has not been previously reported, was found only in trace amounts. Acute peroral LD_{50}'s and 7 d feeding no-ill-effect levels for rats are shown in Table III.H.3.

Table III.H.3. Toxicity of carbaryl and derivatives from plants

Compound	Male rat acute peroral LD_{50} (mg/kg body wt)	Rat 7-day no-ill-effect level (mg/kg body wt)	
Carbaryl	270	> 125	< 250
4-hydroxycarbaryl	1190	> 1000	
5-hydroxycarbaryl	297	> 1000	
7-hydroxycarbaryl	4760	> 1000	
1-naphthyl (hydroxymethyl)-carbamate	< 500	> 250	< 500
1-naphthol	2590	> 500	<1000

Source: Wiggins et al (1970).

An indirect estimate of the toxicity of 5,6-dihydro-5, 6-dihydroxy-carbaryl was obtained through its in vivo formation in rats. Thus, rats showing no ill effects at 10 mg/kg/d of carbaryl were considered to have shown no ill effects from 0.8 mg/kg/d of 5, 6-dihydro-5, 6-dihyroxy-carbaryl since this metabolite accounts for at least 8% of the dose (Wiggins et al, 1970).

Effects of a 2-lb/acre single application of carbaryl to a drop of millet, *Panicum ramosum*, in comparison with a 1-acre control plot were studied by Barrett (1968). Carbaryl residues on plants decreased rapidly from 35 ppm on the first day following spraying to 0.37 ppm on the 16th day. No insecticide effect could be detected on crop production, which averaged for the two areas 567 g dry wt/m^2 for the season or 3.9 g/d.

Huddleston and Gyrisco (1960) studied the residues remaining on forage crops following aerial application of 1 gal carbaryl kerosene mixture (1 lb carbaryl) per acre. Data presented in Table III.H.4. indicate a rapid loss of carbaryl when applied at this rate.

Table III.H.4. Residues of carbaryl and 1-naphthol remaining on legume-grass foliage for various intervals following aerial application, Fulton, N.Y., 1958.

	Residue in ppm remaining on foliage			
Days after application	Carbaryl Rep I	Carbaryl Rep II	1-naphthol Rep I	1-naphthol Rep II
0	34.67	30.37	0.02	0.01
1	15.87	13.67	0.03	0.05
3	14.47	13.57	0.02	0.02
5	10.27	4.27	0.12	0.00
8	1.97	1.97	0.00	0.00
14	0.30	0.97	0.00	0.00
21	0.09	0.23	0.00	0.01
28	0.10	0.10	0.00	0.00
49	0.09	0.08	0.00	0.00

Source: Huddleston and Gyrisco (1960).
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An investigation by Stadnyk et al (1971) evaluated the effects of pesticides on low-density populations of a freshwater alga in terms of changes in growth and metabolism rather than death. They measured the effects of pesticides on cultures of the plankton alga, *Scenedesmus quadricaudata*, as changes in cell biomass, cell number, and carbon-14 assimilation. The most conspicuous effects of pesticides on algal subcultures of *Scenedesmus quadricaudata* were found with the herbicide diuron and the insecticide carbaryl. Carbaryl stimulated cell growth concomitant with an increase in carbon assimilation. Cell biomass at the end of 6 d had increased 44-57% in the 0.1- and 1.0 mg/l treated subcultures as opposed to the controls. A dramatic stimulation of carbon assimilation was noted at the 2-d sampling period of the 1 mg/l culture.

Butler (1963) and Ukeles (1962) showed carbaryl to be toxic to marine phytoplankton. However, these investigators (i.e., Stadnyk et al, 1971) found a marked stimulation of cell growth and carbon fixation in *Scenedesmus*. Perhaps this effect was the result of an increased N source arising from the degradation of carbaryl. Hydrolysis of the ester linkage followed by successive decarboxylation and oxidative demethylation of the N-methyl carbamic acid moiety would release NH_3 and formic acid which could increase the N source (Hassan et al, 1966).

Literature Cited

Abdel-Wahab, A.M., R.J. Kuhr, and J.E. Casida. Fate of C^{14}-carbonyl-labeled aryl methylcarbamate insecticide chemicals in and on bean plants. J. Agric. Food Chem. 14(3):290-298. 1966.

Abo Elghar, M.R., E.A. Elbadry, S.M. Hassan, and S.M. Kilany. Effect of some pesticides on the predatory mite *Agistemus exsertus*. J. Econ. Entomol. 64(1):26-27. 1971.

Adams, C.H., and W.H. Cross. Insecticide resistance in *Bracon mellitor*, a parasite of the boll weevil. J. Econ. Entomol. 60(4):1016-1020. 1967.

Alabaster, J.S. Survival of fish in 164 herbicides, insecticides, fungicides, wetting agents and miscellaneous substances. Int. Pest Control 11(2):29-35. 1969.

Allegrini, J., M.S. de Buochberg, M. Zuccarelli, and B. Soulié. Study of the toxicity of three different types of pesticides to some bacteria involved in the biological purification of waste waters. Trav. Soc. Pharm. Montp. 32(1):65-73. 1972.

Alvarez, C.C., H. Shimanuki, and R.J. Argauer. Oral toxicity of carbaryl to adult honey bees. J. Econ. Entomol. 63(6):1834-1835. 1970.

Aly, O.M., and M.A. El-Dib. Studies on the persistence of some carbamate insecticides in the aquatic environment. I. Hydrolysis of Sevin, Baygon, Pyrolan and Dimetilan in waters. Water Res. 5(12):1191-1205. 1971.

An der Lan, H., and H. Aspöck. The effect of Sevin on rainworms. Anz. Schädlingskd. 35:180-182. 1962.

Anderson, L.D., and E.L. Atkins, Jr. Pesticide usage in relation to beekeeping. Annu. Rev. Entomol. 13:213-238. 1968.

Anderson, L.D., E.L. Atkins, Jr., H. Nakakihara, and E.A. Greywood. Toxicity of pesticides and other agricultural chemicals to honey bees. Field Study. University of California, Agricultural Extension Service, Riverside, California. 1971. 8 pp. [Bull. AXT-251]

Argauer, R.J., R.E. Redfern, and H. Shimanuki. Relative toxicity of several carbamates to the honey bee and the large milkweed bug. J. Econ. Entomol. 65(3):924-925. 1972.

Armstrong, D.A., and R.E. Millemann. Effects of the insecticide carbaryl on clams and some other intertidal mud flat animals. J. Fish. Res. Board Can. 31(4):466-470. 1974.

Aspöck, H., and H. An der Lan. Ecological effects and physiological peculiarities of the plant protection chemical Sevin (1-naphthyl-N-methylcarbamate). Z. Angew. Zool. 50(3):343-380. 1963.

Atkins, E.L., Jr., L.D. Anderson, H. Nakakihara, and E.A. Greywood. Toxicity of pesticides and other agricultural chemicals to honey bees. Laboratory studies. University of California, Agricultural Extension Service, Riverside, California. 1970. 26 pp. [Bull. M-16]

Barber, T.A., and J.G. Nagy. Effects of pesticides on mule deer rumen bacteria. Trans. N. Am. Wildl. Nat. Resour. Conf. 36:153-162. 1971.

Barker, R.J. Cholinesterase reactivators tested as antidotes for use on poisoned honey bees. J. Econ. Entomol. 63(6):1831-1834. 1970.

Barrett, G.W. The effects of an acute insecticide stress on a semi-enclosed grassland ecosystem. Ecology 49(6):1019-1035. 1968.

Bartlett, B.R. The contact toxicity of some pesticide residues to hymenopterous parasites and coccinellid predators. J. Econ. Entomol. 56(5):694-698. 1963.

Bartlett, B.R. The toxicity of some pesticide residues to adult *Amblyseius hibisci*, with a compilation of the effects of pesticides upon phytoseiid mites. J. Econ. Entomol. 57(4):559-563. 1964.

Bartlett, B.R. Outbreaks of two-spotted spider-mites and cotton aphids following pesticide treatment. I. Pest stimulation vs. natural enemy destruction as the cause of outbreaks. J. Econ. Entomol. 61(1):297-303. 1968.

Bednarek, R., and C.S. Davidson. Influence of spraying with carbaryl on nesting success in a sample of bird-boxes on Cape Cod in 1965. Bird-Banding 38:66-72. 1967.

Bodtker, D.J., and P.J. Kingsbury. The effects of DDT and Sevin on litter decomposition and litter fauna. Proc. Iowa Acad. Sci. 77:219-222. 1970.

Bollag, J.-M., and S.-Y. Liu. Hydroxylations of carbaryl by soil fungi. Nature 236(5343):177-178. 1972.

Buchanan, D.V., R.E. Millemann, and N.E. Stewart. Effects of the insecticide Sevin on various stages of the Dungeness crab, *Cancer magister*. J. Fish. Res. Board Can. 27(1):93-104. 1970.

Burdick, G.E., H.J. Dean, and E.J. Harris. Effect of Sevin upon the aquatic environment. N.Y. Fish Game J. 7(1):14-25. 1960.

Burdick, G.E., H.J. Dean, E.J. Harris, J. Skea, and D. Colby. Toxicity of Sevin (carbaryl) to fingerling brown trout. N.Y. Fish Game J. 12(2):127-146. 1965.

Butcher, J.W., J. Truchan, R. Willson, and J. Fahey. Stream sampling for evidence of pesticide effects on aquatic arthropods. Proc. North Cent. Branch Entomol. Soc. Am. 19:130-132. 1964.

Butler, J.A., R.E. Millemann, and N.E. Stewart. Effects of the insecticide Sevin on survival and growth of the cockle clam *Clinocardium nuttalli*. J. Fish. Res. Board Can. 25(8):1621-1635. 1968.

Butler, P.A. Effects of commercial fisheries. In: Effects of Pesticides on Fish and Wildlife: A Review of Investigations during 1960. USDI, Fish and Wildlife Service, BSFW, Washington, D.C. 1962. pp. 20-24, 42-44, 48. [Circ. 143]

Butler, P.A. Commercial fisheries investigations. In: Pesticide-Wildlife Studies: A Review of Fish and Wildlife Service Investigations during 1961 and 1962. USDI, Fish and Wildlife Service, BSFW, Washington, D.C. 1963. pp. 11-25. [Circ 167]

California Department of Fish and Game. An investigation into the effect on fish of (carbaryl) Sevin used in rice culture. California Department of Fish and Game, Sacramento. 1963. 5 pp. [Mimeo.]

Carlson, A.R. Effects of long-term exposure to carbaryl (Sevin) on survival, growth, and reproduction of the fathead minnow (*Pimephales promelas*). J. Fish. Res. Board Can. 29(5):583-587. 1972.

Carriker, M.R., and J.W. Blake. A method for full relaxation of muricids. Nautilus 73(1):16-21. 1959.

Casida, J.E. Mode of action of carbamates. Annu. Rev. Entomol. 8:39-58. 1963a.

Casida, J.E. Radiotracer approaches to carbamate insecticide toxicology. In: Radiation and Radioisotopes Applied to Insects of Agricultural Importance (Proceedings of a Symposium). International Publications, New York. 1963b. pp. 223-239.

Colburn, R., and D. Asquith. Tolerance of the stages of *Stethorus punctum* to selected insecticides and miticides. J. Econ. Entomol. 64(5): 1072-1074. 1971.

Connor, P.F. A study of small mammals, birds and other wildlife in an area sprayed with Sevin. N.Y. Fish Game J. 7(1):26-32. 1960.

Cope, O.B. Sport fishery investigations. In: Pesticide-Wildlife Studies: A Review of Fish and Wildlife Service Investigation during 1961 and 1962. USDI, Fish and Wildlife Service, BSFW, Washington, D.C. 1963. pp. 26-42. [Circ. 167]

Cope, O.B. Contamination of the freshwater ecosystem by pesticides. J. Appl. Ecol. 3(Suppl.):33-44. 1966.

Coutant, C.C. Insecticide Sevin: Effect of aerial spraying on drift of stream insects. Science 146:420-421. 1964.

Cowley, G.T., and E.P. Lichtenstein. Growth inhibition of soil fungi by insecticides and annulment of inhibition by yeast extract or nitrogenous nutrients. J. Gen. Microbiol. 62:27-34. 1970.

Croft, B.A., and L.R. Jeppson. Comparative studies on four strains of *Typhlodromus occidentalis*. II. Laboratory toxicity of ten compounds common to apple pest control. J. Econ. Entomol. 63(5):1528-1531. 1970.

Croft, B.A., and E.E. Nelson. Toxicity of apple orchard pesticides to Michigan populations of *Amblyseius fallacis*. Environ. Entomol. 1(5):576-579. 1972.

Croft, B.A., and R.H. Meyer. Carbamate and organophosphorus resistance patterns in populations of *Amblyseius fallacis*. Environ. Entomol. 2(4):691-695. 1973.

Croft, B.A., and P.G. Stewart. Toxicity of one carbamate and six organophosphorus insecticides to O-P resistance strains of *Typhlodromus occidentalis* and *Amblyseius fallacis*. Environ. Entomol. 2(3):486-488. 1973.

Crosby, D.G., E. Leitis, and W.L. Winterlin. Photodecomposition of carbamate insecticides. J. Agric. Food Chem. 13(3):204-207. 1965.

DeWitt, J.B., and C.M. Menzie. Special report -- Effects of Sevin on quail and pheasants. USDI, Patuxent Wildlife Research Center, BSFW, Laurel, Maryland. 1961. 5 pp.

Dittrich, V., P. Streibert, and P.A. Bathe. An old case reopened: Mite stimulation by insecticide residues. Environ. Entomol. 3(3):534-540. 1974.

Doane, C.C., and P.W. Schaefer. Aerial application of insecticides for control of the gypsy moth. With studies of effects on non-target insects and birds. Connecticut Agricultural Experiment Station, New Haven. 1971. 23 pp. [Bull. 724]

Dorough, H.W., and J.E. Casida. Nature of certain carbamate metabolites of the insecticide Sevin. J. Agric. Food Chem. 12(4):294-304. 1964.

Dorough, H.W., and O.G. Wiggins. Nature of the water-soluble metabolites of carbaryl in bean plants and their fate in rats. J. Econ. Entomol. 62(1):49-53. 1969.

Federal Water Pollution Control Administration (FWPCA). Water quality criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior. USDI, Federal Water Pollution Control Administration, Washington, D.C. 1968. 234 pp.

Felley, D.R. The effect of Sevin (1-naphthyl N-methylcarbamate) as a watershed pollutant. Diss. Abstr. Int. 31(10):6040B. 1971.

Fukuda, H., and T. Masuda. Translocation of NAC (Sevin) in rice plant. Kyushu Agricultural Experiment Station, Entomological Research Laboratory, Chikugo, Fukuoka Prefecture, Japan. 1962.

Gaur, A.C., and K.C. Misra. Effects of insecticides on soil micro-organisms. Pesticides 4(5):24-27. 1970.

Georghiou, G.P., and E.L. Atkins, Jr. Temperature coefficient of toxicity of certain N-methylcarbamates against honeybees, and the effect of the synergist piperonyl butoxide. J. Apic. Res. 3(1): 31-35. 1964.

Georghiou, G.P., S.G. Breeland, and V. Ariaratnam. Seasonal escalation of organophosphorus and carbamate resistance in *Anopheles albimanus* by agricultural sprays. Environ. Entomol. 2(3):369-374. 1973.

Grosch, D.S., and A.C. Hoffman. The vulnerability of specific cells in the oogenetic sequence of *Bracon hebetor* Say to some degradation products of carbamate pesticides. Environ. Entomol. 2(6):1029-1032. 1973.

Hagstrum, D.W. Laboratory studies on the effect of several insecticides on *Tarentula kochi*. J. Econ. Entomol. 63(6):1844-1847. 1970.

Hansen, D.J. Avoidance of pesticides by untrained sheepshead minnows. Trans. Am. Fish. Soc. 98(3):426-429. 1969.

Harries, F.H. Reproduction and mortality of the two-spotted spider mite on fruit seedlings treated with chemicals. J. Econ. Entomol. 59(3):501-506. 1966.

Hassan, A., S.M.A.D. Zayed, and F.M. Abdel-Hamid. Metabolism of carbamate drugs. I. Metabolism of 1-naphthyl-N-methyl carbamate (Sevin) in the rat. Biochem. Pharmacol. 15:2045-2055. 1966.

Haven, D., M. Castagna, P. Chanley, M. Wass, and J. Whitcomb. Effects of the treatment of an oyster bed with polystream and Sevin. Chesapeake Sci. 7(4):179-188. 1966.

Haynes, H.L., H.H. Moorefield, A.J. Borash, and J.W. Keays. The toxicity of Sevin to goldfish. J. Econ. Entomol. 51(4):540. 1958.

Heath, R.G., J.W. Spann, E.F. Hill, and J.F. Kreitzer. Comparative dietary toxicities of pesticides to birds. USDI, Fish and Wildlife Service, BSFW, Washington, D.C. 1972. 57 pp. [Spec. Sci. Rept. - Wildl. 152]

Henderson, C., Q.H. Pickering, and C.M. Tarzwell. The toxicity of organic phosphorus and chlorinated hydrocarbon insecticides to fish. In: C.M. Tarzwell, compiler. Biological Problems in Water Pollution (Transactions of the 2nd Seminar, Cincinnati, Ohio, April 20-24, 1959). USDHEW, Public Health Service, Cincinnati, Ohio. 1960. pp. 76-88.

Hendrick, R.D., T.R. Everett, and H.R. Caffey. Effects of some insecticides on the survival, reproduction, and growth of the Louisiana red crawfish. J. Econ. Entomol. 59(1):188-192. 1966.

Huddleston, E.W., and G.G. Gyrisco. Residues of Sevin and 1-naphthyl on forage from aerial applications of Sevin in oil. J. Econ. Entomol. 53(3):484. 1960.

Hughes, L.B., Jr. A study of the fate of carbaryl insecticide in surface waters. Diss. Abstr. Int. 32(6):3108B. 1971.

Johansen, C., E.R. Jaycox, and R. Hutt. The effect of pesticides on the alfalfa leafcutting bee *Megachile rotundata*. Washington State University, Agricultural Experiment Station, Pullman, Washington. 1963. 12 pp. [Circ. 418]

Johansen, C.A., and F.C. Brown. Toxicity of carbaryl-contaminated pollen collected by honey bees. Environ. Entomol. 1(3):385-386. 1972.

Johansen, C.A. Toxicity of field-weathered insecticide residues to four kinds of bees. Environ. Entomol. 1(3):393-394. 1972.

Johnson, D.P., and H.A. Stansbury. Adaptation of Sevin insecticide (carbaryl) residue method to various crops. J. Agric. Food Chem. 13(3):235-238. 1965.

Karinen, J.F., J.G. Lamberton, N.E. Stewart, and L.C. Terriere. Persistence of carbaryl in the marine estuarine environment. Chemical and biological stability in aquarium systems. J. Agric. Food Chem. 15(1): 148-156. 1967.

Katz, M. Acute toxicity of some organic insecticides to three species of salmonids and to the threespine stickleback. Trans. Am. Fish. Soc. 90(3):264-268. 1961.

Kazano, H., P.C. Kearney, and D.D. Kaufman. Metabolism of methylcarbamate insecticides in soils. J. Agric. Food Chem. 20(5):975-979. 1972.

Korn, S. The uptake and persistence of carbaryl in channel catfish. Trans. Am. Fish. Soc. 102(1):137-139. 1973.

Kuhr, R.J., and J.E. Casida. Persistent glycosides of metabolites of methylcarbamate insecticide chemicals formed by hydroxylation in bean plants. J. Agric. Food Chem. 15(5):814-824. 1967.

Kunkee, R.E., and G. Zweig. Inactivation and reactivation rates of fly and bee cholinesterases inhibited by Sevin. Biochem. Pharmacol. 14:1011-1017. 1965.

Lawrence, P.O., S.H. Kerr, and W.H. Whitcomb. *Chrysopa rufilabris*: Effect of selected pesticides on duration of third larval stadium, pupal stage, and adult survival. Environ. Entomol. 2(3):477-480. 1973.

Lawrence, P.O. Susceptibility of *Chrysopa rufilabris* to selected insecticides and miticides. Environ. Entomol. 3(1):146-150. 1974.

Liu, S.-Y., and J.-M. Bollag. Metabolism of carbaryl by a soil fungus. J. Agric. Food Chem. 19(3):487-490. 1971a.

Liu, S.-Y., and J.-M. Bollag. Carbaryl decomposition to 1-naphthyl carbamate by *Aspergillus terreus*. Pest. Biochem. Physiol. 1:366-372. 1971b.

Lowe, J.I. Effects of prolonged exposure to Sevin on an estuarine fish, *Leiostomus xanthurus* Lacépède. Bull. Environ. Contam. Toxicol. 2(3): 147-155. 1967.

Macek, K.J., and W.A. McAllister. Insecticide susceptibility of some common fish family representatives. Trans. Am. Fish. Soc. 99(1): 20-27. 1970.

Martin, E.C. Pesticides and honey bees. Michigan State University, Cooperative Extension Service, East Lansing, Michigan. 1970. 8 pp. [Bull. E-678, Farm Sci. Ser.]

Masuda, T., and H. Fukuda. Fundamental studies on soil application of insecticide (I) systemic properties of 1-naphthyl N-methylcarbamate into rice plant. Proc. Assoc. Plant Prot. Kyushu (Japan) 7:76-78. 1961.

McEwen, L.C., J.F. Macdonald, J.E. Peterson, M.H. Mohn, and G.H. Ise. The effects of Sevin on sharp-tailed grouse and waterfowl at the Lostwood Wildlife Refuge, North Dakota. Annual progress report for work unit D-4.2. USDI, Denver Wildlife Research Center, BSFW, Denver, Colorado. 1962. 13 pp.

McEwen, L.C., J.E. Peterson, M.H. Mohn, and G.H. Ise. Prairie grouse: Toxicity and tissue residues of Sevin and Dieldrin. In: Pesticide-Wildlife Studies: A Review of Fish and Wildlife Service Investigations during the Calendar Year. USDI, Fish and Wildlife Service, BSFW, Washington, D.C. 1964. pp. 46-47, 64. [Circ. 199]

Moeller, F.E. Effect of pollen availability on poisoning of honey bees by carbaryl applied to sweet corn. J. Econ. Entomol. 64(5):1314-1315. 1971.

Moeller, F.E. Honey bee collection of corn pollen reduced by feeding pollen in the hive. Am. Bee J. 112(6):210-212. 1972.

Moffett, J.O., R.H. MacDonald, and M.D. Levin. Toxicity of carbaryl-contaminated pollen to adult honey bees. J. Econ. Entomol. 63(2):475-476. 1970.

Moffitt, H.R., E.W. Anthon, and L.O. Smith. Toxicity of several commonly used orchard pesticides to adult *Hippodamia convergens*. Environ. Entomol. 1(1):20-23. 1972.

Morse, R.A. The effect of Sevin on honey bees. J. Econ. Entomol. 54(3):566-568. 1961.

Morse, R.A., L.E. St. John, and D.J. Lisk. Residue analysis of Sevin in bees and pollen. J. Econ. Entomol. 56(3):415-416. 1963.

Morse, R.A., and A.F. Gunnison Honey bee insecticide loss -- An unusual case. J. Econ. Entomol. 60(5):1196-1198. 1967.

Mostafa, I.Y., A. Hassan, and S.M.A.D. Zayed. Translocation and degradation of ^{14}C-labelled Sevin in cotton plant. Z. Naturforsch. 21b:1060-1062. 1966.

Muncy, R.J., and A.D. Oliver, Jr. Toxicity of ten insecticides to the red crawfish, *Procambarus clarki* (Girard). Trans. Am. Fish. Soc. 92(4):428-431. 1963.

Naqvi, S.M., and D.E. Ferguson. Levels of insecticide resistance in fresh-water shrimp, *Palaemonetes kadiakensis*. Trans. Am. Fish. Soc. 99(4):696-699. 1970.

Pielou, D.P. The ineffectiveness of Sevin in increasing oviposition in the spider mite, *Tetranychus telarius* (L.). Can. J. Zool. 40:9-11. 1962.

Pimentel, D. Ecological effects of pesticides on non-target species. Executive Office of the President, Office of Science and Technology, Washington, D.C. 1971. 220 pp.

Post, G., and T.R. Schroeder. The toxicity of four insecticides to four salmonid species. Bull. Environ. Contam. Toxicol. 6(2):144-154. 1971.

Root, R.B., and J.J. Skelsey. Biotic factors involved in crucifer aphid outbreaks following insecticide application. J. Econ. Entomol. 62(1):223-233. 1969.

Sanders, H.O., and O.B. Cope. Toxicities of several pesticides to two species of cladocerans. Trans. Am. Fish. Soc. 95(2):165-169. 1966.

Sanders, H.O. Toxicity of pesticides to the crustacean *Gammarus lacustris*. USDI, Fish and Wildlife Service, BSFW, Washington, D.C. 1969. 18 pp. [Tech. Pap. 25]

Saxena, P.K., and S. Aggarwal. Toxicity of some insecticides to the Indian cat-fish, *Heteropneustes fossilis* (Bloch). Anat. Anz. 127:502-503. 1970.

Shaw, F.R. The effects of field applications of some of the newer pesticides on honey bees. J. Econ. Entomol. 52(4):549-550. 1959.

Shilova, S.A., A.A. Smirnov, V.A. Ognev, and L.D. Voronova. The effect of Sevin on the sexual functions of warm-blooded animals. Med. Parazitol. Parazit. Bolezn. 37(5):604-609. 1968.

Soper, R.S., F.R. Holbrook, and C.C. Gordon. Comparative pesticide effects on *Entomophthora* and the phytopathogen *Alternaria solani*. Environ. Entomol. 3(3):560-562. 1974.

Stadnyk, L., R.S. Campbell, and B.T. Johnson. Pesticide effect on growth and ^{14}C assimilation in a freshwater alga. Bull. Environ. Contam. Toxicol. 6(1):1-8. 1971.

Stegeman, L.C. The effects of the carbamate insecticide carbaryl upon forest soil mites and Collembola. J. Econ. Entomol. 57(6):803-808. 1964.

Stephen, W.P. The effects of chronic sublethal doses of pesticides on behavior and longevity of arthropods. ETP Project B-7. In: Environmental Health Science Center Annual Progress Report. Oregon State University, Corvallis, Oregon. 1972. pp. 161-167.

Stern, V.M. The effect of various insecticides on *Trichogramma semifumatum* and certain predators in southern California. J. Econ. Entomol. 56(3):348-350. 1963.

Stewart, N.E., R.E. Millemann, and W.P. Breese. Acute toxicity of the insecticide Sevin and its hydrolytic product of 1-naphthol to some marine organisms. Trans. Am. Fish. Soc. 96(1):25-30. 1967.

Sundaram, A., and K.M.S. Sundaram. Penetration, translocation and persistence of the insecticides 1-naphthyl N-methyl-carbamate (Sevin) and O, O-dimethyl-O-(3-methyl-4-nitrophenyl) phosphorothioate (Sumithion) in cocoa seedlings (*Theobroma cacao* L.). Ghana J. Sci. 7(1):1-17. 1967.

Swift, F.C. Predation of *Typhlodromus (A.) fallacis* on the European red mite as measured by the insecticidal check method. J. Econ. Entomol. 63(5):1617-1618. 1970.

Tewfik, M.S., and Y.A. Hamdi. Decomposition of Sevin by a soil bacterium. Acta Microbiol. Pol. Ser. B 2(19), No. 2:133-135. 1970.

Thompson, A.R., and W.W. Sans. Effects of soil insecticides in southwestern Ontario on non-target invertebrates: Earthworms in pasture. Environ. Entomol. 3(2):305-308. 1974.

Tompkins, W.A. Sevin residues in marine and freshwater aquatic organisms. In: Report of the Surveillance Program Conducted in Connection with an Application of Carbaryl (Sevin) for the Control of Gypsy Moth on Cape Cod, Massachusetts. Commonwealth of Massachusetts, Pesticide Board, Boston, Massachusetts. 1966. pp. 37-46. [Publ. 547]

Tucker, R.K., and D.G. Crabtree. Handbook of toxicity of pesticides to wildlife. USDI, Fish and Wildlife Service, BSFW, Denver, Colorado. 1970. 131 pp. [Resour. Publ. 84]

Ukeles, R. Growth of pure cultures of marine phytoplankton in the presence of toxicants. Appl. Microbiol. 10(6):532-537. 1962.

Union Carbide Corporation. Technical information on Sevin, carbaryl insecticide. Union Carbide Corporation, Salinas, California. 1968. 55 pp.

US Department of Agriculture (USDA). Protecting honey bees from pesticides. US Department of Agriculture, Washington, D.C. 1972. 6 pp. [Leaflet 544]

Waller, G.D. Susceptibility of an alfalfa leafcutting bee to residues of insecticides on foliage. J. Econ. Entomol. 62(1):189-192. 1969.

Wiggins, O.G., M.H.J. Weiden, C.S. Weil, and C.P. Carpenter. Sevin carbaryl insecticide: Plant metabolites and their mammalian toxicity. In: Summaries of Papers, 7th International Congress of Plant Protection, Paris, September 21-25, 1970. pp. 697-700.

Williams, M.W., and L.P. Batjer. Site and mode of action of 1-naphthyl N-methylcarbamate (Sevin) in thinning apples. Proc. Am. Soc. Hortic. Sci. 85:1-10. 1964.

Winterlin, W., G. Walker, and A. Luce. Carbaryl residues in bees, honey, and bee bread following exposure to carbaryl via the food supply. Arch. Environ. Contam. Toxicol. 1(4):362-374. 1973.

Zuberi, R., and M.Y. Zubairi. Carbaryl degradation by *Pseudomonas phaseolicola* and *Aspergillus niger*. Pak. J. Sci. Ind. Res. 14(4-5): 383-384. 1971.

Bibliography

Anderson, L.D., and E.L. Atkins, Jr. Toxicity of pesticides to honey bees in laboratory and field tests in southern California, 1955-1956. J. Econ. Entomol. 51(1):103-108. 1958.

Arrand, J.C., and J. Corner. Observations in the interior of British Columbia during 1959 of the effect of honeybees of orchard spraying with Sevin. Proc. Entomol. Soc. B.C. 57:21. 1960.

Dunachie, J.F., and W.W. Fletcher. An investigation of the toxicity of insecticides to birds' eggs using the egg-injection technique. Ann. Appl. Biol. 64(3):409-423. 1969.

Khera, K.S. Toxic and teratogenic effects of insecticides in duck and chick embryos. Toxicol. Appl. Pharmacol. 8:345. 1966. [Abstracts of Papers, 5th Annual Meeting, Society of Toxicology, Williamsburg, Virginia, March 14-16, 1966.]

Khmelevsky, B.N., and Yu.M. Stepanov. The effect of the extended feeding of Sevin on the hatchability and viability of the offspring. Dokl. Vses. Akad. S-kh. Nauk. 8:36-37. 1969.

Levin, M.D. The effects of pesticides on beekeeping in the United States. Am. Bee J. 110(1):8-9. 1970.

Marliac, J.-P. Toxicity and teratogenic effects of 12 pesticides in the chick embryo. Fed. Proc. 23:105. 1964.

Metcalf, C.L., and W.P. Flint. Destructive and useful insects, 4th edition. McGraw-Hill, New York. 1087pp. 1962.

Thomas, R.F., and J.G. Medley. Effect on eggs of applications to poultry of pesticide formulations contaminated with chlorinated hydrocarbons. J. Assoc. Off. Anal. Chem. 54(3):681-684. 1971.

van der Pol, E.W. Note on the determination of carbaryl residues in hen skin. J. Assoc. Off. Anal. Chem. 51:901. 1968.

Chapter IV

RESIDUES OF CARBARYL IN FOOD AND FEED

Carbaryl is generally applied at rates of 1-2 lb active ingredient/ acre. Initial residues on forage and foliage crops are in the range of 20-100 ppm; on fruits and vegetables at 2-10 ppm. Preharvest crop residues with a half-life of 3-4 d are normally lost, predominately by mechanical attrition and rainfall. Carbaryl reaching soil and water is rapidly degraded to less toxic products. Persistence and bioaccumulation are not characteristic of carbaryl. Consequently, residues caused by occasional drift to adjacent crops have not been a problem. Official U.S. tolerances have been established in over 80 raw agricultural commodities. After harvesting, crop residues may be further reduced by normal washing and processing procedures. As a result, pesticide residues in Food and Drug Administration market basket surveys have been consistently negligible from a human health standpoint.

This section presents data on actual residues on commodities, U.S. tolerances for carbaryl resulting from good agricultural practices, degradation during processing, market basket surveys, and analytical methods for detecting carbaryl residues.

IV.A. Carbaryl residues in raw agricultural commodities

The results of tests for carbaryl residues will be discussed in detail in the following sections which are designated according to the types of agricultural products.

IV.A.1. Leafy vegetables and forage crops: Typical carbaryl residues resulting from normal insect control practices applied to leafy vegetables range up to 100 ppm when deposited. These rapidly degrade by rainfall, wind erosion, and plant growth, so that established tolerances of 10 ppm or so are not exceeded upon elapse of a 10-12 d preharvest interval. Typical examples are given in Table IV.A.1. and Table IV.A.2.

Table IV.A.1. Carbaryl residues in leafy vegetables

Crop	Pounds active ingredient/acre	Number of treatments	Days after last treatment, ppm			
			0-1	2-3	7	14
Head lettuce	2.5	9	16.1	10.3	3.0	-
	2	2	9.8	6.1	3.9	-
	2	2	5.0	2.9	2.0	-
	2	9	7.1	3.8	0.9	-
Leaf lettuce	2	2	83	54	14	2.4
	2	8	51	15	4.5	-
Endive	2	1	23	20	20	5.5
	2	2	17	23	18	0.4
	2	4	31	31	10	-
	2	6	23	8	11	-
Beet tops	2	2	23	14	12	9.0
	2	7	48	2.4	1.1	-
Collards	2	1	19	17	13	2.5
	2	3	17	4.2	1.5	0.6
Kale	2	1	49	43	26	8.5
	2	8	35	1.4	1.0	-
Spinach	2	2	48	49	11	-
	2	3	47	31	6	-
Swiss chard	2	4	58	60	8.1	-
	2	6	94	12	18	-
	2	4	-	5	1.2	0.8
Turnip tops	2	2	71	42	20	1.8
	2	6	54	34	14	-
	2.2	2	28	28	13	-
Mustard greens	1	2	20.4	20	3.8	-
	2	2	86.5	62.4	24.6	-
	2	6	106.3	30.3	11.6	-

Source: Union Carbide Corporation.

Table IV.A.2. Carbaryl residues in soybean foliage

Pounds active ingredient/acre	Number of treatments	Days after last application, ppm						
		0	1	3	7	10	21	28
1	9	9.9	8.1	7	3.1	-	-	-
1	3	28	25	24	14	-	-	-
2	3	35	32	29	19	-	-	-
2	3	43	21	1.5	12	1.3	-	-
2	2	77	-	38	12	-	-	-
2	7	54[1]	-	4.7[1]	-	-	-	-
1	4	6.1	-	2.6	-	-	-	-
1	2	27	-	-	2.4	-	-	-
1	1	12	-	-	26[1]	-	-	-
1.5	1	120	91	79	0.7	0.7	-	-
1.5	2	73	-	36	2.8	-	-	-
2	1	240[2]	263	166	2.8	1.8	-	-
2	1	136	36	24	-	-	-	-
1	1	70	56	13	0.6	-	-	-
1	1	59	66	10	0.4	-	-	-
2	1	720[3]	-	29	0.3	-	0.4	0.1

[1] Indicates dried foliage; all others are analyses of green foliage.
[2] Maximum residues - no rainfall fell over the 10 d sampling period.
[3] Sample consisted entirely of leaves from upper surface of plant vs. standard procedure of analyzing entire plant.
Source: Union Carbide Corporation.

IV.A.2. Fruit and vegetable crops: Typical residues resulting from the use of carbaryl on apples, small fruits, and root crop vegetables provide a range likely to be encountered in normal practice. Tables IV.A.3., IV.A.4., and IV.A.5. show these data.

Table IV.A.3. Carbaryl residues in apples picked shortly after the last spray application applied at maximum label rate of 2 lbs. carbaryl 50W per 100 gal of dilute spray

Location	Number of sprays	Residues in ppm Days from final spray to sampling		
		0	7	14
New York	6	-	2.1	0.9
Ohio	1	1.4	1.3	0.4
Missouri	7	3.1	2.7	2.5
Missouri	7	8.2	4.0	1.5
Missouri	7	7.8	5.8	1.9
Kansas	8	4.5	2.6	-
Michigan	1	4.5	3.0	3.4
Virginia	7	-	0.7	1.1
New York	9	8.1	-	3.5
New York	9	4.2	1.7	-
California	1	4.2	2.0	1.0

Source: Union Carbide Corporation.

Table IV.A.4. Carbaryl residues in strawberries, blueberries and cranberries

Pounds active ingredient/acre	Number of treatments	Residues in ppm Days after harvest			
		0-1	3-5	7	14
Strawberries					
2.0	6	5.3	-	-	-
1.5	1	3.1	0.7	-	-
2.5	1	3.3	-	1.4	0.5
2.0	1	6.7	3.2	0.4	-
2.0	1	5.2	3.3	1.7	-
2.0	1	4.3	-	-	-
2.0	1	9.1	4.2	-	-
2.0	2	3.3	2.3	-	-
Blueberries					
1.25	-	2.4	0.3	0.2	-
1.5	2	-	2.0	-	1.2
1.5	2	3.0	1.6	-	-
2.0	3	5.7	-	-	-
1.0	4	3.1	2.0	1.2	-
2.0	5	-	0.9	0.2	-
Cranberries					
2	1	2.0	0.9	-	-
4.5	1	7.9	-	3.9	1.2
2.4	3	3.7	2.9	0.8	-

Source: Union Carbide Corporation.

Table IV.A.5. Carbaryl residues in root crop vegetables

Crop	Pounds active ingredient/acre	Number of treatments	Days after last treatment, ppm 0	3	7
Carrot	2	11	1.7	-	-
	2	4	0.1	-	-
	2	1	0.5	-	-
Turnip	2	1	0.8	-	-
	2	2	0.6	-	-
	2	6	10.3	1.3	0.9
	2	2	1.2	0.9	0.5
Beet	2	7	6.5	0.3	0.4
	2	1	1.1	-	-
	2	2	0.6	-	-
Radish	2	6	11.0	-	-
Parsnip	2	3	1.2	-	-

Source: Union Carbide Corporation.

IV.A.3. Carbaryl residues in meat, milk and eggs: Meat, milk, and eggs are major components of human diets. Residues in these commodities resulting from registered uses of carbaryl have been studied.

Dairy animals: Tests by USDA at Kerrville, Texas (USDA, 1959) indicated that carbaryl was not detected in milk of cows fed carbaryl levels varying from 2.5 - 50 ppm. Therefore, cattle were fed technical carbaryl for 2 wk at 50, 150, and 450 ppm of the average total daily roughage intake. Samples of milk were taken at regular intervals and the cream analyzed for carbaryl. The concentration, if present, was below the sensitivity of the analytical method, 0.01 ppm. No off-flavors or odors were found.

In early studies, levels of 450 ppm in diets fed to dairy cattle did not cause detectable residues of carbaryl, 1-naphthol, or conjugates of 1-naphthol in milk (Gyrisco et al, 1960; Whitehurst et al, 1963). Tissue of cattle fed diets containing 200 ppm for 27 d was reported to be free of carbaryl residues (Claborn et al, 1963) and trace amounts were detected in some milk and tissue samples following treatment of cattle with sprays and dusts (Baron et al, 1969; Claborn et al, 1963; Eheart et al, 1962; Petrovskii, 1970; Roberts et al, 1960). The method used for detection was later shown to be insensitive and inadequate for detecting carbaryl and its degradation products in animal tissue and milk (Dorough and Casida, 1964; Dorough, 1967).

Carbaryl applied as a dry powder to the backs of 48 dairy cows at 10 g of 50% wettable powder per cow was not detectable in milk 2, 10, or 16 d posttreatment. When 1% carbaryl was sponged onto the backs of 10 dairy cows at 1 qt/cow, carbaryl and 1-naphthol residues were present in the milk for the first 24 h after treatment. Maximum readings were 0.176 ppm carbaryl and 0.076 ppm 1-naphthol. However, 0.5% carbaryl sprayed upon the backs of five cows was not detectable in milk, except in one instance, within 14 d after treatment (Camp et al, 1963).

Carbamate metabolites first detected in goat's milk were conjugated derivatives (Dorough and Casida, 1964). A nonconjugated substance which was tentatively identified as 3,4-dihydro-3,4-dihydroxy-1-naphthyl methylcarbamate was later confirmed to be 5,6-dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate (Leeling and Casida, 1966).

Cattle were sprayed with carbaryl (0.3%) and samples of fat, muscle, liver, and kidney taken from animals slaughtered at 1, 3, or 7 d after single or multiple spray applications. Carbaryl was found in all body tissues examined 1 and 3 d after exposure. There was an initial concentration of the pesticide in the fat (0.1 ppm in omental and 0.17 ppm in perirenal fat), but levels in fat, muscle, liver, and kidney were comparable by the third day. Carbaryl was not detected in samples taken 7 d after treatment. Concentration of carbaryl in milk of dairy cattle given a single treatment tended to remain constant the first 2 d after treatment and then fell rapidly. It was not detected in milk obtained at the seventh milking 79 h after treatment (Hurwood, 1967).

Extensive studies have been performed with ^{14}C carbaryl. Following ingestion of carbaryl^{14}C-labeled carbaryl, radioactive lactose was detected as a major product in milk (Baron, 1968).

Khan et al (1962) reported that partial or complete spraying of cattle with 0.5% carbaryl was equally effective for louse control. Dermal or parenteral administration to the host had no larvicidal effect on migrating cattle grubs, and no lethal effect upon grubs encysted in the back of cattle. Sprays had no noticeable effect on the general health of cattle. Local intramuscular injections were painful and caused lameness for about one week.

This type of labeling was inadequate for detecting metabolism products containing the naphthyl ring, and carbaryl made from ^{14}C-1-naphthol was used in later studies. After oral administration of single doses of 0.25 and 2.05 mg/kg, approximately 0.35% of each dose was detected in the milk (Dorough, 1967). Maximum concentrations found in 6 h samples following the two treatments were 0.063 and 0.95 ppm, respectively. In another study, 1-naphthyl-^{14}C carbaryl was fed to lactating cows at levels of 0.15, 0.43, and 1.35 mg/kg body weight (equivalent to 10, 30, and 100 ppm in the feed) for 14 d (Dorough, 1970). Equilibrium between intake and elimination was reached within 2 d following initiation of the treatment. At each feeding level, approximately 0.2% of the dose was secreted in the milk. Fractionation of the milk into water, butterfat, and solids revealed that most of the ^{14}C-residues (about 90%) were in the water layer. The solid fraction contained the majority of the remaining residues while only trace amounts were present in the butterfat. Complete removal of ^{14}C-residues from solids was achieved by extraction with acetone and acetonitrile (Dorough, 1971). Concentrations of the various metabolites in milk after feeding 100 ppm of 1-naphthyl-^{14}C carbaryl for 14 d are shown in Table IV.A.6. The major compounds in the milk were: 5,6-dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate, 1-naphthyl sulfate, and 1-methoxy-5-(methylcarbamoyloxy)-2-naphthyl sulfate. An earlier study with carbonyl-^{14}C carbaryl confirmed the presence of 5,6-dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate as a major metabolite of cow's milk (Baron et al, 1968).

Table IV.A.6. Chemical nature of carbaryl metabolites in cow's milk and their average concentrations after feeding with 1-naphthyl-^{14}C carbaryl at a level equivalent to 100 ppm in the diet for 14 d.

Metabolites	ppb in milk	% of total
Carbaryl	17	6
3,4-dihydro-3,4-dihydroxy-1-naphthyl methylcarbamate	13	5
5,6-dihydro-5,6-dihydroxy-1-naphthyl methylcarbamate	94	34
5-hydroxy-1-naphthyl methyl-carbamate	3	1
5,6-dihydro-5,6-dihydroxy-1-naphthol	9	3
1-naphthyl sulfate	72	26
1-methoxy-5-(methylcarbamoyloxy)-2-naphthyl sulfate	63	23
5-methoxy-1,6-naphthalenediol	7	2

Source: Dorough, 1971.
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Continuous feeding of 1-naphthyl-^{14}C carbaryl to cows (Dorough, 1970; 1971) established that carbaryl residues do not accumulate in the body tissues; however, a positive correlation was shown to exist between the level of the pesticide fed and that which appeared in the tissues. The distribution of radiolabeled residues in different tissues and organs of cows is shown in Table IV.A.7.

Table IV.A.7. Total carbaryl-^{14}C equivalents in tissues of cows fed carbaryl-naphthyl-^{14}C for 14 d at rates of 10, 30, and 100 ppm in the diet.

	Carbaryl-^{14}C equivalents at feeding levels, ppm		
Tissues	10 ppm	30 ppm	100 ppm
Kidney	0.095	0.531	1.003
Liver	0.033	0.100	0.411
Lung	0.020	0.064	0.207
Muscle	0.009	0.031	0.104
Heart	0.012	0.038	0.095
Fat	0.000	0.015	0.025
Blood	0.008	0.036	0.141

Cows were slaughtered 18 h after the last dose was given.
Source: Dorough, 1971.
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Poultry: In early studies, carbaryl fed at 200 ppm in the diet of hens for 1 wk did not cause detectable residues of the pesticide in eggs (McCay and Arthur, 1962). At a dosage level of 150 mg/kg of body weight, given in a single dose, the highest residue at 24 h (4.1 ppm) was found in the gizzard (Furman and Pieper, 1962). When carbaryl was mixed with the diet and fed for 2 d at 3000 ppm, the maximum residues of carbaryl plus 1-naphthol whick occurred in eggs at 24 h after the end of feeding were less than 1 ppm (Prudich, 1963). Given continuously for 60 d in two daily doses of 90 mg/kg each (calculated to be equivalent to 3000 ppm in the diet), 1-2 ppm of carbaryl were

(Nir et al, 1966). No other tissues contained detectable carbaryl throughout the test period. Prolonged feeding of carbaryl in the diet for 6 months at the level of 500 mg/kg resulted in 0.2 ppm in the eggs and 0.03 ppm in body tissues (Khmelevskii, 1968); carbaryl was not detected in tissue 7 d after termination of the treatment.

Storage of malathion and carbaryl in the eggs increased as the level of pesticides increased. Storage of the two compounds was greater in egg yolk than in egg white. The liver and kidney tissues of hens stored more malathion and carbaryl than other tissues, such as the breast, leg muscles, and gizzard. It should be noted that the levels of pesticide fed were excessive (Ghadiri et al, 1967).

When chickens were dusted three times at 4 d intervals with 4 g of a 5% carbaryl dust, 19.3 ppm carbaryl found in the skin 24 h after the last treatment declined to 2.2 ppm in 7 d. Leg muscle of the 24 h birds, the only other tissue with significant residues, contained 0.9 ppm carbaryl. The eggs were free of residues throughout the study (Johnson et al, 1963).

Radiotracer studies have shown that only a small portion of an oral dose of carbaryl is deposited by hens in the eggs and tissues (Andrawes et al, 1972; Paulson and Feil, 1969). Following administration of 1-naphthyl-^{14}C carbaryl to hens, total ^{14}C residues reached a maximum and dissipated at a much faster rate from the egg white than from the yolk. Following a single dose of 10 mg/kg, maximum concentration of ^{14}C residues in egg white was 0.12 ppm the day after treatment and the residue dropped almost to zero the second day. The yolk residues reached a maximum at the fifth day (0.36 ppm) and had essentially dissipated by the ninth (0.03 ppm).

Under continuous feeding conditions, the total residue content in the yolk or white at individual sampling times was shown to be dosage related (Andrawes et al, 1972). Concentration of ^{14}C carbaryl equivalents (ppm) reached a maximum in the white after 2-6 d and in the yolk after 6-9 d of ^{14}C dosing which continued until the end of the treatment period. After a plateau was established, the amount of carbaryl equivalents in the white was one-tenth that in the yolk. Residues detected in the whites approached the determination limit of the analytical method (0.005 ppm) by the second day after last treatment in all three dosage levels tested. Yolk residues declined at a slower rate with a half-life of approximately 2-3 d. At 7 d after the last treatment, residues in the yolk became less than 5 ppb in the 7 ppm treatment and 40 ppb and 100 ppb in the 21 ppm and 70 ppm treatments, respectively. At 7 d after the last treatment, the total residues in the yolk plus white were 10 ppb and 30 ppb in the 21 ppm and 70 ppm feeding levels.

Table IV.A.8. shows the distribution of carbaryl residues in hen tissues after continuous treatment. Residues in tissue were directly proportional to the concentration of carbaryl in the diet, and the highest amounts were found in the blood and tissues of high blood content (liver, kidney, lung, and spleen). The body fat, brain, and muscles contained the lowest residues. The rate of depletion of residues, after termination of dosing, varied in different parts of the body. Based on the total radioactivity remaining in the hen's body, the rate of residue dissipation was similar in all the dosage levels tested and followed first order reaction kinetics. Half-life of the total body residues was calculated to be 5 d.

Table IV.A.8. Concentration of ^{14}C residues in various tissues and organs of hens treated twice daily with non-radioactive carbaryl for 17 d followed by 1-naphthyl-^{14}C carbaryl for 14 d.

	ppb of ^{14}C carbaryl equivalents after treatment with indicated doses								
	7 ppm			21 ppm			70 ppm		
Tissue	1 d	3 d	7 d	1 d	3 d	7 d	1 d	3 d	7 d
Liver	61	27	14	258	90	42	410	255	120
Kidney	77	43	23	222	118	68	485	305	182
Thigh	5	5	6	11	12	4	30	32	17
Leg	6	5	5	10	8	10	32	27	25
Breast	5	5	5	9	9	5	31	24	19
Skin	5	5	5	12	11	12	43	29	31
Fat	5	5	5	7	6	7	26	22	19
Gizzard	5	5	5	13	11	8	40	32	24
Heart	8	5	5	19	13	12	49	55	40
Brain	5	5	5	7	5	5	17	17	11

Source: Andrawes et al, 1972.
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IV.A.4. Degradation of carbaryl residues during processing of food:

The National Canners Association Research Foundation has studied the degradation of pesticide residues on foods during processing. Degradation and removal of residues during commercial and home preparative procedures have been determined for green beans (Elkins et al, 1968), tomatoes (Farrow et al, 1968), spinach (Lamb et al, 1968), and broccoli (Farrow et al, 1969). The effect of heat processing and storage on carbaryl residues in spinach and apricots has been investigated (Elkins et al, 1972). The study by Elkins et al (1972) involved laboratory fortification of the foods before processing; other studies pertain to field-applied pesticides. Since maximum harvest residues were desired for purposes of studies, application rates were higher, or harvest intervals were shorter than those registered for use in the U.S. Replicated field plots were 0.1 acre in size, and standard spray application techniques were followed. Crops, sampled in an approved manner, were analyzed promptly in the raw unwashed state at numerous points during subsequent processing.

Food preparation techniques of washing, blanching, cooking, canning, and freezing were performed by dieticians in accordance with recognized practices and all conditions were carefully recorded.

In studies with green beans, carbaryl was applied at 4 lb active ingredient/acre in two applications at a 7 d interval which is twice the maximum registered use rate. Unwashed green beans harvested immediately after the second application contained 11 ppm carbaryl. Home preparation of these beans showed that a cold water wash removed 52% of the residues, home blanching removed 81%, and the combination of washing, blanching, and freezing removed 94%. No detectable residues were found in home canned beans. In another instance, where home cooking of unwashed beans contained

8 ppm carbaryl, washing decreased the residues to 4.7 ppm and cooking to 1.7 ppm. No appreciable loss of residue was noted during pre-processing storage at 45°F.

In a similar study on green beans, the same field-treatment levels were used, but the samples taken immediately after the last spray treatment contained 7.9 ppm carbaryl. Home preparation resulted in 0.81 ppm after a cold water wash; and 0.65 ppm after a 3 min blanch in boiling water. Boiling and washing together resulted in an 84% loss of harvest residues whereas pressure cooking resulted in 76% reduction. Commercial processing resulted in about 70% loss of residue by water blanching at 185°F whether the blanching period was 1.5 or 3 min. Steam blanching reduced the residue 52%. No significant additional loss of carbaryl resulted during the canning and heat processing of these samples (Lamb and Farrow, 1966).

Tomatoes were sprayed twice at a 9 d interval with 6 lb active ingredient/acre, an amount three times the maximum recommended use level. Unwashed samples taken immediately after the last application contained an average residue of 5.2 ppm. Subsequently, in home preparation trials, a cold water wash removed 70% of initial residues (which ranged from 13 to 26 ppm); cooking removed 61%. Washing and blanching for home freezing resulted in a 93% loss, and subsequent freezing and cooking provided no further reduction.

Broccoli containing 12.4 ppm of carbaryl had 77% of the residues removed by a water wash, 85% removed by steam blanching, and 98% by water blanching. In home cooking tests, overall removal of residues was about 90% after washing, blanching, and freezing.

Spinach and apricots were fortified with carbaryl, canned, and given a heat treatment representative of that for commercially canned foods. Samples were analyzed before and after heat treatment and after storage of 1 year at ambient temperatures and at 100°F.

Spinach - The spinach was canned at an initial temperature of 65°F and processed at 252°F for 66 min. The canning processes destroyed about 44% of the initial 10.5 ppm residue. An additional 2% reduction was attributed to 1 year can storage at ambient temperature while an additional 23% reduction was noted after storage for 1 year at 100°F.

Apricots - The heat treatment given apricots is not as rigorous as that for spinach. The initial temperature (65°F) was the same, but processing was only 50 min at 217°F. Processing destroyed 12% of the original 11.4 ppm residue. An additional 4-5% was lost during the 1 year storage periods.

IV.B. U.S. carbaryl tolerances and use limitations

Table IV.B. provides a listing by crops of the tolerances for carbaryl, maximum allowable dosages per acre and preharvest use limits in days.

Table IV.B. Summary of Carbaryl residue tolerances and use limitations in the U.S.

Use	Tolerance, ppm	Dosage lb active ingredient/acre	Preharvest limit, days
Alfalfa	100	1.6	None
Almonds, shelled	1	8	None
Almond hulls	40	8	None
Apples	10	12	1
Apricots	10	8	3
Asparagus	10	2	1
Bananas	10	1.1	None
Beans	10	2.125	None
Beets, roots	5	2	3
Beets, tops	12	2	14
Blackberries	12	2	7
Blueberries	10	2	None
Boysenberries	12	2	7
Broccoli	10	2	3
Brussel sprouts	10	2	3
Cabbage	10	2	3
Cabbage (Chinese)	10	2	14
Carrots	10	2	None
Cauliflower	10	2	3
Cherries	10	6	1
Citrus	10	1.25/100 gal.	5
Clover	100	1.5	None
Collards	12	2	14
Corn forage	100	2	None
Corn kernels	5	3	None
Cottonseed	5	2.5	None
Cotton forage	100	2.5	None
Cowpeas	5	2	None
Cowpea forage	100	2	None
Cranberries	10	4	1
Cucumbers	10	1	None
Dandelion	12	2	14
Dewberries	12	2	7
Eggplant	10	4	None
Endive (escarole)	10	2	14
Filberts, shelled	1	5	None
Grapes	10	3	None
Grapefruit	10	1.25/100 gal.	5
Grass and hay	100	1.5	None
Horseradish	5	2	3

Table IV.B. (cont.)

Kale	12	2	14
Kohlrabi	10	2	3
Lettuce (head)	10	2	3
Lettuce (leaf)	10	2	14
Loganberries	12	2	7
Melons	10	1	None
Mustard greens	12	2	14
Nectarines	10	8	3
Okra	10	2	None
Olives	10	8	None
Parsley	12	2	14
Parsnips	5	2	3
Peaches	10	8	1
Peanuts, nut & hull	5	1.5	None
Peanut hay	100	1.5	None
Pears	10	12	1
Peas & pods	10	2.6	None
Peavine forage	100	2.6	None
Pecans, shelled	1	3	None
Peppers	10	4	None
Plums	10	6	1
Potatoes	0.2	2	None
Prunes	10	6	1
Pumpkins	10	1	None
Radishes	5	2	3
Raspberries	12	2	7
Rice	5	2	14
Rice straw	100	2	14
Rutabagas	5	2	3
Salsify roots	5	2	3
Salsify tops	10	2	14
Sorghum grain	10	2	21
Sorghum forage	100	2	21
Soybeans	5	1.5	None
Soybean hay	100	1.5	None
Spinach	12	2	14
Squash	10	1	None
Strawberries	10	2	1
Sugarbeet tops	100	2	14
Swiss chard	12	2	14

Table IV.B. (cont.)

Tomatoes	10	4	None
Turnips	5	2	3
Turnip tops	12		14
Walnuts, nuts	10	5	None
Poultry, meat & fat	5	0.25*	7
Poultry eggs	0.5 interim	0.25*	7

* and ** denote lb active ingredient/100 birds.
Source: Adapted from Sutherland et al, 1972.

IV.C. Market basket surveys for carbaryl residues

The U.S. Food and Drug Administration conducts annual "market basket" studies to determine the exact extent of pesticide residues being consumed in the U.S. These studies provide an index of residues in prepared foods as they are eaten, and no significant changes have been made in the sampling and compositing procedures (Duggan and McFarland, 1967). Briefly, these studies used 82 different food products as purchased by a typical housewife in retail food stores. They were purchased in a quantity sufficient to satisfy the daily food requirements of a 16-19-year-old male weighing 69.1 kg (152 lb) for a 2-wk period. The diet list was developed by the Household Economic Research Division of the U.S. Department of Agriculture. The purchased food was prepared for the table by dieticians and proportioned according to classification. Each portion was analyzed for residues, using the best methods available. Each of about 30 diet samples from 30 cities in five geographical areas was examined.

The first specific determination of carbaryl in a total diet sample was for a market basket purchased in Baltimore, Maryland, in May 1964, one year prior to FDA district laboratory takeover of the program. Analyses were performed on a total diet homogenate and three diet categories. The results (Cummings, 1965) indicated residues of 0.2-0.3 ppm in leafy vegetables and root vegetables, and fruit contained approximately the level of crop blanks (controls). No detectable carbaryl was found in the diet homogenate.

Results have been reported for six 1 year periods of the official FDA total diet residue monitoring studies, starting June 1964, and extending through April 1970 (Corneliussen, 1969, 1970, 1972, Duggan et al, 1966, 1967; Martin and Duggan, 1968). The results of this extensive monitoring are summarized by monitor year.

1st year (June 1964 - April 1965)

- 18 markets, 3 cities, 3 geographical areas
- Foods were divided into 12 classes and each class composited separately for each market. The total of composite samples was 18x12=216.
- Carbaryl was detected in 13 composites at levels of 0.2 - 0.5 ppm (method sensitivity was 0.2 ppm.)

2nd Year (June 1965 - April 1966)

- 36 markets, 25 cities, 5 geographical areas
- Levels of residues for this interval remain about the same as the previous study.
- Carbaryl was detected in 8 composites with 5 of these results below the method sensitivity level of 0.2 ppm. The 3 others were 0.2 - 0.4 ppm.

3rd Year (June 1966 - April 1967)

- 30 markets, 20 cities
- There was no significant change in the levels, frequency, or types of residues found from those in the past.
- Carbaryl was detected in 4 composites, 2 of which were below sensitivity level. Residues found were 0.2 - 0.3 ppm in 2 composites.

4th Year (June 1967 - April 1968)

- 30 markets, 27 cities
- No carbaryl was found during this period in any composite (360 food class composites).

5th Year (June 1968 - April 1969)

- 30 markets, 24 cities
- Significant changes were not observed in the levels, frequency, or types of residues from those in the past.
- Carbaryl was detected in three composites. Two results were below the method sensitivity level of 0.2 ppm. The third was 0.3 ppm. The two trace results ($\leq$0.2 ppm) were found in legume vegetables and the 0.3 ppm result was in a fruit composite. A total of 30 composites were investigated for each of these food classes.

6th Year (June 1969 - April 1970)

- 30 markets, 28 cities
- Carbaryl was not detected in any of the diet composites during this period.

Carbaryl residues in prepared foods have been determined in the Market Basket Survey performed by the Food and Drug Administration. These results have been reported in relation to amounts of pesticides in the diet (Duggan, 1968; Duggan and Corneliussen, 1972; Duggan and Lipscomb, 1969; Duggan et al, 1971; Duggan and Weatherwax, 1967). The estimated amounts consumed daily between 1964 and 1970, which are based on these values are summarized in Table IV.C.

Table IV.C. Incidence of carbaryl residues and resulting daily intake as reported in market basket surveys (1964-1970)

Reporting period	Positive composites, %	Daily intake, mg	Intake* mg/kg/day
June 1964 - April 1965	7.4	0.148	0.0021
June 1965 - April 1966	2.7	0.025	0.0004
June 1967 - April 1968	0.0	0.000	0.0001
June 1968 - April 1969	0.8	0.003	0.0001
June 1969 - April 1970	0.0	0.000	0.0001

* Based on a 16-19-year-old male weighing 69.1 kg (152 lb) consuming 4.0 kg (8.8 lb) of food daily.

As indicated in the above table, daily intakes reported for carbaryl residues declined during the 6 years of the market basket surveys. This decline is believed to be mostly attributable to use of more accurate analytical methods recently developed (Duggan, 1968).

IV.D. Analytical methods for determination of carbaryl residues

Research in methodology for cleanup and detection of carbaryl residue has been under continuous intensive investigation for several years.

IV.D.1. Association of Official Analytical Chemists (AOAC) method: The official AOAC method for carbaryl is based on alkaline hydrolysis of carbaryl and colorimetric determination of the resulting 1-naphthol with *p*-nitrobenzenediazonium fluoborate as chromogenic agent. A discussion of the adaptability of the method to various crops was published by Johnson and Stansbury (1965). This procedure has not been replaced as the most practical for generation of routine data and enforcement tolerances.

IV.D.2. Alternate methods: Alternate methods for detection of residues have been more or less successfully adapted to carbaryl by various investigators.

Thin-layer chromotography: Finocchiaro and Benson (1965) described a thin-layer chromatographic procedure for determination of carbaryl in foods. After the samples were spotted and the plates developed, carbaryl was hydrolyzed by spraying with KOH and then coupled with *p*-nitrobenzenediazonium fluoborate to produce blue spots. The procedure was sensitive to about 0.05 ppm and distinguished carbaryl from 1-naphthol.

GLC-electron capture: Gutenmann and Lisk (1965) used electron capture GLC for the determination of carbaryl in various crops. After extraction and cleanup, the carbaryl was hydrolyzed to 1-naphthol which was then brominated on glacial acetic acid. The brominated residue was taken up in benzene and injected into the GLC, which determined brominated 1-naphthyl acetate.

Oscillographic-polarographic procedure: Gajan et al (1965) reported an oscillographic-polarographic procedure whereby carbaryl could be determined in the presence of 1-naphthol. Using a modified cleanup recoveries of carbaryl from fortified crops averaged 95% at levels from 0.2 to 10.0 ppm. Among a number of pesticides tested, only o-phenylphenol interfered.

The thin-layer procedure has been more extensively used than the various instrumental procedures but primarily for semiquantitative and residue screening work. The instrumental procedures in general suffer from the fact that carbaryl is not stable under the conditions posed by gas chromatography and the formation of undesirable derivatives from characteristics similar to the pesticide confound the results.

IV.D.3. Analyses of residues and metabolites: The official AOAC colorimetric method has been extended recently to include determination of the major carbaryl plant metababolites. Procedures have been developed to determine free carbaryl, combined carbaryl, and the conjugated metabolites, 1-naphthol and methylol carbaryl. Methylol carbaryl is the major metabolite in the plants investigated. Each of the four compounds now can be determined separately in certain crops.

Organo-solubles (free carbaryl): The organo-soluble residue, essentially free carbaryl, was removed by homogenizing the sample with methylene chloride or a mixture of acetone-methylene chloride. The addition of anhydrous powdered sodium sulfate to the extraction mixture prevented the removal of the water-soluble metabolites by forming a hydrate of the water present in the crop. The free carbaryl fraction was cleaned using a coagulation step and Florisil column chromatography. The carbaryl was saponified to 1-naphthol and reacted with *p*-nitrobenzenediazonium fluoborate to form a yellow dye, the intensity of which was proportional to the naphthol present.

Water-solubles (combined carbaryl, conjugated naphthol and conjugated methylol carbaryl): The filter cake was extracted with an acetone-water solvent system containing stannous chloride to remove the water-soluble residues of toxicological significance. Stannous chloride was added to minimize oxidation of naphthol.

The water-soluble residues were acid hydrolyzed to release the corresponding aglycones. Methylol carbaryl was converted to 1-naphthyl carbamate (desmethyl carbaryl) under the conditions necessary to acid-hydrolyze the conjugates.

The aglycones from acid hydrolysis were given further cleanup and separation on a Florisil column. The first fraction to elute from Florisil contained 1-naphthol and the second fraction contained carbaryl and desmethyl carbaryl. These two compounds could not be separated on Florisil. The second fraction was evaporated to dryness and dissolved in methylene chloride. This mixture was extracted with 0.5N aqueous sodium hydroxide which converted desmethyl carbaryl to the water-soluble sodium salt of 1-naphthol without appreciable reaction of carbaryl. The colorimetric procedure was then used on the desmethyl carbaryl fraction to develop color and quantitate the residue. If the carbaryl fraction was still slightly colored, it was saponified to 1-naphthol and eluted from a Florisil column again. Quantitation was by the colorimetric procedure.

Normal fortification techniques could not be used to verify the procedure since high purity standards of the conjugated carbaryl metabolites were not available. A procedure utilizing plants treated with radioactive carbaryl was used to optimize the extraction and acid hydrolysis steps. The recovery of conjugated metabolites was further validated by fortifying, in the proper step, after acid hydrolysis with pure aglycones.

Results obtained with this methodology for total toxic carbaryl residues are presented for barley in Table IV.D.1., wheat in Table IV.D.2, green bean vines in Table IV.D.3., and alfalfa in Table IV. D.4. Samples were taken from fields treated with one or more sprays of carbaryl, and analyzed at indicated intervals after the last treatment.

Table IV.D.1. Total toxic Sevin carbaryl residues in barley

Rate active ingredient/acre	Days after last application	Free carbaryl, ppm	Combined carbaryl, ppm	Conjugates: Naphthol, ppm	Conjugates: Methylol carbaryl, ppm
Heads and grain					
1 lb	7	1.5	0.31	0.06	0.05
	14	0.66	0.17	0.06	0.07
	21	1.0	0.18	0.10	0.11
	48 (grain)	0.28	0.56	0.14	0.12
1 lb + 1 lb	7	3.6	0.31	0.07	0.08
	14	5.6	0.34	0.20	0.35
	21	3.3	0.59	0.37	0.42
	48 (grain)	0.82	1.5	0.20	0.20
Whole Plants					
1.5 lb	0	47.0	0.57	0.08	0.15
	7	33.0	0.75	0.37	1.2
	14	15.1	0.24	0.27	0.88

Source: Union Carbide Corporation.

Table IV.D.2. Total toxic Sevin carbaryl residues in wheat

Rate active ingredient/acre	Days after last application	Free carbaryl, ppm	Combined carbaryl, ppm	Conjugates: Naphthol, ppm	Conjugates: Methylol carbaryl, ppm
Whole Plant					
1.5 + 1.5 lb	0	20.2	0.45	0.05	0.06
	3	11.8	0.29	0.07	0.07
	7	11.5	0.17	0.09	0.03
	14	1.5	0.27	0.08	0.09
	24	0.59	0.22	0.09	0.06

Table IV.D.3. Total toxic Sevin carbaryl residues in green bean vines

Rate active ingredient/acre	Days after last application	Free carbaryl, ppm	Combined carbaryl, ppm	Conjugates: Naphthol, ppm	Conjugates: Methylol carbaryl, ppm
4+4+4 lbs (exaggerated)	0	1680	18.9	0.9	4.1
	1	1328	17.2	3.1	6.8
	2	1172	12.3	3.1	9.4
	4	980	17.1	3.5	11.2
	7	125	5.5	4.2	13.7
	14	76	5.8	3.4	15.5

Table IV.D.4. Total toxic Sevin carbaryl residues in alfalfa

Rate active ingredient/acre	Days after last application	Free carbaryl, ppm	Combined carbaryl, ppm	Conjugates: Naphthol, ppm	Conjugates: Methylol carbaryl, ppm
2 lbs	0	56.9	1.34	0.46	0.24
	3	32.4	0.69	0.46	0.24
	7	20.5	0.59	0.36	0.35
	12	31.1	0.52	0.62	0.73
	30	3.1	0.18	0.29	0.39
2+2+2 lb (exaggerated)	0	333	5.2	0.38	0.78
	2	57.5	3.2	0.31	0.82
	4	52.1	2.4	0.58	0.86
	7	29.3	1.9	0.39	1.1
	14	16.4	1.2	1.1	2.6
	21	14.7	0.37	0.85	0.7

Source for Tables IV.D.2.-IV.D.4.:Union Carbide Corporation.

Total Sevin carbaryl residues in the plants investigated consisted primarily of free carbaryl. Free carbaryl accounted for 70-100% of the total residue for up to 3 wk following the last treatment on foliage and grain. On alfalfa, barley, wheat, and green beans the free carbaryl accounted for about 90% of the residues on the foliar parts of the plants. In barley grain, harvested 48 d after treatment, about 25-30% was free carbaryl, 50-55% was combined carbaryl, and the remainder, about 10% each, was conjugated 1-naphthol and methylol carbaryl. Maximum residues for the conjugated components did not total more than about 2 ppm at label rates of application. The free carbaryl (external residue) declined steadily with time after application. The amount of combined and conjugated residues (internal residues), though changing only a few tenths of a ppm in magnitude, increased until about 2 wk after treatment when they also started to decline. Results with barley grain indicate combined or conjugated residue concentration in this crop may peak somewhat later than 2 wk.

Literature Cited

Andrawes, N.R., E.L. Chancey, R.J. Crabtree, R.A. Herrett, and M.H.J. Weiden. Fate of naphthyl-1-^{14}C carbaryl in laying chickens. J. Agric. Food Chem. 20(3):608-617. 1972.

Baron, R.L., N.J. Palmer, R. Ross, J. Doherty, and W.C. Jacobson. Distribution of radioactivity in milk resulting from oral administration of C^{14}-labeled carbaryl. J. Assoc. Off. Anal. Chem. 51:32-34. 1968.

Baron, R.L. Radioactive lactose in skim milk following administration of carbonyl-^{14}C-carbaryl to a lactating cow. J. Assoc. Off. Anal. Chem. 51(5):1046-1049. 1968.

Baron, R.L., J.A. Sphon, J.T. Chen, E. Lustig, J.D. Doherty, E.A. Hansen, and S.M. Kolbye. Confirmatory isolation and identification of a metabolite of carbaryl in urine and milk. J. Agric. Food Chem. 17(4):883-887. 1969.

Camp, H.B., J.R. Buttram, K.L. Hays, and B.W. Arthur. Sevin residues in milk from dairy cows following dermal applications. J. Econ. Entomol. 56(3):402-404. 1963.

Claborn, H.V., R.H. Roberts, H.D. Mann, M.C. Bowman, M.C. Ivey, C.P. Weidenbach, and R.D. Radeleff. Residues in body tissues of livestock sprayed with Sevin or given Sevin in the diet. J. Agric. Food Chem. 11(1):74-76. 1963.

Corneliussen, P.E. Pesticide residues in total diet samples (IV). Pestic. Monit. J. 2(4):140-152. 1969.

Corneliussen, P.E. Pesticide residues in total diet samples (V). Pestic. Monit. J. 4(3):89-105. 1970.

Corneliussen, P.E. Pesticide residues in total diet samples (VI). Pestic. Monit. J. 5(4):313-330. 1972.

Cummings, J.G. Total diet study -- Pesticide residues in total diet samples. J. Assoc. Off. Anal. Chem. 48(6):1177-1180. 1965.

Dorough, H.W., and J.E. Casida. Nature of certain carbamate metabolites of the insecticide Sevin. J. Agric. Food Chem. 12(4):294-304. 1964.

Dorough, H.W. Carbaryl-C^{14} metabolism in a lactating cow. J. Agric. Food Chem. 15(2):261-266. 1967.

Dorough, H.W. Continuous feeding of carbaryl-naphthyl-^{14}C to lactating cows. Progress Report. January 6, 1970. [Published in: A.S. Tahori, ed. Pesticide Terminal Residues (Invited papers, International Symposium on Pesticide Terminal Residues, Tel Aviv, Israel, February 17-19, 1971). Butterworths, London. 1971. pp. 173-183.]

Dorough, H.W. Carbaryl residues in milk and meat of dairy animals. In: A.S. Tahori, ed. Pesticide Terminal Residues (Invited Papers, International Symposium on Pesticide Terminal Residues, Tel Aviv, Israel, February 17-19, 1971). Butterworths, London. 1971. pp. 173-183.

Duggan, R.E., H.C. Barry, and L.Y. Johnson. Pesticide residues in total-diet samples. Science 151:101-104. 1966.

Duggan, R.E., and F.J. McFarland. Assessments include raw food and feed commodities, market basket items prepared for consumption, meat samples taken at slaughter. Pestic. Monit. J. 1(1):1-5. 1967.

Duggan, R.E., and J.R. Weatherwax. Dietary intake of pesticide chemicals. Science 157:1006-1010. 1967.

Duggan, R.E., H.C. Barry, and L.Y. Johnson. Pesticide residues in total diet samples (II). Pestic. Monit. J. 1(2):2-12. 1967.

Duggan, R.E. Pesticide residue levels in foods in the United States from July 1, 1963, to June 30, 1967. Pestic. Monit. J. 2(1):2-46. 1968.

Duggan, R.E., and G.Q. Lipscomb. Dietary intake of pesticide chemicals in the United States (II), June 1966 - April 1968. Pestic. Monit. J. 2(4):153-162. 1969.

Duggan, R.E., G.Q. Lipscomb., E.L. Cox, R.E. Heatwole, and R.C. Kling. Pesticide residue levels in foods in the United States from July 1, 1963 to June 30, 1969. Pestic. Monit. J. 5(2):73-212. 1971.

Duggan, R.E., and P.E. Corneliussen. Dietary intake of pesticide chemicals in the United States (III), June 1968 - April 1970. Pestic. Monit. J. 5(4):331-341. 1972.

Eheart, J.F., E.C. Turner, and J. Dickinson. Residues of Sevin in whole milk from sprayed and dusted cows. J. Econ. Entomol. 55(4):504-505. 1962.

Elkins, E.R., F.C. Lamb, R.P. Farrow, R.W. Cook, M. Kawai, and J.R. Kimball. Removal of DDT, malathion, and carbaryl from green beans by commercial and home preparative procedures. J. Agric. Food Chem. 16(6):962-966. 1968.

Elkins, E.R., R.P. Farrow, and E.S. Kim. The effect of heat processing and storage on pesticide residues in spinach and apricots. J. Agric. Food. Chem. 20(2):286-291. 1972.

Farrow, R.P., F.C. Lamb, R.W. Cook, J.R. Kimball, and E.R. Elkins. Removal of DDT, malathion, and carbaryl from tomatoes by commercial and home preparative methods. J. Agric. Food Chem. 16(1):65-71. 1968.

Farrow, R.P., F.C. Lamb, E.R. Elkins, R.W. Cook, M. Kawai, and A. Cortes. Effect of commercial and home preparative procedures on parathion and carbaryl residues in broccoli. J. Agric. Food Chem. 17(1):75-79. 1969.

Finocchiaro, J.M., and W.R. Benson. Thin-layer chromatographic determination of carbaryl (Sevin) in some foods. J. Assoc. Off. Anal. Chem. 48(4):736-738. 1965.

Furman, D.P., and G.R. Pieper. Systemic acaricidal effects of Sevin in poultry. J. Econ. Entomol. 55(3):355-357. 1962.

Gajan, R.J., W.R. Benson, and J.M. Finocchiaro. Determination of carbaryl in crops by oscillographic polarography. J. Assoc. Off. Anal. Chem. 48(5):958-962. 1965.

Ghadiri, M., D.A. Greenwood, and W. Binns. Feeding of malathion and carbaryl to laying hens and roosters. Toxicol. Appl. Pharmacol. 10:392. 1967. [Abstracts of Papers, 6th Annual Meeting, Society of Toxicology, Atlanta, Georgia, March 23-25, 1967.]

Gutenmann, W.H., and D.J. Lisk. Gas chromatographic residue determination of Sevin as brominated 1-naphthyl acetate. J. Agric. Food Chem. 13(1):48-50. 1965.

Gyrisco, G.G., D.J. Lisk, S.N. Fertig, E.W. Huddleston, F.H. Fox, R.F. Holland, and G.W. Trimberger. The effects of feeding high levels of Sevin on residue flavor, and odor of the milk of dairy cattle. J. Agric. Food Chem. 8(5):409-410. 1960.

Hurwood, I.S. Studies on pesticide residues. 2. Carbaryl residues in the body tissues and milk of cattle following dermal application. Queensl. J. Agric. Anim. Sci. 24:69-74. 1967.

Johnson, D.P., F.E. Critchfield, and B.W. Arthur. Determination of Sevin insecticide and its metabolites in poultry tissues and eggs. J. Agric. Food Chem. 11(1):77-80. 1963.

Johnson, D.P., and H.A. Stansbury. Adaptation of Sevin insecticide (carbaryl) residue method to various crops. J. Agric. Food Chem. 13(3):235-238. 1965.

Khan, M.H., R.J. Avery, and H.P. Dueck. Toxicity of Sevin (1-naphthyl-N-methyl-carbamate) to cattle grubs, lice, and cattle. Can. J. Comp. Med. Vet. Sci. 26(10):234-237. 1962.

Khmelevskii, B.N. The effect of prolonged feeding Sevin on the chicken organism. Veterinariya, No. 9:59-60. 1968.

Lamb, F.C., and R.P. Farrow. (Project Leaders) Investigations on the effect of preparation and cooking on the pesticide residue content of selected vegetables. Progress report for the period November 13, 1965 to May 13, 1966. National Canners Association, Research Foundation, Washington, D.C. 1966. 64 pp.

Lamb, F.C., R.P. Farrow, E.R. Elkins, J.R. Kimball, and R.W. Cook. Removal of DDT, parathion, and carbaryl from spinach by commercial and home preparative methods. J. Agric. Food Chem. 16(6):967-973. 1968.

Leeling, N.C., and J.E. Casida. Metabolites of carbaryl (1-naphthyl methylcarbamate) in mammals and enzymatic systems for their formation. J. Agric. Food Chem. 14(3):281-290. 1966.

Martin, R.J., and R.E. Duggan. Pesticide residues in total diet samples (III). Pestic. Monit. J. 1(4):11-20. 1968.

McCay, C.F., and B.W. Arthur. Sevin residues in poultry products. J. Econ. Entomol. 55(6):936-938. 1962.

Nir, I., E. Weisenberg, A. Hadani, and M. Egyed. Studies of the toxicity, excretion and residues of Sevin in poultry. Poult. Sci. 45:720-728. 1966.

Paulson, G.D., and V.J. Feil. The fate of a single oral dose of carbaryl (1-naphthyl methylcarbamate) in the chickens. Poult. Sci. 48:1593-1597. 1969.

Petrovskii, V.V. Level and duration of the secretion of Sevin with the milk by cows treated against cattle ticks. Gig. Primen. Toksikol. Pestits. Klin. Otravlenii, No. 8:193-196. 1970.

Prudich, J. Insecticide Sevin and 1-naphthol residues in eggs. Letter dated January 25, 1963 to R.C. Back.

Roberts, R.H., J.B. Jackson, W.E. Westlake, A.J. Ackerman, and H.V. Claborn. Residue studies of livestock sprays containing Sevin. J. Econ. Entomol. 53(2):326-327. 1960.

Sutherland, D.W.S., W.G. Harwood, and H.L. Dozier, Jr. EPA Compendium of Registered Pesticides, Vol. 3. Insecticides, Acaricides, Molluscicides, and Antifouling Compounds. Washington, D.C., Government Printing Office, 1972. pp. III-C-7.2 to III-C-7.69.

U.S. Department of Agriculture (USDA). Results of tests to determine residue of Sevin in milk. USDA, Agricultural Research Service, Kerrville, Texas. 1959. 6 pp. [Special Report K-52]

Whitehurst, W.E., E.T. Bishop, F.E. Critchfield, G.G. Gyrisco, E.W. Huddleston, H. Arnold, and D.J. Lisk. The metabolism of Sevin in dairy cows. J. Agric. Food Chem. 11:167-169. 1963.

Chapter V

AN ANALYSIS OF APIARY LOSSES DUE TO CARBARYL

Carbaryl is one of the less toxic pesticides in use today. Its most severe impact is the effect on honeybees, and one of the major problems facing beekeepers in the United States is potential destruction of bees from inadvertent pesticide chemical poisoning. Bees located in one area (often temporarily because of pollination purposes) may gather pollen from crops treated with toxic chemicals. The problem is further complicated if the chemical is returned to the hive with the gathered pollen. This can result in destruction of the entire brood rather than simply those bees in direct contact with the treated crop. Carbaryl is one of the most toxic pesticides to bees. After a discussion on general carbaryl use and beekeeping practices in the U.S., the magnitude of bee losses due to carbaryl and the implications of such losses are analyzed.

V.A. General use of carbaryl in the United States

Carbaryl has been used as an insecticide in the U.S. since 1958. The sole producer of technical carbaryl in this country is the Union Carbide Corporation.

This widespread use is illustrated in Table V.A.1.

Table V.A.1. Use of carbaryl by crop, area, and amount, 1971

Crop	Area (1000 acres)	Amount[1/] (thousand lb)
Corn	1,203	1,649
Cotton	244	1,214
Wheat	99	114
Other grains	856	1,088
Soybeans	913	1,346
Tobacco	359	1,420
Peanuts	1,164	4,088
Other field crops	169	219
Alfalfa	141	104
Other hay and pasture	207	134
Potatoes	171	357
Other vegetables	699	3,199
Citrus	66	244
Apples	231	583
Other fruits and nuts	406	769
Total	6,928	16,592

1/ Excludes 64,000 lb for nursery and greenhouse use.
Source: USDA, Quantities of Pesticides Used by Farmers in 1971, November 1973.

V.B. Beekeeping in relation to chemical poisoning

Beekeeping is a minor yet important agricultural enterprise in many sections of the U.S. While bees are usually associated with the production of honey and beeswax, an important secondary function is pollination of many agricultural crops.

In 1973, the producer price of honey reached an all-time high of over 44 cents per pound, and the 1973 honey crop was valued at over $105 million (Table V.B.1.). The years 1972 and 1973 showed a rapid increase in honey prices, as evidenced by the tremendous increase in the value of production since 1971. More than half of this honey was produced in commercial apiaries (300 or more colonies), with Florida, California, and South Dakota being the major honey-producing states (Table V.B.2.) Beeswax production is secondary to production of honey, and in 1973 was valued in 1973 at only $3 million (Table V.B.2.).

Although data are not available regarding the importance of commercial apiaries for pollination of various agricultural crops, this practice is widespread in several major agricultural states. Artificial pollination with bees is especially important to many fruit, vegetable, legume, and oilseed crops. Although many kinds of insects visit flowers and affect accidental pollination, the number is small. Bees are the most efficient and only dependable pollinators because they visit flowers methodically to collect nectar and pollen and do not destroy the plant by feeding on it in the pollination process. Although various species of bees contribute to the pollination of crops, an estimated 80% of this pollination is done by the honeybee.[1/]

Much artificial pollination is done on a contractual basis. A typical case is a fruit producer (the State of Washington has many such examples) entering into a contract with an apiarist to place a certain number of colonies throughout his orchard during the 10-14 d flowering period. Currently, the fee for such service would be approximately $10 per colony for the entire period. Prior to this contract, the apiarist may have entered into a similar agreement during the earlier season in California, and so a gross income of $20 per colony in addition to

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1/ Beekeeping in the United States, USDA, 1967.

Table V.B.1. Honey and beeswax: production and value of production, and honey stocks, 1965-73

Year	Honey					Beeswax			
	Colonies of bees	Yield per colony	Pro-duction	Price per lb	Total value	Stocks on hand	Pro-duction	Price per lb	Total value
	1,000 colonies	lb	1,000 lb	Cents	1,000 dollars	1,000 lb	1,000 lb	Cents	1,000 dollars
1965	4;718	51.3	241,849	17.8	43,011	57,679	4,697	44.9	2,111
1966	4,646	52.0	241,576	17.4	41,929	55,340	4,615	46.5	2,148
1967	4,635	46.6	215,780	15.6	33,678	56,733	4,386	58.8	2,580
1968	4,539	42.2	191,391	16.9	32,400	41,021	3,797	61.6	2,340
1969	4,433	60.3	267,485	17.5	46,742	62,743	5,171	61.1	3,162
1970	4,290	51.7	221,842	17.4	38,550	50,575	4,377	60.2	2,638
1971	4,110	48.0	197,428	21.8	43,100	30,907	3,585	61.3	2,196
1972	4,067	52.6	213,959	30.2	64,533	29,786	3,986	62.1	2,474
1973	4,101	58.1	238,213	44.4	105,655	37,845	4,226	74.4	3.144

Source: Honey Production, Statistical Reporting Service, USDA, January 1974.

Table V.B.2. Honey: commercial p[illegible]uction in apiaries with 300 or more colonies in 20 major states, 1972-73

State	Colonies of bees			Yield per colony		Honey production		
	1972	1973	1973 as % of 1972	1972	1973	1972	1973	1973 as % of 1972
	1,000 colonies		%	lb		1,000 lb		%
Arizona	43	47	109	52	77	2,236	3,619	162
California	418	385	92	50	65	20,900	25,025	120
Colorado	32	31	97	71	54	2,272	1,674	74
Florida	130	136	105	97	106	12,610	14,416	114
Georgia	69	70	101	38	49	2,622	3,430	131
Idaho	86	91	106	47	60	4,042	5,460	135
Illinois	11	10	91	63	70	693	700	101
Iowa	42	36	86	80	112	3,360	4,032	120
Michigan	51	54	89	55	85	3,355	4,590	137
Minnesota	91	98	108	98	117	8,918	11,466	129
Montana	72	75	104	10	102	7,920	7,650	97
Nebraska	104	110	106	80	75	8,320	8,250	99
New York	53	54	102	59	61	3,127	3,294	105
North Carolina	6	6	100	60	70	360	420	117
North Dakota	59	68	115	142	100	8,378	6,800	81
Oregon	25	25	100	41	55	1,025	1,375	134
South Dakota	115	125	109	124	110	14,260	13,750	96
Texas	81	83	102	96	61	7,776	5,063	65
Washington	77	76	99	43	47	3,311	3,572	108
Wisconsin	55	50	91	72	120	3,960	6,000	152
20 States	1,630	1,630	100	73.3	80.1	119,445	130,586	109

Source: Honey Production, Statistical Reporting Service, USDA, January 1974.

honey production can be realized. Thus, a particular colony may be used for pollinating almonds in California in March, apples, pears, or cherries in Washington in April and May, and then returned to honey production in June.

While bees in all areas are potential targets for chemical pesticides, those used for pollination purposes are especially threatened. For this reason, chemical use is usually restricted during the flower pollination period. Problems arise, however, when the chemical is used on adjacent crops. Carbaryl is one of the most highly toxic chemicals for bees and, even with reasonable safeguards, often results in damage or destruction to bee colonies.

Because the benefits from pesticide use on the intended insect/crop are significant, and because the beekeeper may suffer financial loss due to pesticide use beyond his control, a Federal Apiary Indemnification Program has been established to reimburse apiarists for pesticide damage. To qualify for payment under this program, four criteria must be met: (1) the apiarist must be registered with the USDA; (2) he must have proof (including a physical inspection) of loss; (3) he must have proof that a pesticide was used within the normal forage area of the bees; and (4) he must have proof that reasonable care was taken to avoid such loss. If all four criteria are met, the beekeeper is eligible for a $5-15 indemnity payment (depending on degree of loss) per colony. In most cases (Arizona is the prime exception) losses are specified by chemical. While no attempt is made to verify the precise chemical in question, most applications are considered accurate. Examination of these indemnification losses, therefore, sheds considerable light on possible apiary losses due to inadvertent poisoning from carbaryl.

V.C. Apiary losses resulting from various pesticides

Examination of USDA Apiary Indemnification Program data from the five major claimant states indicates that from 60 to 108 apiaries have applied for and received indemnification for carbaryl related losses in each of the four years, 1970 through 1973. These losses were valued at $91-$223 thousand, or up to 30% of total apiary pesticide indemnity payments during that period (Table V.C.1.). Tables V.C.2-5. give detailed losses for major affected states by crop and degree of severity. Analysis of the data presented in these tables shows that carbaryl applied to sweet corn accounted for almost three-fourths (72%) of all carbaryl-related apiary damage during the 1970-73 period. In terms of number of colonies, carbaryl appears to have damaged or destroyed 2.5% (26,814 per year) of all colonies in the five-state area examined. The carbaryl damage relating to peas (appearing only after 1972) is concurrent with restriction on DDT use and a substitution of carbaryl for control of insects in pea production.

Table V.C.1. Apiary loss claims, indemnification due to carbaryl insecticide in major affected states, 1970 - 1973

State	Year	Number of claims for carbaryl	Indemnification for carbaryl	Total Idemnification	Carbaryl indemnification as percent of total indemnification
California	1970	10	$ 13,955	$ 428,795	3.25
	1971	17	21,335	666,445	3.20
	1972	18	5,945	361,350	0.16
	1973	10	11,690	144,700	8.07
Georgia	1970	3	$ 3,945	$ 16,365	24.11
	1971	10	13,914	66,712	28.35
	1972	28	47,401	131,560	36.02
	1973	20	49,350	126,145	39,12
Minnesota	1970	16	$ 25,250	$ 30,695	92.03
	1971	13	11,500	28,425	40.45
	1972	10	4,825	6,989	69.04
	1973	13	18,499	20,999	88.78
Washington	1970	16	$ 162,370	$ 272,110	59.67
	1971	5	24,235	582,820	4.15
	1972	10	86,460	344,942	25.06
	1973	N/A	N/A	31,115	N/A
Wisconsin	1970	18	$ 14,685	$ 21,203	69.26
	1971	49	71,153	102,517	69.39
	1972	42	25,511	39,404	64.74
	1973	17	12,130	23,638	51.31
5-State total	1970	63	$ 223,205	$ 768,868	29.03
	1971	94	147,137	1,446,919	10.17
	1972	108	170,142	881,245	19.24
	1973	60	91,625	326,243	28.08

Source: Adapted from USDA, Apiary Indemnification Program data by Economic Analysis Branch, Criteria and Evaluation Division, Office of Pesticide Programs, EPA.

Table V.C.2. Apiary loss claims due to carbaryl* use on sweet corn by degree of severity and amount of indemnification, major affected states, 1970 - 73

State	Year	No. of colonies in state	No. of colonies owned by applicants	No. of destroyed colonies	No. of severely damaged colonies	No. of moderately damaged colonies	Cash indemnification
California	1970	559,000	218	40	178	0	$ 3,470.00
	1971	531,000	532	158	185	165	5,570.00
	1972	500,000	454	2	196	180	2,890.00
	1973	N/A	851	0	0	593	2,955.00
Georgia	1970	174,000	0	0	0	0	$ 0
	1971	162,000	0	0	0	0	0
	1972	104,000	249	34	102	79	1,925.00
	1973	N/A	0	0	0	0	0
Minnesota	1970	177,000	5,353	1,002	446	260	$28,250.00
	1971	156,000	1,449	316	190	439	11,500.00
	1972	140,000	1,567	131	200	137	4,195.00
	1973	N/A	3,069	352	911	139	14,650.00
Washington	1970	93,000	34,052	625	252	29,218	$162,370.00
	1971	90,000	3,484	308	983	666	24,235.00
	1972	97,000	9,838	204	7,659	853	86,460.00
	1973	N/A	N/A	N/A	N/A	N/A	N/A
Wisconsin	1970	121,000	5,849	354	316	381	$14,685.00
	1971	117,000	9,963	959	3,189	1,276	71,153.00
	1972	110,000	2,587	577	991	915	24,631.00
	1973	N/A	1,945	171	416	612	12,025.00
5-State total	1970	1,124,000	45,472	2,021	1,192	29,859	$203,775.00
	1971	1,056,000	15,428	1,741	4,547	2,546	112,458.00
	1972	1,011,000	14,695	948	9,046	2,085	120,101.00
	1973	N/A	5,865	623	1,327	1,344	29,640.00

* In some cases other pesticides were implicated.

Source: Adapted from USDA, Apiary Indemnification Program data by Economic Analysis Branch, Criteria and Evaluation Division, Office of Pesticide Programs, EPA.

Table V.C.3. Apiary loss claims due to carbaryl* use on cotton by degree of severity and amount of indemnification, selected states, 1970 - 73

State	Year	No. of colonies in state	No. of colonies owned by applicants	No. of destroyed colonies	No. of severely damaged colonies	No. of moderately damaged colonies	Cash indemnification
California	1970	559,000	1,168	30	0	1,977	$ 10,485.00
	1971	531,000	2,091	35	537	1,409	15,765.00
	1972	500,000	416	20	175	221	3,055.00
	1973	N/A	1,369	118	205	855	8,725.00
Georgia	1970	174,000	0	0	0	0	$ 0
	1971	162,000	931	234	375	0	10,305.00
	1972	164,000	2,732	453	685	372	14,716.00
	1973	N/A	1,028	81	674	79	8,350.00
2-State total	1970	559,000	1,168	30	0	1,977	$ 10,485.00
	1971	693,000	3,022	269	912	1,409	26,070.00
	1972	664,000	3,148	473	860	593	17,771.00
	1973	N/A	2,397	199	880	934	17,075.00

* In some cases other pesticides were implicated.

Source: Adapted from USDA, Apiary Indemnification Program data by Economic Analysis Branch, Criteria and Evaluation Division, Office of Pesticide Programs, EPA.

Table V.C.4. Apiary loss claims due to [redacted]rbaryl use on peas, by degree of severity and amount of indemnification, selected states, 1970 - 73

State	Year	No. of colonies in state	No. of colonies owned by applicants	No. of destroyed colonies	No. of severely damaged colonies	No. of moderately damaged colonies	Cash indemnification
Georgia	1972	164,000	251	49	93	69	$ 2,010.00
	1973	N/A	471	6	226	51	2,605.00
Minnesota	1972	140,000	67	0	59	8	630.00
	1973	N/A	658	219	52	0	3,805.00
Wisconsin	1972	110,000	96	15	72	20	880.00
	1973	N/A	0	0	0	0	0
3-State total	1972	414,000	414	64	224	97	3,520.00
	1973	N/A	1,129	225	278	51	6,410.00

Source: Adapted from USDA, Apiary Indemnification Program data by Economic Analysis Branch, Criteria and Evaluation Division, Office of Pesticide Programs, EPA

Table V.C.5. Apiary loss claims due to carbaryl* use on soybeans by degree of severity and amount of indemnification, selected states, 1970 - 73

State	Year	No. of colonies in state	No. of colonies owned by applicants	No. of destroyed colonies	No. of severely damaged colonies	No. of moderately damaged colonies	Cash indemnification
Georgia	1970	174,000	172	126	21	17	$ 1,945.00
	1971	162,000	2,631	109	351	116	8,609.00
	1972	164,000	14,361	551	3,375	1,230	28,750.00
	1973	N/A	6,299	508	3,585	438	38,395.00
Wisconsin	1970	121,000	0	0	0	0	0
	1971	117,000	0	0	0	0	0
	1972	110,000	0	0	0	0	0
	1973	N/A	16	3	3	6	105.00
2-State total	1970	295,000	172	126	21	17	1,945.00
	1971	279,000	2,631	109	351	116	8,509.00
	1972	274,000	14,361	551	3,375	1,230	28,750.00
	1973	N/A	6,315	511	3,588	444	38,500.00

* In some cases other pesticides were implicated.

Source: Adapted from USDA, Apiary Indemnification Program data by Economic Analysis Branch, Criteria and Evaluation Division, Office of Pesticide Programs, EPA.

It should be noted that Federal indemnification may not adequately compensate for loss of a colony. With today's higher honey prices, a well managed colony can yield as much as $40 per year in honey alone. If the colony is used for pollination contracting, $10-$20 of additional revenue could be generated. The price of a new colony varies considerably from one location to another, approaching $50 per colony in some locations. While some inequities most likely exist, the value of indemnity payments in relation to the productive value of the colony does not seem sufficient to encourage unnecessary claims.

A final way to examine the carbaryl vs. bee dilemma is with respect to the value of the crop protected by carbaryl. This has been done in Table V.C.6.

Table V.C.6. Apiary indemnification due to carbaryl damage and value of crops on which this carbaryl was applied, selected states, 1970-73

State	Year	Indemnification from carbaryl related losses	Value of crops treated with carbaryl				
			Total	Sweet corn	Cotton	Soybeans	Peas
California	1970	$ 13,955	$ 6,609,520	$ 6,315,460	$ 294,060	a	a
	1971	21,335	5,809,308	5,456,895	352,413	a	a
	1972	5,945	7,270,490	6,754,240	516,250	a	a
Georgia	1970	3,945	b	b	66,021	$ 32,228,750	b
	1971	18,914	b	b	109,507	43,758,000	b
	1972	47,401	b	b	91,800	35,677,500	b
Minnesota	1970	28,250	a	10,374,720	a	a	$ 7,865,000
	1971	11,500	a	10,372,700	a	a	8,228,250
	1972	4,825	a	12,236,950	a	a	9,711,000
Washington	1970	162,370	5,011,305	5,011,305	a	a	a
	1971	24,235	5,141,655	5,141,655	a	a	a
	1972	86,460	5,617,885	5,617,885	a	a	a
Wisconsin	1970	14,888	35,887,785	10,647,225	a	10,024,560	15,136,000
	1971	71,153	37,264,840	12,284,640	a	9,174,400	15,805,800
	1972	25,511	45,132,680	13,191,680	a	13,501,000	18,340,000

a. Limited or no production.
b. Figures not available.
Source: Adapted from USDA, Apiary Indemnification data.

Chapter VI

USE OF CARBARYL INSECTICIDE IN THE UNITED STATES

At present, all carbaryl available for use in the United States is the product of Union Carbide Corporation. Sevin carbaryl insecticide has been used worldwide since 1959 for control of insect pests which attack agricultural crops and certain other nonagricultural pests. Sevin carbaryl is used as an insecticide in areas outside the U.S. on the following crops in declining order of importance: cotton, vegetables, rice, potatoes, fruit, and livestock.

The details of the chemistry, production, and toxicology of Sevin carbaryl as relative to safety in use have been discussed earlier in this study. One important purpose of this chapter is to discuss the principal crop patterns of insecticide use for carbaryl in the U.S. as those patterns may be related to safety review.

Certain aspects of the use patterns for carbaryl are common to most uses for the insecticide and are discussed generally rather than repeatedly under each subsequent crop heading. A brief description of the type and extent of injury caused by each of the major crop pests for which carbaryl is registered is presented. Insects of minor or regional significance are not discussed. The use of common names to identify insect pests is consistent with the nomenclature used on EPA-registered product labels.

Use patterns vary from year to year with fluctuations in acreage, climate, pest complex, and crop conditions. For this reason, averages have been used in presenting information on acreage, production, and value of the various crops.

Although similar in their activity against insects, formulations of carbaryl differ in physical form, concentration, and handling characteristics. Union Carbide sells Sevin carbaryl insecticide in the U.S. as a formulated product, either as a finished formulation or as a manufacturing concentrate for further processing by customers for sale under their own registered labels.

Four carbaryl formulations account for nearly 90% of the U.S. use. Two of these, Sevin Sprayable and Sevimol-4, are made only by Union Carbide and are especially well-suited to use in low gallonage ground or aircraft spray equipment. Both utilize airmilled technical carbaryl with particles in the 3-10 μ range. This microfine technical plus a complex wetting and dispersing system results in a uniform suspension in water, which is compatible with most commonly used pesticides. Although these two formulations were designed specifically for use in low-volume spray equipment common in vegetable, field, and forage crop pest control, they can be utilized equally well in high-gallonage equipment often used on citrus or deciduous fruit.

Sevin 50W is a slightly coarser product and is used primarily in high gallonage, mechanically agitated ground spray equipment. Although it is compatible with other products at high dilution rates (i.e., 1 lb/100 gal water), it should not be used in combination with other products at low dilution rates.

Sevin 80% Dust Base is used by Union Carbide's formulating distributors in the preparation of low-analysis (2.5 - 10%) dust formulations. Many dust formulations may be applied by aircraft, ground, or hand-operated equipment but such use is diminishing.

The cost of applying insecticides varies with the crop, the formulation or spray volume per acre, and the type of equipment used. Expenditures by farmers for custom spraying services averaged $2.60/acre by ground and $1.20/acre by fixed wing aircraft in 1964 (Agricultural Research Service, 1965). Certain crops, such as citrus or apples, normally require high gallonage application by ground equipment and costs may reach $6.60/acre or more. Dusts are generally more costly to apply by air than sprays, averaging $1.50/acre for dust versus $1.20/acre for sprays with fixed wing aircraft and $3.80 versus $1.70/acre for helicopters (Jenkins et al, 1968).

Approximately 60% of the Sevin carbaryl used in the U.S. (primarily Sevin Sprayable and Sevimol-4) is applied by custom aircraft applicators. Water is by far the most common vehicle used in applying carbaryl to all crops, but oils and solid carriers are also used under certain circumstances. In recent years, a major trend towards reducing the volume of spray applied per acre has developed. Concentrate sprays of 40 - 100 gal/acre have replaced the conventional dilute sprays of 400 - 800 gal/acre on many fruit crops. Also, spray volumes applied by aircraft to many vegetable, field, and forage crops have been reduced from 5 - 8 gal to 1 - 5 gal of spray/acre. Sevimol-4, a liquid, has gained wide acceptance by aerial applicators and is often applied at the rate of 1 qt formulation in a total spray volume of 1 gal/acre. As crop registrations for this product are expanded, it is expected to assume a higher percentage of total Sevin carbaryl uses.

The versatility of carbaryl made possible by its registration on over 80 crops for control of more than 160 different insect pests accounts in part for the high-use volume and broad usage in the U.S. (Agricultural Research Service, 1969; Union Carbide Corporation, 1972). Apparent reliable performance against target pests and the seemingly low order of hazard to man and his environment have also been important factors in molding the pattern of use.

Carbaryl is neither the least nor the most expensive insecticide on the market and is usually selected for use by the farmer on the basis of several facts rather than economics alone.

Carbaryl has long been widely recommended for pest control by the U.S. Department of Agriculture, the U.S. Department of the Interior, and the land grant universities (Agricultural Research Service, 1968; Pest Control Guides, 1972; Wester, 1968). Research and extension workers frequently recommend it in preference to more hazardous compounds, especially if the application is to be made by someone other than a professional applicator.

In general, carbaryl is regarded by agricultural experts as being not injurious to plants when label directions are followed. Interaction with certain herbicides has resulted in specific cautions on carbaryl labels to warn the user.

Fruit-thinning on apples was first noted in the early commercial use of carbaryl. It is used now in the apple grower's successful management of fruit set, size, and repeat bloom and has turned out to be a significant additional use. Tests for this physiologic response on other crops have been consistently negative.

A strong influence on the use patterns of carbaryl in recent years has been the reduction in the general use of organochlorine insecticides due to undesirable persistence and biomagnification in the environment. As research and extension entomologists began searching for alternate pesticides, they have often selected carbaryl.

In addition to this discussion of certain major uses for carbaryl, Appendix 1 entitled *Summary of Carbaryl Insecticide Uses in the United States*, presents information on crops, insects controlled, dosages, and use limitations. Appendix 2 summarizes EPA registered labels.

VI.A. Soybeans

An average of 42,522,000 acres of soybeans was grown annually in the U.S. in the period of 1968-1970. Production during this period averaged 1,121,737,000 bushels and had an on-farm value of

$2,843,555,000 per year (Agricultural Statistics, 1971). In the period 1951-1960, annual loss due to insect damage was estimated to be 3% and was valued at $5.7 million (Agricultural Research Service, 1965). Acreage has more than doubled since then, hence, it is assumed that current loss due to insect damage amounts to at least $11 million annually.

Based on 1966 information, 7% of the total soybean acreage is treated annually with insecticides (Fox et al, 1968). In 1964, 4,997,000 pounds of insecticides (active ingredient) were used in treating 4,109,000 acres or 13% of the acreage grown that year (Eichers et al, 1968). This fluctuation in treated acres is largely due to the cyclic nature of certain key pests which attack soybeans.

One of the most destructive pests is the corn earworm. Although sporadic in occurrence, this insect often builds up to high population levels in late August or early September and causes severe damage by feeding on maturing beans. Other lepidopterous larvae, such as velvetbean caterpillar, green cloverworm, and armyworm, are also sporadic in occurrence and although they feed primarily on foliage, can cause serious economic damage when high populations are present. Stinkbugs also attack soybeans and their feeding causes damage to the young pods and discoloration of the beans. Occasionally, other pests, such as the Mexican bean beetle, bean leaf beetle, blister beetle, grasshoppers, and webworms, also damage soybeans by feeding on foliage or pods. Research has demonstrated that soybean plants can tolerate up to 35% defoliation through the bloom period. After bloom, however, when the pods begin to form and fill out, any foliage loss over 20% will decrease yield

An average of one application of carbaryl is made per season for control of these pests. Control practices vary from one area to another and the incidence of crop-damaging pests also varies. Sevin Sprayable or Sevimol is usually applied at the rate of 1 - 1.5 lb active ingredient/acre using either aircraft or ground spray equipment. Lower rates may be used successfully early in the season to control some of the more susceptible insects, such as thrips, leafhoppers, or three-cornered alfalfa hoppers. Recent studies have shown that reduced rates of carbaryl (down to 0.5 lb active ingredient/acre) will give acceptable commercial control of most of the target pests on soybeans without serious adverse effects on the beneficial insects.

Carbaryl should not be applied to soybeans in combination with 2,4-DB herbicide since the two chemicals interact with resultant crop injury. A statement to this effect appears on the label to warn the user.

There are many registered for use on soybeans but the only ones which are alternates to carbaryl are toxaphene, malathion, methyl parathion, and methomyl. Carbaryl has remained popular with the farmers and the applicator because of its proven efficacy and low order of hazard. Also, the 5 ppm tolerance on soybeans and 100 ppm tolerance on soybean hay permit applications on the day of harvest or grazing (Agricultural Research Service, 1969).

Soybeans are reported to represent the largest single crop use for carbaryl as an insecticide in the U.S.

VI.B. Sweet corn

An average of 641,000 acres of sweet corn was grown annually in the U.S. in the 1968-70 period (Agricultural Statistics, 1971). Production averaged 2,746,133 tons and had an on-farm value of $118 million/year during this same period. Loss from production due to damage by insects averaged 19% and amounted to $16,575,000 annually in the last period for which information is available (Agricultural Research Service, 1965). Approximately 75% of the sweet corn is grown for processing and the balance for fresh market. Seventy percent of the processing acreage is in the states of Wisconsin, Minnesota, and Illinois, but Maryland, Washington, Oregon, and Idaho also grow significant acreages. Fresh market corn is produced in many areas but principal production is in the states of Florida, New Jersey, New York, Pennsylvania, Ohio, Michigan, and California.

In most sweet corn-producing areas, except the Pacific States and Florida, the European corn borer is a highly destructive pest of sweet corn grown for fresh market or processing. This insect has caused complete loss of crops, and along with the corn earworm, accounts for most of the insect damage to sweet corn (Metcalf et al, 1962). Sevin Sprayable or Sevimol 4, at the rate of 1.5 - 2 lb active ingredient/acre is used for control of these pests in all areas where they occur.

On fresh-market corn where consumer tolerance of corn earworm-damaged ears is nearly zero, insecticides may be required as often as every 24 h from the time silking begins until the silks have dried and turned brown. Under severe population pressures, such as encountered in Florida and Southern California, as many as 12 applications/season may be required for effective control. An average of 4 - 5 applications are made per season on fresh-market corn.

On processing corn, some corn earworm damage can be tolerated since "trimming" of the damaged kernels at the tip of the ear can be done in the processing plant. Thus, fewer applications are needed for corn earworm control where this is the principal pest. However, where the European corn borer is present, control measures must not be reduced since the borer larvae does not always attack at the tip of the ear and, therefore, the damage portion is more difficult and costly to remove. An average of 3 - 4 applications is usually required on processing corn to obtain satisfactory pest control.

Applications on both fresh-market and processing sweet corn are made by either ground or aircraft spray equipment, with generally better control and higher costs resulting from ground application. Due to variations in insect populations, planting, and maturity dates, a small percentage of corn acreage may not need to be treated. However, virtually all commercially grown sweet corn is treated with insecticides.

Additional insects which occasionally attack corn and are controlled by the application of carbaryl are cutworms, fall armyworms, grasshoppers, and Japanese beetles. These are all rather sporadic in occurrence and although carbaryl may be the material of choice for their control, they do not constitute a significant use for carbaryl. Corn flea beetles are vectors of Stewart's wilt disease and often require control to prevent infection of seedling corn. This is also a minor use but one for which carbaryl may be recommended by some states (Eichers et al, 1968).

Alternative insecticides, such as methomyl or Cardona, are more expensive than carbaryl for corn earworm control. Materials such as diazinon, toxaphene, EPN, or methomyl are approved for control of European corn borer, but are either more expensive or else fail to control corn earworms adequately. Both parathion and methyl parathion alone and in combination are occasionally used for aphid control but neither material is satisfactory for corn earworm and European corn borer. Occasionally parathion is used in combination with carbaryl to gain the benefit of aphid control, but most carbaryl used on sweet corn is used alone.

Carbaryl is considered to be the principal insecticide used for insect control on sweet corn grown for processing. It has been estimated that carbaryl is used on at least 60% of the sweet corn acreage treated for control of corn earworm and European corn borer.

Information on tolerances and use restrictions on sweet corn is listed under field corn in Appendix 1.

VI.C. Ornamentals and turf

This arbitrary grouping includes all lawns, turf, flowers, shrubs, herbaceous and woody plants (except trees) grown by homeowners, municipalities, golf courses, governmental agencies, private or corporate nursery companies, or others in the U.S. The market is extremely large but reliable information is not available on the number of acres planted or treated or on the total amount of insecticide used each year. There is also a paucity of information on annual losses due to insects, although one source estimates that losses on landscape flowers and ornamentals are well above 16% or a total of $768 million annually (Agricultural Research Service, 1965). From the limited information available, it is apparent that significant financial as well as aesthetic losses due to insects occur annually.

Carbaryl is registered for control of more than 20 insect pests of ornamentals and 11 different pests on turf. The diversity of the ornamentals and turf market segment in terms of geography, host plant species, pest distribution, and incidence makes it impossible to single out one pest on ornamentals as being most important. Leaf-feeding beetles and lepidopterous larvae are probably among the more common pests, but scale insects, aphids, leafhoppers, and plant bugs are also of major importance in some areas.

A dilute carbaryl spray containing 1 lb active ingredient/100 gal water will control all the pests listed on the label. Applications are made with ground equipment including high pressure hydraulic sprayers, mist blowers, or hose-end sprayers when damaging insects are present or on an as-needed basis. Application of carbaryl will injure Boston ivy and a caution statement on the label warns the user against treating this plant.

The sod webworm or lawn moth is probably the most important pest of turf because of its widespread occurrence and the extensive damage high populations can cause. Chinch bugs, cutworms, and armyworms are also serious pests in some areas. In addition to those insects which feed on turf, several pests which are bothersome to man may inhabit turf; these include ants, earwigs, millipedes, fleas, and mosquitoes. Carbaryl sprays or granules (granules are not used for adult mosquito control) applied at the rate of 1 lb active ingredient/5,000 ft^2, give excellent control of these pests. Usually one properly timed application per season will control those pests which damage turf. However, in areas where multiple generations of certain pests occur or for control of those pests which bother man, repeat applications at approximately 3-wk intervals may be required.

In addition to homeowner use, golf courses (especially in Florida) use significant quantities of carbaryl and may average 2 - 3 applications/year. These applications are usually made with ground spray equipment although granular formulations may be used also. The homeowner is attracted to the convenience of combination (carbaryl/fertilizer) products for ease of application but may also use sprays or granules.

Many formulations available to the home and garden market are multipurpose and contain other products in combination with carbaryl for control of plant disease organisms, spider mites, or other insect pests on home vegetable gardens or fruit trees as well as on ornamentals. Also, several formulations of carbaryl are marketed for flea and tick control on dogs and cats.

Formulations of carbaryl available under customer labels include emulsifiable concentrates, wettable powders, liquid suspensions or flowables, dusts, granulars, baits, and combinations with fertilizers or other pesticides.

Chlordane, diazinon, malathion, arprocarb, methoxychlor, kepone, and aspon are the principal alternate insecticides used on ornamentals and turf. Carbaryl, malathion, and diazinon are considered the most commonly used insecticides on ornamentals. Chlordane, diazinon, and carbaryl are the most commonly used general-purpose insecticides on turf. The low order of hazard to man and animals and a generally high degree of activity against insects partially accounts for the popularity of carbaryl in this market. Lack of objectionable odor, nonstaining of exterior construction materials, multiple-use aspects, and the consumer's concern for the environment all contribute to acceptance of carbaryl. It is estimated that carbaryl accounts for 60% of the insecticide use on ornamentals and approximately 15% of the insecticide used on turf.

VI.D. Field corn

An average of 65 million acres of field corn was grown annually in the U.S. in the years 1968-70 (Agricultural Statistics, 1971). Of this, 61 million acres were grown for grain, producing 414 billion bushels, valued at $5.2 billion. The remaining 4 million acres were harvested for silage and produced an average of 95 million tons annually. Field corn is attacked by a number of insect pests which caused an estimated 12% average reduction in yield, amounting to $527 million annually in the 1951-60 period (Agricultural Research Service, 1965). This loss was primarily due to the corn earworm (4%), European corn borer (3.5%), and corn rootworms (2.1%).

When compared with sweet corn, a relatively low percentage of the field corn acreage is treated for control of European corn borer and corn earworm. However, in 1966, 33% of the corn acreage was treated with insecticides (includes materials applied for soil insect control) which accounted for 39% of the total dollars spent by farmers (all crops in U.S.) for pesticides (Fox et al, 1968).

Corn rootworms are serious pests of field corn during two stages of their development and require control in many areas if corn production is to be profitable. Sevin Sprayable and Sevimol are both used at the rate of 1 lb active ingredient/acre for control of corn rootworm beetles in August. Usually one (but sometimes two) aerial applications are required to control the beetles during the pollination period. If uncontrolled, incomplete pollination results in unfilled ears due to feeding by the beetles on the newly emerged silk. Applications to control the beetles in August can reduce the number of eggs laid and the resulting larval population in the soil the following spring.

Field corn is not generally treated to control corn earworm or European corn borer. However, during years of high populations of the European corn borer, some growers have found it profitable to apply chemical controls. Formulations of carbaryl used include those discussed plus granular formulations.

Another use for carbaryl on field corn is for control of cutworms (principally the black cutworm) on seedling corn. Although sprays at 1 - 2 lb active ingredient/acre are used, the preferred treatment consists of applying a carbaryl 5% bait either broadcast by air or as a band treatment on the ground by row. The bait remains attractive to the worms over a period of at least a week and may effectively prevent further loss of seedling corn. Cutworms are a severe problem in certain low-lying areas almost every year, and occasionally throughout the corn belt. The decreased use of chlorinated hydrocarbon pesticides for soil insect control has led to increased use of carbaryl for cutworm control.

In Nebraska, Kansas, and Northeastern Colorado, the western bean cutworm has become a serious late-season pest of corn in recent years. The larvae damage the ear by feeding extensively on the kernels, but even greater loss occurs as a result of the subsequent development of fungi on the damaged ears. A single spray containing carbaryl at 2 lb active ingredient/acre applied when 95% of the tassels have emerged will give effective control of this pest.

Tolerances of 5 ppm on corn (kernels and cob with husk removed) and 100 ppm on forage have been established on both field corn and sweet corn which permit use of Sevin on the day of harvest (Agricultural Research Service, 1969). This is an important advantage in some areas since sweet corn stalks, husks, or other waste from processing plants may be fed to dairy or beef animals.

Alternate materials for use on field corn are mainly those discussed under sweet corn.

VI.E. Forest and shade trees

Many destructive insect pests attack deciduous and evergreen trees in the U.S. One author estimated that loss in saw timber in the U.S. in 1952 amounted to 5 billion board feet (USDA, 1958). He also estimated that insects kill twice as much timber as do disease-causing organisms and seven times over losses from fire. In addition to damage caused by outbreaks of pest species, the less conspicuous damage caused by insects present in normal numbers must also be considered. Accurate estimates of loss have never been made, but millions of board feet are probably lost annually (Graham and Knight, 1965).

In many cases, naturally occurring biologic control agents as well as adverse environmental factors are of such impact that most native forest pest species never occur in sufficient numbers to constitute an economic hazard (Baker, 1972). However, introduced pests, such as the gypsy moth, may cause irreparable damage to native forest trees and watersheds before naturally occurring factors can bring the population under control. The decision to use insecticides is generally a last resort, and on land managed for commercial timber production, can usually be justified on an economic basis. Just as in the case of the gypsy moth, efforts by state and federal regulatory agencies to limit the spread of damaging pest species may require the use of insecticides.

In urban surroundings the decision to use insecticides is likely to be based more on the citizens' desire for shade, aesthetic beauty, or fondness for trees than on purely economic grounds. Certain high-use areas, such as campgrounds and parks, are routinely treated for control of defoliating insects since experience has shown that tourists and campers avoid infested areas.

Carbaryl is used throughout the U.S. for control of tree pests, such as scale insects, leaf miners, and the elm leaf beetle, but the major use is concentrated in the New England States, New York, New Jersey, and Pennsylvania. Gypsy moth control accounts for over half the carbaryl used on forest and shade trees, but cankerworms, saddled prominent, and tent caterpillars are also important target species.

One application per year of 1 lb active ingredient/acre by air or 1 lb active ingredient/100 gal water by ground will effectively control the target pests with minimal environmental impact. Due to generally good performance, carbaryl has become the insecticide most frequently used for gypsy moth control. Sevin 4 Oil is usually applied as an ultra low volume (ULV) spray at the rate of 1 qt/acre but may be diluted with kerosene or diesel fuel to increase the spray volume. Sevin Sprayable, Sevin 50W, and several other carbaryl formulations are also used by air or ground for control of forest and shade tree pests. Applications are normally made after the pests have hatched or emerged and before serious damage occurs.

No tolerance requirements or use limitations are imposed on carbaryl for control of forest and shade tree pests, but, as with most insecticides, care should be taken during application to avoid contamination of food, feed, water supplies, streams, or ponds.

Alternate insecticides used for forest and shade tree insect control include Imidan, trichlorfon, methoxychlor, *Bacillus thuringiensis*, malathion, and diazinon. Carbaryl and trichlorfon are the principal insecticides used for gypsy moth control.

It is significant that the Michigan Department of Agriculture selected carbaryl for use in controlling a gypsy moth infestation in Southern Michigan in 1967. Multiple treatments in that year temporarily eradicated this pest from Michigan forests. A new infestation in Southeast Michigan was discovered in 1972 and treatments using Sevin 4 Oil and Sevin Sprayable were applied in 1973.

VI.F. Cotton

In the 1968-70 period, cotton production averaged just under one 500 lb bale/acre in the U.S. An average of 10,409,000 bales was produced on 11,578,000 acres creating an on-farm value for lint plus cottonseed of $1.3 billion annually (Agricultural Statistics, 1971). An accurate measure of annual production loss due to insects for this same period is not available but estimated annual losses of cotton yield in the period 1951-60 averaged 19% and amounted to $477 million. Average annual loss figures attributable to each cotton pest are shown in Table VI.A. (Agricultural Research Service, 1965).

Table VI.A. Cotton: estimated average annual loss due to insects (1951-60)

Insect	Loss from potential production	
	Percent	Value (1000 dollars)
Boll weevil	8.0	200,842
Bollworm	4.0	100,421
Lygus bugs, cotton fleahopper and other sucking insects	3.4	85,358
Thrips, spider mites, cotton aphid, cabbage looper, cotton leafperforator pink bollworm, beet armyworm, cotton leafworm and other insects.	3.6	
Total Losses	19.0	477,000

Source: USDA Agricultural Research Service (1965).

Cotton insect control annually has accounted for approximately 40 - 50% of the total insecticide used in the U.S. (Texas A & M University, 1970). In 1966, 5.6 million acres or 54% of the cotton acreage was treated for insect control (Blake et al, 1970; Fox et al, 1968). In the past, the major insecticides used on cotton were toxaphene, 26.9 million lb on 5.0 million acres; DDT, 23.6 million lb on 6.9 million acres; and methyl parathion, 8.8 million lb on 5.4 million acres. These three products accounted for over 75% of the insecticides used on cotton in 1964 (Eichers et al, 1968).

A tolerance of 5 ppm on cottonseed and 100 ppm on cotton forage permits the use of carbaryl at up to 2.5 lb active ingredient/acre with no preharvest or pregrazing limitation (Agricultural Research Service, 1969). Due to its broad registration on other crops, carbaryl is frequently the insecticide selected for cotton pest control in areas where diversified agriculture is practiced. Concern over possible illegal residues resulting from drifting of applications of materials registered on cotton but unregistered on the adjacent crop has often been the deciding factor in choosing carbaryl. This has been particularly true in areas where dairying or production of feed or forage crops for dairies is a major industry.

Sevin Sprayable and Sevimol 4 are the two principal carbaryl formulations used by the farmer for cotton insect control. Carbaryl dusts are no longer extensively used. For early season insects, such as thrips, fleahoppers, plant bugs, striped blister beetle, and cotton leafworm, 0.5 to 1 lb active ingredient/acre is applied, usually only once.

Occasionally, a second application may be required, but an increase in the use of granular systemic insecticides, such as phorate, disulfoton, or aldicarb, for control of early season thrips, aphids, mites and fleahoppers has reduced the need for insecticidal sprays to control these pests.

Carbaryl is primarily used in mid to late season on cotton for control of bollworms, boll weevils, and pink bollworms. Use of carbaryl for pink bollworm control dates back to 1958 when it was selected by the USDA to replace DDT in suppressing populations to prevent further spread. It was again used during the early and mid-1960's in federal/state cooperative control programs in Arizona and California. Programs of this type have not been in effect in recent years, but in some areas growers have banded together to purchase and apply carbaryl for pink bollworm control on an area-wide basis. Carbaryl is the principal insecticide used for pink bollworm control and is usually applied by aircraft every 5 - 7 d at a rate of 2.5 lb active ingredient/acre. Treatments begin when 10 - 15% (5% in high humidity areas) of the 3-wk-old bolls are infested and continue until all bolls are hard and harvest is near. If not controlled, this pest is capable of damaging 20 - 40% of the bolls and may cause a complete crop loss in some areas (Metcalf et al, 1962). Where humidity is high, damaged bolls may rot resulting in loss of the entire boll rather than only that portion damaged by the larvae. Cultural practices, long an important part of the pink bollworm control, have been augmented by sterile male and pheromone trap techniques in recent years.

However, in heavily infested areas like Arizona and Southern California, growers still rely on chemicals such as carbaryl in integrated pest control programs.

Other than the boll weevil, the remaining cotton pests for which carbaryl is used generally occur all across the cotton belt. Control practices for these pests vary according to the growth stage of the cotton, the insect population composition and severity. Controls are applied by either ground or air when pests reach an economic level and generally continue throughout the growing season. In some areas, carbaryl does not effectively control the tobacco budworm which may attack cotton late in the season along with the cotton bollworm. In these cases methyl parathion is often added. The use of this combination controls both bollworms and the boll weevil. If boll weevil is the only pest to be controlled, alternate insecticides may be used.

A standard treatment for pest control on cotton was toxaphene-DDT-methyl parathion in the ratio of 4-2-1 lb/gal. The favorable economics and efficacy of this combination prevented extensive use of other more costly insecticides, such as carbaryl. With the banning of DDT on cotton, farmers are using alternate control materials. Carbaryl is one such control with more favorable economics, improved formulations, and relatively low toxicity to people, farm animals, birds, and fish. Toxaphene - methyl parathion mixtures, as well as azinphosmethyl and monocrotophos are also used. However, in addition to being relatively more toxic to man and other warm blooded animals, the organophosphate insecticides have been associated with delayed maturity of cotton and some experts feel that use of these materials may be partly responsible for the decreased yields experienced by many growers in recent years (Anon., 1972). Other alternate materials are methomyl, chlordimeform, and endosulfan.

VI.G. Deciduous tree fruits - apples

Annual production of apples in the U.S. in the period 1968-70, averaged 6,138.7 million pounds and was valued at $295,137,000 (Agricultural Statistics, 1971). This production level was achieved on approximately 675,000 acres of which 92% were treated with insecticides in 1966 (Fox et al, 1968). One estimate of average loss due to insect damage on apples covers the period 1951-60 and amounts to $13,295,600 annually (Agricultural Research Service, 1965). Without effective control measures, the quality and keeping properties would be reduced and under severe conditions, the crop could be almost a total loss.

The codling moth is an important insect pest of apples nationally but is readily controlled with proper use of modern insecticides, such as carbaryl. It was once considered to be the most persistent, destructive, and difficult to control of all the insect pests attacking the apple fruit, being capable of infesting 20 - 95% of the fruit if uncontrolled (Metcalf et al, 1962). Carbaryl is also used for several other insects of less economic importance which occur in all principal apple production areas.

Several insect pests of major importance occur only east of the Rocky Mountains or only in specific states or areas. In the Northeastern and Great Lakes States, the apple maggot is one of the most serious pests. If not controlled, it may heavily infest early varieties and reduce each fruit to a brown rotten mass. On later varieties, damage is less severe but still unacceptable from the consumer's point of view. White apple leafhoppers in Michigan and New York are serious pests which were once controlled with DDT. They have developed resistance to organophosphate compounds, and carbaryl, a carbamate, is now the principal insecticide used for control.

Plum curculio occurs in all states east of Nebraska and may be second only to the codling moth in importance as an apple insect pest (Metcalf et al, 1962). Fruit is rendered unfit for sale as a result of oviposition and feeding punctures. In certain other areas, leafrollers and Eastern tent caterpillar are important pests.

The periodical cicada causes severe damage to the twigs and small branches and if uncontrolled, may destroy 95% of the terminals. The injury is not due to feeding but by the female cicada depositing her eggs in the twigs. Due to the cyclic nature of this pest it is not a widespread problem except in years of peak emergence. When this occurs, carbaryl is usually the insecticide of choice.

Generally, Sevin 50W or Sevin Sprayable is applied by ground in dilute sprays at a concentration of 0.5 - 1 lb active ingredient/100 gal for control of these insects. Average volume applied is approximately 300 gal dilute spray/acre except where concentrate spraying is practiced by the growers. In these instances, usually 2 - 10 times the normal rate of carbaryl is added per 100 gal water and the spray volume/acre is reduced so as to apply approximately the same amount of insecticide per acre as for dilute spraying. Cover sprays are applied approximately every 10 - 14 d in the East, beginning about 7 d after petal fall and continuing until harvest is near. Azinphosmethyl, phosalone, Imidan, lead arsenate, parathion, and Gardona® are alternate insecticides recommended and used in the apple spray schedule. Carbaryl is commonly used in no more than 2 or 3 of the cover sprays during the course of the season. Spray practices differ markedly in the West and carbaryl is rarely used on apples there, except for fruit thinning.

One application of carbaryl at 0.25 - 1 lb active ingredient/100 gal timed 10 - 25 d after full bloom will provide fruit thinning of apples. Fruit set is affected by many factors, including variety, age, tree vigor, previous crop, and frost. The need for fruit thinning varies from year to year. Carbaryl is highly effective for this purpose and is used in significant quantities in those years when fruit thinning is required. Carbaryl is a reliable thinning material. It is safer to the tree and less apt to overthin than NAA (naphthaleneacetic acid) or NAD (naphthalene acetamid). Since carbaryl may be applied up to 25 d after full bloom, growers can wait until most danger of frost is past.

A tolerance of 10 ppm allows applications of carbaryl to be made within 1 d of harvest. Based on total insecticide use estimates from 1964, carbaryl has approximately 7% of the use on apples today versus an estimated 24% in that year (Eichers et al, 1968). The decline in carbaryl use on apples since 1964 is probably due primarily to increased pesticide competition and reliance by growers on pest management techniques which attempt to optimize the effectiveness of parasites and predators in controlling target pests.

VI.H. Deciduous tree fruits other than apples

Information on production and value of the crops included in this discussion is listed in Table VI.B.

Table VI.B. Production and value of various deciduous fruit crops

Commodity	Production (Tons)	Value (1,000 dollars)
Apricots	185,410	26,863,000
Cherries	249,004	69,765,000
Nectarines	65,333	9,560,000
Peaches	1,711,250	182,166,000
Pears	621,700	75,532,000
Plums and prunes	560,042	42,238,000

Source: USDA, Agricultural Statistics, 1971.

In 1966, total acreage of these crops amounted to 800,000 acres of which 72% were treated with insecticides. Available information on losses attributable to insect damage on these crops is for the 1951-60 period as shown in Table VI.C (Agricultural Research Service, 1965).

Table VI.C. Deciduous fruit: estimated average annual losses due to insects, 1951-60

Commodity	Loss from potential production	
	Percent	Value (1000 dollars)
Cherries	3	1,544,000
Peaches	4	5,658,000
Pears	6	3,592,000
Plums	6	967,000
Prunes	6	2,937,000

Source: USDA, Agricultural Research Service, 1965.

Several major fruit pests, such as the Oriental fruit moth, peach twig borer, cherry fruit fly, plum curculio, and codling moth, attack the fruit or twigs of several or all the crops discussed here. These pests are all effectively controlled with properly timed applications of Sevin 50W or Sevin Sprayable at a rate of 1 lb active ingredient/100 gal water. Generally, applications are made as a dilute spray by ground at 300 - 500 gal/acre but carbaryl may also be applied by aircraft in dust (10%) or spray form at 4 - 8 lb active ingredient/acre when either time or orchard conditions do not permit ground application.

The established tolerance of 10 ppm permits application within one day of harvest of apricots and nectarines (Agricultural Research Service, 1969). This aspect of the product is a significant factor in its selection by the grower. Close to harvest use accounts for a high percentage of the carbaryl used on these crops.

Generally, only one application is made per fruiting season due to the necessity of controlling other pests not susceptible to carbaryl. The generally recognized toxicity of carbaryl to certain mite predators and the resultant effect on populations of phytophagous mites encourages the use of alternate materials for all but the close-to-harvest applications. Combination sprays of carbaryl or one of the following materials with a miticide (such as dicofol or tetradifon) are often used to control mites as well as insect pests.

The principal alternate materials used on these crops (as registrations permit) are azinphosmethyl, diazinon, endosulfan, Imidan, naled, parathion, and phosalone. Most of these materials may not be used less than 7 d before harvest and may pose a greater hazard to workers in application, thinning, or harvest.

VI.I. Peanuts

An average of 1,506,000 acres of peanuts was grown annually in the U.S. in the period 1968-70. Production during this period averaged 2684 million lb and was valued at $332 million/year (Agricultural Statistics, 1971). In 1966, 70% of all peanut acreage and 80% of the acreage grown on farms grossing over $10,000 annually were treated with insecticides (Fox et al, 1968). Estimates of loss due to damage by insects for this same period are not available, but amounted to 3% of production or $5,755,000/year in the period 1951-60 (Agricultural Research Service, 1965).

The principal use of carbaryl on peanuts is for control of corn earworm, fall armyworm, velvetbean caterpillar, and webworms. These foliage feeding caterpillars are somewhat cyclic in occurrence but cause severe economic loss when abundant. Defoliation by feeding of fall armyworm has caused yield reductions of up to 500 lb/acre (Arant et al, 1951).

Sevin Sprayable or Sevin dust formulations at the rate of 1.5 lb active ingredient/acre are applied with aircraft or ground equipment to control these pests when populations reach damaging numbers. An average of 3 - 4 applications may be made per season for control of the foliage feeding caterpillars as well as thrips, leafhoppers, and cutworms. The tolerance of 5 ppm on peanuts and 100 ppm on peanut hay permits applications of carbaryl on the day of harvest if needed. This is an important advantage if treated vines are to be fed to livestock.

Several alternate insecticides are used on peanuts, including parathion, trichlorfon, methomyl, diazinon, monocrotophos, toxaphene, and malathion.

With the advent of liquid formulations of new organic fungicides, a change in the use pattern of insecticides occurred. Whereas traditional formulations of copper-sulfur dust as a fungicide often included an insecticide such as carbaryl, use of the liquid fungicides has caused a shift away from dust and has generally diminished insecticide usage. Greater awareness by the grower of pest management concepts has also reduced insecticide use.

It is estimated that carbaryl has approximately 20% of the insecticide use on peanuts.

VI.J. Poultry

Poultry production in the U.S. is a major industry generating several billion dollars per year in farm income. In the period 1968-70, the average annual on-farm value of chicken eggs, broilers, and turkeys was $3626 million (Agricultural Statistics, 1971). Insects mites and ticks are common pests of all classes of poultry throughout the country. They cause birds to look unsightly, reduce weight gains and egg production, and mar the skin (Metcalf et al, 1962). The result is a downgrading of quality and lower market value. Heavy infestations of certain pests cause high mortality among young poultry, and it has been shown that poultry lice and mites can reduce weight gain and egg production from 2 - 25% or more (Agricultural Research Service, 1965).

In the period 1951-60, an estimated average annual loss of 89 million dollars occurred due to pests attacking poultry (Agricultural Research Service, 1965). Inadequate information exists on the use of pesticides on poultry, but in 1966, 11% of the poultry producers used pesticides at a cost of approximately $2 million (Blake et al, 1970). In 1964, an estimated 345,000 pounds of insecticides were reported used for poultry pest control (Eichers et al, 1968). However, industry sources believe this reported usage is low.

Carbaryl is used for control of all important ectoparasites of poultry, including those that live on the birds as well as those that feed but do not live on the birds (Union Carbide Corporation, 1972). Chicken mites, fleas, bedbugs, northern fowl mites, and lice are all effectively controlled with sprays of carbaryl containing 0.5% active incredient applied with a hand or power sprayer at the rate of 1 gal spray/100 birds. In addition, carbaryl 5% dust applied with a power-operated or puff duster at 1 lb/100 birds or 1.5 gal 4% carbaryl spray/1,000 birds applied with a fogging machine may be used.

For control of fowl tick in poultry houses, a spray containing 2% active carbaryl is recommended at 1 - 2 gal/1000 ft^2 of wall, ceiling, or floor space. A high-pressure sprayer capable of forcing sprays into cracks and crevices where these pests hide during the day is essential if good control is to be obtained. Use of dust as a litter treatment and also as a dustbath box is recommended in floor management operations for control of fleas, lice, and mites.

For broiler production, 5 - 6 sprays/year are applied to the premises at approximately 9 wk intervals. If good sanitation is practiced and birds are started in the growing houses free of pests, they may not require treatment at all. However, under some circumstances, the birds themselves must be treated once during their 9 wk growth cycle. In the case of laying hens, thorough premise treatments are made much less frequently and treatment of the birds may be required every 6 - 8 wks during periods of heavy infestation (Pest Control Guides, 1972).

Poultry producers generally apply treatment on an "as needed" basis, determined by inspecting the birds. A tolerance of 5 ppm on meat and fat of poultry permits application of carbaryl up to 7 d before slaughter (Agricultural Research Service, 1969). Feed and water troughs should be covered or removed during treatment to prevent contamination. For treatment of laying hens, no time limitation is imposed on meeting the interim tolerance of 0.5 ppm in eggs, but contamination of the nests should be avoided during treatment.

Alternate materials for control of poultry pests are malathion, coumaphos, and Rabon® (Blake et al, 1970). Northern fowl mites have developed resistance to malathion and other organophosphate compounds in certain areas but remain susceptible in others.

VI.K. Tomatoes

An average of 442,000 acres of field-grown tomatoes were produced annually in the U.S. in the period 1968-70. Sixty-six percent were grown for processing with principal production centered in California. Ohio, Indiana, and New Jersey also produce significant acreages of processing tomatoes and together with California account for approximately 67% of the acreage grown. No accurate figures are available on loss caused by insects during the 1968-70 period, but a 7% annual loss was estimated for both fresh market and processing tomatoes in the period 1951-60. This amounted to a $10,600,000 loss for fresh market tomatoes and a $7,594,000 loss for processing tomatoes (Agricultural Research Service, 1965).

Insect problems on tomatoes for processing or fresh market are basically alike. The tomato fruitworm is the principal pest and if not controlled may damage or destroy 50 - 80% of the fruit (Metcalf et al, 1962). Armyworms are also an important pest in some areas causing damage to the fruit similar to that caused by the tomato fruitworm. Tomato and tobacco hornworms often occur in the same field and damage plants by consuming vast quantities of foliage. Sevimol 4, Sevin Sprayable, and carbaryl dust (10% active) are used for control of all of the above insects in the principal tomato-producing areas. Both aircraft and ground spray equipment are used on tomatoes but aerial spraying predominates. Use of carbaryl in dust form on tomatoes has diminished in recent years to the point that now nearly all applications are in spray form.

Generally, two applications of carbaryl at 1.5 - 2 lb active ingredient/acre are recommended for control of these pests on processing tomatoes. Fresh market tomatoes, especially those grown on stakes may require more than two applications depending on pest populations since harvest often takes place over several weeks. Many growers choose carbaryl for insect control because it may be used on the day of harvest to protect the maturing crop without exceeding the established tolerance of 10 ppm on the harvested fruit. Also, the apparent low order of hazard associated with carbaryl is important when workers must enter treated fields soon after application.

Although accurate figures are not available, a high percentage of tomato acreage is treated for insect control each year. Processors maintain vigilant control over the quality of tomatoes produced to prevent insect parts from occuring in the finished pack. Growers of fresh market tomatoes must also prevent damage since the fruit is unacceptable to consumers if marred by insects.

Alternate insecticides used on tomatoes are methomyl, methoxychlor, endosulfan, and azinphosmethyl.

VI.L. Other vegetables

The 30 individual crops listed in Appendix 3 and classed here as "other vegetables" account for a sizeable amount of carbaryl use. These crops are grown to some extent all across the U.S. but tend to be commercially grown in certain key production areas. They are all subjected to modern intensive farming methods and receive frequent applications of insecticides as a means of achieving the quality produce Americans demand. A number of insect pests attack these crops but carbaryl is used only to a limited extent on many of them. Losses due to insects are shown in Table VI.D.

On crops such as eggplant, pepper, and okra, carbaryl is used at 1 - 2 lb active ingredient/acre for control of several pests (principally corn earworm and European corn borer) which attack the fruit. Applications are made by both aircraft and ground spray equipment and Sevin Sprayable is the principal formulation used. Applications may be made on the day of harvest without exceeding the 10 ppm tolerance. This important advantage permits applications more frequently than once-a-week if required by heavy population pressure which occurs in areas such as the Delmarva Peninsula on the eastern shore of the Chesapeake Bay.

Table VI.D. Vegetable crops: estimated average annual losses due to insects, 1951-60

Commodity	Percent	Value ($1000)
Asparagus	15	6789
Broccoli	17	3139
Brussel sprouts	17	1040
Cabbage	17	8443
Carrot	2	961
Cauliflower	17	3137
Cucumber, fresh market	21	2740
Escarole	7	250
Kale	17	148
Lettuce	7	10,077
Melon	8	640
Pepper, green sweet	7	1876
Spinach	4	750
	Total	$ 39,990

Source: USDA, Agricultural Research Service, 1965.

Of the insect pests attacking vegetable crops, the corn earworm is one of the most destructive. The cabbage looper is also a severe pest on leafy vegetables but is controlled with carbaryl only in the first larval instar. Carbaryl is commonly used to control corn earworm but where cabbage looper is the principal pest another insecticide is usually selected.

Alternate insecticides for use on these vegetable crops are methomyl, parathion, diazinon, endosulfan, azinphosmethyl, methoxychlor, mevinphos, toxaphene, and malathion. Each material listed has its own respective advantages and disadvantages according to the particular crop/pest situation and may be used singly or in combination with another pesticide.

Due to the diversity of crops covered in this section and the limited extent to which some are grown, accurate information on acres treated or insecticide usage is not readily available. Carbaryl represents approximately 5% of the total insecticide usage on these vegetable crops.

VI.M. Beans and peas

VI.M.1. Beans: In the 1968-70 period an average of 1.9 million acres of beans was grown annually in the U.S. This total included 1.45 million acres of dry edible beans and 0.45 million acres of green lima and snap beans. Production of dry edible beans averaged 1.8 billion lb and was valued at $148 million, while green lima and snap bean production averaged 1.7 billion lb and was valued at $118 million (Agricultural Statistics, 1971). Bean crops of all kinds, whether for processing, fresh market, or seed, or for sale as dry edible beans, are damaged by insects. The amount of damage and pest complex vary from area to area and from year to year, but in the 1951-60 period, estimated annual losses averaged $42.3 million. Dry beans suffered estimated average annual losses of 20% amounting to $29.3 million. Snap beans and green lima beans suffered 12% and 13% losses amounting to $10.5 million and $2.5 million, respectively, during the same period (Agricultural Research Service, 1965).

Several formulations of carbaryl are registered for use on beans and tolerances established at 10 ppm on the beans and 100 ppm on forage or hay permit application on the day of harvest (Agricultural Research Service, 1969). The predominant formulations used on beans are Sevin Sprayable and Sevimol 4 with lesser amounts of Sevin 50W and various dust formulations occasionally being used. Carbaryl may be applied with equal facility by aircraft or ground spray equipment and no notable differences in control occur due to type of application.

The principal insect pest in all areas except the Pacific States is the Mexican bean beetle which caused an estimated 8% annual loss in the 1951-60 period (Agricultural Research Service, 1965). Where severe infestations are left untreated, the plants may be shredded and dried out so that they die within a month after the attack begins, often before any crop is matured (Metcalf et al, 1962). Sevin is used in all of the major bean growing states for Mexican bean beetle control and is generally the preferred material for foliar application. It is highly effective at the low dosage rate of only 0.5 lb active ingredient/acre. Generally only one or two applications per season is required to control this insect. Systemic insecticides, such as phorate or disulfoton, when used at planting will give control of Mexican bean beetle for a short period of time after emergence, but foliar applications are still required in most instances.

Several other insect pests occur on beans and some of these may require control measures during the growing season. Cutworms are an early season pest that can destroy virtually an entire stand of seedling beans if not controlled. They are not a pest every year in every area. Excellent control can be obtained with carbaryl from a single application of 1 - 1.5 lb active ingredient/acre. Occasionally, leafhoppers build up to damaging levels and must be controlled. Usually, a single application of 1 lb active ingredient/acre is sufficient to achieve control. In different areas, one or more applications of 1 - 1.5 lb active ingredient/acre may be needed for control of pod and foliage feeding pests, such as corn earworms, armyworms, bean leaf beetles, or western bean cutworms. In California only, 2 lb active ingredient/acre are required for control of lima bean pod borer and corn earworm. Spider mites often build up to damaging numbers on beans, particularly in the arid West, and carbaryl may be applied in combination with a miticide, such as dicofol or demeton.

Phytotoxicity in the form of a marginal leaf burn occasionally occurs on the Blue Lake variety of beans grown for canning purposes. However, carbaryl is still used on this variety without apparent effect on yield or quality of beans. Since injury has not been noted on other varieties of beans at registered use rates, no caution statement has been added to the labels of the carbaryl formulations.

Alternate insecticides used on beans include malathion, methoxychlor, endosulfan, parathion, diazinon, azinphosmethyl, and dimethoate. None of these materials is as effective as carbaryl for control of Mexican bean beetle and several present a significant increase in hazard to the user.

VI.M.2. Peas: This crop does not represent a significant use for carbaryl. During armyworm outbreaks or when grasshoppers are migrating, a large portion of the 400,000 acres of green peas may receive one application of carbaryl. Carbaryl is used regularly in the Pacific Northwest to control the alfalfa looper. The larva of this insect rolls up when disturbed and because it is about the same size and weight as a pea, may pass undetected over sorting tables and end up in the processed peas. In some areas, Colorado potato beetles feed on weeds growing in pea fields and carbaryl is used to prevent these insects from being inadvertently "processed" with the peas.

Carbaryl is seldom used on dry peas but is very effective in controlling armyworms and grasshoppers.

Reliable information on the amount of insecticides used or the acreage of beans and peas treated annually is not available. It is estimated that carbaryl has 10% of the combined total insecticide use on beans and peas.

VI.N. Sorghum

In the period 1968-70, production of sorghum grain averaged 40,768 million lb and was valued at $758 million annually. Acreage grown for grain amounted to an average of 13,757,000 acres with an additional 3,800,000 acres grown annually for forage or silage during this period (Agricultural Statistics, 1971). In 1966, an estimated 329,000 acres or approximately 2% of the total acreage was treated with insecticides (Blake et al, 1970). In the most recent period for which information is available, 1951-60, an estimated loss of 9% amounting to $34,072,000 occurred annually due to insect damage (Agricultural Research Service, 1965). If control measures are not applied, losses may run much higher depending on which of several pests are present.

Carbaryl is used at 1 - 1.5 lb active ingredient/acre in either granular or spray form and if sorghum is to be used for forage or silage, may be applied on the day of harvest without exceeding the tolerance of 100 ppm. If sorghum is grown for grain, a tolerance of 10 ppm and a preharvest waiting period of 21 d are in effect (Agricultural Research Service, 1969). Sevin Sprayable is the most commonly used formulation although Sevimol is gaining wider usage because it is a liquid and is the only liquid spray formulation registered for control of southwestern corn borer.

The use of Sevin on sorghum is confined primarily to Texas, Oklahoma, and Arizona. The southwestern corn borer is the only insect pest of sorghum for which carbaryl is used in Arizona and usually two applications per season are required. In Texas and Oklahoma, the sorghum midge is the major insect pest for which carbaryl is used. Unless controlled, eggs are laid in the developing florets and the larvae prevent seed development causing "blasted" heads and reduced yield (Pest Control Guides, 1972). One, but sometimes as many as three applications, are required to control the adult midges during the flowering period.

Sorghum webworm is also an important pest but is limited to the eastern half of Texas. Cutworms, stinkbugs, armyworms, and the corn earworm are occasionally serious pests but insignificant amounts of carbaryl are used in any given year for their control.

Alternate insecticides used for midge control include parathion, ethion, disulfoton, diazinon, and carbophenothion, For webworm control, parathion and toxaphene are the principal alternate materials. In Arizona, for southwestern corn borer control, diazinon is the only alternate insecticide used in significant quantities.

It is estimated that carbaryl has approximately 50% of the use on sorghum exclusive of those insecticides applied for greenbug control.

VI.O. Citrus

VI.O.1. Grapefruit, lemon, lime, orange, tangelo, citrus citron, kumquats, and hybrids: Acreage of all types of citrus grown in the U.S. during the period 1968-70, averaged approximately 1,071,000 acres/year. Production during this same period averaged 242,821,000 boxes and was valued at $625,604,000 (Agricultural Statistics, 1971). In the most recent period for which figures are available, 1950-61, an estimated 6% annual loss valued at $24,502,000 occurred due to insects (Agricultural Research Service, 1965). Virtually all citrus acreage is treated for control of insect or mite pests because of the drastic effects these pests have on production. In 1966, 97% of the total acreage was treated and on the larger farms, 99% of the acreage was treated (Fox et al, 1968).

The principal use for carbaryl on citrus is for scale control. The scale insects are probably the most destructive of any group which attack citrus, and if not controlled, may seriously injure the health of the tree resulting in greatly reduced production and even death (Metcalf et al, 1962). Red, yellow, black, brown, soft, and snow scales are the major pests for which carbaryl is used. Less important insects such as citricola scale, fruittree leafroller, orange tortrix, tussock moth, cutworms, and the California orange dog are also effectively controlled.

Sevin 50W or Sevin Sprayable may be used at the rate of 1 lb active ingredient/100 gal water either with or without oil, as used in common practice on citrus, up to 5 d before harvest without exceeding the tolerance of 10 ppm on the fruit. Generally, applications for scale control are made as a dilute spray by ground, employing 1000 - 3000 gal spray/acre depending on tree size and cultural practices. Thorough coverage is essential if effective scale control is to be obtained. For control of lepidopterous larvae attacking citrus in California, aerial applications of carbaryl at 4 - 6 lb active ingredient/acre in 15 - 20 gal spray/acre have proved effective.

Normally, one application of carbaryl per year, timed to coincide with the presence of scale crawlers, provides control. Because carbaryl does not control the citrus red mite, some growers use other insecticides which offer partial, though not very effective, control of this pest. Petroleum oil alone or in combination with parathion, azinphosmethyl, or malathion are the most commonly used materials.

In Florida, the citrus industry is threatened by the sugarcane stalk borer, introduced from the West Indies. The adults of this insect cause serious defoliation. The infested area is under quarantine and the USDA has been conducting a control program using Sevin 4 Oil carbaryl insecticide, a unique oil-based formulation containing 4 lb active ingredient/gal. This is not a registered use for Sevin 4 Oil but demonstrates the residual advantages of this formulation. Approximately 14,000 gal of Sevin 4 Oil were used in this program in 1972.

VI.P. Forage grass and pasture

In 1966, the total area of all pasture and rangeland in the U.S. amounted to 544.5 million acres (Agricultural Statistics, 1971). Insecticides were used on less than 0.5% of this area or less than 2.7 million acres (Fox et al, 1968). In the period 1951-60, it was estimated that average annual loss on federal, state, and private rangelands in the 17 Western States amounted to $80 million (Agricultural Research Service, 1965). This loss was primarily attributable to damage by about 20 species of grasshoppers.

Armyworms (principally the fall armyworm) are the major pests for which carbaryl is used on pastures, and the area of use is largely confined to the Southwestern States. Armyworms are present in certain areas nearly every year and in the southern portions of their distribution may complete as many as 8 - 10 generations/year (Metcalf et al, 1962). Peak populations occur periodically, usually following a cold, wet spring. During late summer in peak years significant acreages of pasture are infested. Usually only one application of carbaryl at 1.5 lb active ingredient/acre is required to effectively control them. Because of the large areas involved, sprays are usually applied by aircraft, although ground spray equipment is sometimes used.

Sevimol and Sevin Sprayable are registered for rangeland and pasture insect control and may be used interchangeably according to the needs of the user. These formulations are most commonly used by individual farmers for armyworm or grasshopper control on privately owned pasture land. However, they are also used by state or federal agencies for small scale (less than 1000 acres) grasshopper control programs on public lands, including wildlife refuges where only an insecticide of low hazard to wildlife is acceptable. A carbaryl rate of 1 lb active ingredient/acre is normally applied once by aircraft when populations have reached the threshold of economic damage. For large-scale grasshopper control programs conducted by governmental agencies, Sevin 4 Oil is the preferred carbaryl formulation. Aerial application of as little as 0.5 lb active ingredient/acre (1 pt of formulation) gives effective control. The unique ingredients in this formulation prevent evaporation during application, improve sticking properties, and impart longer lasting control under rainfall conditions than other formulations of carbaryl.

The major benefit of carbaryl is the tolerance of 100 ppm on grass and pastures which permits immediate grazing following application and eliminates the need to remove livestock from the area being treated (Agricultural Research Service, 1969). Carbaryl has only a small portion of the total rangeland grasshopper control use. Lower cost per acre favors the use of malathion, but occasional control failures due to rainfall following applications of malathion have stimulated interest in Sevin 4 Oil.

VI.Q. Potatoes

During the period 1968-70, an average of 1,405,000 acres of potatoes was grown each year in the U.S. (Agricultural Statistics, 1971). Information on annual loss caused by insects during this same period is not readily available but was estimated to be 14% in the 1951-60 period (Agricultural Research Service, 1965). Thus, $65,968,000 was lost from potential production as a result of insect damage. In their efforts to reduce this loss, growers treated 89% of the potato acreage in 1966 amounting to 1,332,000 acres (Blake et al, 1970; Fox et al, 1968).

The principal use for carbaryl on potatoes is control of the Colorado potato beetle, which can devour so much of the foliage that plants die and development of tubers is prevented or yield is reduced (Metcalf et al, 1962). In most areas where this insect is present, two generations occur per year, the first in early summer and the second in late July or early August. In some areas, a partial third generation may occur, while in the north only a single generation occurs each year. Sevin Sprayable, 50W, and Sevimol 4 are all used but the Sprayable formulation is the most common. Aircraft or ground spray equipment is used to apply 1 lb active ingredient/acre on overwintered beetles when they appear on the plants in the spring, and repeated as needed.

On Long Island, New York, Colorado potato beetles have developed resistance to carbaryl as well as to the alternate insecticides, azinphosmethyl and endosulfan. Growers have resorted to the use of methoxychlor for control of adult beetles and are in need of a more effective material to control this insect. This resistance to carbaryl is not widespread and its use elsewhere continues, consistent with the need for insect control.

The second brood European corn borer is often a serious pest of potatoes and if not controlled, may cause significant damage to the tubers. Several insect pests of lesser importance, such as flea beetles, leafhoppers, armyworms, and cutworms, are usually controlled as a result of applications directed against the Colorado potato beetle or the European corn borer. Usually, an average of 3 - 4 applications carbaryl/season are needed to control these pests.

A tolerance of 0.2 ppm for carbaryl has been established on potatoes. No preharvest time limitation is imposed.

The use of carbaryl on potatoes probably represents less than 10% of the potato insecticide used in the U.S.

VI.R. Tobacco

All types of tobacco grown in the U.S. during the period 1968-70 averaged approximately 900,000 acres/year. The on-farm value averaged $1,290,987,000/year and is a direct function of leaf quality and weight (Agricultural Statistics, 1971). In 1966, an average of 81% of tobacco acreage was treated with insecticides (Fox et al, 1968). On all but the smallest farms (under $10,000 value of sales), the average was 92%. Overall, approximately 800,000 acres were treated for insect control in 1966 (Blake et al, 1970). The average annual loss attributed to insect damage was 11% and amounted to $132,000,000 in the period 1951-60 (Agricultural Research Service, 1965).

Damage to tobacco leaf by insects is one major factor which can reduce the yield, quality, and hence the price received by the farmer for his crop. Certain insects, such as the tobacco budworm, grasshoppers, and tobacco hornworm, are capable of completely destroying entire fields of tobacco (Agricultural Research Service, 1965). Growers usually apply insecticides several times during the growing season, often starting when the tobacco seedlings are still growing in the plant bed prior to setting in the field.

The tobacco flea beetles and occasionally green June beetle grubs attack tobacco seedlings in the plant beds. Flea beetles are one of the most injurous insects attacking tobacco and if not controlled, may ruin entire beds (Metcalf et al, 1962). Damage is caused by the flea beetle eating small holes in the leaf. Carbaryl is often used for control but only small quantities are used due to the limited area treated. In the plant beds, carbaryl may be used as a spray (0.25%) dust (5%), or soil drench (0.06%) for control of the insect pests listed on the label. Applications are made with hand-operated equipment, again because of the limited area to be treated.

Flea beetles may also attack tobacco plants after they have been transplanted into the field. Severe attack may weaken or kill young plants and economic damage often continues until the crop is harvested. Both the leaf quantity and quality are lessened as a result of the mature leaves being spotted with feeding holes.

In the field, aircraft as well as ground spray equipment are used; however, due to the average small field size, ground spraying predominates. Carbaryl is recommended at a rate of 1 - 2 lb active ingredient/acre principally for control of tobacco hornworms, tobacco budworms, and flea beetles. Sprays directed into the bud or dusts applied in the bud with a puff duster or a shaker can are preferred methods of control. Five percent carbaryl cornmeal bait is also recommended for budworm control in many areas (Pest Control Guides, 1972). The "hand pinch" method for control of budworms utilizes the cornmeal bait, applied by hand directly to the bud where the worm is feeding. Since most farmers make up their own bait from either Sevin Sprayable or 50W, it is not possible to accurately determine spray versus bait. Growers who use carbaryl apply it an average of 2 - 3 times/season. Carbaryl is recommended for use in all the major tobacco-growing states and is often the material chosen by the farmer when applications are made by hand or with hand-held equipment. A waiting period of 3 d is imposed between last application and priming (harvest). No tolerance is required since tobacco is classed as a nonfood crop (Agricultural Research Service, 1969).

Certain types of tobacco are sensitive to many different chemicals. When label directions are followed, phytotoxicity is not a problem with carbaryl. Carbaryl has not been associated with off-flavor or reduced leaf quality and tests conducted by leading U.S. tobacco companies have substantiated these observations.

Parathion, azinphosmethyl, methomyl, and monocrotophos are the principal alternate insecticides used on tobacco for control of hornworm, budworms, and flea beetles. All are of about the same order of efficacy as carbaryl and range in cost from significantly more expensive to significantly less expensive.

Uses of carbaryl on tobacco are usually in the form of Sevimol 4 and Sevin Sprayable.

VI.S. Nut crops

VI.S.1. Almond, filbert, pecan and walnut: In the 1968-70 period, annual production of pecans in the U.S. averaged 188,933,000 lb and was valued at $65,863,000 (Agricultural Statistics, 1971). Loss due to insects in the latest period for which figures are available, 1951-60, was estimated at 12% or $5,693,000 (Agricultural Research Service, 1965). Pecan is the only crop in this group that offers a significant use for carbaryl.

Carbaryl is used for control of the pecan nut casebearer, but the principal use is for pecan weevil control. The weevil causes immature nuts to fall from the tree and also damages mature pecans by piercing the nut. Sevin Sprayable at the rate of 1 lb active ingredient/100 gal H_2O applied in full coverage dilute sprays by ground provides effective control of both pests. An average of two applications are made per season with the last application being made prior to shuck-split (Pest Control Guides, 1972). Alternate insecticides for control of these pests are azinphosmethyl, endosulfan, and EPN. Since stock is commonly pastured under pecan trees, Sevin has the advantages of both an apparent low order of hazard and being registered for use on pasture with a zero day limitation prior to grazing.

VI.T. Small fruits

VI.T.1. Blueberry, caneberry, cranberry, grape and strawberry: Within this crop grouping, only grapes constitute a significant use for carbaryl. The other crops are of limited acreage and some are restricted as to areas of production.

In the period 1968-70, grape acreage in the U.S. averaged 646,000 acres annually (Agricultural Statistics, 1971). Production amounted to an average 7 billion lb with an on-farm value of $109 million. An estimated $7 million loss due to insect pests occurred annually in the period 1951-60 (Agricultural Research Service, 1965). Pests, such as the grapeberry moth, are capable of damaging 60 - 90% of the fruit and the grape leafhopper may cause a 30% reduction in crop due to reduced plant vigor (Eichers et al, 1968). In California, the grape leaf-folder damages both foliage and fruit, reducing vigor and yield.

Little information is available on the number of acres treated with insecticides each year but it is estimated that 80 - 85% are treated. Carbaryl is used only once or twice per season. Applications of 2 lb active ingredient/acre as a spray or dust may be made up to the day of harvest without exceeding the tolerance of 10 ppm (Agricultural Research Service, 1969). Usually, applications are made by ground equipment but aircraft are also employed, especially in California.

Carbaryl has been widely used for grape insect control for over a decade. Grape leafhoppers in certain parts of California's San Joaquin valley have developed resistance to chlorinated hydrocarbons, organophosphates, and more recently, to carbaryl. Combinations of carbaryl with other insecticides, such as naled or azinphosmethyl, still effectively control this insect in areas where the population is resistant.

In the early 1960's, carbaryl was selected by the California Department of Agriculture for control of the grapeleaf skeletonizer, a serious pest not previously found in the Central Valley. Since then, it has been kept from becoming an economic pest of commercial vineyards as a result of diligent control efforts by the State. Carbaryl is still the insecticide of choice whenever infestations are found.

The principal pests of grapes for which carbaryl is used are climbing cutworms, leaffolders, and the previously mentioned grape berry moth and grape leafhopper. Azinphosmethyl is indicated to be the most commonly used alternate insecticide.

Sevin has an estimated 10% share of the total insecticide use on small fruit.

VI.V. Alfalfa and clover

In the period 1968-70, U.S. acreage of alfalfa and clover grown for hay or forage averaged 27,061,000 and 13,327,000 acres, respectively (Agricultural Statistics, 1971). Carbaryl is used sparingly on clover principally for control of sporadic outbreaks of grasshoppers, cutworms, armyworms, and leafhoppers and accounts for less than 10% of combined sales on alfalfa and clover.

Little information is available on the number of acres of clover treated annually for insect control, but 2,031,000 acres of alfalfa were treated with insecticides in 1966 (Blake et al . 1970. In the 1951-60 period, insects caused an estimated 15% average annual loss to alfalfa grown for hay, which amounted to $242,905,000. In the same period, alfalfa grown for seed suffered a 38% loss amounting to $20,060,000/year (Agricultural Research Service, 1965).

The principal use of carbaryl on alfalfa grown for hay is to control the larvae of the alfalfa weevil. This pest is an important insect enemy and if not controlled, is capable of destroying at least one cutting of hay per season (Metcalf et al, 1962). In certain years, outbreaks of armyworms or grasshoppers occur and carbaryl usage may be fairly extensive for control of these pests. Sevin Sprayable, 50W, and Sevimol are registered on alfalfa and are applied at a rate of 1 - 1.5 lb active ingredient/acre by ground or aircraft spray equipment. Applications of carbaryl seldom exceed one per season for control of alfalfa weevil larvae, but additional treatments may be required if other pests occur. Carbaryl may be applied any time up to harvest or grazing without exceeding the 100 ppm tolerance (Agricultural Research Service, 1969). However, if insect populations reach a damaging level immediately prior to normal harvest, the preferred agricultural practice is to cut the crop a little early and apply the carbaryl, if needed, to the stubble after the crop has been harvested.

Under conditions of prolonged humidity or rainfall, the tender new leaves of alfalfa have occasionally shown chlorosis and slight marginal necrosis following applications of carbaryl. Plant recovery is rapid and there is no apparent effect on yield or quality of hay or forage. A caution statement appears on the label to warn growers of this possible effect.

A number of other insecticides, including carbofuran, methyl parathion, azinphosmethyl, Imidan, diazinon, and alfatox are presently registered for use on alfalfa.

Little information is available on the total amount of insecticides used currently on alfalfa and clover but it is estimated that Sevin has about 5% of this use.

VI.W. Small grains

VI.W.1. Barley, oats, rye, and wheat: Use of carbaryl on these crops has been restricted to the State of Michigan in recent years where state registration permits applications for control of cereal leaf beetle.

Acreage of all small grains grown in Michigan in 1968-70 averaged (Agricultural Statistics, 1971):

Barley	26,300
Oats	518,000
Rye	195,000
Wheat	727,000

Although all these crops plus seedling corn may be damaged by the cereal leaf beetle, oats are most likely to incur economic damage if control measures are not applied. In 1971, 35% of oat acreage was treated for control of this insect (Pest Control Guides, 1972). Spring grain is more severely damaged than winter grain and heavy populations may reduce yields by 75% and 25% respectively (Texas A & M University, 1970).

A single application of Sevin Sprayable at the rate of 1 lb active ingredient/acre by aircraft or ground spray equipment will effectively control eggs, adults, and larvae of the cereal leaf beetle. To preserve populations of the larval parasite, *Tetrastichus julis*, treatment should be made when larvae may be easily found but before advanced larval or adult stages are reached. In order to avoid residues in the grain at harvest, applications of carbaryl are not permitted beyond the boot stage.

In addition to carbaryl, endosulfan, azinphosmethyl, and malathion are recommended for control of cereal leaf beetle. None of these is reported to be as effective as carbaryl but malathion may be used after the boot stage if conditions require application.

Other insects, such as grasshoppers and armyworm, often attack small grains and offer a potential for use of carbaryl.

VI.X. Miscellaneous government program uses

In recent years various governmental agencies have applied carbaryl for uses required in their programs. The efficacy of carbaryl in controlling target pests, as well as the generally recognized low order of hazard to man and the environment, are often the decisive factors leading to the selection of carbaryl over other materials. During the early 1960's, carbaryl was used by the California Department of

Agriculture to successfully eradicate the Japanese beetle from an area of downtown Sacramento. In 1972, 10,000 lbs (2,500 gal of Sevin 4 Oil) were used by the USDA in the East St. Louis area of Illinois to control the Japanese beetle. In 1973, the world-famed San Diego Zoo and the adjacent areas of Balboa Park were treated with carbaryl for control of an isolated infestation of Japanese beetle. Applications were continued through 1974.

In 1967-68, multiple applications of Sevin Sprayable helped eradicate the tropical bont tick from the island of St. Croix. Aerial and ground applications of carbaryl every 3 wk over the infested 2600 acre area, as well as a weekly dipping program using coumaphos, prevented establishment of this important pest of cattle (Hourrigan et al, 1969).

A very minor, although interesting, use for carbaryl is found in California where bubonic plague is endemic in the ground squirrel population found along the western foothills of the Sierra Nevada Mountains. In high public use areas, such as parks and campgrounds, the California Department of Agriculture has directed the use of carbaryl 5% dust in and around ground squirrel burrow openings to control fleas which are vectors of the plague, thus preventing transmission to humans and other animals. Consumption of carbaryl for this use amounts to less than 5000 lb annually.

VI.Y. Sevin carbaryl registrants

An EPA computer printout dated October 26, 1976, listed 240 registrants and 1537 products containing Sevin carbaryl insecticide. In response to a survey of these registrants, labels from 152 companies representing 782 products have been studied. Appendix 2 briefly summarizes the labels by type of formulation, products which contain other pesticides, and breakdown by end-use.

Literature Cited

Agricultural Research Service (ARS). Losses in agriculture. USDA, Agricultural Research Service, Washington, D.C. 1965. 120 pp. [Handbook No. 291]

Agricultural Research Service (ARS). USDA summary of registered agricultural pesticide chemical uses. Volume III. Insecticides, repellents, acaricides. 3rd edition. USDA, Agricultural Research Service, Washington, D.C. 1969. pp. III-C-3.1.- III-C-3.7.

Agricultural Research Service/Forest Service (ARS/Forest Service). Suggested guide for the use of insecticides to control insects affecting crops, livestock, households, stored products, forests, and forest products - 1968. USDA, Agricultural Research Service and Forest Service, Washington, D.C. 1968 [Handbook No. 331]

Agricultural Statistics - 1971. USDA, Economic Research Service, Washington, D.C. 1971. 639 pp.

Anonymous. Western growers plot pink bollworm warfare. Calif.-Ariz. Cotton 8(2):22. 1972.

Arant, F.S., et al. The peanut, the unpredictable legume; a symposium. National Fertilizer Association, Washington, D.C. 1951. 333 pp.

Baker, W.L. Eastern forest insects. USDA, Forest Service, Washington, D.C. 1972. 642 pp. [Misc. Publ. No. 1175]

Blake, H.T., P.A. Andrilenas, R.P. Jenkins, T.R. Eichers, and A.S. Fox. Farmers' pesticide expenditures in 1966. USDA, Economic Research Service, Washington, D.C. 1970. 43 pp. [Agric. Econ. Rep. No. 192]

Eichers, T., P. Andrilenas, R. Jenkins, and A. Fox. Quantities of pesticides used by farmers in 1964. USDA, Economic Research Service, Washington, D.C. 1968. 37 pp. [Agric. Econ. Rep. No. 131]

Fox, A., T. Eichers, P. Andrilenas, R. Jenkins, and H. Blake. Extent of farm pesticide use on crops in 1966. USDA, Economic Research Service, Washington, D.C. 1968. 23 pp. [Agric. Econ. Rep. No. 147]

Graham, S.A., and F.B. Knight. Principles of forest entomology. 4th edition. McGraw-Hill, New York. 1965. 417 pp.

Hourrigan, J.L., R.K. Strickland, O.L. Kelsey, B.E. Knisely, C.C. Crago, S. Whittaker, and G.J. Gilhooly. Eradication efforts against tropical bont tick, *Amblyomma variegatum*, in the Virgin Islands. J. Am. Vet. Med. Assoc. 154(5):540-545. 1969.

Jenkins, R., T. Eichers, P. Andrilenas, and A. Fox. Farmers' expenditures for custom pesticide service in 1964. USDA, Economic Research Service, Washington, D.C. 1968. 24 pp. [Agric. Econ. Rep. No. 146]

Metcalf, C.L., and W.P. Flint (Revised by R.L. Metcalf). Destructive and useful insects. 4th edition. McGraw-Hill, New York. 1962. 1087 pp.

Pest Control Guides. Published annually by all states to guide farmers and commercial applicators on recommended procedures for controlling crop pests. 1972.

Texas A&M University. Impact of drastic reduction in the use of agricultural chemicals on food and fiber production and cost to the consumer. Special report. Texas A&M University, College of Agriculture, College Station, Texas. 1970. 62 pp.

Union Carbide Corporation. List of recommended uses for Sevin carbaryl insecticide. Union Carbide Corporation, Salinas, California. 1972. [F-40851 A]

U.S. Department of Agriculture (USDA). Timber resources for America's future. Forest Service, Washington, D.C. 1958. 713 pp. [For. Resour. Rep. No. 14]

Wester, H.V. Spraying and other controls for diseases and insects that attack trees and shrubs. USDI, National Park Service, Washington, D.C. 1968. 52 pp. [Tree Preservation Bull. No. 6]

Appendix 1

SUMMARY OF SIGNIFICANT CARBARYL INSECTICIDE USES IN THE UNITED STATES

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
	Forage, field, and vegetable crop insect control		
Alfalfa,* clovers*	Blister beetles, Mexican bean beetles	1/2 - 1 lb	Day of harvest grazing.
	Alfalfa caterpillar, bean leaf beetle, cucumber beetles, green cloverworm, Japanese beetle, leafhoppers, three-cornered alfalfa hopper, thrips, velvet-bean caterpillar	1 lb	Tolerance, 100 ppm on forage and hay.
	Armyworms, corn earworm, stink bugs, webworms	1 - 1-1/2 lb	
	Alfalfa weevil larvae	Western U.S., 1 lb Eastern U.S., 1-1/2 lb	
	Cutworms	1 - 1/2 lb	
	Clover head weevil on clovers in Texas	1 - 1/2 lb	
Asparagus*	Asparagus beetle on seedlings or spears	1 - 2 lb	1 d before harvest. Tolerance, 10 ppm.
	Asparagus beetle, Apache cicada on ferns or brush growth	2 - 4 lb	

* When label directions are followed, forage, vines, hay, and citrus pulp may be fed to meat and dairy animals.

Source: Adapted from Union Carbide Corporation data by Dr. Homer Fairchild, Criteria and Evaluation Division, Office of Pesticide Programs, EPA.

Crops	Insects controlled	Amount to use (active carbaryl/acre)	Limitations
Beans* (dry, green, lima, navy, snap, southern peas, including crowder and black-eyed peas)	Mexican bean beetle	1/2 lb	Day of harvest. Tolerance, 10 ppm on beans; 100 ppm on forage or hay.
	Bean leaf beetle, cucumber beetles, flea beetles, Japanese beetle, leafhoppers, velvetbean caterpillar, western bean cutworm	1 lb	
	Armyworms, cutworms, corn earworm, stink bugs, tarnished plant bug	1 - 1-1/2 lb	
	Cowpea curculio (on southern peas)	2 lb	
	Corn earworm, lima bean pod borer, lygus, stink bugs in California	2 lb	
Cabbage,* broccoli*	Flea beetles, harlequin bug	1/2 - 1 lb	3 d before harvest. Tolerance, 10 ppm.
Brussels sprouts,* cauliflower,* kohlrabi*	Armyworms, corn earworm, imported cabbageworm	1 - 2 lb	
Chinese cabbage*	Flea beetles, harlequin bug, leafhoppers	1/2 - 1 lb	3 d before harvest of root crops; 14 d leaf crops. Tolerance, 5 ppm on horseradish, radishes, rutabagas, turnips; 10 ppm on Chinese cabbage; 12 ppm for collards, kale, mustard greens, turnip tops.
Collards,* Hanover salad	Aster leafhopper	1 - 1-1/2 lb	
Horseradish,* kale,* mustard greens,* radishes,* rutabagas,* turnips*	Armyworms, corn earworm, imported cabbageworm, stink bugs, tarnished plant bug	1 - 2 lb	

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Carrots,* parsnips,* parsley	Flea beetles, leafhopper	1/2 - 1 lb	Day of harvest of carrots; 3 d of harvest of parsley. Tolerance, 5 ppm on parsnips; 10 ppm on carrots; 12 ppm on parsley.
	Aster leafhopper	1 - 1-1/2 lb	
	Armyworms, corn earworms, stink bugs, tarnished plant bug	1 - 2 lb	
Corn * (field, sweet, pop)	Corn earworm, corn rootworm adults, European corn borer, fall armyworm, flea beetles, Japanese beetle, leafhoppers, sap beetles, southwestern corn borer	1 - 2 lb	Day of harvest. Tolerance, 5 ppm on corn; 100 ppm on forage.
	Cutworms	2 lb	
Cotton*	Cotton fleahopper, cotton leafworm, flea beetles, striped blister beetle, thrips	1/2 - 1 lb	May be applied after bolls open. Tolerance, 5 ppm on cottonseed; 100 ppm on forage.
	Boll weevil, bollworm, cotton leafperforator, fall armyworm, leafrollers, leafhoppers, tarnished plant bug, light to moderate infestations of western lygus bugs (aphids repressed by scheduled repeat applications)	1 - 2 lb	
	Pink bollworm	1-1/2 - 2-1/2 lb	Do not use molasses after bolls open.
	Stink bugs, saltmarsh caterpillar	2 lb	For improved bollworm control, add 1 gal blackstrap per acre.

Appendix 1 (cont.)

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Cowpeas*	Blister beetles, Mexican bean beetle	1/2 - 1 lb	Day of harvest or grazing. Tolerance, 5 ppm on peas; 100 ppm on forage.
	Alfalfa caterpillar, bean leaf beetle, cucumber beetles, flea beetles, green cloverworm, Japanese beetle, leafhoppers, three-cornered alfalfa hopper, thrips, velvetbean caterpillar	1 lb	
	Armyworms, corn earworm, cutworms, stink bugs, webworms	1 - 1-1/2 lb	
	Cowpea curculio	2 lb	
	Corn earworm, lima bean pod borer, lygus bugs, stink bugs in California	2 lb	
Cucumber,* melons,* pumpkins,* squash*	Pickleworm, melonworm	1/2 - 1 lb	Day of harvest. Tolerance, 10 ppm. (Do not use Sevin on watermelons in Florida.)
	Cucumber beetles, flea beetles, leafhoppers, squash bug	1 lb	
Dandelion,* endive* (escarole), lettuce,* salsify*	Flea beetles, harlequin bug, leafhoppers	1/2 - 1 lb	3 d before harvest of lettuce; 14 d before harvest of other leaf crops. Tolerance, 10 ppm on endive, lettuce, salsify tops; 12 ppm on dandelion; 5 ppm on salsify roots
	Aster leafhopper	1 - 1-1/2 lb	
	Armyworms, corn earworm, imported cabbageworm, stink bugs, tarnished plant bug	1 - 2 lb	
Forage grasses,* pasture*	Armyworm, thrips	1 - 1-1/2 lb	Day of harvest of grass and pasture. Tolerance, 100 ppm on grass and hay.
	White grubs (green June beetle, Japanese beetle)	1-1/2 - 2 lb	

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Garden beet,* spinach,* swiss chard*	Flea beetles, harlequin bug, leafhoppers	1/2 - 1 lb	3 d before harvest of garden beet; 14 d for spinach and swiss chard. Tolerance, 5 ppm on garden beet; 12 ppm on spinach, swiss chard.
	Aster leafhopper	1 - 1-1/2 lb	
	Armyworms, corn earworm, stink bugs, tarnished plant bug	1 - 2 lb	
Okra*	Corn earworm, stink bug	1 - 2 lb	Day of harvest. Tolerance, 10 ppm.
Peanuts*	Blister beetles, Mexican bean beetle	1/2 - 1 lb	Day of harvest or grazing. Tolerance, 100 ppm on forage and hay; 5 ppm on peanuts.
	Alfalfa caterpillar, bean leaf beetle, cucumber beetles, green cloverworm, Japanese beetle, leafhoppers, three-cornered alfalfa hopper, thrips, velvetbean caterpillar	1 lb	
	Armyworms, corn earworm, stink bugs, webworms	1 - 1-1/2 lb	
Peas*	Colorado potato beetle, leafhoppers	1 lb	Day of harvest. Tolerance, 10 ppm on peas; 100 ppm on forage.
	Armyworms	1 - 1-1/2 lb	
	Alfalfa looper in Washington State only	2-1/2 lb	
Potato, tomato, eggplant, pepper	Colorado potato beetle, flea beetles	1/2 - 1 lb	Day of harvest. Tolerance, 0.5 ppm (interim) on potato; 10 ppm on tomato, eggplant, pepper.
	European corn borer, fall armyworm, lace bugs, stink bugs, tomato fruitworm, tomato hornworm, tarnished plant bug	1 - 2 lb	
	Cutworms	2 lb	

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Rice*	Armyworms, stink bugs in Mississippi Delta and Texas	1 - 1-1/2 lb	14 d before harvest. Tolerance, 5 ppm on rice; 100 ppm on straw. Do not apply propanil within 15 d of Sevin application.
	Armyworm, leafhoppers and tadpole shrimp in California	2 lb	
Sorghums* (milo, grain sorghum, hybrids)	Armyworms, corn earworm, stink bugs, webworms	1 - 2 lb	21 d before harvest of grain. Tolerance, 10 ppm. No time limit on sorghum forage. Tolerance, 100 ppm.
	Sorghum midge, southwestern corn borer	1-1/2 lb	
	Cutworms	2 lb	
Soybeans*	For light to moderate populations in Southeastern States only:		Day of harvest or grazing. Tolerance, 100 ppm on forage and hay; 5 ppm on soybeans. Do not apply combination of Sevin and 2,4-D herbicide to soybeans.
	Bean leaf beetle, cucumber beetles, green cloverworm, Mexican beetles, velvetbean caterpillar	1/2 lb	
	Corn earworm	1/2 - 3/4 lb	
	For cleanup of existing populations:		
	Blister beetles, Mexican bean beetle	1/2 - 1 lb	
	Alfalfa caterpillar, bean leaf beetle, cucumber beetles, green cloverworms, Japanese beetle, leafhoppers, three-cornered alfalfa hopper, thrips, velvetbean caterpillar	1 lb	
	Armyworms, corn earworm, stink bugs, webworms	1 - 1-1/2 lb	

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Sugar beets*	Armyworms, flea beetles, leafhoppers, webworms	1 - 2 lb	14 d before harvest. Tolerance, 100 ppm on sugar beet tops.
Tobacco	In plant beds:		
	Tobacco flea beetle	0.25% spray	Allow 3 d before priming or cutting.
	Green June beetle grubs		
	In fields:		
	Budworms, flea beetles, hornworms, Japanese beetle, June beetles	1 - 2 lb	
	Grasshoppers		
Forage, field, vegetable crops		1/2 - 1-1/2 lb	Follow preharvest and grazing use limitations for each of previous crops.
	Nymphs on small plants or sparse vegetation in wasteland, ranges, ditchbanks, borders	1/2 - 1 lb	
	Mature grasshoppers or when material is applied to crops requiring greater coverage	1 - 1-1/2 lb	
	Tree fruit and nut insect control		
Almond*	Fruittree leafroller, peach twig borer, San Jose scale	1 lb/100 gal	No time limit. Tolerance, 40 ppm on hulls; 10 ppm in whole almond; 1 ppm in nutmeats.

Appendix 1 (cont.)

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Apples, pears	West of the Rocky Mountains:		
	Apple sucker, apple aphid, apple rust mite, bagworms, California pearslug (pear sawfly), codling moth, eye-spotted bud moth, green fruitworm, lygus bugs, orange tortrix, oystershell scale, pear psylla, pear-leaf blister mite, pear rust mite, San Jose scale, tentiform leafminers, lecanium scales	3/4 - 1 lb/100 gal	1 d before harvest. Tolerance, 10 ppm. Application within 30 d after full bloom may provide apple thinning; to avoid, delay use until at least 30 d after bloom.
	East of the Rocky Mountains:		
	Apple mealybug, apple aphid, codling moth, white apple leafhopper	1 lb/100 gal	For thinning apples, use 1/4 to 1/2 lb active Sevin/100 gal dilute spray. On hard-to-thin varieties, use 1/2 - 1 lb. Apply in one spray timed 10 - 25 d after full bloom.
	Apple maggot, apple rust mite, bagworms, eastern tent caterpillar, European apple sawfly, eyespotted bud moth, fruittree leafroller, Forbes scale, green fruitworm, Japanese beetle, lesser appleworm, lecanium scales, oystershell scale, pear psylla, pearleaf blister mite, periodical cicada, plum curculio, redbanded leafroller, rosy apple aphid, San Jose scale, tarnished plant bug, tentiform leafminers, woolly apple aphid	1 lb/100 gal	
Citrus fruits * (grapefruit, lemons, limes, oranges, tangelos, tangerines, citrus citron, kumquats, hybrids)	California orange dog, citrus cutworm, fruittree leafroller, orange tortrix, western tussock moth	1 lb/100 gal	5 d before harvest. Tolerance, 10 ppm.
	Black scale, brown soft scale, California red scale, citricola scale, citrus snow scale, yellow scale	3/4 - 1 lb/100	

A[redacted]ndix 1 (cont.)

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Filbert	Filbert aphid, filbert leafroller, filbertworm	1 lb/100 gal	No time limit. Tolerance, 5 ppm.
Olives	Olive scale	3/4 - 1 lb with 1-1/2 gal summer oil/100 gal	No more than 2 applications per season. Tolerance, 10 ppm.
Peaches, apricots, nectarines	Apple pandemis, codling moth, cucumber beetles, European earwig, fruittree leafroller, Japanese beetle, June beetles, lesser peachtree borer, lecanium scale, olive scale, orange tortrix, oriental fruit moth, peach twig borer, periodical cicada, plum curculio, *Platynota flavendana*, redbanded leafroller, San Jose scale, tarnished plant bug, tussock moths	1 lb/100 gal	1 d before harvest of peaches; 3 d before harvest of apricots, nectarines. Tolerance, 10 ppm.
Pecans	Pecan weevil, pecan nut casebearer	1.2 - 2.4 lb/ 100 gal	No time limit. Tolerance, 1 ppm.
Plums, prunes, cherries	Black cherry aphid, cherry maggot, cherry fruitworm, eyespotted bud moth, fruittree leafroller, Japanese beetle, lesser peachtree borer, peach twig borer, plum curculio, prune leafhopper, brown soft scale, Forbes scale, lecanium scale, mealy plum aphid, oystershell scale, redbanded leafroller, San Jose scale	1 lb/100 gal	1 d before harvest. Tolerance, 10 ppm.
	Eastern tent caterpillar, codling moth, orange tortrix, tussock moths	3/4 lb/ 100 gal	

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
Walnut	Codling moth, calico scale, European fruit lecanium, filbertworm, fruittree leafroller, frosted scale	1/2 lb/100 gal	No time limit. Tolerance, 10 ppm in whole walnuts; 1 ppm in nutmeats.
	European earwig	2 lbs/100 gal	
	Small fruit insect control		
Blueberries	Blueberry maggot, cherry and cranberry fruitworms, European fruit lecanium, Japanese beetle	1-1/2 - 2 lb	Day of harvest. Tolerance, 10 ppm.
Cranberries	Cutworms, cranberry fire-worms, fruitworms, Japanese beetle, leafhoppers	1-1/2 - 3 lb	1 d before harvest. Tolerance, 10 ppm.
Grapes	European fruit lecanium, grape leaffolder, grape leafhoppers, western grapeleaf skeletonizer	1 - 2 lb	Day of harvest. Tolerance, 10 ppm.
	Cutworms, grape berry moth, Japanese beetle, June beetles, orange tortrix, omnivorous leafroller, redbanded leafroller	2 lb	
Strawberries	Meadow spittlebug, strawberry leafroller, strawberry weevil	1 - 2 lb	1 d before harvest. Tolerance, 10 ppm.
Blackberries, raspberries, dewberries, boysenberries, loganberries	European raspberry aphid, Japanese beetle, leafrollers	2 lb	7 d before harvest. Tolerance, 12 ppm.
	Omnivorous leafroller, raspberry sawfly in California	2 lb	

Appendix 1 (cont.)

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
	Shade tree and ornamental insect control		
Herbaceous annual, biennial, perennial plants	Blister beetles, boxelder bug, flea beetles, Japanese beetle, June beetles, lace bugs, leafhoppers, leafrollers, mealybugs, plant bugs, psyllids, rose aphid, exposed thrips	1 lb/100 gal	
Shrubs, trees,	Apple aphid, bagworms, birch leafminer, boxelder bug, boxwood leafminer, cankerworms, catalpa sphinx, Cooley spruce gall aphid, eastern spruce gall aphid, elm leaf aphid, elm leaf beetle, elm spanworm, eriophyid mites, gypsy moth, Japanese beetle, June beetles, lace bugs, leafhoppers, leafrollers, mealybugs, mimosa webworm, oak leaf miners, orangestriped oakworm, orange tortrix, periodical cicada, plant bugs, puss caterpillar, rose aphid, rose slug, exposed sawflies, scale insects, spruce needleminer, tent caterpillars, thorn bug, exposed thrips, webworms, willow leaf beetles, yellow poplar weevil		No time limit. Do not spray on Boston ivy, Virginia creeper, maidenhair fern.
	Lawn and area insect control		
	Ants, bluegrass billbug, chinch bugs, cutworms, earwigs, European chafer, fall armyworm, fleas, green June beetle, leafhoppers, millipedes, mosquitoes, sod webworms (lawn moths)	1 lb in 150-200 gal water/5000 ft^2 of lawn	No time limit.
	Chinch bug in Florida	1-1/4 lb/5000 ft^2	

Appendix 1 (cont.)

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
	Forest insect control		
	Elm spanworm, fall cankerworm, forest tent caterpillar, Great Basin tent caterpillar, gypsy moth, oak leaf rollers, saddled prominent, spring cankerworm, spruce budworm	3/4 - 1 lb	No time limit.
	Adult mosquitoes		
Pasture, rangeland, nonagricultural lands		1/4 - 1/2 lb in mist blowers; 1/2 - 3/4 lb aerial sprays; 1 lb in low pressure ground equipment	Day of harvest.
Limited areas (grass, lower shade tree foliage, shrubbery, flower beds)		1 lb/100 gal	
	Pest control in and around buildings		
			For use by pest control operators only:
Homes, apartments, warehouses, barns, municipal recreation areas	Cockroaches, ants	3/4 lb/4 gal	Spray surfaces; don't space spray or spray animals. Don't treat fabrics or use in dairy barns. Don't use more than twice per week. Protect all food. Food-handling surfaces should be protected and cleaned after treatment.
	Brown dog ticks, earwigs, millipedes	3/4 lb/10 gal	
Interior and exterior wall surfaces, ceilings, eaves and roofs of dwellings made of wood, metal, bamboo, cement, brick, thatch or white-washed clay	Adult mosquitoes in subtropical and tropical regions	3/4 lb/4 gal water; apply prepared spray/ 2000 ft^2 of surface area	

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
	Poultry insect control		
Chickens, ducks, geese, gamebirds, pigeons, turkeys	On birds: chicken mite, fleas, lice, northern fowl mite	1 lb 5% dust/100 birds; 1 gal 0.5% regular spray/ 100 birds; 1-1/2 gal 4% fog spray/1000 birds	7 d before slaughter. Avoid contamination of nests, eggs, feed, water troughs. Tolerance, 5 ppm on meat and fat; 0.5 ppm interim tolerance in eggs.
	In premises: bedbugs, chicken mite, fleas	1 - 2 gal 0.5% spray/1000 ft^2	
	Fowl tick	1 - 2 gal 2% spray/1000 ft^2	
	On floor litter: bedbugs, chicken mite, fleas, lesser mealworms, lice, northern fowl mite	1 lb 5% dust/40 ft^2	
	Dust bath boxes: chicken mite, fleas, lice, northfowl mite	2-1/2 lb 5% dust/ box each 50 birds	
	Pets-insect control		
Dogs, cats	Brown dog tick, fleas	5% Sevin dust; rub in skin and apply in sleeping quarters weekly	Do not treat kittens under 4 wk
	Cutworm baits containing 5% carbaryl		
Cucumbers,* melons,* squash*	Armyworms, crickets, cutworms, darkling ground beetles, grasshoppers, sowbugs	20 lb 5% bait	No time limit.
		30 lb 5% bait	No time limit on alfalfa, peas; 7 d before harvest or grazing of cotton.

Appendix 1 (cont.)

Crops	Insects controlled	Amount to use (active carbaryl/ acre)	Limitations
		Cutworm baits containing 5% carbaryl (cont.)	
Vegetable* and field crops* (beans, carrots, corn forage, sweet corn, eggplant, okra, pepper, potato, tomato)		40 lb 5% bait	No time limit.
Asparagus,* strawberries		40 lb 5% bait	1 d before harvest.
Root crops,* leafy vegetables* (broccoli, brussels sprouts, cabbage, cauliflower, head lettuce, garden beet roots, horseradish, parsnip radish, rutabaga, turnip)		40 lb 5% bait	3 d before harvest.
Root crops,* leafy vegetables* (sugar beet, collards, endive, garden beet tops, kale, leaf lettuce, parsley, spinach, swiss chard, turnip tops)		40 lb 5% bait	14 d before harvest.

* When label directions are followed, forage, vines, hay, and citrus pulp may be fed to meat and dairy animals.

Appendix 2

SUMMARY OF EPA-REGISTERED LABELS FOR PRODUCTS CONTAINING CARBARYL

Type and total number of formulations

	Total number formulations	Home garden, orchard	Vegetable	Forage, field crops	Cotton	Tobacco	Peanuts	Fruit	Turf	Poultry	Cats, dogs	Manufacturing use only
Aerosol	19	19	–	–	–	–	–	–	–	–	–	–
Dust	575	100	97	114	56	34	66	11	1	9	47	40
EC	3	1	1	–	–	–	–	–	–	–	–	–
Suspension (flowable)	22	13	–	2	1	1	–	1	2	1	1	2
Granular	31	6	2	5	–	–	–	–	17	–	–	1
WP	69	28	1	11	–	1	–	4	5	1	14	4
Bait	10	1	5	4	–	–	–	–	–	–	–	–
Spray	58	16	1	–	–	–	–	7	1	2	27	4
Lawn food	4	–	–	–	–	–	–	–	–	–	–	–

Number of products containing carbaryl only and carbaryl combined with other pesticides

	Carbaryl only	Carbaryl & pesticide
Home garden, orchard	131	129
Field, forage	73	66
Vegetables	28	57
Cotton	36	20
Tobacco	10	27
Peanuts	2	65
Fruit	5	17
Turf	26	7
Poultry	7	5
Manufacturing use only	14	45
Subtotal	332	438
Total	770	

Pesticides combined with Carbaryl

Allethrin	Lindane
BHC	Malathion
Captan	Metaldehyde
Carbophenothion	Metasystox-R®
Chlordane	Methoxychlor
Copper	Monuron
DDT	Naled
Diphenamid	Parathion
Dithane®	Pyrethrins
Endosulfan	Rotenone
Ethion	Sulfur
Fenac	Thiram
Ferbam	Terraclor®
Folpet	Toxaphene
Hexachlorophene	Zinc
Kelthane	Zineb

Products most commonly combined with Carbaryl

Sulfur	Zineb
Pyrethrins	Captan
Malathion	Parathion
Copper	Folpet
Dichlorophen	Maneb

A[redacted]ndix 2 (cont.)

Pesticides most commonly combined with Carbaryl by major crop

Home garden, orchard	Vegetable, field, forage	Peanuts	Fruit
Pyrethrins (synergized with piperonyl butoxide)	Sulfur	Sulfur	Captan
Dichlorophen	Zineb	Copper	Malathion
Malathion	Copper	Zinc	Sulfur
Folpet	Parathion		Ethion
Captan	Maneb		

Cotton	Tobacco	Turf
Sulfur	Parathion	Zinc
Parathion	Zineb	Manganese
Malathion	Malathion	Folpet
Zineb	Naled	
Naled	Endosulfon	

US registration of carbaryl products by end use

I. Agricultural uses

Field crops		233
Cotton	101	
Tobacco	50	
Peanuts	82	
Forage, grain, feed crops		171
Fruit, nut crops		125
Pasture, rangeland		88
Poultry, game birds		41
Vegetable crops		258
Total		916

II. Nonagricultural uses

Home orchard, vegetable garden	17
Pet care	122
Forest, shade trees, flowers, ornamentals	147
Turf	95
PCO (use by licensed pest control operators)	5
Other (wasps, hornets, sowbugs, cutworms)	5
Total	391