parameter (z_0) of 1 cm was assumed in all calculations.

The diffusion equations were solved for two extreme boundary conditions: (i) vanishing daughter concentrations near the ground (*17*); and (ii) a vanishing concentration gradient near the ground, corresponding to a complete reflection of the aerosol-bound daughter products at the surface.

The vertical distribution of the radon isotopes and of their decay products, as calculated numerically for the *L* profile, is shown in Fig. 1. The boundary conditions have a spectacular effect on the near-surface concentration of the short-lived nuclides in the thoron series. Measurement of the disequilibrium between these daughter products seems to be an excellent tool for probing conditions at the interface. The calculated values of the $Pb^{212}:Bi^{212}$ ratios for the different conditions described above appear in Fig. 2a. For the first boundary condition [that is, $(c_i)_{z=0}=0$], this calculated ratio is greater than 2 up to a height of about 10 m. At our sampling height of 8 m, this ratio is 2.1 for all three vertical-diffusion conditions L, L_1, and L_2. However, the measured activity ratios never approached such a high value (except during rain), averaging 1.38; this value is very close to that predicted for the height of 8 m by the model for the *L* profile with complete reflection at the boundary.

Although the true wind-speed profiles were not determined during these preliminary experiments, the measured activity ratios of the daughter products of Rn^{222} gave values consistent with the assumed diffusion conditions. The experimental results thus seem to indicate that during fair weather the transport of the natural aerosol to the surface is considerably hindered. Probably there is a "Brownian barrier" through which molecular diffusion is the dominant mode of transport; such a barrier then effectively limits the removal of aerosol particles whose rate of diffusion is very low. These findings agree with recent results (*18*) on the rate of deposition of Aitken nuclei on rough surfaces. This technique could be used to measure the particle flux into the sea; the very low radioactivities encountered in marine atmosphere may, however, limit its usefulness to areas near the coast.

Figure 2b shows an example of the great disequilibrium between the thoron daughter products that results from continuous scavenging by rain throughout the air column; during rainy periods, however, assumption of a steady-state exhalation of Rn^{220} becomes extremely doubtful and must be verified in every instance.

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6. In principle the β-α coincidence technique of Fontan *et al.* [*Tellus* **18**, 623 (1966)] also could be used for such measurements, but with less sensitivity.
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8. Of 5 g of terphenyl and 0.38 g of *p*-bis-[2-(5-phenyloxazole)]-benzene in 1 liter of toluene.
9. The counting efficiency of the α and β disintegrations is 98 percent. However, only 76 percent of the disintegrations of all $(Bi\text{-}Po)^{212}$ pairs are expected to occur during the time interval between 0.1 and 1.5 μsec. The overall counting efficiency of Bi^{212} by our method is 49.3 percent because of the branching in the Bi^{212} decay scheme.
10. The particular gate-open time of the fast-coincidence channel was chosen so as to minimize the standard counting error of Po^{212} in the presence of such a background. Specifically the value of τ_g' that minimizes the expression,
$$\frac{\sigma(c')}{c'} = \{c_4'[1\text{-exp}\,(\lambda_4'\tau_g')] + c_4[1\text{-exp}\,(-\lambda_4\tau_g')]\}^{1/2}/c_4'[1\text{-exp}\,(-\lambda_4\tau_g')]$$
was computed for a typical case of $c_4' = c_4/30$, c_4 and c_4' being the mean count rates of Po^{214} and Po^{212}, respectively, and λ_4 and λ_4' being their radioactivity-decay constants.
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DDT Residues and Declining Reproduction in the Bermuda Petrel

Abstract. *Residues of DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane] averaging 6.44 parts per million in eggs and chicks of the carnivorous Bermuda petrel indicate widespread contamination of an oceanic food chain that is remote from applications of DDT. Reproduction by the petrel has declined during the last 10 years at the annual rate of 3.25 percent; if the decline continues, reproduction will fail completely by 1978. Concentrations of residues are similar to those in certain terrestrial carnivorous birds whose productivity is also declining. Various considerations implicate contamination by insecticides as a probable major cause of the decline.*

Many oceanic birds nested on Bermuda in 1609 when the first settlers arrived, the most abundant apparently being the Bermuda petrel, *Pterodroma cahow*. Within 20 years man and his imported mammals virtually exterminated this species; for nearly 300 years it was considered extinct. Several records of specimens since 1900 were followed in 1951 by discovery of a small breeding colony (*1*), and in 1967 22 pairs nested on a few rocky islets off Bermuda. With a total population of about 100 the petrel is among the world's rarest birds.

A wholly pelagic species, *P. cahow* visits land only to breed, breeds only on Bermuda, and arrives and departs only at night. The single egg is laid underground at the end of a long burrow. When not in the burrow the bird feeds far at sea, mainly on cephalopods; when not breeding it probably ranges over much of the North Atlantic (*1*).

Reproduction by *P. cahow* has declined recently. The data since 1958 (Table 1) show an annual rate of decline of 3.25 ± 1.05 percent; the negative slope of a weighted regression is significant (*P*, .015; *F* test). If this linear decline continues, reproduction will fail completely by 1978, with extinction of

Table 1. Reproductive success of the Bermuda petrel between 1958 and 1967: percentages of established adult pairs under observation whose chicks survived 2 weeks after hatching. Numbers of pairs of unknown success (not included in calculations) appear in parentheses. Data from 1961–7 are believed to represent the total breeding population; earlier, not all burrows had been discovered. The decline in reproductive success follows the linear relation $y = a + bx$ (y, reproductive success; a, a constant; b, annual percentage decline in success; x, year). The regression, weighted by numbers of pairs: $y = 251.9 - 3.25x$.

Year	Pairs	Chicks	Success (%)
1958	6 (1)	4	66.7
1959	5 (2)	2	40.0
1960	13 (3)	6	46.2
1961	18 (1)	12	66.7
1962	19	9	47.4
1963	17 (1)	9	52.9
1964	17 (1)	8	47.1
1965	20	8	40.0
1966	21	6	28.6
1967	22	8	36.4

the species. Many recent reports have correlated diminished reproduction by certain carnivorous birds with contamination by chlorinated hydrocarbon insecticides (*2–7*). As the terminal member of a pelagic food chain, presumably feeding over much of the North Atlantic, the petrel may be expected to concentrate by many orders of magnitude any stable, lipid soluble chemicals, such as chlorinated hydrocarbon insecticides, present in lower trophic levels (*2, 3, 8*). In fact it should serve as an ideal environmental monitor for detection of insecticide contamination as a general oceanic pollutant, rather than contamination resulting directly from treatment of a specific land area (*9*). When we analyzed several specimens of *P. cahow* for chlorinated hydrocarbon insecticides, all samples contained DDT residues (*10*).

During March 1967 five unhatched eggs and dead chicks were collected from unsuccessful petrel burrows and stored frozen. The small size of the population precluded the sampling of living birds. Samples were analyzed for DDT, *o,p*-DDT, DDE, DDD, dieldrin, and endrin by electron-capture gas chromatography; the results are summarized in Table 2. No *o,p*-DDT, dieldrin, or endrin was detected, but an independent laboratory detected a trace of dieldrin.

Certain identifications were confirmed by thin-layer chromatography (*11*) as follows: After Florisil cleanup (*12*), the unknown sample was spotted on a thin-layer plate with 1-μg authentic standard samples on both sides. After development, the unknown was masked by a strip of paper, and the standards were sprayed with chromogenic reagent (*11*). When spots were visible following exposure to ultraviolet light, the masking was removed, horizontal lines were drawn between the standard spots in order to locate corresponding compounds in the unknown, and these areas were scraped from the plate and extracted with a few drops of a mixture of hexane and acetone (9:1 by volume). Injection into the gas chromatograph confirmed the presence of DDT, DDE, and DDD by showing the appropriate single peaks for these compounds. This confirmation procedure was employed because the electron-capture detector is more sensitive than the chromogenic spray reagent in detecting minute amounts of these materials.

Coincidental with diminishing reproduction by the Bermuda petrel is the presence of DDT residues averaging 6.44 parts per million (ppm) in its eggs and chicks. In itself this coincidence does not establish a causal relation, but these findings must be evaluated in the light of other studies. Whereas a healthy osprey *(Pandion haliaetus)* population produces 2.2 to 2.5 young per nest, a Maryland colony containing DDT residues of 3.0 ppm in its eggs yielded 1.1 young per nest, and a Connecticut colony containing 5.1 ppm produced only 0.5 young per nest; the Connecticut population has declined 30 percent annually for the last 9 years (*4*). In New Brunswick, breeding success of American woodcocks *(Philohela minor)* showed a statistically significant inverse correlation with the quantity of DDT applied to its habitat in a given year. Furthermore, during 1962 and 1963, birds from unsprayed Nova Scotia showed breeding success nearly twice as great as did those from sprayed New Brunswick, where woodcock eggs averaged 1.3 ppm of DDT residues during those years (*5*).

In Britain five species of raptors, including the peregrine falcon *(Falco peregrinus)* and golden eagle *(Aquila chrysaetos)*, carried residues of chlorinated hydrocarbon insecticides in their eggs, averaging 5.2 ppm; each of these species has shown a decline in reproduction and total population during recent years. By comparison, residues in the eggs of five species of corvids averaged 0.9 ppm, and breeding success and numbers have been maintained (*6*). It is noteworthy that during the last decade the peregrine has become extinct as a breeding bird in the eastern United States (*13*). Residues in bald eagle *(Haliaeetus leucocephalus)* eggs averaged 10.6 ppm, and this species also shows declining reproduction and population (*7*). Lake Michigan herring gulls (*Larus argentatus*), exhibiting very low reproductive success, averaged 120 to 227 ppm of DDT residues in the eggs (*3*), the suggestion being that susceptibility varies widely between species.

In most of the above instances, including *P. cahow,* reduced success in breeding resulted primarily from mortality of chicks before and shortly after hatching. Bobwhites *(Colinus virginianus)* and pheasants *(Phasianus colchicus),* fed sublethal diets of DDT or dieldrin, gave similar results (*14*); a mechanism explaining chick mortality from dieldrin poisoning during the several days after hatching has been presented (*15*).

From studies of these birds and other avian carnivores a very widespread, perhaps worldwide, decline among many species of carnivorous birds is apparent. The pattern of decline is characterized by reduced success in reproduction correlated with the presence of residues of chlorinated hydrocarbon insecticides—

Table 2. Residues of DDT (*10*) in parts per million (wet weight) in eggs and chicks of the Bermuda petrel, collected in Bermuda in March 1967; proportions of DDT, DDE, and DDD are expressed as percentages of the total.

Sample	Residues (ppm)	Percentages		
		DDT	DDE	DDD
A, egg †	11.02	37*	58*	5*
A, egg † § ‖	10.71	34*	62*	4*
B, addled egg †	3.61	15	65	20
C, chick in egg ‡	4.52	33	64	3
D, chick in egg ‡	6.08	33	62	5
D, chick brain ‡ ‖	0.57	30	54	16
E, chick, 1 to 2 days old	6.97	29*	66*	5*
			Averages	
	6.44	31	62	7

* Identity confirmed by thin-layer chromatography (*11*). † Egg showed no sign of development. ‡ Fully developed chick died while hatching. § Analysis 5 months later by Wisconsin Alumni Research Foundation, which also detected dieldrin at 0.02 ppm. ‖ Not included in averages.

primarily DDT. Our data for the Bermuda petrel are entirely consistent with this pattern.

Observations of aggressive behavior, increased nervousness, chipped eggshells, increased egg-breakage, and egg-eating by parent birds of several of the above species (*3*, *6*, *13*) suggest symptoms of a hormonal disturbance or a calcium deficiency, or both. Moreover, DDT has been shown to delay ovulation and inhibit gonadal development in birds, probably by means of a hormonal mechanism, and low dosages of DDT or dieldrin in the diet of pigeons increased metabolism of steroid sex hormones by hepatic enzymes (*16*). A direct relation between DDT and calcium function has also been demonstrated, and these endocrine and calcium mechanisms could well be interrelated; DDT interferes with normal calcification of the arthropod nerve axon, causing hyperactivity of the nerve and producing symptoms similar to those resulting from calcium deficiency (*17*). Dogs treated with calcium gluconate are very resistant to DDT poisoning (*18*); female birds are more resistant than males (*19*), perhaps because of the calcium-mobilizing action of estrogenic hormones.

Of major importance, then, was the discovery that a significant ($P<.001$) and widespread decrease in calcium content of eggshells occurred between 1946 and 1950 in the peregrine falcon, golden eagle, and sparrowhawk, *Accipiter nisus* (*20*). This decrease correlates with the widespread introduction of DDT into the environment during those years, and further correlates with the onset of reduced reproduction and of the described symptoms of calcium deficiency. These multiple correlations indicate a high probability that the decline in reproduction of most or all of these birds, including *P. cahow*, is causally related to their contamination by DDT residues.

Other potential causes of the observed decline for the Bermuda petrel appear unlikely. The bird has been strictly protected and isolated since 1957, and it seems that human disturbance can be discounted. In such a small population, inbreeding could become important, but hatching failure is now consistent in pairs having earlier records of successful breeding, and deformed chicks are never observed. Furthermore, the effects of inbreeding would not be expected to increase at a time when the total population, and probably the gene pool, is still increasing. The population increase results from artificial protection since 1957 from other limiting factors, especially competition for nest sites with tropic birds (*21*).

It is very unlikely that the observed DDT residues in *P. cahow* were accumulated from Bermuda: the breeding grounds are confined to a few tiny, isolated, and uninhabited islets never treated with DDT, and the bird's feeding habits are wholly pelagic. Thus the presence of DDT residues in all samples can lead only to the conclusion that this oceanic food chain, presumably including the plankton, is contaminated. This conclusion is supported by reported analyses showing residues in related seabirds including two species of shearwaters from the Pacific (*22*); seabird eggs (*9*, *22*); freshwater, estuarine, and coastal plankton (*2*, *8*, *23*); plankton-feeding organisms (*2*, *8*, *9*, *22*, *23*); and other marine animals from various parts of the world (*8*, *22*). These toxic chemicals are apparently very widespread within oceanic organisms (*8*, *22*), and the evidence suggests that their ecological effects are important.

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Larval-Pupal Transformation: Control by Juvenile Hormone

Abstract. *Purified extract of juvenile hormone from the cecropia silkmoth prevents the transformation of larva to pupa in* Galleria. *The injected extract acts independently of the insect's own corpora allata. A morphological response occurs only when juvenile hormone remains in the body from the time of injection until the end of the period in which any cells are still sensitive to the hormone. The extent of the effect depends upon the age at which the larva receives the injection. The maximum effect (perfect superlarva) is produced when the extract is provided not later than in the first third of the instar.*

Juvenile hormone (JH), which is secreted by the corpora allata, controls differentiation during insect development (*1*). The titer of the hormone is high during larval stages and low during metamorphosis. Metamorphosis can be totally or partially prevented by implanting extra corpora allata; this results in the development of giant, but morphologically perfect, larvae (superlarvae) or intermediate forms having both larval and adult characteristics.