SCIENCE AND SOCIAL RESPONSIBILITY: A CASE HISTORY

Arthur W. Galston
Yale University
New Haven, Connecticut 06520

The only way I can approach this problem is at the personal level. I used to think that one could avoid involvement in the antisocial consequences of science simply by not working on any project that might be turned to evil or destructive ends. I have learned that things are not all that simple, and that almost any scientific finding can be perverted or twisted under appropriate societal pressures. In my view, the only recourse for a scientist concerned about the social consequences of his work is to remain involved with it to the end. His responsibility to society does not cease with publication of a definitive scientific paper. Rather, if his discovery is translated into some impact on the world outside the laboratory, he will, in most instances, want to follow through to see that it is used for constructive rather than anti-human purposes. But I know of no moral imperative to invoke here; some individuals feel moved to respond to the social challenge, while others shun such activity, either through timidity, aversion to political argumentation or a feeling that others, better trained, should handle social problems. One approach to more responsible attitudes would be, of course, the substitution of group wisdom for the decision of the individual scientist. Although scientific societies have in the past avoided involvement in social problems, I believe the time has passed when such a *laissez-faire* attitude is acceptable. Science is now too potent in transforming our world to permit random fallout of the social consequences of scientific discoveries. Some scrutiny and regulation are required, and I believe that scientists must play an important role in any bodies devised to carry out such tasks.

As a graduate student at the University of Illinois, I was fortunate enough to discover that a chemical known to be active in inhibiting certain aspects of vegetative growth in plants could be used to increase vastly the number of floral buds and ultimately the number of harvestable pods produced on soybean plants that were getting ready to flower. At somewhat higher concentrations, the compound could produce deleterious effects on the plant; among such effects were premature shedding (abscission) of leaves and buds. These observations were recorded in my Ph.D. thesis, completed in 1943, just before I went into military service for several years.

After I emerged from service, I discovered two unexpected sequels to the story, one encouraging and one somewhat disturbing in its implications. On the positive side, the International Minerals and Chemical Company had developed the compound (2,3,5-triiodobenzoic acid, or TIBA) into a useful agricultural tool. In certain areas, especially the northerly reaches of the soybean-growing zone, it was sold in large quantities to increase the yield of soybean pods per acre. Under the best of conditions, it increased yield 30%, but because its effects were somewhat erratic and dependent on climatic variables, its use has diminished sharply in recent years as better chemicals were developed. Nonetheless, during the years of its active use, it did result in greater productivity for many farmers, a fact in which I took some satisfaction (although the financial rewards went not to me, of course, but to the company that patented, developed, and exploited the compound).

Several years later, I became aware of the fact that workers at the Fort Detrick laboratory of the U. S. Army Chemical Corps had made extensive studies

of the abscission promoting properties of TIBA used at higher concentrations. They had used it as one of their model compounds, had synthesized many chemical analogs, and had used the structure-activity relationships of such compounds to devise other more effective defoliants. This venture of the Chemical Corps into chemicals that regulate plant growth had begun during World War II; we foresaw the military advantages to be gained by defoliating densely overgrown jungle areas in the Pacific that had been occupied and fortified by Japanese invaders. The compounds were not really ready for military use in World War II; they were ready for use but not approved by the President for use during the Korean War. By the time of massive U.S. involvement in the Indochina war, however, the stage was

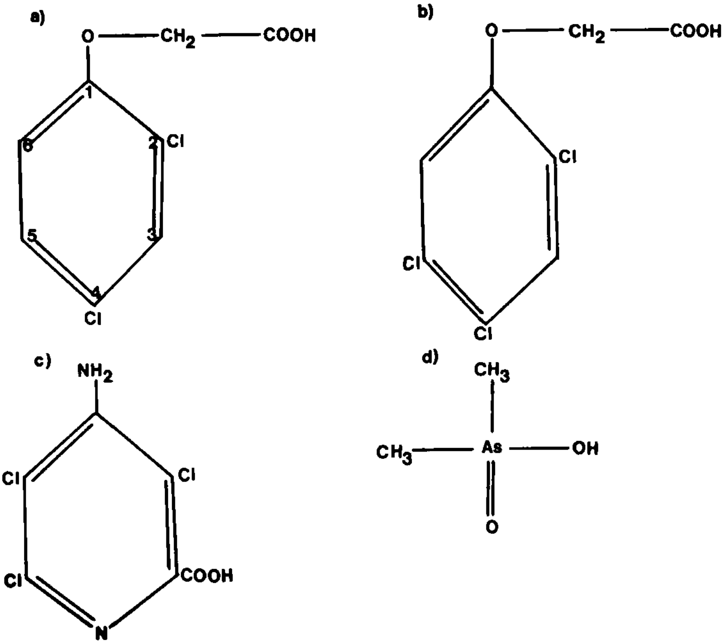

FIGURE 1. a) 2,4-D (2,4-dichlorophenoxyacetic acid); b) 2,4,5-T (2,4,5-trichlorophenoxyacetic acid); c) Picloram; d) Cacodylic acid.

TABLE 1

HERBICIDES USED IN VIETNAM

Agent*	Active Ingredients	Amount used per acre (lbs.)	Major Target
Orange	2,4-D (n-butyl ester)	12	
	2,4,5-T (n-butyl ester)	13	Forest vegetation
White	2,4-D (triisopropylamine salt)	6	
	Picloram (triisopropylamine salt)	1.5	Forest vegetation
Blue	Cacodylic acid and its sodium salt	9	Rice and other food crops

* Names correspond to the color of the coded stripe around the canister in which the agent is packed.

TABLE 2

ESTIMATED AREAS TREATED WITH HERBICIDES IN VIETNAM
(ACRES SPRAYED PER YEAR)

Year	Defoliation	Crop Destruction	Total
1962	4,940	741	5,681
1963	24,700	247	24,947
1964	83,486	10,374	93,860
1965	155,610	65,949	221,559
1966	741,247	103,987	845,234
1967	1,486,446	221,312	1,707,758
1968	1,526,333	170,000	1,696,333
1969	1,404,333	115,233	1,519,567
Total	5,427,096	687,843	6,114,939

FIGURE 2. A forest in S. Vietnam sprayed with agent Orange by air. Note the tree killing in the sprayed swaths (gray). The intervening dark (green) areas were inadvertently not sprayed due to failure of one spray nozzle to function.

set for massive airborne defoliation and crop destruction campaigns.

The compounds used extensively in Vietnam are shown in FIGURE 1. The formulation, dose rate, and major uses are shown in TABLE 1. The extent of the use of such compounds is shown in TABLE 2. It should be noted that well in excess of six million acres have been sprayed with herbicidal compounds; this is roughly equivalent to the area of the state of Massachusetts. Most of the area sprayed is hardwood forest that covers approximately 60% of all of South Vietnam. Some areas have been sprayed only once; forest trees so treated put forth a new flush of leaves after some time and generally recover well. A second spraying soon afterward kills about 40% of the trees, and a third spraying can produce complete kill

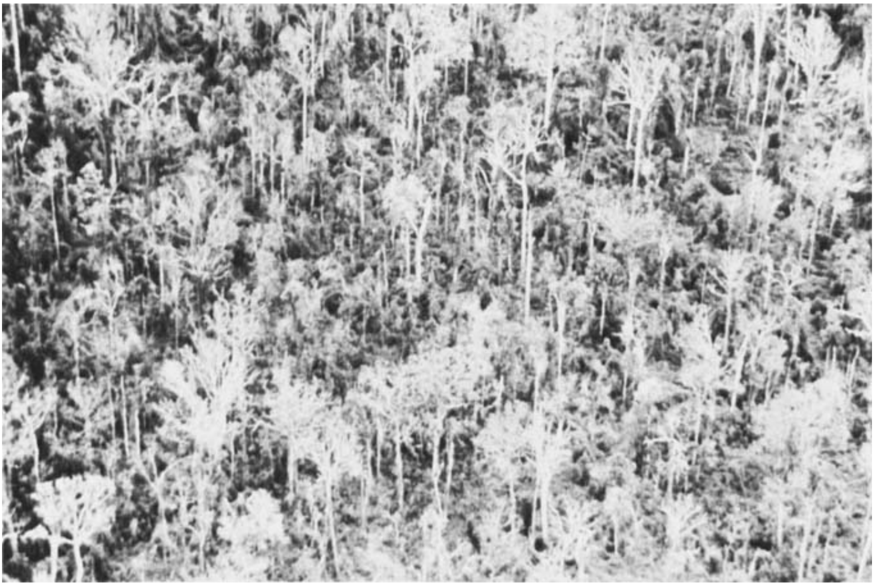

FIGURE 3. A closer view of damaged areas of Figure 2. Note the white, defoliated, probably killed large trees and the luxurious growth of understory bamboo.

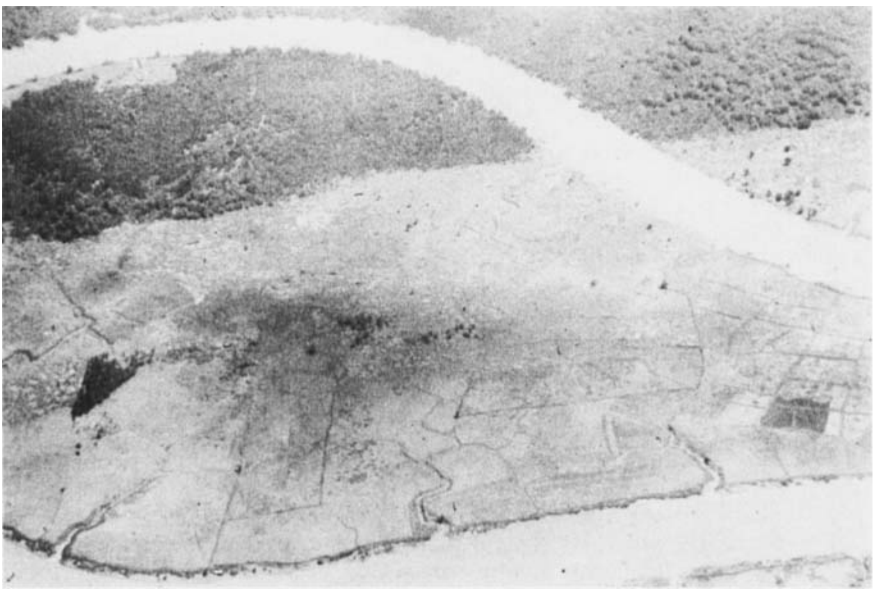

FIGURE 4. A coastal mangrove area sprayed with agent Orange. Note the extensive kill where the spray has fallen, the occasional survivor, and the sharp demarcation with the unsprayed, healthy mangroves above.

FIGURE 5. A closer look at healthy and sprayed mangroves. Note also the numerous bomb craters.

FIGURE 6. Killed mangrove that has been picked over for firewood by natives.

(FIGURES 2, 3). By contrast, the complex mangrove community lining the estuaries is virtually completely killed by a single spray with agent Orange and regeneration takes several decades, at least (FIGURES 4, 5, 6). The killed rice crops are mostly in isolated, remote upland regions, supposedly controlled by guerrilla forces of the National Liberation Front (FIGURE 7).

What are the consequences of the widespread aerial dispersal of more than 100 million pounds of assorted herbicidal chemicals? In the forest, defoliation exposes previously hidden trails (FIGURE 8), but this tactical gain is partially offset by the fact that bamboo, a sparsely growing understory weed, spreads like wildfire once the upperstory leaves are removed, giving it access to brighter light. The dense bamboo stands are favorable for some kinds of guerrilla activity and because bamboo cannot be killed by further herbicidal sprays, the problem is transformed, rather than abolished. Another fringe debit is the killing of nearby useful plants such as rubber plantations (FIGURES 9, 10) or papaya (FIGURE 11) through drifting of the fine droplets of the aerial spray.

The complete killing of the mangroves is certain to have a major effect on the ecology of the estuarine zone. Many important food fish and crustaceans spend a part of their life cycle in this zone, and there is very likely to be some adverse effect on the harvest of such creatures from the sea. In view of the importance

FIGURE 7. Upland rice sprayed and killed with cacodylic acid (gray areas). Much of this rice is probably raised by Montagnard tribesmen.

FIGURE 8. A trail through the forest made more visible by repeated defoliation operations.

FIGURE 9. A healthy stand of rubber trees.

of fish in the Vietnamese diet, both as such and in the form of the fermented *nuoc mam* sauce into which many items are dipped, this loss could be serious. As for the killing of the rice, it is now fairly clear that this food belonged not to guerrillas, but to Montagnard tribesmen who practice slash-and-burn agriculture in the hills. Deprived of their food, these people have migrated to "relocation centers" in the lowlands, their usual culture having been completely disrupted.

The ecological and social effects of our massive use of herbicides have not been properly evaluated, and it is doubtful that they ever will be. Too little is known about the undisturbed ecology of South Vietnam to permit an accurate "before and after" treatment comparison. Furthermore, despite decades of warfare, the South Vietnamese countryside is mainly in the hands of guerrillas, and ecological data are gathered either from the air, which is unsatisfactory, or hurriedly and furtively from selected areas on the ground. Among the probable ecological consequences, however, are partial or complete destruction of much of the potentially exportable timber of the forests, massive invasion by bamboo and other weeds, nutrient dumping into streams as a result of massive vegetational kills, possible induration of denuded lateritic soils, and prolonged toxification of soils, especially those treated with the very stable, long-lived picloram.

There are also probable public health sequels to our massive use of the herbicide 2,4,5-T, many samples of which are capable of producing deformed embryos in pregnant laboratory animals at doses of 30–100 mg/kg body weight. It is not yet entirely clear whether this teratogenic action is due to the 2,4,5-T itself or to impurities of the dioxin type (FIGURE 12) arising from 2,4,5-trichlorophenol used in the synthesis, but much of the 2,4,5-T used in Vietnam was heavily contaminated with dioxin impurities. I calculated that following a usual 25 lbs/acre spray of agent Orange and a 1″ rainfall, drinking water would contain enough terato-

FIGURE 10. Defoliated rubber trees, probably killed.

FIGURE 11. A papaya plant whose leaves have been killed by defoliant spray. The fruit was produced before the spray; it is not known whether the tree can recover.

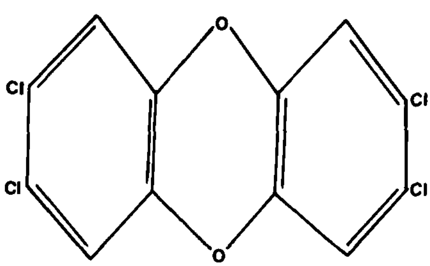

FIGURE 12. Dioxin (2,3,7,8-tetrachloro-p-dibenzodioxin).

genic material to cause embryonic malformations in a pregnant woman who consumed 2–3 liters per day. Whether, in fact, such increased birth abnormalities or stillbirths have occurred is still unknown, despite many attempts to gather data from hospitals. These attempts have been hindered, if not thwarted, by the uncooperative attitude of the U. S. Department of Defense and American and South Vietnamese civil authorities in Saigon.

This brief account should establish that in addition to the agricultural benefits that have flowed from our increased knowledge and use of herbicides, there has

also come a power to destroy. Our country has, for the first time in history, used this power to defoliate and kill plants, with large ecological, public health, and social consequences not yet precisely determined. As a plant physiologist involved in early work on this type of compound, I felt compelled to involve myself in continuing investigation and occasional agitation on this question.

What does international law have to say about the use of chemical weapons against plants? The Geneva Gas Protocol of June 17, 1925 states:

> Whereas the use in war of asphyxiating, poisonous or other gases, and of all analogous liquids, materials or devices, has been justly condemned by the general opinion of the civilized world; and,
>
> Whereas the prohibition of such use has been declared in Treaties to which the majority of Powers of the world are Parties; and,
>
> To the end that this prohibition shall be universally accepted as a part of International Law, binding alike the conscience and the practice of nations;
>
> Declare that the High Contracting Parties, so far as they are not already Parties to Treaties prohibiting such use, accept this prohibition, agree to extend this prohibition to the use of bacteriological methods of warfare and agree to be bound as between themselves according to the terms of this declaration.

Although the U.S. wrote this Protocol, we have never ratified it, and so perhaps cannot be held to account for violating its provisions. Yet we have approved the United Nations Resolution of December 5, 1966, which says:

> The General Assembly,
>
> Guided by the principles of the Charter of the United Nations and of international law,
>
> Considering that weapons of mass destruction constitute a danger to all mankind and are incompatible with the accepted norms of civilization,
>
> Affirming that the strict observance of the rules of international law on the conduct of warfare is in the interest of maintaining these standards of civilization,
>
> Recalling that the Geneva Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases and of Bacteriological Methods of Warfare of 17 June 1925 has been signed and adopted and is recognized by many States.
>
> Noting that the Conference of the Eighteen-Nation Committee on Disarmament has the task of seeking an agreement on the cessation of the development and production of chemical and bacteriological weapons and other weapons of mass destruction, and on the elimination of all such weapons from national arsenals, as called for in the draft proposals on general and complete disarmament now before the Conference,
>
> 1. Calls for strict observance by all States of the principles and objectives of the Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare, signed at Geneva on 17 June 1925, and condemns all actions contrary to those objectives;
>
> 2. Invites all states to accede to the Geneva Protocol of 17 June 1925.

Clearly, then, our government is bound not to use "asphyxiating, poisonous or other gases" or "analogous liquids, materials or devices" in war. Yet we have used in Vietnam more than 14 million pounds of so called "riot-control gas," the

so called CS (o-chlorobenzalmalononitrile) in addition to the 100 million pounds of assorted herbicides. We have taken the position that:

> The Geneva Protocol of 1925 prohibits the use in war of asphyxiating and poisonous gas, and other similar gases and liquids with equally deadly effect. It was framed to meet the horrors of poison gas warfare in the first World War, and was intended to reduce suffering by prohibiting the use of poisonous gases, such as mustard gas and phosgene. It does not apply to all gases. It would be unreasonable to contend that any rule of international law prohibits the use in combat against an enemy for humanitarian purposes of agents that governments around the world commonly used to control riots by their own people. Similarly, the protocol does not apply to herbicides, which involve the same chemicals and have the same effects as those used domestically in the United States, Soviet Union, and many other countries to control weeds and other unwanted vegetation.

President Nixon, in calling upon the Senate to ratify the Protocol last year, made a similar distinction. His desire to exclude CS and herbicides from the ban on chemical weapons led the Senate Committee on Foreign Affairs to decline to recommend ratification, and the U. S. remains the major power yet to ratify.

At the annual meeting of the American Society of Plant Physiologists in 1966, I proposed a letter of inquiry to President Johnson, but the Executive Committee of that Society voted the proposal down and would not even bring it before the business meeting. As a past president of the Society (1962), I was somewhat indignant at this treatment as well as disappointed over what I interpreted as the group's lack of social conscience. My indignation grew when I learned later that the Society's President in 1966, who guided the Executive Committee in its action, had held a research contract on defoliation from the Fort Detrick laboratories. I believe he should have disqualified himself from the deliberations in which he had an obvious conflict of interest, but he failed to do so. Despite the failure of the Society to act, the letter was signed by about a dozen colleagues, and sent to President Johnson. It said in part:

> The undersigned plant physiologists wish to make known to you their serious misgivings concerning the alleged use of chemical herbicides for the destruction of food crops and for defoliation operations in Vietnam. The use of such agents by United States forces was reported in the New York Times of December 21, 1965 and has never been denied by the Administration or by the leaders of our military operations. Our deliberations and our statements below are based on the assumption that this published report is true.
>
> We would assert in the first place that even the most specific herbicides known do not affect only a single type of plant. Thus, a chemical designed to defoliate trees might also be expected to have some side effects on other plants, including food crops. Secondly, the persistence of some of these chemicals in soil is such that productive agriculture may be prevented for some years. Thirdly, the toxicology of some herbicides is such that one cannot assert that there are no deleterious effects on human and domestic animal populations. It is safe to say that massive use of chemical herbicides can upset the ecology of an entire region, and in the absence of more definite information, such an upset could be catastrophic.
>
> Even if we assume that our military leaders have selected reasonably specific anti-rice herbicides, nontoxic to humans or to domestic animals for use in Vietnam, we must still be concerned with the effects

> of large-scale food deprivation on a mixed civilian-military population. As Prof. Jean Mayer of the Harvard School of Public Health pointed out in a letter to Science on April 15, 1966, the first and major victims of any food shortage or famine, caused by whatever agent, are inevitably children, especially those under five. This results mainly from their special nutritional needs and vulnerability to stress. Thus, the effect of our use of chemical herbicides may be to starve children and others in the population whom we least wish to harm.

We received the following reply, dated September 28, 1966 from Under-secretary of State Dixon Donnelley:

> Chemical herbicides are being used in Vietnam to clear jungle growth and to reduce the hazards of ambush by Viet Cong forces. These chemicals are used extensively in most countries by both the Free World and the Communist Bloc for selective control of undesirable vegetation. They are not harmful to people, animals, soil or water.
>
> The elimination of leaves and brush in jungle areas enables our military forces, both on the ground and in the air, to spot the Viet Cong and to follow their movements, and to also avoid ambushes.
>
> Destruction of food crops is undertaken only in remote and thinly populated areas under Viet Cong control, and where significant denial of food supplies can be effected by such destruction. This is done because in the Viet Cong redoubt areas food is as important to the Viet Cong as weapons. Civilians or non-combatants are warned of such action in advance. They are asked to leave the area and are provided food and good treatment by the Government of Viet-Nam in resettlement areas.

This open admission by our government of its chemical warfare policies in Vietnam led to renewed confrontation between scientists and government, and has led ultimately to a drastic phasing down of the use of chemical herbicides in Vietnam. Fixed wing aircraft are no longer being used in these operations, action being limited to helicopter and ground-based sprayings around encampments and along roads. In this struggle, a few key individuals have exerted great and effective pressure and only a handful of scientific organizations have been officially involved. The largest of these, the American Association for the Advancement of Science moved slowly, at first with inquiries of the Department of Defense, later with the funding of $80,000 for an investigation by a Herbicide Assessment Commission. It is regrettable that this body has not yet issued a final report, although unofficial summaries of its findings were presented at the AAAS meetings in Chicago in December 1970. A study funded by the Department of Defense is now being undertaken by the National Academy of Sciences. By the time it is ready to make its report, whatever ecological, medical, and social damage has been wrought by herbicides will be all the more irreversible. There will be little we can do to make retribution to the Vietnamese whose land has been desecrated; at the very most, one can use this experience to prevent a resumption of similar operations elsewhere in the future.

What are the morals of this story for the scientist interested in insuring useful social applications of his findings? First, it would appear that no discovery is immune from the danger of misuse. This means that every scientist must be on the alert to the possibility that his discoveries, however ethically neutral or benign they may seem, can be perverted to antisocial ends. Second, scientific societies must somehow be made to realize and act on their social responsibilities. Those

individual scientists who recognize the importance of such actions must be prepared for long, frequently tedious educational and political campaigns in societies that determinedly seek to avoid any social entanglements. Finally, the individual must be prepared to take what action he can, either alone or with a few like-minded colleagues, to ensure that the perversion of science does not go unchallenged. Such individuals should be encouraged by the successful arousal campaigns mounted by crusaders like Ralph Nader, Barry Commoner, Paul Ehrlich, and the handful of outspoken opponents of chemical warfare in Vietnam.

Acknowledgment

I am indebted to Prof. Arthur H. Westing, Chairman, Department of Biology, Windham College, Putney, Vermont for furnishing FIGURES 2–11.