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**ASSESSMENT OF THE ECOLOGICAL
CONSEQUENCES OF HERBICIDE USE
ALONG TRANSMISSION LINE RIGHTS-OF-WAY
AND RECOMMENDATION FOR SUCH USE**

by

John D. Buffington

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MASTER

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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Environmental Statement Project

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April 1974

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ABSTRACT

Because of the large amount of land involved, the public concern over environmental effects, and the potential for adverse effects on human health and safety, the use of herbicides to maintain transmission line rights-of-way must be regarded as a vital area for environmental assessment. Until recently, vegetation management programs presented to the U. S. Atomic Energy Commission as part of a license application emphasized the use of 2,4-D, 2,4,5-T, silvex, picloram, and dicamba. Review of the literature dealing with these herbicides leads to the conclusion that they should be regarded as hazardous substances which may be used to society's benefit for vegetation management along transmission lines so long as reasonable precautions are followed. A series of recommendations is included which, if followed, should prevent unacceptable environmental damage and hazard to human health.

1. INTRODUCTION

One of the major uses of land in this country is utility rights-of-way. Millions of acres are set aside as corridors for pipelines and cables. For overhead electrical transmission alone, more than seven million acres are presently set aside, with a potential for doubling by the year 2000 (Hammond, Metz, and Maugh; 1973). Such a large-scale enterprise inevitably brings attendant problems. Siting, construction, and maintenance all present opportunity for mismanagement of a variety of natural resources.

One of the major tools for managing vegetation along transmission line rights-of-way (ROW) is herbicides. A wide spectrum of herbicides are available to vegetation managers. They have been employed for several decades as an economically advantageous means of keeping ROW's clear. With increasing

awareness of the environmental results of man's past practices, some segments of society have raised questions concerning current societal practices in a variety of areas, including the use of herbicides.

The question of the ecological consequences of herbicide use has become embroiled in questions of human health and safety because of a number of questions raised in the scientific literature, as well as in moral issues raised by its use in warfare. Both the ecological questions and the human health and safety questions are matters of environmental concern which must be addressed by the vegetation manager.

As part of the review of the environmental consequences of licensing a nuclear power plant for operation, the management program for transmission lines, including vegetation management, is assessed by the regulatory staff. Because of the intense interest in herbicides displayed by some individuals and groups, and because the matter has been raised in licensing proceedings, this paper will examine some of the issues of interest. The scope will be limited to ROW management practices. While much of the discussion is applicable to the use of herbicides for construction of ROW's, this area will not be specifically addressed.

Federal regulation of pesticides was formerly based on the Federal Insecticide and Rodenticide Act of 1947. Late in 1972, Congress passed and the President signed the Federal Environmental Pesticide Control Act of 1972, which made a number of changes in the existing law, some to be implemented immediately, others gradually [Federal Register 38(5), 1142-1145]. Among the more important aspects of the new legislation is that the use of pesticides (including herbicides) in other than the registered manner is now a violation of law.

Problems associated with the introduction of potentially hazardous chemicals into the environment can be viewed in light of (1) the levels necessary to do damage, (2) the nature of the damage, (3) the mobility, residence, and degradation in the environment, (4) bioaccumulation, and (5) the exposure pathways including the influence of the method of application. Consideration of potential environmental hazards of herbicides

must also include assessment of their contaminants. The purpose of the present evaluation is not only to review the situation, but also to offer guidance which will help avoid unacceptable hazards.

2. VEGETATION MANAGEMENT PRACTICES

Vegetation along transmission corridors is managed to insure ease of access, to keep the lines clear, and to prevent trees or limbs from falling on the lines. Among the most common herbicides used in ROW maintenance are one or another of the five chemicals shown in Fig. 1. The phenoxy herbicides include 2,4-D (2,4-dichlorophenoxyacetic acid), 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), and silvex, or 2,4,5-TP [2-(2,4,5-trichlorophenoxy) propionic acid], all sold under a variety of trade names. These are or have been available as acids, salts, and esters. Picloram (4-amino-3,5,6-trichloropicolinic acid) is a picolinic acid derivative, more commonly known by its trade name Tordon. Dicamba (3,6-dichloro-o-anisic acid) is frequently referred to by its trade name Banvel. All of these chemicals are registered for ROW maintenance in a variety of formulations and chemical mixtures for various methods of application.

Fig. 1.

Chemical Structure of the Principal Herbicides Discussed.

There is a variety of application techniques commonly used. A basic distinction can be made between broadcast and selective treatments. Broadcast spraying, as the term indicates, covers a large area in an unselective manner. It is a common method used for rapid and cheap vegetation control, as for example along highways. Although ground-equipment is available for spraying, broadcast application from fixed-wing aircraft and helicopters is common. Since helicopters can fly lower and more slowly, and consequently can direct their spray more closely, they are preferred where aerial application is the only alternative available.

There are a variety of selective application techniques commonly employed. Some, such as foliage sprays, may also be broadcast in actual practice. Foliage application depends on wetting the leaf surface; wetting of the stem is secondary. The herbicide may be applied either by spraying or by misting. For foliage applications, a water-based spray is usually used. For stem-foliage spraying, oil is added to increase bark penetration.

A technique often used along ROW's is basal spraying. Here the bark of the trunk is sprayed to saturation from the ground to about two feet above, usually with an oil-based mixture. This technique may be used during any season. A similar technique is the dormant cane treatment; here stems and branches are soaked during the vegetation's dormant season. The term "stump treatment" designates the technique of spraying or painting an oil or water formulation on the stumps. Individual trees may be killed by injection or by frilling, which consists of making a series of cuts around the trunk, pulling the bark back, and applying the herbicide to the exposed surface. Another technique, the basal soil treatment, which can be used in either a broadcast or selective manner, is the application of pelletized herbicides such as picloram. The pellets are simply scattered on the ground around all vegetation to be killed.

A major adverse impact of the use of herbicides results from the drifting of droplets of spray to vegetation beyond the area of intended application. Consequently, wind is a major factor that must be considered in spraying. House *et al.* (1967) indicate that many commercial firms do not perform aerial application in winds over 5 mph. Another variable which must be taken into consideration at any wind speed is the size of the droplets. Figure 2 indicates the relationship of droplet size to amount of drift in a 5-mph wind. According to Akesson *et al.* (1971), a volume mean diameter of 200-300 μ appears to be the smallest droplet that can be used without incurring unnecessary drift problems. There is a variety of thickeners, etc. currently available commercially which are commonly used to help ameliorate this problem (see, for example, Laning and Holmsen, 1969). The U. S. Forest Service (1973) is limiting application to the use of ground spray equipment with a droplet size in excess of 200 μ . However, since the phenoxy's require about 75 droplets/in²

regardless of size of the droplet (Behrens, 1957), application of too large a droplet ($>800 \mu$) will necessitate a higher rate of application.

Fig. 2. Approximate Lateral Movement of Spray Particles Falling at Terminal Velocity in a 5 mph Cross Wind (from Reimer, *et al.*, 1966).

Another source of off-ROW contamination is the volatilization of the applied materials. For example, propylene glycol butyl ether, butoxy ethanol, and isooctyl esters all have low volatility, while isopropyl butyl, n-butyl, isobutyl, and ethyl esters are regarded as having high volatility (Norris *et al.*, 1972). The U. S. Forest Service (1973) has mandated the use of no high-volatility esters and also prohibits spraying when the atmospheric temperature exceeds 80°F, and the relative humidity is less than 50%. (These restrictions are applied by the Forest Service to aerial application in the Eastern Region only. The 80°F temperature limitation appeared in the Draft Environmental Statement of the cited reference. This was changed in the Final Statement to a restriction of when "temperature is less than 50°". No explanation is offered for the change. Since volatilization will be greater at high temperatures, the 80°F suggestion appears more reasonable.) The limitations indicated in these two paragraphs to ameliorate drift and volatilization problems are implemented in the Recommendations in Chapter 7.

While all of these treatments are utilized to a greater or lesser extent for various purposes including ROW management, the license applications received by AEC frequently refer only to selective application techniques. Consequently, the following discussion will emphasize the potential environmental hazards associated with the selective application of the five herbicides indicated above as being the ones most commonly referenced in AEC license applications. Applications received in recent months suggest a trend away from these herbicides. If a new use pattern becomes obvious, the matter will be again reviewed at an appropriate time.

3. HEALTH AND SAFETY IMPACTS

3.1 Teratogenicity of Dioxin

Much of the public controversy surrounding the use of phenoxy herbicides relates to their potential teratogenicity (ability to cause malformed fetuses) either directly or due to a contaminant present in some of them. This contaminant is 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin, commonly called dioxin or TCDD, and may be produced in the manufacture of 2,4,5-T and 2,4,5-TP. It does not occur in 2,4-D.

Much of the work which raised people's concern about the teratogenic effect of herbicides appears now to have been based upon tests of 2,4,5-T containing several tens of parts per million dioxin contamination (see, for example, Courtney *et al.*, 1970). The herbicides used in Vietnam contained this level of contaminant, but 2,4,5-T with less than 0.05 ppm dioxin is currently available (Edmunds, *et al.*, 1973).

That dioxin is a powerful and dangerous substance is well demonstrated. The administration of 0.125 µg/kg body weight/day of dioxin to pregnant rats through the 20th day of gestation produced noticeable effects in the fetuses. Higher concentrations had greater effects, while there was no detectable effect at 0.03 µg/kg (Sparschu *et al.*, 1971). The substance has been found to be metabolically active at 4.66×10^{-12} moles per chick egg (Poland and Glover, 1973). Both physical and biochemical disturbances have been noted in rats exposed to dioxin one time at a rate of 1 µg/kg (Buu-Hoi *et al.*, 1972). The LD₅₀ for guinea pigs is 0.6 µg/kg (Johnson, 1971). Baughman and Meselson (1973) have reported concentrations in Vietnamese fish from sprayed areas such that if a guinea pig were to eat his own body weight of fish it would ingest approximately this LD₅₀ amount.

Because there are absolutely no benefits associated with introduction of dioxin into the environment and because of the potential hazard even at low concentrations, care must be exercised to avoid creating a hazard where none need exist. Commonly used detection techniques are several orders of magnitude

less sensitive than the level at which dioxin is metabolically active, consequently unnecessary human exposure must be avoided.

3.2 Teratogenicity of Phenoxy Herbicides

Since much of the early work, such as the famous Bionetics study for the National Institute of Health, is based upon the use of contaminated herbicides, and since the levels of contamination were such that it is difficult to define the source of teratogenicity, the early studies will be ignored. Instead, recent more definitive work will be used as the basis for an evaluation.

A study by Emerson *et al.* (1970) failed to demonstrate teratogenicity of 2,4,5-T with less than 1 ppm dioxin in Sprague-Dawley-derived rats. Thompson *et al.* (1971) similarly could demonstrate no teratogenicity in either Sprague-Dawley rats or New Zealand white rabbits at up to 50 and 40 mg/kg, respectively, of 2,4,5-T. More detailed treatment is given by Emerson *et al.* (1971). These results were confirmed with CD rats in a study by Courtney and Moore (1971). However, these authors did determine that this herbicide was teratogenic in several strains of mouse. Analytical grade 2,4,5-T produced fetal abnormalities at 100 mg/kg with some indication of dose-related response. Impurities in the analytical grade herbicide are listed as "0" on the basis of analysis by the manufacturer. The same authors (Courtney and Moore, 1971) found the butyl, isooctyl, and propylene glycol butyl ether esters all teratogenic at this concentration in CD-1 mice. Interestingly, a single dose of this magnitude apparently can be fatal to dogs (Drill and Hiratzka, 1953). Roll (1971) states that 20 mg/kg/day is the "teratogenic no-effect" level in NMRI mice. As further evidence of the species-specific nature of the substance, Table 1 indicates the effects of 100 mg/kg doses administered chronically (Palmer and Radeleff, 1969). The differences in experimental design between this and the other cited studies are recognized. The table is included for comparative purposes.

If anything is apparent from these difficult-to-compare experiments, it is that there is a large and unpredictable interspecific difference in

Table 1. Results of Multiple Oral Dosing of
2,4,5-T at 100 mg/kg*

Animal	No. of Doses	Means of Dosing	Results
Cattle	10	Drench	No ill effects
Sheep	8	Drench	Poisoned after 3 doses and died
Chicken	10	Capsule	36% weight gain

*Palmer and Radeleff (1969)

response to exposure to 2,4,5-T. As might be expected, such variables as nutrition also affect response to 2,4,5-T exposure (Hall, 1972).

To date less public attention has been fixed on 2,4-D. Dioxin contamination does not appear to be formed in the manufacture of 2,4-D (Norris *et al.*, 1972). Consequently, teratological and other effects should be ascribable to the herbicide itself. Khera *et al.* (1971) produced teratogenic effects in rats with 100 mg/kg of 2,4-D, while 25 mg/kg had no apparent malformative effects, and experiments at 50 mg/kg were inconclusive. Collins and Williams (1971) reported teratogenic effects on the Syrian hamster at concentrations of 60 mg/kg, which they translate into a permissible human dietary intake at a 0.3-ppm tolerance level. Cherry (1970) speculates on the mode of biochemical action of 2,4-D and 2,4,5-T in animals.

Silvex has not received much experimental attention, although Courtney and Moore (1971) report that it is teratogenic to neither the CD-1 nor the CD rat.

3.3 Non-teratogenic Effects

Regarding the question of other damage at the cellular level, Anderson *et al.* (1972) indicate that herbicides in general, including the phenoxy, dicamba, and picloram, are not demonstrably causative agents of point mutations. However, work with *Drosophila* (Dävring and Sunner, 1971) indicates that butoxyethyl ester of 2,4,5-T with a guaranteed dioxin contaminant level of <0.1 ppm affects early oogenesis and causes chromosome disturbances at

concentrations approximating field applications. An examination of phenoxy herbicide factory workers showed no chromosomal effects (Johnson, 1971). At concentrations of 2,4,5-T and 2,4-D less than 100 mg/kg/day, Walker *et al.* (1972) demonstrated inhibition of ascites tumor development. While in part this may be due to demonstrated effects on nucleic acid and protein synthesis, Björklund and Erne (1971) found morphological kidney changes in chickens exposed to 2,4-D and 2,4,5-T. Consequently, at this time there are suggestions in the literature that the cellular and subcellular effects of phenoxy herbicides may include responses in addition to teratogenesis. The area certainly needs more attention from the scientific community.

While picloram has received less attention than the phenoxys, Johnson (1971) reports that a three-generation study of rats on diets containing up to 3000 ppm picloram showed no adverse effects with respect to indexes of fertility, gestation, viability, and lactation or with respect to body weight or fetal teratology. In separate experiments, 1000 mg/kg/day resulted in a small increase in fetal resorption; at 2000 mg/kg/day most females died by day 20 although their fetuses appeared normal.

Acute toxicity does not appear to be a problem for application at the rates expected along ROW's. For the phenoxies and picloram to be toxic to rodents the dose required is several hundred to several thousand mg/kg body weight (Johnson, 1971). The LD₅₀ for dicamba also appears to be several hundred mg/kg (Pond, 1972).

3.4 Effects on Man

The matter of herbicide effects on humans has not wanted for attention. The extensive use of herbicides in Vietnam prompted the American Association for the Advancement of Science to send a team of investigators in 1970 to assess the situation. A final report of their investigations is not yet available; however, preliminary reports have been issued (Meselson *et al.*, 1970, 1971). The team noted suggestive indications of herbicides affecting human births but concluded (Meselson *et al.*, 1970, p. 7): "The survey approach offers little hope of proving or disproving any relation between herbicide exposure and the incidence of birth defects unless one can find sizeable groups

of similar people living under similar conditions, one heavily exposed and the other not exposed." In other words, they regard the question as remaining open. This Report of the Advisory Committee on 2,4,5-T (Environmental Protection Agency, 1971) concluded that, despite the manifold difficulties confronting the efforts of the AAAS commission: "It must be emphasized, however, that the searches that have been made almost certainly would have revealed any marked increase in the incidence of birth defects or the introduction of a striking defect such as that produced by thalidomide. In spite of considerable effort, no such occurrences were found." In his minority report appended to that document, T. D. Steele indicates dissatisfaction with such a strong presumption of no effect because of the admitted problems associated with the uncertainty of the AAAS data.

In any application of the Vietnam findings to questions relating to domestic use for right-of-way maintenance, one must remember that in Vietnam the concentrations used, the frequencies of delivery, and the contamination level were all far greater than those applicable domestically.

Several other presumed cases of human teratogenicity based on the use of 2,4,5-T were examined by the Advisory Committee. These include a situation in Globe, Arizona, where phenoxy herbicides were used over a several-year period allegedly resulting in two human miscarriages and abnormal births in some domestic animals. The Commission concluded that: "In all likelihood none of these reported effects was due to the spraying."

In the case of Swedish Lapland where abnormal births of both reindeer and humans were allegedly caused by phenoxy herbicide spraying, the Commission reiterated the findings of German and Swedish scientists that there was no evidence to relate the human birth defects to herbicide use.

A more recent paper of alleged 2,4,5-T-induced abnormal human births was not available to the Commission (Sare and Forbes, 1972). If this case is the result of more than coincidence, a combination of unknown dioxin level and contamination of drinking water supplies might be responsible.

In humans, the major non-teratogenic problems identified have been (1) chloracne and mucous membrane irritation, (2) hepatotoxicity, neuromuscular symptoms, psychologic alterations, and other systematic symptoms, and (3) porphyria cutanea tarda (Poland *et al.*, 1971). These symptoms, it must be emphasized, have been found in industrial workers chronically exposed to high concentrations of herbicides. Reports also exist in the literature of adverse physiological effects in persons applying phenoxy herbicides (Goldstein *et al.*, 1959; Sare, 1972). However, there is apparently no indication that persons not engaged in the application or manufacture of these substances develop these problems.

Objections have been raised and will continue to be raised to experiments which rely on large doses of an investigated substance applied to an animal phylogenetically remote from man. Sterling (1971) discusses the issue at some length for herbicides. The fact remains that contemporary decision making almost universally relies on such analysis for a variety of reasons, principally because of cost-benefit considerations. Until such time as society is willing to invest the necessary resources to investigate *chronic* effects of low-level exposure, the positive results obtained from short-term *acute* experiments must be heeded. As Zimdahl (1972) points out, man is 60 times more sensitive to thalidomide than the next most sensitive animal (mouse). The whole question of acceptable risk is, in his view, a societal problem. Consequently, conservatism requires that the phenoxy herbicides and dioxin, their sometime contaminant, are to be regarded as teratogenic; therefore, appropriate care must be exercised in using them. This does not preclude employment of herbicides, however, so long as their use is such as to not result in exposure of the population to levels such that adverse consequences will develop.

Obviously the cost/risk relationship for ROW maintenance will differ substantially from other uses such as aquatic weed control of potable water supplies.

4. PERSISTENCE, MOBILITY, AND DEGRADATION

4.1 Herbicides

The potential adverse impacts of a substance introduced into the environment can be magnified or ameliorated by its behavior in the system into which it has been introduced. Substances present in the parts-per-million range may be major environmental contaminants if they are persistent and magnify in the food chain, while materials originally present in amounts several orders of magnitude greater may turn out to be of no concern if they decompose quickly to nontoxic components (cf. Menzie, 1969). Likewise, the physical pathway may be extremely important as, for example, when a substance is removed from the topsoil by precipitation only to pass to the groundwater or to running water. Quantification of the pathways illustrated in Fig. 3 is, of course, desirable, especially since they, and consequently their impacts, will differ, depending on the nature of the substance and the character of the application.

Fig. 3.
Potential Pathways of
Applied Herbicides.

Biological decomposition appears to be affected by temperature, moisture, and, of course, microbial activity (DeRose and Newman, 1947), as well as type of litter, formulation, and presence of other pesticides (Norris and Greiner, 1967). Physical degradation of 2,4-D is accomplished by light in dilute aqueous solutions of humic acid (Crosby and Tutass, 1966), although the significance of this in nature is unclear in view of the work of Aly and Faust (1964). Picloram may behave similarly (cf. Buttery *et al.*, 1972). Bovey *et al.* (1969) have noted photodecomposition of picloram under field conditions. Decomposition of dioxin is discussed below.

Decomposition is not an instantaneous process, and mobility in the soil is one pathway of potential concern. An application of picloram, for example, may result in contamination of watersheds with enough herbicide to damage irrigated sensitive crops, while that which does not leach may be highly persistent (Davis *et al.*, 1968). The literature on dicamba is poorly developed; however, Salman *et al.* (1972) have shown that in spring, residues of 0-1.6 ppb occur in water from ditchbanks that were sprayed the previous fall.

Norris and Moore (1970) review much of the literature of stream contamination, including the earlier observations by Norris (see citations therein). It appears that aerial spraying of forests with phenoxy herbicides will result in some contamination of local streams, but only in the 0.1-ppm or lower range and then only for a short period immediately after the spraying. Contamination with amitrol to 0.4 ppm for a short period has also been observed. Norris concludes (1968): "Unless heavy application is made directly to the stream, the major potential for stream contamination is from heavy rain or land movement resulting in heavy overland (surface) flow of water and sediment shortly after application." It should be recalled that Norris is talking in this context of broadcast as opposed to selective application. Runoff of picloram to 3.8 ppm has been observed by Trichell, Morton, and Merkle (1968). Both the rate of application and the slope of the land influenced runoff. In observations on a transmission-line ROW (Fig. 4), peak runoff occurred during the first storm after application. This case also involved a broadcast application. The herbicide used was a mixture of 2,4-D and picloram, and the combined total of both herbicides was less than 1 ppm in the runoff. Evans and Duseja (1973) conclude that if the initial precipitation after spraying

Fig. 4. Relationship of Herbicide Runoff to Precipitation (from Norris and Moore, 1970).

is insufficient to transport the herbicide across the soil, there appears to be little future danger of herbicide movement.

Figure 5, from Norris (1970), compares the degradation rates for several herbicides. While 2,4,5-T is shown to be somewhat more persistent than 2,4-D, it is reasonable to consider that both will degrade completely during the course of one growing season. If the shortest-term persistency is desired for a particular application, 2,4-D would appear to be preferable. Bovey and Baur (1972) observed that 2,4,5-T in grassland may disappear in as quickly as six weeks in some localities, and that in 12 weeks it was less than 10 ppb at all sites. Picloram, on the other hand, degrades much more slowly than 2,4,5-T. It appears possible that under some conditions long-term concentrations of picloram may build up, with as yet undetermined consequences.

Bovey and Scifres (1971) observed a picloram loss rate of 2.5 to 3%/day for 30 days in dry areas of Texas, but they mentioned the importance of chemical

Fig. 5. Recovery of 2,4-D, 2,4,5-T, Amitrole, and Picloram from Red Alder Forest Floor Material (from Norris, 1970).

persistence and suggested that dilution in the soil may be an important dissipation mechanism. They could detect residues in a semiarid site one year after application at 0.5 lb/acre, but not after three years. Lutz *et al.* (1973) found 10% persistency after 100 days in North Carolina loams planted to orchard grass. Hamaker *et al.* (1967) found that the half-life for picloram under various conditions ranges from 1 to 13 months, and David, Ingebo and Pase (1968) showed that stream contamination continued for several months after an application of picloram pellets to the soil of a watershed. In fact, the persistency of picloram is such that Lange *et al.* (1968) even recommended against its use in crop rotation.

As far as dicamba is concerned, the literature reviewed by Pond (1972) indicates that residues should also be negligible after a year (see citations in that reference), and Lange *et al.* (1968) state that even with an application rate of 16 lb/acre only minor plant damage resulted from dicamba residue.

It seems that even in different types of communities, the degradation pattern of these herbicides is similar enough so that one can assess the impacts of persistency without becoming bogged down in site-specific details. Obviously, if one ROW receives more rain than another, the dispersion will be more rapid in the wetter region. However, since it is prudent to restrict the application of any herbicide to once a year, the knowledge that the persistency of residues of those mentioned above, except picloram, is usually a year or

less should suffice, unless one encounters site-specific problems. Evidently one must be more careful with picloram than with the others since its persistency under some conditions may produce undesirable impact. It should be used only where there is specific reason for not using other, less persistent, herbicides. Even then the potential damage should be carefully assessed beforehand. If repetitive applications are made, the potential for buildup in the soil should be carefully examined.

Annual use of the phenoxies or dicamba should not result in long-term soil contamination. Moreover, selective application on ROW's where direct spraying of bodies of water does not occur should not result in any adverse effects to water resources including their biota.

4.2 Dioxin

As indicated above, the root of much of the public concern over the use of phenoxy herbicides is the presence in some formulations of 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin as a contaminant with potentially severe hazard to human health and safety. There is an obvious technological problem in detecting a compound present in the ppm range as a contaminant of a substance which itself is thinly distributed in the environment. The problems of the sensitivity limits obviously make early reports of no detectable residues of little value.

More recent work has been performed at the Eglin Air Force Base in Florida where from 1962-1970 massive dosing of a soil type known as Lakeland Sand was done by aerial bombardment. Within a three-year period, as much as 947 pounds per acre of 2,4,5-T were applied (Anonymous, 1972). Between November 1969 and May 1971, Woolson *et al.* (1972) gathered soil cores from the upper three feet of soil and analyzed them for dioxin contamination. Using electron-capture gas chromatography they were unable to detect any dioxin down to their minimum detection level of 1 ppb. The herbicide used for these applications was probably highly contaminated with dioxin. Explanations for the absence of dioxin have been offered (Anonymous, 1972) and include microbial degradation, photodecomposition, volatility and/or wind erosion. [In contrast with this opinion, Crosby *et al.* (1971) found

negligible photodecomposition in aqueous suspensions and on wet or dry soil.] The same investigators report no dioxin contamination of bald eagle tissue obtained from 15 widely separated states at a level of sensitivity of 0.05 ppm. This species was chosen because as a top carnivore it would be likely to display any bioaccumulation effects.

The results of these observations have been widely distributed as evidence that no long-term hazard from dioxin contaminants is associated with use of phenoxy herbicides. The observations by Baughman and Meselson (1973) have reintroduced the issue as a major potential problem. These investigators used mass spectroscopy with a cleanup procedure including gas chromatography to remove interfering substances. They claim resolution approaching 10^{-12} or one part per trillion (ppt). This is three orders of magnitude more sensitive than the methodology of the Eglin Air Base study. Using these techniques, Baughman and Meselson claim to have detected dioxin levels of 18-814 ppt in fish and crustacea caught in 1970 in South Vietnam near areas which had been heavily sprayed. They further hypothesize bioaccumulation.

The first observation that must be made is that the *highest* concentration observed by Baughman and Meselson is still below the limits of sensitivity of the best available earlier studies claiming no residues (the Eglin study). This is not too surprising since the furor over many environmental pollutants is based upon analytical refinements permitting us to discover hitherto undetectable concentrations. Given that this particular contaminant is now detectable in the biosphere by improved analytical techniques, what are the impacts at that level? Baughman and Meselson hypothesize that the substance will accumulate in food chains. Storage to lethal levels has been reported in primates (Allen and Carstens, 1967). Consequently, there is some evidence that even if undetectable residues of dioxin were in the environment, they may be concentrated in higher trophic levels. Furthermore, as noted above, the levels detected in fish would be lethal to guinea pigs, thereby suggesting that residues in the 10^{-10} to 10^{-12} range are of concern.

To properly assess the import of these data to ROW considerations, we must recall that the typical level of herbicide application for brush control on grazing land would be six pounds per acre over a three-year

span as opposed to the 947 pounds per acre in the Eglin case. This is well over a two order of magnitude difference. Moreover, the dioxin contamination during the period when herbicides were being manufactured for use in Vietnam was reported to be as high as 40 ppm. Currently available supplies can meet a 0.05 ppm residue limitation. Consequently, we are again speaking of well over a two order of magnitude difference. Information on Vietnam spraying rates and frequencies are not readily available, but if we assume conservatively that a situation such as Eglin results in contamination at a level of 10^{-9} , then a more typical domestic broadcast spraying program should result in residues well under 10^{-13} . Selective spraying will further reduce this by perhaps two orders of magnitude. While dioxin is potentially a sufficiently potent substance to indicate that any intrusion into man's immediate environment as by contamination of foodstuffs, contamination of potable water supplies, or unnecessary direct exposure is to be avoided (a fact implicitly recognized by the EPA suspension of 2,4,5-T for household use), residues at the level which appear to concern us here should not constitute a hazard to human health and safety *when proper application procedures are followed*. Moreover, as will be discussed below, selective application in wildlife habitat does not seem to have an unacceptable impact on biota. Consequently, unless future research indicates that dioxin accumulates to dangerous levels in the food chain, ROW application does not appear to present problems in this area.

An additional issue of dioxin hazard has been raised, namely as to whether dead vegetation containing 2,4,5-T might give off dioxin as combustion product upon incineration. Johnson (1971) offers experimental evidence to the contrary, but since the limit of detection for these studies was 5 ppm, the question is not resolved. Increasingly more stringent air quality requirements make burning of slash less common than formerly. Many utilities allow the slash to decay naturally, thereby providing additional wildlife habitat. Hopefully, the improved methodology of Baughman and Meselson will provide data to more rigorously define the areas of concern and indicate if further adjustments in herbicide application techniques are necessary.

5. ECOLOGICAL EFFECTS

5.1 The Soil

There is ample documentation of the fact that some soil bacteria degrade herbicides. Since the soil is a dynamic system and may be considered a control valve in the nutrient cycles, it is vital that its functioning not be altered in such a way as to disturb the nutrient and productivity dynamics of the system. Specifically, since herbicides are metabolic modifiers for some organisms and since they persist in the soil for a period of time ranging from days to years, there must be some assurance that the soil fauna and flora and the biogeochemical cycles of which they are a part will not be adversely affected.

One of the fundamental soil processes is the nitrogen cycle. Jones (1956) examined the effects of a variety of pesticides on different microbial soil processes. The only herbicide he examined was 2,4-D, which at 1% demonstrated no effects on aerobic nonsymbiotic nitrogen-fixing bacteria. Ammonifying organisms were not inhibited at 0.25% or less, while nitrifying flora were toxified at 0.1% but unaffected at 0.01%. Since the latter concentration corresponds to an application rate of 200 pounds per acre, one could tentatively conclude that current practices should not disturb the nitrogen cycle. Kratochivil (1950) could not detect an effect of 2,4-D on the metabolic activities of soil microorganisms, which he regards as being in agreement with similar conclusions from earlier plating-out studies. However, since Lenhard (1959) demonstrated shifts in *Azotobacter* nitrogen fixation, growth, and dehydrogenase activity, the question is not settled. There is some evidence (Klyuchnikov and Petrova, 1960) that 2,4-D will affect soil fungus, but it is difficult to relate this fact to a real impact. Although the evidence that there is no discernable effect of 2,4-D on larger soil fauna (Rapoport and Cangiolli, 1963) appears reasonable, apparently the substance will inhibit protozoa, which results in an accompanying increase in some soil micro-organisms (Ill'in 1961).

Despite minor discrepancies, the work of other authors, as reviewed by Fletcher (1960) and House *et al.* (1967) for example, generally substantiates the above observations. Skimpy though it may be, the evidence indicates that while these are some detectable alterations in soil biota exposed to 2,4-D, they do not constitute adverse impacts. A similar conclusion was reached by Goring *et al.* (1967) regarding the effects of picloram. Likewise, Tu and Bollen (1969) found no effects of this herbicide on ammonification, nitrification, sulfur oxidation, and decomposition. It is doubtful that herbicides applied to ROW's as in current vegetation management programs will result in adverse impact to the soil biota.

5.2 Community Level

A body of theory and literature concerning vegetation management along ROW's has developed through the years relating to both construction and maintenance. An extensive discussion of construction philosophies would be inappropriate here except in so far as construction techniques modify the nature of the ROW vegetation and consequently the extent and nature of herbicide application for maintenance.

Techniques vary all the way from bulldozing and broadcast application of herbicide to selective killing of tall woody vegetation only. Herbicide use varies all the way from broadcast application of foliage sprays resulting in dramatic "brownouts" of vegetation which must be repeated frequently, to the selective application of herbicides in such a way as to result in root kill of tall woody species only. Of course by cutting or burning, crews can maintain a ROW without the use of herbicides. Vegetation managers appear to be evolving techniques that are less likely to result in ecological damage. ROW's which were heavily and frequently treated a few years ago are now reverting to a more stable shrub and bramble community as management techniques change. Some companies appear to be modifying their techniques far more rapidly than others. For various reasons, in part no doubt because of the regulatory agency and public scrutiny which applications for a nuclear power plant receive, recent requests to the AEC for construction permits tend to propose vegetation management techniques which will have less impact than those which might have been proposed ten years ago. For example, selective

application of herbicides is the predominant technique presented in applications for construction permits. In many cases a serious attempt is made to preserve vegetation, including woody plants, which will not adversely affect transmission line functions and maintenance. To a large degree this increased environmental sophistication appears to be an outgrowth of response to criteria published by the Department of the Interior (U. S. D. I., 1971). The reader is referred to this publication for a discussion of guidelines to reduce adverse environmental impact across a broad spectrum of ROW construction and maintenance problems.

The primary effect of herbicides is, of course, that they kill vegetation. Killing or altering vegetation off the ROW is undesirable and unnecessary. The likelihood of such events can be reduced by avoiding spraying conditions which might result in volatilization or drift as discussed in an earlier section. When extremely sensitive plants are growing near the ROW, alternate management techniques should be considered. Such restrictions are sometimes written into law. The State of New York for example (N. Y. Dept. Env. Conser., 1971) can prohibit or restrict use of phenoxy herbicides in areas where damage to grapes has been caused. Since woody plants can exude herbicides into the soil (Reid and Hurtt, 1970) there is still the possibility of some damage occurring adjacent to the ROW even when all precautions are taken.

The ecological consequences of floristic manipulation on the ROW will depend to a large degree on the objectives of the managers. A ROW with a diverse flora, including both forbs and shrubs, will display an "edge effect" resulting in a richer fauna because of the variety of available habitat, while a ROW planted to grass of low palatability with little shrub growth even along the edges will provide a relatively sterile environment, even though to an uncritical eye it may appear neater. The former is the preferable alternative, but it is not necessarily the result of herbicide use; either general community type can be created without the use of herbicides. Nevertheless, in so far as the more complex community type is desirable, for those ROW's where herbicide is the management technique employed (in fact the majority of ROW's), selective spraying is to be preferred to broadcast spraying. The obvious result of broadcast spraying is that much vegetation, such as woody shrubs and low growing trees, which does not have to be removed is killed.

This results in a simpler community with less desirable characteristics for the biota which use the corridor. Furthermore, the broadcast method frequently does not result in root kill of the undesirable species, necessitating more frequent repetition of spraying operations. Except for special cases where the ROW is remote or the terrain forbidding, selective application of herbicides appears to be the clearly superior alternative as far as adverse impacts are concerned. For over 20 years Frank Egler has reviewed and contributed to the literature on environmental effects of vegetation management in ROW's. Although some of his conclusions may differ from those presented here, the reader is referred to this literature for a more complete review of the philosophy of vegetation management techniques (Egler, 1973). On the question of the more immediate effects of herbicides on wildlife, the reader should consult Environmental Protection Agency (1969) and Pimentel (1971).

There are several long-term plots displaying various management techniques around the country. A well-known long-term experimental area has been maintained by Bramble and Byrnes in Pennsylvania. A recent publication (Bramble and Byrnes, 1972) describes the current state of the vegetation and reviews their earlier work. Of interest is the fact that a variety of treatments ranging from broadcast treatment to selective treatments all end up with similar community types, namely a bracken-sedge-herb-blueberry community. However, the more drastic the original treatment, the more serious the initial disruption of the community (Fig. 6). For example, broadcast treatment reduced cover by as much as 90%. Consequently, the soundness of selective application is again indicated.

The value of ROW's to wildlife is a frequently cited benefit in the cost-benefit analyses of transmission lines. The promotion of a forest edge habitat where a forest formerly existed is presumed beneficial since most game species prefer the edge habitat. While there is a great deal of truth in this idea, caution must be exercised in its use to promote a particular management practice since it is a frequently abused concept. The mature forest itself is an essential habitat.

A body of literature has developed concerning wildlife response to man-created habitat. A good idea of the specificity of wildlife's response is

Fig. 6. Recovery of Vegetation Following Various Application Techniques. Spraying was done in 1953, and vegetation allowed to recover. Note the severe short-term impact which spraying at frequent intervals would tend to perpetuate. (From Bramble and Byrnes, 1972.)

obtainable from the long-term work of Bramble and Byrnes. Once again their earlier publications should be consulted for details; however, Table 2 provides the basis for some interesting comparisons.

Table 2. Number of Times Common Wildlife Species or Signs Were Observed on Treatment Areas from October 1, 1953 through October 1957 (Bramble and Byrnes, 1972)

<i>Treatment</i>	<i>Deer</i>	<i>Grouse</i>	<i>Rabbit</i>	<i>Squirrel</i>	<i>Turkey</i>
A Unsprayed	83	12	51	6	0
B Broadcast D + T	45	8	8	2	31
C Semi-basal	62	7	3	6	1
D Summer basal	53	5	12	8	1
E Winter basal	59	8	25	11	1

Within the context of their experiments, there is a very clear species-specific response ranging from deer preferring no spraying to turkeys preferring broadcast sprayed areas. Nevertheless, herbicide-managed vegetation is usually regarded as offering good deer habitat (Krefting and Hansen, 1963).

There has been some interest in the potential effects of herbicide treatment on plant biochemistry resulting in modified toxicity and/or palatability

with postulated adverse effects on fauna consuming the vegetation. Although Richter (1952) as cited by Pimentel (1973) reported that rabbits found 2,4-D-treated vegetation less palatable, there is concern that phenoxy herbicide application may make some undesirable plants more palatable. Particular interest has arisen concerning the possibility of hydrocyanic acid poisoning. Apparently there is no marked increase in hydrocyanic acid content of cherry species after herbicide application (Grigsby and Ball, 1952; Lynn and Barrons, 1952) while in Indian grass the opposite is true (Swanson and Shaw, 1954). There is also the potential for nitrate poisoning due to herbicide treatment causing increased levels of nitrate in forage species (Berg and McElroy, 1953; Frank and Grigsby, 1957). An additional adverse impact on large grazers can result from herbicides inhibiting the action of their rumen flora (Kutches *et al.* 1970) although the observations of Smith (1973) make this seem less likely. Consequently, there appears to be a yet undefined potential for damage to herbivores. In the absence of large scale or repeated incidents being reported in the literature, it seems likely that if mammalian herbivores are adversely affected, such effects are localized and probably do not have a long-term effect in the exposed population. Carvell (1973) suggests that the possibility of hydrocyanic poisoning is greater in areas cut over than in those which have been sprayed. In light of the several mechanisms by which poisoning is possible and because of the large number of plant species which may be involved, regulation appears difficult. An assessment of potential harm from an herbicide ROW management program must be made on a case-by-base basis in light of local vegetation. Willard (1950) suggests keeping stock out of pastures containing poisonous weeds for three to four days after spraying.

To avoid endangering domestic animals, if a pasture area along a ROW is to be sprayed, at a minimum the owner should be notified in advance both of the date of the spraying, and of the nature of the material to be applied. This will not only enable the owner to avert potential problems, but will ensure his ability to prevent residues in his meat and milk products.

There appears to be little potential danger from direct lethality from exposure to the phenoxy or picloram (Tucker and Crabtree, 1970), or from dicamba (Pond, 1972) at levels expected from any reasonable spraying program.

Since the phenoxy herbicides appear to be teratogenic, we must assume that wildlife exposed to them could adversely be affected in this manner. In fact, work by Lutz-Ostertag and Lutz (1970) indicates that in France, population of pheasant, red partridge, and gray partridge may be suffering from exposure to 2,4-D. In light of the work that has been done on rodents, it would be surprising if at least some species of wild rodents were not affected by exposure to sprayed herbicides. Since exposure of wildlife to herbicides would be severely limited by a selective application program, the further advantage of such a program in avoiding unacceptable impacts is again demonstrated. If a truly exceptional situation existed such as an endangered species of rodent occurring in an area, whose life history might lead it to frequent or nest along a ROW, serious consideration should be given to alternate management techniques. Such a situation will be infrequently encountered.

Another area of potential impact that has not received the research attention it deserves is the effect of herbicides on insects. This is of special interest since herbicides can act synergistically with insecticides (Lichenstein *et al.* 1973). Predator-prey balances may be upset where a predator such as the coccinellid beetle is adversely affected by spraying (Adams, 1960). Furthermore, several observers such as Palmer-Jones (1964) have noted toxic effects on honey bees including population declines in sprayed areas. The potential damage to the overall structure of the community is apparent from either of these effects. Fortunately, neither of them should occur if selective application techniques are used.

It appears that incautious application of herbicides may have adverse impacts on the fauna, especially when one considers the possibility of site-specific problems (e.g., Keith *et al.* 1959). The probability of adverse effect and the magnitude of such effect will be far less where broadcast techniques are avoided. If the recommendations discussed below are observed, in most cases the impacts on the fauna are expected to be unmeasurable.

6. ECONOMIC CONSIDERATIONS

Any method of vegetation control is going to have an associated economic cost. Unfortunately, a cost comparison between chemical techniques and manual or other techniques is difficult because of the paucity of data. In particular, comparisons more than several years old must be viewed with a jaundiced eye for use in contemporary cost-benefit determinations because there has been disproportionate shift in costs associated with manpower, materials, and equipment over the last several years. Vegetation managers are fond of pointing out the site-specific nature of costs as a difficulty in quoting cost estimates.

Care must be shown in using those statistics that are available. For example, using the Bonneville Power Administration figures given by House *et al.* (1967) for 56,000 acres of "brush" under 10,000 miles of ROW treated with herbicide at a cost of \$35-40/acre in comparison with the \$300-500/acre for manual treatment is probably of questionable validity for the eastern deciduous forest. The Consumers Power ROW figures quoted by House *et al.* indicate a clear cost advantage of chemical techniques over combined manual and chemical treatment. The figures offered by Fox *et al.* (1970) for rangeland seem to indicate approximately a 10:1 ratio in favor of herbicide treatment. The comparison figures offered by the U. S. Forest Service (1973) are given in Table 3.

There is a variety of additional considerations which must be included in a cost-benefit determination of this matter. The ecological and public health problems of alternative techniques, which have not been considered in this paper, must also be considered. Vegetation type, weather, soil conditions, potential for erosion, and other environmental factors must enter into consideration both because they modify the cost of management techniques and also because the use of a particular management technique will have different environmental impacts depending on them.

It is further necessary to ensure that a valid comparison is made. For example, a broadcast foliage treatment would be an inadequate basis of comparison

Table 3. Cost Comparison of Various Techniques^a

<i>Method</i>	<i>Purpose</i>	<i>Cost per Acre</i>
Helicopter herbicide spray	Conifer release Site preparation	\$5.50-\$10.00
Modified ground spraying	Treating prepared planting sites	\$8.50-\$30.00
Hand clearing	Roadside maintenance	\$140-\$270
Mowing	Roadside maintenance	\$20
Nonselective herbicide	Roadside maintenance	\$30
Selective herbicide with mowing	Roadside maintenance	\$10
Individual stem treatment ^b	Cull tree removal	\$4.10-\$21.75

^aU. S. Forest Service (1973).

^bThe above document references Worley and Hoyt (1968).

with manual clearing or selective herbicide application techniques for cost-benefit consideration where it is judged that broadcast spraying will result in avoidable and unacceptable environmental damage.

Nevertheless, it appears that there is a clear economic benefit to the use of herbicides as a vegetation management technique. As is discussed elsewhere, if adequate precautions are taken in their use, such application should not result in unacceptable adverse environmental impacts.

7. CONCLUSIONS AND RECOMMENDATIONS

The assessment of potential impact of a technology must explore the environmental interactions from the broadest possible perspective. Consequently, this paper has explored not only the strictly ecological questions, but also the problems of man-herbicide interaction--especially the public health considerations. The conclusion that is implicit in much of the discussion elsewhere in the text is that herbicides must be regarded as a potentially hazardous chemical, arguments on experimental design notwithstanding. This is not to say that the use of herbicides must be banned. Hazardous chemicals are commonly utilized to take advantage of their special attributes so long as the public welfare is protected by the observation of appropriate use restrictions. Consequently, a list of recommendations follows whose observation is expected to permit the use of a cheap and effective technology for vegetation management without attendant adverse impact to either man or other biota. There will be times when the observation of these recommendations will be unwise or unnecessary. Herbicide application, like everything else, must be considered in its site-specific context.

In the first place, the greatest potential for harm is the presence of dioxin in some preparations. Since commercial lots with a dioxin content less than 0.05 are available (Edmunds *et al.* 1973), and since there is no benefit to using preparations with a higher dioxin content, it seems to be reasonable to recommend that

The dioxin content of undiluted phenoxy herbicides should be no greater than 0.05 ppm.

A series of recommendations to insure no off-ROW contamination also is desirable.

Aerial spraying should be avoided except in extreme circumstances. When it is employed, helicopters should be used.

Spray droplets should be greater than 200 μ for ground spraying. Use of thickeners etc. is to be encouraged. Formulations with high volatility should be avoided.

Spraying should not be performed when the wind is greater than 5 mph, or the temperature greater than 80°F. Spraying should not be performed during precipitation or when precipitation is likely.

In the period 1-3 months after spraying, but within the same growing season, visual inspection should be made for drift or volatilization contamination and damage of the vegetation off the ROW.

Because of the problems inherent with persistent herbicides, herbicides which are persistent in the environment should be avoided. Where they are employed, soil residues should be monitored every several years.

Even given these considerations, it is necessary to further remove the possibility of unnecessary direct or indirect human exposure. Therefore, the following should be observed.

No area of intensive human use should be sprayed.

No spraying should be permitted within 100 feet of a body of water.

If pastures or other grazing areas are to be sprayed, the owner or lessee should be notified of the spraying operation, the nature of the material to be used, and potential adverse effects to his livestock (e.g. residues in milk affecting marketability, etc.) He should be informed in sufficient time to remove his livestock if he desires.

For many of the above considerations, the overall suggestion can be made that

Broadcast spraying is to be avoided except in extreme and unusual circumstances. Selective application is to be preferred even where economic costs are higher. Treatments should not be more often than once a year.

The importance of this recommendation cannot be overemphasized.

And finally, although the presumption is usually valid that all parties will act within the framework of the law, it has been our experience that

there are some individuals responsible for vegetation management decisions who do not even know what is meant by a registered pesticide. Consequently,

All herbicide use will be in accordance with appropriate local, state, and federal requirements. Specifically, all herbicides will be used in accordance with their registration.

Since the new pesticide law provides for certification of professional applicators, as soon as the certification procedure is implemented

All application of herbicides will be performed by an individual professionally certified to do so, or under the immediate supervision of such an individual.

Although much persuasive information concerning the potential for harm from misuse of the phenoxy herbicides exists, in part this may be a reflection of the amount of investigatory attention these substances have received. Decisions to substitute an inadequately investigated herbicide for one whose known but undesired side effects may be dealt with by intelligent management cannot be lightly made. The need for substantive increments to our knowledge in this area is both obvious and unfortunate.

It is my conclusion that the observation of these recommendations strikes a balance between economic benefits and environmental costs that should be acceptable to society. Of the herbicides discussed here, the one most likely to be removed as a tool to the vegetation manager is 2,4,5-T, for which hearings are scheduled in the spring of 1974. Societal acceptability and scientific data will continue to change, as well as the vegetation management techniques themselves. Those whose profession is environmental assessment must continue to give this area ongoing scrutiny.

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