Toxicology and Potential Health Risk of Chemicals that May Be Encountered by Workers Using Forest Vegetation Management Options

PART II: EXPOSURE TO AND ABSORPTION OF HERBICIDES USED IN FORESTRY

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Abstract

To predict possible harmful effects of a herbicide on workers in forest vegetation management, the toxicology of the herbicide must be known, including the dose-response for any effects it may cause. Also, the amount or dose that workers might acquire in the course of their occupation must be determined. Dosage depends on exposure, which is the amount of herbicide that will contact skin, respiratory tract or digestive tract.

This paper reviews a variety of research studies of worker exposure in forestry and agriculture as well as some observations of homeowners and lawn-care workers. All are useful in considering forest worker exposure. There are several reviews that estimate public exposure, which is very low and infrequent compared to worker contact. The emphasis in this report is on occupational exposure of forest workers.

Regardless of application method, the most important route of exposure for workers is the skin, and the skin of the hands and forearms is the most important area. With hand-held equipment the lower legs are also very important. Inhalation of herbicides is minimal. Oral intake occurs almost exclusively through eating or smoking without washing. The most accurate method of measuring intake of herbicides is by analysis of urine of exposed workers for several days after application. All of the herbicides used in forest vegetation management in British Columbia are entirely excreted in the urine with little or no change. If the methods of application are similar, data from study of one herbicide is useful in predicting the exposure to others.

Exposure research has shown that workers and supervisors can control exposure without compromising work output. It is evident that simple precautions in the form of proper clothing, training, working methods, equipment maintenance and response to mishaps bring exposures down to levels that are a small fraction of the upper ranges of exposures that have been commonly measured.

Exposure of forest workers, such as planters, who enter herbicide-treated areas after application is minimal. Even an hour after application, removal of herbicides from foliage to the skin is slight, and after 24 hours will be practically zero. Exposure to herbicides or their combustion products as a result of burning of treated vegetation is also not significant.

With the current work practices, a general statement may be made that exposures to herbicides used in forestry in British Columbia do not represent a health threat to forest workers. Several recommendations for exposure management are made in the report.

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Foreword

Vegetation management is an important reforestation activity for controlling competing vegetation or brush encroachment of young tree seedlings. The activity is necessary to get tree seedlings to free-growing status in most new forest sites established in areas that have been harvested or denuded by wildfire, insects and disease.

There are a number of options for managing forest vegetation. The treatment options include prescribed fire, herbicides, manual removal with hand and power tools (e.g., girdling and slashing tools, chain saws and brush saws), placement of mulch mats, mechanical techniques with heavy machinery, and biological methods. The use of livestock (e.g., sheep) is currently the common biological control technique employed in reforestation areas in British Columbia. Biological methods with insects or specific pathogens is used on forest rangelands for noxious weed control but not commonly used for vegetation control in young forest stands.

The selection of a treatment option involves a decision-making process based on integrated vegetation management concepts that include evaluation of the need for treatment, consideration of all the approved treatment methods and choosing the most appropriate treatment method, monitoring and evaluation. Factors considered in selecting a particular method are the ability of the method to meet the required reforestation objectives, the impact of the treatment at the specific site on human safety and the environment (e.g., recreational resources, fish and wildlife and their habitat, range resources and water supply), as well as the economics of the treatment.

This publication is one of a series of papers that evaluates the potential health effects on forest workers using the commonly employed methods of vegetation control. Other papers in the series are listed at the end of this paper. The emphasis is on risks associated with exposure to chemicals during the use of two most important methods for controlling competing vegetation in regenerated (natural or planted) forest areas. These methods are the use of herbicides and manual removal or control with handheld-motorized (power) equipment.

The herbicides discussed are those that have been commonly used in forestry in Canada. The database on health effects of herbicides is extensive and permits reliable estimates of risk. For components of chain saw exhaust and fuels, there is also voluminous background of toxicological information, but exposure data in forestry is limited. Nonetheless, there is enough information to develop preliminary assessments of potential health effects. While there appears to be a high incidence of physical injury associated with manual methods of brush control, there is virtually no validated data on which to base estimates of risk. The existing data are those of workers compensation boards and insurance companies but such data are generally difficult to obtain or are not specifically enough to characterize the kind of activity that leads to injury.

The information in these reports should provide the basis for important decisions about the way vegetation management in forestry should be carried out, and the use of some forestry activities as a source of assisted employment.

Contents

Introduction

Exposure is defined as the amount of a chemical that comes into contact with a body surface from which it may be absorbed. The amount absorbed is the dose. The surfaces the chemical may come in contact with are the skin, the digestive tract and the respiratory system. A chemical that reaches a body surface will either react at the surface or will be absorbed to be distributed throughout the body. If a chemical is corrosive or caustic it may cause damage where it touches the skin, digestive tract or nose, and may go no farther. Pesticides are usually not very reactive, but many may cause irritation. After contact, some fraction of the pesticide, usually small, will be absorbed into the circulation and distributed throughout the body. If the exposure is great enough, even the small fraction absorbed may be significant. The very toxic herbicide paraquat fits both categories, in that it will cause damage to skin and nails, but is absorbed well, especially from the digestive tract. It is not used in forestry.

If a chemical does not reach a surface from which it can be absorbed into the bloodstream, it cannot reach organs and tissues and it cannot do harm. An adage worth remembering is: “If you don’t want it in you, don’t get it on you.” Deposition and retention of a pesticide on protective clothing without body contact is not part of the exposure, nor is pesticide that is nearby but not contacted.

Evaluation of the potential risk associated with use of a herbicide or any chemical depends on two kinds of factors. One is the basic ability of the chemical to cause harm, which is its *toxicity*. The other factor is the *dose*, which is the amount of the material that enters the body. By themselves, neither the toxicity nor the dose is enough to determine the potential for harm. An extremely toxic substance will do no harm if the dose is low enough, and many common chemicals presumed to be harmless because of low toxicity can cause injury because substantial amounts are absorbed over long periods.

It is obvious that forestry workers who handle herbicides will be exposed to some extent. A number of investigations of herbicide exposure during forestry application have been made. They provide much of the basis for the assessment in this paper. There has been very little direct study of exposure resulting from passage through forest areas immediately after treatment completion. However, there is enough information from studies of other kinds of vegetation to make valid assessments for workers who are in treated areas after application. Prescribed or wildfire after application of a herbicide may also be perceived to result in exposure of forest workers to the herbicide or its combustion products. There is enough information to assess exposure from that source, as well.

In this report, non-occupational contact is not included in the estimates of worker exposure. A worker is subject to the same general exposure that might be encountered by any member of the public, but exposure in this way is very small relative to occupational contact and does not change the eventual conclusions about worker safety or risk. Examples of such exposure would be off-site drift, ingestion of deposits on garden produce, or consumption of game, livestock or fish that may have been in contact with the herbicide. Non-occupational exposure is also very infrequent, compared to that which occurs during work.

Estimates of public or non-occupational exposure from various sources have been made by several public agencies (see USDA-Forest Service Pacific Southwest Region (1988), USDA-Forest Service Southern Region (1989, Washington State Department of Natural Resources (1986) and California Department of Transportation (1991)). It is quite clear from the published reports that public exposure resulting from forestry activities is extremely small and represents no risk.

The most important route of exposure for workers is the skin, regardless of the method of application. The hands and forearms account for most of the skin exposure. Spillage of dilute or concentrated material on the skin, contact with vegetation at the time of treatment and deposition of airborne droplets on the skin are the most important sources. Intuitively, one may assume that inhalation exposure to a “spray” would be extensive, but exposure by inhalation has been shown to be very low compared to skin exposure (Grover et al, 1986b; Chester and Hart, 1986; Abbott et al, 1987). The reasons lie in the very large volume of air in which suspended droplets might be distributed compared to respiratory ventilation, and the fact that a very small fraction of spray droplets is carried into the lower air passages. The simple hygiene of washing before eating or smoking, and keeping the hands away from the face while working can prevent oral intake almost entirely. Of equal importance, the studies show clearly that worker exposure can be brought down to much lower levels than are presently accepted, through use of simple protective clothing, careful maintenance of equipment, and reasonable training and discipline. There are guidelines on use and care of protective clothing and equipment for workers involved with herbicide application in British Columbia forestry (Boateng, 1998). Pesticide Applicator training and certification are also required.

General Approaches to Assessment of Worker Exposure to Herbicides

Exposures of workers who apply herbicides can be measured directly because the chemical moves from the application device directly to the worker, or is contacted immediately afterward as the applicator moves through freshly treated vegetation. In either case there is little opportunity for change or movement of the herbicide, other than binding to or absorbing into the vegetation. Methods are available for estimating surface contact and for directly measuring the amount absorbed.

The various studies of absorption in experimental animals are useful for study of mechanisms of absorption and excretion but are only marginally useful for predicting movement from the skin into the blood in humans. There is high variability of dermal absorption among species, and great differences in absorption rate for the various areas of body surface. The inconsistencies are well illustrated by Moody et al (1990).

The most useful direct measure of exposure is actually a measure of dosage. Most forestry herbicides are essentially unchanged in the body and are excreted rapidly in the urine. A few are changed slightly, but they too emerge quickly. Therefore, collection and analysis of urine for a few days after exposure to the herbicides of concern here gives an accurate measure of the amount absorbed by all routes. Absorbent patches attached to the skin and clothing during application and analyzed for trapped herbicide after an operation are also useful for estimating external contact, although much less accurate than urine sampling. Patches have the advantage of showing what part of the body is most heavily exposed. Dyes, particularly fluorescent dyes added to the formulation are extremely useful in visually showing effectiveness of technique and protective gear.

Protocols for exposure measurement are becoming standardized internationally. The various guidelines are reviewed by Curry and Iyengar (1992) of Health and Welfare Canada. A compendium of exposure data bases for agriculture (van Hemmen, 1992) has value for comparative purposes, but it includes poor practices as well as exemplary and does not assist in judging exposure in forest vegetation management.

Measurement of worker exposure to any given herbicide can be used to estimate exposure to other herbicides if the method of application is similar. The most important variable is the rate of absorption across the skin, which has been measured in humans for some of the herbicides used in forestry in Canada. For those herbicides without specific exposure data, enough is known to make reliable assumptions about absorption rate. 2,4-D is often used as the model compound from which predictions can be made for other herbicides in similar uses. Its chemistry and biological effects are very well understood, it is widely used, it is excreted completely and unchanged and numerous studies of exposure have been made.

When the rate or percentage of absorption from the skin or other surfaces is known, an estimate of the amount originally contacted is possible. For example, if about two percent of a herbicide "A" is known to be absorbed across the skin over a given period of contact and excretion in urine is known to be complete, it follows that the total amount contacted was 50 times the amount excreted.

The exposure data obtained in this way is transferable to other herbicides if the application is similar. If the absorption rate for another herbicide "B" is known to be 4%, the actual dose for an exposure similar to that of "A" can be estimated as twice that of "A." The key word is "estimate," because there is considerable variability in absorption rates on different parts of the body.

Herbicides for which there is no skin absorption data are usually assumed to be absorbed at a rate of 10% if left in contact over a 24-hour period, with no wash-off. This is a deliberately high estimate in the interests of conservatism.

Exposure figures estimated from only deposition rates and assumptions about exposed body surface are usually presented on the basis of an application rate of one kilogram per hectare or one pound per acre which can then be scaled according to the actual application rate (one kg/ha = 0.89 lb/a). For example, if 0.2 of a square metre of skin is directly exposed to an application of one kg/ha (i.e., 100 mg/m^2) the amount contacted is 20 mg. If 5% is absorbed the internal dose is 1.0 mg. If body weight is 50 kg the dose per kg is 0.02 mg/kg. Only in case of an accidental direct exposure to spray would this approach be useful.

The important information is the total amount of herbicide acquired by the body, and excretion in the urine integrates the absorption from all areas.

The published exposure research reviewed below provides two kinds of critical information. First, these studies are the basis for estimates of the amounts of herbicides that workers may contact and absorb in the course of applying herbicides or working near them under usual practices. That information is used with studies of the toxicology of the chemicals to judge the probability of harm.

Findings of Exposure Research

This section includes observations from direct field studies of forestry, agricultural and home maintenance users of herbicides, under a variety of conditions, use rates and application methods. Most measure the herbicide in urine following exposure to directly determine actual doses in the working world. That information can then be related to the extensive toxicological database for each of the herbicides to develop estimates of risk to workers.

It is evident that exposures in the forest workplace extend across a broad range, but in spite of the variation the limits can be visualized. The variation and its sources are in themselves valuable information, because they show the effect of good and bad practices in the real world. In fact, the most important lesson from these studies is the universal finding that proper equipment, and correct handling and application procedure bring exposure and subsequent absorption to very low levels relative to average measurements. The studies by Nash et al (1982), Grover et al (1986 a, b), Harris et al (1992), Libich et al (1984) Taskar et al (1982) and others show without question that managers, applicators and others working with herbicides have the power to control exposures and intake, without compromising work output.

Perhaps the most important part of the work discipline is proper use of the correct type of gloves, because as much as 90% of dermal exposure is on the hands and forearms (Grover et al, 1986b, Abbott et al, 1987). Gloves should be unlined and impermeable. Lined gloves retain spilled herbicide and hold it in contact with the skin. Nigg et al (1986), however, found that gloves led to increased exposure for mixer-loaders, apparently because of inside contamination. Unlined gloves can be washed, and if several pairs are available, they can be changed frequently and as necessary, and washed at the end of the work day. Failure to change contaminated gloves and wash the hands simply accelerates movement from the skin to the blood stream.

During application of pesticides using handheld equipment the lower body is also subject to considerable exposure from contact with wet foliage, short range drift and the equipment itself (Abbott et al, 1987, Lengerich and Burroughs, 1989). Fenske (1990) has illustrated this dramatically for greenhouse applicators with fluorescent dyes. For applications in which spray is directed downward, exposure of the legs and feet may predominate. Studies of aquatic weed treatment from airboats and of lawn applicators showed the greatest total deposition to be on the legs, although deposition on hands was greatest per unit surface area. (Nigg and Stamper, 1983; Slocum and Shern, 1991).

The same effects can be expected with backpack forestry application, and can be reduced sharply with proper unlined boots and resistant clothing. Ordinary full coverage work clothing intercepts a great deal of incidental herbicide; cotton fabrics have a very high surface area of fibres, which adsorb chemicals well. There is a practical limit to the amount that can be intercepted, and Wester et al (1996) have shown that cotton cloth to which glyphosate or malathion have been adsorbed will liberate part of the adsorbed material when the cloth is moistened. The implication for sweating in contaminated clothing is obvious.

There is a point where protective measures can impair health; excessive protective clothing may raise risks of other health impacts, such as heat stroke. An example of an unworkable requirement was proposed but not enacted by the U.S. Environmental Protection Agency (USEPA) several years ago. Forest applicators (but not agricultural applicators) were to be required to wear very complex and impermeable protective gear, until it was shown that in a work situation the garments would result in heat prostration and possibly death for workers, with little real reduction in exposure.

Immediate cleanup of spillage on skin or clothing is critical, and all operations should be organized for easy personal and equipment cleanup. Wester and Maibach (1985) have shown that immediate washing can sharply diminish absorption. In the case of 2,4-D, washing 15 minutes after application to the skin limited absorption to only about 20-25% of the amount absorbed when washing was delayed to four hours. The efficiency of washing appeared to be about the same regardless of the amount applied. Such a finding should not be a surprise because absorption is not instantaneous; the longer the period of contact, the more material can be expected to enter the body. Another factor is the binding of a chemical within the skin itself, from which it may eventually either enter the body or move outward to be sloughed away. Binding to skin tissue also takes time, and quick removal limits trapping of a chemical within the skin itself.

The role of solvents in which the herbicides are dissolved is also important to absorption. Moody et al (1992) showed that 2,4-D in acetone was absorbed about twice as effectively from the human forearm as when dissolved in water. (7% and 13%; variability among subjects was very high.) There may be a similar differential in the case of kerosene or similar hydrocarbons. They also evaluated the effect of the insect repellant DEET (N,N-diethyl-m-toluamide) on absorption of 2,4-D, and found little difference. This is important because DEET is very commonly used and is known to enhance absorption of some drugs from the skin.

A common source of exposure is equipment and facilities that have not been kept clean. Frank et al (1985) examined vehicles, dwellings, appliances and other items handled by workers and found 2,4-D to have been conveyed away from the application site in amounts possibly sufficient to be secondary exposure sources to workers, family and associates. All of these exposure factors can be easily controlled by workers and managers exercising basic care.

The work most frequently used as a basis for estimates of forestry ground applicator exposure was published by Lavy et al (1987) (Appendix Tables 1: A-1, A-2). They measured urinary excretion of 2,4-D in four groups of 20 workers for a week following application by several methods. On day seven, they repeated the application, then collected urine through day 12. In the second application new leather gloves and boots were used to test protective measures, and workers washed immediately if any spillage occurred. Unfortunately, those measures made no real difference in exposure. Leather soaks up and retains the herbicide and holds it in contact with the skin. Good gloves, preferably of unlined nitrile, and unlined rubber boots (both with replacements immediately available for use as needed), would have made a significant difference in exposure. The real value of this work is its description of the range of exposures that occur when applicators work without elementary protection other than work clothing. The absence of proper gloves is of particular importance.

Deficiencies aside, the work provided a great amount of information. The striking finding for backpack applicators was the difference between the high and low values. At the end of the week following the first application the highest total recovery of 2,4-D from an individual was five times higher than the lowest. At the end of the second week the highest total excretion was eight times higher than the lowest in that set (Appendix Table A-1). Average doses were 0.088 mg/kg for week one and 0.098 for week two; it is apparent that "protective" measures were not well conceived. In the same study, backpack application of dichlorprop, another phenoxy herbicide, also led to wide differences between high and low intake.

For two methods using injection of concentrated herbicide, exposures during the second week were lower. Usually a dye is added for these methods to show where the treatment has been done, and it may heighten consciousness as well. Insistence on gloves may also have been beneficial by bringing worker attention to good hygiene even if the type of glove was not useful.

The program produced another interesting insight into applicator diligence. In one segment, five of the subjects were employees of private contractors, 15 were US Forest Service employees. Average excretion by the contractor group for the first week was on the order of ten times greater than that of the USFS employees, 0.089 mg/kg vs. 0.0085 mg/kg. For the second week the difference was almost as great (Appendix Table, A-1). There may have been a difference of about 25% in the amount of material applied, and the commercial workers reported that their equipment was leaky. The lessons in that information about careful work, well maintained equipment and proper supervision seem obvious.

An earlier study by Lavy et al (1980a) measured total urine recoveries over five days after a single operation with 2,4,5-T. The doses to backpack operators ranged between 0.015-0.081 mg
2,4,5-T/kg body weight (Appendix Table 1-B). The supervisor/mixer for the group excreted only 0.009 and 0.008 mg/kg after the two applications. This individual routinely wore gloves, while others did not. The pilots of the two crews had sharply different exposures; one excreted 0.0004 and 0.01 mg/kg, the other excreted 0.033 and 0.035 mg/kg. The difference was in the habit of the second pilot of inspecting and cleaning nozzles after each application, an inappropriate practice. Mixer/loaders of the two

crews excreted a range of 0.042 to 0.116 mg/kg in the four applications, averaging 0.077 mg/kg. Exposures of flaggers and supervisors were quite low. (It appears that there are discrepancies in the arithmetic in Table III of Lavy et al (1980a), which contains the essential data of the study. The daily outputs of 2,4,5-T in urine have been re-added and the pre-treatment backgrounds subtracted).

Observations of 2,4,5-T are applicable because 2,4,5-T too is excreted completely and unchanged in a few days, thereby serving as a good indicator of the actual amount of herbicide that reached a surface from which it could be absorbed. Although there have been no direct measurements of the efficiency of skin absorption for 2,4,5-T, it is likely that it is similar to that of 2,4-D because of the similarity in the chemical and physical character of the two compounds. Triclopyr also should be expected to be processed similarly to 2,4,5-T. Absorption of the ester form of triclopyr across the skin of the forearm of humans was found to be less than 2% after eight hours of contact (Carmichael et al, 1989). In this study the applied material was covered by a bandage, which increases absorption and would lead to higher estimates than would occur under normal field conditions. An ester formulation was used, which should have a greater absorption potential than an amine, so the amounts found should represent the high end of expected intake.

Laboratory studies of 2,4-D absorption from the forearm suggest that about 6% will be absorbed in 24 hours (Feldmann and Maibach, 1974). Similar evaluation of triclopyr indicates a rate of 2% in eight hours. It may be inferred from Wester and Maibach (1985) that at 8 hours 2,4-D absorption may be comparable with that of triclopyr. Other work (Moody et al, 1990) indicates that some areas of the body may absorb as much as 50% of applied material. It is unwise to accept any of these absorption rates as representative, because absorption rates vary with site on the body surface. Excretion in urine after field application is the best indicator of absorption because movement through all skin areas is integrated. Various field observations suggest that operational exposures lead to absorption rates of about 2%.

Another study by Lavy et al (1982) evaluated aerial applications of 2,4-D, with crews wearing special clothing intended to maximize protection, although not to the extent of wearing “moon suits.” Of more than 500 urine samples, only 30% contained detectable residues, still another testimony to the value of reasonable care. (Data not shown)

Grover et al (1986a, 1986b) observed farmers as they applied 2,4-D amine, using their own equipment and procedures, at rates they judged appropriate for their needs. In spite of widely divergent conditions, it was still possible to learn a great deal about exposure and work habits. Total exposure of the hands was usually much greater than total exposure of the rest of the body, despite the much greater surface area. There were two exceptions, both of which involved high total exposure, possibly from spills. Patches located under two layers of clothing were found in most cases to contain quite small amounts of herbicide, illustrating the protective role of ordinary clothing. Inhalation accounted for a very small fraction of total exposure, which is consistent with many other studies. Inhalation exposure is measured with samplers located in the breathing zone, and correlated with the respiration of the subject. (See also Chester and Hart, 1986; Abbott et al, 1987.)

Knopp and Glass (1991) measured excretion by two operators of tractor mounted sprayers. Total dose absorbed by an operator who was fully clothed was 0.0057 mg/kg, and 0.085 mg/kg for the other, who was scantily clad above the waist. These numbers are consistent with the findings of Grover et al (1986b, 1986b). Nash et al (1982) found ground applicators to have average total urinary 2,4-D outputs of about 0.005 mg/kg over a week following a single exposure. Average doses of workers who mixed herbicide and loaded spray equipment were similar to those of applicators. Doses to workers who mixed, loaded and applied herbicides were about twice as high as doses to those who only applied the material (Appendix Table C-1.). The ranges of findings were very large, with only a limited relation to amount applied.

Right-of-way sprayers using handguns fed from vehicles, and mistblowers, were observed by Libich et al (1984). Average amounts of 2,4-D excreted by applicators using handguns was on the order of 2 mg, presumably per day. For a 60-kg worker, that amount represents a daily dose of 0.03 mg/kg body weight. (In this paper there is some confusion about time periods. Also, concentration in urine output is expressed as mg/kg. In this case this means parts per million in the urine, which should be stated as mg per litre. Terminology of mg/kg can easily be misinterpreted to mean dosage per unit body weight.)

Harris (1991) reported on exposures of professional urban applicators, home gardeners and bystanders in a thesis and in subsequent publications. (Harris et al, 1992, Harris and Solomon, 1992) The higher homeowner exposures were consistently associated with spills of concentrate or excessive amounts of dilute material, on unprotected body surfaces. Professional lawn-care applicator exposures ranged between 0.0017 and 0.0055 mg/kg/day. The differences were apparently associated with worker discipline and care, not the amount applied (Appendix Table E). Yeary (1986) also observed lawn care applicators, finding a somewhat lower minimum and similar maximum (Appendix Table F)

Urinary output of 2,4-D by aircraft mixer/loaders and pilots with intermittent to continuous exposure over a 12-day period was reported by Nash et al (1982). The average daily urinary output of 2,4-D for mixers was 0.02 mg/kg body weight/day and was 0.006 mg/kg/day for pilots. The highest daily output was 0.054 mg/kg/day among mixers and 0.020 mg/kg/day among pilots. (Appendix Table C-2)

Frank et al (1985) followed six workers and a “bystander” involved in aerial application of 2,4-D iso-octyl ester in conifer release operations. In one sequence, three workers mixed 109 loads over 11 days, leading to maximum daily excretion of 0.0003, 0.00094 and 0.0096 mg/kg. (Appendix Table D-1) Two of these workers also rinsed drums, cleaned nozzles and repaired leaks, activities that lead to significant exposure. In a second series, three workers were observed, one who mixed and loaded and two who marked swaths with balloons. Over an 18-day period the highest daily outputs of 2,4-D in urine for each were 0.0077, 0.0084 and 0.0222 mg/kg. (Appendix Table D-2) In extended exposures such as these, with a more or less constant input, it is expected that the urinary excretion will reach a steady state. Ideally, the output will be the same as input, and the maximum daily output would be a conservative indication of daily dose. These figures illustrate the low actual exposures that can be maintained in a potentially high-exposure activity.

The “bystander” deliberately allowed himself to be sprayed directly while wearing shorts and short-sleeved shirt. Two accompanying subjects wore full protective gear, which was analyzed to provide an estimate of the amount that had reached the skin and clothing of the unprotected subject. The maximum daily excretion was 0.005 mg/kg, leading to a conclusion that less than one half percent had been absorbed. If it is assumed that 65% of the body was protected, the absorption rate may be estimated at about 1.5%. This finding for 2,4-D ester is consistent with other information about absorption of the amine salt of 2,4-D. The low absorption of triclopyr ester has already been mentioned. These findings do not support the assumption that ester formulations should be absorbed more readily than either the parent acid or amine salts because of their greater lipid solubility.

Chester and Hart (1986) compared percentage absorption with a method that indicated the rate of absorption per square centimetre per hour. They found that rate estimation per unit area was more consistent than a whole-body estimate of the fraction of exposure actually taken into the body. They used Fluazifop-butyl as a model compound, which should have absorption and excretion characteristics similar to those of 2,4-D. The study compared deposition on full protective gear with collection in urine from applicators working with bare arms and legs who showered after eight hours. The reasoning was similar to that of the single subject experiment of Frank et al (1985) mentioned above. The calculated rate of absorption was about 0.00005 mg per square centimetre per hour. About one percent of the skin exposure was absorbed, which is on the same order as other estimates of 2,4-D absorption. As have other investigators, they found that inhalation accounts for a very small fraction of the herbicide brought into the body.

It is important to do other work to confirm this kind of method, because it should provide more accurate dosage information, and will incidentally encourage greater care in handling pesticides.

In a somewhat different approach, Abbott et al (1987) studied two applicators who worked in turn with each of five kinds of equipment (tractor drawn, tractor carried, controlled droplet mounted on tractor, backpack boom, backpack lance). The applicators did six replications for each method. The operators wore full protective suits with face exposed. After each run the whole suit was cut up according to body regions and analyzed for 2,4-D. Urinary excretion was not measured. Unlike some observations, operation of backpack equipment produced lower exposures than the machine systems, but variability was very high. There was a common thread in this work. As in all other studies, during application by each method as well as in mixing and loading, exposure on the hands was much greater than on the rest of the body by at least ten fold. Respiratory exposure was again found to be low.

Another important observation was that most of the exposure to areas other than the hands was on the lower legs. Lengerich and Burroughs (1989) have made the same observation.

In the tabulated findings of the reports mentioned above, it is obvious that there is considerable variation in the findings, and that the various methods discussed are quite different. Even with the broad variation in findings, specific data on real applicators, shown in items A through H provide a realistic “sense” of what a forest worker is likely to encounter.

Contact with Treated Vegetation

Contact with vegetation at the time of herbicide application is likely to be a significant source of exposure to applicators. Such exposure is automatically included in total exposure findings from studies of ground application on brush discussed above, but there has been little effort to separate exposure acquired from the spray itself from that picked up from wet foliage. It may eventually be possible to estimate the direct deposition and wet vegetation contact exposures separately with the methods described by Lengerich and Burroughs (1989) but such work has yet to be done.

Other forest workers, such as planters, may be concerned about entering an area that has been treated at some time. Apparently the only information describing dislodgement from vegetation in the forest context arose from one subject wearing collector patches who walked through brush two hours after treatment with an ester of 2,4,5-T (Lavy et al, 1980b). No measurable residues were found on the patches, but this information is too scanty to permit judgement.

The question has been studied in more detail with respect to applications on lawns and turf. The information seems quite pertinent to the forestry question, with the caveat that there may be some differences among chemicals because of differences in their interaction with components of the environment. However, it is likely in each case that when the application has dried, very little transfer will take place.

Two studies are particularly informative. Thompson et al (1984) applied 2,4-D amine to grass plots and found that less than 5% could be dislodged with a cheesecloth wipe immediately after application. After one day and 18 mm rainfall, less than 0.01% could be removed by wiping. Without rain, the same decrease was achieved in seven days. After application of 2.24 kg acid equivalent 2,4-D liquid formulation/hectare dislodgeable residues were less than 1% in three days. Harris and Solomon (1992) exposed volunteers to turf at one and 24 hours after it had been treated with 2,4-D, as well as measuring surface dislodgement by scrubbing the turf with cheesecloth. The subjects stayed on a 2 m x 15 m area of turf, alternating among walking, sitting and lying on the surface for a period of one hour. One group was exposed at one hour after application, the other at 24 hours. Urine was collected for 96 hours. The highest individual uptake of 2,4-D in the first group was 0.0054 mg/kg. 2,4-D could not be detected in the urine of six of the nine subjects. No urinary 2,4-D was detected in the group exposed 24 hours after application.

Dislodgement from foliage should not be expected to differ appreciably among vegetation species, although waxy species may not absorb or bind water-soluble formulations efficiently. Contact as soon as one hour after treatment will probably result in minimal exposure, and after 24 hours exposure should not be detectable. It is extremely unlikely that workers (or passers-by) who enter a treated area the day after application will have a detectable exposure.

Exposure Following Burning of Treated Vegetation

There is widespread perception that when herbicides burn, products of great toxicity may be produced, leading to both respiratory and dermal exposure. Certainly, when large amounts of chemicals in storage burn, the parent substance, solvents and any combustion products may be in high concentration in the smoke, and opportunity for exposure in the immediate vicinity is high. Structural materials also contribute combustion products to the mix. Smoke is hazardous regardless of the source.

The question of potential health impacts resulting from burning herbicide-treated vegetation was examined by Dost (1982) in a report to the Bonneville Power Administration. The first part of the question is identification of the potential products of herbicide combustion in the presence of oxygen. Almost all of the carbon of any herbicide that is broken down in a fire will become carbon dioxide and carbon monoxide. However, in a fire in the woods, the amounts are trivial compared to the thousands of times greater production of the same substances from burned vegetation.

There is sufficient information on combustion of organic compounds in general and herbicides in particular to enable worst case estimates of products that can arise and concentrations that may be encountered. Almost all of the chlorine from chlorine-containing molecules such as 2,4-D and triclopyr will be converted to hydrogen chloride (in water solution, hydrochloric acid). This reaction is analogous to the formation of water from oxygen and hydrogen. In the laboratory very small amounts of chlorine gas and phosgene can be produced from 2,4-D under forced, high pressure, high concentration conditions, so it was assumed for the analysis that they were possible products in the field. It was also assumed that ammonia and cyanide could arise from nitrogen containing herbicides such as glyphosate, triclopyr and hexazinone. The phosphorus of glyphosate has been shown to form some phosphorus pentoxide (in solution, phosphoric acid), and glyphosate also produces a small amount of acetonitrile when burned.

The next part of the question is estimating how much of each product will be formed, and the maximum exposures that might occur.

For purposes of the estimation, it was assumed that no degradation of herbicide occurred in the period following application. The amount of smoke produced per unit fuel is reasonably known, as is the visibility limit relative to smoke concentration. This information provided an estimate of the volume of distribution of the herbicide or its products in the air, which could be related to respiratory ventilation of an active person. It was also assumed that the entire available amount of herbicide was converted to each possible product in turn, including the parent compound, and distributed in the smoke. For example, in one exposure scenario all of the chlorine in 2,4-D was assumed to form phosgene, and in another it was assumed that all of the chlorine became chlorine gas. These assumptions were used even though it is known that such reactions are difficult to accomplish even in the laboratory. However, they provide the absolute theoretical upper limit of production, and therefore exposure.

Assumptions for the burning site were: 1 pound herbicide/acre (1.12 kg/ha) and 20 tons fuel/acre (45,000 kg/ha), and 8.5 gm particulate/kg fuel. 45,000 kg x 8.5 g = 382 x 10^6 mg particulate. Visibility in smoke is assumed to be 100 metres with a light extinction of 0.5 gm particulate/ square metre; this translates to 5 mg/cubic metre. With those conditions the combustion products are distributed in 76.5 x 10^6 cubic metres of air. The fire fighter was assumed to weigh 70 kg and experience one-hour exposure, at a respiratory ventilation rate of 3 m^3/hr. Different assumptions of application rate, fuel load, visibility or exposure time can be incorporated by simple arithmetic. The hypothetical exposures are compared with exposure limits set by the Workers' Compensation Board of B.C., effective 1999.

With these assumptions, if all of the nitrogen in glyphosate formed ammonia, the concentration cannot be more than 0.0023 $mg/m^{3,}$ compared with a WCB 8-hour exposure limit of 17.4 mg/m^3. The difference is more than 7000 fold. Application of ten times more herbicide or a decrease of ten fold in distribution volume would have little effect. For hydrogen cyanide (HCN) the WCB limit is an instantaneous maximum of 5 mg/m^3, compared with a hypothetical yield of 0.0056 mg/m^3, a difference of almost 900 times. If the chlorines of triclopyr emerged entirely as chlorine gas the concentration would be 0.0065 mg/m^3, compared with the WCB figure of 1.45 mg/m^3. For phosgene the numbers are 0.0091 compared with 0.405 mg/m^3. For all other possible products, similar comparisons emerge.

All of the potential products of forest herbicide combustion are common industrial chemicals for which workplace standards are established. Even with the extreme maximizing assumptions used, it is clear that the amounts of herbicides or their combustion products that can move into the atmosphere following burning of herbicide-treated land do not approach levels that can produce adverse responses.

Attempts to measure herbicides in smoke from prescribed fires on treated areas have not been successful, at sensitivities as low as 0.1 ug/m^3 (McMahon and Bush, 1992).

Recommendation of Exposure Standards

As a means of generating useful discussion of questions relating to exposures of forest workers to herbicides and other forestry chemicals, this report suggests that consideration be given to development of exposure standards for forest workers, particularly those handling herbicides.

If standards are established, they can be based on both health criteria and best management practices. Because the margins of safety for herbicides are high, they represent a reasonable point of departure. For exposures to chemical insecticides, or to power tool exhaust, which represent vastly greater risks, development of exposure criteria and monitoring will be a much more delicate process.

What should be the standard that governs exposures of workers in the forest to herbicides? There are no existing data to show what lower limit of exposure can be achieved through best management practices. It is not possible to estimate current exposures to forest workers, other than historical information already reported. It is also impossible to employ some statistical protocol that distinguishes sloppy workers or project managers from those who are careful. These necessary objectives can only be met through application of diligence and care out on the ground.

The wide variation in the data shown in the Tables (Appendix) tells us that application of herbicides in all uses has resulted in much greater exposure than is necessary. Common sense tells us, just as do numerous research papers, that the higher exposures result from poor equipment, improper clothing, lack or misuse of hand and leg protection, poor training and poor management. It is immaterial that the exposures represent very low risk.

In the past, data arising from both good and poor operations have been used to arrive at some average exposure to be used as a predictor of field exposure and risk. That approach is no longer appropriate because it implies that less than careful work is acceptable.

Procedures are improving continually, but the fact that forestry chemicals as a class are not significant toxicants has led to a more casual attitude than even these rather benign substances can justify. It is necessary to invoke both common sense and professional judgement to propose an exposure standard that can be achieved with reasonable care and discipline in the workplace. Worker protection policy should then be constructed to assure that those limits are met and that standards should be reviewed periodically. At the same time, there must be caution that policy does not overreact to produce unworkable demands.

The problem that remains after a commitment to lower exposures is to determine what level of exposure is acceptable, then to learn how well workers and crews are meeting that objective, then to learn how to further reduce exposures.

Suggested courses of action toward this objective are as follows:

1. A provisional maximum generic herbicide intake standard for workers should be established. An initial arbitrary working standard of 0.02 mg/kg/day for ground applicators (using hand-held equipment) and mixer/loaders seems reasonable for these functions which confer the greatest exposure. The same standard can initially be used for all forest herbicides, with evaluation by urine sampling or other measurement of absorbed dose.
2. An advisory body should be established to examine and modify the provisional standard as needed, determine if standards should be applied to other job functions, and define simple work practices that will meet requirements.
3. A series of worker monitoring studies based on urinary sampling should be devised by the advisory body that will show clearly the results of good practices and provide an empirical database to support the standards to replace the generic level. A program of random sampling should be considered.
4. A program should be established for investigating, analyzing and responding to any herbicide (or other pesticide) related events that might lead to undue exposure or perception of exposure of workers or the public. There are highly successful programs elsewhere that can serve as models; the Oregon and California programs deal with all pesticide incidents (the author was associated with the Oregon program for 11 years).
5. Worker training should be evaluated and if necessary modified to aid in meeting the standards.
6. Excellent exposure histories as demonstrated by sampling should be rewarded. This report does not attempt to advise how this might be accomplished.

7. Any formal standards should become part of the standards for best management practices overseen by professionals from appropriate agencies.

Use of urine sampling as a means of detecting poor practices is likely to raise objections until workers are assured that the program is not a cover for other kinds of observations.

A common exposure standard for all forest herbicides may logically be questioned because of differences among the chemicals. However, handling and application procedures are reasonably similar, characteristics of absorption across the skin are similar to the extent they have been studied. Glyphosate, 2,4-D esters and amine salts, and triclopyr ester appear to be absorbed only to the extent of about two percent of surface contact in field operations, on a whole body basis. At most 5% absorption may be expected. Skin areas of high permeability, such as the forehead, neck and scrotum are not usually exposed if suitable safety clothing and equipment are worn. Absorption of hexazinone across skin has not been measured, but its solubility characteristics and animal experiments indicate that absorption is very limited.

It remains to ask whether the toxicology of the respective herbicides, as distinguished from use patterns, justifies a common standard. They certainly vary in both the toxicological pattern and their general potency, but the dose-response for each provides an adequate margin of safety at the suggested provisional exposure limit. Differing criteria within the group of registered forestry herbicides would probably create practices based on a lowest denominator, and generate confusion among workers. If a common standard for herbicides is adopted, every precaution must be taken that the same standard is not applied to insecticides, a much more toxic group of pesticides.

Public apprehension about use of herbicides in forestry is real, and quite out of proportion to very limited concerns about agricultural and household uses of the same chemicals. Establishment of exposure standards for applicators is another way of demonstrating that forestry operations are not indiscriminate and threatening, and may lead to better practices in areas outside forestry.

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Glossary

Acute toxicity – (Short term toxicity) –Acute toxicity is the quality or potential of a substance to cause injury or illness from a single dose or short period of exposure. See **subacute, subchronic and chronic.**

Adjuvant – Any additive to a pesticide formulation that is not active itself, but is intended make the active ingredient work better.

Cancer – A malignant growth of potentially unlimited size that invades local tissues, and may spread to other parts of the body

Carcinogen – A chemical capable of inducing cancer.

Carcinogenic – Capable of causing cancer

Chronic toxicity – (Long-term toxicity)- Chronic toxicity is the quality or potential of A substance to cause injury or illness after repeated exposure for a long period of time. Chronic toxicity tests run for a year or more; for rodents the period may extend through the entire life span. A chronic effect persists for months or years and may arise from acute or long term exposure. See **acute, subacute, subchronic.**

Deoxyribonucleic Acid – See **DNA**

Degradation – Breakdown of a compound by physical, chemical or biochemical processes into basic components with properties different from those of the original compound.

Detection limit – The lowest concentration of a chemical that can be identified in a substance (e.g., soil, foliage or body fluids). Analytical sensitivity varies among chemicals, and in different media. The detection limit is usually lower than the level that can be reliably measured. For example, it may be possible to find a substance present at 0.01 parts per billion, but only at levels above 0.03 ppb can the amount be stated.

Dose – The amount of a chemical that actually enters the body to be distributed to all of the organs and cells. Distribution to tissues and cells is selective, and depends on the nature of the chemical and characteristics of each kind of cell.

Dose-response relationship – The central idea in toxicology and in pharmacology (which is the science dealing with beneficial effects of therapeutic drugs). As the dose (or concentration) of a chemical increases, the effect increases, and as the dose is lowered, the effect becomes less. This response pattern applies to every interaction between a chemical and a biological system, whether human, fish, bacteria or any other kind of organism or tissue. The dose-response relationship is absolutely essential to judgement of the effect of any chemical.

DNA (Deoxyribonucleic Acid) – The genetic library in each cell that contains all of the instructions for building and operating the body. Each kind of cell contains all of the information for the whole body. Only the information needed for each kind of cell is used by that cell; the rest is repressed. Liver cells do not try to be muscles, and muscles do not try to become brain cells, but they contain all of the information**.**

Epidemiology – The scientific study of the cause, distribution, and control of epidemics or other disease in a region. In the context of these reports, epidemiology is the study of possible associations between environmental and occupational chemicals and occurrence of diseases. The term “associations” is used in its statistical sense, which means that the relationship cannot demonstrate cause and effect.

Exposure – Amount of a chemical that reaches a surface from which it might be absorbed. The dose is some fraction of the exposure. Exposure does not include material that is on nearby foliage or other surfaces. It is only the material that reaches the skin (by contact), respiratory tract (by inhalation) or digestive tract (by ingestion).

Formulation – A complete pesticide preparation as sold by a manufacturer for practical use. It includes the active ingredient and any necessary adjuvants and solvents. For use, it may or may not require further dilution or mixing with other substances. Formulation can also be defined as the process used by manufacturers in preparing a pesticide for practical use.

Half-life – The length of time required for disappearance of half of the material present in an organism or in environmental media. It is a more useful idea than "persistence" because it allows prediction of the time required to reach low target levels with out making measurements over exceedingly long periods. A better term is "Half-time," because the information only relates to a given location, and says nothing about the processes that deplete the chemical. If it evaporates or is carried away intact by water it may still exist in its original form. The term "half-life" originated with description of radioactive decay, in which elements become a totally different substance. The English language sometimes loses precision as it evolves.

Hazard – The kind of effect that a chemical can cause. Cancer, liver disease, skin irritation, reproductive problems, or some other more or less specific response that can be defined and measured. The term is also used non-specifically to signify any dangerous situation.

Herbicide – A chemical substance or cultured biological organism, used to kill or suppress the growth of plants.

Immune system – All of the structures and cells and their products that protect against infectious organisms and against cells of the body that have become altered in the very early development of cancer.

Irritation – A purely local or topical reaction which may include redness, blistering, swelling, burning or itching.

LD_{50} – Acronymn for Median lethal dose.

Lethal – Causing death.

LOAEL – Acronym for lowest-observed-adverse-effect level.

Lowest-observed-adverse-effect level (LOAEL) – The lowest measured amount of a chemical that produces significant increases in frequency or severity of adverse effects in exposed subjects. in the general sense it includes all biochemical, pathological, behavioral, reproductive, genetic and other measurable changes. the term may also be applied to any specific parameter under observation.

Malignant – Deadly or very injurious. As applied to cancer, invasive of local tissues and metastatic (migration of cancer cells to other tissues).

Margin of Safety (MOS) – The difference between the estimated dose of a pesticide and the NOAEL. A **MOS** of 100 (estimated dose 100 fold less than the NOAEL) is usually considered to assure that no adverse effects will occur.

Median lethal dose (LD_{50}) – The dose of a chemical, biological agent, or other substances that causes death in 50% of defined test animals.

Metabolism – the sum total of the biochemical reactions that a chemical undergoes in an organism. The processes include biochemical (enzymatic) reactions in the cells of the body that convert nutrients to energy and structural materials of the body; reactions that change wastes so they can be removed; and reactions that convert foreign substances, such as some pesticides to forms that can be excreted.

MOS – Acronym for margin of safety.

Mutagenic – Capable of producing genetic changes.

Mutagens – Chemicals that are able to induce gene or chromosome damage that is stable and survives cell division to reach the next generation of cells. See **mutation.**

Mutation – Genetic change in DNA of a cell that can be transmitted to the next generation of cells. If in sperm or egg cells, a mutation may be transmitted to offspring. If in somatic (body) cells such as liver, muscle or other organs, a mutation may pass to daughter cells in the organ. The change may have no effect on cell function or it may damage the cell, or even imaginably improve it.

NOAEL – Acronym for **no-observed-adverse-effect level.**

No-observed-adverse-effect level (NOAEL) – The dose rate or concentration at and below which no adverse effects can be detected. (See **threshold; SEE LOAEL)** If the estimated dose of a herbicide to a worker is very low compared to the **NOAEL** for the most sensitive effect found in the laboratory, no harmful effect is to be expected.

NOEL – Acronymn for **no-observed-effect level.**

No-observed-effect-level – (NOEL)-Dose of a chemical or biological agent at which there are no biologically or statistically significant effects attributable to treatment. The term can refer to adverse, beneficial or meaningless effects and is falling out of use in toxicology.

Persistence – The duration of measurable concentrations of a pesticide in soil, foliage or other media. See **Half-life**.

Pesticide – Any chemical (or biological product) intended to control or kill pests. Herbicides, insecticides, fungicides are all pesticides. The term is sometimes incorrectly used to mean only insecticide, for example "pesticides and herbicides."

Pharmacokinetic – Relating to the rate and pattern of the absorption, distribution, metabolism and excretion of drugs in an animal.

Registration – The process by which government (e.g., Canadian federal government) authorities determine that a pesticide is suitable for use. Standards of public and worker safety, environmental impact, and usefulness must all be met.

Risk – The probability (likelihood) that some adverse or undesirable effect will take place in the future, as a result of some specified activity. Risk may relate to health, finances or any other kind of undesirable impact. Real risk may be so small that it cannot be distinguished from zero, or so great that it is a certainty. In the context of pesticides, risk is the probability that use of the pesticide will result in some specified harmful effect on workers or the public. Risk assessment is the process of estimating that probability.

Safety Factor – See **Margin of Safety**

Subacute – Extending over a few days to perhaps a month. This and related terms do not carry defined time periods; consequently there is overlap in the way they are used. See **Acute, subchronic and chronic.**

Subchronic – For experimental studies, relatively long term, but not as long as a chronic study. Typically three to six months. See **acute, subacute, and chronic.**

Teratogen – A chemical that can cause birth defects.

Teratogenic – Relating to or able to produce birth defects.

Threshold – The lowest dose that will produce a given effect. As a practical matter, the threshold is little different from the **NOAEL.**

Tolerance – Lesser than normal sensitivity of an individual to the adverse effect of a chemical. also, the allowable residue of a pesticide on a food or feed crop.

Toxicant – A toxic agent; a poison.

Toxicity – The whole pattern of harmful effects (illness and other undesirable effects) that a chemical can cause. It is a property of the chemical; it does not change.

Toxicology – The group of scientific disciplines that identifies and studies the adverse effects of chemicals on biological systems, whether in the laboratory or in the field.

APPENDIX: Herbicide Exposure Data and Estimates from Various Sources

Table A-1: Description: US Forest Service and contractor applicators, backpack and hack and squirt. Two single applications of 2,4-D on day 1 and day 7; urine collection for six days including before application. Source: Lavy et al (1987)

			mg/kg		
			low	high	average
Backpack	Week I	n=20	0.036	0.184	0.088
2,4-D	Week II	n=20	0.03	0.245	0.098
Hack&Squirt	Week I [1]	n=15	nd	0.031	0.008
Week II,[1]		n=15	nd	0.019	0.004
Week II,[2]		n= 5	0.012	0.060	0.034

[1] USFS employees

[2] Contractor employees

Table A-2: Description: Backpack, same program as B1, with dichloprop. Source: Lavy et al (1987)

			mg/kg		
			low	high	average
Backpack	Week I	n=20	0.043	0.124	0.085
	Week II	n=20	0.026	0.178	0.083

Table B: Description: Doses of 2,4,5-T acquired by six backpack sprayers, the supervisor/mixer for the crew; pilots and mixer/loaders of two helicopter crews. Each worker observed following two applications. (One backpack sample series was lost.) Urine collected over four days post application. Data from publication appears to contain arithmetic errors and has been recalculated. Source: Lavy et al (1980)

		mg/kg		
		low	high	average
Backpack sprayer	(n=11)	0.015	0.081	0.045
Supervisor/mixer		0.009	0.008	
Pilot # 1		0.004	0.010	0.007
Pilot # 2		0.033	0.035	0.034
Mixer/loader	(n=4)	0.042	0.116	0.077

Table C-1: Description: Ground rig application in agriculture. Single application, six day urine collection. Values for one applicator, one M/L/A omitted because levels absurdly high. Source: Nash et al (1982)

		mg/kg		
		low	high	average
Application only	n=9	nd	0.018	0.005
Mixer/loader	n=7	0.002	0.016	0.007
Mixer/loader/applicator	n=8	0.004	0.035	0.018

Table C-2: Description: Aerial application in agriculture. 12 day exposure. Values are average daily excretion. Source: Nash et al (1982)

		mg/kg		
		low	high	average
Mixer/loader	n=7	0.001	0.054	0.02
Pilot	n=10	0.001	0.02	0.006

Table D-1: Description: Aerial. Two workers and supervisor. Mixed and loaded 4,797 kg 2,4-D ae in 109 loads over 11 days. 18 day urine collection. Dose estimates based on highest (not average) daily excretion. Source: Frank et al (1985)

	mg/kg
Supervisor	0.0003
Mixer/loader I	0.0009
Mixer/loader II	0.0096

Table D-2: Description: Three workers. Mixed, loaded, flagged over 18 days, with urine collections additional 13 days. Dose estimates based on highest daily excretion. (1982 study). Source: Frank et al (1985)

	mg/kg
Mixer/loader (5658 kg 2,4-D ae total)	0.022
Mixed (1553 kg 2,4-D ae, balloon marker)	0.008
Flagger (balloon marked 498 swaths)	0.008

Table E: Description: Eleven lawn care applicators, working over 14 day period and one manager/mixer/loader. Formulations were 2,4-D with other herbicides.
Source: Harris (1991)

		mg/kg		
		low	high	ave
Applicators	n=11	0.0017	0.005	0.003
Manager/mixer/loader	n= 1			0.001

Table F: Description: 45 lawn care applicators. Each provided a single 24 hour sample assumed to represent steady-state urinary output of 2,4-D over work season. Source: Yeary (1985)

		mg/kg		
		low	high	ave
Applicators	n=45	0.0003	0.006	–

Table G: Description: Eight agricultural ground rig operators conducting one to seven operations, spraying 22.7 to 186 kg 2,4-D ae over varying time periods. Urine collections from first operation to seven days after last spray. Values are total excretion, not single day value. Two subjects omitted because of serious data inconsistencies. Source: Grover et al (1986b)

		mg/kg		
		low	high	ave
Applicators, ground, (Ag)	n=8	0.002	0.013	0.006

Titles in this Series

1 Principles of health effects evaluation and risk estimation for chemicals that may be encountered in forest vegetation management

2 Pesticide testing for registration: toxicity, environmental behaviour, and epidemiology

3 Toxicology and potential health risk of chemicals that may be encountered by workers using forest vegetation management options. Part I: Risk to workers associated with exposure to emissions from power saws

4 Toxicology and potential health risk of chemicals that may be encountered by workers using forest vegetation management options. Part II: Exposure to and absorption of herbicides used in forestry

5 Toxicology and potential health risk of chemicals that may be encountered by workers using forest vegetation management options. Part III: Risk to workers using 2,4-D formulations

6 Toxicology and potential health risk of chemicals that may be encountered by workers using forest vegetation management options. Part IV: Risk to workers using glyphosate formulations (e.g., Vision®, Roundup®, Vantage Forestry® and Forza®)

7 Toxicology and potential health risk of chemicals that may be encountered by workers using forest vegetation management options. Part V: Risk to workers using hexazinone formulations (Pronone®, Velpar® L)

8 Toxicology and potential health risk of chemicals that may be encountered by forest vegetation management workers. Part VI: Risk to workers using triclopyr formulations (Release®, or Garlon 4®)

9 Toxicology and potential health risk of chemicals that may be encountered by workers using forest vegetation management options: Summary

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For more information contact:
Dr. Jacob O. Boateng
Vegetation Management Specialist
BC Ministry of Forests
Forest Practices Branch
P.O. Box 9513 Stn. Prov. Govt
Victoria, BC V8W 9C2
Phone: (250) 387-8905
Fax: (250) 387-2136