
Fire Management

**ASSESSMENT OF THE EFFECTIVENESS AND
ENVIRONMENTAL RISK OF THE USE OF RETARDANTS
TO ASSIST IN WILDFIRE CONTROL IN VICTORIA**

Research Report No. 50

Prepared by CSIRO Forestry and Forest Products for the Department of Natural Resources and Environment.

February 2000

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FOREWORD

Topography, vegetation and climate combine to see Victoria, southern California and the south of France as places experiencing the most severe wildfire climates on Earth.

One third of Victoria comprises publicly owned land. These parks and forests are often rugged and remote, with limited access. In an average year around 600 wildfires occur on these lands, and between 20-30% of these are caused by lightning. Over the last twenty years the average annual area of public land burnt by wildfire has exceeded 100,000 hectares. In the last 150 years in Victoria wildfires have resulted in considerable loss of life, and much property damage.

These factors have led to the development in Victoria of a range of approaches to deal with wildfires. With few large natural water sources available, techniques developed are generally known as ‘dry firefighting’. They primarily involve removing fuels from the path of the wildfire using hand tools and/or machinery. Fire is also sometimes used in combating a wildfire. Firefighters light fires, at times of the day or night when fire behaviour is more predictable, to burn fuels ahead of the main fire.

The use of aircraft to assist in wildfire management commenced in Victoria in 1925. In 1939 Victoria was one of the first locations in the world to trial the ‘bombing’ of fires using aircraft. Since that time dramatic developments have taken place in all aspects of fire related aviation. From an international perspective Victoria, and North America have led this field and close liaison between fire managers in both locations continues.

In 1967 Australia’s first operationally assisted control of a wildfire using two agricultural aircraft ‘bombers’ occurred in Victoria’s Great Dividing Range. These days, in an average year fire retardant chemicals are used on around ten percent of all public land fires. Retardants are particularly useful in slowing the spread of lightning caused fires in inaccessible mountain terrain, thereby improving the chances and safety of follow-up fire crews.

Building control lines (either with hand-tools or bulldozers), ‘backburning’ and the application of chemicals in wildfire suppression all have environmental impacts. So too do large uncontrolled wildfires. Park, forest and fire managers clearly have to make regular judgements about these matters and often in dramatically changing situations. Victoria’s 1995 *Code of Practice for Fire Management on Public Land* sets out several over-riding ‘wildfire’ and ‘environmental care’ principles that underpin all fire management activities.

To assist land managers in better evaluating the wildfire control options available, and as part of its normal fire management continuous improvement program, the Department last year commissioned CSIRO to assess the effectiveness and environmental risk associated with wildfire related retardant use. The report subsequently provided by CSIRO represents the most detailed Australian examination of the subject yet undertaken. NRE welcomes the report’s findings and is moving to address the report’s key recommendations.

In particular NRE has already further strengthened its training programs and the relevant operations manual. Further, discussions with the United States Department of Agriculture are continuing in relation to the need for additional testing of retardant chemicals. Finally, and while Victorian rangers and forest officers have not in the last thirty years reported obvious impacts of retardant on local ecosystems, a specific research program, consistent with the CSIRO findings, is currently being designed to examine this issue.

In the last fifty years the number of wildfires occurring in Victoria's parks and forests has continued to grow. The consequent area burnt however, and particularly the number of large fires each year, has declined quite significantly. There are many reasons for this. Victoria cannot afford to be complacent however, and innovation, training and a commitment to excellence will continue to underpin the approach to all aspects of fire management. The safety of firefighters, and the well being of the community, and of our unique flora and fauna demands nothing less.

In conclusion I would like to thank the officers from CSIRO who contributed so professionally to this report. I would also like to thank the officers from NRE and from Parks Victoria who gave so willingly of their time and expertise in assisting with the review.

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Assessment of the effectiveness and environmental risk of use of retardants to assist in wildfire control in Victoria



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Prepared for
Department of Natural Resources and Environment, Victoria

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EXECUTIVE SUMMARY

- Fire retardant chemicals are classified as either short-term or long-term retardants. Short-term retardants are used in direct suppression of flames but do not have significant flame retardant properties after the water contained in them has evaporated. Long-term retardants remain effective when the water carrying them has evaporated. A fireline of long-term retardant may hold a fire for up to 18 hours or more, but usually needs to be supported by ground crews to construct a mineral earth trail to secure the fire. Retardants can be applied from the air in fire situations where it is not possible to rapidly deploy any other suppression technique.
- Fire retardant chemicals can provide an initial effective barrier to fires up to a fire intensity of 3000 kW m^{-1} . Fires beyond this intensity will breach the retardant barrier by spotting, but when strategically placed fire retardant barriers may slow fires of higher intensities and assist suppression by other means.
- Long-term fire retardants are considered essential for efficient fire suppression in Victoria. Small fires in inaccessible terrain (often started by lightning) can be contained for many hours by aerial application of retardant, until ground crews arrive. Short-term retardants are not effective for this purpose.
- The fire retardant Phos-Chek D75R is a long-term type of fire retardant that is approved for use in natural environments by the USDA Forest Service. This retardant is most effective when applied to fuel surfaces prior to the arrival of fire. The effective retarding ingredients in Phos-Chek are ammonium salts of sulphate and phosphates, that coat the surface of the fuels, and which are converted to sulphuric acid and phosphoric acid with loss of ammonia when heated. This reaction suppresses complete flammability of the fuel and promotes charring or carbonisation. The effectiveness of Phos-Chek depends upon its method of application, time of application in relation to fire, and the amount applied to cover the fuel surfaces. Therefore, its proper application in front of the fire at a sufficient application rate is critical.
- Phos-Chek is mainly supplied in a powder and is mixed with water to form a solution ranging in concentration from 12 to 15 percent (kg/100L) retardant for aerial delivery. Australian experiments suggest that a coverage level on the fuel of this solution of 1 L m^{-2} is required to stop a fire of 2000 kW m^{-1} intensity. However, extensive operational studies in the USA have found that an average coverage level of 0.5 L m^{-2} (range $0.3 - 0.8 \text{ L m}^{-2}$) was effective on fires up to this intensity in a wide range of fuel types. The pattern of dispersion of the retardant dropped from aircraft used in Australia is such that the maximum ground coverage through the tree canopy rarely exceeds 2.5 L m^{-2} . The area covered at this rate is small and is generally less than 10% of the total area of the drop.
- When heated to high temperatures Phos-Chek produces sulphur dioxide, ammonia and oxides of nitrogen as gases. The retardant also contains <5 % by weight of a range of performance additives that are confidential to the manufacturer, but the composition of which were made available to the consultant under a confidentiality agreement. The effect of high temperatures on these compounds is unknown.

- Operational practice is to drop retardant chemical on fuels ahead of the fire (see Appendix III). It is physically very dangerous to drop retardants directly onto high-intensity fires, and this rarely occurs during operational fire fighting. However, fire retardants may be dropped directly onto low-intensity fires when the flame depths are less than a few metres, but the amount of retardant directly in contact with flames is low.
- Any amount of unaltered (unburnt) Phos-Chek (in tree canopies, on burnt ground and on unburnt fuel) would act as a direct source of N, P and S to the environment. Although the ammonium salts of sulphates and phosphates are also used as agricultural fertilizers, the effects of fire retardants and fertilizers on the environment may differ in significant ways. The method of application (soil versus canopy or fine litter fuels), the reaction process (solubilization versus heating in fire) and amount applied per unit area (much greater for retardant) are significantly different between fertilizer and fire retardants. However the area affected by retardant is usually small. The spatial scale of impact of retardants must be considered: whilst local effects will be large, dilution will be considerable at catchment or landscape scales. Information on the transport of retardant components, especially the small amounts (<5% by weight of retardant) of performance additive materials, in the environment is non-existent. This is an area worthy of investigation – especially the transport to and fate in stream water.
- Following rainfall, fire retardant residues (the added chemicals or heat-modified products) will be either washed into the soil, or be transported via overland flow on impermeable soil (especially in steep terrain and after high intensity rainfall events). Clearly threats to stream pollution are greatest in run-off prone environments and if retardants are dropped near to water courses. Nothing is known about transport of retardant under Australian conditions. High nutrient inputs are likely to affect plant communities, especially in Australian ecosystems that are generally nutrient-poor. However effects will be local, and the main threat could be to rare or sensitive communities. Again no Australian information is available.
- The effects of Phos-Chek on soil processes will depend upon application rate, changes in retardant constituents during fire, reaction mechanisms with soils (affected by soil characteristics such as pH, organic matter content, and clay content), water entry and flow characteristics, and soil biological activity. Effects on soil chemistry relate primarily to adsorption of phosphorus, nitrification of residual ammonia, leaching of nitrates and sulphates and associated loss of cations. These effects will however be localised. Effects of some components in the retardant on soil biology are unknown.
- There are no data on the effects of fire chemical retardants on Australian aquatic ecosystems. The impact of N and P additions will be local. Of much greater concern is the local impact and transport of potentially hazardous components (which may have a concentration of around 1900 mg L⁻¹ at the source) to water supply sources.
- Some of the additive compounds in Phos-Chek are potentially harmful to biological systems and human health. Very little is known of the impacts of these in natural environments, including their longevity or transport to aquatic systems. The studies so far conducted overseas have involved limited testing of the impacts of the full formulation, but have not examined the importance of individual components.

- The potential human health hazards during the preparation and handling of Phos-chek are minor skin and eye irritation. Although sufficient information on the procedural guidelines for the use of retardants are provided by Solutia in the material safety data sheet (Appendix I) and incorporated into NRE Air Operations Manual (Appendix III), the Department should ensure that workers strictly follow the safety guidelines.
- The potential risk to public health is considered to be very small. From the published literature and chemical data sheets available, Phos-Chek components can be considered to have low short-term toxicity and very low risk of long term/delayed toxicity to humans. With the exception of one component for which it has not been possible to locate data on its environmental fate, none of the chemicals in Phos-Chek have propensity to accumulate in biological systems.
- Actual risk from fire suppression chemicals must be addressed on a site by site basis, depending on local characteristics. Many of the potential risks can be mitigated by careful mixing and application practices, and through local restrictions on their use in a sensitive environment, if conditions, such as the presence of endangered or threatened aquatic species, are warranted. Some risks may not be eliminated, but these risks must out weighed be evaluated against the necessity for fire suppression activities.
- Phos-chek D75R has been used over a long period by the USDA Forest Service and appears as safe as any alternative long-term retardant and probably less harmful than many short-term retardants currently available. Proper management of its use will assist NRE in its legal responsibility to manage both fire and the natural environment.

RECOMMENDATIONS

- 1) That Phos-Chek D75-R, or other long-term retardants approved for use in natural environments continue to be used both for initial attack and for support of ground suppression operations. Retardant use should be under the supervision of qualified air attack supervisors who would locate and direct the position of each drop to ensure that retardant is applied safely and efficiently.
- 2) That air attack supervisors be trained in the potential environmental impacts of fire retardant on waterways and plant communities on nutrient poor soils so that the relative risks of both retardant application and damage by wildfire or alternative suppression strategies can be evaluated.
- 3) That NRE undertake or commission research into the impact of Phos Chek D75-R on specific Australian ecosystems. These should include:
 - impact on native aquatic organisms,
 - impact on heathland communities on nutrient poor soils , and
 - impact on selected species considered rare or endangered.Recommended application rates are 0.5, 1 and 2.5 L m⁻² and, where appropriate, changes in populations should be compared with changes caused by wildfire.
- 4) That NRE adopt a containerised system (e.g. Phosbin) for handling retardants to minimise contact with operators.
- 5) That the NRE Air Operations Manual should be modified to stress the absolute need to follow procedures of handling.
- 6) That the USDA Forest Service be asked to undertake research into the fate and effects of the specific “commercial in confidence” chemicals used in the current formulation of Phos Chek D75-R. This should include:
 - identification of the products of thermal decomposition and their potential toxicity;
 - the transport and longevity of these chemicals in soil and aquatic environments; and
 - the transformation and solubility in water of the potentially harmful compounds in Phos-Chek as affected by application rates, fuel types, and burning temperatures.
- 7) That research should be undertaken to evaluate transformation and dilution characteristics of varying additions of Phos-Chek, and Phos-Chek-coated fuel residues on the concentrations of potentially harmful compounds in stream water meant for human consumption.
- 8) That care should be exercised in the use of Phos-Chek in important water supply catchments until the above testing has been conducted and there is greater certainty that risks to human health are negligible. Steep terrain and impermeable soils may be useful criteria for identifying high risk situations.
- 9) That an evaluation of the potential risk of fire suppression chemicals and alternative suppression tactics in relation to the potential effect of destructive wildfires be undertaken in different ecosystems in Victoria.

TERMS OF REFERENCE OF CONSULTANCY

The agreed terms of reference for this review are:

1. Review the national and international scientific literature on fire retardants, with special reference to “Phos-Chek D75-R” in relation to:
 - effectiveness of fire retardants in assisting with fire suppression activities relative to alternatives,
 - impacts of retardants on the environment including water values, soil chemistry, and vegetation composition and nutrient status,
 - impacts on human health associated with the handling, application and subsequent fate of the applied retardant, and
 - the role of management systems for the safe handling and application of fire retardants.
2. Evaluate and report on the adequacy and accuracy of the technical information provided by “Solutia Australia Pty. Ltd.” in relation to Phos-Chek D75-R in Australian context, and the related environment and health effects testing conducted by the United States Department of Agriculture (USDA).
3. Recommend any additional tests that USDA should be encouraged to conduct to address any critical gaps in our knowledge on health and/or environmental issues.

NRE’s Fire Management Branch will provide background material on retardant use and management in Victoria.

Phos-Chek D-75R contains trade secret chemicals. Solutia Australia Pty. Ltd. provided CSIRO with the exact composition of the material under a confidentiality agreement. CSIRO sought the services of a toxicologist to advise on matters relating to human health also under a confidentiality agreement. This is referred to as the ‘toxicologist report’ in the document.

ASSESSMENT OF THE EFFECTIVENESS AND ENVIRONMENTAL RISK OF THE USE OF RETARDANTS TO ASSIST IN WILDFIRE CONTROL IN VICTORIA

1. INTRODUCTION

Chemicals are frequently used to control and suppress bushfires in a wide array of ecosystems, especially those that are not easily accessible and in those where the effectiveness of other fire fighting methods is low. There are two general types of fire control chemicals: long-term fire retardant chemicals which remain effective after the water originally contained in them has evaporated, and fire suppressant foams. Long-term fire retardant chemicals are mainly composed of ammonium-based phosphates and sulphates. They also contain additives to thicken and bind, anticorrosive substances, flowing agents and colouring substances. These chemicals provide a long-term capability of the retardant to remain effective (i.e. effectiveness is not related to the presence and evaporation of water in the retardant solution). Thus the effectiveness of these salt formulations in retarding combustion depends greatly on the amount of ammonium phosphate and ammonium sulphate deposited per unit surface area of the fuel (Van Meter *et al.* 1985, McDonald *et al.* 1998).

Fire suppressant foams are short-term fire retardants and contain wetting agents that enhance the extinguishing ability of water by increasing its retention on fuel surfaces and reducing its evaporation. Fire suppressant foams are composed of a mixture of foaming agents (surfactant) as well as foam stabilisers, corrosion inhibitors and solvents (Anon 1993). The foam solutions are applied at concentrations ranging from 0.1 to 1.0 percent. The use of fire suppressant foams in bushfire fighting is becoming more prevalent because the amount of water required can be reduced significantly. However, the effectiveness of fire suppressant foams decreases as water is evaporated from the foam (Buhl and Hamilton 1998).

Victoria has the most severe bushfire environment of any State in Australia. Over the last 150 years more than half the economic damage caused by bushfires in Australia has occurred in Victoria (Luke and McArthur 1978). The frequency of summer dry lightning storms that start bush fires in inaccessible mountainous terrain is also greater than in any other State. As a result the use of aircraft for fire fighting is also more advanced than in any other part of Australia.

1.1 Use of fire retardant in Victoria

On average about 120,000 litres of fire retardant chemicals are used to control bushfires in Victoria each year by the Department of Natural Resources and Environment (NRE). The use rate ranges from about 86,000 litres during a low to moderate fire season, up to 205,000 litres during a severe season (e.g. 1997/98 fire season). The 20-year average of 584 ignitions per fire season result in an average area burnt per fire season of 101,460 ha of public land managed by NRE (Bennetton *et al.* 1997). Fire retardant chemicals are used on less than 10 percent of all the fires.

The Caledonia fire in January 1998 burnt part of the Alpine National Park and part of Carey State forest in Gippsland. Of the total area of 32,000 ha burnt, some 22,000 ha was in National Park, and 10,000 ha was in State forest reserves located in two major water catchment areas:

1. Caledonia / Macalister
2. Moroka / Wonnangatta

The fire severely burnt large areas of steep forested country adjacent to tributary streams in these catchment areas. On 12 January a significant localised rainfall event washed away large amounts of ash and surface soil and deposited them into the Caledonia and Macalister rivers causing discolouration and turbidity in the streams. Concern has been raised by some community members that the chemical fire retardant used on the Caledonia fire, Phos-Chek D-75R, was washed down stream into their water supply and posed a threat to human health.

Community concern about the use of chemical fire retardants and the requirement for due diligence by Fire Management Officers was the basis for NRE commissioning CSIRO Forestry and Forest Products to conduct this review of the literature on fire retardants with special reference to Phos-Chek D75-R. The terms of reference for this review are given in Section 3. Although the terms of reference required assessing the relative effectiveness of long-term retardants in suppression activities relative to alternatives it was considered necessary to consider the impacts of not using Phos-Chek D75-R for fire suppression in Victoria. This is addressed in section 7.

2. FIRE RETARDANT FORMULATION

Wildland fire retardant chemicals are composed of a combination of ammonium phosphates and ammonium sulphates, metal corrosion inhibitors, thickeners, colouring agent and flow conditioners. The compositions of the two fire retardant chemicals used mostly in Australia are listed in Table 1.

Table 1. Composition of long-term fire retardant chemicals used in Australia

Name ¹	Category of Fire control	Manufacturer	Ingredients
Fire-Trol GTS-R	Fire-retardant powder	Chemonics Industries Inc.	Ammonium sulfate, diammonium phosphate, guar gum, thickener, spoilage and corrosion inhibitors and iron oxide (1)
Phos-Chek D75-R	Fire-retardant powder	Solutia Inc.	Diammonium sulfate, Monoammonium phosphate, diammonium phosphate, guar gum, iron oxide, performance additives (2)

Source:

- (1) Chemonics Industries Ind. Material safety data sheet. March, 1989
- (2) Solutia Inc. Material safety data sheet. August, 1998 (See Appendix I)

¹The use of trade, firm or corporation names in this report is for information and convenience of the reader. Such use does not constitute an official endorsement or approval by CSIRO Forestry and Forest Products of any products or service to the exclusion of others that may be suitable.

The fire retardant chemical Phos-Chek D75R is used extensively in the USA and the manufacturer claims that the formulation has remained unchanged for over 20 years. (pers. comm. L. Vandersall). The powder is mixed with water at a recommended rate of 12% but operationally this mixing rate may be as high as 15% (150g L^{-1}). The composition and ingredients of Phos-Chek D-75R are:

	% dry weight	% of solution
1. Ammonium salts		
Diammonium sulfate	>65	>82
Monoammonium phosphate	>15	>1.9
Diammonium phosphate	>5	>0.6
2. Thickener		
Guar gum	<10	<1.3
3. Performance additives		
Trade secret chemicals	<5	<0.6
4. Colouring agent		
Red iron oxide	<1	<0.1
	100	<12.7

The exact composition of the dry powder concentrate of Phos-Chek D-75R is considered by Solutia Inc. as commercial-in-confidence and was disclosed to CSIRO Forestry and Forests Products for this review under a confidential agreement between the two organisations. For this reason the discussion of the potential impacts of the performance additives can only be presented in a general way in this report (i.e. without reference to specific compounds, although the consultants conclusions are based on assessment of these). Solutia Inc. discloses on the Material Safety Data Sheets (MSDS) the potential hazards posed by any of the components in their fire retardant products (See Appendix I).

The ammonium salts of sulfate and phosphates are the active fire retardant component. The guar gum thickener is prepared from the extract obtained from cultivated guar beans. The thickener holds the retardant solution “cloud” together during free fall from airtankers and acts as gum so the applied solution lands in the target area and clings to the fuel where it will be effective. The colouring agent red iron oxide is added to the retardant mixture which leaves a rust red colour on the vegetation to provide visibility to the air tanker pilots and ground crews to guide further air tanker drops. The performance additives provide free flowing characteristics to retardant powder so they can be easily transferred and mixed to form retardant. It also contains corrosive inhibitors to protect handling, mixing and delivery hardware from corrosion.

3. EFFECTS OF LONG-TERM FIRE CHEMICAL RETARDANTS ON FLAMMABILITY

Ammonium phosphates and ammonium sulfates when applied to fuels alter or inhibit thermal degradation and combustion reactions. Because of the reduced flammability of the chemically treated fuels, the use of these wildland chemical fire retardants is an important tool in bushfire suppression. The majority of the research on the effects of fire retardants on flammability and combustion of cellulose has been conducted by researchers at the Intermountain Fire Science Laboratory, USDA Forest Service, Missoula, Montana (George and Susott 1971, George and Blakely 1972, Hardy 1977 and Blakely 1983).

Their studies on combustion retarding effectiveness were done on mat-type fuel beds treated with different retardants. The two fuels used in these studies were ponderosa pine needles and aspen (George and Blakely 1972). Australian fuel and vegetation conditions are different to those tested in the US but they are similar in chemical content to many fuels encountered on wildland fires in North America. By comparison, Australian forest fuel is high in cellulose and lignin, low in nutrients, and being generally denser will yield more heat per unit volume of fuel. However, the structure and arrangement of the fuel has more influence on fire behaviour than the chemical composition.

The tests by Blakely (1983) and George and Susott (1971) indicated that ammonium phosphates are the most effective fire retardant compounds followed by ammonium sulphate. Heating of these salts, releases ammonia and the phosphates are converted to phosphoric acid (H_3PO_4) and sulphates to sulphuric acid (H_2SO_4). These acids hinder the complete oxidation of organic carbon (C) in the fuel to CO_2 so that unoxidised C is left after pyrolysis. Both diammonium and monoammonium phosphates are converted easily to H_3PO_4 because the ammonia (NH_3) is driven off at low temperatures (166 °C). Phosphate anions (PO_4), if combined with cations other than ammonium (e.g., sodium, calcium, potassium and magnesium), do not convert to H_3PO_4 readily, and therefore do not make PO_4 available in the most effective form to act as a fire retardant. The fire-retarding effectiveness of monoammonium phosphate or diammonium phosphate when in pure form is directly proportional to P or P_2O_5 content. Any formulation containing impurities may change its effectiveness.

George and Susott (1971) indicated that ammonium phosphate was much more effective in decreasing the rate of weight loss and increasing residue than was ammonium sulfate, which had little effect on the residue. As the decomposition of ammonium sulfate occurs around 425°C, while ammonium phosphate decomposition is not completed until around 675°C (George and Blakely 1972; George and Susott 1971), there is every possibility that more sulphate than phosphate in the retardant is lost by volatilization in wildland fires.

Flame temperatures measured in jarrah forest fires during CSIRO/CALM Project Vesta experiments ranged between 600 and 1200°C depending on the length of flame (Canadian Forest Service and CSIRO FFP, unpublished data). In high-intensity fires the retardant will be exposed to temperatures in excess of 675°C. At these temperatures the ammonium salts are likely to be decomposed to oxides of nitrogen and sulphur dioxide and P_2O_5 . The gum thickener will decompose to CO_2 and H_2O . Iron oxide will be largely unaltered. The decomposition products of some the performance additives at high temperatures are unknown.

In practice, only a small proportion of the retardant dropped is likely to be directly exposed to high temperatures. Fire retardants may be dropped directly on very small fires (e.g. extinguishing spot - fires). Otherwise, the most efficient location of a retardant drop is ahead of the fire so that the fire has to burn through the full width of the applied chemical. Fire retardants may be dropped directly onto low-intensity fires where it is difficult to establish the precise location of the fire edge beneath the canopy, but in this situation only a small proportion of the retardant drop falls onto the narrow (1-5 m) zone of flaming combustion. In practice fire retardant is rarely dropped directly into the flame zone of high-intensity fires because the pilots visibility is obscured by smoke and the turbulence in the convection above the fire make flying highly dangerous.

Therefore, while it is possible for some of the chemical to be exposed to decomposition at high temperatures, in practice this occurs only on a small fraction of the total load.

4. APPLICATION OF FIRE RETARDANT CHEMICALS

To achieve efficient aerial suppression of wildland fires, optimum conditions on the performance of the air tankers, drop pattern (or footprint of the retardant drop) and retardant coverage are required for specific fuel and fire situations. The USDA Forest Service Intermountain Fire Science Laboratory (George 1992, George and Johnson 1990, George 1982, Blakely *et al.* 1982, Anon. 1982, George 1981 and Hardy 1977) has conducted most of the research on the performance of air tankers. Research on performances and effectiveness of aerial suppression in Australia was mostly done in the 1980's by Rees (1983), Rawson and Rees (1983), and Loane and Gould (1986). A study in evaluation of aerial suppression in Western Australia has been conducted in the outer metropolitan region of Perth (Anon 1997). A wide range of fixed-wing aircraft is available for aerial suppression delivering long-term fire retardant. In Victoria, the main aircraft are single-engine fixed-wing agricultural aircraft (e.g. Air Tractor, Dromader) which can carry loads of between 1500 and 2000 litres depending on the aircraft and operating conditions. The suppressant foams are applied from rotary wing aircraft and ground tanker units.

The effectiveness of the retardant application depends on:

- amount of retardant actually needed on the critical fuel,
- interception of retardant by the forest canopy above the critical fuel,
- pattern of the retardant drop, and
- chemical characteristics of the retardant reaching the fuel.

One of the prime aims of Project Aquarius (Loane and Gould 1986) was to gather evidence on the effect of fire retardants on the behaviour of moderate to high-intensity fires in dry eucalypt forest. The depth (application rate) required to stop the fire burning through the retardant-coated fuel in the drop zone is shown in Figure 1. The Aquarius studies indicated that unsupported retardant drops in stringy-bark forests were ineffective when fire intensities were $>2000 \text{ kW m}^{-1}$ due to heavy spotting across the drop zone. If ground crews supported the retardant drops within one hour after the retardant had been dropped, the effective limit would be around 3000 kW m^{-1} (Loane and Gould 1986).

Loane and Gould (1986) concluded that there was no useful retarding effect for forest fire intensities $>5000 \text{ kW m}^{-1}$, i.e. rate of spread around 700 m hr^{-1} in a forest litter fuel load of

15 t ha^{-1} . Although the retardant drops may have a temporary dampening effect on the flames and fire intensities as shown in Figure 2, the fire will throw numerous spotfires across the retardant line which rapidly reform a new fire front. Thus even if the retardant coated fuels remain unburnt the progress of the fire may be delayed by only a few minutes.

Low-intensity fires may be completely extinguished by a retardant drop, or halt a fire until fire weather conditions improve. Long-term retardant provides a fire retardant effect even after drying out. However, fire controllers expect the fire to creep through gaps in the retardant line where coverage is low, for example in the lee of large logs etc. The time taken for the fire to burn through the drops depends mainly on fire intensity, retardant type, concentration and width of the retardant drop and fuel type. The burn-through time is shown in Figure 3 for water and long-term retardant for different fire intensities.

The application of fire-fighting chemicals is accomplished using a wide variety of aircraft equipped with different configurations and aircraft speeds, which results in a wide range of drop patterns. Drop patterns and the resulting ground pattern are also modified by drop height, retardant type, canopy interception, relative humidity, temperature, and wind speed and direction. Although there has been a substantial effort to improve the performance of fire-retardant delivery via fixed-wing aircraft (George 1992, George and Johnson 1990), it is still difficult to quantify the effectiveness of retardant drops delivered to the fire.

The wide range of aircraft delivery systems (Rees 1983) can be modified to deliver similar amounts of fire retardant chemicals. Retardant required to be effective ranges from $<0.5 \text{ L m}^{-2}$ for grass fires to $>1.5 \text{ L m}^{-2}$ for eucalypt forest (providing a “holding” time up to 2 hours). The retardants are prepared by mixing the dry powder chemicals with water to produce a slurry. The recommended mixing ratio for Phos-Chek D-75R (Appendix I) is 0.144 kg of retardant powder per litre of water to produce 1.069 litres of slurry (equivalent to a concentration of 144 g per litre). A single drop from an 1800 litre capacity airtanker would contain around 242 kg of retardant chemical in a drop area of 1020 m^2 with a coverage of at least 0.125 L m^{-2} . Table 2 gives a summary of a drop pattern distribution of the Bull Thrush aircraft.

Table 2. Drop pattern distribution of a 1740 litre drop from a Bull Thrush aircraft in the open⁽¹⁾ (Source: Rees 1983).

Volume class (L m^{-2} or mm)	Area (m^2)	Length (m)	Maximum width (m)	Volume (L)
> 1.00	407	52	14	966 ⁽²⁾
0.500 to 0.999	570	71	24	427
0.125 to 0.499	1017	89	35	254
0.002 to 0.124	1544	136	37	93

⁽¹⁾ Bull Thrush drop pattern was used to represent the Dromader aircraft.

⁽²⁾ This is equivalent to 2.37 L m^{-2} (12 % of the area with high concentration).

Theoretically the application rate required to suppress fires in heavy fuels or logging slash may be as high as 4.0 L m^{-2} , but in practice the effective coverage levels are considerably lower. An extensive operations study of the use of aerial suppression in the USA found that an average coverage level of 0.5 L m^{-2} (range $0.3 - 0.8 \text{ L m}^{-2}$) was effective on fires with flame lengths up to 2 m (intensity approximately 2000 k W m^{-1}) in a wide range of fuel types. (George *et. al.* 1990).

The pattern of dispersion of the retardant when dropped from aircraft used in Australia (e.g. Bull Thrush, Dromader, Air Tanker) is such that maximum ground coverage through the canopy rarely exceeds 2.5 L m^{-2} . The area covered at this rate is small and is estimated to be less than 10 percent of the total area covered.

The aerial application of long-term retardant is simply another tool in the fire controller's cache. It is generally used in combination with another form of fireline construction such as hand tools or bulldozers or may be used to assist suppression crews holding a fire on an established trail. It may also be used to slow the progress of a fire towards the location of a proposed or established fireline.

The main advantages of using retardant are:

- speed of application particularly early in the history of a fire in remote terrain,
- access to small fires, particularly spot fires that can be difficult to locate from the ground,
- safety for suppression crews. Fire retardants can be applied to fires effectively from the air under conditions where the fire has the potential to escalate and threaten ground crews, and
- in rugged and rocky terrain where fire line construction by other means is extremely difficult.

Clearly, the most efficient time to use aerial suppression is the early stages of the fire before other forms of fireline construction can be deployed. The prime aim is to keep the fire to the smallest area possible even though the fireline may need to be secured by hand tools or mechanical equipment.

Long-term retardants are around 3 times more efficient than plain water when applied directly to burning slash fuels (Luke and McArthur 1978). In most fire suppression activities this increased suppression efficiency does not justify the additional costs of the retardant and so they are rarely used for direct suppression e.g. from ground tanker units.

When applied from the air, long-term retardants are required to hold the fire for some period. The USDA Forest Service has devised a relative rating for long term fire retardants called a "superiority factor" that is based on a combination of factors including effect on rate of spread and combustion rate of a fire burning in a standard test bed after the water carrying the retardant has evaporated (Celia Johnson *pers comm.*). To be accepted for use by the USDA Forest Service as a long-term retardant, any formulation is required to have a superiority factor of 60 or above, which means that the formulation is at least as effective in reducing combustion characteristics as a 10.6% solution of diammonium phosphate (the USDA Forest Service standard). Plain water has a superiority factor of zero.

Wildland fire fighting foams have a superiority factor of -1 to -3 which means they are marginally worse for holding a fire than using plain water (Johnson and George 1997). Although there are anecdotal reports of enhanced suppression capability of wildland fire fighting foams, as yet no standard test has been devised which demonstrates this. The main advantage of using foam instead of water for aerial suppression is that the drop pattern is visible from the air. In this report we have assumed that foams have the same holding capacity, or burn through time, as plain water (see Figure 3). However the surfactants in the foam enable more efficient direct suppression than plain water, particularly during mop-up.

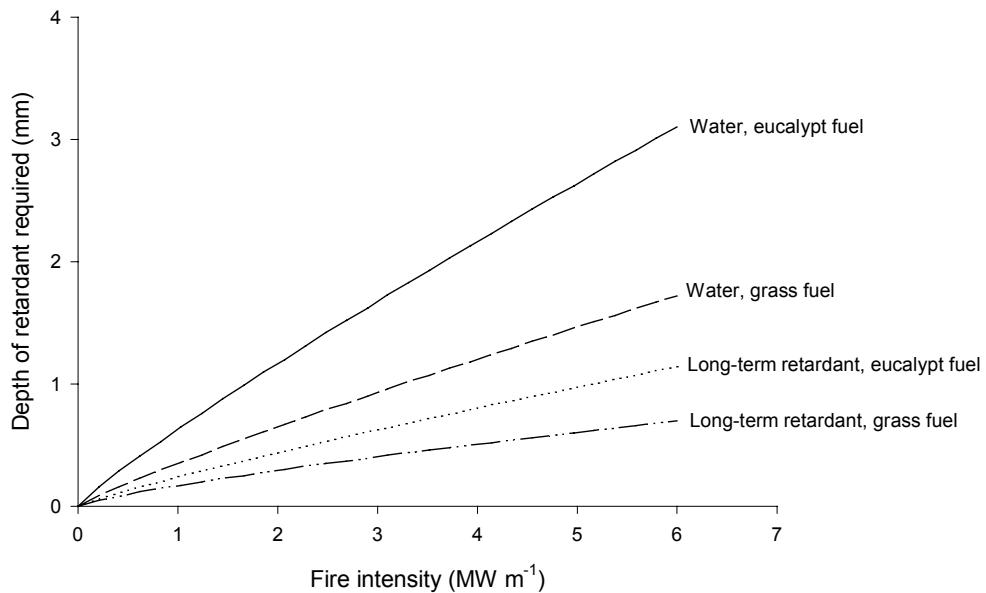


Figure 1. Depth of water and long-term retardant required to hold a fire at different intensities in grass and *Eucalyptus* fuel. 1 mm is equivalent to 1 L m⁻². (Source: Loane and Gould 1986)

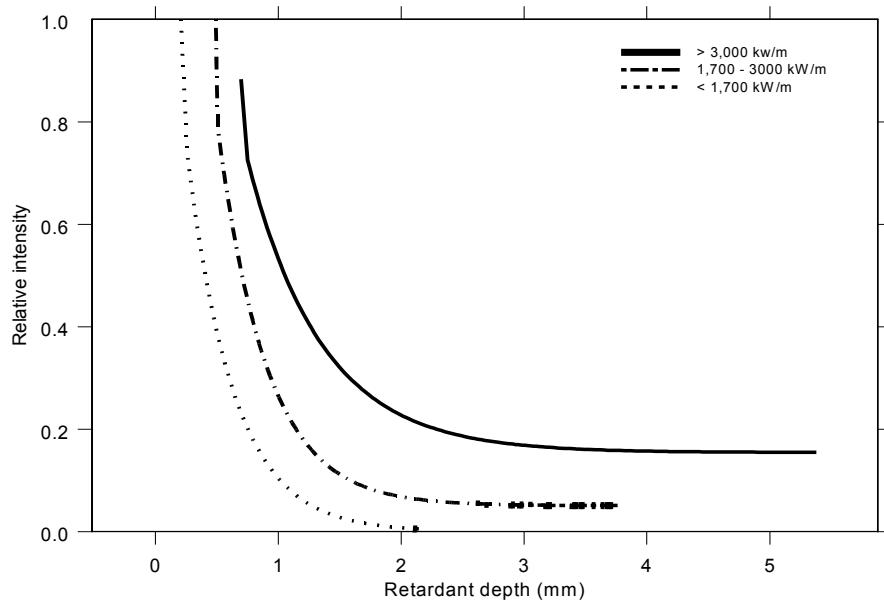


Figure 2. Proportion of the original fire intensity remaining after the first retardant drop. (Source: Loane and Gould 1986)

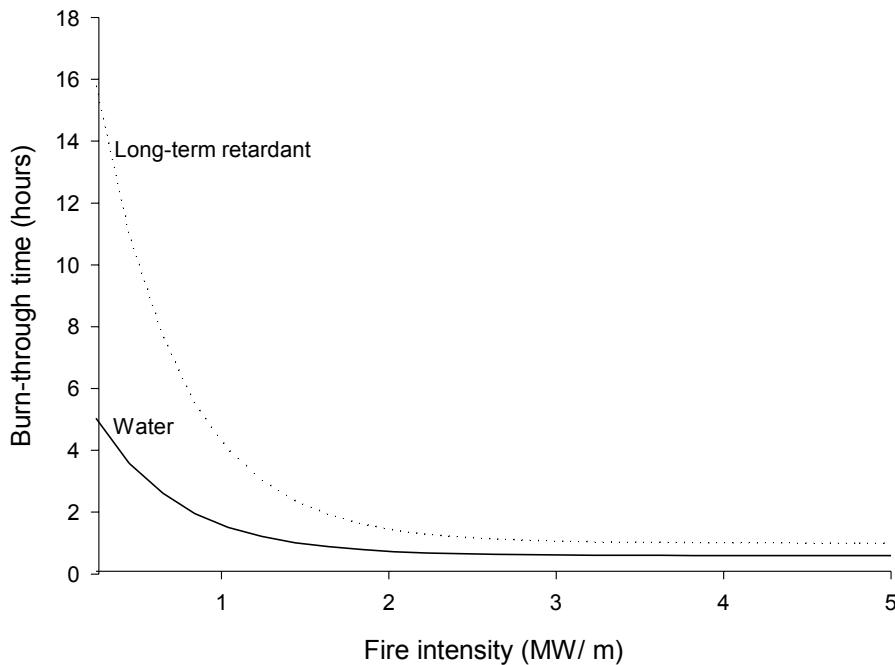


Figure 3. Water and long-term retardant burn-through time based on 30m drop width.
(Source: Loane and Gould 1986)

In Victoria the average fraction of lightning-caused fires per fire season is 25.9% and these burn 46% of the average annual area burnt on public lands. The seriousness of lightning fires is greater than the average suggests. On 26 – 27 November 1997, lightning strikes from thunderstorms imbedded in a dry front (i.e. a frontal system without rain) started 193 bushfires on public land across Victoria (NRE Fire Records). Such an event places an enormous load on fire suppression resources.

Many of these lightning fires are in inaccessible mountainous terrain and ground crews may take 6 to 12 hours to reach the fire. We consider that the aerial application of long-term term fire retardant which meets or exceeds the USDA Forest Service performance standard is essential for efficient fire fighting in the Victorian environment.

5. ENVIRONMENTAL RISK

Controlling wildfires includes suppression actions of building fire control lines, burning-out and the application of water, dirt and fire suppression chemicals. The use of fire suppression chemicals may be an alternative to, or in support of more drastic measures (e.g., bull dozing large fire breaks, and massive burning-out operations). These methods involve varying effectiveness and environmental risk. In order to assess the possible environmental effects of using fire retardant chemicals, it is important to outline their chemical composition, reactions in fire, soil reactions and transport to water.

The fire retardant Phos-Chek is basically ammonium salts of sulphates and phosphates with additives to thicken, inhibit corrosion and spoilage and to colour the retardant slurry. Retardants may come in contact with all constituents of the environment - soil, water, air, plant and animal life (including people), and may affect them to varying degrees depending upon the initial concentration (and dilution in time), duration and frequency of contact, and the toxicity of individual retardant components. Although the ammonium salts of sulphates and phosphates are also used as agricultural and forestry plantation fertilisers, the effects of fire retardants and fertilizers on the environment may differ in a significant way. The method of application (soil versus canopy or fine fuel litter), the reaction process (solubilization versus burning in fire) and amount applied per unit area are significantly different between fertilizer and fire retardants. However, the area affected by retardant is usually small. The spatial scale of impact must also be considered: whilst local effects will be large, dilution will be considerable at catchment or landscape scales. Information on the transport of retardant components in the environment, especially the small amounts of the performance additives, is non-existent. This is an area worthy of further investigation – especially transport in stream water.

No experiments have so far been done in Australia to examine the effects of the individual components or the complete fire retardant on native flora and fauna. This lack of scientific data for Australia and the fact that the Australian flora and fauna have evolved under special environmental conditions and thus may react differently to those of the Northern Hemisphere (for which some, but scanty data are available), means that much of the following discussion is based on expert opinion rather than direct evidence. Uncertainty about the possible impacts of fire retardants at the species level, lends to concern about effects at the community and ecosystems level. The review that follows on the effect of fire retardants on soils, plants, fauna and aquatic systems is confined to Phos-Chek D-75R and its components unless otherwise stated.

5.1 Effect of retardants on soils

The effects of Phos-Chek on soils will depend upon a multitude of factors including the amount of Phos-Chek deposited on the fuel or subsequently washed from tree canopies, changes in its constituents during fire, reaction mechanisms with soils, soil characteristics (e.g., pH, organic matter content, clay content), water entry and flow characteristics and rates of biological activity in soils. No experimental evidence is available to assess the effects of Phos-Chek or to assess the possible patterns of response to any degree of accuracy. The following discussion is therefore primarily theoretical.

The constituents of Phos-Chek can be basically divided into four different types:

- 1) Ammonium sulphates and phosphates
- 2) Guar gum
- 3) Colouring reagent
- 4) Performance additives – a number of compounds, which are added to check corrosion, improve flow conditions, and act as wetting agents.

The Material Safety Data Sheet (Appendix I) recommends that Phos-Chek D-75R should be dissolved at 1.2 pounds per US gallon of water which gives 144 g of material for each litter of solution (14.4%). The application rate for maximum effectiveness of the retardant (amount of P and S needed) is considered to be 3.8 L m⁻² for heavy logging slash or Chaparral (a tall

scrubland plant community). As mentioned above maximum application rates are likely to be about 2.5 L m^{-2} but the application rate of 1.5 L m^{-2} may be required to cover the ground fuel with less than 1 L m^{-2} . Table 3 summarises the chemical composition and typical nutrient application rates associated with 1.5 L m^{-2} application.

Table 3 shows large amounts of retardants and major nutrients could be added per unit treated area of the forest. The storage capacity of canopies of eucalypt forests is likely about 1-2 mm (or $1-2 \text{ L m}^{-2}$) (Aston 1979, Prebble and Stirk 1980). In practice the additions are about 1.5 L m^{-2} with the aim of achieving less than 1 L m^{-2} on the ground. This equates to retardant and nutrient inputs per ha of about 2100kg, 337 kg N and 94 kg P. The capacity of a forest canopy to intercept aerial applied solutions (or rain) depends primarily on the surface area, configuration, orientation and texture of the above-ground biomass.

Some retardant will remain in the crown, where it may not be affected by fire and will subsequently contribute its N and other elements as an input to the soil. However, most of the added retardant will be intercepted by the understorey and surface litter. There is very little chance that much retardant applied to a closed canopy forest will land directly on the soil. After any fire, two types of retardant residues exist: an unburned part of retardant, and that which has undergone change because it was involved in controlling the spread of fire. The following discusses these two types of retardant residues.

Table 3. Composition of Phos-Chek D-75R in relation to the amount in one liter of application solution and amounts ($\text{kg treated ha}^{-1}$) of retardant and N, P and S added when retardant applied at the rate of 1.5 L m^{-2} . DAS = Diammonium sulfate, MAP = Monoammonium phosphate, DAP = Diammonium phosphate.

	DAS	MAP	DAP	Guar gum	Rest	Total
Composition by weight (%)	>65	>15	>5	<10	<5	100
Grams in one litter solution						
Containing 14% retardant	91	21	7	14	7	140
N (%)	21	10	18			
P (%)		23	20			
S (%)	24					
N (g L^{-1})	19.1	2.1	1.3			22.5
P (g L^{-1})		4.8	1.4			6.2
S (g L^{-1})	21.8					21.8
Retardant kg/ha treated (1.5 L m^{-2})	1365	315	105	210	105	2100
N (kg/ha)						337
P (kg/ha)						94
S (kg/ha)						328

5.1.1. Unchanged retardant

Nitrogen – The unchanged retardant will release very high concentrations of ammonium N into the system. The total amount of soluble N added with the retardant is many times more than the growing vegetation can take up. Some may be volatilized, and most soils may not

have the capacity to retain the excess N. Therefore a major part of the N in the retardant may be lost from the site of its application depending upon the meteorological and hydrological conditions. Conversion of the large amounts of added ammonical N into nitrates render the N mobile which will be leached to groundwater and be diluted before ultimately entering a stream. Leaching of nitrate may cause some acidification of soils due to losses of base cations. If retardant drops occur near streams, then high N inputs may cause significant transfer to streams depending upon meteorological conditions and hydrology of sites.

Phosphate – Phosphorus in the unused retardant residue will remain water soluble and in the absence of overland flow will enter the soil. Again the concentrations of P in soil solutions will increase many fold and may be harmful to components of vegetation. Most of the P entering the soil will however be retained. Soils usually have a high adsorption capacity for P. Surface flow of water can transport P to streams.

Sulphate – The unused retardant contains a very large amount of S. In the absence of an overland flow most of it will enter the soil. Most soils have very low capacity to retain sulphur especially when it enters the soil together with phosphorus. Sulphate will thus be leached from the soil and as for N has the potential to enter the aquatic system.

Guar gum – A significant amount of guar gum will remain attached to the tree canopy, underground vegetation and litter layer. Nothing is known about its decomposition pattern, but it is expected to decompose with time without affecting soils.

Coloring agent – The iron oxide type of coloring agent will have no effect on soil processes.

Performance additives – From the list made available, it appears that some of the additives will have a significant effect on biological processes in soils. Others are expected to have little effect on soils. No information was available from Solutia Inc. on the interaction of various retardant components with soils or their effects on soil processes. There is a need to understand the effects of the performance additives on soil processes especially biological processes and to better understand the longevity and mobility of these compounds.

5.1.2. Heated retardant residue

Various chemical components of the retardant undergo significant changes when they come in contact with fire. Ammonium sulphate and ammonium phosphates lose their ammonium at temperatures <200°C. Sulphate is transformed into sulphuric acid and phosphate into phosphoric acid. Under high temperatures as reported in wildland fire a significant part of these acids may also be volatilized. The residual acids will either combine with the cations produced by partial combustion of fuel or will leach and percolate into the soil. Most of the phosphates will react with the soil and be adsorbed and fixed, but most of the sulphate will be leached as discussed above.

It is assumed that most of the guar gum will undergo oxidative decomposition during the fire. However it is not known whether the oxidation will be complete or partial. A number of performance additives will also be oxidised, but some of them will be little affected because of the high temperatures required for complete decomposition. Unfortunately, no information was provided by Solutia Inc. or is available in the literature on oxidation mechanisms (complete or partial oxidation) at temperatures these materials can experience in fires, or on

the products formed during heating, their solubilities or potential toxicities. This is a key gap in available information.

Ash or charred materials produced after fire are highly hydrophobic in nature and it is expected that with the following rain (depending upon the intensity and duration of rain) on impermeable soils most of the fire retardant residues, and ash or charred materials will be prone to surface runoff. Leitch *et al.* (1983) reported that an intense thunderstorm six days after a wildfire on Ash Wednesday (16 February 1983) near Warburton caused erosion losses of 22 t ha⁻¹ of ash plus soil sediments. Nothing is known of the chemical interaction, which might occur between ash and charred material and retardant residues. In steep erodible country, and without the protection of the canopy and other cover, a thunderstorm will increase the chances of erosion losses of ash and retardant residues.

5.2 Effect of retardants on plants

The literature searches relating to fire retardants or their ingredients revealed very little information regarding their effects on Australian plants. In the single reference identified that discusses phytotoxicity, Bradstock *et al.* (1987) reported dramatic short-term effects (widespread leaf death in trees, shrubs and ground cover plants) in a *Eucalyptus* forest that was sprayed with a mixture of ammonium sulfate (standard agricultural fertilizer) and a thickener (kelzan). The exact application rate was not given, but the retardant covered areas ranging from zero to a heavy coating of 2 L m⁻² at ground level (one liter of retardant contained 0.20 kg of ammonium sulphate and 0.01kg of thickner). Leaf death occurred within a week of treatment and continued for many months in both the overstorey (*Eucalyptus gummiifera*, *E. globoidea* and *Angophora costata*) and understorey (*Acacia longifolia*, *Dodonaea triquetra* and *Leptospermum attenuatum*), the most common species. In general where the retardant concentration was highest, death of foliage was most extensive and rapid (Bradstock *et al.* 1987). Greenhouse experiments also showed that leaf death was caused solely by the ammonium sulfate component of the mixture and total plant death was frequently observed with the complete mixture, depending on the species (Bradstock *et al.* 1987).

No studies on the effect of heavy application of ammonium phosphates on forest canopies have been made. It is possible that the effects of ammonium phosphate will be similar to those reported for ammonium sulphate by Bradstock *et al.* (1987). However, casual observation by two of the authors (N.P. Cheney, J.S. Gould) of the crowns of mixed stringybark species which had been subjected to repeated applications of diammonium phosphate during trials to measure the aircraft drop patterns, suggested no obvious death of the crown foliage; one year later the crowns appeared unchanged. In any case, any effect on the canopy should be viewed as a short-term effect of fire retardant on the vegetation, which has escaped fire.

Many of the Australian understorey and overstorey vegetation species have evolved under low soil P availability (Attiwill and Adams 1996, Heddle and Specht 1975, Specht *et al.* 1997). High levels of phosphates and sulphates in soil solutions may present a risk to plant health. The Victorian Code of Practice for use of retardants already recommends that heathland ecosystems are not to be treated. Some of the substances (e.g. phosphates), and probably some of the performance additives in the fire retardant, may be absorbed and retained for a long time in the soil, thus changing soil processes. These long-term changes in soil processes may affect plant growth and plant populations, affecting species richness.

Again, casual observations have been made by two of the authors of the response of understorey species subjected to repeated applications of diammonium phosphate estimated to be in excess of 10 L m⁻². The areas were dry eucalypt forest in Victoria (Nowa Nowa SF) and ACT (Black Mountain Nature Reserve) with a dominant understorey of *Davesia* sp. By the following summer, the understorey species in the treated area appeared to be more vigorous than those in adjacent areas.

No detailed studies of the ecological effects of Phos-Chek have been carried out on Australian plants and it is recommended that research be undertaken. These studies should focus on communities growing on soils of low nutrient status and include rare species to ensure the use of retardant for fire operations are not unnecessarily restricted under the current guidelines. One must remember that only small areas of landscapes will be directly affected by fire retardants, where rare or sensitive communities are of greatest concern.

5.3 Effect of retardants on fauna

Some toxicity data for the long-term retardants Phos-Chek D-75F and D-75R are summarised in Table 4. The data includes information on rodents, rabbits and a bird species. In acute toxicity studies the endpoint of interest is often the median lethal dose (LD₅₀) which is calculated on the basis of being lethal to 50 percent of the tested animals. However, lethal dose is a very insensitive (extreme) measure of impacts on biological systems, where health and fecundity are also of fundamental concern.

Table 4. Terrestrial species toxicity data for long-term retardant formulations.

Formulations	Toxicity and test species	Relative toxicity
Phos-Chek D-75R (at recommended solution mixed ratio)	> 5,050 mg/kg, rat > 2,020 mg/kg, rabbit Eye irritation , rabbit Skin irritation, rabbit	Nontoxic (1) Slightly toxic (2) Practically nonirritating (2) Nonirritating (2)
Phos-Chek D-75F (at recommended solution mixed ratio)	> 5,000 mg/kg, rat > 2,00 mg/kg, white-footed mouse > 2,000 mg/kg, bobwhite quail Eye irritation, rabbit Skin irritation, rabbit	Nontoxic (1) Slightly toxic (1) Slightly toxic (1) Practically nonirritating (2) Nonirritating (2)

Source:

(1) Anon. 1996

(2) Solutia In. Material Safety Data Sheet (Appendix I)

Other investigations of the toxicity of long-term fire retardant to terrestrial wildlife by Patuxent Wildlife Research Center found no toxic effects of retardant to mammals and birds (Anon. 1996, Vyas and Hill 1996). Beyer and Olson (1996) investigated the toxicity of long-term fire retardant to earthworms and found that Phos-Chek D-75 retardant was nontoxic to earthworms when applied at 1,000 ppm.

Boivin and Bailor (1996) used a model to assess the ecological risk to terrestrial species of applying fire retardant. They estimated the exposure dose of retardant and foams to terrestrial species based on dietary exposures. The dietary doses of representative species were estimated based on the assumption that 25 percent of their diet was unburned vegetation and contaminated with fire retardant chemicals. The estimated doses for long-term retardant ranged from 10 mg/kg/day for a squirrel to 1,673 mg/kg/day for blue jay at a retardant

application rate of 0.41 L m⁻². The model predicted that the diet contaminated with retardant had no adverse effect on squirrels and a possible effect on the blue jay. Similarly no effects were predicted for cattle but a possible adverse effect on rabbits. These results have a high degree of uncertainty and an estimate of the likelihood of fire retardant effects on native Australian fauna is difficult to make.

The likelihood of physical injury to wildlife from retardant aerial drop is remote and insignificant compared to the risk of death and injury from the fire. When the fire is small large animals leave the area and small mammals seek shelter in burrows etc. If the fire is large and of high-intensity whole populations suffer death through burning, and those that survive the fire usually die from starvation or predation by ferals.

A potential indirect effect of long-term retardant may include the increase in nitrate concentration in vegetation and subsequent nitrate toxicity to herbivorous animals. However the scale of any such impact is likely to be very minor.

Overall little information exists to indicate potential adverse effects to terrestrial wildlife from fire suppression chemicals. The literature search revealed no information regarding potential toxicity to Australia fauna.

5.4 Retardants and aquatic systems

The constituents of concern include the ammonia/phosphate/sulfate compounds (primary ingredients), and the specific ingredients of Phos-Chek D-75R. Impacts on streams depend on composition and longevity of retardant compounds at the soil surface, soil transformation and fixation rates, pathways of water movement (affected by storm intensity, soil permeability and terrain), distance between retardant drop and waterways, and the population and diversity of life forms in the aquatic system and their sensitivities to the retardant and breakdown products.

The pathways illustrated in Figure 4 describe the predominant mechanisms by which contaminants could be transported into waterways. Thus, these pathways identify the primary environmental process, which can be used to assess the impact and risk of using wildland fire retardant chemicals. For example, contamination of municipal water supply is possible as a result of either leaching or runoff from treated areas, or unintentional direct application of retardant to a surface water body.

The standard application method describes the transport of fire suppression chemicals from the vegetation and soil to a stream, followed by dispersion and flow within the water body (See Figure 4). After application, the chemicals could be either washed off the land surface into a receiving water body or infiltrated to the subsurface soil. It is also possible for the infiltrated chemicals to follow groundwater movement and enter the stream. The constituents of concern are either added nutrients, or the low levels of specific chemicals. During subsurface transport, it is likely that these chemicals will be absorbed and retained in the soil. Percolation through the soil is likely to reduce the risk of stream contamination to negligible levels, unless the retardant is dropped adjacent to a water course.

Most study of the potential environmental risk of fire retardant chemicals to aquatic systems has been conducted in North America. These studies were either laboratory studies and/or stimulation modeling of the transport of retardant contaminants in watershed areas to

determine the acute toxicity and environmental risk to aquatic life (Buhl and Hamilton 1998, McDonald *et al.*, 1998, Boivin and Bailor 1996, Hamilton *et al.* 1996, Anon. 1996).

Boivin and Bailor (1996) evaluated the risk to aquatic ecosystems using a hydrology computer simulation model to predict the amount of fire suppression chemicals entering a stream after application in a watershed. The model tried to simulate infiltration, surface runoff, sediment transport, nutrient cycling (nitrogen and phosphorus), and adsorption and degradation of receiving waterways after application of long-term retardants. Accidental scenarios in which the stream was in the path of an aerial drop were also evaluated. The results of their simulation studies predicted ammonia concentrations in the stream ranging from negligible to 0.8 mg/L from runoff and from 0.4 to 50 mg/L following accidental drops in the stream. The application of foam suppressants in the simulated model estimated stream concentrations ranging from 0.3 mg/L to 6 mg/L from runoff and 6 to 400 mg/L following an accidental drop of retardant. The reliability of the models and the conclusions drawn from them are unknown.

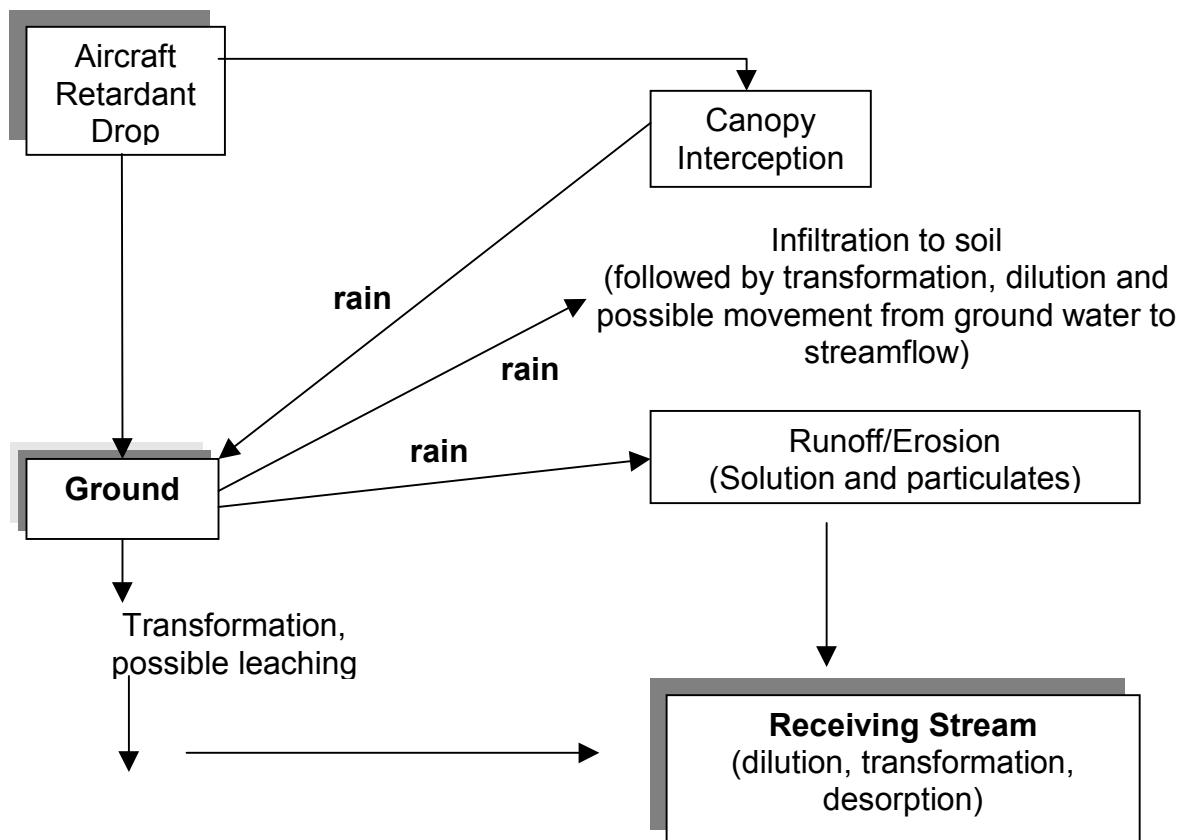


Figure 4. Conceptual pathways for transport of wildland fire chemical into catchment streams.

The major finding of the study was that fire-fighting foam was predicted to be significantly more toxic to aquatic species than the long-term fire retardant. However, long-term retardants are applied in far greater quantities in remote areas. The toxicity of these ammonia-based salts

is determined by pH and temperature of the receiving body of water. In general, the following are some of the other factors that increase the potential for adverse impacts on streams:

- high soil clay and low organic matter content,
- steep slopes,
- shallow soil or low permeability of soil,
- high pH in receiving body of water, and
- small stream or low flow.

The dilution rate is a function of the volume and flow in streams - small streams and low or stagnant flow may not dilute the incoming chemicals to a safe level. The physical and chemical properties of the fire chemical retardants, and watershed and soil characteristics are required to evaluate potential risk in specific situations

There is little information on the effects of fire chemical retardants on aquatic ecosystems or water quality in Australia. Addition of nitrogen and phosphorous can be a major risk to water quality and aquatic ecosystems. The other risk is from the performance additives, which are not disclosed to the public and may be added at a rate around 1900 mg L^{-1} in the applied retardant solutions.

6. RETARDANTS AND HUMAN HEALTH

There are two main areas of concern with respect to human health in the use of fire retardants:

- safety issues during the preparation and application of fire retardants (handling of and coming in direct contact with fire retardant) – guidelines for safe handling are given in the Material Safety Data Sheet (Appendix I), and
- public health issues due to release of components of fire retardants into the water, air and soil environments.

6.1 Health risk involved during direct handling of the retardant

Sufficient information is available from the suppliers of the various components of retardants to develop procedures required for safe handling. Material handling requires: avoiding inhaling of fine dust (proper mask), avoiding direct contact with the skin (use of gloves, wash hands and contaminated skin thoroughly after handling), and protecting eye contact (use of good industrial practice to avoid eye contact). The only potential health hazards during Phos-Chek handling are minor skin and eye irritation ('toxicologist report'), but these can be minimised if appropriate recommended handling procedures are used, including good industrial practice to avoid eye contact and skin contamination. There is no apparent Phos-Chek related health hazard in applying the material. Obviously the fire crews on ground may be exposed to it under certain situations.

Although sufficient information on the procedural guidelines for the use of retardants are provided by Solutia in the Material Safety Data Sheet (Appendix I), the Department should stress in its Code of practice for use of retardants that the users strictly follow the safety guidelines. The Material Safety Data Sheet (Appendix I) recommends mandatory use of safety equipment. NRE should make the use compulsory.

6.2 Public health risk due to contamination of water ways and food chains

Public health is a complex issue and is mostly concerned with minimum exposure to fire retardant components through air, water or soil. Contaminants should not enter the food chain in amounts that can have any harmful effect in the short term or long term. Some of the short term effects have been addressed in section 6.1. From the information so far available, Phos-Chek components can be considered to have low acute toxicity and very low risk of long term/delayed toxicity to humans ('toxicologist report').

There are no data indicating a tendency for any of the components of Phos-Chek to accumulate in biota. There is no expectation of accumulation of the highly water soluble components in the food chain. With the exception of one component for which it has not been possible to locate data on its environmental fate, none of the chemicals in Phos-Chek have propensity to accumulate in biological systems.

7. ALTERNATIVES TO USING PHOS-CHEK D75-R

This report reviewed the application, effectiveness, ecological and health risk of using the long-term retardant Phos-Chek D75-R for wildfire suppression. Although the Department of Natural Resources and Environment has adopted a policy of using commercial formulations which are approved for use in natural environments by the USDA Forest Service, this review has shown that there are still some areas of uncertainty about the effects of the chemicals, particularly those which are commercial-in-confidence, in the Australian environment. However, the potential risks need to be weighed up against the risks of adopting alternative strategies. These may include:

- using other formulations of long-term retardant,
- using short-term chemical suppressants like fire fighting foam, and
- banning fire fighting chemicals altogether and adopting other fire fighting strategies.

A full evaluation of the risks associated with alternative strategies would need to consider not only the risks to human health and environment but also alternative criteria such as the statutory responsibility to control wildfires, logistics, manpower and known capacity to control the spread of wildfire and the economic and environmental consequences of increased area burnt. Such an evaluation is beyond the scope of this report. The following section discusses briefly some alternative strategies to using Phos-Chek D75-R.

7.1 Long-term retardant

The development of long-term retardants was rather rapid during the late 1960 when the ammonium-base phosphates and sulphates were tested and more easily available. This development phased out most of the early retardant products, such as bentonite, algin-gel and sodium carboxy methylcellulose because of the problems associated with the mixing of the materials for spread, and their lower affectivity compared to the phosphate retardants. Borate and sodium calcium borates showed some retarding qualities but were not used, partly due to their abrasive qualities but also primarily due to their environmentally detrimental soil-sterilant characteristics (Hardy 1977).

“Home-mixing” of long term retardant (e.g. Bradstock *et al* 1987, Project Aquarius- Albright and Wilson products) were done for a while. The errors in the mixtures were too prevalent when spoilage and corrosion inhibitors and colouring agents had to be added to the ammonium phosphates and sulphates either by the manufacturer or by the user at the mixing base. This lead to the use of commercial long-term fire retardant products supplied mainly by two manufacturers located in the United States:

1. Solutia Inc. (Phos-Chek trade name products)
2. Chemonics Industries Inc. (Fire-Trol trade name products)

Both manufacturers use similar ingredients mainly composed of ammonium-base phosphates and sulphates, and contain additives thickeners, anticorrosive substance, flowing agents and colourng substance (Table 1) and are commercially available as dry powder or liquid concentrate. The fire suppression chemical that are qualified or approved by the USDA Forest Service and are commercially available are listed in Appendix II.

The commercial long-term fire retardants, supplied as either dry powder or liquid concentrate formulations , - have long been considered to be have minimal human health and ecological risk. The research has been mostly confined to the effects on aquatic organisms. Several authors have reported on toxicity of the active ammonium salts found in most fire retardants (Finger 1997). Their research has been mostly done on the commercial products e.g. Phos-Chek D75F, Phos-Chek D75R and Fire-Trol GTS at the mixture and application rate recommended for field use. Very little research has been done on the impacts of the individual minor ingredients Which make up around 5% of the long-term retardant products. Appendix II lists the commercially available fire suppression chemicals that are fully qualified or have conditional approval by the USDA Forest Service (USDA Forest Service 1999).

Fire retardants without corrosive inhibitors are conducive to corrosion, stress corrosion and corrosion fatigue. Gehring (1978) found that uninhibited diammonium phosphate and ammonium sulphate mix in a 15 percent solution by weight would:

- severely corrode aluminum, magnesium, copper and steel alloys (10-250 mm per year (mpy) depending on conditions of exposure,
- increase the susceptibility to stress corrosion cracking in aluminum, and
- reduce the lifecycle fatigue of aluminum.

In producing a “home-made” mix the corrosion inhibitors may be the most toxic ingredients. Hardy (1977) lists some of the corrosion inhibitors that can protect some of the metals associated with long-term retardant delivery. Example, sodium ferrocyanide when heated to decomposition by emitting highly toxic fumes of hydrogen cyanides gas. Therefore, in producing “home made” long-term retardant will require testing, chemical hazards assessment, certification and assessment on the risk on human health and environment before using these “home made” products. All the commercial fire suppression chemicals have material safety data sheets (MSDS) available which include most of the following headings and should be done for the “home made” products before using:

- Chemical Product and company identification
- Composition / information on ingredients
- Hazards identification
- First aid measures

- Fire fighting measures
- Accidental release measures
- Handling and storage
- Exposure control and personal protection
- Physical and chemical properties
- Stability and reactivity
- Toxicological information
- Ecological information
- Disposal considerations
- Transport information
- Regulatory information
- Other information

The chemistry of fire retardant action is well established and it is highly unlikely that any new product will perform any better or have fewer environmental impacts than existing approved products.

7.2 Short-term retardant

Short-term retardant relies almost entirely on its water holding capacity and cooling ability for its effectiveness. Water is the simplest of short-term retardants. The effectiveness of water and its drop characteristics are improved by the use of thickeners. The thickened water holds together while cascading from the airtanker, coats the fuel and retards fire's rate of spread. Wetting agents can be added to water to decrease the surface tension, thus increasing the ability of water to spread and penetrate into the fuels. Wetting agent is not recommended for aerial suppression and is most commonly used in ground crew mopping up of large logs and peat soils.

Short-term retardant is used primarily as a suppressant, i.e. applied directly to the fire (usually at the base of the flame). When supported by ground forces, such as hand crews and tanker units, it can be an effective suppression tactic to control wildfires. Class A foams are considered as short-term retardants. Appendix II lists the approved fire suppressant foams by the USDA Forest Service. Some of the claimed advantages of Class A wildland fire foams are:

- increase the effectiveness of water (by requiring less water when applied as a foam for direct suppression),
- extend the useful life of water,
- provide short-term fire barrier,
- are effective on fires in all types of class A fuels (such as wood and cellulose material),
- are relatively easy to use (mixing and handling), and
- are visible from ground and air.

Wildland fire foams do not have the long-lasting effect of long-term retardant, and it is difficult to substantiate the anecdotal reports that foams remain effective longer than straight water. Johnson and George (1997) conducted a pilot study to determine the long-term combustion retarding effectiveness of foam suppressants. Their study compared the performance of the foams with DAP (diammonium phosphates), the test standard, which has a superiority factor of approximately 60, the minimum allowable to be an acceptable product. The foams had superiority factors of -1 and -3 (water has a superiority factor of 0).

Toxicity tests by Buhl and Hamilton (1998), Hamilton *et al* (1996), McDonald *et al* (1998) Vyas and Hill (1996) and Finger (1997) concluded that fire suppressant foams were more toxic to aquatic ecosystem than long-term fire retardant if there were accidental inputs of these chemicals into the stream environment. No studies of the ecological effects of foam suppressants have been carried out on Australia's flora and fauna communities. The limited information from studies in United States (Finger 1997, Larson and Newton 1996) concluded that foam suppressant did not effect plant growth, but did depress species diversity in a mixed-grass prairie ecosystem (change in number of species in burn plot) when using foam to control prescribed burns. Commercial foam products all have commercial-in-confidence chemicals in their formulations. These were not identified for this review but would need to be considered if a full evaluation against long-term retardants were to be undertaken.

Health and safety testing of wildland foams found that all foam concentrates cause moderate to severe irritation to eyes. To prevent eye injury splash goggles be worn when handling the concentrates. In addition, exposure can cause slight to moderate skin irritation and chapping. Wearing of suitable impervious gloves is recommended to prevent exposure.

7.3 Retardant and foam composites

Several operational trials between 1988 and 1992 by the British Columbia Forest Service to evaluate the effectiveness of retardant and foam composites (Beck *et al.* 1996). Preliminary trials suggest that retardant and foam composite offer a number of advantages over straight retardant:

- canopy penetration, drip and fuel wrap around are superior,
- drop perimeters are sharper and well defined in comparison to the dispersed edge of conventional retardant drop, and
- the visibility of the composite is enhanced significantly.

Although drop patterns and visibility of the drops was improved further studies were done to evaluate the effectiveness of the retardant and foam composite. Beck *et al.* 1996 studies concluded that there were no gains in the suppression efficiency using the retardant and foam composite over the conventional retardants. Furthermore, environmental studies of the component products may not be applicable to composites, and some work may be required if retardant and foam composites have an adverse effect on species composition or vegetation growth.

7.4 No use of chemicals

An alternative strategy is to ban the use of chemical retardants altogether. Because of the way chemical retardants are used (see section 4) there are many situations where there are no practical alternative suppression techniques. As a result the areas burnt by wildfires will increase with a concomitant increase in environmental damage and economic loss.

Wildfires starting on forest land have no respect for jurisdictional boundaries. Under extreme conditions they can cause extensive losses to timber values and burn onto private land causing millions of dollars of damage to structures, livestock, agricultural production, fencing and other capital assets. An economic assessment of the Fire Management Program (FMP) of DNRE simulated the economic consequences of different suppression strategies on 606 fires attended by FMP fire fighters during the 1991-92 fire season. Replacement of FMP fire fighters by fire fighters from private land holders and volunteer groups (e.g. CFA) was estimated to increase the loss from fire to around \$772 million. The FMP was calculated to yield a benefit-to-cost ratio of 22 to 1 to the State of Victoria from its investment in suppression (Bennetton *et al.* 1997). This return underestimated the true value of the FMP as losses by damage to flora and fauna, public infrastructure, tourism and recreation, water quality and quantity, erosion and human life were not included. An evaluation of the effects of not using fire retardants was not carried out but could be reasonably expected to reduce the benefit to cost ratio.

There is little information available to compare the ecological and health impacts of alternative suppression chemicals to the potential impact of a wildfire. A comparison of this nature can only be done on a site-specific basis, and depends on many variables, including fire size and intensity, the ecosystem affected and the type and amount of chemicals required to assist in controlling the wildfire. Most ecological studies have compared no-fire conditions with prescribed burns (low-intensity fires); it is very difficult to evaluate the effects of catastrophic fires compared with the effects of fire suppression chemicals on forest ecological values.

When considering the possible damage to the environment from chemical retardants it is needs to be appreciated that the effect of wildfires on the environment is not necessarily benign. It is generally accepted that fire is part of the Australian environment, essential for maintaining biodiversity, and in many ecosystems detrimental effects are short-lived and decrease over time as natural recovery and succession occurs. However, in some ecosystems the change can be devastating. For example fires burning alpine peat lands which are thousands of years old have caused local extinction of several species, severe erosion and damage to the hydrology of the catchment (Gill 1996). Such areas are unlikely to regain their prefire state within the next several thousand years and may be permanently changed if the successional vegetation is flammable and predisposes the area to repeated fires. The use of chemical retardants in such areas, even when their effects on the vegetation are unknown, may well be justified in order to limit the known detrimental effects of fire. In areas containing endangered species the use of fire retardants to build a fireline is likely to be far less devastating than using machines, such as bulldozers, to contain the fire.

Likewise the possibility of fire retardant chemicals or their combustion products impairing the health or fecundity of native fauna appears low when compared to the known effects of wildfires. Large wildfires kill native fauna in large numbers. Sometimes it is rapid but in other

cases it may be slow and (in human terms) agonising over several days. When fires burn large areas survivors within the area may starve to death or, since their cover has been removed, suffer mauling and predation from feral foxes and cats. Although this is usually accepted as “natures way”, there are situations where endangered species are limited to restricted habitats. When small and restricted habitats are burnt by large fires, the possibility of re-population is remote and local extinction occurs (Possingham and Gepp 1996). The chemicals contained in Phos-Chek are unlikely to accumulate in the food chain, and thus pose a long-term risk to animal health.

The combustion of forest fuels produces a large number of toxic products. When large volumes of smoke from wildfires are blown into urban airsheds these can combine with industrial/urban pollutants to provide an even more toxic mix of pollutants. These have been known to persist over several weeks and cause an increase in respiratory complaints. It is known that all organic compounds in Phos-Chek decompose into simple compounds which would probably be indistinguishable from those produced in vegetation fires. Thus any proposal to determine the combustion and/or degradation products of Phos-Chek or other long-term retardants and test them for toxicity, must also evaluate the products formed in wildfires.

As there is no long-term/delayed toxicity associated with any component of Phos-Chek, the low toxicity needs to be evaluated relative to the physical dangers of fire fighting ('toxicologist report'). The skin and eye irritancy of the dry powder can be prevented with safe handling procedures, and is not relevant following mixing. Given the highly destructive and unpredictable nature of wildfires, it appears to be in the interest of both human health and safety, and the environment, to use the most efficient and reliable means of control currently available when deemed necessary. Phos-Chek D75-R has evolved in conjunction with long term evaluation and testing by the USDA Forest Service, and appears as safe as any other alternative long-term retardant and probably less harmful than alternative short-term retardants currently available. Proper management of its use will assist DNRE in its legal responsibility to manage both fire and the natural environment.

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Appendix I**Material Safety Data Sheet for Phos-Chek Fire Retardant D-75F and D-75R**

***Material Safety Data
Sheet***

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: PHOS-CHEK® FIRE RETARDANT GRADES D-75F AND D-75R

MSDS Number: M00009911 Date: August 27, 1998

SOLUTIA INC., 10300 OLIVE BOULEVARD, P.O. BOX 66760, ST. LOUIS, MO 63166-6760

FOR CHEMICAL EMERGENCY, SPILL, LEAK, FIRE, EXPOSURE, OR ACCIDENT
Call CHEMTREC - Day or Night - 1-800-424-9300 Toll free in the continental U.S., Hawaii,
Puerto Rico,
Canada, Alaska, or Virgin Islands. For calls originating elsewhere: 703-527-3887 (collect
calls accepted)

For additional non-emergency information, call: 314-674-6661

2. COMPOSITION/INFORMATION ON INGREDIENTS

<u>Component</u>	<u>CAS No.</u>	<u>% by weight</u>
Diammonium Sulfate	7783-20-2	> 65
Monoammonium Phosphate	7722-76-1	> 15
Diammonium Phosphate	7783-28-0	> 5
Guar Gum, hydroxypropyl	39421-75-5	<10
Performance Additives +	Trade Secret	<5

+The specific chemical identities are being withheld because they are trade secret information of Solutia Inc.. They will be disclosed on a confidential basis to regulatory authorities and health professionals.

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Appearance and Odor: Reddish colored mixture of powdered and granular components with little or no odor.

WARNING STATEMENTS

WARNING!

CONTAINS GUAR GUM WHICH CAN CAUSE ALLERGIC RESPIRATORY REACTION
MAY CAUSE RESPIRATORY TRACT IRRITATION

POTENTIAL HEALTH EFFECTS

Likely Routes of Exposure: skin contact and dust inhalation

EYE CONTACT: No more than slightly irritating based on toxicity studies. The dry powder may cause foreign body irritation in some individuals.

SKIN CONTACT: No more than slightly toxic based on toxicity studies. Non irritating based on toxicity studies. The dry powder may cause drying or chapping of the skin.

INHALATION: May cause nasal and respiratory tract irritation based on toxicity information of components. May cause an allergic respiratory tract reaction based on toxicity information of guar gum.

INGESTION: Not toxic if swallowed based on toxicity studies. No significant adverse health effects are expected to develop if only small amounts (less than a mouthful) are swallowed.

Refer to Section 11 for toxicological information.

4. FIRST AID MEASURES

IF IN EYES OR ON SKIN: immediate first aid is not likely to be required. However, this material can be removed with water. Wash heavily contaminated clothing before reuse.

IF INHALED: remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen. Get medical attention. Remove material from eyes, skin and clothing.

IF SWALLOWED: immediate first aid is not likely to be required. A physician or Poison Control Center can be contacted for advice. Wash heavily contaminated clothing before reuse.

5. FIRE FIGHTING MEASURES

FLASH POINT: not combustible

HAZARDOUS PRODUCTS OF COMBUSTION: not applicable

EXTINGUISHING MEDIA: not applicable

UNUSUAL FIRE AND EXPLOSION HAZARDS: none known

FIRE FIGHTING EQUIPMENT: not applicable

6. ACCIDENTAL RELEASE MEASURES

In case of spill, sweep, scoop or vacuum and remove. Flush residual spill area with water.

Refer to Section 13 for disposal information and Sections 14 and 15 for reportable quantity information.

7. HANDLING AND STORAGE

Handling:

Avoid breathing dust.

Keep container closed.

Use with adequate ventilation.

Emptied container retains dust and product residue. Observe all labeled safeguards until container is cleaned, reconditioned, or destroyed. The reuse of this material's container for nonindustrial purposes is prohibited and any reuse must be in consideration of the data provided in the MSDS.

Storage:

Product is stable under normal conditions of storage and handling.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION: This product does not cause significant eye irritation or eye toxicity requiring special protection. Use good industrial practice to avoid eye contact.

SKIN PROTECTION: Although this product does not present a significant skin concern, minimize skin contamination by following good industrial practice. Wearing protective gloves is recommended. Wash hands and contaminated skin thoroughly after handling.

RESPIRATORY PROTECTION: Avoid breathing dust. Use NIOSH/MSHA approved respiratory protection equipment when airborne exposure is excessive. Consult respirator manufacturer to determine appropriate type equipment for given application. Observe respirator use limitations specified by NIOSH/MSHA or the manufacturer. Respiratory protection programs must comply with 29 CFR ' 1910.134.

Attention! Repeated or prolonged inhalation may cause allergic respiratory reaction in some people.

VENTILATION: Provide natural or mechanical ventilation to minimize exposure. If practical, use local mechanical exhaust ventilation at sources of air contamination such as open process equipment.

AIRBORNE EXPOSURE LIMITS:

Product/Component

Grades D-75F AND D-75R

OSHA PEL

None Established

ACGIH TLV

None Established

OSHA and ACGIH have not established specific exposure limits for this material. However, OSHA and ACGIH have established limits for particulates not otherwise classified (PNOC) which are the least stringent exposure limits applicable to dusts.

OSHA PEL

15 mg/m³ (total dust) 8-hr TWA
5 mg/m³ (respirable) 8-hr TWA

ACGIH TLV

10 mg/m³ (inhalable) 8-hr TWA
3 mg/m³ (respirable) 8-hr TWA

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance: Reddish powder

Odor: Essentially odorless

Viscosity: 1000-2000 centipoise @ 21 degrees C (70 degrees F) when dissolved in water at the recommended level of 1.20 pounds per gallon of water.

NOTE: These physical data are typical values based on material tested but may vary from sample to sample. Typical values should not be construed as a guaranteed analysis of any specific lot or as specifications for the product.

10. STABILITY AND REACTIVITY

STABILITY: Product is stable under normal conditions of storage and handling.

MATERIALS TO AVOID: None known

HAZARDOUS DECOMPOSITION PRODUCTS: Ammonia and phosphoric acid may be formed when these products are heated above 90 degrees C (194 degrees F). Further decomposition resulting in sulfur dioxide may occur at approximately 250 degrees C (482 degrees F).

HAZARDOUS POLYMERIZATION: Does not occur.

11. TOXICOLOGICAL INFORMATION

Data from laboratory studies conducted by Solutia with PHOS-CHEK Fire Retardant, Grades D-75F and D-75R are summarized below.

	<u>Oral LD50 (Rat)</u>	<u>Dermal LD50 (Rabbit)</u>	<u>Eye Irritation (Rabbit)</u>	<u>Skin Irritation (4-hr, Rabbit)</u>
PHOS-CHEK D-75F dry-powder	No More Than Slightly Toxic (>505 mg/kg)	No More Than Slightly Toxic <td>Slightly Irritating</td> <td>Nonirritating</td>	Slightly Irritating	Nonirritating
PHOS-CHEK D-75F solution @ recommended mix ratio	Practically Nontoxic <td>No More Than Slightly Toxic<br (>2,020="" kg)<="" mg="" td=""/><td>Practically Nonirritating</td><td>Nonirritating</td></td>	No More Than Slightly Toxic <td>Practically Nonirritating</td> <td>Nonirritating</td>	Practically Nonirritating	Nonirritating
PHOS-CHEK D-75R dry-powder	No More Than Slightly Toxic <td>No More Than Slightly Toxic<br (>2,020="" kg)<="" mg="" td=""/><td>Practically Nonirritating</td><td>Nonirritating</td></td>	No More Than Slightly Toxic <td>Practically Nonirritating</td> <td>Nonirritating</td>	Practically Nonirritating	Nonirritating
PHOS-CHEK D-75R solution @ recommended mix ratio	Practically Nontoxic <td>No More Than Slightly Toxic<br (>2,020="" kg)<="" mg="" td=""/><td>Practically Nonirritating</td><td>Nonirritating</td></td>	No More Than Slightly Toxic <td>Practically Nonirritating</td> <td>Nonirritating</td>	Practically Nonirritating	Nonirritating

Components

Data from laboratory studies conducted by Solutia and from the available literature on components of these products which have been identified under the criteria of the OSHA Hazard Communication Standard (29 CFR 1910.1200):

Diammonium Sulfate

Diammonium sulfate was slightly toxic orally and no more than slightly toxic after skin application (rabbits). It was slightly irritating to rabbit eyes and nonirritating to rabbit skin. Inhalation of diammonium sulfate by guinea pigs was reported to produce lung effects and, at high level exposures, animal deaths due to shock and airway constriction. Repeated inhalation had no effect on lung defense mechanisms of hamsters, but was reported to increase the incidence of emphysema in comparison to controls. Aerosols of diammonium sulfate aggravated artificially induced emphysema in rats. Diammonium sulfate produced no genetic changes in standard tests using bacterial cells.

Guar Gum, hydroxypropyl

PHOS-CHEK Fire Retardant, Grades D-75F and D-75R contain hydroxypropylguar, which was reported to be irritating to eyes and respiratory tract. Respiratory allergenic responses were reported following repeated exposures in a study of a small group of exposed workers.

12. ECOLOGICAL INFORMATION

The following data have been classified using the criteria adopted by the European Economic Community (EEC) for aquatic organism toxicity. A legend summarizing the classification scheme appears below.

24-hr LC50 Daphnia Magna: > 1,000 mg/l Practically Nontoxic
48-hr LC50 Rainbow Trout: > 1,000 mg/l Practically Nontoxic
48-hr LC50 Fathead Minnow: > 1,000 mg/l Practically Nontoxic

Legend for Aquatic Organism Toxicity (Journal of the European Communities, Annex VII A, Section 5.2.1)

Values	Classifications
LC50 or EC50 < or = 1.0 mg/L	Very Toxic
LC50 or EC50 > 1.0 mg/L and < or = 10 mg/L	Toxic
LC50 or EC50 > 10 mg/L and < or = 100 mg/L	Harmful
LC50 or EC50 > 100 mg/L	Practically Nontoxic

13. DISPOSAL CONSIDERATIONS

When discarded this material is not a hazardous waste as that term is defined by the Resource, Conservation and Recovery Act (RCRA), 40 CFR 261. Dispose by landfill or recycle in accordance with local, state and federal regulations. Consult your attorney or appropriate regulatory officials for information on such disposal.

14. TRANSPORT INFORMATION

The data provided in this section is for information only. Please apply the appropriate regulations to properly classify your shipment for transportation.

This product is not hazardous under the applicable DOT, ICAO/IATA, or IMDG regulations.

15. REGULATORY INFORMATION

TSCA Inventory: All components are listed.

SARA Hazard Notification

Hazard Categories Under Title III Rules (40 CFR 370): Immediate
Section 302 Extremely Hazardous Substances: Not Applicable

Section 313 Toxic Chemical(s): When put in solution, this product contains aqueous ammonia from dissociable ammonium salts. 2.2 percent of this dry powder product is reportable under the requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

CERCLA Reportable Quantity: Not Applicable.

California Proposition 65: Not Applicable.

Refer to Section 11 for OSHA Hazardous Chemical(s) and Section 13 for RCRA classification.

16. OTHER INFORMATION

Reason for revision: Minor formatting changes. Supersedes MSDS dated 07/23/98.

Phos-Chek ® is a registered trademark of Solutia Inc.

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Responsible Care ® is a registered trademark of the Chemical Manufacturers Association

Phos-Chek D75FR.898.doc

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Appendix II

Fire Suppression Chemicals

(USDA Forest Service Fire and Aviation Management Qualified or Approved and commercially available)
Source: <http://www.fs.fed.us/rm/fire/download/chemical> Amended July 1999

Chemical	Viscosity ¹	Mix Ratio	Status	Qualified/Approved Applications ²			Ground Engine				
				Fixed-Wing Airtanker	Fixed-Tank Helicopter	Helicopter Bucket					
LONG-TERM FIRE RETARDANTS (Qualified under specification 5100-304-a)											
Dry Powder											
Gum-thickened											
Fire-Trol GTS-R	1000+	1.66 lb/gal	Qualified	●			●				
Phos-Chek D75-R	1000+	1.20 lb/gal	Qualified	●			●				
Phos-Chek D75-F	1000+	1.20 lb/gal	Qualified	●			●				
Fire-Trol 300-F	1000+	1.77 lb/gal	Qualified	●			●				
Phos-Chek 259-F	50-150	1.14 lb/gal	Qualified	●	●		●				
Phos-Chek G75-W	50-150	1.12 lb/gal	Qualified			●	●				
Phos-Chek G75-F	50-150	1.12 lb/gal	Qualified	●			●				
Unthickened - None available											
Liquid Concentrates											
Gum-thickened											
Phos-Chek HV-F	1000+	3.6:1	Qualified	●			●				
Phos-Chek HV-R	1000+	3.6:1	Conditional ³	○			○				
Phos-Chek MV-R	450-750	3.6:1	Conditional ³	○			○				
Phos-Chek MV-F	450-750	3.7:1	Conditional ³	○			○				
Phos-Chek LV-R	75-225	3.6:1	Conditional ³	○			○				
Unthickened											
Fire-Trol LCA-R	10-25	5:1	Qualified	●			●				
Fire-Trol LCG-R	10-25	4.75:1	Qualified	●			●				
Fire-Trol 931-R	10-25	4.75:1	Conditional ³	○			○				
Fire-Trol LCA-F	10-25	5:1	Qualified	●			●				
Fire-Trol LCG-F	10-25	4.75:1	Qualified	●			●				

¹ Based on supplier target viscosity, where known.

² ● Fully Qualified ○ Conditional Approval

³ A monitor level field evaluation must be completed to upgrade product status to qualified. The evaluation will be scheduled when a product is selected for use.

Fire Suppression Chemicals

(USDA Forest Service Fire and Aviation Management Qualified or Approved and commercially available)

Source: <http://www.fs.fed.us/rm/fire/download/chemical> Amended July 1999

Chemical	Mix Ratio	Status	Qualified/Approved Applications ¹			Ground Engine
			Fixed-Wing Airtanker	Fixed-Tank Helicopter	Helicopter Bucket	

WILDLAND FIRE FOAM (Administrative approval using “Interim Requirements for Wildland Fire Foam”)

Ansul Silv-Ex	0.1-1.0%	Adm. Approval		•	•	
Fire-Trol FireFoam 103	0.1-1.0%	Adm. Approval		•	•	
Fire-Trol FireFoam 103B	0.1-1.0%	Adm. Approval ²	○	•	•	
Phos-Chek WD 881	0.1-1.0%	Adm. Approval ²	○	•	•	
Fire-Trol FireFoam 104	0.1-1.0%	Adm. Approval		•	•	
Angus ForExpan S	0.1-1.0%	Adm. Approval		•	•	
Pyrocap B-136	0.1-1.0%	Adm. Approval		•	•	
Fire Choke	0.1-1.0%	Adm. Approval	•	•	•	

¹ • Fully Qualified ○ Conditional Approval

² Temporary administrative approval for use from fixed-tank helicopters.

Fire Suppression Chemicals

(USDA Forest Service Fire and Aviation Management Qualified or Approved and commercially available)
 Source: <http://www.fs.fed.us/rm/fire/download/chemical> Amended July 1999

Chemical	Mix Ratio	Status	Qualified/Approved Applications ¹			Ground Engine
			Fixed-Wing Airtanker	Fixed-Tank Helicopter	Helicopter Bucket	
SHORT-TERM FIRE RETARDANTS (Qualified under specification 5100-00306)						
Fire-Trol ST-F	0.50-0.75%	Qualified	•			
	0.25-0.50%	Qualified			•	•
Phos-Chek FS IIP-F	0.50-0.75%	Qualified	•			
	0.25-0.35%	Qualified			•	•
Fire-Trol STH-F	0.71%	Qualified	•	•	•	•
Fire-Trol ST2-U	0.2-0.75%	Qualified	•		•	•
WETTING AGENTS (Qualified under specification 5100-305a)						
KCR	1 qt/500 gal	Qualified			•	•

FIRE SUPPRESSANT GELS (Qualified under Administrative Work Plan)

Chemdal	0.4-1.2%	Approved	○	○
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¹ • Fully Qualified

○ Conditional Approval

Appendix III

NRE Air Operation Manual - August 1999

This 250 page Manual, and particularly the sections relevant to this report, can be inspected by arrangement at NRE's Fire Management Branch (Level 6, 240 Victoria Parade, East Melbourne) or at NRE's Regional Offices throughout Victoria.

