# Effectiveness of SIROFLO® in vertical silos

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*Abstract*

During the current season it is expected that approximately 6 Mt of grain will be treated with SIROFLO® in Australia. Most of this tonnage will be treated in vertical silos. SIROFLO® was initially developed in vertical silos, because of its inherent advantages in overcoming the factors that give rise to gas loss in this type of structure. The principal factor in this context is the chimney effect. In leaky silos, the chimney effect can give rise to a rapid loss of gas from the structure. This results in a general reduction in concentrations and pockets of low or zero concentrations of gas, the net effect of which is to increase the probability of survival of insects and selection for resistance. Even in silos sealed to the pressure standard, the chimney effect can result in failure of some fumigations.

SIROFLO® is currently, the only method *designed* to overcome the chimney effect and therefore provides a means whereby effective phosphine fumigations can be carried out in a wide range of silos including silos that are uncapped. The various trials of SIROFLO® in vertical silos were aimed at determining the factors that influence gas distribution, particularly the significance of chimney forces. Results are given of some of the gas distribution profiles obtained from a trial at Millmerran, Queensland in 1993.

## Introduction

SIROFLO® was first installed on a commercial scale in Australia in 1988 at a number of sites in New South Wales (Winks, 1993). Since that time it has been installed in silos in all of the major grain producing states in Australia. During the current season, estimates suggest that approximately 6 Mt of grain will be treated with SIROFLO® in Australia. Most of this tonnage will be treated in vertical silos that are either unsealed or poorly sealed. In these silos, conventional methods of fumigating with phosphine would not be effective and failures could be expected with consequent selections of strains for resistance. Even in silos sealed to the gas-tightness standard which specifies, as a minimum, that *an increased or decreased pressure in the fumigation enclosure will decay to half the initial value in not less than 5 minutes with the enclosure filled to its normal* capacity, conventional methods of application would fail in most parts of Australia unless some form of gas recirculation was used. The principal reason for this is the 'chimney effect' induced by temperature differences between grain and the surrounding atmosphere and the consequent differences in the density of the air within the grain and of the air surrounding a silo.

It can be shown that with even small temperature differences, significant air displacement will occur with loss of fumigant from the silo and, more importantly, ingress of air that will dilute or displace the fumigant concentration. For example, if the grain temperature is higher than that of the surrounding atmosphere, there will be a net ingress of air through leaks in the base of the silo with a dilution of concentration in the lower parts of the bin. If, on the other hand, the grain temperature is lower than that of the surrounding atmosphere, air ingress will occur into the top of the bin with a consequent lowering of concentration in this region. In Australia, the former situation is more common, i.e. with grain temperatures higher than the surrounding atmosphere for a significant portion of the day. During the winter months, in many parts of Australia, the grain temperature will be higher than the surrounding atmosphere throughout the day, leading to a unidirectional chimney flow. In this situation, rapid reduction of fumigant concentration in the base of the bin can be expected to occur. Indeed, there are cases where bins meeting the gastightness standard have shown zero concentration in the base of the silo 24 hours after gas was applied to the bottom of the bin (Allanson, R.A., pers. comm.).

These problems are common to vertical grain storages throughout the world. Adding more gas at intervals to try to overcome these problems has been attempted including trickling of gas into unsealed farm bins and larger grain bulks from cylinders containing phosphine in carbon dioxide (Chakrabarti et al. 1990; Bell et al. 1991). However, such methods cannot be expected to overcome the forces that give rise to gas loss and at best will only be partially successful when conditions are favourable. In vertical silos (height greater than twice width), only SIROFLO® or sealing of the bins to the gastightness standard, combined with recirculation, will achieve satisfactory fumigation with phosphine.

SIROFLO® is a pressurised gas distribution system. Phosphine is introduced into the base of the silo in an air stream that produces a positive pressure in the base of the bin. The flow into the bin is adjusted so that the pressure in the bottom of the silo is positive for most of the day and sufficient to compensate for the chimney effect. In this situation, concentration throughout the grain can be expected to vary little, affected only by the level of sorption on the commodity. Although wind on a vertical silo can affect the concentration, our observations during numerous field trials (Winks, R.G., Waterford, C.J. and Russell, G.F., unpublished data) have shown that wind forces in vertical silos are relatively minor compared to the chimney effect.

SIROFLO® has been applied in a range of vertical silos in Australia ranging from 50 t bolted-steel farm bins to 10000 t bins and has included both concrete and metal bins with a range of configurations of silo bottoms and some capped but most open-topped. In the open-topped silos, air movement over the surface of the grain can cause dilution of the gas concentration in the surface layers under some circumstances. To

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overcome this, various methods have been examined including increasing the air flow and covering the grain with plastic sheeting. During a field trial to evaluate surface layers of Dryacide® as a means of preventing reinfestation of open-topped bins following SIROFLO® fumigation, pest control officers of the New South Wales Grain Corporation observed improved concentrations of phosphine in the surface layers of the grain (Desmarchelier, J.M., pers. comm.). From this it was believed that Dryacide® was acting as a barrier to the mixing of air in the surface layers that could otherwise occur. Dryacide®, is a proprietary diatomaceous earth material that has been shown to be effective in controlling insects when applied to surfaces of buildings. To examine the efficacy of this material as a gas barrier in more detail, a number of trials were conducted during which gas concentrations were monitored both before and after the application of Dryacide® or the application of plastic covers over the grain. This paper reports some of the results from one such trial.

## Materials and Methods

The trial reported here was conducted in vertical silos at Millmerran, Queensland and with the support and cooperation of GRAINCO, the bulk handling authority in that State.

The silos in which the trial was conducted, consisted of two banks of four 2000 t, open-topped bins with one interspace bin. SIROFLO® was installed in all 10 bins. Trials were carried out in 4 of the 10 bins.

The purpose of the trial at this site was to evaluate different methods of covering the grain in these open-topped bins. The 2 methods evaluated were covering the grain with plastic tarpaulins and covering the grain with a layer of the Dryacide®. In this trial, the value of Dryacide®, as a gas barrier only was evaluated and it was applied as a dust, at a rate of 100 g/m$^2$, from a venturi air gun with compressed air at 100 psi.. Separate studies(Desmarchelier, J.M. and Allen, S.E., pers. comm.) have shown that the layer applied as a gas barrier is unlikely to act as a significant barrier to reinfestation under strong invasion pressure.

During this trial, phosphine concentrations were monitored at 45 locations within the 4 bins distributed between the bottom of the bin, 5 m into the grain and at 150 mm into the grain. Concentrations were measured using a modified gas chromatograph based on a Sycopel Scientific electrometer and fitted with a phosphorus specific flame photometric detector. A calibration gas of phosphine in nitrogen was used to check the detector response prior to each set of 16 samples. Both calibration gas and samples of intergranular air were injected onto the column of the gas chromatograph, from a sampling loop, by an automatic valve.

Temperature and pressure were also monitored at several positions in each bin. Pressures were measured as the difference between the static pressure in the grain and that outside the silo at approximately the same height above ground, using an electronic manometer. Temperatures were measured using AD592 precision integrated circuit temperature transducers.

Phosphine was applied from cylinders of Phosfume into the airstream of the SIROFLO® system at a rate sufficient to produce a concentration of 35 ppm in the inlet duct to the silo. Phosfume contains 2% w/w phosphine in carbon dioxide and is manufactured by Commonwealth Industrial Gases Ltd, Sydney.

## Results

Temperatures and pressures were recorded in the grain and surrounding atmosphere during the 4 phases of the trial:

1. the period before SIROFLO® was applied,
2. with SIROFLO® but no cover on the grain,
3. with SIROFLO® and with a plastic tarpaulin over the grain surface and
4. with SIROFLO® and with a layer of the Dryacide® applied to the grain surface.

These data are given in Figures 1–4 respectively. The pressure data refer to a single location at the base of the bin.

Concentration profiles recorded at the base of the bin, 5 m below the grain surface and at 150 mm below the surface of the grain for each of the three SIROFLO® phases are given in Figures 5–7 respectively.

## Discussion

The data of Figures 1–4 show the clear correlation between the difference in temperature between the grain and the atmosphere surrounding the silos, and the static pressure produced in the base of the bin (the chimney pressure). The diurnally fluctuating ambient temperatures gave rise to a pressure profile that also fluctuated diurnally. It may also be seen from the data that the temperature difference progressively increased during the 4 phases of the trial.

The temperature differences observed throughout the trial were sufficient to produce a significant chimney effect that would have caused rapid decay of the fumigant concentration in the base of the bin from 'static' fumigation methods. Static methods include the addition of tablets or pellets of aluminium phosphide formulations to a grain stream during the filling of a bin and also include methods such as 'one-shot' when the total amount gas is introduced to the bin in a short period of time, e.g., over a few hours or less. These static methods are based on an expectation that the gas concentration will remain more or less uniformly dispersed throughout the grain mass for the full exposure period. In leaky vertical silos with chimney forces operating this is clearly not possible. The generally negative pressures observed at the base of the bin during the period before SIROFLO® and after the end of the fumigation in phases 2 and 4, would have produced an almost continuous ingress of air into the base of the bin. The effect of this is evident from the decay of concentrations after SIROFLO® was switched off (Figs. 5 and 7).

With SIROFLO® operating, pressures in the base of the bin were mostly positive and sufficient to overcome the chimney effect during the major portion of the day. The concentration profiles obtained at the base of the bin in all phases of the trial provide clear evidence of this. The concentrations achieved, at all locations and in all phases of the trial, were sufficient to achieve effective fumigation based on laboratory studies (Winks, Waterford and Hyne, unpublished data) and exceeded the required minimum concentration of 15 ppm for a 28-day fumigation for all strains of all species likely to be found infesting grain in Australia at temperatures greater than 20C (Winks, R.G., unpublished data). It should be noted however, that with this method, the concentration may easily be varied to accommodate higher rates of sorption on the commodity or higher rates necessary for shorter exposure periods. The differences in concentration between the three levels sampled in the bin, are believed to be due to sorption on the grain.

The phosphine concentrations obtained with a Dryacide® layer over the grain were as good as, if not slightly better than, those obtained with a plastic tarpaulin over the grain. This is even more significant when the greater temperature differences are taken into account. However, the stable concentrations during the phase without any cover on the grain, were similar to both covered phases and the only significant difference was in terms of the rate at which stable concentrations were achieved. Without a cover on the grain it

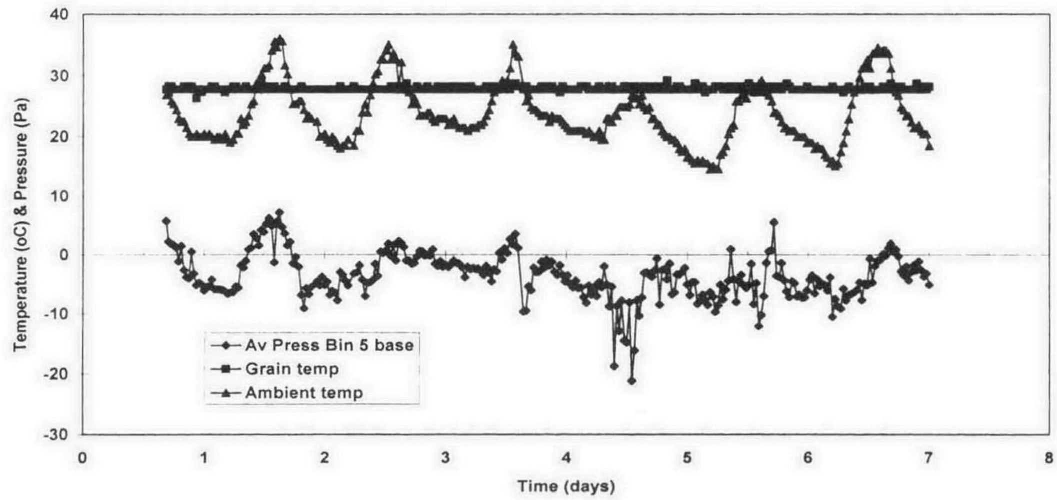


**Fig. 1.** Temperature and pressure profiles associated with Bin No. 5 of the Millmerran, Queensland, grain storage complex, before the commencement of a SIROFLO® trial

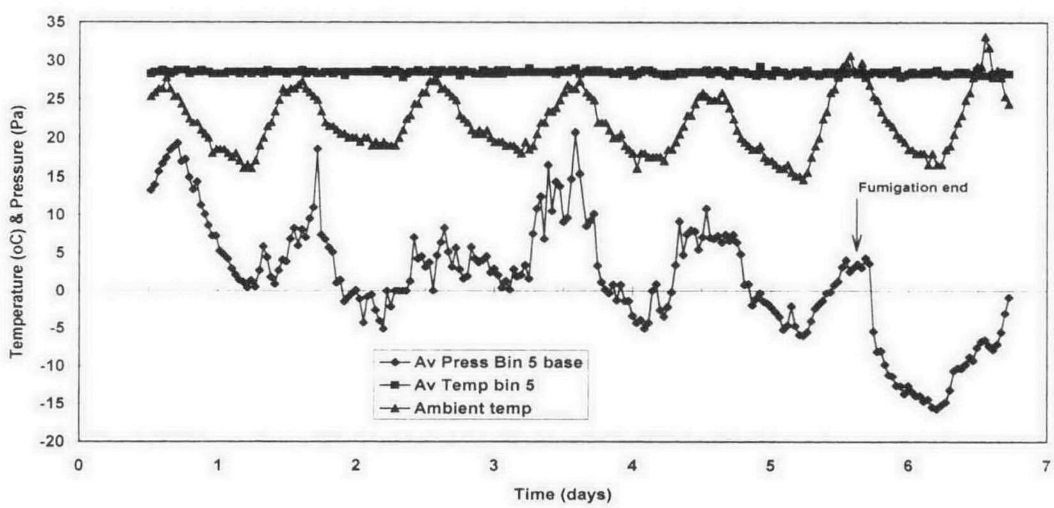


**Fig. 2.** Temperature and pressure profiles associated with Bin No. 5 of the Millmerran, Queensland, grain storage complex, during a SIROFLO® fumigation without any cover on the grain surface.

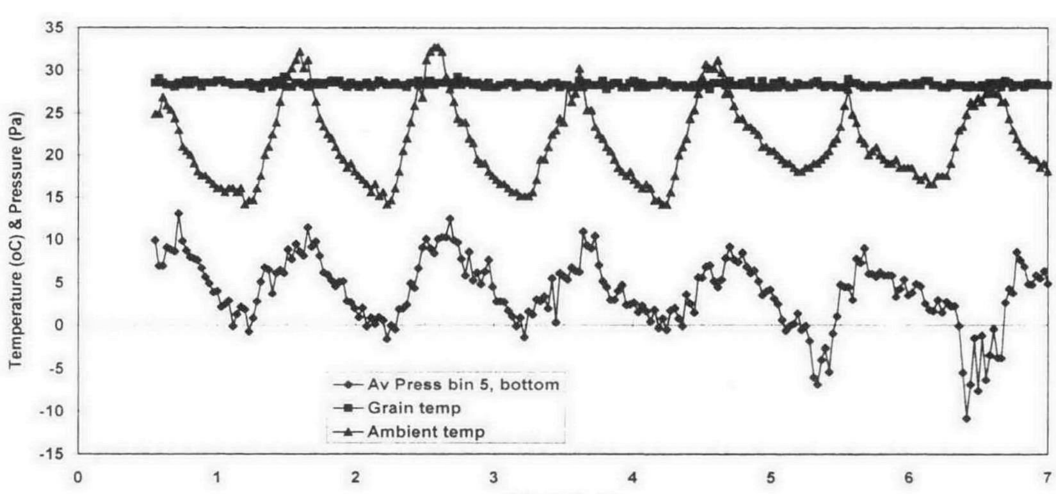


**Fig. 3.** Temperature and pressure profiles associated with Bin No. 5 of the Millmerran, Queensland, grain storage complex, during a SIROFLO® fumigation with a plastic tarpaulin placed over the grain surface.

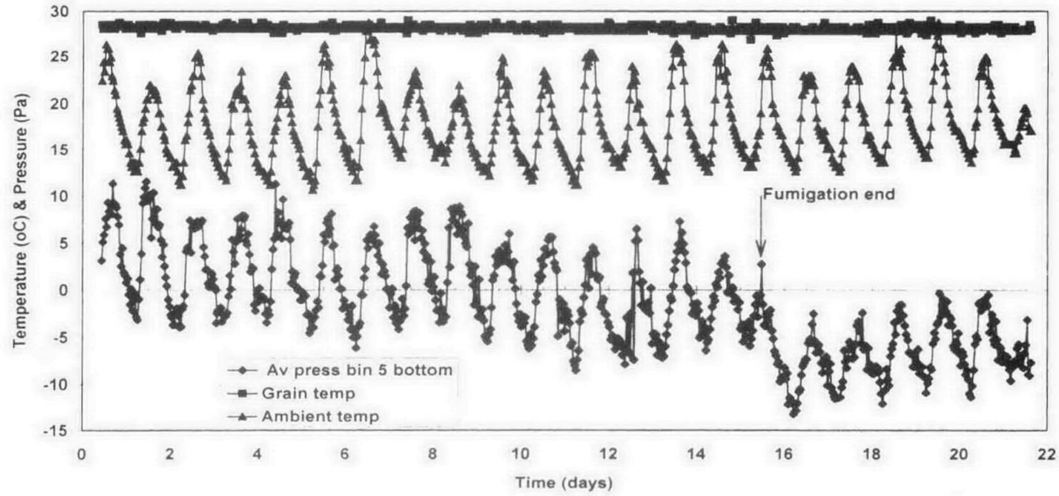


**Fig. 4.** Temperature and pressure profiles associated with Bin No. 5 of the Millmerran, Queensland, grain storage complex, during a SIROFLO® fumigation after a layer of Dryacide® had been applied to the grain surface.

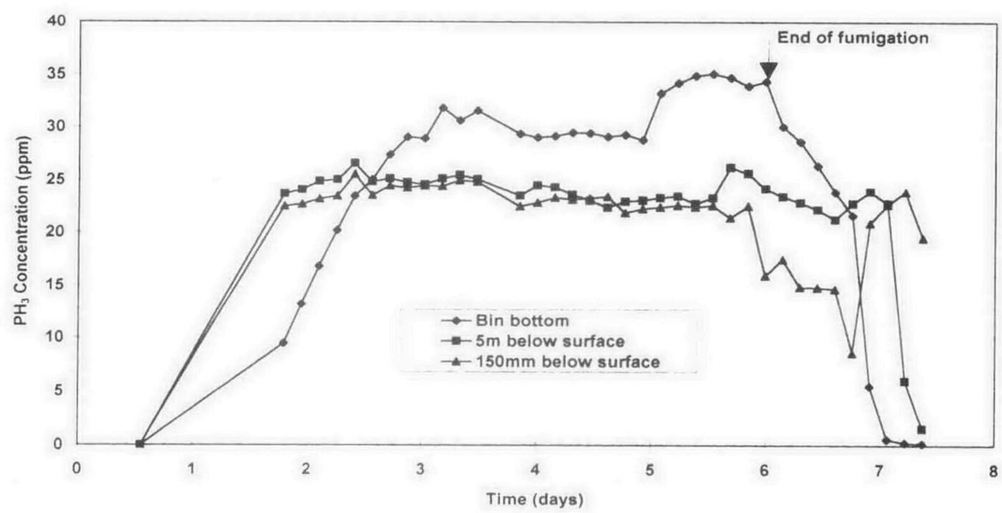


**Fig. 5.** Phosphine concentration profiles in Bin No. 5 of the Millmerran, Queensland, grain storage complex, during a SIROFLO® fumigation without any cover on the grain surface.

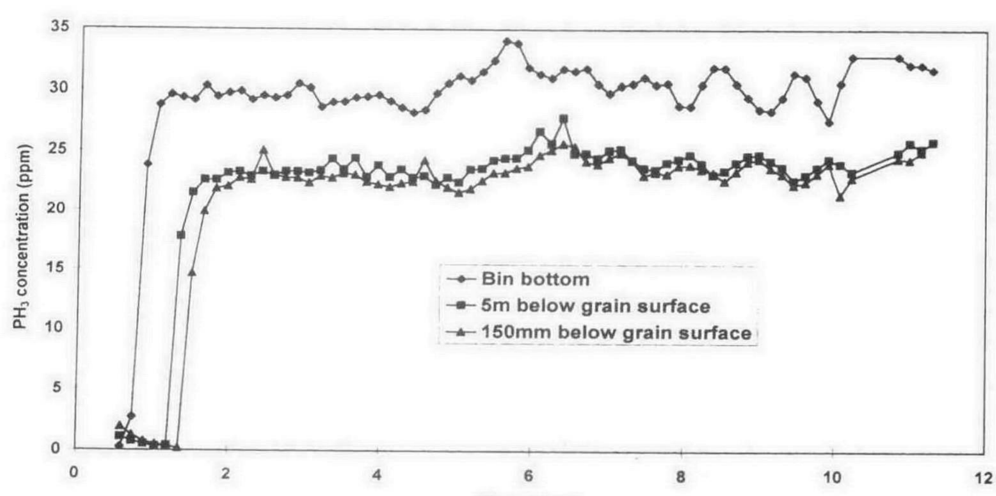


**Fig. 6.** Phosphine concentration profiles in Bin No. 5 of the Millmerran, Queensland, grain storage complex, during a SIROFLO® fumigation with a plastic tarpaulin placed over the grain surface.

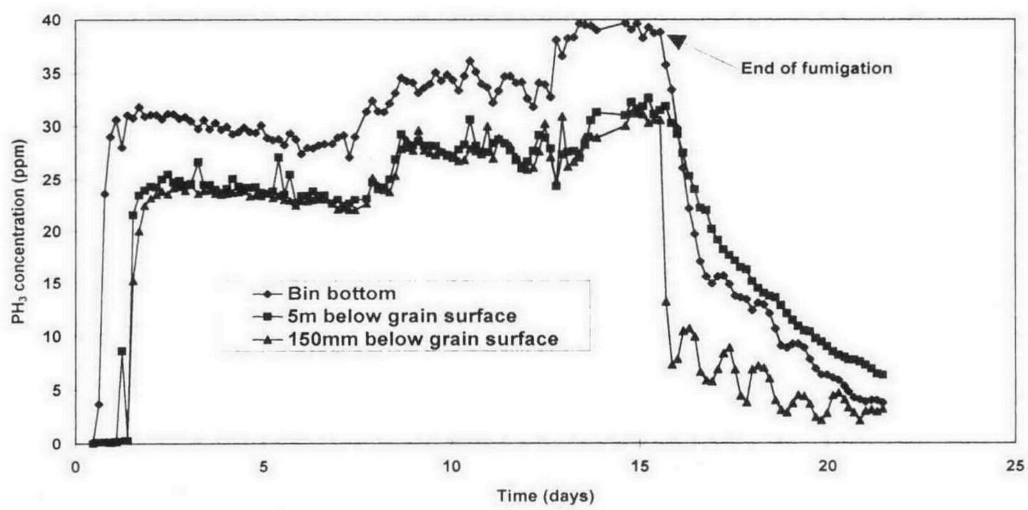


**Fig. 7.** Phosphine concentration profiles in Bin No. 5 of the Millmerran, Queensland, grain storage complex, during a SIROFLO® fumigation after a layer of Dryacide® had been applied to the grain surface.

required almost 3 days to achieve stable concentrations whereas with covers on the grain, stable concentrations were achieved in less than 2 days. The rise in concentrations during the second half of the trial with the Dryacide® is associated with a rise in concentration in the gas from cylinders of Phosfume when all liquid in the cylinder has been vaporised.

## Conclusions

The results of this trial showed that a cover of Dryacide® over the grain surface was as effective as a cover of plastic sheeting but neither cover appeared to provide a significant improvement in gas concentrations over the fumigation without a cover on the grain. Other trials, however, in other open-topped vertical storages, have demonstrated a significant improvement in gas concentrations in the surface layers of a grain bulk (Winks, R.G., Waterford, C.J. and Russell, G.F., unpublished data). Because of this and the observations of pest control staff of the NSW Grain corporation, the use of Dryacide® or plastic sheeting to cover grain in open-topped bins is recommended with SIROFLO® fumigations.

Overall, the results of this trial demonstrated the efficacy of the technique in these bins and demonstrated that SIROFLO® can overcome the chimney forces observed. It follows that the chimney forces associated with much larger temperature differences can be overcome but would clearly need flows commensurate with the magnitude of the temperature differences. A trial is currently in progress to evaluate an automatic flow-controller that establishes airflows based on the magnitude of the temperature differences ( Winks and Russell, unpublished data). This method of flow control is the subject of a current patent application.

## References


Bell, C.H., Chakrabarti, B. and Mills, K.A. (1991) New application methods for the use of phosphine to disinfest bulk grain. Report to Home-Grown Cereals Authority, No. 41, Ministry of Agriculture Fisheries and Food, Slough, England, December, 1991, 41 pp plus figs.

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