Precision Fumigation™ and ProFume® gas fumigant

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ProFume®
GAS FUMIGANT

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Topics to review

ProFume® GAS FUMIGANT

- History of ProFume® gas fumigant
- Packaging
- General Use Patterns
- Key attributes, including
  - > Fumiguide™ and Precision Fumigation™
  - > Stewardship by Dow AgroSciences
  - > No adverse effects on equipment, electronic, and commodities
- Diversity of fumigation uses
  - > Grain
  - > Quarantine
  - > Seed

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History of ProFume® gas fumigant

- Early 1950's - Research by The Dow Chemical Company for an alternative to methyl bromide (MB) for structural fumigation
- 1961 – Vikane® gas fumigant, sulfuryl fluoride (SF) as active ingredient, introduced to protect homes and structures from drywood termites and other pests
- Today - More than two million structures, including museums, cathedrals, historical landmarks, rare book libraries, and scientific and medical research laboratories, have been fumigated with Vikane to eradicate pests

Fumigation of Chemistry Research Building (39,600 m^3) University of Florida, USA

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History of ProFume® gas fumigant

- SF does not interact with or contribute to local ozone formation or stratospheric ozone depletion
- 1995 – At request of progressive food industries, Dow AgroSciences investigated SF as an MB alternative for post-harvest insect control
- Dow AgroSciences formed partnerships with leading stored product researchers, fumigators and food industries around the world to develop ProFume®

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History of ProFume® gas fumigant

ProFume® GAS FUMIGANT

- 2003 - First global registration in Switzerland for use in flour mills
  - > ProFume® uses are now registered in 18 countries
- 2007:
  - > ProFume registered in Mexico
  - > Dow AgroSciences named a winner of the United Nations Montreal Protocol Innovators Award

History of ProFume® gas fumigant

ProFume® GAS FUMIGANT

- 2007:
  - > Dow AgroSciences commissioned a new sulfuryl fluoride manufacturing plant in Pittsburg, California
    - State-of-the-art manufacturing technology - Helps ensure product quality and integrity
    - World scale production - Ability to meet long term global needs

Packaging of ProFume® gas fumigant

ProFume® GAS FUMIGANT

- 99.8% sulfuryl fluoride
- Packaged as liquid under pressure
- 57 kg (125 lbs) in steel cylinders
- 12 cylinders per pallet
- All packaging materials (hardwood pallet, metal top collar, strap with ratchet buckles) are reusable and tested for shipping durability

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General Use Patterns

ProFume® GAS FUMIGANT

Varies based on country registration

- Residential and/or non-residential structures
- Stationary transportation vehicles (railcars, shipping containers, trucks, etc., excluding aircraft)
- Temporary and permanent fumigation chambers
- Storage structures
- Food handling establishments (e.g., pet food facilities, bakeries, food production facilities, mills, warehouses, etc.)

Key Attributes of ProFume® gas fumigant

ProFume® GAS FUMIGANT

- Broad-spectrum, effective and reliable control of rodents and all pest life stages
- Fumiguide® program and other Precision Fumigation™ tools and techniques
- Flexibility to optimize current schedules and downtime
- Non-corrosive to equipment or electronics
- Non-flammable
- Low reactivity (no odor potential or off flavors)
- Excellent penetration and rapid aeration

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Precision Fumigation™ Tools and Techniques

ProFume® GAS FUMIGANT

Precision Fumigation is:

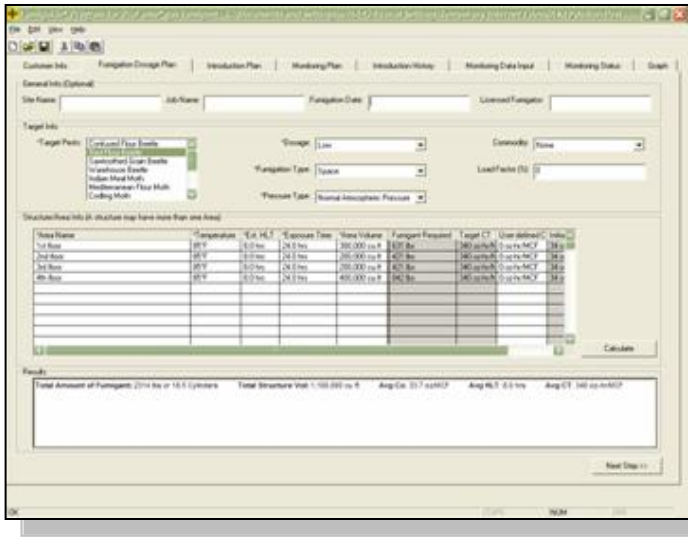
"Optimizing fumigant use to maximize efficiency and minimize risk."

PRECISION FUMIGATION™

Precision Fumigation™ Tools and Techniques - Fumiguide™

ProFume® GAS FUMIGANT

- Extensive laboratory and field trials conducted to define the SF dosages required to control all the life stages of 20+ key stored product pests under a wide range of conditions
  - > USDA-ARS in California, USA
  - > DFA of California, USA
  - > FERA (Food & Environ. Res. Agency), UK
  - > Julius Kuehn Institute, Germany
  - > University of Milan, Italy
  - > Laboratoire National des Denrées Stockées, France



- Dosages implemented in the ProFume® Fumiguide™ - A MS-Windows based program

Precision Fumigation™ Tools and Techniques - Fumiguide™

ProFume® GAS FUMIGANT

- Dosage calculation tool - Takes the guesswork out of fumigation:
  - > Dose based on pest species, desired level of control, temperature, exposure time, volume, half loss time (HLT)
  - > Gives gas introduction instructions
  - > When monitoring data are entered, program will calculate actual HLT, accumulated and predicted dosage, and update instructions on exposure time and fumigant introduction
  - > Allows “what if” scenarios to help plan and conduct fumigations

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Precision Fumigation™ Tools and Techniques - Fumiguide™

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  - > Gives gas introduction instructions
  - > **When monitoring data are entered, program will calculate actual HLT, accumulated and predicted dosage, and update instructions on exposure time and fumigant introduction**
  - > Allows "what if" scenarios to help plan and conduct fumigations

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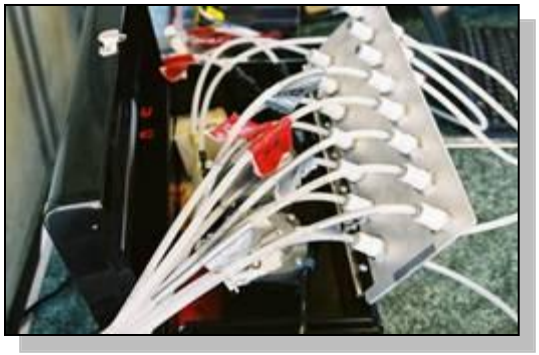
Precision Fumigation™ Tools and Techniques - Monitoring

ProFume® GAS FUMIGANT

- Air sampled remotely from outdoors using hoses placed at strategic locations within the fumigated space



Hoses connected to a manifold and pump to extract air samples

SF concentrations measured using a Fumiscope, SF-ReportIR or similar device

- Air sampled at two or more time intervals to calculate actual HLT

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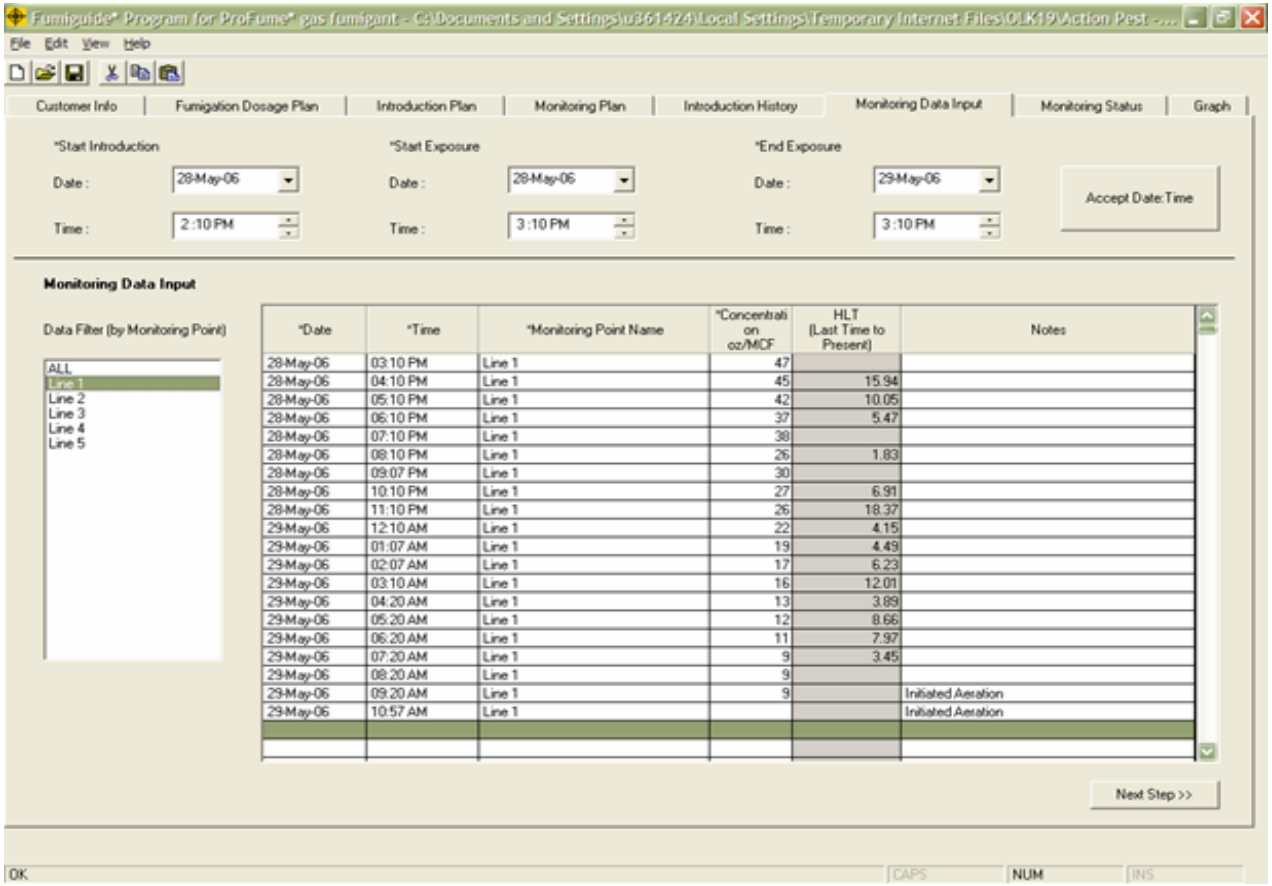
Precision Fumigation™ Tools and Techniques - Monitoring

ProFume® GAS FUMIGANT

Monitoring data is input into the Fumiguide™



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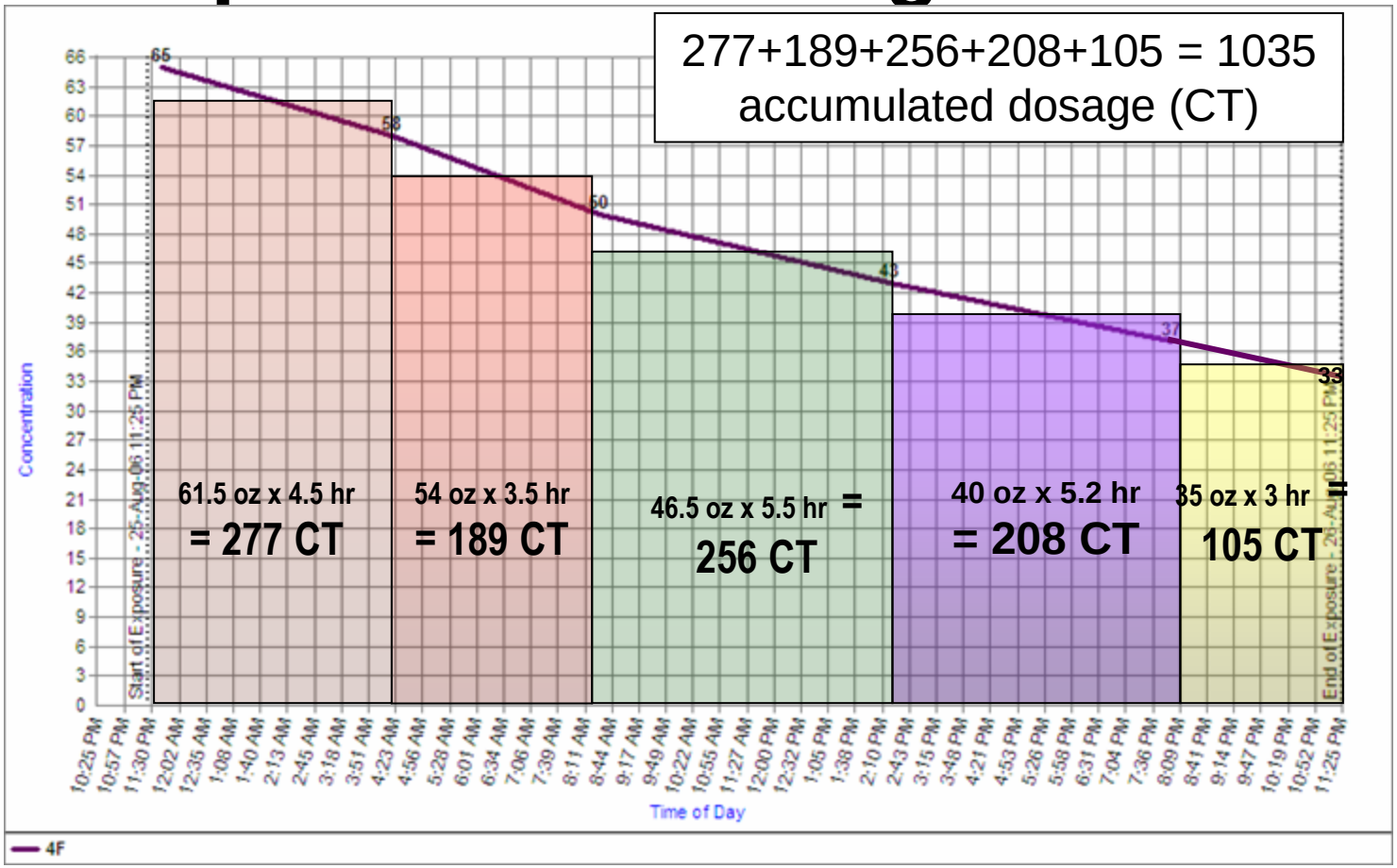
Precision Fumigation™ Tools and Techniques - Monitoring

ProFume® GAS FUMIGANT

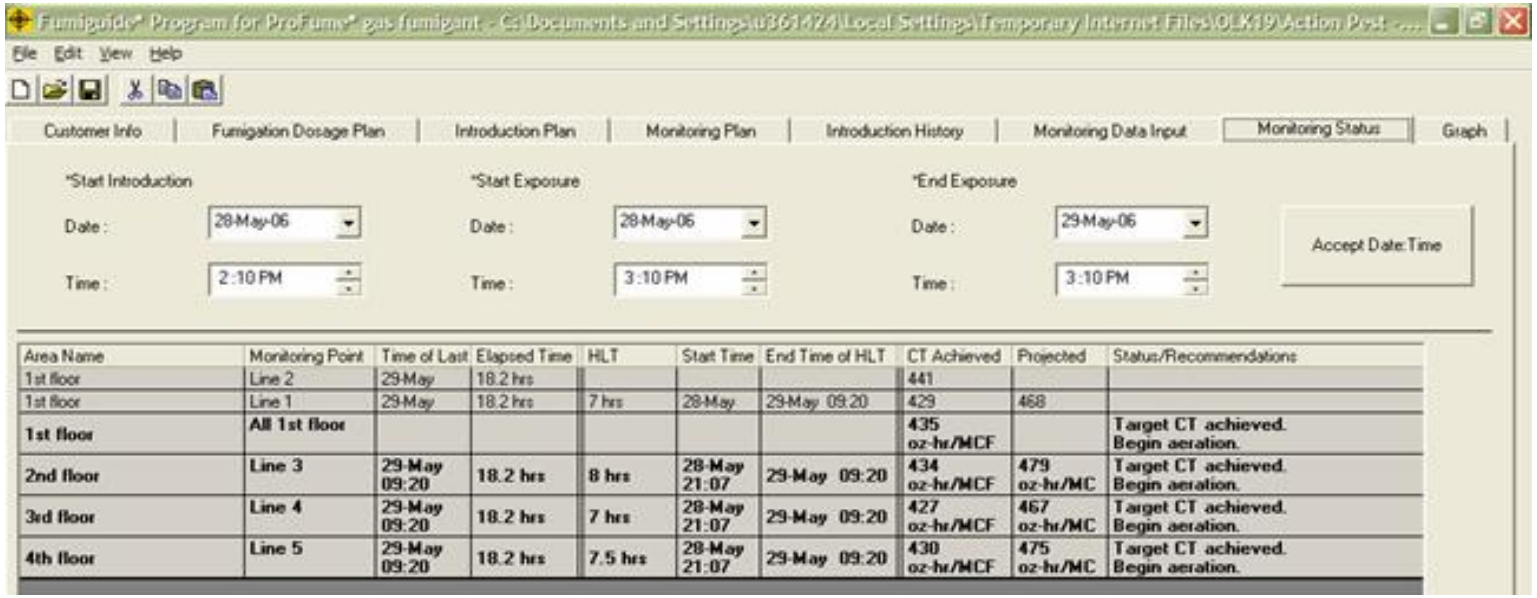
The Fumiguide™ calculates accumulated dosage (CT) = average concentration x time



Precision Fumigation™ Tools and Techniques - Monitoring

ProFume® GAS FUMIGANT

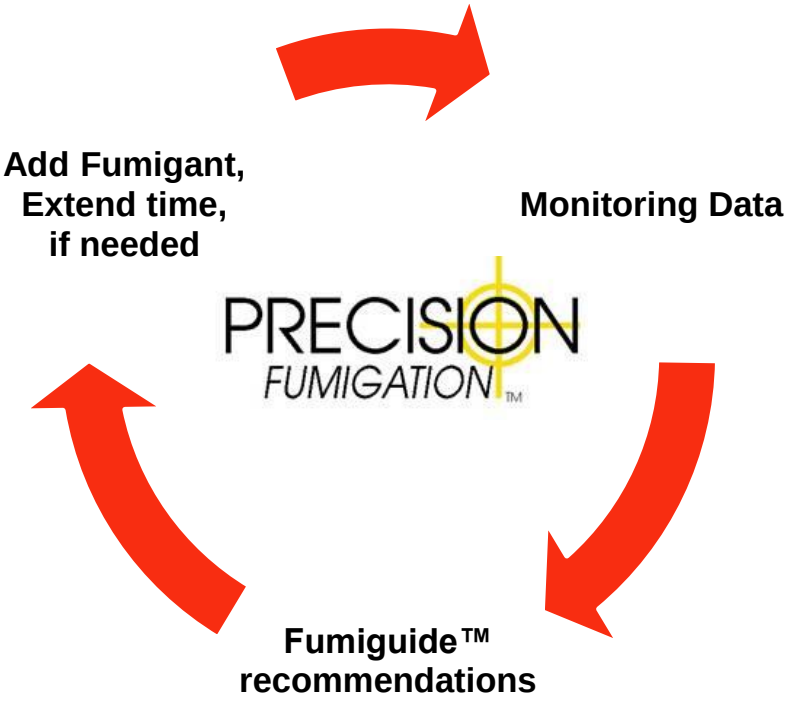
- Monitoring data is analyzed by the Fumiguide™: calculates actual HLT, accumulated dosage (CT) and projected dosage
- Fumiguide calculates additional gas to be added and/or additional time required if projected dosage insufficient



Area Name	Monitoring Point	Time of Last	Elapsed Time	HLT	Start Time	End Time of HLT	CT Achieved	Projected	Status/Recommendations
1st floor	Line 2	29-May	18.2 hrs				441		
1st floor	Line 1	29-May	18.2 hrs	7 hrs	28-May	29-May 09:20	429	468	
1st floor	**All 1st floor**						**435 oz-hr/MCF**		**Target CT achieved. Begin aeration.**
2nd floor	**Line 3**	**29-May 09:20**	**18.2 hrs**	**8 hrs**	**28-May 21:07**	**29-May 09:20**	**434 oz-hr/MCF**	**479 oz-hr/MC**	**Target CT achieved. Begin aeration.**
3rd floor	**Line 4**	**29-May 09:20**	**18.2 hrs**	**7 hrs**	**28-May 21:07**	**29-May 09:20**	**427 oz-hr/MCF**	**467 oz-hr/MC**	**Target CT achieved. Begin aeration.**
4th floor	**Line 5**	**29-May 09:20**	**18.2 hrs**	**7.5 hrs**	**28-May 21:07**	**29-May 09:20**	**430 oz-hr/MCF**	**475 oz-hr/MC**	**Target CT achieved. Begin aeration.**

Precision Fumigation™ Tools and Techniques - Monitoring

ProFume® GAS FUMIGANT



Note: Fumiguide™ is available in Spanish with metric conversions and at no charge to fumigators using ProFume® gas fumigant

Precision Fumigation™ Techniques – Adding Fumigant

ProFume® GAS FUMIGANT

- ProFume® cylinders are located outside the fumigated space for the fumigation process
- ProFume is introduced through hoses into the fumigated space
  - > Reduces potential for applicator exposure to fumigant
  - > Simplifies introduction of additional fumigant if needed based on monitoring results

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Precision Fumigation™ Tools and Techniques - Fumiguide™

ProFume® GAS FUMIGANT

- Dosage calculation tool - Takes the guesswork out of fumigation:
  - > Dose based on pest species, desired level of control, temperature, exposure time, volume, half loss time (HLT)
  - > Gives gas introduction instructions
  - > When monitoring data are entered, program will calculate actual HLT, accumulated and predicted dosage, and update instructions on exposure time and fumigant introduction
  - > **Allows "what if" scenarios to help plan and conduct fumigations**

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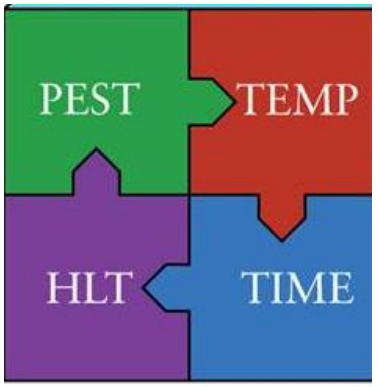
Precision Fumigation™ Tools and Techniques - Fumiguide™

ProFume® GAS FUMIGANT

- Applied dose depends upon on pest species, temperature, half-loss time, exposure time

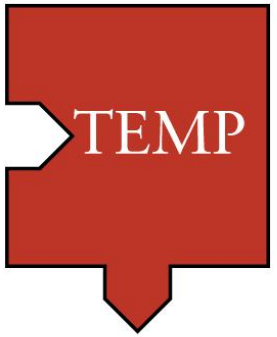
- Fumigator can run scenarios on the Fumiguide™ to determine how modifying temperature, half-loss time, exposure time will change the required dose



Precision Fumigation™ Tools and Techniques - Temperature

ProFume® GAS FUMIGANT

- Increasing temperature increases insect metabolism and reduces the fumigant dose required:



Pest	Temperature (C)	HLT (hrs)	Hours Exposure	Application dose (g/m³)
Red flour beetle	26.5	10	24	83
Red flour beetle	29.5	10	24	56

3C increase = 33% dose reduction

Precision Fumigation™ Tools and Techniques - Heating

ProFume® GAS FUMIGANT

- Ways to increase temperature
  - > Keep windows closed and ventilation systems turned off when sealing food processing facilities - retain heat radiating from milling and processing equipment
  - > Use permanent/built-in heaters
  - > Use temporary/leased heaters

Precision Fumigation™ Tools and Techniques - Confinement

ProFume® GAS FUMIGANT

- Increasing fumigant confinement (= higher HLT) reduces the fumigant dose required:

Pest	Temperature (C)	HLT (hrs)	Hours Exposure	Application dose (g/m³)
Red flour beetle	26.5	7.5	24	70
Red flour beetle	29.5	10	24	56
Red flour beetle	29.5	15	24	45

20% dose reduction

20% dose reduction

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Precision Fumigation™ Tools and Techniques - Confinement

ProFume® GAS FUMIGANT

- Ways to improve confinement
  - > Check for SF leakage using TIF detector (Limit of Detection: 25 ppm) or clearance detectors such as SF-ExplorIR (LOD: 1 ppm)
  - > Seal detected leaks

TIF detector

SF-ExplorIR, IR sensor, Spectros Instruments

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Precision Fumigation™ Tools and Techniques - Confinement

ProFume® GAS FUMIGANT

- Ways to improve confinement
  - > Use appropriate sealing methods for doors, windows, vents, ducts, augers, and other openings
    - Tape – can use spray adhesive, double layers to improve confinement
    - Spray foam
    - Polyethylene sheeting (> 4 mil)
    - Tarp and snakes

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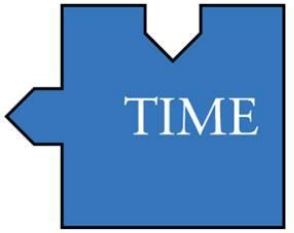
Precision Fumigation™ Tools and Techniques – Hrs Exposure

ProFume® GAS FUMIGANT

- Increasing exposure time, particularly if HLT is high, reduces the fumigant dose (CT) required:



Pest	Temperature (C)	HLT (hrs)	Hours Exposure	Application dose (g/m³)
Red flour beetle	26.5	7.5	24	70
Red flour beetle	29.5	7.5	36	59
Red flour beetle	29.5	15	24	45
Red flour beetle	29.5	15	36	33

14% dose reduction

27% dose reduction

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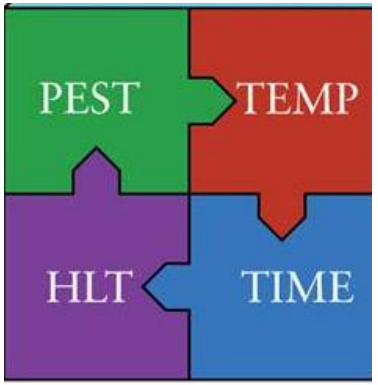
Precision Fumigation™ Tools and Techniques - Fumiguide™

ProFume® GAS FUMIGANT

- Fumigators report that over time the Fumiguide™ Program data helps:
  - > Increase dosing efficiency
  - > Enhance fumigation practices, such as enhanced sealing to reduce fumigant leakage and improve confinement



Stewardship - ProFume® gas fumigant

- Fumigators using ProFume® gas fumigant are required to:
  - > Participate in an initial training program
  - > Adhere to a Stewardship Policy
  - > Allow Dow AgroSciences representative to observe initial ProFume fumigation
  - > Complete annual stewardship training
  - > Participate in quality checks

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Stewardship – ProFume®

- Initial training reviews the following:
  - > Physical properties of SF
  - > Required personal protective equipment
  - > Symptoms of overexposure, first aid
  - > Cylinder handling
  - > Treatment sites
  - > Monitoring and clearance detection equipment
  - > Dosage calculation – Fumiguide™
  - > Site preparation
  - > Fumigant introduction
  - > Aeration
  - > Site specific procedures

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Key Attributes of ProFume®

ProFume® GAS FUMIGANT

- Broad-spectrum, effective and reliable control of rodents and all pest life stages
- Fumiguide® program and other Precision Fumigation™ tools and techniques
- Flexibility to optimize current schedules and downtime
- Non-corrosive to equipment or electronics
- Non-flammable
- Low reactivity (no odor potential or off flavors)
- Excellent penetration and rapid aeration

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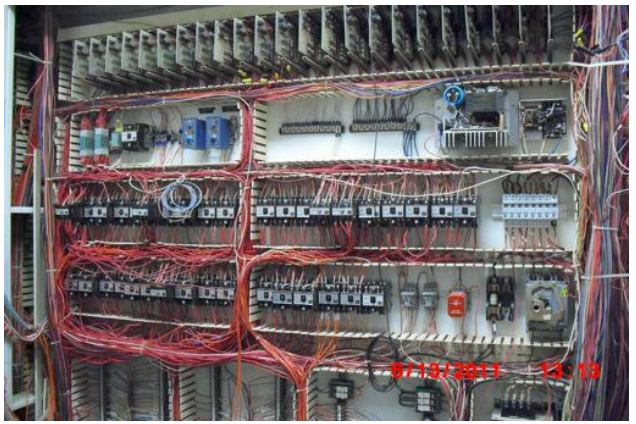
Inert Properties of ProFume® gas fumigant

- ProFume® as a gas is considered relatively inert
- Research (Bell et al., 2003, CAF) showed:
  - > No adverse effects on computers fumigated repeatedly at high SF dosages and high (40-50ºC) temperatures
  - > No corrosion of copper fumigated at high dose at 40ºC or 70% RH



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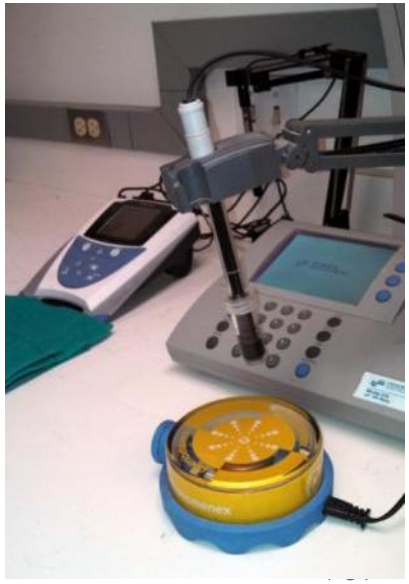
Photos of milling electrical relays and equipment provided by James Bair, Vice President, NAMA

Inert Properties of ProFume® gas fumigant

ProFume® does not leave detectable residues on inert surfaces (Nead-Nylander and Thoms, 2013, MBAO):

- Samples of stainless steel, glass and ceramic were fumigated in small chambers
  - > Maximum label dosage (~1500 g-h/m^3)
  - > 24 h exposure, 35^{o}C, 3 replicate fumigations
  - > Control samples not fumigated
  - > SF Concentrations measured using gas chromatography
- After fumigation, fumigated and control wipe sampled, F- extracted and measured using a pH/mV/ion meter with a F- Combination Electrode



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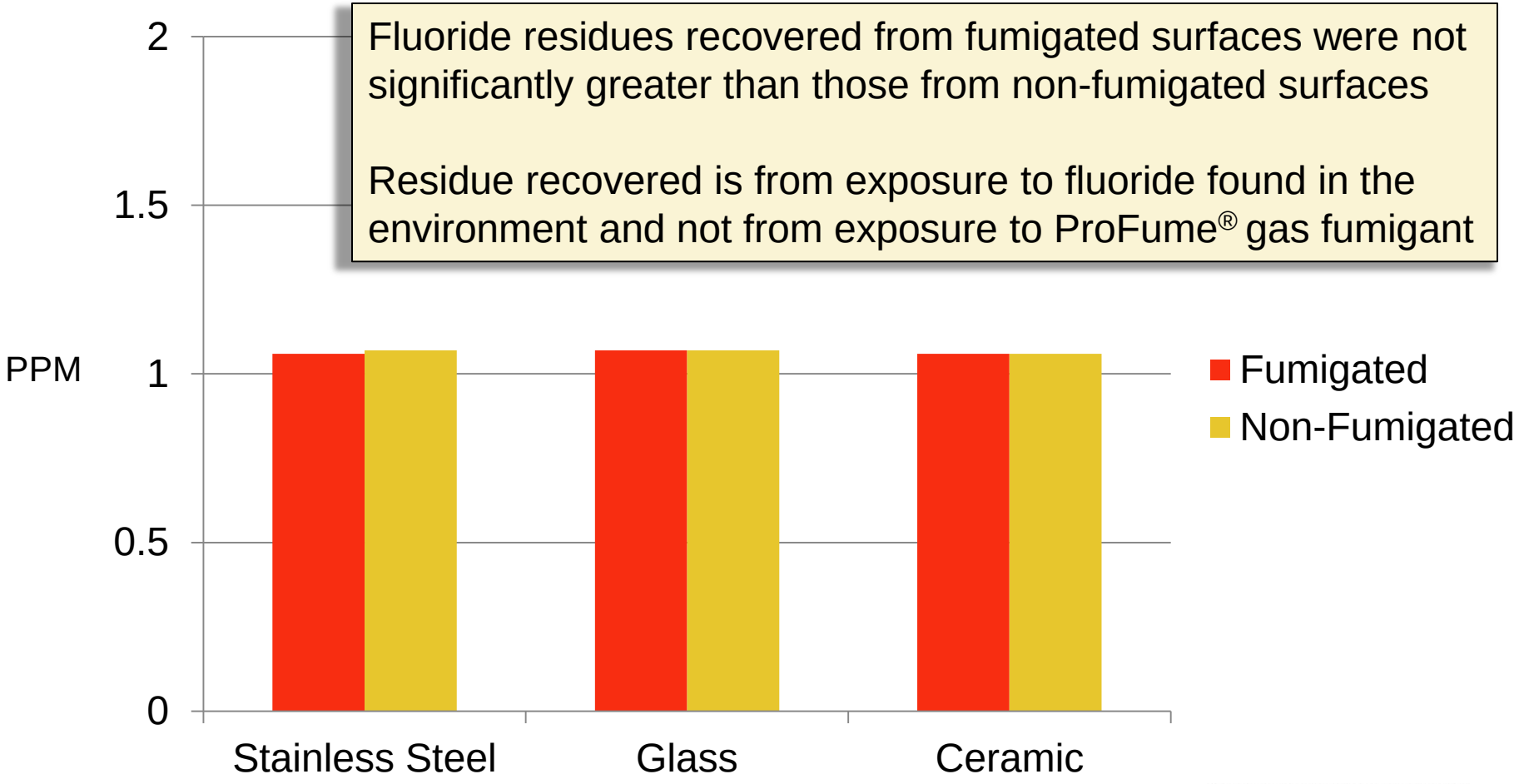
Fluoride Residue Recovered on Fumigated and Non-Fumigated Surfaces

ProFume® GAS FUMIGANT

Fluoride residues recovered from fumigated surfaces were not significantly greater than those from non-fumigated surfaces

Residue recovered is from exposure to fluoride found in the environment and not from exposure to ProFume® gas fumigant



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No adverse effects on Commodities

ProFume® GAS FUMIGANT

- The quality of many commodities(raison, apricots, dates, prunes, figs, walnuts, pistachios, almonds, wheat, and cocoa) after fumigation with ProFume® have been evaluated by independent experts*
- Test confirmed taste, quality, and commercial value of commodities were not affected by fumigation
- Wheat and pasta was also evaluated for nutritional and baking qualities, which were not affected by fumigation

* Results of these studies are summarized in Buckley and Thoms, 2013, Proceedings of the 9th International Conference on Controlled Atmospheres and Fumigation in Stored Products

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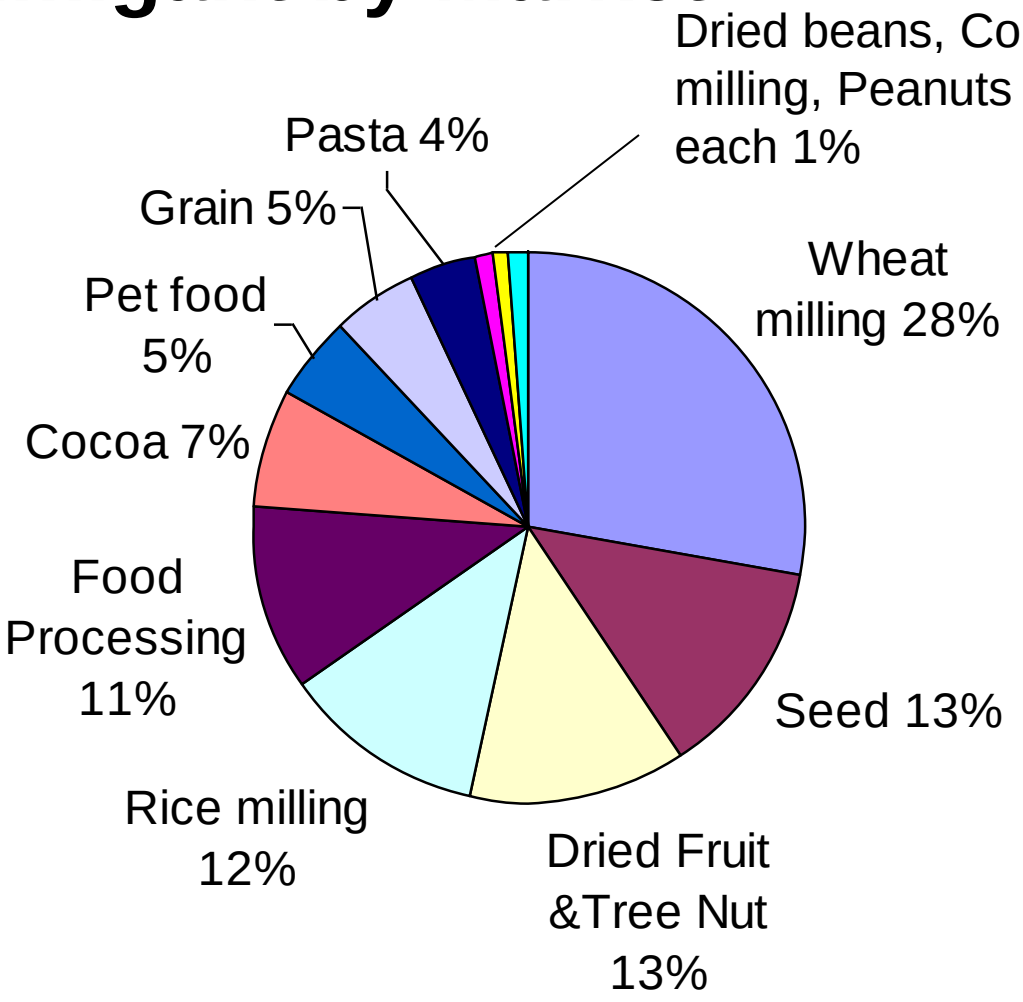
Percent of US Sales of ProFume® gas fumigant by Market



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Grain fumigation using ProFume® gas fumigant

ProFume® GAS FUMIGANT

- ProFume® gas fumigant offers fast, flexible timing to clean-out grain prior to shipment
- ProFume is non-flammable and does not affect the taste or quality of grain

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Fumigant Comparison

ProFume® GAS FUMIGANT

Attribute	ProFume®	Cylinderized phosphine	Metal phosphides
Controls all life stages of a broad pest range	✓	✓	✓
Distributes into structural pest harborages	✓	✓	✓
Penetrates deeply into commodities	✓	✓	✓
Not flammable or combustible	✓	Lower flammable limit for VAPORPH_3OS is 8,000 ppm	Lower flammable limit for phosphine is 8,000 ppm
No adverse effects on food commodities	✓	✓	✓
No adverse effects on buildings, equipment, and other contents	✓	Can react with certain metals to cause corrosion, especially at high temperatures or RH	Can react with certain metals to cause corrosion, especially at high temperatures or RH
Flexible, including short exposure times	✓Gen. 4 to 36 hours	24 – 144 hours dependent upon label directions	34 – 240 hours dependent upon label directions

Grain fumigation using ProFume® gas fumigant

ProFume® GAS FUMIGANT

Dow AgroSciences conducted field trials with fumigators to develop best practices for grain fumigation - sealing bins:

- Seal plenum opening and vents
- Use polyethylene to seal large bin openings and polyurethane foam to seal cracks or small openings

Sealed vent to bin aerating system

Polyurethane foam sealant

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Grain fumigation using ProFume® gas fumigant

Introducing and circulating ProFume® gas fumigant in grain storage bins:

- The J-system can be used to introduce and monitor ProFume
  - > Introduce into the top of the bin
  - > Introduction hoses and monitoring hose can be inserted into J-system ducts
  - > Using narrow ID hose of long length to have a slow introduction rate for ProFume

J-fan system with yellow introduction hose installed in front of fan

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Grain fumigation using ProFume® gas fumigant

Aerating ProFume® gas fumigant from grain storage bins:

- After fumigation, remove seals and
  - > Use the J-system aerate ProFume from the grain
  - > Built-in blowers can be used to aerate ProFume

Lower right: This sealing will be removed for aeration, and the “boot” will be reinstalled to reconnect the vent (right) to the blower (box on left)

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Grain fumigation using ProFume® gas fumigant

- ProFume® used in Australia since 2007 for control of all stages of grain infesting insects, particularly phosphine-resistant *Cryptolestes ferrugineus*
- 2011 -Trials conducted at 4 sorghum bunkers to measure SF concentrations in and adjacent to bunkers fumigated with ProFume
  - > Purpose of trials – to verify commercial fumigation procedures using ProFume for bunkers provided the required insect control and safety standards for worker and bystander exposure

Typical grain bunker storage in Australia

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Grain fumigation using ProFume® gas fumigant

- Study sites:
  - > Jondaryan - Metal-sided; 33,500 metric tonnes
  - > Malu - Earthen-walled; 16,000 metric tonnes
  - > Goondiwindi (2 bunkers) - Concrete-walled; 30,000 metric tonnes

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Grain fumigation using ProFume® gas fumigant

- Monitoring hoses inserted into at least 20 locations: peripheral near bunker base and top, middle and bottom of the grain mass from the bunker peak
- Hoses extended outside the grain mass to a manifold attached to a battery-powered pump
- SF concentrations measured 2 – 3 times daily using monitor with infrared (IR) sensor (SF-ContainIR, Spectros Instruments)

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Grain fumigation using ProFume® gas fumigant

ProFume® GAS FUMIGANT

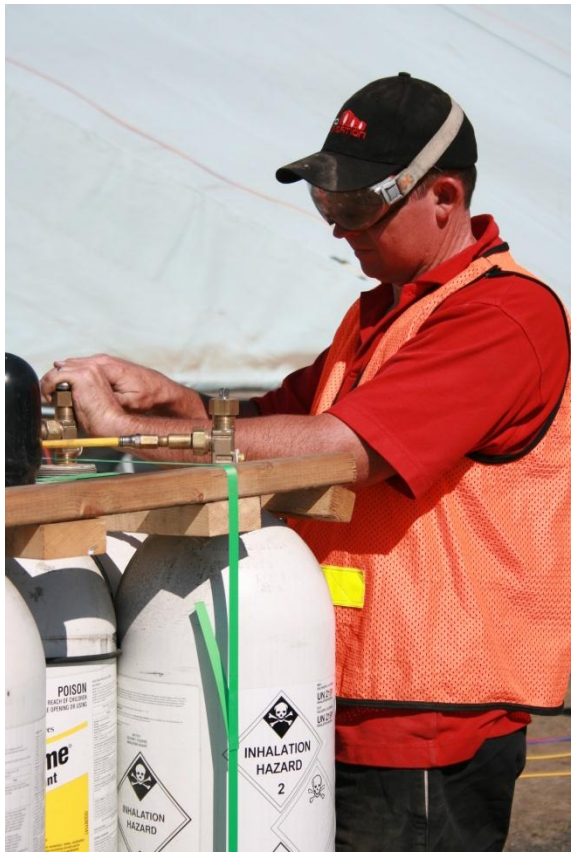
- The target dose - 24 g/m^3 of ProFume® for 10 day exposure*
- Ambient air continuously collected around each bunker during fumigation and aeration
  - > Air collected in gas-resistant bags using calibrated pumps
  - > SF concentrations in bags measured using SF-ExplorIR

* Complete report - Thoms and Annetts, 2012, MBAO

Grain fumigation using ProFume® gas fumigant

ProFume® GAS FUMIGANT

- Monitoring ProFume® concentrations in grain bunkers:
  - > Confirmed sufficient dosage accumulation to control all life stages of target grain pests
- Monitoring ProFume concentrations adjacent to grain bunkers:
  - > Current exclusion zones around bunkers required for phosphine (e.g. 3 m during fumigation) are also sufficient for ProFume – ensure potential worker and bystander exposure to SF are below the permissible TWA



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Seed fumigation using ProFume® gas fumigant

- Dow AgroSciences conducted extensive research evaluating seed of grass, wheat, corn, cotton, and soybean in collaboration with three major seed companies
- Comparative tests were conducted between phosphine and ProFume, under varying exposure periods and temperatures
- Results concluded that fumigating all tested seed types at 750 g-h/m^3 did not negatively impact germination or interact with seed treatments, and compared well with phosphine regarding germ impact

Seed fumigation using ProFume® gas fumigant

- Major seed companies in the USA have adopted ProFume® for their seed fumigations
  - > ProFume offers flexibility compared to phosphine in reducing the fumigant exposure time, important when seed warehouses are on tight schedules to fumigate seeds prior to shipment

  - > All areas of a seed production facility can be fumigated with ProFume, including those with valuable electronic equipment (sizing towers, packaging lines) that could be damaged from phosphine

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Quarantine fumigation using ProFume® gas fumigant – ISPM-15

- 2013 – INIAV in Portugal, in conjunction with Dow AgroSciences, completed validation of fumigation schedules using SF for control of pine wood nematodes, *Bursaphelenchus xylophilus,* in wood packaging material
- Approval of SF for ISPM-15 would be the first global quarantine treatment for sulfuryl fluoride

Quarantine fumigation using ProFume® gas fumigant – ISPM-15

- Pine boards naturally infested with PWN incubated to PWN population
- 36 boards placed in 1 m^3 fumigation chamber in temperature controlled container (15^{o}C, 20^{o}C and 30^{o}C)

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Quarantine fumigation using ProFume® gas fumigant – ISPM-15

ProFume® weighed during introduction

SF concentrations measured in fumigation chambers using SF-ContainIR

Aeration of ProFume

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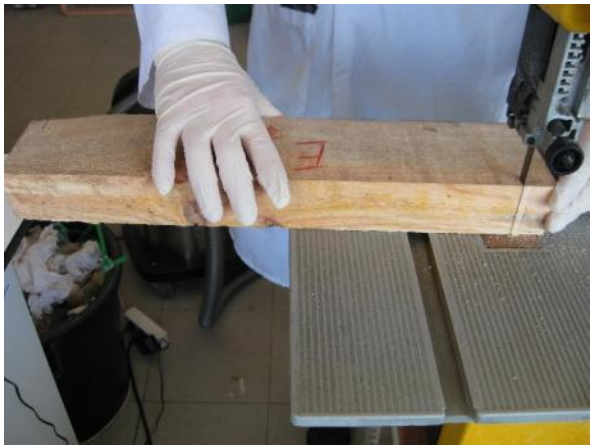
Quarantine fumigation using ProFume® gas fumigant – ISPM-15

ProFume®
GAS FUMIGANT



Processing wood for PWN extraction

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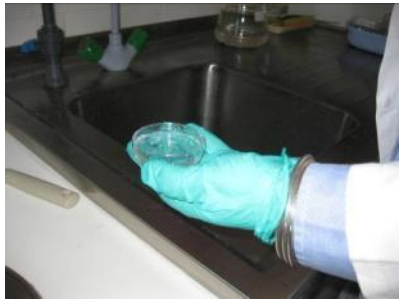
Quarantine fumigation using ProFume® gas fumigant – ISPM-15

ProFume® GAS FUMIGANT



PWN extraction and counting – labor intensive!

- PWN survival assessed in 9 boards/chamber - prefumigation, 3 days and 21 days after fumigation

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Quarantine fumigation using ProFume® gas fumigant – ISPM-15

- Report on study and proposed SF treatment dosage (below) submitted to TPPT in July 2013 for review – awaiting completion of TPPT review*

Temperature Range	Accumulated Dosage ($g\text{-}h/m^3$)	Exposure Time (h)
Below 20C	3,200	24
20 - 29.9C	3,000	48
30C and above	1,400	24

* Complete summary of research - Bonifacio et la., 2013, MBAO

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Quarantine fumigation using ProFume® gas fumigant – Logs

- Dow AgroSciences and USDA APHIS PPQ conducted monitoring research of a tarped containers of logs fumigated with ProFume® for control of wood-infesting insects (Jeffers et al. 2012, MBAO)
- Multiple trials have verified the procedures required by ProFume labeling and PPQ will"
  - > Result in required dosage accumulation of ProFume
  - > Not expose workers to concentrations of ProFume above 1 ppm

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Quarantine fumigation using ProFume® gas fumigant

ProFume® GAS FUMIGANT

- Published research on efficacy of SF for control of timber pests and red oak wilt fungus
- Additional research on quarantine pests currently being conducted:
  - > European Corn Borer, *Ostrinia nubilalis* (Phillips, Kansas State University)
  - > Khapra beetle, *Trogoderma granarium* (Myers et al., 2013, MBAO)

European corn borer

Khapra beetle
(Photo: Univ. of Florida)

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ProFume® Gas Fumigant Summary

ProFume® GAS FUMIGANT

- Sulfuryl fluoride, recognized as an excellent wood fumigant for more than 50 years (Vikane®), has been used commercially for 10 years to fumigate commodities and food processing facilities (ProFume®)
- Extensive research in the USA, EU and Australia have shown ProFume fits the needs of agriculture and food industry for fast and effective fumigation of commodities, food storage, mills and food processing plants with no adverse effects on equipment and food quality when used according to label

- Development and commercial launch success in many countries proves that ProFume is a technically and economically viable alternative to methyl bromide (and to phosphine where damage, resistance, or time constraints are issues)

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Conclusion

ProFume® GAS FUMIGANT

- Thank you for your time!
- Questions?