Current control standards for tasks with high exposure to grain dust

Prepared by the Institute of Occupational Medicine for the Health and Safety Executive 2010
Current control standards for tasks with high exposure to grain dust

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Six sectors of the British grain industry were investigated to try to identify and characterise exposure-significant tasks in terms of the inhalable dust, microorganism, endotoxin and mycotoxin exposures associated with these tasks. Information was collected from stakeholders in the industry by telephone interviews and during visits to company premises. In addition, the available scientific literature was reviewed to identify relevant exposure data.

It was judged that some cleaning activities and certain process tasks may create airborne inhalable dust levels in excess of the British Workplace Exposure Limit (WEL) of 10 mg m\(^{-3}\). Long-term average levels are probably generally less than about 3 mg m\(^{-3}\), with perhaps 15 to 20% of individual exposures above the WEL. Endotoxin levels were judged likely to be less than 104 EU m\(^{-3}\) throughout the industry provided inhalable dust levels are less than 10 mg m\(^{-3}\). There is no published exposure data on mycotoxin, respirable crystalline silica and mite contamination but these are not considered to present widespread problems in the British industry.

Further improvements in control technology and the use of respiratory protection are needed in some sectors of the industry.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.
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EXECUTIVE SUMMARY

Airborne grain dust is a complex mixture of fragments of organic material from grain, plus possible fungal, bacterial or insect contamination or their toxic products such as endotoxin, and mineral matter from soil. In the 1990s grain workers in Britain were frequently exposed to inhalable dust above 10 mg m$^{-3}$ (8-hr), with particularly high exposures being found at terminals where grain was imported or exported and in drying operations (personal exposure typically about 20 mg m$^{-3}$). Since then the industry has made substantial progress in improving the control of airborne dust through better-designed processes, increased automation and an improved focus on product quality. We have used information from the published scientific literature and a small survey of industry representatives to estimate current exposure levels, both long-term average and task-specific exposures.

Workers are most highly exposed to grain dust during manual tasks such as cleaning plant and premises and maintenance. These, like farming tasks carried out in the yard, were of short duration but had potentially high exposures if respiratory protection or other controls were not used. The high level of automation in the import/export, commercial grain storage, milling and malting sectors has led to many fewer operators routinely manning the plant compared to the past. The plant is now largely enclosed, often under negative pressure and there is considerable use of remote operating from control rooms.

We have estimated average levels for a range of tasks and judge that the highest levels, for example during some cleaning activities and certain process tasks, are probably around 10 mg m$^{-3}$. Exposure-significant tasks which could result in exposures above the British Workplace Exposure Limit of 10 mg m$^{-3}$ if carried out for a whole day are: Store work, Blending additives, Packing, Clearing blockages, Ship loading, Cleaning - dry sweeping, Other cleaning – malting, Loading – shovel and Cleaning – using compressed air. However, in most cases operators do not spend all day involved with dusty tasks. The data we have obtained suggest that current long-term exposure to inhalable dust for most workers is on average less than about 3 mg m$^{-3}$, with perhaps 15% to 20% of individual personal exposures being above 10 mg m$^{-3}$. Further reduction of exposures is needed in some sectors of the industry during exposure-significant tasks such as loading and packing.

Data for exposure to biological agents in the British grain industry are limited. Endotoxin levels were judged likely to be less than 10$^4$ EU m$^{-3}$ throughout the industry, provided inhalable dust levels are less than 10 mg m$^{-3}$. There is no published exposure data on mycotoxin, respirable crystalline silica and mite contamination but these are not considered to present widespread problems in the British industry.

Suitable respiratory protection is generally available throughout the grain industry, although the procedures for managing its use, the training of operators and the fit-testing of users all need to be improved.

Further research should be carried out to confirm the findings from this research to provide a reliable picture of exposure in the British grain industry.
## GLOSSARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinomycete</td>
<td>A group of gram-positive bacteria, generally with a filamentous structure.</td>
</tr>
<tr>
<td>Alternaria</td>
<td>Alternaria fungal species may cause adverse health effects if inhaled by humans.</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance statistical analysis.</td>
</tr>
<tr>
<td>Aspergillus</td>
<td>Aspergillus is a genus of fungus. Inhalation of spores does not normally cause illness, unless the individual has a weakened immune status.</td>
</tr>
<tr>
<td>Botrytis</td>
<td>A fungi genus.</td>
</tr>
<tr>
<td>CFU m⁻³</td>
<td>Colony-forming units per unit volume of air</td>
</tr>
<tr>
<td>Cladosporium</td>
<td>Cladosporium is a genus of fungi that includes some of the commonest indoor and outdoor moulds. Cladosporium fungi rarely cause infection in humans.</td>
</tr>
<tr>
<td>DNA</td>
<td>Deoxyribonucleic acid</td>
</tr>
<tr>
<td>DON</td>
<td>The mycotoxin deoxynivalenol</td>
</tr>
<tr>
<td>ELISA</td>
<td>Enzyme Linked Immunosorbent Assay. ELISA is a biochemical analytical technique used to detect the presence of and quantify an antibody or an antigen in a sample.</td>
</tr>
<tr>
<td>Endotoxins</td>
<td>Endotoxin is an insoluble structural component of bacteria that is toxic, endotoxins are released when bacteria are lysed, i.e. when the bacteria dies and the cell wall breaks down.</td>
</tr>
<tr>
<td>Epicoccum</td>
<td>A mould genus.</td>
</tr>
<tr>
<td>EU</td>
<td>Endotoxin Unit, which is commonly used in the measurement of endotoxin exposure. The conversion from endotoxin units to nanogram of endotoxin will vary, although in this report it is assumed there is 10 EU/µg.</td>
</tr>
<tr>
<td>Exposure significant task</td>
<td>Those activities where exposure could exceed the exposure limit for grain dust (10 mg m⁻³ as an 8-hr average) or where elevated exposure to some component in the grain dust could give rise to adverse health effects.</td>
</tr>
<tr>
<td>Fungal spores</td>
<td>A spore is the reproductive structure that is adapted for dispersal from the fungi. Spores, unlike seeds, have very little stored food resources. Microscopic fungal spores are released into the atmosphere where they can be breathed in or ingested.</td>
</tr>
<tr>
<td><strong>Fusarium</strong></td>
<td>Fusarium is a genus of filamentous fungi commonly found in soil and in association with plants.</td>
</tr>
<tr>
<td><strong>Genus</strong></td>
<td>A classification unit of plants or animals with common distinguishing characteristics. It is a group of closely related species, or a single species.</td>
</tr>
<tr>
<td><strong>GM</strong></td>
<td>The geometric mean (GM) is a type of average that indicates the central tendency of a set of numbers. For a log-normal distribution it has the same value as the median.</td>
</tr>
<tr>
<td><strong>Grain dust</strong></td>
<td>Grain dust is a complex mixture of fragments of organic material from grain, plus possible fungal, bacterial or insect contamination or their toxic products such as endotoxin and mineral matter from soil.</td>
</tr>
<tr>
<td><strong>GSD</strong></td>
<td>The geometric standard deviation (GSD) describes the spread of a set of numbers whose average is the geometric mean.</td>
</tr>
<tr>
<td><strong>HT-2</strong></td>
<td>HT-2 toxin is a trichothecene mycotoxin, closely related to T-2 mycotoxin.</td>
</tr>
<tr>
<td><strong>Inhalable dust</strong></td>
<td>Inhalable dust is the size fraction of airborne dust that may be inhaled into the nose or mouth.</td>
</tr>
<tr>
<td><strong>LAL</strong></td>
<td>Limulus Amebocyte Lysate is an extract of blood cells from the horseshoe crab (Limulus polyphemus). LAL is used in a test for the detection and quantification of bacterial endotoxin.</td>
</tr>
<tr>
<td><strong>Mesophilic bacteria</strong></td>
<td>Bacteria that grows at moderate temperature.</td>
</tr>
<tr>
<td><strong>Microorganism</strong></td>
<td>Microorganisms include bacteria, fungi and other microscopic organisms.</td>
</tr>
<tr>
<td><strong>Mycotoxin</strong></td>
<td>Mycotoxin are substances produced by fungi that have been identified as being toxic to humans and animals.</td>
</tr>
<tr>
<td><strong>OTA</strong></td>
<td>Ochratoxin A is a mycotoxin.</td>
</tr>
<tr>
<td><strong>PCR</strong></td>
<td>Polymerase chain reaction (PCR) is an analytical technique used to identify fungal DNA.</td>
</tr>
<tr>
<td><strong>Penicillium</strong></td>
<td>A genus of fungi found in the environment.</td>
</tr>
<tr>
<td><strong>Psychrophilic bacteria</strong></td>
<td>Bacteria capable of growth at cold temperatures</td>
</tr>
<tr>
<td><strong>T-2</strong></td>
<td>A mycotoxin closely related to HT-2 mycotoxin.</td>
</tr>
<tr>
<td><strong>Trichothocenes</strong></td>
<td>A group of mycotoxin, e.g. Deoxynivalenol (DON), HT-2 toxin. Trichothocenes are associated with chronic and fatal toxic effects in animals and humans.</td>
</tr>
<tr>
<td>Viable bacteria</td>
<td>Bacteria than may be cultured under favourable conditions.</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>α-(1→3)-glucans</td>
<td>A soluble fibre polysaccharide made up of units of the monosaccharide D-glucose.</td>
</tr>
</tbody>
</table>
1 INTRODUCTION TO THE INDUSTRY, PROCESSES AND TASKS

Grain dust is generated during the harvesting, drying, handling, storage or processing of barley, wheat, oats, maize and rye. The dust includes contaminants such as fungal spores, endotoxin and mycotoxin; bacteria and actinomycetes; insects, fragments of bird feathers, animal hairs and excreta from animals plus fungicide, pesticide and fertiliser residues and derivatives.

Grain dust is defined in HSE Guidance Note EH 40/2005 as ‘dust arising from the harvesting, drying, handling, storage or processing of barley, wheat, oats, maize and rye, including contaminants or additives within the dust’.

The sectors in the grain industry are shown in Figure 1.1. This diagram shows the structure of the grain industry from source (farm or importation) through processing (commercial storage by grain merchants is optional) at barley malting houses, flour mills, animal feed mills or ports for grain export and into finished product.

Exposures to, some or all of, dust, fungi, bacteria, endotoxin, mycotoxin, dust and storage mites in the industrial sectors have been linked with work activities including:

- Harvesting on farms;
- Storage and distribution, including grain silo cleaning;
- Milling;
- Malting;
- Animal feed milling/mixing;
- Terminals and docks (imports and exports).

Activities such as grain cleaning and drying occur is several of these sectors.

Each sector in the grain industry produces a different finished product. For example, milling produces wheat flour and maltings produce malted barley. The lines and arrows in the diagram represent distribution by road vehicle.
The industry process is the combination of machinery (plant) and manpower used in the manufacture of a finished product. In some cases a particular work site may contain one or more processes. For example, a malting may also produce animal feed on a pellet or loose feed line.

Tasks are considered as the individual steps that make up one or more processes. Mixing, grain cleaning and drying and silo cleaning (and other premises and plant cleaning) are considered as tasks found in many of processes operating in the industry sectors.

Grain dust is defined as a hazardous substance under the Control of Substances Hazardous to Health Regulations (COSHH) 2002 as amended and has been given a workplace exposure limit (WEL) of 10mg m$^{-3}$ (first introduced in 1992). For the purpose of compliance with the WEL grain dust is considered to be dust arising from the harvesting, drying, handling, storage or processing of barley, wheat, oats, maize and rye. This definition includes any contaminants or additives within the dust. Under the COSHH Regulations, control of exposure to grain dust is adequate only if the exposure is reduced as far below the WEL as is reasonably practicable. This should involve considering the potential for short-term peaks of exposure as well as longer-term time-weighted averages. General guidance on exposure to dusts suggests that short-term exposure (15-min) should not exceed 30 mg m$^{-3}$. 


2 SCOPE AND AIMS

The aim of the project was to gather baseline information on the generation, exposure to and control of airborne dust in the British grain industry, and to use this information to characterise exposure significant tasks for the different sectors of the industry.

We considered ‘exposure-significant tasks’ to be those activities where exposure could exceed the exposure limit for grain dust or where elevated exposure to some component in the grain dust could give rise to adverse health effects. The first criterion broadly corresponds to a geometric mean exposure level of 1 mg m\(^{-3}\) for a task, assuming a geometric standard deviation of 4.5 (based on data for millers from Meijster et al; 2007) and that the task could last for most of the day.

The information related to airborne dust exposure was gathered and collated for processes or tasks in the processes or tasks that have previously been identified as having high grain dust exposures (Table 2.1).

<table>
<thead>
<tr>
<th>Process or task</th>
<th>Grain industry sector or other industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting</td>
<td>Farm</td>
</tr>
<tr>
<td>Grain cleaning</td>
<td>Commercial storage, Flour mill, Maltings, Malt mill</td>
</tr>
<tr>
<td>Grain drying</td>
<td>Farm, Commercial storage, Flour mill</td>
</tr>
<tr>
<td>Storage and distribution</td>
<td>Farm, Commercial storage, Flour mill, Maltings, Malt milling, Road hauliers, Stevedores</td>
</tr>
<tr>
<td>Grain silo cleaning</td>
<td>Farm, Commercial storage, Flour mill, Maltings</td>
</tr>
<tr>
<td>Milling/grinding</td>
<td>Flour mill, Malt mill, Distillery</td>
</tr>
<tr>
<td>Animal feed production</td>
<td>Feed mill</td>
</tr>
<tr>
<td>Mixing</td>
<td>Commercial storage, Flour mill, Feed mill, Malt mill</td>
</tr>
<tr>
<td>Transferring and storing grain at terminals and docks (imports)</td>
<td>Stevedores, Flour mill, Road hauliers</td>
</tr>
</tbody>
</table>

Central to the success of the project was the collection of meaningful exposure-related data directly from the industry. Further, published exposure measurements and their determinants (task duration and frequency and operational practices) were sought from the British and international literature. The information on processes and tasks sought by the study is given in broad terms in Table 2.2 and the research methodology used to achieve this is discussed in Section 3.
<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Data sought</th>
</tr>
</thead>
</table>
| A process on a company site | Types of grain being handled  
Current processes involved with handling, transferring and processing grain  
Stages in the process where dust may be generated  
Current control measures in place on the process, including the use of respiratory protective equipment (RPE)  
Implementation of control measures and ease/difficulties of introducing further control  
Procedures for monitoring airborne dust exposures  
Composition of the grain dust |
| Tasks making up the process | Description of task - equipment and materials used (and formed) and the manual, mechanised or automated work practices and procedures followed in using them  
Duration of task  
Frequency of task  
Number of operators involved in task  
Control measures on plant, equipment and machinery used in task  
Control measures operators wear themselves when carrying out the task  
Monitoring of exposures for tasks and/or of operators when performing the task  
Administration/management/maintenance of control measures and plant  
Any perceived or established exposure or health risks |
3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

We reviewed the published data and collected new data from interviews and visits to companies. The new data was collected in two rounds: a series of telephone interviews followed by site visits at selected company premises. The methods of data collection are summarised in Table 3.1.

Table 3.1 Data collected for the grain industry dust survey

<table>
<thead>
<tr>
<th>Data</th>
<th>Data and Data Collection Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field studies</td>
<td>Round 1 Preparing a checklist for telephone surveys  \  Conducting telephone surveys with senior production or health and safety specialists within a company having multiple factory sites</td>
</tr>
<tr>
<td></td>
<td>Round 2 Conducting on-site visits at a factory with plant production and/or health and safety managers  \  Measuring of airborne dust exposure levels using a direct reading instrument on-site  \  Observing work practices, process operations and plant on-site  \  Informal discussion with factory operators and management on-site</td>
</tr>
<tr>
<td>Published</td>
<td>Obtain relevant information provided by HSE  \  Search the published scientific literature for information relevant to grain dust exposure in Great Britain and the rest of the world</td>
</tr>
</tbody>
</table>

3.2 DATA COLLECTION BY LITERATURE REVIEW

This literature survey sought to identify exposure data for the grain industry published over the last ten to fifteen years. It did not review the occupational diseases that have become synonymous with grain dust during that or earlier times. Instead it has focused on reviewing exposure data reported across the grain industry in order to establish which are the exposure-significant tasks undertaken by grain industry workers.

HSE provided a number of key publications that were used by ACTS/WATCH for limit setting purposes. A literature search was carried out to update this information and identify key publications that were published after the documentation provided by HSE. This literature search focused on studies investigating grain dust exposure levels and control in the relevant industries, particularly in Great Britain. Electronic databases such as PubMed, Canadian Centre for Occupational Health and Safety (CCOSH) OSH Reference, Highwire Press (Stanford University) and Google Scholar were used for these searches. In addition, we specifically searched in occupational hygiene journals, such as Annals of Occupational Hygiene and Journal of Occupational and Environmental Hygiene.

The literature review focused on:

- identifying exposure-significant tasks in the grain industry using existing direct reading or gravimetric measurements (full-shift, task-based or peak exposures) of personal or
static exposure to components described as dust, mycotoxin, endotoxin, bacteria, insects, vegetative and crystalline silica as reported in the literature;

- estimating the approximate exposure levels in exposure-significant tasks, in terms of these grain dust components;
- using the trends in monitoring results from airborne ‘dust’ of non-cereal crops and settled dust from cereal crops as exposure predictors for exposure-significant tasks where air monitoring data was lacking;
- establishing any patterns in exposure levels between various (exposure-significant) tasks and the different constituents of the dust;
- considering the effect exposure variables such as control measures and respiratory protection on achieving exposure reduction.

Few publications in these areas report on research conducted in Great Britain whereas European, North American and other international papers featured more widely. The results contained in publications from outside Britain were assessed cautiously in terms of their relevance to the British situation.

### 3.3 DATA COLLECTION BY INDUSTRIAL SURVEY

The industry sectors where interviewees were sought during the project were:

- farms;
- flour mills;
- malting houses including malt milling;
- animal feed millers plus
- grain merchants and
- importers/exporters.

Recruitment of study participants from these sectors started by contacting the relevant trade organisations (Table 3.2). These organisations then generated a list of candidates from their membership who might be approached. These potential candidates were then contacted directly and invited to participate in surveys about their operations and experience in the industry. This first communication took place by email with a project summary attached and a tentative date for a telephone interview. The telephone interviews were then confirmed or rescheduled to suit the company. Companies were asked during the telephone interviews if they would be willing to participate in the site visits. No companies interviewed refused to host a site visit.

The first round of data collection involved a short (~40 minutes) telephone survey. A checklist (Appendix 1) was designed in order to collect information through informal telephone interviews with senior production or health and safety personnel. In three cases, the information was collected via email.

As shown in Table 3.2, farmers were poorly represented in the telephone survey. This was despite rigorous efforts to engage with them through a range of organisations including the National Farmers Union, the National Farmers Union of Scotland (Cereals Committee), the Scottish Agricultural College (SAC) and another study participant. Assistance was sought from SAC in order to try and secure some site visits during harvest time. The Farm Business Services’ Lothians’ Office selected and approached three farms to see if they would be willing to host a site visit. These farm visits, plus one other that was arranged directly by the IOM, were carried out towards the end of harvesting when the farmers were less busy.
Three port authorities/services were contacted. However only one responded, and this organisation was exceptionally helpful. One other small importer participated, however there were no storage facilities on their premises for grain. Only one animal feed company was identified by the organisations contacted in the recruitment stage of the project. This company participated in both rounds of the study. It emerged during the study that two of the malting houses had malt milling production lines. Only one of these malt mills was available to participate in the telephone study. Similarly it had not been possible to schedule times for telephone interviews with two of the malting houses prior to visits.

Two large grain merchants were identified and approached directly by the IOM.

In the second round of the study, companies were chosen for site visits based on simple selection criteria, namely:

- maximising the range of process technologies observed in the available time;
- optimising the visiting schedule to more distant sites in the same geographical area.

There were a total of 32 participants in the study overall (Table 3.2). Site visits were made to 17 premises, 11 of which belonged to companies participating in Round 1. It should be noted that the small number of companies participating in the survey does not provide a representative sample of the industry.

<table>
<thead>
<tr>
<th>Contact for industrial sector</th>
<th>Industrial sector</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scottish Agricultural Scientific Agency (SASA)</td>
<td>Farming</td>
<td>Phone Site Total</td>
</tr>
<tr>
<td>Scottish Agricultural College (SAC)</td>
<td>Farming</td>
<td>- 3 6</td>
</tr>
<tr>
<td>Referred by another participant</td>
<td>Farming</td>
<td>1 -</td>
</tr>
<tr>
<td>Direct contact by IOM</td>
<td>Farming</td>
<td>- 1</td>
</tr>
<tr>
<td>Direct contact by IOM</td>
<td>Merchanting &amp; Storing</td>
<td>1 2*</td>
</tr>
<tr>
<td>Direct contact by IOM</td>
<td>Importing</td>
<td>1</td>
</tr>
<tr>
<td>Grain and Feed Trade Association (GAFTA)</td>
<td>Merchanting &amp; Importing</td>
<td>1 -</td>
</tr>
<tr>
<td></td>
<td>Pest controller</td>
<td>1 - 1</td>
</tr>
<tr>
<td></td>
<td>Animal feed production</td>
<td>1 1 2</td>
</tr>
<tr>
<td>Maltsters Association of Great Britain (MAGB)</td>
<td>Malting</td>
<td>7 5** 9</td>
</tr>
<tr>
<td></td>
<td>Malt milling</td>
<td>1 - 1</td>
</tr>
<tr>
<td>National Association of British and Irish Millers (NABIM)</td>
<td>Flour milling</td>
<td>6 3 9</td>
</tr>
</tbody>
</table>

* one company visited, but not called
** two companies visited, but not called
During the site visit data was collected by:

- visual observation;
- informal discussion with production and/or health and safety managers (and in two cases directly with plant operators);
- camera and
- a direct reading dust monitoring instrument (TSI SidePak AM510 Aerosol Monitor fitted with a 10 µm aerodynamic diameter sampling orifice).

Dust concentrations were measured using a direct reading dust monitoring instrument (TSI SidePak AM510 Aerosol Monitor fitted with a 10 µm aerodynamic diameter sampling orifice). This data is uncorrected and in the absence of a reliable calibration gives only an estimate of the relative level of exposure compared to the more accurate measures using gravimetric techniques. The monitor was worn at company premises by the researcher undertaking the site visits. On one occasion (animal feed mill) the dust emitted from specific dust generating sources was monitored for between 5 and 15 minutes. On all other occasions dust was monitored continuously during a tour of the site led by the production or a health and safety manager. It was impossible to measure the time spent at a particular point in the production process for several reasons; not being able to wear a watch in some instances because of bio-security issues and therefore being unable to measure the time; not knowing the layout of the site and the best way to navigate during a tour; and not inconveniencing the host company by taking up too much of their time with stoppages. In the case of malting facilities this involved walking between and through buildings housing the plant. In flour mills the visit was spent largely indoors and covered many (up to 6) levels. The dust monitoring data are summarised in Section 6 of this report and these data provide background information for our exposure assessments.
4 RESULTS FROM LITERATURE REVIEW

4.1 INTRODUCTION

Grain dust is a complex mixture of organic and inorganic materials, mainly comprising the cellulose-based seed coating and the carbohydrate. Exposure is generally assessed as either the total mass concentration of respirable dust and/or the concentration of inhalable dust. Grain dust may also contain bacterial and fungal contamination and airborne dust samples may therefore be analysed for their endotoxin\(^1\) and mycotoxin\(^2\) content.

In this review we focus on exposure to inhalable and respirable dust exposures, plus airborne endotoxin and mycotoxin concentrations. Where there was limited data on airborne dust for other components of the aerosol, we have explored the possibility of using data from settled dust to infer something of the likely levels of exposure. We also comment on the likely exposure levels of bacteria, insects, vegetative and crystalline silica, as reported in the literature.

The main focus of the review has been to attempt to identify those tasks that may produce significant exposure to any of the above aerosol components, to estimate the approximate level of exposure in these tasks, including any variation in exposure parameters between tasks, and comment on the significance of exposure controls and the use of respiratory protection.

4.2 STATUS OF MICROORGANISM EXPOSURE MONITORING OF GRAIN DUST COMPONENTS

The lack of any single or composite standard method for sampling and analysis of the microorganism content in grain dust has led to researchers using more than one monitoring method at a time in order to quantify the airborne concentrations of micro-organisms. New monitoring techniques are also being developed and moving away from using microorganism cultivation methods (Dowes \textit{et al} 2002, Pasanen, 2001 and Macher, 2001). However this has not significantly reduced the variability in measured values for grain dust exposures during specific grain handling tasks.

Analysis methods used in monitoring exposure to microorganisms include:

- microscopic;
- chemical, e.g. thin layer chromatography/fluorescence spectrophotometry, gas chromatography/mass spectrometry;
- biochemical (Enzyme Linked Immunosorbent Assay (ELISA) and Limulus Amebocyte Lysate (LAL) and
- molecular biological e.g. Polymerised Chain Reaction (PCR) techniques.

Microscopy can involve simple analysis of the sample directly on a slide or be preceded by a cultivation of a colony of fungi spores or bacteria cells on agar plates. The latter has been more frequently used in order to grow specific species for a compositional analysis of the dust. This technique requires some knowledge of the microorganism species expected in order to choose the correct agar type to develop the colony. Microorganism colonies are identified by staining cells and determined by counting the colonies with characteristic structures and morphology.

\(^1\) Endotoxin is an insoluble structural component of bacteria that is toxic, endotoxin is released when bacteria are lysed, i.e. when the bacteria dies and the cell wall breaks down.

\(^2\) Many moulds produce ‘mycotoxin’, which are metabolites that have been identified as being toxic to humans.
through direct observation or instrumental means. The concentrations are reported as colony-forming units per unit volume of air (CFU m\(^{-3}\)) for airborne grain dust.

Identification by cultivation has limitations. There are three broad situations that have been recognised as resulting in an underestimation of exposure:

1. Some agriculturally important species of Aspergillus and Penicillium genera cannot be distinguished easily from each other with this method;
2. The in-field fungal genus Fusarium does not culture well and often does not produce enough colonies to be determined microscopically. Variations in Fusarium species have also made it difficult to identify them unequivocally at species level.
3. There may be an underestimation of the naturally low levels of some microorganisms in a dust and of microorganisms present as small structural units, compared to larger aggregates and clusters of these microorganisms.

In addition, impinger sampling, one of the traditional air sampling methods, has been linked with splitting aggregates into such smaller units, which would increase the level of measurement error.

Overestimation of fungal exposure levels has been considered possible when fungal fragments such as hyphae and mycelium are counted during enumeration. Plants and yeasts are also known to produce these during growth and it is conceivable that they could contaminate a grain dust sample during harvest and lead to a falsely high level of fungi. The number of sources of error which have led to unreliable and varying results from the monitoring of fungi and bacteria have led to the measurement of markers such as \(\beta-(1\rightarrow3)\)-glucans, found in the cell walls of fungi, and particularly endotoxin, arising from bacteria, becoming more widespread (Pasanen, 2001).

Different dust samplers collect different fractions of airborne dust and many samplers have been used to measure grain dust and its components, making studies difficult to compare. Viable airborne dust samples have been taken directly onto plates using Anderson six stage volumetric static samplers. Midget impingers and personal dust samplers collecting particulates on cassettes and filters are also used to collect grain dust and its components. Inhalable dust sampling heads such as the Institute of Occupational Medicine (IOM) sampling head are being increasingly used for bioaerosol collection. Sampling using the portable Burkard spore trap has been conducted in a few studies. Portable sampling equipment that can collect enough airborne dust to quantify mycotoxin using established analysis techniques is not commercially available and no reliable data on personal monitoring of mycotoxin has been found in the literature.

PCR detected fungal DNA has been investigated as an indicator of mycotoxin contamination. In this method identification of the fungi has to be carried out at the species level in order to relate the particular fungal DNA to the mycotoxin that they produce. This means a good correlation between chemically measured trichothecene levels and a specific species of PCR-determined Fusarium DNA has to be achieved. In Norway this relationship has been established for HT-2 and T-2 with Fusaria poae and langsethiae. Similar correlations have been found for DON with Fusarium graminearum and culmorum in the USA and warmer European countries such as Britain. However sometimes mycotoxin persist long after the fungi are dead and fungi would not be a good indicator of mycotoxin in this situation.

The PCR method does not rely on microbiological assaying and cultivation (Halstensen et al., 2006) of colony forming units and so provides a measurement method for fungi that are not viable after becoming airborne and being sampled. Live intact microorganisms are not needed for PCR, which can detect both live and dead fungi. Further, this method is more sensitive than cultivation and can determine fungal species not observable in agar plates. However, the method
relies on there being a good correlation between fungi and mycotoxin; on having stable DNA, which must not disintegrate during the monitoring process; and on having a suitable biomolecular system for reacting with and quantifying the DNA. Mycotoxin contamination would be underestimated where these analytical conditions are not fulfilled.

When certain types of bacteria break down, endotoxin found on the outer layer of the cell is released into the environment. Endotoxin is more sustainable than bacterial cells and contamination can remain high even if bacterial levels fall due, for example, to dehydration and death. Consequentially, gram negative bacteria cannot be considered an indicator of endotoxin. Air sampling has been widely used for collecting grain dust for endotoxin determination and analysis is normally carried out by the kinetic chromogenic LAL method. It has been observed that there is less variability in measured endotoxin concentrations in grain dust samples compared to that for many other microorganisms.

Penicillium and the Aspergillus species flavus (not found in Great Britain) and Parasiticus have been associated with aflatoxin and ochratoxin A (OTA) production. They are not usually found on growing crops in Western Europe but are known to infect stored cereals with moisture contents in excess of 16-20% (depending upon the temperature). OTA is usually analysed using ELISA and measurements taken using this technique have been widely reported in the literature.

Studies have been carried out that document the number and effects of experimental variables on the analytical techniques (Douwes et al., 2003 and Macher, 2001). They show that the sampling and analytical errors associated with identifying and quantifying concentrations for a diverse range of microorganisms in a grain sample are extensive. The practical difficulties in obtaining accurate culture-based measurements (efficient sampling to avoid overload but collect sufficient sample for analysis and analytical interferences and variable sensitivity) have led to a move towards assessing biological agents such as β-(1→3)-glucans and especially endotoxin as markers of fungi and bacteria. Similarly PCR methods are being used to identify and quantify fungi species for use as indicators of trichothecene mycotoxin (Srikanth et al., 2008). The results from analysis of settled grain dust samples have shown concentrations of microorganisms to be poorly related to those obtained from air samples of grain dust. This is because some of the physical/morphological forms of the spores do not easily become airborne. Analysis of components of settled grain dust tends to give higher measurements of personal exposures for these components compared to the true value. Similarly subsamples of fine and coarse dust have been shown to give rise to different numbers of CFU, with fine dust giving higher concentrations than coarse dust. This highlights the need to establish a standard approach that comprehensively describes sample collection, handling and analyses in order to allow meaningful comparison of findings across different studies.

### 4.3 PAST EXPOSURE TO GRAIN DUST IN GREAT BRITAIN

Phillips (1993) summarised HSE’s knowledge of occupational exposure to grain dust, including the results from an extensive survey of grain dust exposures in agriculture, grain storage and handling and transport in the major grain terminals. In total, almost 250 measurements of 8-hour personal exposure to inhalable dust were made as well as a small number of respirable dust measurements. The inhalable dust concentrations are summarised in Table 4.1.
Table 4.1 Inhalable 8-hour dust exposure levels reported by HSE in 1993

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number of samples</th>
<th>Mean and range of inhalable exposures (mg m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting</td>
<td>40</td>
<td>6.8 (0.2 – 41)</td>
</tr>
<tr>
<td>Grain drying/unloading‡</td>
<td>11</td>
<td>19 (4.1 – 56)</td>
</tr>
<tr>
<td>Milling and mixing animal feed on farm</td>
<td>24</td>
<td>3.1 (0.1 – 21)</td>
</tr>
<tr>
<td>Animal feed manufacture</td>
<td>33</td>
<td>1.8 (0.1 – 11)</td>
</tr>
<tr>
<td>Malting and distilling</td>
<td>44*</td>
<td>9.2 (0.4 – 57)</td>
</tr>
<tr>
<td>Grain storage</td>
<td>56</td>
<td>7.1 (1.3 – 29)</td>
</tr>
<tr>
<td>Grain terminals</td>
<td>31+</td>
<td>22 (1 – 119)</td>
</tr>
</tbody>
</table>

*excludes one measurement on the dust plant of 317 mg m⁻³
+ excludes three measurements during loading barges with mean exposure of 150 mg m⁻³ (range 69 – 267)
‡ based on measurements made at a grain terminal

The highest average exposure levels were in the grain terminals where the main tasks contributing to the high exposures were cleaning (average 51 mg m⁻³). There were only three measurements during the loading of barges at grain terminals but these data were all very high. The next highest average exposures were found in grain drying on farms where the average figure was 19 mg m⁻³. Cleaning in malting and distilling also showed elevated exposures: average 34 mg m⁻³.

There were clearly different levels of exposure for harvesting with and without air conditioned cabs on the combine harvesters: with cabs the average exposure level was 1.2 mg m⁻³ and without 29 mg m⁻³. Phillips noted that in many tasks there were high airborne dust concentrations close to the sources but that operators tended to stand back from these points and consequently had relatively low personal exposures.

About 66% of exposure measurements in the grain terminals exceeded 5 mg m⁻³. In all of the other sectors combined about 35 to 40% of measurements were above 5 mg m⁻³. Respirable dust made up between 2% and 15% of the total inhalable aerosol.

The above data were also published in papers presented to the Advisory Committee on Toxic Substances (ACTS) and Working Group on Action to Control Chemicals (WATCH) papers between in 1988 and 1992 (Phillips et al, 1992).

4.4 SUBSEQUENT STUDIES CARRIED OUT IN GREAT BRITAIN

Data from the published literature are available for a range of components in grain dust and for inhalable dust, as summarised in Table 4.2.
Table 4.2  Components of grain dust for which exposure data have been published

<table>
<thead>
<tr>
<th>Exposure measure</th>
<th>Inhalable dust</th>
<th>Viable bacteria</th>
<th>Endotoxin</th>
<th>Fungi</th>
<th>Mycotoxin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>β-(1→3)-glucans, Ochratoxin A (OTA), Trichothocenes – e.g. Deoxynivalenol (DON), HT-2 toxin</td>
</tr>
</tbody>
</table>

There are very few published exposure studies from Great Britain. Swan and Crook (1998) describe the results from measurements of airborne viable bacteria and fungi in farming and during grain handling at terminals. Samples were collected for up to 4 hours. These data showed concentrations higher than $10^4$ bacteria and fungi per cubic metre in all areas with concentrations around $10^7$ m$^{-3}$ while harvesting wheat and during unloading grain at a dock. The authors noted that the highest microorganism contamination levels were measured when handling barley.

On farms the predominant microorganisms were mostly ‘field fungi’ such as Cladosporium and Alternaria, which colonise the grain during growth. In terminal work it was generally Aspergillus, which grows in storage if the moisture content rises above about 13%. The study also showed the potential importance of gram-negative bacteria and the consequent exposure to endotoxin, although this was not measured directly. They also discussed the likelihood of low concentrations of mycotoxin in grain dust.

Simpson et al (1999) published a comparative study of personal exposure to inhalable dust and endotoxin in nine different work environments, including handling of grain in docks and storage and milling tasks in a flour mill. These samples were collected over a working shift. The geometric mean inhalable dust exposure in these grain processes was 4.4 mg m$^{-3}$, with a range of <1 to 72 mg m$^{-3}$. On individual tasks monitored the highest levels were associated with silo cleaning (median 25 mg m$^{-3}$). The geometric mean endotoxin level was 115 ng m$^{-3}$ (equivalent to approximately 1,150 EU m$^{-3}$) with individual measurements ranging from 3 to 2,200 ng m$^{-3}$ (30 – 2.2 x $10^4$ EU m$^{-3}$). The highest median endotoxin exposure level was again associated with silo cleaning (650 ng m$^{-3}$, which is about 6,500 EU m$^{-3}$), although there were also relatively high levels associated with silo work (3,900 EU m$^{-3}$). There was a statistically significant correlation between endotoxin and inhalable dust exposure levels ($r = 0.71$) in the grain sector, although the authors note that endotoxin exposures might be expected to vary in different parts of an industry due to processing of the materials and so any correlation should be interpreted cautiously.
Of the nine industry sectors investigated by Simpson and colleagues, the grain industry was comparable to exposure in swine handling, wool mills and the animal feed industry in terms of geometric mean inhalable dust exposure levels and comparable to wool mill exposure to endotoxin. In both cases grain had the fourth highest geometric mean exposures out of the nine sectors investigated.

Swan et al (2007) reported on two successive studies looking into exposures during harvesting (thirteen farms) and storage tasks (four farms) and loading/unloading, grain transfer and control room tasks at two ports respectively. The findings of the first study were published in a paper and the second of these studies, which ran from 1997 to 2003, was published as a HSE document. Inhalable dust, endotoxin, bacteria, and fungi levels were reported. It was established that Alternaria and Cladosporium were the dominant genera of fungi (air concentrations of 1,000 to 1,000,000 CFU m$^{-3}$) found on farms while Penicillium and, to a lesser extent yeasts, were dominant in stored grain. Alternaria was found to persist in stored grain at concentrations between 1,000 and 1,000,000 CFU m$^{-3}$. There was over a 100 fold reduction in Alternaria and Cladosporium exposure levels recorded inside the combine harvester cab compared to those measured outside. Aspergillus, Cladosporum and Penicillium were the dominant species in the samples taken at the docks.

A large port was investigated in the second study described by Swan et al (2007). The intake task at the port was identified as being dusty but it was noted that operators did not stand next to the pit while the grain was being tipped. Moving and dropping grain using open conveyors and outloading of grain was observed to be dusty. Unloading ships was not dusty but loading from a chute was dusty. Control rooms and other office type accommodation, where respiratory protection would not be used, were dustier than expected.

There are no other published studies of exposure to grain dust in Britain during the last 10 to 15 years.

### 4.5 OTHER STUDIES RELEVANT TO GREAT BRITAIN

Studies of exposure to grain dust have been reported in Europe, North America, Africa and Asia. It is difficult to be sure how relevant these studies may be to the British industry because of differences in agricultural practices, handling procedures, climate and other factors. In this section we summarise the most relevant studies and attempt to identify possible patterns in the data.

#### 4.5.1 Tasks on Farms

Halstensen et al (2007) describe a study to measure exposure of Norwegian farmers to inhalable dust, fungal spores, hyphae, $\beta$-(1$\rightarrow$3)-glucans, bacteria and endotoxin in 92 farms. They also aimed to identify exposure determinants associated with weather and production practices. Personal samples were collected for between 10 and 60 minutes. The geometric mean inhalable dust exposure level was 4.4 mg m$^{-3}$ (geometric standard deviation (GSD) = 4.0) and there were similarly $4 \times 10^6$ fungal spores and $4 \times 10^6$ bacteria per cubic metre. The geometric mean endotoxin exposure level was 5,900 EU m$^{-3}$ (GSD = 8.6).

The researchers found that wet and warm weather throughout the growing season significantly increased average exposure to inhalable dust, endotoxin and other components of the dust. This was indicated by the observation of visible fungal damage to the grain. From an analysis of variance (ANOVA), visible fungal damage was associated with geometric mean inhalable dust exposure levels of 7.7 mg m$^{-3}$ compared with 3.3 mg m$^{-3}$ for grain with no visible damage (p=0.003). There was a similar difference in endotoxin exposure levels associated with visible...
fungal damage (14,000 vs 3,800 EU m$^{-3}$). It is notable that in this study about a third of the samples collected were associated with grain with visible fungal damage.

The significant determinant of exposure was storage work where the geometric mean exposure over all the variables measured was higher compared to those for harvesting (inhalable dust 7.6 vs. 1.2 mg m$^{-3}$, endotoxin 11,500 vs. 1,200 EU m$^{-3}$). This is in part due to the harvesting being carried out with combine harvesters with filtered air cabins where the geometric mean exposures for workers with cabins and those without cabs was 0.9 vs. 3.1 mg m$^{-3}$ for inhalable dust and 800 vs. 6,600 EU m$^{-3}$ for endotoxin, both differences were statistically significant (p<0.05). Inhalable dust, endotoxin and fungal spore levels measured for those operators using hot air (7.9 mg m$^{-3}$, 11,900 EU m$^{-3}$ and 6,800,000 counts m$^{-3}$) were not significantly different from those using ambient air for drying grain (7.2 mg m$^{-3}$, 11,200 EU m$^{-3}$ and 6,300,000 counts m$^{-3}$). Personal exposures measured for manual and for mechanical or pneumatic storage tasks, which included ventilation, rotation and release of grain in the bins, had similar values to threshing (6.9 mg m$^{-3}$ and 8.0 mg m$^{-3}$, 9,100 and 13,300 EU m$^{-3}$ and 5,300,000 and 7,500,000 counts m$^{-3}$). Mechanical or pneumatic storage techniques had the highest values measured for these three agents.

Previously, Halstensen et al (2004) reported results for inhalable dust, fungal spores (Penicillium and Aspergillus) and OTA exposures at 84 Norwegian farms located in three geographical districts. The authors sought to identify exposure determinants associated with climate and production practices that lead to Ochratoxin A (OTA) contamination of grain from fungi. Samples of newly settled dust generated from the tasks being monitored were taken from surfaces by suction. The tasks included threshing (31 samples) and storage of grain dried at ambient temperature (40 samples) and with hot (28 samples) air. Fungal counts were determined in Czapek-Dox agar and expressed as CFU mg$^{-1}$. Personal air samples were collected for between 6 and 60 minutes for the above tasks and emptying bins.

In addition to the bulk sampling already described, personal inhalable dust monitoring was carried out for between 6 and 60 minutes for threshing (31 samples), storage of grain (34) and emptying storage bins (31 samples). The geometric mean inhalable dust exposure level was highest for emptying bins (p<0.001) at 7.5 mg m$^{-3}$ (range 1.1 to 110 mg m$^{-3}$), followed by storage at 5.9 mg m$^{-3}$ (range 1.1 to 32 mg m$^{-3}$) and was lowest for threshing at 1.2 mg m$^{-3}$ (range 0.2 to 15 mg m$^{-3}$). The dust exposure was reduced by 70% by placing a cab on the combine harvester but this difference had only marginal significance in the statistical analysis. Insufficient dust was collected for direct determination of OTA from these pumped samples. The authors used the OTA concentration measured in the bulk settled dust to estimate the following inhalable OTA exposure levels in air: 40 pg m$^{-3}$ (range 2 to 600 pg m$^{-3}$) for storage, 37 pg m$^{-3}$ (range 3 to 14,000 pg m$^{-3}$) for emptying bins and 4 pg m$^{-3}$ (range 0.6 to 200 pg m$^{-3}$) for threshing.

Fungal contaminations in settled grain dust were reported as an overall value and values for individual threshing and storage tasks. Median values of 40 CFU mg$^{-1}$ for Penicillium (range 0 to 32,000 CFU mg$^{-1}$) and zero CFU mg$^{-3}$ for Aspergillus (range 0 to 32,000 CFU mg$^{-1}$) were reported from all the measurements. Penicillium was the dominant fungi, detected in half the samples and Aspergillus was found in one fifth of the samples. Storage dust was reported as containing more Aspergillus (p<0.05) and Penicillium (p<0.01) than threshing dust. Median Aspergillus concentrations in both threshing and storage dust and Penicillium in threshing dust were zero CFU mg$^{-1}$. Penicillium concentrations rose to 40 CFU mg$^{-1}$ in storage dust. The maximum values of Aspergillus and Penicillium in threshing dust were 120 CFU mg$^{-1}$ and 4800 CFU mg$^{-1}$ and these values increased to 5300 CFU mg$^{-1}$ and 32000 CFU mg$^{-1}$ respectively in storage dust.
OTA (median concentration 4 µg kg\(^{-1}\) and range 2 to 128 µg kg\(^{-1}\)) was detected in every sample but only correlated with Penicillium (p<0.001). This was observed for all grain types, namely spring wheat, barley and oats and for 2 of the 3 districts occupied by the farms. A statistical comparison of OTA counts in settled dust showed that the difference in OTA contamination recorded for threshing and storage (median 3 µg kg\(^{-1}\) and maximum 13 µg kg\(^{-1}\) and median 4 µg kg\(^{-1}\) and maximum 128 µg kg\(^{-1}\) respectively) were not significant. No results were presented on fungi or OTA concentrations in dust collected after emptying bins.

Raised Penicillium contamination were found to be consistent with longer storage times in two districts (p>0.001) and OTA contamination increased with storage time (p=0.03) and closely with Penicillium concentration (p=0.001) for one type of barley. Drying the grain with hot air was the grain handling practice reported to produce grain with the highest OTA concentrations. The OTA concentrations in dust from hot air driers (median 5 µg kg\(^{-1}\)) were significantly (p=0.09) higher than the results from ambient driers (median 3 µg kg\(^{-1}\)). This trend was most pronounced for barley (p=0.02). The authors concluded that three findings (OTA concentrations were largely unchanged after storage, fungal growth in the field crop was related to weather conditions of higher rainfall and temperature and OTA was detected in threshing samples) supported the view that OTA was present in field grain. The reverse relationship was found for Penicillium. Higher concentrations were recorded for ambient air driers (80 CFU mg\(^{-1}\), range 0 CFU mg\(^{-1}\) to 4,400 CFU mg\(^{-1}\)) than for the hot air driers (40 CFU mg\(^{-1}\), range 0 to 32,200 CFU mg\(^{-1}\)). Penicillium and therefore OTA had been considered more likely to persist after ambient air drying, which takes weeks to complete. The higher concentrations of OTA in hot dried grain contradicted this. However the results would be consistent with priority drying of very wet grain and rapid growth of Penicillium in the threshed grain at the start of drying giving rise to high levels of OTA. This also explains the low concentrations of Aspergillus, which grows better in warmer climates.

It was found that wet and warm weather earlier in the growing season was linked (p<0.1 to p<0.05) to the OTA released from grain dust during threshing, while wet (to a lesser degree) and warm weather throughout the growing season was linked to higher Penicillium concentrations. OTA concentrations were also correlated with altitude for threshing samples but this was more consistent with the weather conditions. No such relationships between climactic conditions and OTA and Penicillium were seen for storage samples.

In this study about 25% of the operators were reported to wear respirators during dusty tasks but this was not detailed further.

Halstenen et al (2004) presented trichothecene mycotoxin concentrations in settled grain dust originating from barley (59 samples), spring wheat (13 samples) and oats (32 samples). Threshing (34 samples), storage (70 samples), drying (41 ambient air drier samples and 29 hot air drier samples) and mixing (11 manual mixing of grain and 59 mechanical/pneumatic mixing of grain) tasks were monitored in 92 Norwegian farms. Deoxynivalenol (DON) and HT-2 toxin (HT-2, precursor to T-2 toxin) concentrations were reported as µg of the trichothecene per kg of grain dust. Mean values of 31 µg kg\(^{-1}\), 62 µg kg\(^{-1}\) and 130 µg kg\(^{-1}\) were measured for DON, T-2 and HT-2 respectively over all the tasks.

Measurements made during the farm-based tasks of threshing, drying and mixing showed no DON was detected in dust recovered during threshing. The highest concentrations of DON were measured in dust from grain dried with hot air (33 µg kg\(^{-1}\)). The DON concentrations in the grain dust generated by the mechanical or pneumatic mixing grain (20 µg kg\(^{-1}\)) and storage (18 µg kg\(^{-1}\)) were the next highest recorded and the lowest concentrations were found for ambient air dried grain and manual mixing of grain (11 µg kg\(^{-1}\)). Threshing was however found to have the highest concentrations of HT-2 (70 µg kg\(^{-1}\)). Thereafter the values of HT-2, in
descending order, was similar to that found for DON namely: grain dried with hot air (65 µg kg⁻¹), mechanical or pneumatic mixing grain (58 µg kg⁻¹), storage (50 µg kg⁻¹), ambient air dried grain (41 µg kg⁻¹) and manual mixing of grain (35 µg kg⁻¹). The differences in concentrations in the grain dust were considered statistically significant for DON (p<0.05 for all but drier results which were p<0.01) but not for HT-2 except for those for the drier (p=0.1). DON concentrations were moderately related to storage time and strongly related to weather conditions (used in forecasting) linked to fungal infection, namely a day when the following weather conditions were met: maximum temperature of 17°C or above, minimum temperature of 10°C or above, noon-time relative humidity of at least 75 % or and at least 1 mm of rain. Concentrations of HT-2 were also related to the weather forecasting criteria described above but not to storage time.

Further studies by these researchers published in 2006 have looked at developing new analysis techniques for measuring Fusaria fungi at the species level and identifying, assessing and validating Fusaria DNA as indicators of exposure to mycotoxin.

In one study, the authors (Halstenen, 2006) looked at determining the relationship between the concentrations of Fusarium (quantified by measuring its DNA using semi-quantitative polymerase chain reaction, PCR, and by traditional cultivation methods) and different trichothocenes in settled grain dust samples collected during threshing (combine harvesting and carting) and storage (grain elevating and drying) on 92 Norwegian farms. A median concentration of 69 µg of trichothocenes (range 0 to 6000 µg kg⁻¹) per kg of settled dust was recorded and this rose to 73 µg kg⁻¹ when OTA results were included. The individual trichothocenes HT-2, T-2 and DON were found with overall median (above the limit of detection) concentrations of 114 µg kg⁻¹, 94 µg kg⁻¹ and 17 µg kg⁻¹. No mycotoxin contamination was reported using a task based approach. PCR analysis of settled dust showed that DNA of three species (Fusaria avenaceum, poae, and langsethiae) was present in most of the samples, DNA of Fusarium culmorum in just under half of the samples and DNA of Fusaria sporotrichoides and graminearm in only a few samples. Fusarium avenaceum was found to be the most abundant species in the dust but, as expected, did not give rise to any trichothocenes. Fusaria culmorum and graminearm, taken together, were found to correlate (p<0.01) with DON while Fusaria poae and particularly langsethiae were observed to show a strong association with HT-2 and T-2. It was noted that Fusarium graminearum, a known DON producer, could be under estimated by this technique because it tends to deteriorate prior to analysis. However this species is considered to be more significant in warmer climates than Great Britain.

In an earlier publication in 2006 real-time polymerase chain reaction with fluorgenic probes had been used to measure the concentrations of Fusaria avenaceum and langsethiae/sporotrichiodes DNA in the above samples, and on airborne grain dust samples (Halstenen, 2006). These results were related to trichothocenes concentrations for the settled dust results only. Settled dust showed the DNA of the three species was present in most (94%) of the samples. Just over half of the personal samples were positive for Fusaraia langsethiae DNA and 40% of these samples were positive for Fusarium culmorum avenaceum DNA. Fusarium avenaceum was found not to give rise to any trichothocenes. Settled dust contained more picograms of Fusarium DNA per milligram of dust than airborne dust. Estimates of these average DNA levels are made here from the paper’s graphed results. The average concentrations obtained for Fusarium avenaceum DNA and Fusarium langsethiae DNA in settled dust were about 100 pg mg⁻¹ and 0.5 pg mg⁻¹ respectively and for airborne dust were about 1 pg mg⁻¹ and 0.01 pg mg⁻¹. All measurements had broad ranges reaching up to 10⁵. Fusarium langsethiae DNA was observed to show a weak correlation (p<0.01) between the settled and airborne values and significant formation of HT-2 and T-2 was identified for this species. Airborne concentrations of mycotoxin could not be measured directly due to sampling issues and were not determined from settled dust measurements because
airborne Fusarium DNA concentrations obtained did not correlate with the settled dust concentrations.

Geng (2008) published the results of a pilot study amongst Swedish farmers handling grain (conference proceedings - not in a peer-reviewed journal). These data were collected on five farms and represent a mixture of task-based sampling and longer shift-length data. Information was also presented from measurements using real-time aerosol monitors. The moisture content of the grain varied between 12% and 16% and the work comprised loading or unloading of grain. Very high aerosol concentrations were measured with the direct reading monitor during cleaning a combine harvester with compressed air (230 mg m\(^{-3}\)) and while shovelling and sweeping grain (50 – 60 mg m\(^{-3}\)). The average endotoxin concentrations ranged from 18 ng m\(^{-3}\) to 1,000 ng m\(^{-3}\) (180 EU m\(^{-3}\) and 10,000 EU m\(^{-3}\)) depending on the farm, with the highest concentrations from a farm where dried grain was being loaded into a flat bed store. Total bacteria and fungi concentrations were each approximately 2 x 10\(^6\) m\(^{-3}\).

Lugauskas et al (2007) investigated how grain drying techniques could affect the level of fungal contamination in grain of over 16% water content. Graphed results for the in-field grain, the combine harvested grain and the grain prior to drying showed the fungi contamination increased steadily from 100 CFU g\(^{-1}\), to 150 CFU g\(^{-1}\) and lastly to 200 CFU g\(^{-1}\). One reason suggested for difference in fungal levels between field and harvested grain was that soil fungi are also drawn into the harvested grain during combine harvesting. The increased levels of fungi present in stored grain were associated with broken grains that had one third higher infection than intact grains. Shaft drying of grain with hot (usually above 75°C) air was reported to reduce the fungi concentrations by between 2 and 9 times that of the original value, around 8,000 CFU g\(^{-1}\) to under 1,000 CFU g\(^{-1}\) in some cases. Fungi contamination in ventilated barleys and non-ventilated wheat showed an increase after nearly 2 days drying.

Dominant fungi population i.e. made up over half cultured colonies fungi identified for wheat were Alternaria (as Alternaria alternata), Fusaria (as Fusaria culmorum, avenaceum and tricintum) and Penicillium (as Penicillium chrysogenum). DON concentrations in wheat had been reported by the Lithuanian Ministry of Agriculture to range from 32 µg kg\(^{-1}\) to 147 µg kg\(^{-1}\). Malting barley (18.7 % water content at intake) was found to contain Fusaria culmorum, clamydosporum and tricintum, Aspergillus and Bipolaris species while fodder barley was found to contain the same fungi as wheat but with no Penicillium. Aflatoxins (associated with Aspergillus flavus) and ochratoxins were also identified in barley.

Viet et al (2001) undertook a larger study into inhalable dust and endotoxin exposure in Colorado during wheat harvesting in 25 farms. A geometric mean inhalable dust concentration of 0.83 mg m\(^{-3}\) (range 0.09 to 15.33 mg m\(^{-3}\)) and total endotoxin concentration of 54.2 EU m\(^{-3}\) (range 4.4 to 744.4 EU m\(^{-3}\)) was measured by sampling 98 harvest operators for 6 hours or more. About 8 of these operators had exposure levels above 4 mg m\(^{-3}\). This was considered a poor harvest season. The correlation between the logarithms of inhalable and endotoxin mean exposures was r=0.69. This was considered to show that total dust measurements were a fairly good indicator of endotoxin exposure levels whereas humidity had no influence on either measurement. Some exposure data was presented graphically under separate task-related categories (Table 4.3) representative of tasks.
Table 4.3 Mean exposures for harvesting by job title, total number of samples =98

<table>
<thead>
<tr>
<th>Job title</th>
<th>Number of samples</th>
<th>Mean inhalable exposures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mg m⁻³</td>
</tr>
<tr>
<td>Harvesting with combine</td>
<td>NR</td>
<td>0.5</td>
</tr>
<tr>
<td>Truck</td>
<td>NR</td>
<td>1.2</td>
</tr>
<tr>
<td>Cart</td>
<td>NR</td>
<td>1.1</td>
</tr>
<tr>
<td>Auger</td>
<td>NR</td>
<td>1.5</td>
</tr>
<tr>
<td>Maintenance</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>1.5</td>
</tr>
</tbody>
</table>

NR = not reported

Although limited task related information was reported for these jobs (for example two operators wore disposable dust masks and two wore half face air-purifying respirators during dusty tasks like dumping wheat in to the auger but their exposures have not been reported separately) exposures to dust and endotoxin was reported as being significantly different between the tasks (p=0.005 and p=0.062 respectively). Combine harvester operators had the lowest dust and endotoxin exposure levels. This is consistent with harvester cabs being enclosed and ventilated and levels reported are less than half the exposure level measured in cabs by Phillips (1993). The endotoxin to dust ratio for harvesting was the highest of all the job categories. This was attributed to a lack of road dust contributing to the atmospheric dust in the fields and the presence of more small particles, likely to be rich in endotoxin, in the atmosphere of the cab. Maintenance and ‘other’ categories are not well defined in terms of the tasks making up these jobs but the number of samples was reported. However, blowing grain out of vehicles was highlighted as a contribution to the high exposure levels measured for these jobs. This presumably involved using compressed air to clean out settled dust from engines and radiators. The high exposures for the auger and truck operating tasks were experienced by more operators but numbers were not given.

4.5.2 Grain Delivery Tasks

Spaan et al (2008) describe an analysis of a very large dataset of endotoxin and inhalable dust measurements from 46 industrial sectors in the Netherlands. These data were collected in a number of different studies between 1991 and 2006, with slightly different study protocols in each case. The mean sampling time was 7.2 hours with 99% of the samples collected over more than 4 hours. Despite the large dataset there were only a small number of measurements relevant to grain dust: three in harvesting, two from cereal seed and 19 in trans-shipment of grain; only the latter data are discussed further here. The geometric mean inhalable dust level was 6.7 mg m⁻³ (range 0.77 – 98 mg m⁻³) and the corresponding data for endotoxin exposure levels was 2,150 EU m⁻³ (110 – 130,000 EU m⁻³). The correlation between the inhalable and endotoxin exposures was 0.79, which was statistically significant (p<0.05).

This study showed that for broadly defined industry sectors, e.g. grain, seeds, and legumes or animal production, the between worker variance component was larger than the within worker component for both inhalable dust and endotoxin. The authors identified that the dustiness of the material handled, contact with animals, bulk production, presence of plant material and cyclic processes mostly explained differences between workers. There was more variability between workers for endotoxin measurements compared with inhalable dust exposures, which was attributed to variations in factors that promote the growth of bacterial contamination.
4.5.3 Milling Related Tasks

Meijster et al (2007) presented results for airborne dust exposure for flour millers amongst data for workers exposed to flour dust in bakeries and other situations. These data cover 154 measurements at 7 mills and they represent full-shift samples (4 to 10 hours). The geometric mean inhalable dust level was 2.7 mg m$^{-3}$ with a range 0.2 to 1,800 mg m$^{-3}$ (geometric standard deviation, GSD = 4.5).

Karpinski (2003) presented inhalable dust results from 113 personal samples taken at 15 flour mills in Canada. One of these mills was a highly automated plant and 9 samples were taken there on 5 operators (Table 4.4). The results were reported according to exposure groups. This is considered to be as close to a task-based sampling approach as is reported in the literature. The highest individual exposure level determined was for a cleaning task classified under exposure group ‘Other’. This is described as a non-routine task, the ‘cleaning operation of a vacuum system’, which was carried out only as needed on one of the maintenance days. Tasks described as ‘Chokes’, presumably meaning manual clearing blockages by ‘Others’, were also cited as dusty. Bakery mix operators had the highest reported geometric mean exposure level followed by ‘Other’ and Packers. No further task details were reported for ‘Others’ or for Bakery mix tasks associated with the highest exposures in the mills. The second highest single level recorded was for a packing operator and this was put down to the dust generated from the packing machine being used. Observed leakage around and spillage from the nozzle of the packing machine were also attributed to high exposures of dust measured for Packers. The geometric mean exposure of sweepers using compressed air (4 mills) for cleaning purposes was 17 mg m$^{-3}$ (range 9.6 to 27 mg m$^{-3}$) and was 2.5 mg m$^{-3}$ (range 1 to 4.7 mg m$^{-3}$) when compressed air was not used (5 mills). In the highly automated mill the ‘Other’ classification represented a flour process operator working largely in a control room and they had the lowest exposure measured across all 15 mills. One miller and two sweepers had exposures measured for a full 12-hour shift at this mill. This would be equivalent to 8-hour TWA geometric mean concentrations of 2.2 mg m$^{-3}$ and 4.4 mg m$^{-3}$ respectively. These data suggest an opportunity for a 2 fold reduction in millers’ and a 27 fold reduction in ‘others’ exposure levels on moving to more automated plant. However, little reduction in exposure appeared achievable for sweepers working in the more automated plant.
Table 4.4  Personal inhalable dust exposures for milling reported by Karpinski in 2003

<table>
<thead>
<tr>
<th>Exposure group</th>
<th>Number of samples</th>
<th>Inhalable exposures</th>
<th>Geometric mean (range)</th>
<th>Geometric standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millers</td>
<td>23</td>
<td>5.1 (0.9 to 25)</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Miller*</td>
<td>1</td>
<td>1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miller**</td>
<td>1</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packers</td>
<td>41</td>
<td>9.0 (0.5 to 250)</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Sweepers</td>
<td>27</td>
<td>4.8 (below detection limit to 27)</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>Sweepers**</td>
<td>2</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bakery mix operator</td>
<td>4</td>
<td>13 (5.3 to 22)</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
<td>11</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>Other*</td>
<td>1</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 8-hour TWA exposure measurements at the highly automated mill
** 12-hour TWA exposure measurements at highly automated mill

Dacarro et al (2005) collected static task-based (storage, cleaning, grinding, filling and laboratory) and personal (loading/unloading) exposure measurements to determine inhalable dust, respirable dust, bacteria and fungi in an Italian grain mill. Dust samples were taken over a 4-hour period and control samples were taken 200 m away in the car park outside the mill.

Inhalable and respirable dust exposure levels were low for tasks and personal exposure (Table 4.5). One personal sample was taken on a loading/unloading operator who worked throughout the plant. The results show that tasks associated with the cleaning unit generate the most dust and concentrations measured at the other sampling points were less than 1 mg m$^{-3}$. The term ‘cleaning unit’ is presumed to mean operation of a grain cleaning machine but this is open to other interpretations.
Bacterial data were presented separately for mesophilic and psychrophilic bacteria cultured together in the same (carbon rich tryptone soya agar, TSA) medium and for psychrophilic bacteria cultured on its own in a different (carbon poor R24) medium. Fungal counts were determined in Sabouraud dextrose agar (Oxoid) and expressed in CFU m$^{-3}$ of total moulds and by genus, Aspergillus, Penicillium, Cladosporium, Botrytis and Epiococcum. The average concentrations of psychrophilic bacteria, when cultured alone, were higher than those cultured along with mesophilic bacteria.

All storage unit and laboratory measurements were lower than the control measurements taken outside in the car park. All measurements had very large standard deviation values. However from a one way analysis of variance (ANOVA) using an F-test, mean airborne mesophilic bacteria concentrations measured for the cleaning unit (1,491 CFU m$^{-3}$) were found to be significantly higher than the mean values for the grinding unit (414 CFU m$^{-3}$), the filling unit (352 CFU m$^{-3}$), the storage unit (166 CFU m$^{-3}$), the laboratory (108 CFU m$^{-3}$) and outside (638 CFU m$^{-3}$). The mean level of 7,236 CFU m$^{-3}$ for similarly cultured psychrophilic bacteria was found to be only significantly greater than the mean value of for the storage unit and for the laboratory (779 CFU m$^{-3}$ and 282 CFU m$^{-3}$). The mean 1,607 CFU m$^{-3}$ and the 1,291 CFU m$^{-3}$ mesophilic bacteria concentrations measured for the grinding and filling unit respectively were not considered to be significantly different to those measured for the cleaning unit given the large measurement range.

Maximum values for psychrophilic bacteria cultured in both mediums, measured over the highest detection limit of 52,280 CFU m$^{-3}$ for the cleaning unit. However in each of three analyses for bacteria and the results for fungi, the outdoor concentrations were higher than the storage and laboratory (all) and the filling unit (Mesophilic bacteria). Operators were exposed to over 1,000 CFU m$^{-3}$ of fungi and over at least 10,000 CFU m$^{-3}$ bacteria from dust generated by the cleaning unit. The variance of bacterial and fungal measurements was considered to result from differential diffusion of bacterial through the workplace atmosphere rather than from measurement errors.

The total mould concentrations followed the same measurement trend as the bacteria in the Dacarro et al study. The greatest mean value was for the cleaning unit (1,992 CFU m$^{-3}$, range 180 to 13,050). The grinding and filling units were next highest (779 CFU m$^{-3}$ and 755 CFU m$^{-3}$).
and the storage unit and the lab were the lowest (236 CFU m$^{-3}$ and 183 CFU m$^{-3}$). The highest value for the cleaning unit was found in the winter (5,365 CFU m$^{-3}$). Aspergillus was present only in the storage, cleaning and grinding units at the lowest concentrations recorded for the fungi (2.5 CFU m$^{-3}$, 5.0 CFU m$^{-3}$ and 7.5 CFU m$^{-3}$ respectively). Cladosporium had the largest mean CFU m$^{-3}$ concentrations for all the tasks of all the fungi types. These were highest in the filling, cleaning and grinding units (677 CFU m$^{-3}$, 576 CFU m$^{-3}$ and 550 CFU m$^{-3}$) and lowest in storage and the laboratory (152 CFU m$^{-3}$ and 98 CFU m$^{-3}$). Pencillium recorded much lower concentrations in the storage, cleaning and grinding units (48.6 CFU m$^{-3}$, 47.5 CFU m$^{-3}$ and 35.0 CFU m$^{-3}$), which dropped further in the filling unit and the laboratory (25 CFU m$^{-3}$ and 10 CFU m$^{-3}$). All other measurements were 40 CFU m$^{-3}$ or below apart from the outside measurements for Cladosporium (569 CFU m$^{-3}$ cleaning and filling values are higher), Botrytis (60 CFU m$^{-3}$, highest value after that for filling unit with 75 CFU m$^{-3}$) and Epicoccum (68 CFU m$^{-3}$).

### 4.5.4 Storage Depot Tasks

Two Indian studies (Krysinska-Traczyk et al., 2007; Chattopadhyay et al., 2007) focused on ‘godowns’, which are central processing and storage facilities for many types of grain. Chattopadhyay sampled static inhalable dust, respirable dust and fungal spore concentrations inside and outside flat-bed stores holding sacks of grain. The inhalable and respirable mean dust exposure levels were 2.7 mg m$^{-3}$ (standard deviation taken to be 1.9 mg m$^{-3}$) and 1.8 mg m$^{-3}$ (standard deviation taken to be 0.6 mg m$^{-3}$), respectively. Total spore concentrations were found to be lower outside the godown compared to inside and also greater in winter (27 to 31°C) than in summer (34 to 38°C). The highest spore concentrations recorded in summer (from 12 warehouses) is 506.9 (standard deviation taken to be 999.7 and range 8 to 3150) as number m$^{-3}$ while in winter was 600 m$^{-3}$ (standard deviation taken to be 1127.1 m$^{-3}$ and range 33 m$^{-3}$ to 3732 m$^{-3}$ ) as number m$^{-3}$. There were five (Aspergilla, Alternia, Curvulari, Drechslera, Epicocum, Nigrospora and Periconia) major fungal species identified and an additional one (Cladosporium), which was only found in summer.

Krysinska-Traczyk took two personal samples at 5 farms, a grain mill and 6 godowns, one of which dealt with wheat. Cleaning of wheat grain at godowns was found to have airborne microorganism concentrations of 54,000 CFU m$^{-3}$ and was made up of almost half bacteria and half fungi and low concentrations of Fusarium. The highest dust and endotoxin concentrations (257.5 mg m$^{-3}$ and 1,250,000 EU m$^{-3}$) were recorded at a godown. Harvesting at three of the farms had dust exposure levels of 7.5 mg m$^{-3}$ and below and these represented the lowest dust levels. The mill has the second highest dust level but a very low endotoxin level.
5 RESULTS FROM INDUSTRY SURVEYS

5.1 INTRODUCTION

New exposure information collected via the telephone survey and during site visits includes, direct measurement of airborne dust concentrations, estimates of task frequency and duration, throughput rates and processing time and capacity. Work practices, including processing and protective equipment used were also observed and accounts of work practices recorded. The information gathered from both rounds of the study is presented together. Flow diagrams have been prepared to show the sequencing of tasks and material flows within each sector’s production line. This applies the same assumptions as used in Figure 1.1 and identifies which operators’ carry out which tasks.

Most of the industry sectors (commercial grain storage by a merchant, wheat milling, barley malting and animal feed milling) have a number of similar tasks in their processing techniques. The survey findings for two of these ‘generic’ tasks will be presented in Section 5.4 (Intake) and 5.9 (Outloading). The sector-specific information gathered is presented in Sections 5.2, 5.3 and 5.5 to 5.8. The bulk of the information obtained during the study is on flour milling and barley malting. These findings will be presented in Sections 5.7 and 5.8.

Respirators were widely available throughout the industry and we describe their use in each section below. Only a few companies have undertaken face fit tests for wearers of respiratory protective equipment used by their employees. Many organisations approached in this project knew they should have their operators fit-tested and are in the process of scheduling these tests. However, it was not clear whether their contract workers (e.g. silo cleaners, cleaners and grain hauliers) would also be included in this assessment and what other routine arrangements were made for these workers to be supervised in their use of respiratory protection when coming on site.

5.2 GRAIN IMPORT/EXPORT (PORT SERVICES)

Neither of the larger port authorities approached participated in the study. One of the two grain importers who were involved in the study would more correctly be classified as a stevedore as the company loads and unloads all types of cargo, not exclusively grain. There was no grain storage on the company’s premises because no store could be dedicated to this task. All imported grain was taken directly by lorry to a merchant or processors’ store.

Grain docks are typically manned by two to four (if there are stores to run) outside operators and they wear helmet respirators for any dusty work. Most operators are multi-skilled. They load (tasks 3 and 4 in Figure 5.1 and Section 5.2.2) and unload (tasks 7 to 11 in Figure 5.1 and Section 5.2.3) cargo ships, fill and empty quayside storage facilities (if they have them) (tasks 8, 10 and 11 in figure 5.1 and Section 5.2.3) and clean premises and plant (Section 5.2.4). Operators must be licensed to drive certain vehicles such as forklift trucks, trucks and cranes. There is usually one or two inside operators working in the weighbridge and laboratory and extra laboratory staff at harvest time. Some docks operate and equip a labour pool and a crane (with crane driver) and lorries (with drivers) can be hired by the grain importer when needed for this sort of work. Any (grain) insecticide application is carried out by a contracted company.
Small to medium sized importers would have about three working berths at the docks and this was the case for the importers interviewed and visited. In the case of the stevedore two were next to each other on the near side and the one for loading grain was on the far side of the water. This positioning of the berths had reduced complaints about airborne dust spreading outside the premises during grain handling.
Dust masks, high visibility jackets, gloves and protective footwear are supplied to outside operators. Dust masks (typically P2-type or helmet respirators) are worn for dusty tasks.

5.2.1 Intake

Typically there are two employees in the office operating the weighbridge and the laboratory, if there is on-site testing. Sampling is carried out on incoming and outgoing grain with an automatic sampler at the weighbridge. The sample is ground to a powder to measure the moisture content and the sample is sieved for a visual inspection. If the moisture test result is above 17% then the batch is rejected and sent back to the farm to be conditioned again or a new contract is negotiated. Ideally moisture content should be no more than 15%. The driver is then directed to tip the grain into a hopper for loading onto the ship. An independent cargo superintendent is present during the loading to check the grain quality, ensure that the elevator and ship are clean and that no extraneous materials are pulled through the hatch and into the hold when it is closed. Otherwise the grain will be tipped into the store. Exposure would be considered low where sampling is done automatically, the office is air conditioned and the grain sample is tested and disposed of carefully. No dust masks are used here.

5.2.2 Loading ships’ cargo

Because ports are in the open air, wind can create airborne dust during loading or unloading of grain. If the wind direction and speed are causing too much dust to become airborne during loading, the process is postponed. In routine loading and unloading of grain outside, workers reportedly stand upwind and away from any dust clouds that form and wear dust masks as felt necessary.

These docks use mobile electrically powered grain elevators for loading grain into the ship’s cargo hold and cranes for unloading grain cargo (Figure 5.2).

![Figure 5.2 Typical dockside plant used by the importer/exporter](image)

The lorry tips its load through its grain hatch into the hopper (Figure 5.3) on one end of the elevator (Figure 5.4).
The elevator arms are covered over with sheeting to minimise airborne dust generation when the grain is being transferred along the belt and into the ship’s hold (Figure 5.5). This is not fully enclosed because of the danger of the grain igniting and catching fire.
Export wheat is sprayed with pesticides on the elevator belt while loading takes place. Routine blood tests need to be taken on operators undertaking this work and at the site visited in-house staff did not do this task. A contractor’s truck with the pesticides was used to spray loading wheat using a dispensing nozzle above the conveyor belt. The contractor remained inside the cab during the spraying and wore a dust mask when carrying out the task. The grain cargo is treated with phosphine gas in the hold if shipping takes more than about 5 days to complete. A contractor carries out this task. The cargo is added after checking the ‘gas’ tightness of the ship’s hold. Sealed sachets containing aluminium phosphide are dropped into the load. These sachets open when the cargo is sealed and release phosphine gas that percolates through the grain shipment. The sachets are retrieved at the port of arrival. Quayside exposure monitoring for phosphine has been carried out by the company visited, although data were not made available for this study.

### 5.2.3 Unloading and storing ships’ cargo

Cranes fitted with clam-shell grabs are used for discharge at the docks visited. The grain is scooped up in the clam-shell and dropped through a hopper into an open topped lorry. These grabs can lift almost 5 tonnes of grain. It takes about 1.5 days to unload 2,500 tonnes of grain from a ship. The grabs tend not to be dusty but can cause spillage. Operators sweep this up as they carry out the task. Unloading grain onto the ground at quayside is avoided because it devalues the grain consignment. All equipment is kept outside.

The grain going into store from ships is loaded onto lorries at the dockside, driven into the shed and tipped. The shovel lorry, fitted with a blade or bucket, is used to push the grain into a pile (Figure 5.6).
The grain is normally stored for an average of 6 weeks and is dusty when it comes out of store. A shovel lorry fitted with a bucket (5 m$^3$) is used to fill the lorry. Operators wear a disposable filtering facepiece respirator (P2 type) during this task and move outside when it gets too dusty. Diatomaceous earth is used on some premises to treat local infestation of insects. The material is sprinkled on top of the grain and dug in. Usage rate is about 3 kg m$^{-2}$.

5.2.4 Cleaning plant and premises

All outside operators carry out the cleaning tasks described below.

The elevators are cleaned with water between ship loads using high pressure hoses. This takes one man an hour to complete. Alternatively, they can be steam cleaned by holding the cleaner against the elevator belt and switching it on. This takes about half an hour. Cleaning removes any seeds trapped in the mechanism and bird droppings. The shovel lorry is steam cleaned once a week.

Large storage sheds are rarely completely empty. About one third of the store will be cleaned every year. At the site interviewed, wet washing using a water jet was discontinued because it was messy to clean up afterwards. Brushes are used to sweep down the walls and floors. During this task operators are suited up in white dust boiler suits, goggles and half-face disposable respirators. Full-face positive pressure respirators were tried but workers found them difficult to wear while undertaking this task. Disposable half-face (P2 type) respirators are issued three times each day.

5.3 FARMS

Six farms have been involved in the study. One is a pilot project farm of about 600 acres and the other five are privately owned working farms of around 1000 acres in size.

The pilot project farm runs trials on new crops and farming practices and provides agricultural testing and information services to farmers. The pilot farm is staffed by four people but usually only one person works the drier at a time. Another farm operator brings the grain from the field and the lorry driver comes at unloading to pick up the grain for the purchaser.
The working farms are operated by the farmer together with one full time and one seasonal or part-time farm worker employed full time at harvest time. According to the interviewees, crops harvested with a combine make up between 50 and 75% of the total acreage. The remainder of the land produces non-food use crops such as oil seed rape, seed crops and root crops.

Drying techniques used on farms and in grain merchants’ depots are described in Appendix 3.

Figure 5.7 shows some of the important tasks carried out on an arable farm on a yearly cycle. The first cultivation stage comprises tillage and ploughing and sowing the seed (task 1). Winter wheat is sown in autumn or winter and harvested the following summer. Spring wheat is sown in spring and reaches maturity quicker than winter wheat. It is planted in areas that have hard winters. Seeds sown in the winter can be brought back to the surface by frost and the ensuing exposure to cold weather kills spring wheat seed. The production season includes growing winter wheat and barley (task 2) and spraying the field crop with nitrogen fertilisers in the spring and herbicides, fungicides, phosphate fertilisers and sulphur in the autumn (task 3).

Harvesting the grain takes place from about mid July to mid September. It lasts for about 14-21 days in total. This is made up of harvesting the grain in the field and of yard work, namely drying and storing the grain in the farm premises.

Field harvesting is represented by task 4 in Figure 5.7. This is carried out by two operators, one driving the combine harvester and the other carting, driving the tractor and trailer. This task is discussed in Section 5.3.1.

Although the field grain has reached its lowest moisture content at maturation, it can be damp following wet weather and so usually needs drying. This gives rise to a number of wet grain drying and dry grain handling and management tasks (tasks 5 to 9 in Figure 5.7). These are discussed in Section 5.3.2. Malting barley is accepted by the market at around 17% moisture whereas winter wheat has to be below 15% moisture. Some malting barley will be uplifted without drying but is dried if the moisture content is around 21% or more.

Harvesting the crop in the field may not take place on consecutive days because of delays brought about by bad weather conditions. When field harvesting is delayed during the harvest season or large amounts of stock piled grain have to be dried, then operators may be switched between tasks and the allocation of manpower to task may not be that shown in Figure 5.7.
Figure 5.7 Summary of farm tasks carried out annually and harvest tasks (4-8)

5.3.1 Field harvesting

Harvesting (task 4) can be broken down into the field work (combine harvesting the crop and discharging grain from the combine harvester to the trailer) (Figure 5.8) and transfer work (carting or hauling the trailer back to the farm to the intake area).
The combine harvester will be in use for about 200 hours in an average harvest period of between 10 and 14 days and can harvest over 300 tonnes a day using a large harvester. About 50 acres would be harvested per day. A medium sized combine harvester can hold 3.5 tonnes of grain in its tank and fills about half hourly. The grain is emptied from the tank into a 14 tonne trailer pulled by a tractor (Figure 5.8). This can be done when the vehicles are moving or parked. During combining and transferring both drivers sit in air conditioned cabs.

The transferred grain is then tipped into the intake pit and any excess grain is tipped into a wet grain store or onto concreted part of the yard. The grain is released automatically from the cab and it takes 2 to 5 minutes to empty the cart. This process can generate a dusty backdraught but the operator works from the cab during this task.

5.3.2 Drying and managing grain in the farm yard

Grain carted from the field is often temporarily stored prior to drying undercover in a wet grain store or stockpiled outside in open piles. This means that (farm-based) conveying and drying of wet grain and conveying of dried grain into longer term storage can carry on independently of harvesting while wet grain stocks last. These and other tasks described below (Sections 5.3.2.1 to 5.3.2.5) are routinely undertaken by one operator (the farm owner) throughout the day during grain drying and sending to storage. They are usually of short duration with the maximum time of 20 minutes being spent on preparing the shed.
Drying involves drawing warm air through a moving (continuous tower drying shown in Figure 5.10 and continuous belt drying in Figure 5.11) or stationary (batch or bin drying) bed of grain in order to remove the water without igniting the grain.

![Tower grain drier](image1)

**Figure 5.10** Tower grain drier

![Belt grain drier](image2)

**Figure 5.11** Belt grain drier

Usually the drier is run for 12 hours a day or longer (up to 18 hours) when there is grain to dry. The dust and chaff from the exhausted air is collected in a trailer, a shed or outside and removed at the end of harvest. This is operated from a control room. It can take about 30 days to dry the harvest. Drying capacity ranges between about 10 and 20 tonnes per hour. About 200 tonnes can be dried in a day but this drops to about 50 tonnes if the grain is wet. During the harvest season the drier is not cleaned out. At the end of the harvest season the drier is run empty to blow out any debris and the residuals are vacuumed out with an industrial vacuum cleaner. Every farm visited was equipped with a vacuum cleaner for cleaning the plant.

### 5.3.3 Transferring wet grain

Stored or stockpiled wet grain is shovelled to the intake pit using a bucket loader. This takes place about once or twice an hour and lasts about 10 minutes. The cab of the loader is air conditioned but often the windows were open during this short task.

The pile of grain falls through the grid onto the auger where it is aspirated into the elevator and then to the top of the drier. The dried grain passing out of the bottom of the drier is lifted by an
elevator into the dry grain storage. Grain is typically stored in flat bed stores or sheds. Intermediate temporary bins are used after batch drying prior to the grain going into long term (shed) storage. The different drying techniques used on farms and in grain merchant depots are considered in more detail in Appendix 3.

5.3.4 Testing during drying

Each farm visited had a control room where the grain is routed through the drier remotely and the temperature and transfer or dump times are set. Every half hour the grain was moisture tested in the control room. The grain was sampled by hand from a port in the drier and hand ground and moisture measured in a portable ‘Protimer’ instrument.

5.3.5 Conveying dry drain

Overhead conveyors are used to transfer the grain from the drier to the shed for storage. The sheds can vary in area and shape but are generally around 750 m². One of the farms visited had closer to 1000 m² of storage space. Grain is stored and managed in a number of different piles in the same shed.

This transfer rate is set in the control room and there is a continuous delivery or intermittent dumping (releasing grain for 1 minute out of every 2 minutes) grain to the shed. Chain and flight conveyors are enclosed and have fixed openings points for the grain that slide open to release the grain into the store. This requires the use of an auger if the discharged grain is to be moved to a different area of the store. The auger is manually placed in the correct position to transfer grain from the drop point to an empty part of the shed. With a belt overhead conveyor a ‘bogey’ runs along the length of the belt and can be stopped at any point where grain is to be stockpiled. The grain drops through the air onto the centre of the pile and the grain flows down the sides of the pile as the peak in the centre rises higher.

This conveying is operated from the control room and the bogey position is set remotely with a hand held or wall mounted control panel. Therefore the operator is not usually in the shed at this time unless the floor is being swept or grain is being moved into or around in the shed.

Edges are swept manually with a brush to put any loose grain back into the pile. This takes around 3 minutes. Larger shed areas are often swept with a hand pushed mechanised power sweeper. Workers wear a FFP3 respirator while undertaking this task.

5.3.6 Storing dry grain

Stored grain is ventilated by extracting air through the grain piles in order to maintain the temperature inside the storage warehouse between 10°C and 15°C. The air flows out naturally or is pumped out of the pile through ventilation tubes or pedestals. These are manually placed on the floor of the empty shed and the dry grain is shovelled (this takes about twenty minutes) (Figure 5.12) or conveyed round them in the shed (Figure 5.13).

Fans placed in the open end are switched on in sheds at night and these motors are moved from one ventilation tube to another. This inhibits the grain respiratory and germination processes thus avoiding the absorption of oxygen and generation of heat, carbon dioxide and water production leading to the loss of product weight and quality (softening by the water).
5.3.7 Unchoking plant

Grain elevators, unlike conveyors, are always enclosed. When these get chocked up with grain they have to be manually unblocked to get the grain flowing through the system again. This involves opening up a hatch in the elevator walls and releasing the grain out onto the floor. The moving column of grain generates rising dust therefore a mask is worn during this task. The task takes about 2 minutes to complete. Vacuum cleaners are also used to clear blockages.

5.3.8 Cleaning plant and premises

The front of the combine harvester has a rake system to lift any flattened stalks off the ground, a reciprocating blade to cut the grain, a rotating wheel to lift the cut grain into the auger that conveys the grain into the threshing drums. Threshing dislodges the seeds from the heads and the sieves separate the chaff and the grain from the straw and then the chaff from the grain. The straw and chaff falls out the end of the combine. Straw spreaders lay out the straw ready for baling. A trap for capturing stones and other foreign material is usually positioned under the drivers’ seat. This is emptied daily.

The combine harvesters’ engine is positioned behind the cab. The cabs of farm vehicles including combine harvesters, tractors and front loaders are fitted with air filters and air
conditioned cabs. Filters are typically changed after few hundred hours of work. The cabs are fitted with on-board computers that can adjust the machine parameters and carry out in-line monitoring of grain moisture content. Remote cleaning of the fan and sieves is carried from the cab. Each day after harvesting the fan and the sieves are opened up and blown out. Cabs of other vehicles are often blown out daily with compressed air. The combine harvester is usually power washed at the end of the harvesting season.

5.4 INTAKE

The basic tasks of an intake department are:

- receiving grain at around 14% moisture by a mill and higher by a malting house (maltings) or central store;
- giving the grain a preliminary clean; and
- intermediate storing of grain.

The pre-cleaned raw material will be held in intake bins until it is sent for by the mill or malting house (on-site) or sent off-site by the grain merchant to the customer, usually a mill or maltings. Over 20 lorries a day come through the intake and more during harvest time.

Figure 5.14 shows the tasks involved in the intake of the grain. Grain merchant depots’ intakes carry out all these tasks including drying, which is the basis of their processing.

A maximum of two people undertake this work, namely the lorry driver (tasks 1 to 4) and an intake operator (task 1 and tasks 5 to 9). Occasionally process operators carry out the intake duties as well as the milling or malting. The lorry driver will either be employed by a separate road haulage company or drive one of the company’s fleet vehicles. Intakes are normally made during the day shift and operate for 5 days a week, although many of the intakes operate extended hours during the harvesting period.

Section 5.4.1 describes the lorry drivers’ and Section 5.4.2 describes the intake operators’ tasks and likely exposures. The grain sampling is carried out automatically at intake and the sample is conveyed to the laboratory for multiple testing for compliance and quality testing for invoicing.
1) Weighbridge
Tare weight & samples taken automatically

2) Park
Awaiting sample test and authority to tip

3) Tip load into intake pit

4) Scrape last of load from lorry

5) Transfer Elevator & conveyor

6) Store raw grain

7) Transfer Elevator & conveyor

8) Preliminary clean

9) Drying

10) Store dirty grain

Figure 5.14 Grain intaking tasks
5.4.1 Lorry drivers’ tasks

The lorry driver takes the covered lorry onto the weighbridge and the grain stock is weighed and sampled remotely with a pneumatic ‘spear’ sampler (Figure 5.15).

![Figure 5.15 Spear sample for collecting grain](image)

Multiple samples of a load are often taken and these are conveyed automatically to the laboratory. Laboratory testing of the grain takes between 10 and 30 minutes and if the load is accepted then the lorry will proceed to the pit to tip the load.

There can be up to three tipping points at any one site where a lorry can discharge its load. The front end of the lorry is hydraulically lifted and the grain slides out through the back end. The load is discharged though a dust sock. One end of the sock is fitted to the grain hatch (Figure 5.16) at the back of the lorry while the other end sits on the mouth of the grain pit (Figure 5.17).

![Figure 5.16 Grain hatch at the back of a delivery lorry](image)
The dust sock is designed to flood feed a ‘solid’ column of grain into the pit. The transfer is not generally dusty except sometimes at the start and finish of tipping. Lorries are not permitted to open the tailgate and empty the load by tipping it out over the entire width of the lorry. Tipping can take anywhere between 20 minutes and 70 minutes, depending on the grain transfer system that is in place to elevate and convey the grain from the pit and into the holding bins. A load is usually 28 tonnes.

While the load is tipping the driver stays away from the pit. Drivers tend to sit in the cabs or move up-wind of the pit if they are standing outside. Dust masks (usually P3 type) should be worn during the scraping out of the tailings from the inside of the lorry. On one occasion observed during a site visit the pit was fitted with slit extract ventilation along the sides in order to remove dust at the entry to the pit (Figure 5.18).

The last remnants of the load, about a tonne, are manually scraped from the corners and edges of the inside of the lorry by the driver, which takes about 5 to 10 minutes. The driver is supposed to wear a half face piece respirator during this task, although we have no confirmation that this is always done.
5.4.2 The intake operators' tasks

There is continual movement of the raw grain out of the pit and into the storage bins or sheds using augers, elevators and conveyors. These are aspirated and so operate under negative pressure in order to uplift any light material that is disturbed when moving the grain stream. This is known as air handling and these processes are enclosed. The grain is transferred again in a similar way through a preliminary cleaner to remove farm debris and cleaned again on the malting or milling side before being stored in holding bins prior to processing.

This is largely an automated process where the intake operator routes the grain streams through the transfer system using a computer in a control room.

The situation is different when storing the pre-cleaned dirty grain in flat bed stores or sheds. Grain is transported into these sheds by roof-mounted overhead conveyors. There are openings along the length of the conveyor through which the grain can be dropped onto the shed floor. A front end loader fitted with a blade is then used to push the grain up into a stockpile. The floors of these sheds are often fitted with floor level ventilating tubes and ceiling level extractor fans which circulate the air and keep the grain cool. This task and the emptying of the store using a forklift truck, fitted with a bucket, to load the lorries can be dusty and operators generally wear half-face piece disposable respirators (P3 type).

5.4.3 Laboratory Testing – Sampling and Analysis

Sampling is done on the whole grain in the lorry at the mill or maltings intake, on the flour process at various stages in the mill and as the malt is put into a silo as it leaves the kiln.

There are usually one or two laboratory employees. However in the harvest season temporary staff (often university students) may be recruited to help with the increased intake deliveries. Laboratory staff commented that the laboratory atmosphere can become quite dusty during busy periods.

A sampling spear dips into the lorry load and uses suction to convey the sample to the laboratory. It is delivered into a hopper, usually located in the laboratory, and then emptied into a bag or bucket (Figure 5.19).

![Figure 5.19 Laboratory hopper which receives grain from sampling spear](image)

The incoming grain is tested for moisture, protein, α-amylase and mycotoxin such as deoxynivalenol, (DON). The wheat is accepted and graded or rejected altogether and either
returned or sold on the basis of these results of these tests. Rejection rarely happens because contamination with mycotoxin is rarely a problem.

For wheat, wet test tube scale Hagberg analysis for $\alpha$-amylase is carried out on a ground subsample. This requires preparation of a sub-sample by hand sieving and grinding the wheat. At one site visited the laboratory grinding machines had been moved into a fume cupboard to reduce dust emissions into the laboratory. The wheat left over after testing is usually thrown out in a laboratory bin emptied at the end of the day. Instrumental (near Infra Red spectroscopy) testing of water and protein and kit testing of DON are routinely carried out in the laboratories. There are many other tests that are carried out of which sieving of the sample to visually check for insect infestation is the simplest.

Direct monitoring of the mill stock is carried out to check that the moisture and protein levels are within the target values. This continuous sampling and analysis and immediate display of results on a screen in the mill control room is carried out by a commercially available on-line measurement and control unit. This allows the miller to automatically add appropriate ingredients such as gluten in order to raise the protein content of the flour. This is complemented by manual collection of the flour samples. These samples are taken automatically at preselected intervals during hourly production and uplifted by a technician for laboratory analysis.

5.5 COMMERCIAL GRAIN STORAGE

In recent years there has been a contraction in the number of small independent companies trading in the merchanting sector of the grain industry. This has happened as a result of the large commodity producing companies becoming involved in sourcing (locally and from overseas) and off-site storing of raw grain. This is in addition to their traditional role of processing and manufacturing the finished product. It has also led to farmer owned co-operatives buying and selling grain via central marketing and storing systems. Openfield, formed in 2008 when Centaur and Grain Farmers joined forces, is a marketing agent for a number of large-scale farmer owned merchanting/storage sites around the country. It handles about 4 million tonnes of grain annually.

This section discusses the tasks of the grain merchants and importers in their grain processing and handling operations (Figure 5.20). Grain is stored carefully in order to avoid damage which might adversely affect its quality and therefore its value. Large grain merchants, such as the two visited, employ seasonal staff to deal with large intakes of grain during harvesting. This means that the number of personnel working in the depot can rise to 6 outside operators and 4 in the laboratory. About 45,000 tonnes of grain is handled at these depots annually.

One operator mans the weighbridge and intake area (Section 5.5.1). The other outside workers are involved in working from the control room, working in the drier sheds (Sections 5.5.2), trucking grain from one shed to another, monitoring the stored grain (Section 5.5.3), and cleaning and maintaining (engineering and welding) the plant and premises (Section 5.5.4). During harvest time a night shift is worked and the operators take turns working that shift.

At the sites visited, health and safety procedures are enforced through staff meetings and dust monitoring surveys. Hard hats, high visibility jackets and protective footwear must be worn on the premises. Filtering half face piece masks (P2 type) are worn to provide respiratory protection and the operators have been trained in how and when to use this equipment and the appropriate maintenance procedures. The condition of these respirators is checked every six months and replacement filters are readily available. At the time of the visit, operators had been
Grain merchants providing commercial storage sell off-farm cleaning, dressing and storage services to farmers and find customers to buy the grain once it has been dried and dressed by the store. Stores tend to be made up of a number of separate buildings, housing the dressers and driers and between 8 and 10 storage sheds, and a road network that can deal with a high volume of delivery and outgoing traffic and offer a quick turn around of vehicles. Stores can operate several intake pits from which the grain is routed into the correct intake bin from a control room. The grain is then sent for pre-cleaning and drying and finally conveyed into the quality segregated storage silos or sheds.

**Figure 5.20** Summary of grain merchanting tasks

### 5.5.1 Intake

Storage depots intake grain for about 12 hours a day during harvest time. This lasts for about 8 weeks, between August and mid October. Depots handle anywhere between about 2,000 and 3,500 tonnes of grain each day during harvest. The grain is brought to the store by the farmers or hauliers, directly from the combine, so it can be processed (cleaned and dried) at the store. A
30 tonne lorry takes about 30 minutes to tip its grain into the pit. Stores tend to be full at the end of harvest. Occasionally grain is taken in after harvest. This means it has been stored on the farm for a period of time. Such grain will be tested before it is purchased and generally a buyer is quickly found so the grain will not require extended storage.

5.5.2 Dressing and Drying

The grain is aspirated at intake and blown in an elevator into an intermediate store or directly into the dresser and driers. Some processes dry the grain then dress it; others dress it first to remove ignitable materials. The dresser takes out impurities such as stones, straw and dust using a cyclone to clean the dirty air. The depots visited ran three continuous driers for about 12 hours a day during harvest time. About 25 to 30 tonnes of grain is dried an hour in each drier. Driers are often fitted with alarms to summon the operator when there is a blockage.

Samples are taken from the drier on a regular basis. Respirators are worn for this task when sampling from inside a belt drier.

5.5.3 Long-term Storage

Some depots employ dust extraction on the plant and sheds are fitted with roof fans to remove dust when the dry grain is dropped down the conveyor onto the shed floor. Dried grain is dressed to remove dust therefore dry grain going into store is typically relatively dust free. The doorways to the shed can be boarded up to half the height of the building in order to totally wall in the shed and maximise the storage capacity.

When kept at a low storage temperature dried grain can be stored for over a year. The temperature and air flow conditions under which the grain is stored are carefully controlled from a panel in the control room. The pedestal ventilation (as used on farms) and under floor ventilation (as used in the pilot plant farm) are used in commercial grain stores to ventilate the grain piles. Fans may also be used to suck cold air into the silos from the outside environment on cold nights in order to keep temperatures low. Gas and oil fired heating is used to heat the stores if the temperature needs to be adjusted upwards. Feedwheat is normally kept at about 8°C and barley at about 11°C.

The grain temperature is monitored manually weekly during an inspection tour of the storage sheds or continually with temperature probes inside bins and silos. The grain is tested continually during storage in order to monitor its moisture levels.

5.5.4 Cleaning and maintenance

Driers are typically vacuum cleaned once a week during harvest and again at the end of the harvest.

In the months when grain is not being received, the grain stores are run down so as no grain is taken forward into storage for a second year. This allows for maintenance, repair and cleaning of the sheds and drier.

The empty sheds are vacuumed out and fumigated. It takes two operators about 3 days to vacuum clean the inside of a shed. The floor and walls take half a day but the roof takes longer. Dry cleaning is used to eliminate the need for drying time. The surfaces are then sprayed with insecticide. Pressure washing is the preferred option but there is often insufficient time to wet clean. Drier sheds are often pressure washed or steam cleaned and vehicles are pressure washed.
Elevators and conveyors are stripped of their covers, flights are changed and they are vacuumed out.

5.6 MILLING

The processes involved in milling are described in more detail in Appendix 4.

Figure 5.21 shows that flour milling can be broken up into three sets of tasks, namely wheat handling and preparation (pre-milling tasks 1 to 5 in Figure 5.21), production of four (milling tasks 6 to 8 in Figure 5.21) and treating and handling finished flour (post-milling tasks 10 to 13 in Figure 5.21). Harvesting waste (straw, husks and chaff), grain dust, foreign seeds and irregular wheat grains, which are separated during the pre-milling and milling, are collected in bins and filters and turned into animal feed pellets. This process involves combining all these ingredients, adding steam to the mix, sending it through a pellet press and cooling the resulting pellets. The press and cooler machines are largely enclosed but there may be some spillage from these machines. However, the machinery is usually housed separately and like most equipment in a flour mill is set up, started and operated remotely from a control panel located elsewhere. In some cases bran and wheat germ, separated during grinding, are sold as co-products.

Mills operate 24 hours a day for 7 days a week using an overlapping shift system. There is usually one miller on shift at a time. The millers’ tasks are discussed in Sections 5.6.1 and 5.6.2. Sometimes the miller runs the intake department as well as the milling process. Tasks 11 and 12 are covered in Section 5.9 (Outloading).
Figure 5.21 Tasks in the wheat milling process
5.6.1 Miller’s Tasks (excluding cleaning and maintenance)

The major duties of the miller include:

- bringing the wheat forward from the intake side and preparing it for milling by cleaning and drying it (tasks 1, 2, 3 and 5);
- routing the wheat streams through the mill stands (recycling unfinished flour back through break and reduction rolling for further milling after sifting) (tasks 6, 7, 8 and 9);
- mixing the flours to get the required grade (tasks 4 and 10);
- monitoring the flour quality and adding ingredients to bring the finished flour up to the required specification (task 10);
- data logging e.g. recording (flour) extraction rates, protein and moisture analyses data;
- setting up the plant, monitoring tasks in progress and plant operating conditions;
- vacuuming of all the cleaning and milling equipment, plus vacuuming and/or sweeping up spills and settled dust.

Most tasks in the mill are computer controlled. The miller inspects the plant directly after initiating the task remotely. It is estimated that the miller might spend more than half of her/his working shift in the control room. This is usually located overlooking the roll mill floor.

The plant that the miller operates is largely enclosed so there is very little exposure to dust during time spent on the mill floor. There are two exceptions to this, namely exposure to grain and/or flour dust when dealing with blockages (choke) and breakdowns in the system that could stop production and adding auxiliary ingredients to the flour (task 11).

In the first case the miller would be required to inspect the problem, attempt to clear any blockage in the system and/or summon maintenance/engineering for help. Opening up machines for such work requires the miller and engineers to wear respiratory protection (minimum of disposable half-face piece P3 respirator) and clean up any ensuing spills or leaks.

Addition of ingredients to the blended flour can take place on the mill floor or in a separate room. This usually involves opening sacks of the ingredients and emptying them into a hopper (‘ripping and tipping’) that feed a storage bin.

Control measures are used when undertaking this task. This includes wearing a dust mask, limiting the frequency of the task to once per week and using a ventilated table. However the hazards associated with ingredients like α-amylase can make this task more exposure significant than any of the others.

5.6.2 Cleaning and maintenance tasks

Cleaning tasks are carried out by the milling and engineering departments. These include cleaning of the:

- inside of machinery, e.g. conveyors, sifters, packaging plant;
- inside of the building and the outside of some plant (floors, ceilings, ledges, pipes, roofs, stairs and hand rails).

Maintenance/engineering staff (up to six operators) out number the millers and work on three shifts with the night shift often being an ‘on-call’ service.
The cleaning and maintenance of machinery has to be undertaken when the plant is not running. The operation of flour mills is a practically continuous process therefore in order to allow cleaning and maintenance of machinery many flour mills devote one day shift every fortnight or month to vacuuming the machines. During vacuuming particular attention is given to dead spaces where ventilation is not able to remove dust and waste; checking, cleaning and replacing screens and filters; and carrying out routine maintenance. These duties would generally be carried out by the miller and engineers. Many premises have in-line vacuum systems for cleaning. Flexible hoses can be plugged into sockets in the line for easy and immediate vacuuming of settled dust in the building and in machinery (Figure 5.22). At some sites portable industrial vacuum cleaners are moved round the plant during the cleaning operation. The operators wear dust half-face piece respirators (P3 type) and dust suits when undertaking this task. Scissor mops and brushes and shovels are routinely used to clear up any spills or leaks while the process is running. This was reflected in the high standard of house keeping observed during the site visits.

Day shift cleaning staff is employed at one site visited to clean the inside of the building. These hygiene staff’s sole job is to clean the building and plant. They work their way through the premises vacuuming floors, walls, stairwells, ledges etc. and wear boiler suits and dust half-face piece respirators (P3 type) for this work. The whole premises would take about three days to clean in this way on a one or two shift system (excluding nights).

Millers are expected to keep the floors etc. free of spillages and settled dust whether or not cleaners are employed. The cleaning and maintenance duties are largely manual tasks and involve a very hands-on approach for both routine and novel tasks. Operators wear half-face piece disposable respirators (P3 type) and boiler suits for this work.

Silos and bins are cleaned out annually by a contract company.

5.7 MALTING

The processes involved in malting are described in more detail in Appendix 5.

Tasks in the malting process (Figure 5.23) are grouped under three headings namely preparing the barley (pre-malting tasks 1 to 3), malting the barley (malting tasks 5 to 7) and dressing the malted barley (tasks 8 and 9). The pre- and post-malting tasks represent dry processing while malting the barley is a wet process.
There is a wide selection of commercial production technologies available to the malting sector. This is particularly true for the malting stage itself. A number of the technology options are listed below:

- conical steeps, Circular Flatbed Germinating Vessels and Circular Kilns;
- conical steeps, Circular Flatbed Germinating and Kilning Vessels (GKV);
- conical steeps, Drum Germinating and Rectangular Kilning Vessel;
- conical steeps, Drum Germinating and Circular Kilning Vessel;
- single Steeping, Germinating and Kilning Vessel (SKGV);
- Saladin boxes (not discussed here);
- floor maltings (not discussed here).

Maltings operate 24 hours a day for 7 days week using an overlapping shift system. Usually there is an intake operator to move the dry raw material (barley) from the store to the steep and the dry product (malted barley) from the kiln to dispatch bins for bulk outloading, which is carried out remotely from a control room using a computerised grain transfer system. There is usually one maltster on shift at a time. The maltster steeps and germinates the grain and may carry out the kilning. Occasionally there is a kilning operator as well as a maltster. Night shift cover may be provided by a multi-skilled operator with engineers on call.

Signs indicating the requirement to wear ear defenders and hard hats were clearly displayed in all relevant areas and buildings of the malting houses visited. They all required that safety footwear and high visibility jackets be worn at all times. One of the sites visited had head torches fitted to all company personnel’s hard hats. There was an unlimited supply of disposable dust masks (P3 type) available and easily accessible to all staff. For some tasks specialised personal protective equipment is mandatory (see cleaning germinators and kilns in Section 5.6.7). On two sites visited, airflow rates are measured in the local exhaust ventilation ducting on a weekly basis to identify any likely leaks or constrictions to airflow.

The intake operator’s tasks have been described in Section 5.4. The maltsters’ tasks are described in Section 5.7.1 and the cleaning and maintenance tasks in Section 5.7.2.

The elevators and conveyors are enclosed and aspirated when moving dry barley to the steep (between tasks 1 to 5 and after task 7) and kilned barley out of the kiln. The wet malting tasks use a belt conveyor open at the top to transfer wet grain from steep and from the germination vessel. A second process, which uses waste material extracted from the grain (by local exhaust ventilation) and malted barley rootlets (malt culms) to produce animal feed pellets, is represented by task 10.
5.7.1 Maltsters’ Tasks (excluding cleaning and maintenance)

Malting is more a batch process. Steeping, germination and kilning take about 2, 5 and 1.5 days to complete respectively. However the provision and operation of the plant is such that every piece of plant is in continual use making the process effectively continuous. Like milling, the
The malting process is largely automated and most manual tasks are related to cleaning, maintenance and unblocking chokes during routine production. Maltsters are based in the control room but do spend more than half their time on inspections rounds to monitor the condition and modification of the barley. Therefore after initiating a process, maltsters go onto the plant to check that it is underway and to carry out other routine inspections of the barley/malt line.

The major duties of the maltster include:

- bringing the barley forward from the intake side for steeping (task 5). Operators tend not to stay in the steep room during barley filling. The atmosphere in the steep room can be dusty during filling. They go to the control room or to inspect another part of the plant. However if operators have to work in the steep room during filling, for example to check newly commissioned installations, they would wear dust masks (P3 type).
- routing the barley streams through steeping and germinating (tasks 5 and 6);
- routing the green malt and malt (tasks 7 and 8);
- setting up the plant, monitoring tasks in progress and adjusting plant operating conditions.

### 5.7.2 Cleaning and maintenance tasks

Similar to flour milling, the cleaning and maintenance work involves mainly manual tasks. The batch nature of malting means that there are more cleaning tasks undertaken. More frequent cleaning operations together with the larger size of the equipment means cleaning takes longer. There is no dedicated operator for any one task. The cleaning of dry processing plant and storage facilities are the tasks most likely to have exposure to dust. Silos and bins are cleaned in-house. This is in contrast to what was observed in flour mills. The cleaning tasks are discussed briefly below.

#### 5.7.3 Drier cleaning

Driers are cleaned once a year after harvest. The hot air chamber is vacuumed and this work takes half a day. This is usually carried out by the intake operator.

#### 5.7.4 Silo cleaning

Barley bins are cleaned when empty. One silo is cleaned approximately every 3 to 10 days. The grain residuals or ‘trim’ remaining after the sweep auger has gone round, for example stuck in the (floor/wall) join, are manually swept into a central pit fitted with a screw auger to remove material. This task takes about 2.5 hours but is split into 15 minute time periods and completed over two working shifts. It takes half that time with two operators on the job. Operators wear paper suits, gloves, air stream helmets or dust masks (with eye protection). The silo is gas tested before entry.

#### 5.7.5 Flat bed store cleaning

These types of stores are less common than silos. They are cleaned once a year before the harvest intake. The walls, ceiling and floors are manually pressure washed and a road sweeping lorry is contracted to clean the floors. The shed is left to dry naturally and sprayed with insecticide. It takes three operators 2 weeks to complete the cleaning. Operators wear oil skins and wellington boots.
5.7.6 **Dresser cleaning**

Barrel dressers are cleaned once or twice a week. The screens are pulled out and checked for holes and the barrel turned by hand and vacuumed out. This takes about half an hour.

5.7.7 **Steep cleaning**

Vessels are cleaned after every batch going through the steep. Some steeps were cleaned using a remotely operated automatic ring clean system. Otherwise the steep is hosed out by the operators for between 15 minutes and 1 hour, depending on steep size. Most steeps are annually cleaned by power washing or foam spraying, and on some occasions this work is out-sourced. This takes half a day.

5.7.8 **Germinator cleaning**

It takes about 2 hours to clean a circular germinator after every use. Two thirds of the time is spent underneath the germinator pressure washing all the surfaces with a sodium hypochlorite solution. The operator wears oils skins and a visor during this task. Occasionally plants may use automated germinator cleaning with manual cleaning of blind spots.

5.7.9 **Kiln cleaning**

The space underneath the kiln is swept out from daily to once a week and the culms are conveyed to the animal feed process. This work takes between a few minutes and an hour depending on the size and structure (and is over an hour for GKV where it is washed as well). Airstream helmets are worn and operators undertaking this work are issued with their own helmet for such tasks.

5.8 **ANIMAL FEED MILLING**

Milling of commercial animal feed is much simpler than flour milling in terms of the plant and tasks involved. Most tasks (Figure 5.24) are automated as part of a continuous production process.

In the mill there can be up to two people in the control room and another two on the plant, a press operator and a plant operator. The control room operator (tasks not identified on Figure 5.24) carries out all the intakes, material transfers and pellet extrusion using a fully automated system. The plant operator works all over the production line including the grinders. On the site visited, one grinder is enclosed in a separate room and the other is close to the pellet plant in the main production area. There are also about three maintenance engineers working on the plant with less during the night shift. A full-time cleaner was employed at the animal feed plant to go round and vacuum all the floors, walls and surfaces where dust could lodge.

The plant is ventilated and largely enclosed but significant dust escapes through the open hatches and blockages in the machines lead (Figure 5.25) to spills.
Figure 5.24 Animal feed milling tasks

Figure 5.25 Grinder with magnet (underneath cream-coloured hopper)
Spills from the presses are swept down through a grating in the floor and conveyed back into the process. Any minerals are added automatically to the feed before it is pelletised (Figure 5.26).

The press operator uses a hand brush to sweep dust off the high conveyors and from around the plant.

The full time cleaner wears a disposable respirator, gloves and jacket and vacuum cleans all the floors and stairs in the plant. However dust takes only two or three days to deposit on surfaces and rails again. Operators vacuum external surfaces and brush down the areas they work in, and there is an annual contract clean of the plant. There are scheduled inspections of the bins, which are self cleaning, in order to check their integrity.

Vitamins, enzymes and antibiotics for pedigree feed milling are measured out and added by hand via a ventilated booth with a down draught extraction. The measured quantity is passed from the drugs room to the mill floor in a bag or bucket and is then added to the feed stream through a ventilated hopper by a malt process operator. It was not possible to visit this production line during the site visit.

5.9 OUTLOADING

Outloading is the dispatch of finished product to the customer. All of the finished malt and 70% of the finished flour is sent off in bulk using tanker lorries. In the case of flour milling, some of the product may be packaged in 1 tonne bulk containers or 10 kg, 16 kg or 25 kg paper bags.

Normally one operator mans the packaging facility and bulk outloading. Alternatively bulk outloading may be run by the intake operator. In flour mills where warehousing of goods is a large part of the trade, another operator might be employed. The filling station is usually located on the ground floor of the building in an internal area between the mill and the warehouse. Some natural ventilation of these areas may come from open doors leading from the warehouse to the yard, which is used by the forklift trucks. However like many work areas, general ventilation here is mostly provided by the extraction system ventilating the plant.

Bulk containers are manually filled by the operator. The operators wear half-face piece disposable dust (P3 type) masks when filling the bulk containers. The bags are hung on a frame underneath the bin and the flour is dropped in from the bin through a conduit. The filled bag is
lowered on to the scale beneath it and weighed before closing and being moved into the warehouse with the forklift truck.

Once an automated packaging plant is running the operator is not required to be present other than to top up the bags in the magazine. Alarms will sound to call the operator if the plant stops for any reason. The packaging task is largely automated. The bags are manually loaded into a bag magazine. The bag is then picked up, placed on a spout and taken into the partially enclosed carousel. There it is filled with flour and shaken to release the air. The air displaced during bag filling is extracted by a local ventilation system. Alternatively the bag can be manually secured to the spout prior to entering the carousel for filling. The filled bag is then sent down a line that closes the bag, seals and weighs it. The filled bags are then automatically stacked and palletised ready for wrapping and then warehoused until dispatched to the customer.

Bulk outloading begins when the tanker is driven into the bay and stopped underneath the bin (Figure 5.27).

![Figure 5.27 Bulk outloading conduit on the bottom of a storage bin](image)

The spout at the bottom of the bin is pulled down and placed into the hatch at the top of the tanker. A moveable extract ventilation hood can also be placed inside the hatch to remove dust escaping into the atmosphere in displaced air during tanker filling.
6 DUST MONITORING DATA

During the project we attempted to obtain data on airborne dust concentrations, both from the site operators and by making measurements using a portable TSI Sidepak direct-reading dust monitor. It is important to realise that there is only a small set of data and so the description provides a crude impression of the likely exposure levels. In addition, the direct reading monitor was not specifically calibrated for grain dust and so is not as reliable as data obtained from personal sampling followed by gravimetric analysis. Measurements were generally as inhalable dust. We were unable to identify any information about airborne endotoxin or mycotoxin air concentrations in the plants investigated.

Most, if not all, large companies have dust monitoring surveys carried on a rolling basis where personal and static exposure monitoring is carried out at one of their production premises annually. If HSE were able to collect and analyse these data it could provide a clearer picture of airborne dust exposures in the industry.

Company monitoring data and real-time measurement data obtained during site visits are reported in Sections 6.1 to 6.4 below.

6.1 FARMS

Monitoring data was collected from one farm during harvesting. The field harvesting showed a 30 fold difference in average dust concentrations for measurements taken inside (0.035 mg m$^{-3}$) and outside (0.99 mg m$^{-3}$) the combine harvester’s cab and a 20 fold difference between their maximum values (0.24 mg m$^{-3}$ vs. 4.8 mg m$^{-3}$ respectively). It should be noted that the detector plate of the TSI Sidepak dust monitoring instrument was coated with about 0.5 mm thick pad of residue after monitoring outside the cab for about one hour. However it should also be noted that the highest dust concentrations were recorded in the last 25% of the monitoring period.

Measurements were made for a number of short (2 minute) tasks associated with drying and managing the grain in the farm yard. Dust concentrations of 1.4 mg m$^{-3}$ were recorded for manually unblocking a choked elevator and lower concentrations of about 0.5 mg m$^{-3}$ and 0.3 mg m$^{-3}$ were measured for sweeping by pushing a mechanised sweeper and using a brush respectively.

Measurements were made in the dry grain shed, around the driers and during tipping and shovelling into the drier intake. Dust concentrations of around 0.3 to 0.4 mg m$^{-3}$ were recorded close to where the overhead conveyor was dropping dust into the dry grain shed. Dry grain stores had an ambient airborne dust concentration of about 0.2 mg m$^{-3}$. Natural ventilation was provided by open doors. Similar values (0.3 to 0.5 mg m$^{-3}$) were recorded close to driers operating inside a building while lower values where found for an outside drier (0.01 to 0.1 mg m$^{-3}$). However the outside drier was under two years old while the inside driers used by the majority of farms visited were older. Only one farm was carting grain to the farm on the day of the visit. Dust concentrations measured between 0.03 and 0.4 mg m$^{-3}$ during tipping. During the other farm visits farmers were shovelling wet grain from stockpiles into the intake pit for the drier. Dust concentrations ranged from 0.3 to 0.7 mg m$^{-3}$ for this task. Similar values were measured at ground level for shovelling grain out of a flat bed store. Concentrations of 1.3 mg m$^{-3}$ were measured at a height of about 2 m from the ground during shovelling grain out of storage.
6.2 MILLING

Monitoring results obtained for two flour mills showed that filling station operators, millers and day shift cleaners had personal inhalable dust exposures of around 1 mg m\(^{-3}\), as an 8-hour time-weighted average (TWA) concentration. The dust monitoring readings collected during a walk-through tour of three flour mills showed average values ranging between 0.5 and 0.05 mg m\(^{-3}\).

6.3 MALTING

Static measurements of dust, made with a direct reading instrument, were obtained from a malt house’s survey report. These were highest at just under 5 mg m\(^{-3}\) next to the dust filter bags of the extract ventilation system. The dust readings for the bagging line (filling station) and dressers (screens) were less than 0.3 mg m\(^{-3}\). The results of personal monitoring carried out at another malt house showed considerably higher concentrations of dust exposure during the kiln cleaning task. The level was around 10 mg m\(^{-3}\), although this task took under 15 minutes to complete. It is conceivable that the 8-hour TWA level would have been lower if the remainder of the shift was spent in the control room and carrying out less dusty tasks, for example on the wet processing side of production. The short-term exposure limit for a 15-minute reference period is 30 mg m\(^{-3}\) and this would not have been exceeded in this task. These data suggest that kiln cleaning tasks are associated with high dust concentrations, which was the view of the staff involved.

The dust monitoring readings collected on a walk-through tour of malt houses were about 1 mg m\(^{-3}\) and lower when it was wet weather. However, very few of the dust significant tasks were underway at the time the appropriate part of the premises was toured. One steep filling task was monitored for about 4 minutes. Dust concentrations of between 12 and 15 mg m\(^{-3}\) were recorded. This was a newly commissioned steep and there were some teething problems with its operation, which were being resolved at this time.

6.4 ANIMAL FEED MILLING

One of the site visits was carried out at a commercial animal feed processing plant. The main area contained a large mezzanine level with pellet presses and mixers. This provided access to smaller mezzanine levels, one with another grinder, and upper levels containing the tops of raw material and finished product bins and the conveyors.

Airborne dust concentrations were measured for between 5 and 15 minutes at two areas on the largest mezzanine level, at a grinder (enclosed in a room 10 m by 11 m on the ground floor of the mill) and outside at the intake where grain was tipping.

Large, clearly visible, dust particles filled the atmosphere in the grinder room when the grinder was running. The portable dust monitor measured an average of 6 mg m\(^{-3}\) over 10 minutes with a maximum value of 9 mg m\(^{-3}\).

The readings recorded in the press area were just under a tenth of that value, averaging about 0.4 mg m\(^{-3}\). There was also airborne and settled dust clearly visible here.

The tip area was partially enclosed on three sides and the lorry backed up into the open side in order to tip into the pit. A dust sock was used when discharging the load. An average dust reading of 0.3 mg m\(^{-3}\) was recorded here.

A cleaner was employed at the animal feed plant to go round and continuously vacuum clean inside the premises. It was commented on that 2 or 3 days after cleaning the settled dust has re-
established itself indoors. There was dust leaking from the grinders and the presses through inspection hatches and output chutes near the floor. The dust present at the higher levels of the building suggest there were leaks in the conveyors and elevators taking grain and feed into the storage bins and in the extraction system. Personal dust monitoring carried out at another animal feed mill show production operators’ personal exposure level to be around 7 mg m\(^{-3}\), drivers’ personal exposure level to be around 2 mg m\(^{-3}\), and that of an operator adding drugs to pedigree feed to be just under 4 mg m\(^{-3}\). Static monitoring of intake and bulk outloading were about 1 mg m\(^{-3}\) and 16 mg m\(^{-3}\), respectively. No personal samples were taken for these tasks because they were not manned. Background dust concentrations in the mill room were below the detection limit.
7 TASKS AND EXPOSURE

The grain industry is a well established part of today’s agricultural market. Within the last thirty years it has gone through major redevelopment and investment to take it from a labour intensive industry to a capital/infrastructure intensive industry. This shift to a more automated means of production has meant the work force has substantially reduced in number, all aspects of the business are mainly in the hands of a few major companies and plant operation has become remotely controlled. The impact of this on exposure to grain dust in different sectors of the industry has been studied in this project. In this section we draw together information about the tasks and exposure, identify ‘exposure significant’ tasks and attempt to estimate exposure for inhalable dust and component parts of the aerosol.

7.1 TASKS GENERATING AIRBORNE DUST – INFORMATION FROM THE PRESENT PROJECT

Managers and operators are very aware of the tasks that generate airborne dust in the processes they work on. Tasks identified as likely to generate dust during processing grain were:

- tipping at intake;
- screening raw grain;
- milling wheat- and barleyfeed grain;
- filling steeps when malting barley;
- cleaning under kilns when malting barley;
- cleaning inside empty silos and vessels when malting barley;
- adding auxiliary ingredients to hoppers during flour milling and
- cleaning and maintenance of production and dust extraction plant.

Farmers identified intaking the harvested grain, moving harvested grain across the farmyard and into the driers (blowing and conveying), emptying the driers and emptying the silos as tasks releasing airborne dust. Dockside tasks are largely carried out in the open air and consequently are exposed to the weather. The wind can act to create or increase the level of airborne grain dust on the quayside during moving grain and from spills from crane scoops etc. control measures.

The changes listed below have been mainly identified from the telephone interviews and site surveys carried out on this study as contributing to controlling exposure, for example by process/control change and ventilation and organisational (administrative/procedural) control, eliminating tasks and using respiratory protective equipment.

Some of the biggest changes that have been observed in the grain industry include:

1) Automation of production and transfer systems in stores, mills and malting houses leading to
   - 24 hours a day/7 day a week/365 day a year production usually using 3 shifts for grain merchants (during harvest), mills and malting houses;
   - introduction of plant aspiration for grain elevation and processing;
   - remote working from control rooms with inspection rounds on the factory floor and less time spent stationed at production plant) with use of process alarm systems;
   - merging of several tasks to one task e.g. miller may intake the wheat or discontinuing tasks e.g. miller may use in-line analysis instead of laboratory for adjusting flour composition;
   - outsourcing of indirect production tasks such as grain and silo spraying, silo cleaning, driving lorries and cleaning premises;
• reduction in numbers of operators involved in tasks at any one time;
• a greater number of engineers compared to operators (1:2 or 1:3 ratio of operating to engineering staff members);
• introduction of animal feed production which uses up organic waste materials and aspirated grain dust;
• introduction of in-line vacuum systems to encourage vacuum cleaning of premises and plant and less use of sweeping.

2) Driving tasks replacing some manual tasks on farm yards and in stores where
• small silo storage of wet and dry grain on farms and in grain merchants’ depots has changed to floor storage in sheds;
• the use of shovel and bucket vehicles in flat bed stores and in yards has reduced the manual handling of grain by operators during grain transfer and storage. This is a move away from a very labour intensive ‘filling and emptying’ of grain stores where an estimated 6.25 tonnes an hour moved is from bins toward a shed and vehicle based approach where hundreds of tonnes an hour can be moved.

3) Eliminating or reducing the incidence of dusty tasks by
• less use of extraction fans in storage shed walls, favoured in 1960s, because of the dust generated with this fast drying approach;
• prohibition of compressed air to blow dust off high areas and out of inaccessible dead spaces.

4) Increased awareness of respiratory and other grain related diseases and grain contamination by microorganisms leading to:
• introduction of the laboratory task for checking the quality and contamination of incoming grain to ports, stores, mills and malting houses;
• increased use of respiratory protection (P3 disposable dust masks) through a help-yourself/self regulating approach;
• demarcation of areas requiring the use of PPE.

Dust was observed in the general workplace environment of flour mills, malting house and commercial animal feed mills. This comprises settled dust, observed coating surfaces including handrails, machines (Figure 7.1) and conveyors, and airborne dust, directly visible in air (Figures 7.2 and 7.3) or when lit by shafts of natural light. However the lighting was poor in many of the pre-milling and malting tasks and it was not always possible to produce good photographic evidence. Also, settled dust was often difficult to photograph because it did not show up clearly against plant painted in beige, cream or pale yellow colours (Figure 7.4). There were sometimes bird droppings around the premises but this was not as common as might be expected.
Figure 7.1 Settled dust on a motor in a processing plant

Figure 7.2 Stairwell in a grinding room as grinding starts

Figure 7.3 Stairwell in grinding room once grinding in progress
Settled dust was observed on the floor and plant of the screen rooms and animal feed pelletising (press and cooler) plants of most premises visited. Dust was observed in the atmosphere of the animal feed plant visited. However, air measurements taken by the direct reading instrument during the visit, did not tend to indicate this was representative of high concentrations of inhalable dust.

Screen rooms are generally housed on a number of floors built around silos. The floors are open to each other but not the rest of the mill. Pelletising plants are usually placed in their own rooms and on one site visited the pelletising plant had been moved outside. Both machines are ventilated and largely enclosed. However, in one site visited dust billowed out of open inspection hatches and output channels when the material stream was flowing through the pellet press. The operator’s process control console was in the same work area and so he did tend to spend time in this area to operate the system and to clear blockages. Older grain driers tend to be operated from a console close to the drier. This was only observed on two driers during the site visits but the operators were only stationed at the consul to check the drier and make changes to the operating parameters.

Operators do not need to be constantly beside any of the machinery when it is running in farms, stores, mills and malting houses which allows operators to position themselves away from dusty tasks and minimise their time close to such a dust source. Machinery tends to require some manual set up, checking once initiated from a control room or panel and manual cleaning out. Operators are not permanently stationed beside production equipment during operation. Production machinery would be switched off during vacuum cleaning and so the extract ventilation would not function during the cleaning task. Respirators and boiler suits are worn for such dusty tasks. Two of the sites visited were planning to upgrade their current extract ventilation systems. One company was commissioning new extract ventilation in the screen room and the feed mill visited was looking at improving ventilation throughout the production plant.

Dry sweeping is widely used to clean high areas such as pipes, conveyors and ledges and to brush out underneath the kilns. Vacuuming is used on machinery such as the packing machines, driers, screens and floors, which are easy to reach with the vacuum. Half face piece disposable dust masks (generally P3 type) are provided in most plants for use during cleaning and other dusty tasks. The wearing of dust masks is mandatory when undertaking cleaning tasks.

Barley is recognised to be considerably dustier during handling and transferring than wheat. Variable weather conditions during growth and harvesting can also affect the dustiness of the
grain from one year to the next. Wet weather immediately prior to harvesting has been observed by farmers to contribute to increased dustiness of the grain. The changing exposure arising from this variability of the raw grain used may make it difficult for companies’ to feel the introduction of new local ventilation would be beneficial. The extended and often complicated plant layout also makes introduction of new local ventilation complicated and expensive. However, as mentioned above they have been willing to invest in such control measures and respiratory protection is freely available for operators. Grain merchants have introduced helmet respirators to provide their employees with comfortable and effective respiratory protection.

The processing side of the grain industry, in particular flour milling, has come under strict regulation for explosive hazards, food hygiene and worker health and safety. This, together with the grain industry coming under large corporate ownership, has lead to the introduction of procedural initiatives for good operating and commercial practice. These changes have enforced the requirements for wearing of respiratory protection, maintenance and testing of local exhaust ventilation and personal exposure monitoring of airborne dust. These improved maintenance procedures are in keeping with looking after the expensive and highly automated plant and process operating systems. The mature and trained workforce brings a strong skills and knowledge base, together with a culture of hard work, which has an impact on exposure to grain dust and its minimisation. Operators are in general trusted to follow recommended practices and to be self regulating in their use of control measures and personal protective equipment.

Control measures used in the modern grain industry have developed along with the new production technology. Much of the grain industry’s production plant is now under negative pressure and automation means an operator need not be permanently stationed beside it in order to operate it. Housing of bigger plant, such as that found in maltings, in separate buildings serves to prevent the spread of potentially airborne dust into clean areas. This, together with RPE and simply standing back from dust clouds raised during a task, have been the main ways in which exposure has been controlled in the industry. The extensive use of RPE has arisen from the changeable nature of the dust with every new harvest and the intermittent and short duration of many tasks which bring operators into dusty environments (cleaning, filling steeps and the large plant used in the processing tasks). It should be noted that these tasks often require the operator to move around and up and down plant and across the factory floor. Installation of LEV to control exposure, given the short duration of such tasks and the ‘operator mobility’ required by the task, may be difficult to achieve. However this makes the effectiveness of the RPE and how it has been selected (it is unclear if this has been based on measurement or operators’ preference) critical issues especially as new staff will be coming in to replace the ‘aging’ work force and with driving and cleaning tasks being contracted out.

7.2 TASKS GENERATING AIRBORNE DUST – INFORMATION FROM THE PUBLISHED LITERATURE

In this review, tasks are considered to mean the steps that make up a production process. Exposure reporting has tended to classify personal monitoring by job title or exposure groups and static sampling as a company department or as a machine making up a room housing or department of the production plant. For the purposes of this study, such descriptions have been taken as being synonymous with using a task-based approach in order to evaluate exposures. A task will be carried out by an operator who may or may not spend their entire working shift on this activity. The task may be manual (carried out by hand with simple tools), mechanised (operating a machine) or automated (started and controlled remotely by control panel or computer). This means task duration, frequency and working practices are important pieces of contextual information to have in order for example to establish 8-hour Time Weighted Average concentrations for comparison of exposure levels obtained by different researchers and to assess potential risks.
Many researchers have studied grain dust exposure over a range of industry sectors (cross-sectorial) while others have focused on one or more site(s) of a single grain sector. This section will present a task analysis carried out using all the published results from both cross-sectorial and single-sectorial studies. The use of respirators and other control measures will be highlighted as a qualitative indicator of dusty tasks.

Classifying tasks as ‘dusty’ and assigning an exposure level to these tasks using literature data and information is problematic. This is largely because many of the individual measurements recorded during the studies have been presented as a single consolidated average value for an industry sector (from multiple site surveys) or for the premises at which the measurements were taken. Consequently the measurements often represent mixed grain exposures. Such average values are expressed as medians, geometric and arithmetic means and frequently have large standard deviations. This is especially true for measurements of microorganism concentrations. Sampling time or length of time spent on a task is often not clearly stated. This means only a few of the papers reviewed here are useful, to a greater or (more often to a) lesser degree, in establishing exposure significant tasks.

A task based approach for classifying published grain dust exposures is most easily carried out using inhalable dust monitoring results.

- inhalable dust is well defined as are measurement techniques;
- more of these results have been reported in the literature than for individual bioaerosol components;
- many measurement techniques are available for bioaerosols and direct comparison between papers is difficult;
- it is difficult to make meaningful comparisons between different components;
- the measurements of inhalable dust are less variable and more differentiated than those obtained from microorganism monitoring; and
- personal monitoring has been widely used. Personal monitoring requires some characterisation of the tasks carried out by the operators in order to develop and implement a comprehensive and sensible sampling strategy. This means these results are reported with some level of task identification and differentiation, albeit often only as a job or exposure group classification.

Assumptions about how the task may have been carried out have been made where the necessary descriptive data was lacking. Static sampling reported in the literature has also been considered as using this approach, for example where the grain related tasks are largely mechanised (threshing, drying and storing). However results from static sampling have traditionally been found to underestimate personal exposure in the workplace. Therefore results from static sampling have only been used where these measurements have some degree of agreement with airborne dust levels obtained from personal sampling in the same study. Otherwise the trends in measurements have been used to check the ranking of exposure significant task presented in Table 7.1. Further details of these tasks are contained in Appendix 2.

Analyses of settled dust or bulk grain samples have provided most of the data on grain dust composition with respect to mycotoxin, which we have previously noted may give biased estimates. Airborne measurements have not been reported for endotoxin bacteria and fungi.
# Table 7.1 Ranking of tasks in the grain industry according to approximate exposure levels (data from several countries)

<table>
<thead>
<tr>
<th>Task</th>
<th>Sample type</th>
<th>Inhalable (mg m⁻³)</th>
<th>Endotoxin (ng m⁻³)</th>
<th>Mycotoxin (pg m⁻³)</th>
<th>Fungi and bacteria (counts m⁻³)</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning of premises &amp; plant</td>
<td>RT</td>
<td>&gt;200</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>- compressed air</td>
<td>RT</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>- sweeping</td>
<td>PS</td>
<td>60</td>
<td>650</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Harvesting tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- tractor driver</td>
<td>PPS</td>
<td>10</td>
<td>5</td>
<td>100,000</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>- grain store</td>
<td>PPS</td>
<td>10</td>
<td></td>
<td>1,000</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>- hot air drier</td>
<td>PS</td>
<td>5</td>
<td>1,200</td>
<td>50 OTA 250 DON 500 HT-2</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>- no cab or outside combine harvester</td>
<td>PS</td>
<td>5 - 40</td>
<td>100,000</td>
<td></td>
<td></td>
<td>3,4</td>
</tr>
<tr>
<td>- inside enclosed cab combine harvester</td>
<td>PS</td>
<td>1</td>
<td>350</td>
<td>2,000</td>
<td>50 OTA 0 DON 700 HT-2</td>
<td>3,4,5</td>
</tr>
<tr>
<td>Grain terminal tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- loading ship</td>
<td>PPS</td>
<td>150</td>
<td>1,000,000</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>- unloading ship (in hold)</td>
<td>PPS</td>
<td>100</td>
<td>1,000,000</td>
<td></td>
<td></td>
<td>3,6</td>
</tr>
<tr>
<td>- unloading ship (crane)</td>
<td>PPS</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>3,6</td>
</tr>
<tr>
<td>- transferring grain (open conveyor)</td>
<td>PPS/PS</td>
<td>10</td>
<td>100,000</td>
<td></td>
<td></td>
<td>3,6</td>
</tr>
<tr>
<td>- unloading ship (bucket elevator)</td>
<td>PPS</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td>3,6</td>
</tr>
<tr>
<td>- loading lorry</td>
<td>PPS</td>
<td>5</td>
<td>10,000</td>
<td></td>
<td></td>
<td>3,6</td>
</tr>
<tr>
<td>- transferring grain (control room)</td>
<td>PPS/PS</td>
<td>1</td>
<td>10,000</td>
<td></td>
<td></td>
<td>3,6</td>
</tr>
<tr>
<td>Milling tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixing ingredients (bakery)</td>
<td>PS</td>
<td>15**</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>shovelling grain</td>
<td>PS</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>milling</td>
<td>PS</td>
<td>2* &amp; 5**</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>packing flour</td>
<td>PS</td>
<td>10**</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>mill sweeping</td>
<td>PS</td>
<td>3* &amp; 5**</td>
<td></td>
<td></td>
<td></td>
<td>7,9</td>
</tr>
<tr>
<td>grain cleaner</td>
<td>ST</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>bag handling/storage</td>
<td>PS</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Cleaning unit</td>
<td>ST</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>lorry driving</td>
<td>PS</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Loading/unloading</td>
<td>PS</td>
<td>&gt;1</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Malting tasks</td>
<td>PPS</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
Table 7.1 lists task under the broad headings of Cleaning, Farm tasks including harvesting and drying grain, Grain terminal tasks, Milling and Malting. The exposures are given (column 2, Table 7.1) as (probably) personal (PPS), (probably) static (PS) sampling results, static (ST) or real-time (RT). There was no information available on which to break down Malting tasks’ into individual task-based exposures. The data for milling tasks is split between automated milling (*) and traditional milling (**).


Exposure data for microorganisms in grain dust is very limited for most tasks. Only grain terminal and harvesting, drying and storing tasks have any significant compositional data measured for grain dust. This has been largely compiled by two research group’s lead by Halstenen et al (2004) and Swan and Crook (1998). Personal exposure levels to microorganisms and endotoxin were obtained from two publications by Swan and Crook (1998) and endotoxin exposure levels for farm tasks were also reported by Halstenen in 2007. Some endotoxin exposures reported by Spaan et al (2008) and Veit et al (2001) have also been included in this table.

Dust exposure levels were reported by Phillips (1993) for grain terminals and harvesting. Personal exposure levels for milling obtained by Karpinski (2007) - automated milling, more traditional milling and packing flour) and Bachman and Myers (1991) and one static sampling result obtained by Dacarro et al (2005) have been included in the table. Exposures presented for cleaning tasks are obtained from exposures measured by Geng (2008) for real-time individual cleaning tasks and from one task-based personal exposure measured by Simpson (Britain).

Mycotoxin exposure levels were calculated for the inhalable dust exposure levels and the concentrations of mycotoxin in the settled dust (Nordby et al, 2004). This assumed that the proportion of mycotoxin in the settled dust and airborne dust is similar (Halstenen et al, 2004).

Alternia and Cladosporium and to a lesser extent Fusarium were associated with freshly harvested grain. The fungal composition changed when the grain was put into storage however. Aspergillus and Penicillium were more common in ‘storage’ grain dust and levels increased with storage time. Fungal concentrations were seen to increase during drying and storage tasks after harvest but endotoxin and OTA concentrations were steady. This was linked to breakage of grains from transferring and heating, making them more susceptible to fungal infections. Endotoxin concentrations where higher by a factor of 100 for tasks performed outside in the fields during harvest compared to those carried out inside the grain store and the combine harvester. DON concentrations increased but HT-2 concentrations fell in grain dust when the harvested grain went through drying and into storage. This suggests Fusarium is present in stored grain or another species is releasing the mycotoxin. However, the data on mycotoxin is from non-British studies and is probably of limited relevance (in Britain all grain, including imported grain is tested).

Table 7.1 shows endotoxin concentrations were highest for ship-related tasks at grain import and export port terminals and ten times higher than that for moving grain in open conveyors inside the terminal. The dust from the conveyors is generated from the fast flow of moving grain. The terminal control room has similar endotoxin concentrations for loading lorries but fungi and bacterial levels were similar to the driver of a combine harvester with a ventilated cab. Cladosporium, Alternaria, Penicillium and sometimes Aspergillus have been observed in the grain stock.
The cleaning tasks appear to be the most exposure-significant tasks for grain dust. None of the cleaning tasks have been fully described in the literature so it must be assumed these involve cleaning of grain dust from plant and premises. This has remained a largely manual task over the last 10 years. One aspect of the task that has changed however is the reduction in the use of compressed air jets to blow out (and re-suspend) dust resting on high or inaccessible surfaces. Little microorganism monitoring has been carried out for this task, despite the high airborne dust concentrations associated with it. The dust composition has only been reported in terms of endotoxin concentrations. However the usefulness of such measurements is questionable, given that replicate measurements taken on the same task can vary by a factor of $10^3$. Another change in cleaning has been the introduction of a dedicated cleaning staff, employed to clean the premises on a continuous basis. For ‘Millhouse sweepers’ we have assumed represents cleaning shift operators in a largely automated flour mill. This means they would not be cleaning with compressed air but presumably using an in-line vacuum system to clean up heavy dust spills or depositions and using dry brushing as little as possible. The exposure for this task is far below that of the other cleaning tasks but is consistent with the changes in milling brought about by the automation (enclosure and ventilation) of the process. No control measures, over enclosure and automation, to reduce exposure are described in the literature.

Harvesting, perhaps surprisingly, appears as the task with lowest exposure. However this is observed for cases where a cab was fitted to fully enclose to the combine harvester driver. Supply of filtered air into the cab is used to control dust concentrations inside the cab. A number of fungi have been identified in the air during harvesting. Numerical values for fungi measurement are not helpful when trying to rank exposures because they are quoted on average as zero or very low but maximum values can be high. The sampling and analyses methods for these dust components are not as well established as those for inhalable and respirable dust and there is no single standard method for this complicated analysis. A maximum value of 4800 CFU m$^{-3}$ was quoted which show that measurements of fungi may differ by a factor of over $10^4$ for the same task. This makes these measurements unsatisfactory indicators of exposure.

One study reported exposure levels for additional harvesting tasks as well as combine harvesting. This showed that driving the truck, carting, operating the auger (presumably to transfer the grain into a store or into the drier from the cart), where there is likely to only be respirators available to reduce exposure, have slightly higher exposures (1 to 2 mg m$^{-3}$) than combine harvesting itself.

The bacteria concentrations are higher than the fungi concentrations for harvesting but only by up to a factor of 10. The combine harvester driver has the lowest exposure level, which is consistent with the use of control measure in the form of enclosure by a ventilated cab.

New analytical methods, which have been developed for measuring individual fungal species, have eased identification of the Fusarium species responsible for giving rise to specific trichotheccene mycotoxin. This has been used for bulk grain dust (and tentatively in pumped air) samples in order to measure Fusarium concentrations by species and so estimate the concentrations of DON, HT-2 and T-2 trichotheccenes indirectly. The mycotoxin HT-2, arising for Fusarium poae and Fusarium langsethiae, was measured in Norwegian farms during harvesting. The fungi Aspergillus and Penicillium were found to be present in some of the samples taken during threshing and the latter gave rise to OTA. Such measurements provide little useful information on which to characterise task-based exposures for these toxins as they are often only useful in confirming the presence or absence of microorganisms.

Just above harvesting in the ranking of exposure to grain dust in Table 7.1 is milling, with an average exposure level of 19 mg m$^{-3}$ reported by Phillips (1993). Ten years later this was
observed to be around 5 mg m\(^{-3}\) in a traditional mill for which no technological process information was reported. However, the value of 2 mg m\(^{-3}\) was reported in the same paper for milling exposure in a highly automated mill. The plant used in such production would be largely enclosed and ventilated with the miller spending less time on the mill room floor and more time running the production process from a control room. A control room was operating in this plant and value of 0.4 mg m\(^{-3}\) was reported for the operator working there. This indicates that the control room with filtered air supply reduces exposure. Exposure levels for the actual milling task would be expected to be higher than this because the task included unblocking a choke in the conveyors, spouts and milling machinery. Indeed this was reported as a dusty task but no airborne concentrations measurements or time spent releasing the blockage were given for and no information on the use of respiratory protection was mentioned in use during this task. This is an intermittent task and usually will be for short duration for the miller. Maintenance staff would take over dealing with this production issue if it were serious. This has lead to milling being given an estimated exposure value of 2 mg m\(^{-3}\).

Above the miller in Table 7.1 are the exposures for Packing and Mixing. Flour bagging is not popular with mills and there has been a move to bulk dispatch of flour from the mill to the client in tanker lorries. However, many mills still blend and bag flour for bakery or retail customers. No details of this task were presented in any of the papers reviewed although the filling machines are usually largely automated for small bags of 25 kg or under. Most automated plants enclose, ventilate and alarm the packing machines and the operator is summoned to the machine by personal beeper, in an emergency or when the bag magazine needs filling. In some cases bags need to be secured by hand onto the filling spout and this, together with displaced dusty air from the bags entering into the workplace atmosphere during filling, can lead to dust generation. Filling bulk container bags (100 kg) is a largely manual operation and can lead to exposure when filling, closing and moving the bags. The Bakery mixing task is not described in the reviewed papers but is taken to mean the adding of auxiliary ingredients such as gluten, α-amylase, minerals and vitamins to the flour. This still involves ‘ripping’ open the bags of the ingredients and ‘tipping’ the contents into the hoppers from which they are transferred to a mixer for blending. This is a manual task and may also include cleaning of the mixer after a run. Although this is an intermittent task, it does have the potential to raise clouds of dust and give rise to high short-term exposures. Static samples taken by Dacarro et al in an Italian mill tended to underestimate exposure but did show that cleaning and packing (filling) units had the highest exposures levels.

Storage tasks may include drying as preparation for long term storage, forced aeration of a fixed bed of grain or transfer of grain between bins (turning) for ventilation of stored grain and emptying of sheds and bins at the end of storage. This makes it difficult to get a meaningful description of storage from the published information. This is important contextual information as storage can be highly automated and involve remote transfer and turning of grain (usually in bins) or be more mechanised and involve driving a forklift to shovel grain into stockpiles in flat bed sheds. The latter would generate considerable grain dust making it a high level exposure task. Grain drying has been reported as a separate task from storage but other tasks such as ‘silo work’ appear more like storage tasks. The Norwegian studies have looked at storing and drying of grain along with harvesting. Hot air drying and ambient air drying tasks in Table 7.1 are distinguished from each other by their DON mycotoxin concentrations and to a much smaller extent by OTA concentrations. Fusarium, Aspergillus and Penicillium were identified in the stored grain and quantified for Penicillium in stored and dried grain. However, the relevance of the Norwegian data to Great Britain is questionable. The ambient grain drying task may be associated with high Penicillium concentrations. Respirators were used by one quarter of the operators in order to control personal exposure to dust but there is no information on exactly when these were used and for which tasks. It would be conceivable that the masks were used when emptying bins into a lorry or using a forklift to stockpile or transfer grain.
Numerous studies have reported exposures for Maintenance and Other tasks. These, like the other tasks are poorly defined, but it is further complicated here as in the latter case it is difficult to interpret what may be involved in the task from the name. There is the possibility it could refer to a multi-skilled worker who provides relief or night cover for the miller for example. But it could include other tasks not already covered, for example intake or outloading. Maintenance can represent a number of tasks that would involve grain dust exposure like dislodging chokes in the conveyors, pipes and plant, inspecting and repairing plant, ventilation systems and the buildings and other tasks that give rise to different exposures such as carrying out electrical repairs, painting and welding etc. The operators will most likely work from a maintenance shop and may even be on call and so would only spend time in the factory as needed.

Monitoring in malting houses have also been largely absent in these studies. This probably arises from the fact that for over half of the time the process is wet and so not dusty. However malting does involve a lot of grain intake, drying and storage work, silo cleaning, kilning and outloading which are potentially dust significant tasks in relation to airborne dust exposure.

7.3 ESTIMATION OF EXPOSURE IN THE BRITISH GRAIN INDUSTRY

Classifying tasks in British industry as ‘dusty’ and assigning an exposure level using literature data and information has been problematic, largely because many of the individual measurements recorded during the studies have been presented as a single consolidated average value for an industry sector. These data were frequently associated with high variability, which was especially true for measurements of airborne microorganism concentrations. Sampling time or length of time spent on a task was often not clearly stated. This meant that only a few of the available published papers provided useful data, as described in the previous section.

We have mainly relied upon the measurements of inhalable dust. Firstly, more of these data have been reported in the literature, secondly, the measurements were generally less variable and more differentiated than those obtained from microorganism monitoring and, thirdly, because personal monitoring has been widely used for these samples. Assumptions about how the task may have been carried out have been made where the necessary descriptive data were lacking. Static sampling reported in the literature has been used in some situations, for example where the grain related tasks were largely mechanised such as in threshing, drying and storing, but the results from static sampling have traditionally been found to underestimate personal exposure in the workplace (Cherrie, 1999). Therefore static sampling data have only been used where these measurements were considered to be broadly consistent with personal airborne dust levels. Analyses of settled dust or bulk grain samples have provided most of the data on grain dust composition with respect to mycotoxin, although these data may give a biased estimate because it is unclear whether the composition of airborne grain dust is equivalent to settled dust and/or bulk grain samples. Data on endotoxin concentrations are available for some situations in relation to inhalable dust concentrations and the relationship between these two measures has been used to infer the possible concentrations of endotoxin.

Table 7.2 lists the range of tasks that we have identified as being carried out in handling or processing grain and we have assigned an approximate arithmetic average inhalable dust level to each of these based on the reviewed literature. A more detailed breakdown of the tasks and the control measures in place are shown in Appendix 2. The estimated inhalable dust concentrations ranged from 0.1 mg m$^{-3}$ for work inside control rooms with filtered air to 200 mg m$^{-3}$ during the use of compressed air to clean settled dust. For each of the six sectors in the grain industry we have allocated the approximate average percentage of time workers spend in these tasks based on our interviews with industry representatives. For example, it can be seen that operators in milling spend the largest proportion of their time in control rooms (56%) and
fanners the least time (2%). Although it is possible that there is still some limited cleaning with compressed air, the information from the interviews suggested this is now unlikely. Based on the time budgets and the estimated task exposure levels we have estimated the average inhalable dust level in each sector, which is shown in the penultimate row of Table 7.2. These values range from 0.9 mg m\(^{-3}\) for animal feed manufacture to 3.2 mg m\(^{-3}\) for farming.

Exposure-significant tasks which could result in exposures above the British WEL of 10 mg m\(^{-3}\) if carried out for a whole day are: Store work, Blending additives, Packing, Clearing blockages, Ship loading, Cleaning - dry sweeping, Other cleaning – malting, Loading – shovel and Cleaning – using compressed air. However, only Store work and Ship loading are typically carried out for more than a quarter of a working day. Typical control measures and exposure rating for tasks in the grain industry where significant exposures have been identified are shown in the Appendix alongside the control measures currently utilised during these tasks (tasks identified with the letter S in the Appendix table).

There is some uncertainty in the data available to construct this matrix since the time budgets for each sector are based on a limited survey of stakeholders, and we cannot be certain about the work practices of all individuals or organisations. For example, we do not know whether the contractors carrying out silo cleaning do this work for a few hours or a whole day, i.e. they may work at more than one site on the same day. In addition, there are uncertainties about the level of exposure for some tasks such as shovel loading on farms or at merchants, during dry sweeping, ship loading and in pedigree animal feed production because of the limited data available to us (see Appendix 2 for identified uncertainties in exposure levels). Also, we are less certain about practices in smaller companies involved in the grain sector. However, despite these reservations we consider these data provide an insight into current exposures in the grain industry.

There is a great deal of information that suggests that exposure to hazardous substances tends to decrease over time. Creely et al (2007) reviewed the literature on temporal trends and identified 38 data sets that were informative for aerosols. They analysed the temporal trends on the log-scale assuming an exponential decline in exposure level over time. For 58% of these situations there was a statistically significant reduction in exposure, generally between about 5% and 10% per year. Only one dataset (3%) showed a significant increase in average exposure over time.

In the review by Creely and her co-workers (2007) there was no data for grain dust. However, we have looked more specifically at flour dust exposure using a database of measurements from the British Health and Safety Executive and a large bakery company (van Tongeren et al, 2009). This study involved an analysis of 1,451 inhalable flour dust measurements obtained over an 18-year period using linear mixed effect models. The overall mean flour dust exposure levels ranged from 7.8 mg m\(^{-3}\) in the bakeries to 17.9 mg m\(^{-3}\) in the flour mills; there were no statistically significant temporal trends in exposure. There were only data for 5-years for mills and these data showed no statistically significant change. From a separate study it appears that poor work practices are still prevalent in the bakery industry. Elms et al (2005) observed that activities such as dry sweeping and flour dusting by hand were still repeatedly undertaken by the majority of bakeries they visited, local ventilation was present in only 28% of companies and less than half of the bakeries were judged to have adequate control measures. We have seen a very different picture in our investigation of the grain industry where there are generally good technological controls and a positive attitude to minimising exposure of workers.
Table 7.2 Percentage time on each task by sector in the grain industry and estimated inhalable dust levels

<table>
<thead>
<tr>
<th>Task</th>
<th>Inhalable dust exposure levels during task (mg m⁻³)</th>
<th>Farming</th>
<th>Import/Export</th>
<th>Commercial storage</th>
<th>Malting</th>
<th>Milling</th>
<th>Animal feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control room with filtered air</td>
<td>0.1</td>
<td>2%</td>
<td>25%</td>
<td>25%</td>
<td>15%</td>
<td>56%</td>
<td>20%</td>
</tr>
<tr>
<td>Loading – bulk</td>
<td>0.5</td>
<td>-</td>
<td>10%</td>
<td>5%</td>
<td>15%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>Intake</td>
<td>0.5</td>
<td>5%</td>
<td>14%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Routine inspection of plant</td>
<td>0.5</td>
<td>-</td>
<td>10%</td>
<td>10%</td>
<td>24%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Harvesting - inside cab with air filtration</td>
<td>1</td>
<td>30%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drying - local controls</td>
<td>1</td>
<td>1%</td>
<td>-</td>
<td>10%</td>
<td>5%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other cleaning - non-malting</td>
<td>1</td>
<td>9.50%</td>
<td>2.5%</td>
<td>2%</td>
<td>-</td>
<td>1%</td>
<td>10%</td>
</tr>
<tr>
<td>Pelletising</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>41%</td>
</tr>
<tr>
<td>Store work</td>
<td>5</td>
<td>50%</td>
<td>10%</td>
<td>22%</td>
<td>14%</td>
<td>-</td>
<td>1%</td>
</tr>
<tr>
<td>Blending additives</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Packing</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23%</td>
<td>-</td>
</tr>
<tr>
<td>Clearing blockages</td>
<td>5</td>
<td>0.50%</td>
<td>0.50%</td>
<td>0.50%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Ship loading</td>
<td>5</td>
<td>-</td>
<td>27%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cleaning - dry sweeping</td>
<td>10</td>
<td>1%</td>
<td>1%</td>
<td>0.5%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Other cleaning - malting</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>15%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Loading - shovel</td>
<td>10</td>
<td>1%</td>
<td>-</td>
<td>15%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cleaning – using compressed air</td>
<td>200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Estimated industry long-term (8-hr) average exposure level (mg m⁻³)</td>
<td></td>
<td>3.2</td>
<td>2.2</td>
<td>2.9</td>
<td>2.7</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>90th percentile long-term (8-hr average) exposure level (mg m⁻³)</td>
<td></td>
<td>19.0</td>
<td>14.0</td>
<td>18.0</td>
<td>17</td>
<td>10.0</td>
<td>6.3</td>
</tr>
</tbody>
</table>
We have attempted to estimate the current average eight-hour exposure to inhalable dust in the key industry sectors in two ways: first we have used the temporal trends described above (assuming a 5% decline per annum based on the extent of changes in the industry) to extrapolate from the measurements made by Phillips and, secondly, we have used the task-based estimates of exposure as inhalable dust in Table 7.2 along with our best estimate of the proportion of time spent in each activity obtained from our survey of the industry, and calculated the time-weighted average exposure level. In the case of the measurements we have also extrapolated the range of reported data to represent likely variability in exposure. For the task-based estimates we assumed a geometric standard deviation of 4.5 (i.e. as found by Meijster et al; 2007) to estimate the 90th percentile of the distribution assuming it was log-normally distributed (Table 7.2, last row). These data are summarised in Figure 7.1 along with the Phillips data.

![Figure 7.1](https://via.placeholder.com/150)

**Figure 7.1** Inhalable dust exposure levels measured in the British grain industry in the early 1990s and estimated levels in 2010 – long-term (8-hr) average data

Note, in the figure the bars either represent the upper measured value (Phillips), the upper extrapolated measurement from Phillips or the estimated 90\textsuperscript{th} percentile from the task-based assessments, assuming GSD=4.5.

There is reasonably good agreement between the estimates of current exposures using the two approaches. In five of the six processes the mean was within about 0.5 mg m\(^{-3}\) or less. Only in the case of grain import/export was there an important discrepancy (8 mg m\(^{-3}\) for the extrapolation from the Phillips data and 2.2 mg m\(^{-3}\) using the task data). The main reason for the difference is probably the dramatic reduction in the amount of cleaning undertaken; Phillips notes that in the 1990s there were teams of cleaners ‘employed to pile the deposited dust back on the fast moving conveyors’ with exposures during this work being as high as 100 mg m\(^{-3}\) and seldom less than 20 mg m\(^{-3}\), whereas today terminal operators spend only about 3 or 4% of their time cleaning, using methods where less airborne dust is generated. If the task-based estimates are correct then for all six sectors between approximately 5% and 20% of inhalable grain dust exposures are above 10 mg m\(^{-3}\). 

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The data from Simpson et al (1999) in various grain handling activities, Swan et al (2007) for work at docks and Spaan et al (2008) in shipping activities suggest that in some situations there is a good correlation between inhalable dust and endotoxin but in other situations such as farming (Swan et al, 2007) there was no relationship between these measures. However, the data suggest that in Britain for inhalable dust exposure levels less than 10 mg m\(^{-3}\) the endotoxin level would not be expected to exceed 104 EU m\(^{-3}\), i.e. 103 EU per mg inhalable dust. Higher levels of endotoxin per mg inhalable dust were reported elsewhere, e.g. Halstensen et al (2007), but these data were linked to visible fungal damage to grain, which we do not believe is typical of current conditions in Britain. There are no data on airborne mycotoxin concentrations in the British grain industry, although Swan and Crook (1998) consider that any contamination is likely to be at low levels. We do not believe the data from the Norwegian industry are necessarily a good indicator of exposures in Britain because of differences in agricultural practice, i.e. the high levels of fungal damage reported.

Exposure to storage mites and other insects is a possible cause of allergic disease amongst grain workers. Armentia et al (1997) found between 450 and 10,000 mites per gram of grain dust, and in a group of 50 Spanish grain workers more than half of them were sensitised to at least one species of mite. The prevalence of sensitisation in these grain workers was about twice that in the general population in the area where they worked. However we were unable to find information about exposure to mites or mite sensitization in British grain workers, and do not consider the Spanish data to be representative of conditions in Britain.

Although some papers suggest that there may be exposure to respirable crystalline silica during harvest (Nieuwenhuijsen et al, 1999), we have found no quantitative data to suggest this is an important health risk for British grain workers.
8 DISCUSSION

The inhalable dust levels in the British grain industry were high in the 1990s, with many workers in all sectors being frequently exposed to 8-hour average inhalable dust levels above 10 mg m\(^{-3}\) (Phillips, 1993). Key high exposure tasks were associated with cleaning and maintenance. Since this investigation there have been considerable changes in the technology and work practices in the industry. In general there is more automation and fewer workers employed in grain handling processes. In addition, there appears to be a greater focus on minimising the release of dust into the work environment, both from process-related activities and from cleaning, and more consistent use of RPE. Finally, there is a greater focus on the quality of the finished products and this should contribute to lower emissions into the workplace and less bacterial and fungal contamination in grain. All of these changes will have tended to reduce exposures compared to the past, both to inhalable grain dust and toxic components such as endotoxin or mycotoxin.

In recent years there has been a range of exposure measurements made for components of grain dust, although none of these provides a clear picture of conditions in the British grain industry. Measurements of inhalable dust are probably the most reliable because of standardization of the sampling methods and the relative simplicity of the gravimetric analysis. Measurement of components such as mycotoxin or endotoxin is less standardised and the inter-study difference from sampling and analysis are likely to increase uncertainty about how well such data can be generalised. For endotoxin, for example, samples may be collected onto filter or into a liquid medium. Stephenson et al (2004) compared side-by-side endotoxin sampling using a liquid impinger and two fibre filter systems. The concentrations of detected endotoxin appeared to be highest with the impinger whereas the results for the glass fibre filter showed the least variability when sampling was conducted at the highest endotoxin levels. In addition, inter-laboratory analytical variability for endotoxin of up to four orders of magnitude has been reported for replicate samples (Jacobs & Chun, 2004).

Our best estimate is that the average exposure to inhalable dust associated with all tasks in the British grain industry are generally below 10 mg m\(^{-3}\) (Table 7.2) and that taking account of the pattern of work for operators in the key industry sectors the average 8-hour personal exposure levels are probably less than about 3 mg m\(^{-3}\), although perhaps 5% to 20% of individual personal exposures in the industry are still more than 10 mg m\(^{-3}\) (most probably people engaged in the identified exposure significant tasks for a substantial proportion of their working day). Endotoxin exposure levels are likely to be less than 104 EU m\(^{-3}\), which is comparable to other industries where endotoxin is found but higher than the levels some have suggested may be associated with adverse health effects (Douwes et al, 2003). Although exposure to both dust and endotoxin should be controlled to as low a level as is reasonably practicable. Mycotoxin, respirable crystalline silica and mite contamination are not considered to present widespread problems in the British industry.

Of course these estimates are all based on information from the published literature and a limited survey of representatives of the industry, and as such there are undoubtedly some uncertainties. For example, there is no information about current exposure levels during silo cleaning and some other exposure significant tasks, although historically these activities were associated with high airborne dust levels. However, we have used two independent approaches to estimate the inhalable dust exposure levels and these were generally in good agreement. Nevertheless we consider that it would be prudent to verify the actual levels in an industry-wide exposure survey. As we have indicated, grain dust is a complex mixture and there is evidence that in some sectors or processes there is a good association between the airborne concentration
of components in the grain and inhalable dust levels, although not in all cases. Therefore to ensure that there is a clear picture of the potential risks from grain dust it may be necessary to measure several parameters. We suggest that if further research is carried out then estimates of inhalable endotoxin, mycotoxin and mite allergen should be made along with inhalable dust concentrations.

Cleaning and some maintenance tasks are probably still associated with higher exposures, although this work is also less common than in the past and is generally done while the operator is wearing respiratory protection. It is likely that the RPE would reduce the dust concentration inhaled during the task by about a factor of twenty or more (HSE, 2005), but the impact on 8-hour average exposure would not be substantial because such tasks are generally a small part of the operator’s working day. Further work is needed to improve the quality and consistency of the RPE programmes delivered within the industry, particularly in relation to fit testing, wearer training and the “help-yourself approach” to use that has been identified in this study. Procedures should be put in place to ensure that respirators are used during exposure-significant tasks. The industry has made substantial progress in introducing exposure controls on plant and equipment over the last 15 years and further progress in this respect should be encouraged.
9 REFERENCES


Krysinkay-Traczyk E, Perowski J, Dutkiewiz J. (2007). Levels of Fungi and Mycotoxins in the
Samples of Grain and Grain Dust collected from Five Cereal Crops in Eastern Poland. Annals of Agricultural and Environmental Medicine; 14: 159.


Swan JRM, Blainey D, Crook B. (2007). The HSE Grain Dust Study - workers exposure to grain dust contaminants, immunological and clinical response. RR540. HSE.


APPENDIX 1 – CHECKLIST FOR STAKEHOLDER ENGAGEMENT

A1.1 INTRODUCTION

The Checklist seeks to aid in both the collection and storage of data obtained during a telephone survey of companies situated in key sectors of the grain industry. It is intended to gather information from companies on all the points appearing in the Checklist during the interview. A flexible but consistent application of the Checklist will be used in order to promote the collection of good quality data. This is discussed below.

A certain degree of flexibility will be used when administering the Checklist. For example, this means that the order in which the points appear in the Checklist need not be the same as the order in which they are discussed during the interview. It is therefore intended to pursue any new and existing (Checklist) points when they are raised, rather than postponing discussion of those points until they are reached in the Checklist. This will maintain a natural flow in the conversation and minimise unnecessary disruptions to the interview.

Efforts have been put in place to ensure consistency in the interviewing approach. This includes developing a set of standard statements and questions for use along with the Checklist and also clearly defining the terminology used. The former are being devised in order to provide a format with which to initiate and optimise discussion and to cross check the validity of the information obtained. Definitions have to be drawn up in order to avoid any ambiguity or misunderstandings phrasing questions and interpreting responses. This includes, for example, differentiating between terms often used interchangeably, such as job, task and process and giving values and visual interpretation to concentration terms such as high concentration, moderate concentration and low concentration.

The information will be recorded on paper during the interview and an electronic report prepared after the interview.

A1.2 BACKGROUND

The sectors of the grain industry are shown in bold in Figure A1.1 below together with some potential inputs and exposures. The gathered data will be used to characterise exposure patterns within these sectors.
These sectors incorporate six key work activities identified as having significant exposures to (some or all of) dust, fungi, bacteria, endotoxins, mycotoxin, dust and storage mites, namely:

- harvesting;
- grain cleaning and drying;
- storage and distribution (including grain silo cleaning);
- milling;
- animal feed milling/mixing;
- terminals and docks (imports).

The key activities within sectors can be considered as being made up of a number of steps or tasks. The harvesting, terminals and docks (importing), storage and milling activities appear in discrete industrial sectors in Figure A1.1. However each is made up of several tasks. The activity, animal feed milling/mixing, can be found in three sectors in the figure: firstly as a step in harvesting, where farmers process grain into feed; secondly as a step(s) in the sector
Processing (milling and malting); and thirdly (as mixing) in the sector Processing into Product. Milling and malting produce wheat and barley based animal feedstock, respectively. These feed streams can go on to further processing in the Processing into Product sector, including processes associated with feed merchants such as ‘pelletisation’ of loose feed and blending of different feed streams to give multi-component formulations. Grain cleaning and/or drying will be considered as a special task as it is likely to be found in most of the sectors. Distribution is represented by the lines and arrows in Figure A1.1.

The (mass) ratio of cereal production in Great Britain (103:40:6:1 for wheat: barley: oats: others) in 2007 shows that wheat production makes up nearly 70% of the annual cereal output. The sectors described by the flow Figures focus on wheat and barley producing, processing and end-use (Figures A1.3 – A1.6).

A1.3 THE CHECKLIST STRUCTURE

The checklist will be used to guide the discussion during telephone interviews and as a basis for recording the information obtained.

The Checklist is made up of

I. General company ‘questions’

II. Sector-specific clarification ‘questions’

which can be used together with the…

III. Generic process flow Figures for certain company sectors

In most cases we expect individual companies to be represented by one flow diagram. However, this will be checked and if necessary refined during the survey.

Table A1.1 and Figure A1..2 show the information-seeking questions or prompts to be used in telephone interviews with the companies. Responses can be entered either directly into the tables or into spaces provided on the list for later computer entry. It is envisaged the question tables and listing will be developed and refined as information is gathered during the survey.

The general company questions (see Table A1.1) seek to:

- Establish contact person and details for a Company;
- Place the Company in the appropriate sector;
- Gather some routine Company and task information;
- Identify and broadly detail the steps in the Company’s process.

The list of questions in Figure A1.2 will be used to gather information on each task making up the company’s production process(es). Consequently Figure A1.2 will be used more than once for each company.

The process flow Figures use a series of boxes to show the sequence of individual steps or tasks and material flows from material receipt through every step of production and storage to dispatch of the end product. Input materials are given on the left hand side of the boxes and potential exposures are shown as outputs on the right hand side of the boxes. One task that is not included on the process flow Figures is sampling of grain material for compliance and quality...
assurance purposes. This will be entered during the interview process. It is hoped that the flow figures can be used as a summary method of presenting the findings from the study.

The black arrows can be considered to represent distribution or transport of grain materials between different sites where the different process steps are carried out and between sectors. This means that distribution does not currently have a process flow Figure.

A1.4 THE QUESTIONS

Table A1.1 Company Contact and Operations Details

<table>
<thead>
<tr>
<th>Establishment name</th>
<th>Contact’s name and designation</th>
<th>Address</th>
<th>Post code</th>
<th>eMail</th>
<th>Tel</th>
<th>Mobile</th>
<th>Ref no</th>
<th>Interview date</th>
<th>Sector</th>
<th>Market</th>
<th>Number of employees</th>
<th>Working days/year</th>
<th>Hours/week</th>
<th>Tasks</th>
<th>Grain type</th>
<th>Use</th>
<th>Grain condition</th>
<th>Consignment size</th>
<th>Delivery method</th>
<th>Delivery frequency</th>
<th>Storage conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

86
Figure A1.2   Listing of Sector (Task) Characterisation Questions

**Company’s Task Name**  Formal……………………Informal…………………………

**Task Site**

**Project Task Name** cleaning grain/ transporting grain/mixing grains/grain treatment/grain storage/cleaning equipment/waste disposal (recycling, reuse, off-site disposal)

1. **WORKER PROFILE**

<table>
<thead>
<tr>
<th>Number of workers</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male/Female</td>
</tr>
<tr>
<td></td>
<td>Smokers/Non-smoker</td>
</tr>
<tr>
<td></td>
<td>Years of service</td>
</tr>
<tr>
<td></td>
<td>Age range of workers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Employment type</th>
<th>Seasonal/All year round</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contract/Permanent</td>
</tr>
<tr>
<td></td>
<td>Full time/Part-time</td>
</tr>
<tr>
<td></td>
<td>Other work if seasonal/part-time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration</th>
<th>Time spent on task/time period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overtime/Extended hours e.g. summer</td>
</tr>
<tr>
<td></td>
<td>Other work if not spending all day on task</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Number of times carried out/representative time period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Representative time period = 1 day or 1 week or assigned value</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Work organisation</th>
<th>Individual/Team work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participate in job rotation Formal/Informal</td>
</tr>
</tbody>
</table>

2. **DUST PROFILE**

Defining, as %H/M/L/none released, other possible hazardous substances added or produced during task and already present in the grain stock.

**Materials previously added to or naturally present in received grain** (present in dust as original substances or residues) and any documentation/quantification

- Herbicides
- Pesticides
- Fungicides
- Fumigants
- Other additives
- Silica/Silicates

**Materials added to grain during task** (present in dust as original substances or residues) and any documentation/quantification

- Pesticides
- Fungicides
- Fumigants
- Other additives

**Biomaterials derived from/contained in dust** and any documentation/quantification

- Bacteria/endotoxin
- Fungi/mycotoxin
- Rodents/ Birds/ Insects (storage mites, house mites)/Other animals
- Indicators of above (skin/hair/feathers/other)
- Other

3. **DUST GENERATING OPPORTUNITIES IN THE GENERAL WORK ENVIRONMENT**

Opportunities for materials to become airborne & dispersed from secondary dust sources.
Outside - Prevailing weather conditions
- Proximity to other dusty tasks
- Nature of surrounding environment (e.g. sewage works, roads, housing, industry, mining)

Inside - Volume of workroom
- General ventilation: good/poor natural; good/poor forced or mechanical
- Dust observed in general work environment: coating surfaces; visible in air; visible in light beam

4. DUST GENERATING OPPORTUNITIES WITHIN THE TASK
Opportunities for materials to become airborne, dispersed throughout workplace environment and become a significant exposure issue during task performance.

Duration of exposure to dust during task: Duration of task
Amount of grain handled in task (processing rate)
Performance of task impacting on exposure:
- Nature of task: Manual task: shovelling/tipping/sweeping/wiping/vacuum/other
- Mechanised task: dropping/conveying (open/closed; mobile/fixed)/sieving/sucking/drying/aerating/other
- Automated task: remotely controlled
- Equipment used e.g. brush and shovel, barrow, loader type
- Proximity of worker to dust generating source: Near field < 1 m/Far field >1 m

5. EXPOSURE CONTROL MEASURES
Work management, environmental and personal exposure reduction interventions.

Controls - Enclosure of dust generating activity: full/partial, room, fume cupboard, glove box
- Local exhaust ventilation:
  - receiving (receptor hood, canopy hood)
  - capturing (movable capturing hood, rim or lip extraction, capture hood, downdraught table)
  - other (to be specified)
- Enclosure of operator: full/partial, ventilated/not ventilated
- RPE - types (disposable masks, half/full-face masks), models
- PPE - clothing (issued by employer Yes/No)
- Cleaning programme; Storage programme: Replacement policy
- Job rotation
  - Good work practice stand back from source

Ensuring Effectiveness and Operation of Controls
- Maintenance of controls: in-house/contractor, frequency e.g. annual shutdown
- Correct usage and storing: Training, Checking, Supervising
- Measurements from personal/static dust or bio-aerosol monitoring
- Information from SDS, suppliers, trade organisations, advisory bodies

Control effectiveness with respect to industry standards: H/M/L

7. ESTIMATED LEVEL OF EXPOSURE DURING TASK
This will be used for analysis of the survey findings and not discussed during the interview.
Figure A1.3 Wheat Harvesting

Figure A1.4 Importing Grain
Figure A1.5 Wheat Milling Flow Figure showing Potential Exposures
**Figure A1.6** Malting Flow Figure showing Potential Exposures
# APPENDIX 2 – TYPICAL CONTROL MEASURES AND EXPOSURE RATING FOR TASKS IN THE GRAIN INDUSTRY

(Exposure codes - insignificant exposure (I), significant exposure (S) or unknown exposure (U))

<table>
<thead>
<tr>
<th>Task</th>
<th>Industry sector</th>
<th>Task elements</th>
<th>Typical control measures</th>
<th>Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control room operations</td>
<td>Farming</td>
<td>Grinding and measuring the grain moisture</td>
<td>Segregation</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Import/export Commercial storage</td>
<td></td>
<td>General ventilation and Segregation</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Milling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Malting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Import/export Commercial storage</td>
<td>Monitor the grain quality (including moisture) remotely via sensors</td>
<td>General ventilation (air conditioned room) and Segregation</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Milling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Malting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Animal feed</td>
<td>Grind and analyse sample - laboratory bench work</td>
<td>General ventilation (air conditioned room) LEV not routinely applied (occasionally performed in fume cupboard)</td>
<td>I</td>
</tr>
<tr>
<td>Farming</td>
<td>Import/export Commercial storage</td>
<td>Transferring grain (into and out of drier) by operating overhead conveyors and elevators</td>
<td>General ventilation (air conditioned room) and Segregation</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Malting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Animal feed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Import/export Commercial storage</td>
<td>Malting</td>
<td>Transferring grain through processing plant beyond the drier by operating overhead conveyors and elevators</td>
<td>General ventilation (air conditioned room) and Segregation</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Malting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Animal feed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Import/export Commercial storage</td>
<td>Milling</td>
<td>Process control operations (setting operational parameters, initiating/terminating and running processes)</td>
<td>General ventilation (air conditioned room) and Segregation</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Malting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Animal feed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task</td>
<td>Industry sector</td>
<td>Task elements</td>
<td>Typical control measures</td>
<td>Exposure</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
</tbody>
</table>
| Bulk Outloading                  | Import/export         | Lower the delivery spout on the bin and the mobile local extract ventilation hood into the tanker ‘hull’ and fill tanker. During filling the tanker is parked in the loading bay but operators do not need to stay in this yard or building. | LEV and Segregation
During filling tanker driver spends time in weigh bridge office, vehicle cab or dust free area of yard
Outloading operator initiates/terminates the tanker filling from weigh bridge office | I        |
<p>|                                  | Commercial storage    |                                                                               |                                                                                           |          |
|                                  | Malting               |                                                                               |                                                                                           |          |
|                                  | Milling               |                                                                               |                                                                                           |          |
|                                  | Animal feed           |                                                                               |                                                                                           |          |
| Intake                           | Import/export         | Fit/remove dust sock onto/off hatch before/after tipping                      | None                                                                                     | I        |
|                                  | Commercial storage    |                                                                               |                                                                                           |          |
|                                  | Milling               |                                                                               |                                                                                           |          |
|                                  | Malting               |                                                                               |                                                                                           |          |
|                                  | Animal feed           |                                                                               |                                                                                           |          |
|                                  | Farming               |                                                                               |                                                                                           |          |
| Routine inspection of plant      | Import/export         | Walking though the plant and premises to carry out a visual monitoring/observation of automated processes initiated in the control room | None                                                                                     | I        |
| operations                       | Commercial storage    |                                                                               |                                                                                           |          |
|                                  | Milling               |                                                                               |                                                                                           |          |
|                                  | Malting               |                                                                               |                                                                                           |          |
|                                  | Animal feed           |                                                                               |                                                                                           |          |
|                                  | Farming               |                                                                               |                                                                                           |          |
| Harvesting                       | Farming               | Combine harvesting the field crop and tipping from the cart into the yard     | General ventilation and Segregation (air conditioned and filtered cabin enclosing driver) | I        |
| Drying grain                     | Import/export         | Manual operation of drier from consul beside drier.                           | None                                                                                     | I        |
|                                  | Commercial storage    |                                                                               |                                                                                           |          |
|                                  | Most malting          |                                                                               |                                                                                           |          |</p>
<table>
<thead>
<tr>
<th>Task</th>
<th>Industry sector</th>
<th>Task elements</th>
<th>Typical control measures</th>
<th>Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other cleaning – non-malting</td>
<td>Farm Import/export Commercial storage Miller Maltings</td>
<td>Vacuum cleaning drier at the end of harvest Vacuum cleaning premises and plant using in-house vacuum line on a regular basis (continuous cleaning of premises; dedicating one shift a week to cleaning plant and premises or cleaning work area every shift)</td>
<td>RPE (FFP3)</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Maltings</td>
<td>Wet cleaning shed floor with road sweeper vehicle</td>
<td>Segregation (cabs on vehicle enclosing driver)</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Farms Commercial storage Maltings Animal feed</td>
<td>Manual pressure washing premises &amp; vehicles</td>
<td>RPE/sometimes no RPE</td>
<td>U</td>
</tr>
<tr>
<td>Pelletising</td>
<td>Milling Maltsters Animal feed</td>
<td>Organic waste from flour production (fines, dust from LEV systems, bran etc.) is mixed with water and sometimes a binding agent and pressed into animal feed product Commercial and pedigree animal feed made by pressing feed grain and animal feed from mills</td>
<td>Segregation (housed in a dedicated room in mill) None</td>
<td>I U *</td>
</tr>
<tr>
<td>Storage operations</td>
<td>Farms Import/export Commercial storage Maltings Animal feed</td>
<td>Install pedestal ventilation pipes or augers in shed Inspect automated shed operations Unblock obstructions in transfer systems e.g. elevators Sweep edges (of grain piles) with brush Transfer grain around yard &amp; into and around sheds by vehicle</td>
<td>None None RPE (FFP3) None Segregation (air conditioned and filtered cabin enclosing driver)</td>
<td>I I I U</td>
</tr>
<tr>
<td>Blending additives</td>
<td>Milling Animal feed</td>
<td>Flour is mixed with nutrients removed during the milling operation and additives using a manually operated batch process</td>
<td>RPE(FFP3) /LEV/limit frequency of operation</td>
<td>S</td>
</tr>
<tr>
<td>Task</td>
<td>Industry sector</td>
<td>Task elements</td>
<td>Typical control measures</td>
<td>Exposure</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Packing</td>
<td>Milling</td>
<td>Operation of a manual bagging unit to fill bulk containers</td>
<td>LEV and may be enclosed by pulling the ‘spout’ on bulk container over the mouth of the flour dispenser pipe and securing it on the pipe</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation of a mechanised/automated filling station to fill 25-75 kg bags</td>
<td>LEV and bleeper (alarm summons in event of interruption to operation or breakdown)</td>
<td>I</td>
</tr>
<tr>
<td>Clearing blockages</td>
<td>All sectors</td>
<td>Unblock obstructions in transfer systems e.g. elevators or processing plant e.g. screens</td>
<td>RPE (FFP3)</td>
<td>S</td>
</tr>
<tr>
<td>Ship loading</td>
<td>Import/export</td>
<td>Sweeping up spills from lorries tipping and clam-shell grab on crane</td>
<td>Segregation of crane operator (air conditioned and filtered cabin enclosing driver) and RPE (FFP3) for outside operators</td>
<td>U</td>
</tr>
<tr>
<td>Cleaning - dry sweeping</td>
<td>All sectors</td>
<td>Sweep shed floor between grain piles and emptied sheds with mechanised sweeper</td>
<td>RPE (FFP3)</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sweeping up spills from leaks or opened plant with brush or scissors mop</td>
<td>RPE (FFP3)</td>
<td>U</td>
</tr>
<tr>
<td>Other cleaning malting</td>
<td>Malting</td>
<td>Sweeping dry waste and culms out from underneath/inside the kiln</td>
<td>RPE (powered full-face respirator - TM2 or 3)</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hosing/power washing inside steeps and germinators and underneath germinators and kilns</td>
<td>Oil skins and visor</td>
<td>I</td>
</tr>
<tr>
<td>Silo cleaning</td>
<td>Malting</td>
<td>Scraping and sweeping inside empty silo</td>
<td>RPE (FFP3)</td>
<td>S</td>
</tr>
<tr>
<td>Loading with a shovel</td>
<td>Farms Merchants</td>
<td>Loading open-topped lorry with shovel loader</td>
<td>Segregation (air conditioned and filtered cabin enclosing driver)</td>
<td>U</td>
</tr>
<tr>
<td>Cleaning using compressed air</td>
<td>All sectors</td>
<td>Blowing out settled dust from high level surfaces and ledges in premises and inaccessible spaces in plant and vehicles</td>
<td>RPE (FFP3)</td>
<td>S</td>
</tr>
</tbody>
</table>

*Note exposure during commercial feed pelletising is judged insignificant (I)*
APPENDIX 3 - HOT AIR GRAIN DRYING TECHNIQUES

The basic principle underpinning grain drying is that air is heated in a furnace and is then drawn by a fan through a moving or stationary bed of grain. The hot air passes in through the bottom of the grain bed and out through the top, in a counter current direction (sometimes together with a co-current air flow) when the grain is mobile. Chaff, straw and other impurities are entrained in the extracted air coming out of the drier.

Three drying systems were observed during the site visits, namely floor, continuous and batch. All of the four farms and pilot farm visited operated one drier whereas the grain merchants used three driers and one depot pre-dried the grain for 3 days (Table A3.1). The systems are described briefly in Sections A3.1, A3.2 and A3.3.

<table>
<thead>
<tr>
<th>Drying system</th>
<th>Farm</th>
<th>Grain merchant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Continuous - tower</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Continuous - belt</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Batch</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

A3.1 Floor (Bin or Tray) Drying

The basic system of floor drying comprises a perforated floor, a grain spreader (manual or mechanised), a fan and heater, and a sweep auger. In this system, grain is loaded into the bay in which it remains stationary throughout the drying and storage period.

This system is widely used in north Scotland around the Aberdeen area and was the system used at the pilot farm visited (Section A3.4) and was the preferred system in some commercial grain merchants in the same region.

A3.2 Continuous Flow Drying

In continuous drying grain is moved either on an encased and ventilated inclined belt (belt drying) or as a ventilated column of grain contained in a drying shaft (tower drying).

In a continuous belt drier, hot air passes through a moving bed (about 25 cm thick) of grain on an enclosed inclined louvered conveyor belt. The hot grain falls off the end of the 3 m belt onto a return belt moving underneath and in the opposite direction to the first belt. Dust and chaff is lifted by the exhaust air rising from the bottom bed. This air is exhausted out the top of the drier in one case through a cyclone. The dust and chaff from the exhausted air is collected in a trailer, a shed or outside and removed at the end of harvest. Cool air is blown through the grain on the second traverse. The cleaned warm air is recycled into the drier building. The drier can be fitted with an overflow mechanism to return wet grain back to the intake side.

In the tower drier the wet grain is conveyed up to the top of the drier and drops down the shaft on an open cycle (once every 50 seconds for a distance of about 6 cm) through a blast of hot air. It is held in a stationary position for a short time on a closed cycle and then descends again giving rise to a slightly staggered flow. The grain has a residence time of nearly 1 hour in the drier and the dried grain is released at the bottom.
A3.3 Batch Drying

In the batch drying process a column of grain is loaded, dried in hot air for a set time and then unloaded from the drier. Moving air is not used but the grain can be mixed with the hot air using an auger during its residency time in the drier. The dried grain is then released into storage bins where it cools before it is sent into the dry grain store. This dries between 10 and 20 tonnes per hour.

A3.4 The Pilot Farm

The pilot farm visited is to all intents and purposes a smaller version of a working farm. The farm was visited in May when the store was empty and then again in September during unloading of the filled shed.

The farm has its own combine harvester and a newly installed drying facility. This uses a drying system designed to minimise the movement of grain hence the generation of dust. These systems are used on commercial farms and stores. The grain is dried on the floor in two bays separated by a covered timber frame chamber that supplies under floor heating to the bays on either side (Figure A3.1). The hot air currents are forced out of the chamber by a fan through floor level vents (Figure A3.2), up into the grain via strips of ventilation in the floor and are vented outside through the high level louvers in the walls.

Figure A3.1 Grain drier bays

Figure A3.2 Manually controlled floor vents for under floor drying of grain
Gas burners are used to fuel the drier. In warm weather there is the option of switching to using hot air sucked from the outside environment for drying grain. In front of the bay is an open area where vehicles can turn and manoeuvre to tip out the grain. The harvested grain is dumped automatically from a door in the trailer, undercover and without the driver getting out of the cab. A forklift truck fitted with a shovel pushes the grain up to a height of about 3 m. A disposable respirator (P3 type) is worn by the forklift driver. The grain is turned using vertically mounted screws (Figure A3.3, shows the screws lying on the floor prior to use), which are moved forward and back through the grain on a high level track. The grain produced is sold on for processing in the normal way.

![Screws](image)

**Figure A3.3** Screws for turning the grain bed

The store (Figure A3.4) is emptied in stages by filling open top lorries from a transport fleet hired or owned by the purchasing company. The farm operator drives a shovel to scoop up the grain from the stock pile (Figure A3.5) and empties it into the lorry (A3.6). It takes about 15 minutes (18 trips) to fill the 28 tonne lorry with grain. The lorry driver sweeps the edges of the stockpile with a brush to push the grain back into a pile (A3.7). Each of the two piles contains about 6 lorry loads worth of grain.

![Stored grain](image)

**Figure A3.4** Stored grain in a floor drier
Figure A3.5 Shovelling grain from stockpile

Figure A3.6 Transferring grain from shovel to lorry

Figure A3.7 Sweeping the edges
APPENDIX 4 - MILLING

A4.1 INTRODUCTION

Flour milling is a capital equipment intensive process. Machinery is seldom laid out in a traditional easy-to-follow production line fashion and there are two very practical reasons why this is so. Firstly, a mill is ideally a ‘tall thin’ operation where grain is elevated upwards in order to be gravity fed down through the various tasks performed on it in order to turn it into flour. Mill houses therefore have a natural tendency to be constructed as multi-storey buildings rather than long, flat buildings. Secondly, grain storage silos and the transferring systems, which link them to each other and to the rest of the plant, are central not only to storage of raw wheat, dirty wheat (cleaned and stored on the intake side) and clean wheat (cleaned and held on the mill side) but also to the wheat blending task. Silos need to have differential storage capacity to enable mill houses to hold and handle large quantities of different grain types. This means there needs to be numerous grain silos, rather than a single enormous one. This often requires a considerable amount of land for silos serving both the intake and mill sides of the mill. Most of the plant associated with milling tasks tends to be built around (under the same roof) or near to the silos. The grain is transferred between task areas by enclosed and aspirated elevators, conveyors and pipes. This means that grain transferring and extract ventilation systems (fans and filters) may take considerable space. It is usual to use long surface mills with a floor area of about 150 m² to house the mill stands and purifiers.

Mill houses have no wall or ceiling fans and are lit by artificial lighting. Where glass windows are present they are not opened. The entire milling plant is operated under negative pressure and air is pulled from the mill floor through the plant to aspirate the wheat. Light materials, such as grain dust, are filtered out of the aspirated air and collected to make animal feed pellets. The negative pressure inside these spaces is evident when doors quickly slam shut after these areas are entered. Air vents are used to supply intake air. The casing for the extraction filters is fitted with explosion vents.

A4.2 THE MILLING PROCESS AND PLANT

In most mills the machinery used to carry out the grain cleaning tasks (Figures A4.1 and A4.2) is distributed over small areas of different floors of buildings on the sides of silos. This is commonly referred to as the screen room.

Figure A4.1 Separator table
The separator table is basically an enclosed screen onto which the incoming dirty wheat stream falls. The aspirator lifts off the dust and the chaff, straw and foreign seeds fall over the edge while the good quality grain goes through the screen.

![Figure A4.2 Indented cylinder separator](image)

The indent separator (trieur cylinder) removes grain of the desired size which lodges in the cavities of a rotating cylinder.

Combination cleaners incorporate about four cleaning mechanisms in one machine and remove large items such as small stones and string; ferrous metals; chaff and straw; foreign seeds and sand. A scourer removes the dirt adhering to the surface of the broken wheat by beating the wheat against a screen or rough surface with rotating paddles. Cleaning is a continuous and automated process and it takes about 10 minutes for the wheat to flow through the screen room.

Traditionally, gristing is done at the beginning of the milling process and finished flour is obtained directly after milling. Gristing is the combination of different types of wheat for grinding together in order to produce a specific grade of flour. This process is represented by the flow diagram, excluding task 10 (see Figure 5.21 in the main text for the flow diagram). More recently mills have moved towards homogenising flour in blending plants after the milling process. This uses a batch system in order to blend the base flour streams into the finished flour after milling (by turning it over in silos). This is represented by the flow diagram in the main text (excluding task 4). Today mills tend to both homogenise wheat and blend flour in their production process in order to optimise their product range.

After cleaning, wheat coming into the mill is blended to a grist or part-grist and then conditioned (dampened) prior to milling. Milling is the gradual grinding of wheat into mixtures of flour, course flour (semolina), endosperm (precursor to course flour), bran and bran with endosperm still attached. After milling the flour streams are mixed into a commercial product, auxiliary ingredients are added and the finished product is packaged and warehoused or stored in silos for bulk outloading.

Conditioning involves getting water into the bran and endosperm. This is done in order to toughen the bran so it separates well from the underlying endosperm which is then more easily ground to flour. The wheat goes through a preheat section, which heats it to about 45°C; a water addition section where the wheat absorbs water and a cooling section which cools the wheat to room temperature. Cooling is carried out by allowing evaporation from the grain surface, blowing cold air over the grain or dipping the grain into cold water and spinning off the water in a centrifuge. Conditioning takes about 1.5 hour to complete. The conditioner is totally enclosed.
and in line with the grain conveyor system. The wheat is then stored in the holding bins for 8 to 18 hours. Sensors are used to automatically monitor the moisture content of the wheat and from this result the amount of water added to the grain can be adjusted.

Cleaned and conditioned wheat passes to the break rollers. These are designed to separate the grain into its three parts using pairs of grooved rollers (Figure A4.3).

![Figure A4.3 Break mill rollers](image1)

The top roller is set to rotate in the opposite direction to the bottom one and at a faster speed. The wheat stream is passed between the rollers where the bran coating is removed from the underlying endosperm. The rollers are enclosed in ventilated metal cabinets called mill stands (Figure A4.4). There are usually five or six different break roller mill stands which are used to ensure all the endosperm is separated from the bran.

![Figure A4.4 Mill roller stands](image2)

The stands are fitted with an inspection window covering the rollers, beneath which there is an inspection door covering the output stream. Little flour is produced on the first passage (called the ‘first break’) of wheat through the first mill stand. This ‘first break’ product stream is mainly bran, bran with some endosperm still attached and large pieces of endosperm. Many different types of cleaning plant are commercially available for separating the ‘crude’ flour into semolina.
and bran. Sifters and purifiers are always part of the process. The bran with endosperm attached will continue through the break roller machines.

The crude stream is pneumatically conveyed (blown in pipes) to the sifters via a cyclone seal. This serves to slow down the rate at which the first break product enters the sifter. Sifters are basically oscillating screens (see Figure A4.5) encased in a ventilated box which is weighted in the centre.

![Figure A4.5 Flour sifters](image)

They separate a stream from a roller into at least 6 fractions. The box is rotated around the weight by an external roof mounted drive. A typical sifter might contain over 20 different screens. These are mounted horizontally in the box in a series of layers. Each layer is made up of successively finer screens running down the height of the box. The stream enters at the top of the box and may be fed into 2 different feed streams by a plate. The large material in the stream flows over the coarse screen and the fines fall through to the next screen. This action is repeated down each level of the box until the final screen is reached. The separated streams pass down (internal) vertical channels and out of the sifter through a flexible conduit at the base. The screen apertures can clog (blind) and this is reduced by placing a cotton pad or a plastic ball between the upper and lower mesh of the screen frame. These strike the sides of the frames and knock out the material lodged in the mesh.

The stream containing endosperm pieces and the flour coming from the sifter may still contain bran. This has to be removed from the mixture by passing the stream through a purifier (Figure A4.6).

![Figure A4.6 Purifier](image)
A purifier consists of a longitudinally oscillating screen about 2 m long which slopes downwards. There are three or four layers of screens and these get coarser the closer they are to the bottom end of the purifier. It is enclosed and extracted. The compartment above the screen is connected to a plenum. Air is drawn through the entire compartment and the air flow can be adjusted. This is called aspiration. Light material is sucked through the air ducts above the compartment and carried to a dust collector. The shaking movement together with sliding down the inclined bed separates out semolina at the head, courser semolina at the end and light extraneous material falling over the edge at the back of the purifier.

Ingredients are added to the flour to replace the natural nutrients removed by the milling process and to enrich the flour in order to achieve nutritional benefits for the community. Auxiliary ingredients added include gluten (as replacement for natural protein removed in the milling process and as a flour improver), α-amylase (flour improver), minerals and vitamins required by law [calcium as creata preparata, pharmaceutical grade calcium carbonate, iron, nicotinic acid, vitamin B1 (thiamine) and vitamin C]. These are manually tipped from bags through a free standing or table mounted hopper into bins from which they are automatically dispensed into the flour. The table mounted hopper has local exhaust ventilation fitted to a table with low walls on three sides. This ‘ripping and tipping’ of bags to top up the bins is estimated to be carried out once a week and could be a source of ingredient dust exposure.
APPENDIX 5 - MALTING

A5.1 INTRODUCTION

Intake, pre-malting tasks and steeping will be discussed in this section. Flatbed germination and drum germination are discussed in Sections A5.3 and A5.5 respectively.

The ‘tall thin’ approach for the construction of the buildings to house the milling plant is equally well suited to the malting process. However, malting houses tend not to be high, reaching two or three storeys at the most, or have mezzanine levels. Taller malt houses are found more often in England than Scotland. Maltings are of lower height for two reasons. Firstly, the large size of the malting process plant makes it is easier to install the machinery on the ground level. Wire grating flooring is used to provide access around large pieces of machinery and to locate plant at one or two levels above ground floor. Secondly, different tasks in the process require different humidity and temperature conditions for operation. In order to effectively set and control these conditions for each task it is easier to house the plant in individual buildings or dedicated rooms. This is in contrast to flour mills, which tend to have solid flooring at all levels.

There is no air conditioning or forced general ventilation in the buildings. However the general ventilation provided naturally by opening screened windows and doors when entering and leaving the buildings appears adequate given the working conditions (large buildings with high ceilings and open grid floors) and because the routine duties of operators do not require them to be on the floor continuously.

A5.2 THE MALTING PROCESS AND PLANT

The barley is cleaned in a drum dresser and then dried. Barley from Scotland can have 20% water content and barley from other places generally has around 14%. Tower driers are commercially available and are used to reduce the moisture content of the barley to around 12% for storage. The grain flows in the top and passes out through the bottom. Grain spends about 2 hours in the driers. Up to 20 tonnes of grain can be dried every hour.

The dried grain may be cleaned again before going into storage using a flat bed dresser, to remove small corns and husks. After kilning the malt may be cleaned once more before being stored for outloading. There are usually at least two separate grain cleaning tasks carried out in the process giving a maximum of four cleaning stages.

Malting houses usually have an overall steep capacity of around 500 tonnes of barley. These are generally conical steeps which extend over two storeys within the building from rim to bottom (Figure A5.1). They can stand over 7 m high with about 5 m diameter at the rim. The steep is loaded with grain from an overhead conveyor.
The grain passes vertically down a chute into the centre of the steep, which has been partially filled with water (Figure A5.3). The grain undergoes breakage as it loads into the steep and this generates dust. The stream of barley is sprayed with water through nozzles positioned in a ring around the mouth of the chute (Figure A5.3). Some steeps also have nozzles spraying out water on the rim of the steep.
Figure A5.3 Section of the top of a steep showing ring mounted dust suppression spray nozzles fitted to grain chute and steep rim

The steep takes about 15 minutes to fill. They are often filled and worked through the process in pairs. The barley stays in the steeps for about 40 hours. During this time the bed of grain goes through a soaking (3 waters) and air resting (3 dry) cycle. The immersion periods range from 4 to 6 hours and the resting periods are between 13 and 17 hours long. Residence time in the steeps is strictly monitored because if the grain is over-steeped it can become difficult to release it through the bottom of the vessel. At one site visited the grain is still moved from one steep tank to another during the air resting period. This helps to keep the barley aerated and flowing well through the process. The latter is important in preventing barley sticking in the grain valve at the bottom of the steep.

More recently aeration has been achieved by grain ventilation of the bed when the grain is resting (Figure A5.4). Maltsters frequently refer to this as carbon dioxide extraction. As the barley absorbs the water it begins to respire and sprout. Consequently oxygen is taken in and carbon dioxide is released. Therefore oxygen must be supplied to and carbon dioxide removed from the barley. Air is sucked down though the top of the bed in order to ‘entrain’ the carbon dioxide building up in the sprouting barley. This is known as downward aeration of the bed. Because carbon dioxide is denser than air it moves towards the base of the steep where it is withdrawn. There are some sophisticated steep designs in use that use a plenum system between the inner and outer layers of the cone to even out the airflow across the grain bed. Compressed air is blown up though the bed using nozzles embedded in or on pipes attached to the cone sides or through a centrally mounted steep rouser. The latter is a pipe through the grain and water is lifted from the bottom by compressed air and spills out over the top and falls through the air back into the steep.
Steep emptying takes a maximum of 35 minutes to complete. The moisture content of the grain is taken up to 44% by the end of the second soak. The atmosphere in the steep room can be dusty during filling.

After steeping the barley is then ‘cast’ or released from the release valve and conveyed to the germinator or to the GKV. The immersion water is drained off before the chitted grain is released from the steep. Wet casting (of water and grain) which appears to help limit germination in the steep has become less used.

A5.2 CIRCULAR FLATBED GERMINATING VESSELS AND CIRCULAR KILNS AND CIRCULAR GKV

Circular flatbed germinating vessels which can kiln the malt (GKV) are commercially available. Otherwise kilning is carried out as separate tasks. Circular flatbed kilns are usually slightly bigger in diameter than the germinating vessels and two steeps often fill a kilning vessel (Figure A5.5). Germination turns the steeped barley into what is termed ‘green malt’ which is considered to be ‘modified’.

Temperature controlled germination takes place over about 4 days at around 20°C. The grain is loaded from above and is discharged into an under floor conveyor from the side. This uses a
horizontally mounted auger which is lowered into the vessel when emptying is required. Cool, wet air is blown up through the bed of barley usually via vents in the rotating floor. The bed is turned mechanically with vertical screws attached to a fixed walkway extending from the centre to the side of the vessel. The left hand side of Figure A5.5 shows a section the grain bed on the moving floor as seen from the walkway. It shows the walls and centre of the vessel. Alternatively if the floor is stationary, the turning equipment can be rotated around a central point. This was not observed on any site visit. Turning is carried out to stop the rootlets entangling and forming a matte, to aerate the bed (take in oxygen and release carbon dioxide) and to prevent localised temperature rises. If the air is not humidified, then the grain will dry out, sprouting will stop and modification will be incomplete. The fan creating the air currents is situated on the side of a roughly 2 m high space underneath the germinator. The carbon dioxide released during kilning is vented outside through louvers. Temperature is controlled by altering the temperature of air passing through the bed ('air on' temperature). Louvers in the walls of the building are used to let in usually cold air from outside if the temperature is too high. This mixes with and cools down the air coming off the bed which is warmer after passing thorough the germinating grain. This air is still saturated with moisture mixture because it has removed water from the grain and this can be re-circulated through the venting system.

The green malt is moved to the kiln for about 2 days or less to be dried to 3 to 4% moisture. Kilning uses a double deck system where the grain bed is walled in and sits on a perforated floor above a hot air chamber. Air is heated using gas or oil and a fan is used to pull the air into the chamber underneath the floor and then force it up through the vents in the floor and through the grain bed. In this case the kilning vessel is a ‘two storey’ vessel and there is single entry access room where it is housed. Alternatively, there is separate access via a doorway (for operators to enter) or a hatch (for equipment to enter and operators remain outside) into each level of the kiln. Conveyors load the grain into the kiln from the top level.

The process temperature is usually raised during kilning to give the desired product. In this way kilning defines the colour and the flavour of the malt. Peat smoke can be piped into the kiln in order to give malt that characteristic flavour. The kilned malt is friable and rootlets can break off and fall though the vents in the kiln floor and into the air space beneath.

A5.3 DRUM GERMINATING VESSELS WITH CIRCULAR AND RECTANGULAR KILNS

Drums are long horizontally roller mounted cylinders used to germinate and turn grain. Figure A5.6 shows a bank of germinators and an operator (foreground) inspecting one of the drums.
They can hold around 32 tonnes of barley. The rollers rotate the drum once an hour to provide 2 revolutions every 8 hours in order to turn the grain. Of the two standard types of drums, the box drums are more widely used by malting houses today. In this design, water is sprayed under and through a perforated plate supporting the barley only when the drum is stationary with the plate horizontal. The grain is about 1.5 m deep. Fins extend from the sides of the drum and spread the grain out evenly during filling (through pipes at one end) and emptying into hoppers (through opened hatches around the curved side (Figure A5.7).}

As for flatbed germinators, the temperature of the ‘air on’ is used to regulate temperature through the bed.

The green malt is then conveyed to the kiln. About two drums will fill three rectangular kilns. The grain is dropped into the middle, close to the floor and spread over the floor using a screw, which rises as the bed gets deeper. The bed can be about 2 m. At one site visited the ducting on the kilns had been inter-connected in order to exchange air during kilning and conserve energy.
A5.4 SINGLE VESSEL PROCESSING

It is possible to have multi-use vessels for carrying out steeping, germinating and kilning of barley. Certain malting houses do have these, but there are some drawbacks in energy and water consumption. Since all the tasks are carried out in one vessel, process management is made easier in that no time or equipment for transferring grain between vessels is needed. The barley is less likely to break or become damaged when it is stationary and this adds value to the product. This compartment or box type malting uses a rectangular open sided container. This side is closed when the box is in operation. There is a vented floor to support and aerate the barley. The bed is usually 1 m deep and can take 40 tonnes. Tracking is attached to the long side walls and the there is access through the near short wall. The track is used to move equipment such as screws and scrapers into and out of the box. Scrapers are used to level the bed during filling and pull the grain to the end of the box for emptying into a conveyor. There is an external rail for moving this equipment between boxes. Some equipment is mounted on wheels so that it can be pushed along the gantry built in front of the boxes. Grain is loaded into the box from above via a spout or thrown in from the side using a portable pneumatic conveyor (Figure A5.8).

![Image of loading barley into the box](Figure A5.8)

Water is added to completely immerse the grain for 24 hours (Figure A5.9).

![Image of adding water to the box](Figure A5.9)
The boxes are on a raised floor. Air is blown into a void underneath the boxes by a fan and the air currents move up through the bed from below.

**A5.5 PROCESSING CO-PRODUCT**

Roots are removed from the sprouted barley in a deculmer. Rootlets are stored in a silo then blended with barley and silo dust and put through a pellet press, cooler and silo in outloading. These are high in fibre with about 20% protein and are sold to the animal feed industry.
Current control standards for tasks with high exposure to grain dust

Six sectors of the British grain industry were investigated to try to identify and characterise exposure-significant tasks in terms of the inhalable dust, microorganism, endotoxin and mycotoxin exposures associated with these tasks. Information was collected from stakeholders in the industry by telephone interviews and during visits to company premises. In addition, the available scientific literature was reviewed to identify relevant exposure data.

It was judged that some cleaning activities and certain process tasks may create airborne inhalable dust levels in excess of the British Workplace Exposure Limit (WEL) of 10 mg m\(^{-3}\). Long-term average levels are probably generally less than about 3 mg m\(^{-3}\), with perhaps 15 to 20% of individual exposures above the WEL. Endotoxin levels were judged likely to be less than 104 EU m\(^{-3}\) throughout the industry provided inhalable dust levels are less than 10 mg m\(^{-3}\). There is no published exposure data on mycotoxin, respirable crystalline silica and mite contamination but these are not considered to present widespread problems in the British industry.

Further improvements in control technology and the use of respiratory protection are needed in some sectors of the industry.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.