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- Share information about health and safety interventions;
- Share information about solutions to health and safety problems;
- Encourage intellectual debate around propositions for improvements in practice.

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19 GETTING THE BEST ANSWER BY ASKING THE RIGHT QUESTION - CASE STUDIES IN OCCUPATIONAL EXPOSURE TO MOULD Claire Bird, Sita Balshaw, Wayne Anderson
Case severity and OHS observed risk and outcome performance

STEPHEN ALTREE-WILLIAMS

ABSTRACT
A numerical measure of case severity is important because it allows quantitative evaluation of the second independent characteristic (i.e., in addition to case rate) of OHS observed risk for a work environment. The nature of the case severity characteristic in OHS is considered and the observed numerical data on case severity for serious OHS cases in the Australian national OHS outcome data are evaluated. The case distribution by Safe Work Australia severity groupings is documented and the ‘mean time lost’ parameter is calculated for Mechanism of Incident group and for industry.

Mean time lost is sensitive to variation in high value outliers in the case severity distribution and can be readily calculated for the local workplace, for intra-industry aggregations made up of independent businesses, and nationally.

Mean time lost data for the National OHS Strategy priority industries (together with mining and education) are provided. The results show that all these industries have achieved a substantial reduction in their case severity for serious OHS injury cases by the middling-period of the National OHS Strategy 2002-2012, with parity-attenuated case severity in Australia reducing by 11% over the five year duration to 2006-07.

INTRODUCTION
It is self-evident that severity is an important priority in OHS prevention. The performance test of ‘reasonably practicable’ in OHS legislation takes into account both likelihood (i.e., the case rate) and degree of harm (i.e., the case severity) (Australia, 2011; section 18). The National OHS Strategy (NOHSC, 2002) highlights the importance of reducing both case rate and case severity with its national priority to “reduce high incidence/severity risks”. Safe Work Australia (2010, 2011a) brings strong attention to this matter with its actions and statistical reports on occupational fatalities.

The Australian national OHS outcome statistics (Safe Work Australia, 2011b,c; WRMC, 2010) contain an inherent severity weighting because only serious OHS cases (resulting in one week or more off work) are logged. Nevertheless, the difference in severity between cases of 1 to 5 weeks duration, 12 to 25 weeks duration and 52 or more weeks duration is significant and it is important to have a numerical measure of such differences for use in the assessment of observed risk and outcome performance in a work environment.

Numerical estimates of the likelihood component of the observed risk begin by expressing case rates as case numbers per million work-hours (frequency rate) or case numbers per thousand full time equivalent (FTE) employees (incidence rate [BM]). Consideration of the natural characteristics of frequency and incidence (Altree-Williams, 2010) indicates that both frequency rate and incidence
rate [BM] have functional roles in the documentation of observed risk and outcome performance for a workplace. The frequency rate measure is directly relevant to the Occupational Injury (Safety) domain and its component Mechanism of Incident groups (ASCC, 2008). Incidence rate [BM] is the appropriate measure to use for the two health domains – Occupational Disease and Public Health Influence – and their component groups (Altree-Williams, 2011), as summarised in Table 1.

Table 1 Prevention-focussed OHS case domains and their appropriate rate parameter for the quantitative assessment of observed risk and outcome performance (Altree-Williams; 2010, 2011)

<table>
<thead>
<tr>
<th>Prevention-focussed OHS case domain</th>
<th>Appropriate rate parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCCUPATIONAL INJURY(SAFETY) domain</td>
<td>frequency rate</td>
</tr>
<tr>
<td>OCCUPATIONAL DISEASE domain</td>
<td>incidence rate [br]</td>
</tr>
<tr>
<td>PUBLIC HEALTH INFLUENCE domain</td>
<td>incidence rate [br]</td>
</tr>
</tbody>
</table>

CASE SEVERITY

Conceptually, case severity for a work environment provides a second independent numerical indicator of OHS performance. Like case rate, it would be reasonable to expect a case severity measure to decrease through time if health and safety was being improved at a work environment as called for under the Work Health and Safety Act 2011 (Australia, 2011; section 3(1)(g)).

Under the National Data Set (NOHSC, 2004), both categorical and numerical data are available on the severity of each serious OHS case. Categorical data are provided in the Nature of Injury/Disease occurrence classification schedule (ASCC, 2008). Numerical data on the severity of serious OHS cases (as mediated by the inputs of first aid, medical treatment and rehabilitation) are provided through the National Data Set Item E1 – Time lost.

These latter data are used to generate the ‘median time lost from work per case’ which is the numerical case severity measure currently used in Australia (Safe Work Australia, 2011b,c; WRMC, 2010).

The median parameter provides a rather insensitive measure of range in an origin-bounded skewed distribution like that of case severity. However, the time lost datum is available for each serious OHS case and thus it becomes practicable to determine the observed ‘mean time lost from work per case’ parameter. These data are held by Safe Work Australia (2011d) and the mean time lost may therefore be determined at a national level. Importantly, mean time lost is quite sensitive to variation in high value outliers in the case severity distribution.

‘MEAN TIME LOST FROM WORK PER CASE’ FOR A WORK ENVIRONMENT

The practice of using observed ‘mean time lost from work per case’ as the numerical measure of case severity is well established in Australia, under the terminologies of ‘duration rate’ (Standards Australia, 1976) and then ‘average time lost rate’ (Standards Australia, 1990). However, while time lost data provide a reasonable measure of case severity for serious OHS cases, including most impairment cases, it significantly under-weights both disability cases (e.g. industrial deafness) and fatality cases. It is noted that fatality cases are assessed separately in Australia (Safe Work Australia, 2010; NOHSC, 2002). The mean time lost parameter is broadly applicable (i.e. useable with local work environment data, intra-industry data, and national data) and it is sensitive to reduction in the number of the more serious cases. For national data from Safe Work Australia, for data for an individual workplace, and for data sorted by case into the prevention-focussed domains (Table 1), this parameter can be directly calculated from the individual case time lost datum,

\[
\text{Mean time lost, } \mu = \frac{\sum \text{time lost in each case}}{\text{number of cases}} \text{ weeks}
\]

For intermediate applicability (e.g. for intra-industry sector aggregations), the mean value of a parameter for a population can be obtained by summing the occurrence fraction multiplicand of the mean value of the
parameter for each fraction of the population,

\[
\mu_{\text{total}} = f_1 \mu_1 + f_2 \mu_2 + f_3 \mu_3 + f_4 \mu_4 + \ldots \text{weeks}
\]

where \( \mu_{\text{total}} \) is the mean time lost for the total population of interest and \( \mu_1, \mu_2, \ldots \) are the mean time lost values respectively, for the individual cohorts making up the total population, and \( f_1, f_2, \ldots \) are the case number occurrence fractions, respectively, of the individual cohorts in the population, and \( f_{\text{total}} = 1 \).

Each serious OHS case is logged by Safe Work Australia (2011b) in its Statistics Online database under one of five severity groupings,

a. 1 to 5 weeks duration,
b. 6 to 11 weeks duration,
c. 12 to 25 weeks duration,
d. 26 to 51 weeks duration,
e. 52 weeks and over duration.

Such severity grouping data are obtainable on request from Safe Work Australia (2011d) and provide the observed ‘mean time lost’ in each severity grouping by year (see Table 2), or by Mechanism of Incident group, or by industry, etc.

From these base data, the observed ‘mean time lost’ for the national work environment population of interest can be calculated,

\[
\mu_{\text{total}} = f_a \mu_a + f_b \mu_b + f_c \mu_c + f_d \mu_d + f_e \mu_e \text{ weeks}
\]

where \( \mu_{\text{total}} \) is the mean time lost for the total population of interest and \( \mu_a, \mu_b, \ldots \) are the mean time lost values, respectively, in each of the five severity groupings, and \( f_a, f_b, \ldots \) are the case number occurrence fractions, respectively, in each of the five severity groupings, and \( f_{\text{total}} = 1 \).

For example, in each severity grouping, using the case occurrence fraction for total OHS cases in Australia for the year 2007-08 (Table 3c) and the data for mean time lost for total OHS cases, Australia (Table 2), then

\[
\begin{align*}
\text{Mean time lost (Aus, total cases, 2007-08)} &= f_a \mu_a + f_b \mu_b + f_c \mu_c + f_d \mu_d + f_e \mu_e \\
&= (0.589 \times 2.21) + (0.149 \times 8.41) + (0.118 \times 17.5) + (0.0706 \times 35.3) + (0.0723 \times 85.8) \\
&= 1.30 + 1.25 + 2.07 + 2.49 + 6.20 \\
&= 13.3 \text{ weeks}
\end{align*}
\]

OBSERVED MEAN TIME LOST VALUES

Case severity mean time lost data by causation are obtained via the Mechanism of Incident classification (ASCC, 2008). The mean time lost values for total OHS cases in Australia and for those Mechanism of Incident groups that make the largest contribution to the Occupational Injury (Safety) and Public Health Influence domains for the year 2007-08 are listed in Table 3a, b, & c. The number and occurrence fraction of cases in each of the Safe Work Australia severity groupings are also provided.

<table>
<thead>
<tr>
<th>SWA severity grouping Fiscal year</th>
<th>1 – 5 weeks</th>
<th>6 – 11 weeks</th>
<th>12 – 25 weeks</th>
<th>26 – 51 weeks</th>
<th>52 + weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-01</td>
<td>2.15</td>
<td>8.40</td>
<td>17.5</td>
<td>36.0</td>
<td>161.0</td>
</tr>
<tr>
<td>2001-02</td>
<td>2.17</td>
<td>8.37</td>
<td>17.6</td>
<td>35.8</td>
<td>153.9</td>
</tr>
<tr>
<td>2002-03</td>
<td>2.23</td>
<td>8.34</td>
<td>17.5</td>
<td>35.5</td>
<td>154.8</td>
</tr>
<tr>
<td>2003-04</td>
<td>2.18</td>
<td>8.37</td>
<td>17.6</td>
<td>35.4</td>
<td>142.9</td>
</tr>
<tr>
<td>2004-05</td>
<td>2.20</td>
<td>8.37</td>
<td>17.5</td>
<td>35.4</td>
<td>134.3</td>
</tr>
<tr>
<td>2005-06</td>
<td>2.21</td>
<td>8.38</td>
<td>17.5</td>
<td>35.2</td>
<td>121.3</td>
</tr>
<tr>
<td>2006-07</td>
<td>2.21</td>
<td>8.41</td>
<td>17.5</td>
<td>35.3</td>
<td>105.1</td>
</tr>
<tr>
<td>2007-08</td>
<td>2.21</td>
<td>8.41</td>
<td>17.5</td>
<td>35.3</td>
<td>85.8</td>
</tr>
</tbody>
</table>

NOTE:
The observed mean time lost value for the ‘52+ weeks’ severity grouping for 2007-08 and, perhaps, for 2006-07 may increase because the post-incident cumulative ‘from-work’ time to case closure can be protracted for some cases. Modelling on the annual ‘52+weeks/26-51weeks’ ratio through time allows for a) the possibility of no increase in the 52+weeks value for either year, b) a maximum increase to 97 weeks for 2007-08 and to 109 weeks for 2006-07.
Interestingly, and perhaps somewhat surprisingly, the results show that the case occurrence fraction by case severity distribution has a similar profile for each of the Mechanism of Incident groups. All Mechanism of Incident major groups (and Australia) show a distribution that has a mode at the 1–5 weeks grouping, a substantial reduction in occurrence fraction to the 6–11 weeks grouping, followed by a more subdued decay through the remaining groupings. Mechanism of Incident groups “Hitting objects with a part of the body” and “Mental stress” are a little different; the former has its cases concentrated within the lower severity groupings, while the latter has its cases more uniformly spread through all groupings. These differences are clearly registered in their observed annual mean time lost values.

The annual mean time lost values (together with case numbers and occurrence fraction by severity grouping) for some industry divisions (ABS/SNZ, 1993) are provided in Table 4 for the year 2007-08; Table 4a summarises the total OHS case data and Table 4b the subset of data for Occupational Injury (Safety) domain cases. The five priority industries under the National OHS Strategy 2002-2012 are included, together with the mining industry and the education industry.

Table 3  Annual mean time lost, μ, weeks (together with case numbers and occurrence fraction by severity grouping) for some Mechanism of Incident major groups, Australia, 2007-08 (Safe Work Australia, 2011b,d; ASCC, 2008)

<table>
<thead>
<tr>
<th>Mechanism of Incident major group</th>
<th>1 – 5 weeks</th>
<th>6 – 11 weeks</th>
<th>12 – 25 weeks</th>
<th>26 – 51 weeks</th>
<th>52 + weeks</th>
<th>Annual mean time lost, μ weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Falls, trips and slips of a person</td>
<td>15 145</td>
<td>4 670</td>
<td>3 915</td>
<td>2 050</td>
<td>2025</td>
<td>14.3 weeks</td>
</tr>
<tr>
<td></td>
<td>0.54</td>
<td>0.17</td>
<td>0.14</td>
<td>0.074</td>
<td>0.073</td>
<td></td>
</tr>
<tr>
<td>1 Hitting objects with a part of the body</td>
<td>7 490</td>
<td>1 335</td>
<td>665</td>
<td>325</td>
<td>270</td>
<td>7.2 weeks</td>
</tr>
<tr>
<td></td>
<td>0.74</td>
<td>0.13</td>
<td>0.066</td>
<td>0.032</td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>2 Being hit by moving objects (less subgroup 27)</td>
<td>12 495</td>
<td>2 925</td>
<td>1 905</td>
<td>1 030</td>
<td>1 050</td>
<td>10.8 weeks</td>
</tr>
<tr>
<td></td>
<td>0.64</td>
<td>0.15</td>
<td>0.098</td>
<td>0.053</td>
<td>0.054</td>
<td></td>
</tr>
</tbody>
</table>

b) For the major groups in the Public Health Influence domain

<table>
<thead>
<tr>
<th>Mechanism of Incident major group</th>
<th>1 – 5 weeks</th>
<th>6 – 11 weeks</th>
<th>12 – 25 weeks</th>
<th>26 – 51 weeks</th>
<th>52 + weeks</th>
<th>Annual mean time lost, μ weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Body stressing</td>
<td>30 795</td>
<td>8 685</td>
<td>7 210</td>
<td>4 420</td>
<td>4 440</td>
<td>14.5 weeks</td>
</tr>
<tr>
<td></td>
<td>0.55</td>
<td>0.16</td>
<td>0.13</td>
<td>0.080</td>
<td>0.080</td>
<td></td>
</tr>
<tr>
<td>8 Mental stress</td>
<td>2 280</td>
<td>925</td>
<td>1 045</td>
<td>840</td>
<td>1 175</td>
<td>26.0 weeks</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>0.15</td>
<td>0.17</td>
<td>0.13</td>
<td>0.19</td>
<td></td>
</tr>
</tbody>
</table>

c) Australia, total OHS cases

<table>
<thead>
<tr>
<th>Mechanism of Incident major group</th>
<th>1 – 5 weeks</th>
<th>6 – 11 weeks</th>
<th>12 – 25 weeks</th>
<th>26 – 51 weeks</th>
<th>52 + weeks</th>
<th>Annual mean time lost, μ weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia total OHS cases</td>
<td>79 570</td>
<td>20 070</td>
<td>15 890</td>
<td>9 540</td>
<td>9 765</td>
<td>13.3 weeks</td>
</tr>
<tr>
<td></td>
<td>0.59</td>
<td>0.15</td>
<td>0.12</td>
<td>0.071</td>
<td>0.072</td>
<td></td>
</tr>
</tbody>
</table>
The distribution of case occurrence fraction with severity groupings by industry division in Table 4 show a similar profile to those shown in Table 3 by Mechanism of Incident.

**VARIATION THROUGH TIME**

The observed annual mean time lost values for the five priority industries together with mining and education and the Australian workforce in toto for Occupational Injury (Safety) domain cases through the period

<table>
<thead>
<tr>
<th>SWA severity grouping Industry division</th>
<th>1 – 5 weeks</th>
<th>6 – 11 weeks</th>
<th>12 – 25 weeks</th>
<th>26 – 51 weeks</th>
<th>52 + weeks</th>
<th>Annual mean time lost, μ weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, forestry &amp; fishing</td>
<td>2285</td>
<td>745</td>
<td>575</td>
<td>315</td>
<td>365</td>
<td>14.8 weeks</td>
</tr>
<tr>
<td></td>
<td>0.53</td>
<td>0.17</td>
<td>0.13</td>
<td>0.074</td>
<td>0.085</td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td>1550</td>
<td>410</td>
<td>330</td>
<td>210</td>
<td>180</td>
<td>12.7 weeks</td>
</tr>
<tr>
<td></td>
<td>0.58</td>
<td>0.15</td>
<td>0.12</td>
<td>0.078</td>
<td>0.067</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>16235</td>
<td>3520</td>
<td>2625</td>
<td>1505</td>
<td>1680</td>
<td>11.9 weeks</td>
</tr>
<tr>
<td></td>
<td>0.64</td>
<td>0.14</td>
<td>0.10</td>
<td>0.059</td>
<td>0.066</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>8550</td>
<td>2315</td>
<td>1725</td>
<td>1005</td>
<td>1170</td>
<td>14.6 weeks</td>
</tr>
<tr>
<td></td>
<td>0.58</td>
<td>0.16</td>
<td>0.12</td>
<td>0.068</td>
<td>0.079</td>
<td></td>
</tr>
<tr>
<td>Transport &amp; storage</td>
<td>6455</td>
<td>1780</td>
<td>1440</td>
<td>870</td>
<td>835</td>
<td>13.5 weeks</td>
</tr>
<tr>
<td></td>
<td>0.56</td>
<td>0.16</td>
<td>0.13</td>
<td>0.076</td>
<td>0.073</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>3595</td>
<td>870</td>
<td>685</td>
<td>440</td>
<td>390</td>
<td>12.8 weeks</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>0.15</td>
<td>0.12</td>
<td>0.074</td>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td>Health &amp; community services</td>
<td>8855</td>
<td>2565</td>
<td>2295</td>
<td>1435</td>
<td>1145</td>
<td>14.2 weeks</td>
</tr>
<tr>
<td></td>
<td>0.54</td>
<td>0.16</td>
<td>0.14</td>
<td>0.088</td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td>Australia total OHS cases</td>
<td>79 570</td>
<td>20 070</td>
<td>15 890</td>
<td>9 540</td>
<td>9 765</td>
<td>13.3 weeks</td>
</tr>
<tr>
<td></td>
<td>0.59</td>
<td>0.15</td>
<td>0.12</td>
<td>0.071</td>
<td>0.072</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SWA severity grouping Industry division</th>
<th>1 – 5 weeks</th>
<th>6 – 11 weeks</th>
<th>12 – 25 weeks</th>
<th>26 – 51 weeks</th>
<th>52 + weeks</th>
<th>Annual mean time lost, μ weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, forestry &amp; fishing</td>
<td>1495</td>
<td>520</td>
<td>395</td>
<td>195</td>
<td>210</td>
<td>13.7 weeks</td>
</tr>
<tr>
<td></td>
<td>0.53</td>
<td>0.18</td>
<td>0.14</td>
<td>0.069</td>
<td>0.075</td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td>810</td>
<td>245</td>
<td>180</td>
<td>100</td>
<td>95</td>
<td>12.8 weeks</td>
</tr>
<tr>
<td></td>
<td>0.57</td>
<td>0.17</td>
<td>0.13</td>
<td>0.070</td>
<td>0.066</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>7775</td>
<td>1700</td>
<td>1140</td>
<td>575</td>
<td>605</td>
<td>10.5 weeks</td>
</tr>
<tr>
<td></td>
<td>0.66</td>
<td>0.14</td>
<td>0.097</td>
<td>0.049</td>
<td>0.051</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>4670</td>
<td>1390</td>
<td>985</td>
<td>550</td>
<td>600</td>
<td>14.8 weeks</td>
</tr>
<tr>
<td></td>
<td>0.57</td>
<td>0.17</td>
<td>0.12</td>
<td>0.067</td>
<td>0.073</td>
<td></td>
</tr>
<tr>
<td>Transport &amp; storage</td>
<td>3000</td>
<td>880</td>
<td>750</td>
<td>440</td>
<td>425</td>
<td>14.2 weeks</td>
</tr>
<tr>
<td></td>
<td>0.55</td>
<td>0.16</td>
<td>0.14</td>
<td>0.080</td>
<td>0.077</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>1870</td>
<td>395</td>
<td>255</td>
<td>145</td>
<td>115</td>
<td>9.5 weeks</td>
</tr>
<tr>
<td></td>
<td>0.67</td>
<td>0.14</td>
<td>0.092</td>
<td>0.052</td>
<td>0.041</td>
<td></td>
</tr>
<tr>
<td>Health &amp; community services</td>
<td>3395</td>
<td>870</td>
<td>670</td>
<td>400</td>
<td>310</td>
<td>12.6 weeks</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>0.15</td>
<td>0.12</td>
<td>0.071</td>
<td>0.056</td>
<td></td>
</tr>
<tr>
<td>Australia occupational injury(safety) domain cases</td>
<td>39205</td>
<td>9685</td>
<td>7010</td>
<td>3840</td>
<td>3805</td>
<td>12.0 weeks</td>
</tr>
<tr>
<td></td>
<td>0.62</td>
<td>0.15</td>
<td>0.11</td>
<td>0.060</td>
<td>0.060</td>
<td></td>
</tr>
</tbody>
</table>
2000-01 to 2007-08 are provided in Table 5. The annual mean time lost results for a given industry show a consistency over time, within a discernable trend of a reducing mean time lost through time.

**CONCEPTUAL NATURE OF CASE SEVERITY**

As mentioned, the case severity characteristic is independent of case rate. Case severity considers the severity distribution within the cases that occur and this distribution is independent of both the number of cases that occur or their case rate. Further, case severity is secondary to case rate in evaluating a work environment’s observed risk and outcome performance because case prevention eliminates the severity datum. Concerning case rate, each logged case is a serious OHS case and each case raises anew the issue of legislative compliance. Concerning the mean time lost parameter, it significantly under-weights disability and fatality cases and it is mediated by the effectiveness of the post-incident actions of first aid, medical treatment and rehabilitation.

Finally, it is noted that case rate measurements always have uncertainty attached to them due to Poisson variability inherent in the case numbers (Altree-Williams, 1990) and sampling variability if work-hours are determined using Labour Force Survey data (ABS, 2005). This is not the situation for case severity which is fundamentally determinate in its nature; once a case occurs, its time lost datum is determined absolutely by the cumulative ‘from-work’ time until case closure.

**NON-PARITY OF TEMPORAL VARIATION IN CASE RATE AND CASE SEVERITY**

In assessing the outcome performance of a work environment, a judgement needs to be made concerning the relative parity of observed changes in case rate and in case severity. The approach suggested here is to apply an attenuation factor to the percentage change in mean time lost to achieve that parity. Such an attenuation factor could reasonably be named the ‘parity factor’. For current working purposes (see Table 6), the parity factor was taken as 0.35.

The parity factor, as hypothesised here, is generated from two multiplicands; one for the non-parity between the percentage

<table>
<thead>
<tr>
<th>Industry</th>
<th>Annual mean time lost, μ, weeks</th>
<th>Occupational Injury (Safety) domain cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>22.8 19.6 17.3 17.9 16.1 12.6 14.9 12.8</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>17.8 17.1 14.9 13.8 13.4 12.2 11.6 10.5</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>24.9 23.9 22.1 19.3 18.2 18.1 15.9 14.8</td>
<td></td>
</tr>
<tr>
<td>Transport &amp; storage</td>
<td>21.4 21.3 19.5 18.3 18.6 16.6 15.7 14.2</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>16.4 17.9 21.1 14.3 11.8 10.9 10.1 9.5</td>
<td></td>
</tr>
<tr>
<td>Health &amp; community services</td>
<td>23.3 19.1 19.1 16.6 15.5 15.3 13.7 12.6</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>20.7 19.3 17.7 16.4 15.2 14.4 13.4 12.0</td>
<td></td>
</tr>
</tbody>
</table>
change through time of case rate and of case severity, and the second multiplicand for the effect of the efficiency of the post-incident services of first aid, medical treatment and rehabilitation, as follows,

\[ \text{Parity factor} = \text{[non-parity multiplicand]} \times \text{[post-incident services multiplicand]} \]

For current working purposes in this paper, for the industries and time frame considered (see Table 6), the non-parity multiplicand has been taken as one-third (i.e. 0.33) and the post-incident services multiplicand has been set at 1.1, to give an overall parity factor of 0.36, rounded to 0.35. It is noted that the non-parity multiplicand, once established by Safe Work Australia, would remain constant thereafter for all workplaces and for all times.

The post-incident services multiplicand, however, would be expected to take different values depending on the work environment and the time period of the observation. If the efficiency of the post-incident services of first aid, medical treatment and rehabilitation was at practical perfection for the work environment throughout the period of observation, then any observed temporal variation in mean time lost would be totally due to case severity and, hence, the value of the post-incident services multiplicand would be unity (i.e. the number 1), its default value. But in the real world, post-incident services are always less than totally efficient and, hence, would conceptually be considered to make some ‘contribution’ to the observed mean time lost. Broadly, there are nine possible combinations of circumstances as summarised in Table 7.

The common circumstance should see case severity reducing and post-incident services becoming more efficient through the time period of observation. This is reasonably taken as the situation through the five years, 2001-02 to 2006-07, reported in Table 6. Because of this, the value 1.1 was taken for the post-incident services multiplicand for use with the data in Table 6.

### Table 6: Case severity %change through time; serious OHS cases, Occupational Injury (Safety) domain, Australia, by industry division, 2001-02 to 2006-07 (Safe Work Australia, 2011b,d)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Annual mean time lost, μ, weeks</th>
<th>Five-year period % change in μ</th>
<th>As attenuated by parity factor of 0.35</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occupational Injury (Safety) domain cases 2000-01 2001-02 2002-03 average</td>
<td>2006-07</td>
<td></td>
</tr>
<tr>
<td>Agriculture, forestry &amp; fishing</td>
<td>20.2</td>
<td>15.1</td>
<td>- 27%</td>
</tr>
<tr>
<td>Mining</td>
<td>19.9</td>
<td>14.9</td>
<td>- 26%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>16.6</td>
<td>11.6</td>
<td>- 32%</td>
</tr>
<tr>
<td>Construction</td>
<td>23.6</td>
<td>15.9</td>
<td>- 34%</td>
</tr>
<tr>
<td>Transport &amp; storage</td>
<td>20.7</td>
<td>15.7</td>
<td>- 25%</td>
</tr>
<tr>
<td>Education</td>
<td>18.5</td>
<td>10.1</td>
<td>- 48%</td>
</tr>
<tr>
<td>Health &amp; community services</td>
<td>20.5</td>
<td>13.7</td>
<td>- 35%</td>
</tr>
<tr>
<td>Australia</td>
<td>19.2</td>
<td>13.4</td>
<td>- 32%</td>
</tr>
</tbody>
</table>

Note: Because the minimum value of mean time lost is 1 week (i.e. rather than zero), the %change denominator for use with mean time lost needs to incorporate this minimum value of unity (i.e. rather that zero, the usual minimum value in %change calculations).
OUTCOME PERFORMANCE, SERIOUS OHS INJURY, AUSTRALIA

The premise of the National OHS Strategy 2002-2012 (NOHSC, 2002) is that improvement in OHS is “best sustained through a focus on performance outcomes, which can be reported and monitored over time”. If the National OHS Strategy’s performance target for serious OHS injury is interpreted to collectively include the improvements forged under both case rate (Altree-Williams, 2011) and case severity (Table 6) then the results demonstrate a substantial OHS achievement. This reflects positively on the National OHS Strategy and on the subsequent efforts of stakeholders. By the midpoint of the Strategy duration, 30 June 2007, the observed outcomes put Australia on-pace to broadly achieve the Strategy target for serious OHS injury.

CONCLUSION

A substantial challenge exists to maintain the trend of continuing improvement in the OHS performance for the work environments of Australia. The importance of case severity to this endeavour is established.

Mean time lost provides a numerical parameter by which case severity (the second characteristic of OHS observed risk for a work environment) can be quantitatively evaluated for serious OHS cases, not including disabilities or fatalities.

The practical application of mean time lost is an important development that will further assist the tripartite partners and the regulatory agencies in their quest to translate the societal goals enacted in OHS legislation into reality.

### Table 7  Range of values for the post-incident services multiplicand in each of the nine general combinations of circumstances pertaining to temporal variation of mean time lost

<table>
<thead>
<tr>
<th>Case severity</th>
<th>More efficient through time</th>
<th>Constant through time</th>
<th>Less efficient through time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10% 20% 40%</td>
<td>10% 20% 40%</td>
<td>10% 20% 40%</td>
</tr>
<tr>
<td>Reduces through time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>1</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>20%</td>
<td>1.1</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>40%</td>
<td>1.2</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>Constant through time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any observed temporal variation in mean time lost is due to changes in post-incident services efficiency</td>
<td>No change through time will be observed for mean time lost.</td>
<td>Any observed temporal variation in mean time lost is due to changes in post-incident services efficiency</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>1.9</td>
<td>3.2</td>
<td>-6.5</td>
</tr>
<tr>
<td>20%</td>
<td>1.5</td>
<td>1.9</td>
<td>3.2</td>
</tr>
<tr>
<td>40%</td>
<td>1.4</td>
<td>1.5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**NOTE:** 1. The range of values for the post-incident services multiplicand shown above were calculated from linear modelling. Initial mean time lost value made up of 10 units due to case severity and 3 units due to post-incident services inefficiency. Final mean time lost values were then calculated, as relevant, for case severity changes and services efficiency changes of 10%, 20% and 40%. The multiplicand was the number that returned the final mean time lost value to the “true” value of the case severity variation calculated assuming perfect post-incident services.

2. The default value of the post-incident services multiplicand, where the work environment is provided with perfect first-aid, medical treatment and rehabilitation services throughout the time of observation, is 1, regardless of case severity variation through time.
ACKNOWLEDGEMENT
I would like to especially thank Alison Yardley, Assistant Director, Strategic Policy Branch, Safe Work Australia for providing, a) expert guidance on the intricacies inherent in the National Data Set/Safe Work Australia data collection and reporting systems, and b) data from the Statistics Online database prior to its official launch by Safe Work Australia to the public domain.

REFERENCES


Effects of street clothing, sunscreen, and temperature on skin absorption of organophosphate pesticides – a review and case study of diazinon

LINDSEY TE BRAKE1,3, SHARYN GASKIN1,2, DINO PISANIELLO1, JOHN W. EDWARDS2, DAVID BROMWICH3, SUE REED4, PAUL SCHEEPERS5

ABSTRACT
There is increasing concern about occupational and community exposure to accidental or deliberate release of organophosphate pesticides (OPs). The protection afforded by street clothing and personal skin products for dermal exposure is poorly understood. A literature review was conducted and an in-vitro study carried out with diazinon, as a case example. The objectives were to assess the modifying effects of sunscreen, clothing, and temperature, on epidermal absorption and penetration.

Diazinon in-vitro work was performed with static Franz cells in accordance with OECD protocols. Application of oil-based sunscreen on hydrated exposed skin was performed as per Australian Standard 2604:1998.

A formal review of the literature revealed a significant knowledge gap with respect to dermal exposure and uptake of OPs in civilian exposure incidents. Recent work in the United Kingdom showed cotton shirt material significantly reduced dermal absorption of dichlorvos and chlorpyrifos, and post-exposure removal of clothing with immediate skin surface decontamination further reduced absorption compared with removal of clothing alone. Diazinon in-vitro studies revealed the skin to be a good barrier to penetration. Sunscreen and denim fabric seemed to act as an extra barrier for absorption and penetration, whereas elevated temperatures (37°C) seemed to aid diazinon penetration through the skin.

The findings suggest emergency responders and hygienists recommend removal of bulky clothing and early decontamination of the skin following OP exposure to minimise the potential for dermal absorption and localised toxicity within the skin. Further studies of street clothing and sunscreen should be conducted with a wide range of substances.

INTRODUCTION
There is a heightened concern about occupational and community exposure to accidental or deliberate release of chemicals, such as organophosphate pesticides (OPs). Dermal contact with various pesticides can occur during manufacture, formulation, transport, application, harvesting procedures, and under many home-use scenarios. Typically, agricultural and pest control workers are the primary occupational exposures (accounting for 60-70% of all acute pesticide poisonings (Pont et al 2004; Lee et al 2009)), but secondary exposures to emergency responders and health care professionals may also occur. Furthermore, individuals not directly using pesticides in the workplace may still be exposed by walking through a recently sprayed field. To evaluate the risk to workers and other exposed individuals to pesticides, it is important to understand the influences on their absorption. Studies have demonstrated
that temperature, humidity and occlusion all have an influence on the extent of skin hydration and permeability (Jones et al 2003). In particular, higher temperatures and humidity can increase the penetration of liquid chemicals through the skin. The chemical protection afforded by street clothing and personal skin products such as sunscreen is poorly understood.

A literature review was conducted and an empirical in-vitro study carried out with diazinon, as a case example. Diazinon is considered a chemical of national security concern by The Council of Australian Governments (COAG), and is still currently in use in Australia. The objectives were to assess the modifying effects of sunscreen, “street” clothing, and temperature, on epidermal absorption and penetration with respect to OPs.

METHODS

LITERATURE REVIEW

A wide variety of public domain and proprietary bibliographic and full text databases were searched, including Medline, TOMES, HSEES and ARIA for accounts of dermal exposure to OPs. Generic search engines such as Google Scholar were also used. Reference lists from retrieved reports, as well as publications from selected authors, were also explored. The Hazardous Substances Emergency Events Surveillance (HSEES) system was established by ATSDR to collect and analyse information about acute releases of hazardous substances and threatened releases that result in a public health action such as an evacuation. The French ARIA (Analyse, Recherche et Information sur les Accidents) database includes more than 25,000 accidents or incidents both in France and abroad.

DIAZINON EXPERIMENTS

Diazinon in-vitro work was performed in accordance with conventional approaches (static diffusion Franz cell with test chemical applied in a liquid form) (OECD 2004). Three variables affecting skin penetration were tested: temperature (23°C vs 37°C), oil-based 30+ SPF sunscreen (Hamilton Pharmaceuticals, South Australia), and clothing (denim vs polyester). The chosen fabrics represent examples of light and heavy ‘street clothing’, thereby allowing characterisation of potential absorptive capacities of different common textiles. Infinite dose conditions of pure diazinon (purity 98.3%) were tested to eliminate the effect of additives present in the formulated products. Chemical application conditions (100 µl of 100 µg/ml diazinon in acetone) ensured that the amount of test chemical applied on the skin (in this case dissolved in an acetone vehicle) allows for a maximum rate of penetration of the test substance (per unit area of skin) to be obtained. Aqueous ethanol 50:50 v/v was the receiving fluid. Both human (abdomen) and pig skin samples (epidermis) were used in this study. Although the use of human skin represents the most robust approach, pig skin is more easily available and can be a very useful model for in-vitro dermal absorption studies (Davies et al 2004), provided that the skin integrity is checked prior to skin exposure. Ethics approval was obtained from Southern Adelaide Health Service Clinical Research Ethics Committee. Excised human skin was obtained (with written consent) from individuals undergoing cosmetic reduction surgery. Pre-exposure skin barrier integrity testing was performed in two steps: microscopy to exclude samples with obvious physical damage, and using a Tinsley LCR Databridge 6401 (Fasano & Hinderliter 2004) to assess membrane electrical impedance.

Application of commonly available oil-based sunscreen (at 2 mg/cm²) on hydrated exposed skin was performed as per Australian Standard 2604:(1998) Evaluation and Classification of Sunscreen Products. Typically worn fabrics were commercially available textiles including 100% cotton (denim) (thickness 0.7716 ±0.011 mm) and 100% polyester (thickness 0.2767 ± 0.005 mm) and were
prepared for experimentation according to the Australian Standard AS 2001.5.4-2005 Methods (2005) of test for textiles.

Diazinon concentration was determined by HPLC analysis: GBC, LC 1120 pump connected to a Perkin Elmer Series 200 UV/Vis detector, SUPELCO, Supelcosil™, LC-18, 5-8985 column, mobile phase acetonitrile/water mixture of 70/30 (v/v), flow rate 1.0 ml/minute, with the UV detector set to a wavelength of 250 nm. The following variables were used as descriptors for the ability of diazinon to penetrate skin: lag-time for penetration (min), flux (µg/cm²/min), permeability coefficient (cm/h) and maximum penetration (mass).

RESULTS AND DISCUSSION
LITERATURE REVIEW

There have been a number of occupational studies of dermal exposure to OPs (see review Gold et al 1984). The evidence of uptake potential of organophosphate insecticides is that OPs are generally well absorbed through skin, both in their concentrated formulations and when diluted to ready-to-use concentrations (Kamanyire & Karalliedde 2004; Riviere 2006). Dermal absorption following skin contact, especially to aerosols, can result in significant systemic symptoms in the absence of inhalation (for example if those exposed adequately cover the nose and mouth to prevent aerosol inhalation). The extent and speed of dermal absorption and the severity of symptoms depends on formulation characteristics and the inherent toxicity of the OP concerned. Furthermore, dermal uptake is not linearly related to applied dose; there is evidence at lower concentrations of OPs, preferential attraction to skin may occur (Edwards et al 2007).

Our objective was to assess the literature for evidence on the dermal protective (or uptake enhancing) properties of personal items (sunscreen) and “street” clothing, particularly in relation to OPs. The literature indicates that a variety of factors can play a significant role in the dermal absorption of chemicals. These include skin thickness and lipid content, occlusion, clothing, temperature and humidity and skin damage/disease. Some of these factors are correlated with anatomical region, age, gender and ethnicity. There do not seem to be any systematic studies of the chemical protection afforded by street clothing or personal items. Indeed, it is only recently that the community usage of personal items has been studied for risk assessment purposes (Loretz et al 2005; Loretz et al 2008).

PERSONAL ITEMS EFFECTS ON SKIN ABSORPTION:

Personal items applied to the skin, such as sunscreen and cosmetics may enhance, buffer or reduce dermal exposure. They may also act as a chemical reservoir. The ability to enhance or reduce skin uptake appears to depend primarily on whether the product is oil or water based (Bronaugh et al 1981), although some active ingredients can enhance penetration (Pont et al 2004). There are some studies on the influence of skin absorption of sunscreen with vehicles. With hairless mouse skin (Brand et al, 2002; Pont et al, 2004), the active ingredients of several sunscreen formulations (i.e. the UV absorbing components and insect repellents) on the skin significantly enhanced skin absorption of a herbicide, 2,4-dichlorophenoxyacetic acid within 24 hours, compared with the control where sunscreen was not applied.

Agricultural and pest control workers and related outdoor workers are encouraged to use sunscreen to decrease the risk of UV-related skin cancer. Sunscreen use carries an added risk, however, as several commercial sunscreen formulations have been shown to enhance penetration of potentially harmful chemicals (Pont et al, 2004).

CLOTHING EFFECTS:

Clothing has the potential to act as a barrier to chemical exposure (protecting individuals) or as a reservoir (trapping or holding chemicals and facilitating uptake),
or acting as an occlusive barrier to enhance absorption. As a barrier, chemical resistance is important, in the same way that intrinsic resistant properties are used in personal protective clothing. Street clothing may serve to initially protect and buffer the skin from toxic chemicals, depending on the material, thickness, cover and yarn twist (Lee & Obendorf 2005). However, significant skin uptake of chemical may occur if contaminated clothing is in contact with, or occludes, the skin.

The impact of clothing on dermal exposure of chemicals has been extensively studied in relation to chemical protective clothing (Davies et al, 1982; Fenske, 1988; Stull & Pinette, 1990; Leung & Paustenbach, 1994; Driver et al, 2007). Few studies have been undertaken on the effectiveness of general “street” clothing except in relation to spraying of pesticides and in one case exposure to mustard gas. In a study by Protano et al (2009) the impact of different clothing types on reducing skin exposure to a range of pesticides commonly applied using a sprayer was verified. The study showed that cotton clothing had a protection factor of greater than 84% whereas chemical protecting clothing (tyvek suits) had a performance greater than 97%. Recent work in the United Kingdom showed cotton shirt material significantly reduced dermal absorption of dichlorvos and chlorpyrifos, and post-exposure removal of clothing with immediate skin surface decontamination further reduced absorption compared with removal of clothing alone (Moore 2010).

Occlusion of the area of skin enhances skin absorption because occlusion causes increased hydration and temperature of the skin. Occlusion of chemicals on personal protective equipment (PPE-overalls, gloves, socks and hat) may increase skin absorption. From a recent study with pesticide spray workers applying OPs (malathion and fenthion) (Edwards et al, 2007), the deposition of OPs on PPE was determined rather than the amount present on skin as this acted as a surrogate model for the deposition upon unprotected skin. Contamination of cotton liner gloves within gauntlets was measured as an estimate of possible contamination during glove donning and removal and this contamination is able to persist within gloves representing an occluded exposure.

**TEMPERATURE/HUMIDITY EFFECTS:**

One study by Chang and Riviere (1991) explored the effects of temperature and humidity on skin absorption of the OP insecticide parathion in an in-vitro pig skin model. Elevated air temperatures (42°C) and humidity (90%RH) were shown to significantly enhance (almost 2-fold) the penetration of parathion over an 8 hr period compared with lower temperature/humidity conditions (37°C, 60%RH). Meuling et al (1997) studied the dermal absorption of the pesticide propoxur at 30°C under various humidities (50, 70 or 90%). The percentage body burden attributable to dermal absorption increased from 13% (at 50% relative humidity) to 63% (at 90% RH), indicating that skin moisture is important in dermal absorption of propoxur.

In occupational settings, personal protective equipment will be affected by increasing temperature. One laboratory study assessed the degree of malathion permeation through PVC glove material in different temperature conditions (22±1 °C and 37±1 °C) (Lee et al, 2009). It was found that increasing temperature reduced breakthrough times and increased permeation rates which may cause increasing skin absorption, as reported by other studies (Klinger & Boeniger, 2002; Cherrie et al, 2004; Semple 2004).

Jones et al (2003) is one of few studies assessing both environmental conditions and clothing factors on dermal absorption, in this case for solvent vapours. An increase in 2-butoxyethanol vapour absorption was noted with increased temperature and humidity (as shown in Figure 1). Furthermore, the wearing of whole-body overalls did not attenuate absorption. This
could have been because the rate of gas exchange through the clothing exceeded the absorption rate of 2-butoxyethanol through the skin. By combining several factors together in the ‘industrial scenario’, the authors noted dermal absorption of vapours was significantly increased with a mean of 39% of the total absorbed dose.

Figure 1: Effect of environmental conditions on dermal absorption (% mean with range, N = 4). *Statistically significant (P < 0.005) (after Jones et al 2003).

IMPLICATIONS FOR OCCUPATIONAL HYGIENISTS:

The importance of this review for occupational hygienists is in highlighting the significance of issues relating to clothing, personal products and environmental factors influencing the dermal absorption of OPs. Exposure can occur where workers are unprotected, or in the event of civilian exposure scenarios involving emergency response. In these circumstances occupational hygienists may be called upon to provide advice on the dermal protective (or uptake enhancing) properties of personal items and street clothing in the assessment of exposure. One such analogy can be drawn from the recent pandemic of avian influenza A (H1N1) where a shortage of disposable respirators occurred, and evaluation was sought on the respiratory protection afforded by common fabric materials (e.g. t-shirt, scarves) against infection (Rengasamy et al, 2010). The outcome was that common fabrics afforded marginal protection against aerosols/nanoparticles, but with obvious high variability due to not fit-for-purpose design.

DIAZINON EXPERIMENTS

Table 1 shows the descriptors of skin penetration of diazinon in all set variable conditions: lag-time for penetration (minutes), maximum penetration (µg), flux (µg/cm²/min) and permeability coefficient (cm/h). The set conditions were: pig skin in ambient (23°C) and in elevated (37°C) temperature conditions; pig skin with added oil-based 30+ SPF sunscreen in ambient (23°C) and in elevated (37°C) temperature conditions; pig skin with added denim or

<table>
<thead>
<tr>
<th>Experimental conditions</th>
<th>Lag-time (min)</th>
<th>Maximum penetration (µg) ± Std. Error of the Mean</th>
<th>Flux (µg/cm²/min) ± Std. Errorb</th>
<th>Permeability coefficients (cm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig at 23°C</td>
<td>53</td>
<td>2.0 ± 0.4***</td>
<td>0.089 ± 0.022</td>
<td>0.0534</td>
</tr>
<tr>
<td>Pig at 37°C</td>
<td>7</td>
<td>2.8 ± 0.4***</td>
<td>0.105 ± 0.030</td>
<td>0.063</td>
</tr>
<tr>
<td>Pig + sunscreen at 23°C</td>
<td>118</td>
<td>1.0 ± 0.2</td>
<td>0.014 ± 0.006</td>
<td>0.0084</td>
</tr>
<tr>
<td>Pig + sunscreen at 37°C</td>
<td>78</td>
<td>0.9 ± 0.2</td>
<td>0.031 ± 0.023</td>
<td>0.0186</td>
</tr>
<tr>
<td>Pig + denim at 23°C</td>
<td>204</td>
<td>0.2 ± 0.09&quot;&quot;</td>
<td>0.002 ± 0.001</td>
<td>0.0012</td>
</tr>
<tr>
<td>Pig + polyester at 23°C</td>
<td>90</td>
<td>0.8 ± 0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Human at 23°C</td>
<td>418</td>
<td>0.3 ± 0.05***</td>
<td>0.004 ± 0.002</td>
<td>0.0024</td>
</tr>
<tr>
<td>Human at 37°C</td>
<td>98</td>
<td>0.3 ± 0.07***</td>
<td>0.001 ± 0.001</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

a Was not possible to calculate lag-time by linear regression. Value based on results of experimental data.
b Reported as Standard Error, displaying the standard error for the estimate of the slope, following linear regression.
*** " " " " " ** " " " " " Pairs of variables that show a statistically significant difference (p < 0.05).
polyester in ambient (23°C) temperature conditions; and human abdominal skin in ambient (23°C) and in elevated (37°C) temperature conditions. Results revealed the skin to be a good barrier to penetration. Less than five percent (3.1% ± 0.5) of applied dose penetrated the human skin. Sunscreen and denim fabric seemed to act as an extra barrier for absorption and penetration, whereas elevated temperatures (37°C) seemed to aid diazinon penetration through skin (Table 1).

Results presented in table 1 show that an elevated temperature decreases the time required for diazinon to penetrate the pig skin (lag-time). In addition, the maximum penetration seems to be higher, although the difference is not statistically significant. An elevated temperature also decreases the lag-time for diazinon penetration when sunscreen is added to (pig) skin. Furthermore, the lag-time of diazinon penetration is much longer when sunscreen is added on skin compared to when no sunscreen is added, under both temperature conditions. Also, the maximum penetration of diazinon with sunscreen added seems to be lower in both temperature conditions. However, a statistically significant difference is only found for addition of sunscreen on skin in elevated temperature (37°C) conditions (p = 0.005).

With respect to clothing, table 1 shows that the lag-time of diazinon penetration is much longer when denim is added on (pig) skin compared to when polyester is added. In addition, maximum penetration of diazinon with denim added on skin was found to be significantly lower from when no denim is added (p = 0.003).

Finally, the results in table 1 show that an elevated temperature (37°C) decreases the time required for diazinon to penetrate human skin, as found for pig skin. However, no comparable increase in the maximum penetration of diazinon in elevated temperature conditions can be observed. Overall, smaller amounts of diazinon penetrated human skin compared to pig skin. This difference is found to be statistically significant for ambient (23°C) (p < 0.001) as well as elevated (37°C) temperature conditions (p = 0.001).

Therefore, these results seem to indicate that sunscreen acts as an extra barrier for penetration. Comparable to sunscreen, also denim seems to act as an extra barrier for skin penetration. Denim increases the lag-time of diazinon penetration and, in addition, lowers maximum penetration significantly compared to when no denim is added. Polyester does not seem to show a similar trend.

When comparing the human skin penetration data to the pig skin penetration data, it can be concluded that human skin seems to act significantly more as a barrier, because lag-time is higher (6.97 h versus 0.88 h) and flux and maximum penetration (3.1 ± 0.5% versus 20 ± 4.2%) are lower. Therefore, it could be concluded that using pig skin in an in-vitro model, under the relatively short exposure times applied in this study, will probably result in conservative estimates for human skin penetration.

A study by Moody and Nadeau (1994) showed similar lag-times for penetration of diazinon compared to findings in this study, except they did not find a lower maximum penetration of human skin compared to pig skin. In their study, %-recovery in receiver solution amounted to 5.8 ± 1.31% for pig skin and 6.0 ± 1.36% for human skin after 48 hours of exposure. The lower amount of diazinon penetration through pig skin compared to findings in this study (20 ± 4.2%) could be explained by the use of dermatomed skin (0.5 mm) by Moody and Nadeau (1994).

Furthermore, other studies have reported higher percentage of applied dose penetrating the human abdominal skin compared to the results in this study (Wester et al 1993; Moody and Nadeau 1994). The in-vitro study of Wester et al (1993) showed that 14.1 ± 9.2% of the applied dose accumulated in the receptor fluid over 24 hr of exposure to 0.25 µg/cm². Most probably, the discrepancy with findings in
this study can be explained by the longer exposure time applied in the mentioned studies. In the in-vivo study by Garfitt et al (2002), 1% of the dermal dose was excreted as urinary DAP metabolites, with 90% of the dermal dose being recovered from the skin surface after 8 hours of exposure. These results are comparable with the percentage of dose that penetrated human skin in this study (3.1 ± 0.5%). These data underpin the conclusion that pig skin in this study (maximum penetration 20 ± 4.2% of applied dose) overestimates the in-vivo human absorption of diazinon.

The importance of outcomes from this empirical study relate to the moderating effects of sunscreen, clothing and temperature conditions on dermal penetration of diazinon. This has not previously been explored. The findings show sunscreen and denim (“heavy”) fabric act as an extra barrier for absorption and penetration, whereas elevated temperatures (37°C) seemed to aid diazinon penetration through skin. This has important implications for assessment of exposure and uptake potential in occupational settings where diazinon is used.

CONCLUSIONS: INTERPRETATION OF REVIEW AND CASE STUDY EXPERIMENTAL OUTCOMES

Based on findings observed for different OPs, temperatures, sunscreen and clothing parameters a set of practical guidelines can be derived for occupational hygienists, emergency responders and medical personnel in the event of work-related or civilian exposures to OPs.

With respect to clothing, as a general rule “heavy” or bulky, porous fabric provides an initial buffer against but potential ongoing reservoir for contaminant exposure. Our literature search found evidence to suggest removal of the exposed individual’s clothing eliminates 80-90% of the contaminants and minimises the risk of spreading the toxic agent to others (Levitin et al 2003; Houston et al 2005). If feasible this outer clothing should be removed as soon as possible after exposure. On the other hand, lightweight clothing is unlikely to represent a reservoir for ongoing exposure (as shown by diazinon results using polyester), and so the imperative is less apparent. This is in contradiction to the current dogma which is to remove all clothing.

Personal products applied to the skin may or may not enhance the barrier protection provided by naked skin. The passage of some chemicals into the skin may be assisted by sunscreen. For other hydrophilic substances, the barrier effectiveness provided by oil-based sunscreens can be quite marked. Conclusions able to be drawn from the sunscreen barrier effectiveness outcomes are limited, except where we may be dealing with hydrophobic contaminants, where physical removal of sunscreen is likely to be beneficial. More research is needed to clarify the role of personal items applied to the skin on dermal absorption of chemicals. In practice, the protective benefits of sunscreen for UV cancer risk in occupational settings will continue to outweigh the potential added risk associated with its use.

In summary, this research verified that in addition to the usual primary consideration of concentration/duration of chemical exposure, the fundamental parameters influencing dermal absorption of OPs is clothing, with secondary effects due to humidity and temperature, and sunscreen. The work also confirms that diazinon penetration can be influenced by (“heavy”) clothing and sunscreen, with protective effects. This work will hopefully contribute to a better understanding of the issue for occupational hygienists who may be called upon to provide advice and assistance on these issues.
REFERENCES


INTRODUCTION

Health risks associated with exposure to mould in the indoor environment are of increasing concern. Currently no safe levels are set for airborne microorganisms in the residential or occupational setting in Australia or overseas. Previous World Health Organisation criteria for moulds were later rescinded, and current guidelines do not specify safe levels (WHO, 2009). Instead the WHO recommends in the current absence of a link between dampness, microbial exposure and health effects, mould should be prevented and where present, remediated.

Moulds arising in association with water ingress or condensation are potentially allergenic and pathogenic to sensitive individuals and those with compromised immune systems (Pettigrew et al., 2010). Non-viable spores can illicit allergic and toxic reactions; viable spores can be allergenic and/or pathogenic, thus site assessment plans must consider potential exposure risks on a site by site basis.

Inhalation or ingestion of fungal spores or mycelial fragments (Rakkastad et al., 2010), or toxicigenic, teratogenic, mutagenic and carcinogenic fungal toxins (mycotoxins) can occur. Current toxicological understanding relies heavily on tissue culture and animal-related dose-response data; exposure in contaminated environments may result in simultaneous inhalation and/or ingestion of multiple mould types and other pollutants, hampering epidemiological analysis (Gravesen, 1986).

Hazard severity is often microbial-strain specific (Kuhn and Gahinnoum, 2003), dependent on airborne or surface concentrations, airborne particle size...
distribution and moisture source. Identification of individual mould strains demands DNA/RNA or antibody-based analyses requiring expert analysis, as results can be misleading (Bridge et al., 2003). Culture- and microscopy-based methods whilst requiring limited resources, can miss harmful moulds because they respectively do not compete well on an agar plate (Durand et al., 2002), or are outnumbered by less harmful moulds. Approximately 90% of moulds from an air sample are non-culturable, thus exposure assessment may require molecular approaches to mould identification.

Risk of uptake, and development of adverse health effects are dependent on age, physiological status and physical activity of the receptor, exposure time, available exposure routes and spore viability.

Management decisions to remove water and/or occupants is required within 48 hours to prevent mould proliferation and exposure. Sound judgement is further needed around remediation procedures and re-occupation of restored buildings. The precautionary principle must be followed, including an appropriately detailed site assessment and management plan based on site use during and after remediation. In some cases it is effective to devise risk management strategies based on site investigation without intrusive monitoring, whilst in others conventional techniques may miss hazardous microorganisms at low concentrations and molecular approaches may be necessary.

By examining three PAEHolmes case studies, this paper aims to show how a 4-tiered site assessment approach safely delivered outcomes based on the precautionary principle to manage and mitigate site-specific exposure risks.

**Figure 1: Tiered approach to managing risks from mould contamination. Viable/non-viable microorganisms can be measured using flow cytometry coupled to fluorescent staining or DVC-FISH = “Direct Viable Count Fluorescent in situ Hybridisation” (Armisen and Servais, 2004).” FISH was not employed during the case studies reported in this paper due to high costs and lack of service provision. Tape-lift sampling protocols are set out under the proposed standards ASTM WK17177. MSQPCR = mould-specific quantitative (real-time) polymerase chain reaction (USEPA, 2010). Dashed lines should be followed for a negative answer to the questions in Tier 1, and solid line for a positive response. Cultutable surface swabs may be taken under ASTM WK233334.
A FOUR-TIER APPROACH TO MOULD ASSESSMENT

As shown in Figure 1, Tier 1 comprises an initial site assessment, including examination of existing site history and reports relating to the incident. If mould is suspected under Tier 1, Tier 2 examines the likelihood of exposure to mould by all individuals entering the site until it is fully remediated. Likelihood of exposure varies with building occupant activity type/level, physiological status and relevant personal factors. The level of mould identification required under Tier 3 is based on this assessment. Tier 3 sampling and analysis provides specific hazard identification and based on personal or area air sampling and/or surface sampling, assessment of the potential for inhalation or ingestion respectively.

If culture-based analysis to genus or species level is used and suggests elevated or unique indoor moulds, species/strain identification of isolates may be required. When sensitive individuals may have already been exposed, identification of a microbial isolate based on antigen, or on gene sequence information is possible. Analysing mould DNA sequences of a gene that is common to all moulds, but showing inter-species or inter-strain hypervariability, allows indicative identification based on online sequence libraries. Detailed DNA identification increases confidence in the assessment of hazard severity of the organism.

As shown in Figure 1, Tier 4 involves the production of a Remedial Action Plan (RAP) for the site comprising risk evaluation based on findings of Tiers 1-3 including; hazard description; qualitative probability of exposure; and possible susceptibility/response of individuals entering the site during site assessment and restoration. The RAP includes health and safety instructions, detailed remediation plans and lists measures for future site and occupant protection, including testing of building contamination post-remediation. Importantly, plans for permanent removal of the moisture source are vital, as site validation is otherwise misleading.

CASE STUDY 1: BUILDING A, YEERONGPILLY, QUEENSLAND, JANUARY 2011.

Background

Building A comprised an eight-storey purpose-built office block inundated to the second floor during the Queensland floods of 11 January 2011. The Brisbane River and Oxley Creek, the sources of flood water, were each located approximately 2 km from the building. The objective was to return staff safely to work whilst minimising the impact of the flood on the business.

The building was evacuated on the 10 January 2011 and had remained unoccupied for 14 days at the time of site investigation. Above-ground water had subsided and residual water pumped out of the premises; standing water remained in the lift shaft.
Methods
A Tier 1 site investigation recorded visible mould and odour. Triplicate temperature and relative humidity readings were taken at a minimum of two locations on each storey, using a Krestel Model 4000 meter. Building fabric moisture and carbon dioxide concentrations were measured at three locations on each floor of the building (using a Protimeter Moisture Meter Plus and Landcom Series II gas analyser respectively).

Results
Site observations
No visible mould was observed, however there was an overpowering mould odour by the building entrance and up to the 4th Floor. Internal walls of the Ground to 7th floors were made entirely of concrete. Desks and soft furnishings showed no signs of mould infestation.

Moisture measurements
As shown in Figure 2, moisture levels were elevated in internal walls of the Ground floor and Floor 1, where moisture reached 100 ± 0% and 95.3 ± 4.7% saturation respectively (n=3). Wall moisture content fell sharply on higher floors, and remained consistently below 17%, that potentially triggers mould growth. RH readings were elevated on the Ground to 4th floors of the building, falling in a linear pattern from Floor 2 to Floor 5, before reaching approximately 60% throughout the remainder of the building, 1.3% lower than that outdoors. Temperatures were conducive to mould growth, increasing from 29 ± 0.5 °C on the ground floor to 31 ± 0.5°C (n=3) on Floor 7. Calculated saturated vapour pressure of the air was 27.4% in Floor 1 and 26.8% in Floor 7, indicating that the increase in RH was due to elevated air moisture content in the lower levels, and not just to difference in temperature (List, 1951).

A Tier 2 exposure assessment was made. The building was unoccupied by staff, exposure risk was considered negligible, therefore no further testing was required.

Conclusion
It was concluded that there was a high risk of mould contamination on the first five floors due to high moisture content of the building fabric, elevated water vapour and optimum temperatures, and possible indoor air mould spore transport from lower floors. The client terminated their lease and moved to new premises without the need for further testing.

CASE STUDY 2: FACTORY B, SOUTH EAST QUEENSLAND.

Introduction
Wood was moved from a storage area, and handled on a conveyor belt. Staff handled several thousand pieces of heavily mould-contaminated wood per week. Handling periods were intermittent during a shift.

An image of a piece of the most heavily contaminated timber is shown in Figure 3:
Workers were equipped with safety glasses and heavy duty gloves but limited respiratory protection. Exposure assessment during hand-loading the conveyor and stacking the wood for storage was required. As the mould source was known, there was no requirement for a Tier 1 assessment, thus a Tier 2 (exposure assessment) was carried out. It was assessed that there was a high likelihood of worker exposure, therefore a Tier 3 investigation was required.

Methods
Worker activity data
Workers were asked to record their activities over the sampling periods. Activity data was analysed to examine time spent handling contaminated material. Further, analysis of time spent carrying out activity within the affected area adjacent to the conveyor was also included in our investigation. That area was delineated based on ambient monitoring data.

Personal exposure monitoring
Personal exposure in the conveyor/handling area was compared to exposure in a factory area without contaminated material. Air was sampled onto 0.2 µm pore size, 37
mm diameter polycarbonate filters housed in IOM® personal dust samplers at a flow rate of 2 L/min using Universal personal sampling pumps.

Ambient monitoring
Mould concentrations in the conveyor/handling area and the storage area were examined. Air samples were collected in the handling area during conveyor belt loading, at 1.5 m height using a Surface-Air-System (Dr. James Smith Consulting) (SAS) at a flow rate of 100 L/min for 1 min with direct impaction onto DRBC® mould-selective agar. Transect samples were collected at 5 m or 10 m intervals from the conveyor belt and stored wood respectively, up to a distance of 20 m.

Peak total (non-viable) spore concentration during conveyor belt operation were monitored by collecting paired samples at 1.75 m distance and 2 m height from the conveyor belt as described for personal monitoring. One sampler was operated only during handling, whilst the other was operated for the entire shift. Samples were analysed by Dr. James Smith Consulting and Biotech Laboratories.

Surface mould monitoring
Tape-lift samples were collected using clear adhesive tape, and mounted onto microscope slides. Spores were enumerated and identified where possible to genus level by Dr. James Smith Consulting.

Risk evaluation
To prepare a Remedial Action Plan under Tier 4, qualitative risk analysis was conducted based on mould genera.

Results
Worker activity in relation to handling of mould infested material
Handling periods of workers were intermittent, each handling period lasting for 18.7 +/- 2.40 minutes (n=7) for a total handling time of 35.0 +/- 8.66 minutes (n=3) during a 12-hour shift.

Personal exposure monitoring
Workers handling contaminated material were exposed to total mould spore concentrations of $2.43 \times 10^6$ spores/m$^3$ of air in their breathing zone, 1000 times greater than workers in the control location as shown in Figure 4. Further, airborne concentrations during handling of the contaminated material within 2 m of the conveyor belt elevated from a 12-hour mean average of 1,467 spores/m$^3$ to 883,000 spores/m$^3$ during peak periods (Figure 4), suggesting extreme elevation of mould concentrations during handling.

Of concern was the dominance of airborne fungi by Aspergillus/Penicillium species (spp.), whereby 96.6% of the airborne

**Figure 3: Changes in moisture content with building height.**
mould spores immediately adjacent to the conveyor belt were identified as Aspergillus/Penicillium.

**Ambient monitoring**
Analysis of transect samples revealed that the percentage of mould genera comprising Aspergillus/Penicillium spp. inversely correlated with distance from the source as shown in Figure 5, indicating that the timber was a source of Aspergillus/Penicillium.

**Surface mould monitoring**
Surface spores were dominated by Chrysosporium spp. in a highly localised pattern; 2,569 ±1,638 spores/cm² (n=3) were recorded from wood surfaces, 31,200 ±3,270 spores/cm² (n=6) from horizontal structural supports immediately adjacent to the storage area, and 3,435 ±137 spores/cm² (n=3) on surfaces adjacent to the conveyor. No evidence of Chrysosporium was found elsewhere at the site or in air samples, thus accumulation on localised surfaces was observed that correlated with the presence and movement of contaminated wood. These findings suggested either that the Penicillium/Aspergillus were remaining airborne, or that the high concentrations of Chrysosporium were sufficiently high to mask their presence.

**Risk evaluation**
Twenty of the 185 currently identified species of Aspergillus have been shown to elicit adverse health effects (de Hoog et. al., 2000). Collectively termed aspergillosis, recorded illnesses comprise allergic aspergillosis (Galimberti et. al., 1998), invasive aspergillosis, allergic bronchopulmonary aspergillosis (Seltzer and Fedoruk, 2007; Harley et. al., 1995) and aspergilloma (Patterson, 2005).
Penicillium comprises more than 200 species and commonly grows on wood. Some species are proven allergens causing Type I and Type III allergenic activity (Shen et al. 2007; Wilkin-Jensen and Gravesen, 1984). Acute exposure to high concentrations of Penicillium can cause bronchospasm, longer-term exposure may cause pulmonary emphysema (Crissy et al., 1995). Penicillium species can produce a range of mycotoxins (Pitt et al., 2000). Inhalation of mycotoxin-containing spores has been connected with Organic Dust Toxic Syndrome (Mackiewicz et al., 2008). A recent study (Eduard, 2009) recommended exposure limits of 10,000 spores/m³ Penicillium chrysogenum; concentrations experienced by workers reached 14,300 spores/m³. The strain identity of the moulds were not determined, thus the precautionary approach dictated that the moulds may be hazardous to susceptible workers facing chronic exposure during wood handling and transport.

A RAP including clean-up methods for the affected areas, with advice on personal protection, and source elimination based on the Hazard Control Hierarchy was provided (Main, 2004).

Conclusion
As all workers were in good health at the time of sampling, with no historical records of mould allergies or suppressed immune function, there was a low risk of retrospective infection or allergic reaction amongst existing staff. In response to RAP recommendations, the client refused contaminated wood from their supplier, and developed a safe clean-up strategy.

CASE 3: KINDERGARTEN C, VICTORIA.

Introduction
A mould investigation at a water-damaged kindergarten in Victoria identified signs of visible mould (EML Laboratories). Moisture was seeping through a wall abutting damp soil with compromised damp proofing.

Based on colony morphology and microscopy, the presence of Stachybotrys chartarum and Aspergillus versicolor was suspected. MicroGenetix, Victoria carried out 28S rRNA gene sequencing of three mould isolates and gene library identities were provided.

The moulds were already identified to strain level, the source and receptors were known, therefore a risk assessment was required for deriving a RAP under Tier 4.

Method
Assessment of 28S rDNA sequences was made to improve risk assessment based on hazard description. Data was analysed based on DNA sequence length, percentage sequence homology, and other closely related strains to establish a qualitative likelihood that the identities were accurate. Health risks from these moulds for pre-school children and staff were assessed assuming potential exposure from surfaces and air (Rosenblum et al., 2010; Cho et al., 2005) based on possible exposure routes and mould concentrations.

Results
DNA sequence examination revealed high confidence in the hypervariable 28S rRNA region sequence identities which indicated the presence of airborne toxic S. atra (chartarum) var. corda and Aspergillus versicolor var. fulvus strains, with 100% sequence homology only to these toxic strains. Mould was also visible on surfaces posing potential risk from ingestion.

Both strains can produce highly hazardous mycotoxins (Bae et al., 2009; Rakkastad et al., 2008; Islam et al., 2006; Rotoli et al., 2001; Perica et al., 1999; Hodgson et al., 1998; Paul and Thurm, 1979) and grow on water-damaged building materials (Engelhart et al., 2002).

Conclusions
Serious concerns about prior exposure of children at the site, high confidence in the DNA findings, and the closeness of DNA sequences to known strains of highly toxic mould resulted in recommendations of detailed delineation investigations, and containment of the property until fully remediated.
CONCLUSION
A flexible approach to site-specific mitigation following mould contamination events was successfully demonstrated. Using logical tiered progression, an appropriate level of detail was selected for each site investigation. Whilst commonly used techniques allow mould assessment, there is a need to target assessments such that site-appropriate risk mitigation can take place. In cases where sensitive individuals may be exposed, it is imperative to understand potential hazard severity of moulds, whilst in other cases where there may have been no retrospective or perceived exposure, it may be justifiable to assume the worst case scenario rather than eliminating it prior to taking action. Until Australia adopts mould exposure guideline values, such an approach may assist those assessing and managing risks around mould exposure.

REFERENCES:

List, R.J. (1951) *Smithsonian meteorological Tables*, Smithsonian Institute Press, Washington DC.


