Assessment and Management of Chemical Risks in Academic Laboratories (3)

- Observing behavior of experimenter and chemical reagents in an actual chemical laboratory-

Yoshito Oshima¹) Yukiko Nezu¹), Hitoshi Yamamoto²)

1) Graduate School of Frontier Sciences, The University of Tokyo
2) Department for the Administration of Safety and Hygiene, Osaka University
Chemical Reagent Handling

In chemical laboratories, many chemical reagents are handled at various places for various purposes according to various factors.

- fume hood
- lab bench
- reagent storage cabinet
- waste container ...
- reactant
- solvent
- standard
- coolant ...
- type of work (routine or new)
- number of experimenters
- time
- scale (amount) ...

To reduce the risk of chemical substances in laboratories, knowing **HOW** experimenters use chemicals is important.
Information currently available on Japanese universities

- Registration system of chemicals
- Laboratory waste management system
- Working environment measurement
- Inspection by industrial physician

Characteristics of laboratory research

✓ use of large number of various chemical substances
  approx. 350,000 chemical bottles in UTokyo (as of 2011)[1]

✓ transdisciplinarity and diversification of research areas
  chemistry, physics, biology, physics, mechanics, pharmaceuticals ...

How should chemical risks be assessed in research labs?

Chemical safety in lab.

What kind of operations are there in lab?

How much chemicals are used in lab?
Chemical safety in lab.

- **who** uses chemicals
- **what** kind of chemical reagents are often used
- **where** chemicals are used
- **when** chemicals are used
- **why** chemicals needs to be used
- **how** chemicals are used

This information should be combined to analyze and reduce chemical risks in laboratories.
Case Study Approach

The characteristics in the usage of chemical substances in the chemical lab are analyzed by collecting the following data:

- movement of reagent bottles during experiments by Radio Frequency Identification (RFID) System
- experimenter actions captured by web cameras
- purpose and procedure of experiment

Radio Frequency Identification (RFID) System & Motion Monitoring by Web Cameras

- All the chemical bottles in this lab (213 bottles) are “tagged”
- Device that reads “tag” from a distance using radio waves to identify objects
- Recorded when chemicals are used at a designated location
- Checkout log of chemicals from storage
- Motion of experimenters monitored by web camera
Laboratory layout

Monitoring

- research field: polymer chemistry
- 10 experimenters
- number of tagged bottles: 213
- June 18 - August 9 (53 days)
Checkout log of reagents (example)

<table>
<thead>
<tr>
<th>Reagent</th>
<th>9AM</th>
<th>noon</th>
<th>3PM</th>
<th>6PM</th>
<th>9PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Experimenter actions (example)
Analysis on checkout log data of reagents

Checkout duration:
- less than 10 min: 23.0% (refrigerator), 50.6% (desiccator), 40.9% (cabinet)
- 10 - 30 min: 21.8% (refrigerator), 23.7% (desiccator), 20.4% (cabinet)
- more than 30 min: 55.2% (refrigerator), 25.7% (desiccator), 39.8% (cabinet)

Average checkout time:
- Refrigerator: 73.3 min
- Desiccator: 26.1 min
- Cabinet: 48.9 min

43% of bottles returned to original storage within 5 mins.

- Reagents from refrigerator must be warmed up before use.
- Reagents from desiccator disfavor humidity.
Where chemicals are frequently used

<table>
<thead>
<tr>
<th>Place</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab bench</td>
<td>39</td>
</tr>
<tr>
<td>Fume hood</td>
<td>15</td>
</tr>
<tr>
<td>Scale</td>
<td>19</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>73</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Place of usage</th>
<th>Place</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Lab bench (L)</td>
<td>39</td>
</tr>
<tr>
<td>F</td>
<td>Fume hood (F)</td>
<td>5</td>
</tr>
<tr>
<td>S</td>
<td>Scale (S)</td>
<td>4</td>
</tr>
<tr>
<td>L→F</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>L→F→L</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>F→L</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>L→S</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>L→S→L</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>L→S→L→S</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>S→L</td>
<td>S</td>
<td></td>
</tr>
</tbody>
</table>

Results & Discussion

Lab bench functions as a critical “hub”
# How long are chemicals used in the lab

<table>
<thead>
<tr>
<th>Start</th>
<th>Stop</th>
<th>Time</th>
<th>Operation</th>
<th>Reagent</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>10:45:00</td>
<td>10:51:00</td>
<td>0:06:00</td>
<td>measuring</td>
<td>PEG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10:52:54</td>
<td>10:55:10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10:55:30</td>
<td>10:55:35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13:33:46</td>
<td>13:34:21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13:34:22</td>
<td>13:34:50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13:39:53</td>
<td>13:40:06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13:40:21</td>
<td>13:40:42</td>
</tr>
<tr>
<td></td>
<td>14:37:24</td>
<td>14:38:45</td>
<td>0:01:21</td>
<td>measuring</td>
<td>2–bromoisobutyryl bromide</td>
</tr>
<tr>
<td></td>
<td>14:37:24</td>
<td>14:38:40</td>
<td>0:01:16</td>
<td>loading</td>
<td>2–bromoisobutyryl bromide</td>
</tr>
<tr>
<td>Day 2</td>
<td>10:46:45</td>
<td>10:47:00</td>
<td>0:00:15</td>
<td>dissolution</td>
<td>N,N–dimethyl acetamide</td>
</tr>
<tr>
<td></td>
<td>10:47:03</td>
<td>10:47:45</td>
<td>0:00:42</td>
<td>dissolution</td>
<td>diethyl ether</td>
</tr>
<tr>
<td></td>
<td>11:16:13</td>
<td>11:16:29</td>
<td>0:00:16</td>
<td>measuring</td>
<td>methanol</td>
</tr>
<tr>
<td></td>
<td>11:16:13</td>
<td>11:16:28</td>
<td>0:00:15</td>
<td>measuring</td>
<td>methanol</td>
</tr>
<tr>
<td></td>
<td>11:17:15</td>
<td>11:17:41</td>
<td>0:00:26</td>
<td>loading</td>
<td>diethyl ether</td>
</tr>
<tr>
<td></td>
<td>11:17:15</td>
<td>11:17:35</td>
<td>0:00:20</td>
<td>loading</td>
<td>diethyl ether</td>
</tr>
<tr>
<td></td>
<td>11:25:10</td>
<td>11:28:02</td>
<td>0:02:52</td>
<td>measuring</td>
<td>reactant (mixture)</td>
</tr>
<tr>
<td></td>
<td>11:28:05</td>
<td>11:31:33</td>
<td>0:03:28</td>
<td>still standing</td>
<td>reactant (mixture)</td>
</tr>
<tr>
<td></td>
<td>11:31:35</td>
<td>11:32:25</td>
<td>0:00:50</td>
<td>loading</td>
<td>reactant (mixture)</td>
</tr>
<tr>
<td></td>
<td>11:32:20</td>
<td>11:32:25</td>
<td>0:00:05</td>
<td>loading</td>
<td>reactant (mixture)</td>
</tr>
<tr>
<td></td>
<td>11:37:08</td>
<td>11:37:25</td>
<td>0:00:17</td>
<td>washing</td>
<td>diethyl ether</td>
</tr>
<tr>
<td></td>
<td>11:37:08</td>
<td>11:39:41</td>
<td>0:02:33</td>
<td>washing</td>
<td>diethyl ether</td>
</tr>
<tr>
<td></td>
<td>11:38:34</td>
<td>11:38:37</td>
<td>0:00:03</td>
<td>washing</td>
<td>diethyl ether</td>
</tr>
<tr>
<td></td>
<td>12:32:10</td>
<td>12:35:22</td>
<td>0:03:12</td>
<td>loading</td>
<td>reactant (mixture)</td>
</tr>
<tr>
<td></td>
<td>12:36:07</td>
<td>12:36:24</td>
<td>0:00:17</td>
<td>washing</td>
<td>diethyl ether</td>
</tr>
</tbody>
</table>
## Length of time for chemicals to escape into air

<table>
<thead>
<tr>
<th>Operation</th>
<th>Length of time (a)</th>
<th>Total (b)</th>
<th>Ratio (a)/(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction</td>
<td>17.5 min</td>
<td>60.8 min</td>
<td>28.7 %</td>
</tr>
<tr>
<td>Precipitation</td>
<td>4.1 min</td>
<td>23.5 min</td>
<td>17.4 %</td>
</tr>
<tr>
<td>Filtration</td>
<td>5.6 min</td>
<td>25.0 min</td>
<td>22.4 %</td>
</tr>
</tbody>
</table>

cf. total time length of entire experiment: 694 min

Chemicals escaping into the air for a certain length of time is unavoidable, though it may be negligibly short compared with the duration of the entire experiment.
Washing bottles

Total number of usage (5 days)

Rinsing Glassware
Experiment

Purpose
64.3 % for rinsing glassware before and after use

Frequency
65.6 times/day (average)

How are washing bottles used in lab

1. Acetone: 100
2. Methanol: 75
3. DMSO: 75
4. Dichloromethane: 120

Total number of usage

Results & Discussion
Rinsing with “washing bottle”

- “non-essential” operation to experiment purpose
- as frequently as glassware used
- indefinite time until completion of rinsing
- indefinite place (bottle is movable)
- volatile solvents exposed to the air during operation until dumped into waste tank

a risky procedure that may influence on the chemical exposure
### Experimental protocol (from Experimenter A’s notebook)

**three necked flask (50 mL)**
- PEG 2 g
- DMAP 2.8 mg
- magnetic stirring bar
- vacuum drying (2 hrs.)
- replace with Ar
- DMAc (dehyd.) 8 mL
- TEA 0.8 mL
- dissolved at 40 °C
- 2-BIB 0.22 mL
- stirring at 30 °C
- separatory funnel (300 mL)

**erlenmeyer flask (50 mL)**
- ice bath
- ether 30 mL
- MeOH 0.2 mL
- taking fraction (2 mL)
- precipitation tube (50 mL)
- centrifugation 3100 rpm, 15 min

---

**Results & Discussion**
Classification of experimenter’s behavior in lab

in Lab

[1] operation in the protocol

[2] operation not in the protocol

[3] moving around in Lab

[4] not staying in the laboratory

a: observation
b: preparation
c: confirmation and recording
d: cleaning
e: exit operations
f: protection
g: changes and adjustments
h: others
i: non-experimental

Results & Discussion
Distribution of time-duration classified by type of operation

Risks during operation “not in the protocol” are crucial!
Summary

Chemical reagent behavior and experimenter behavior in an actual laboratory analyzed through a case study approach.

Chemical Reagent Behavior
- outing from storage
- trajectory characteristics

Experimenter Behavior
- time duration for operation
- chemical usage

Discussed: how key unit operations affect chemical exposure
- risk in operations not in protocol
- handling chemicals in “shared circumstances

Confirmed as crucial: Laboratology concept is critical for ...
- scientific and quantitative discussion based on data of visible, measurable phenomena collected in actual laboratories
- assessing chemical risks in experimental laboratories.
Acknowledgement

Financial Support by Grants-in-Aid for Scientific Research (25242014, Scientific Research (A), 2013-2015) from the Japan Society for the Promotion of Science