Risk Management
by Risk Magnitudes

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We've been hearing and reading plenty lately about "risk management," "risk assessment," and other risk-related terms. You may feel that you already have a pretty good handle on what they mean, but are you really managing your risks right now, on an ongoing basis? This article gives a strategy for lab managers, lab safety officers, emergency planners, and others to move ahead with real laboratory risk management and get some immediate benefits.

Hazards and Risks

First, to understand risk assessment and risk management, it is essential to understand the difference between *hazard* and *risk.* A good definition of *hazard* is

HAZARD

The presence of a material or condition that has the potential for causing loss or harm.

Thus, as soon as a hazardous material or condition is introduced into the lab, a hazard is present. That hazard will continue to be present, no matter how carefully it is handled and regardless of whether or not any spills or other incidents occur with it, until the hazardous material or condition is converted or removed.

Examples of other typical lab hazards are elevated or cryogenic temperatures, centrifuges, compressed gases, radiation, and glassware. As long as such a material or condition is present, a hazard exists.

By contrast, *risk* always has two components, *severity* and *likelihood.* A general definition of *risk,* and the one that will be used here, is

RISK

A combination of the severity of consequences and likelihood of occurrence of undesired outcomes.

Costs and Risks

Another way of understanding risk is to compare risks with costs, which all lab managers understand. *Costs* are <u>expected</u> expenses or liabilities that can be included in a budget or financial forecast. *Risks*, by contrast, are <u>unexpected</u> expenses or liabilities. Because an organization does not expect to incur these liabilities within the same economic time frame as costs (usually a fiscal year), they are not generally included in budgets or financial forecasts. These two terms are more fully compared as follows:

COMPARISON OF COSTS VS. RISKS

COSTS	RISKS
Near certain; expected	Uncertain; unexpected; probabilistic
Cost estimates are usually available	Risk estimates are usually not available
Higher-precision estimates	Lower-precision estimates, if available
Predictable benefits if cost incurred	Negative consequences if outcome realized
Incurred every year over life of project	Liability incurred only if outcome realized
Can vary from year to year as work activities change during the life of a project	Can vary from year to year if budgeted work activities change

Even though we do not see risks included in the annual lab budget, they must still be managed, just as costs must be managed, to stay in business. Losses and liabilities can be very high if an incident such as a lab fire occurs, and can severely affect business operations and profitability.

Risk Management

Risk management, then, is doing all the things that need to be done to continually and economically control risks. Since resources are limited, risk management implies that resources need to be prioritized so they are not wasted on ineffective activities.

This article gives an order-of-magnitude strategy for identifying your risks and determining where your greatest risks are. The framework given here also allows the combining of costs and risks so they can be managed together. The application of this strategy to a hazardous waste operation is also highlighted.

The key questions to be answered in risk-based prioritization follow from our definition of risk:

1. What are my **undesired outcomes**?
2. What is the **severity of consequences** of each undesired outcome?
3. What is the **likelihood of occurrence** of each undesired outcome?
4. How do I use this information to **manage risks**?

Undesired Outcomes

Time to roll up our sleeves, find our risks, and then determine the magnitudes of the various risks. The first step is to identify all of the important undesired outcomes that go along with your lab operations. A good way to do this is to start with a list of the *hazards* inherent in the lab operations, then determine what could happen if these hazards got out of control. Other undesired outcomes can then be added to the list.

If you're handy with tables or spreadsheets, you can easily set up a table like the one below. We will use three additional columns when we get to severity, likelihood, and risk.

EXAMPLE HAZARDS, UNDESIRED OUTCOMES

Lab Area:	Lab 1A
Hazards:	5 liters acetone (flammable), 2 liters acetic acid (corrosive, combustible), argon cylinder, nitrogen cylinder, glassware, oven, hotplates, compressed air, laser
#	**Undesired Outcome**
1A-1	Acetone fire in lab room outside hood; sprinkler-protected
1A-2	Acetic acid fire in lab room outside hood; sprinkler-protected
1A-3	Acetic acid splashing or spill; eye/skin burn
1A-4	Reportable-quantity spill of acetic acid
1A-5	Gas cylinder dropped on valve w/o cap on; valve broken off
1A-6	Large N_2 leak in room; inadequate ventilation; asphyxiation
1A-7	Glassware broken; no injuries
1A-8	Glassware broken or mishandled; severe cut
1A-9	Oven temperature control failure; overheating of contents; fire
1A-10	Burn from contact with hotplate or other hot surface
Etc.	

For each lab area to be considered for risk management, start by making a list of the hazards that are present. This can be done by knowledge, inspection, or systematic review. For each hazardous material, it will be helpful to also include the quantity and form of material and its hazardous properties, as shown in the example.

Next, list the undesired outcomes that are possible with these hazards present, as well as other undesired outcomes that need to be managed. As you do this, think broadly! "Undesired Outcomes" can include many things that may have a low likelihood of occurrence, but severe consequences if they do occur. Possibilities include losses of a key staff person, experimental data, electrical power, or lab funding; unfavorable audits; contracting of an occupational illness; or mechanical failure of critical equipment.

Severity Magnitudes

The next step is to assign an order-of-magnitude severity to each of the undesired outcomes that were identified. This will be done using a novel approach developed for this purpose.

Most people are familiar with the “Richter Scale.” The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude.[1]

The same kind of logarithmic (powers-of-ten) scale will be used here for expressing the severity of consequences of various undesired outcomes. Just as a Magnitude 7 earthquake could result in extensive losses and injuries, so a lab incident with Magnitude 7 severity will be thought of as a catastrophic event. Most lab incidents and other undesired outcomes have lower-magnitude severities. The table below gives an example scale for measuring the severity of consequences of undesired outcomes related to facilities handling hazardous materials.[2]

SEVERITY MAGNITUDES TABLE

Magnitude	Cost, Loss or Liability	Worker Effects	Public Effects	Env. Effects
7	$10MM	Fatality or permanent health effect	Fatality or permanent health effect	Widespread and long-term or permanent
6	$1M		Severe or multiple injuries	Widespread and short-term or localized and long-term
5	$100,000	Severe or multiple injuries	Injury or hospitalization	
4	$10,000	Lost workday(s)	Exposure above limits	Localized and short-term
3	$1,000	Medical treatment	Exposure below limits	Reportable spill
2	$100	First-aid case	Odor/noise concern	Variation from permit

This table can be simplified by omitting columns, such as if only dollar-denominated consequences and/or worker health effects are of concern. Note that the establishment of the Severity Magnitudes table is actually a risk management activity, and as such it should be reviewed and “bought into” by lab management before proceeding further.

Adding a Severity column to the Example table shown on page 2 can capture the Severity Magnitude for each Undesired Outcome. Likelihood and Risk Magnitude columns will also be needed, as explained below.

Likelihood Magnitudes

The likelihood of occurrence of each Undesired Outcome can be thought of as the bridge between the Severity and the Risk. An outcome with a given severity will have a greater risk if it is more likely to occur, and a lesser risk if it is less likely to occur.

An order-of-magnitude scale, as shown in the table below, can also be used for capturing the likelihood of occurrence of each Undesired Outcome. For the mathematically minded, the integer for this scale is just the base ten logarithm of the annual frequency of occurrence. Thus, an Outcome with a Likelihood Magnitude of +1 has a frequency of 10^{+1} per year, or ten times a year.

LIKELIHOOD MAGNITUDES TABLE

Magnitude	Times Per Year	Alternate Description
+2	100	Twice a week
+1	10	Once a month
0	1	Once a year
-1	0.1	Once every 10 years, or 10% chance per year of operation; once a year in collection of ten similar lab areas
-2	0.01	Not expected to occur during facility life, but may occur; 1% chance per year of operation
-3	0.001	Would be very surprising if occurred during facility life; 1 chance in 1000 per year of operation
-4	0.0001	Extremely unlikely, or not expected to be possible

[1] U.S. Geologic Survey, National Earthquake Information Center, 1997

[2] R.W. Johnson, T.I. McSweeney, and J. S. Yokum, “Use of Risk Mapping for Resource Optimization,” *International Conference and Workshop on Risk Analysis in Process Safety* (New York: American Institute of Chemical Engineers–Center for Chemical Process Safety, 1997)

Likelihood of Rare Outcomes

The more frequent an Undesired Outcome occurs, the better estimate can be made of its Likelihood Magnitude. It is relatively easy to decide at what Likelihood Magnitude temporary power outages occur that necessitate resetting equipment or restarting experiments. It is much more difficult to determine the Likelihood Magnitude of rare events, such as fires and explosions, which usually involve multiple causative factors. You may want to get help from a risk analyst at this point. However, the Likelihood Magnitude of many such Undesired Outcomes can be quickly estimated by remembering the following rule: combine one frequency with any number of probabilities.

As an example, take the Undesired Outcome of an acetone fire in the lab outside of a hood. The most likely scenario for this occurring may be the dropping and spilling of a container of acetone, followed by ignition of the vapors from the spill. The frequency of interest is how often acetone is handled in the lab; the more often it is handled, the more likely a spill is to occur. The other two factors are the probability of the acetone being dropped and spilled each time it is handled and the probability that the spill will ignite. If the handling frequency is an average of three times a day (1000 times a year), this can be combined with a probability of 0.1% per handling operation of dropping and spilling the acetone, and a 1% probability of ignition (since acetone is above its flash point at room temperature). The product of these numbers gives a predicted frequency of acetone fires in this lab area of 0.1 per year (= 1000/year x 0.001 x 0.01), which corresponds to a Likelihood Magnitude of –1.

Risk Magnitude

Since we have been using magnitude numbers, determining the Risk Magnitude is a simple task. The Risk Magnitude is just the sum of the Severity Magnitude and the Likelihood Magnitude. (This can be done because adding exponents is the same as multiplying numbers; for example, 1000 x 0.1 = 100 in scientific notation is $10^{3} \times 10^{-1} = 10^{2}$, and $10^{(3+(-1))} = 10^{2}$.)

The table below shows example severity and likelihood estimates for the Undesired Outcomes from the preceding table, along with the Risk Magnitude determined by adding the Severity Magnitude and the Likelihood Magnitude. Note that a frequency of occurrence of once a year can be thought of as a "base" frequency. If an Undesired Outcome has a Likelihood Magnitude of **0**, then the Risk Magnitude will be the same as the Severity Magnitude. If the Outcome is more likely than once a year, the Risk Magnitude will be greater than the Severity Magnitude, and conversely if the Outcome is less likely.

EXAMPLE RISK MAGNITUDES TABLE

Lab Area: Lab 1A

Hazards: 5 liters acetone (flammable), 2 liters acetic acid (corrosive, combustible), argon cylinder, nitrogen cylinder, glassware, oven, hotplates, compressed air, laser

#	Undesired Outcome	Magnitudes		
		Severity	Likelihood	RISK
1A-1	Acetone fire in lab room outside hood; sprinkler-protected	4	-1	**3**
1A-2	Acetic acid fire in lab room outside hood; sprinkler-protected	3	-2	**1**
1A-3	Acetic acid splashing or spill; eye/skin burn	4	-1	**3**
1A-4	Reportable-quantity spill of acetic acid	3	-1	**2**
1A-5	Gas cylinder dropped on valve without cap on; valve broken off	5	-4	**1**
1A-6	Large nitrogen leak in room; inadequate ventilation; asphyxiation	6	-3	**3**
1A-7	Glassware broken; no injuries	2	0	**2**
1A-8	Glassware broken or mishandled; severe cut	5	-1	**4**
1A-9	Oven temperature control failure; overheating of contents; fire	5	-2	**3**
1A-10	Burn from contact with hotplate or other hot surface	2	0	**2**
…				

The results in the preceding table are, of course, only examples. Both the severities and the likelihoods will vary from lab area to lab area and from company to company.

Using the Risk Magnitude Results

Here is where risk management begins. The most obvious use of the Risk Magnitudes is to work toward reducing each lab area's greatest risks. In the example above, the risks vary over a range of three orders of magnitude, from a +1 to a +4. (Many lesser risks could no doubt also have been identified.) Resources and efforts should be directed, in this case, toward reducing the severity and/or likelihood of severe injuries from glassware, rather than reducing an acetic acid fire risk that is both less severe in its consequences and less likely to occur.

Risk results can also be compared between lab areas. This can be done most simply by ranking lab areas by the highest Risk Magnitude in each area. If the results have been captured in a spreadsheet or database, the total risk for each lab area can also be determined by converting each risk to a linear value (i.e., taking 10 to the Risk Magnitude power) and then summing these linear values. If desired, this sum can be converted back to a Risk Magnitude by taking its base 10 logarithm. (The total Risk Magnitude for all of the risks in the example table above comes out to be 4.2, if you want to crosscheck your equations.)

Other uses of Risk Magnitudes include:

- Deciding on a maximum tolerable Risk Magnitude and reducing all risks below this threshold
- Comparing risk-reduction costs with risk-reduction benefits, recognizing that the units of measure of the dollar-denominated risks are all in dollars per year
- Using the approach as a means of conducting Process Hazard Analyses (PHAs) that can include business and environmental as well as safety and health consequences.[3]

Further Suggestions

If you've gotten this far with the approach, there are also several other considerations that will help you succeed.

- Don't rely on the judgment and experience of only one person to identify Undesired Outcomes and determine the Severity and Likelihood Magnitudes; a team approach is much more effective, by involving a variety of knowledgeable persons from lab technicians to research chemists and lab safety officers
- Use all information available from incident reports and other sources to determine what has happened in the past
- Begin to develop a standardized set of severities and likelihoods that can be used as a starting point for each area and enhance consistency between areas
- Aggressively review each area and each new lab-use proposal for opportunities to make lab operations inherently safer; i.e., to eliminate or reduce the underlying hazards that must be contained and controlled
- Look for possible interactions between lab areas, such as whether a fire or explosion in one lab area can result in loss of containment of a highly toxic material in an adjacent area.

With the approach given in this article, you now have a technically correct and powerful tool for identifying and analyzing laboratory risks and allocating resources for risk reduction. This is a key element, but of course not the only element, of risk management. It presupposes that all other loss prevention activities will continue to be in place, such as fire protection, emergency procedures, equipment maintenance, permitting systems, and housekeeping. You do not need even an order-of-magnitude analysis to say what will happen if any of these are neglected.

[3] R.W. Johnson and M. Elliott, "Integrated Safety Analysis Project," and T.I. McSweeney, "Benefits of Quantifying Process Hazard Analysis," *International Conference and Workshop on Risk Analysis in Process Safety* (New York: American Institute of Chemical Engineers–Center for Chemical Process Safety, 1997)

Waste Management Risk Magnitudes

Battelle Memorial Institute applied the risk magnitude approach presented in this article to all waste operations at a government-owned, contractor-operated facility that generated hazardous, low-level radioactive and mixed wastes. A team review approach was used to identify Undesired Outcomes and determine severities and likelihoods. Seven categories of Undesired Outcomes were considered: worker and public safety and health, environment, compliance, mission, avoidable costs, and social/cultural/economic impacts. The table below shows the combined Risk Magnitude for each of the 32 waste management activities having identified risks. These results show that the five highest-risk activities pose two-thirds of the total waste operations risk, and several of the activities do not contribute significantly to the total risk.

RISK MAGNITUDES FOR WASTE MANAGEMENT ACTIVITIES

Activity	Risk Magnitude	% of Total Risk	Cumulative %
Waste characterization	**6.2**	16.0%	16.0%
Generator accumulation activities at < 90-dy and < 55-gal sites	**6.1**	13.7%	29.7%
Reclassification/recharacterization of waste	**6.1**	11.9%	41.7%
Down-grading "legacy" mixed waste	**6.1**	11.4%	53.1%
Off-site waste acceptance criteria	**6.0**	11.3%	64.4%
Spill response	**5.7**	4.6%	69.0%
Off-site treatment	**5.6**	4.3%	73.3%
Waste receipt and inspection	**5.5**	3.3%	76.7%
RCRA-B permit training	**5.5**	3.2%	79.9%
Division Waste Coordinator	**5.4**	2.8%	82.6%
Waste minimization/pollution prevention	**5.3**	2.2%	84.9%
Burning ground operations	**5.3**	2.2%	87.1%
Nevada Test Site Waste Acceptance Criteria requirements	**5.2**	1.6%	88.6%
12-73 Building (steam cleaning)	**5.2**	1.5%	90.1%
Recycling opportunities	**5.2**	1.5%	91.6%
Waste Operations Department provides container	**5.1**	1.4%	93.0%
Explosive safety examination of high explosive level	**5.1**	1.4%	94.4%
On-site transportation of wastes	**5.1**	1.3%	95.6%
Generator requests container (excluding biohazard waste)	**5.1**	1.2%	96.8%
Pre-audit checks	**5.0**	1.1%	97.9%
Waste disposal and receipt of Certificate of Destruction	**4.8**	0.7%	98.6%
12-42 Waste staging facilities	**4.6**	0.4%	99.0%
Waste Tracking System	**4.4**	0.2%	99.3%
Shipping manifest, procedures, and certification	**4.4**	0.2%	99.5%
On-site permitted storage	**4.4**	0.2%	99.7%
Disposal site selection	**4.2**	0.1%	99.9%
On-site treatment	**3.9**	0.1%	100.0%
Waste certification	**3.5**	0.0%	100.0%
Existing Material Evaluation Request Form determination	**3.0**	0.0%	100.0%
Audits/surveillances of storage areas	**2.8**	0.0%	100.0%
Division Waste Coordinator approves Request Form	**2.1**	0.0%	100.0%
Preliminary waste characterization	**2.0**	0.0%	100.0%
		100.0%	