LES 9

OBSERVATORY
SCIENCE AND TECHNOLOGY (ST)
Teacher's Guide A
Second Year of Secondary Cycle Two

DISASTER
AHEAD

STUDENT LOG

WORKING DOCUMENTS

EVALUATION DOCUMENTS

INFORMATION DOCUMENTS

PROCEDURE AND EVALUATION: SSC1 – SCIENCE

Observatory / Guide
11129-A

ERPI

The problem to solve

TRAIN DERAILMENT
Sulphuric acid spill in Lake Timiskaming

Updated Monday April 2, 2007, 16:46

The derailment of a freight train caused 150 000 L of sulphuric acid to spill into Blanche River, an important tributary of Lake Timiskaming.

The 22-car train went off the track on Friday in an isolated area on the Ontarian side of the lake.

The spokesperson for the Ontario Ministry of the Environment, John Steele, qualified the spill as *considerable*, due to the volume of sulphuric acid discharged.

Riverside residents who live downstream of the derailment site received a warning not to drink the river water.

Emergency teams managed to seal the cracks in the damaged cars, and limestone was poured into the river to neutralize the acid.

The cause of the derailment, which occurred on a bend in the track, is still unknown. Work to clear the railway is underway, and rail traffic should resume on Thursday.

This is not the first time that a train has derailed on this section of the track . . .. In 2000, a derailment farther south caused a spill of 386 000 L of sulphuric acid. The Transportation Safety Board of Canada concluded that the accident could be explained, at least in part, by the poor condition of the rails.

Source: Radio-Canada Ontario, "Déraillement ferroviaire. Déversement d'acide sulfurique dans le Témiscamingue" [online article] (accessed April 6, 2009). *[Translation]*

Summary Findings for Spills of MIACC List 1 Substances

The Major Industrial Accidents Council of Canada (MIACC) was created in 1987. MIACC is a non-profit, multi-stakeholder organization dedicated to reducing the frequency and severity of major industrial accidents involving hazardous substances. The focus of MIACC is on emergencies prevention, preparedness and response (PPR) activities dealing with the manufacture, storage, transportation, distribution, handling, use and disposal of hazardous substances. MIACC also promotes harmonization in the implementation of PPR measures in Canada.

MIACC partners have developed lists of hazardous substances that have a potential for causing harm to people and the environment if released in an industrial accident. "List 1" is the short list of high priority substances which are commonly found in Canada, in facilities and transport. The list includes substances that are considered to be highly hazardous (flammable, reactive, explosive, toxic) and that have a history of spill events.

The five List 1 substances involved in the highest number of spills are ammonia, chlorine, hydrochloric acid, propane and gasoline.

Source: Environment Canada, Environmental Emergencies Program, *Summary of Spill Events in Canada: 1984-1995* [PDF document], 1998 (accessed May 14, 2009).

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The problem to solve (*continued*)

Press briefing with the Environment Minister

Tuesday April 3, 2008

(13:33)

Minister: Good afternoon, everyone. I have invited you here today because I wanted to bring you up to date on the methods we are implementing at the Environment Ministry to respond to incidents that can have a major environmental impact. I am referring, of course, to accidental spills of hazardous materials such as gasoline or hydrochloric acid.

In the event of a hydrochloric acid spill, for example, the Environment Ministry's emergency team would respond very rapidly, as they already do. Chemists on the team would be dispatched to the site to neutralize the acid as quickly as possible.

Ms. Cohen (Rachel): Minister, although certain substances can neutralize an acid, their application may have disastrous consequences for the surrounding area.

Minister: You are absolutely right. While the top priority of the specialists on the emergency team would be to find the most effective way to neutralize the acid, their decisions would nonetheless take local geographic features into account.

Ms. Cohen (Rachel): Is it possible to predict how an accidental spill of acid will spread?

Minister: Yes. Watershed-based management greatly facilitates this task.

Mr. Gagnon-Smith (Thomas): What do you mean exactly?

Minister: Our specialists always consider the entire area around a spill site. They know what path the toxic substance will take because all the rivers and streams in that area flow toward the same outlet. We have maps of these watersheds. Our experts can thus identify the zones most at risk from the spilled acid.

(End 13:40)

In this context, you will play the role of a chemist who has been dispatched by the Environment Ministry to the site of a hydrochloric acid spill. You will determine the best way to neutralize the spilled acid, taking into account the toxicity of the possible neutralizing substances and the geography of the area. Since the acid will be diluted in nearby rivers and streams, its average concentration will be assumed to be 0.4 mol/L.

Using your knowledge of watersheds, you will also identify the areas most at risk from the spilled acid.

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Name: ______________________ Group: ____________ **ST**

Creating the context

I ask myself questions

1. a) What is a chemical change?

b) What signs point to the occurrence of a chemical change?

c) How can a chemical reaction be represented symbolically?

d) Below is an example of a chemical reaction.
$2\ H_2O_{(l)} \rightarrow 2\ H_{2(g)} + O_{2(g)}$
What are the reactants? What are the products?

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Creating the context (*continued*)

e) What do the subscript letters next to each molecule mean?

f) What does the expression *balancing a chemical equation* mean?

g) How can you make sure a chemical equation is balanced?

h) Why does a chemical equation have to be correctly balanced?

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Creating the context (*continued*)

2. a) What is an acid? Name some acids that are relevant to the problem-solving situation.

b) Which tests or procedures are used to find out whether a substance is an acid? What do these tests or procedures involve? What type of results show that a test substance really is an acid?

c) What are the environmental consequences of an acid spill?

3. a) What is a base? Name the bases or basic salts mentioned in the information texts for this problem-solving situation.

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Creating the context (*continued*)

b) Which tests or procedures are used to find out whether a substance is a base? What do these tests or procedures involve? What type of results show that a test substance really is a base?

4. a) What is acid-base neutralization?

b) Write the chemical equation for acid-base neutralization.

c) What gas is produced when an acid is neutralized by a carbonate?

d) How could you monitor such a reaction? Explain your answer.

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Creating the context (*continued*)

e) Find the acids and bases mentioned in this log. If each of the acids were mixed with each of the bases, acid-base neutralization reactions would occur. Write the chemical equations for these reactions. Make sure the equations are balanced.

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Creating the context (*continued*)

5. a) What is a mineral?

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b) What are the properties of minerals?

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6. a) What are soil horizons?

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b) Which horizons are most at risk from an acid spill? Explain your answer.

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c) What do these horizons contain?

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d) What purpose do the minerals in the soil serve?

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Name: ____________________ Group: __________ **ST**

Creating the context (*continued*)

e) What is permafrost?

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f) Do you think that permafrost would be affected by an acid spill? Explain your answer.

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7. a) What is a watershed?

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b) Studying watersheds helps identify areas most at risk from a toxic spill. Explain this fact, supporting your explanation with an example from your reading on the subject.

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Creating the context (*continued*)

I must

8. What are the independent and dependent variables in this problem-solving situation?

9. Reformulate the goal of the problem-solving situation.

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Creating the context (*continued*)

I think

10. What method do you think will be the most effective at neutralizing the acid and will cause the least damage to the environment? Formulate a hypothesis and justify it.

Reflection

Do I fully understand the following concepts:	Yes	No
• the law of conservation of mass?	☐	☐
• balancing chemical equations?	☐	☐
• the pH scale?	☐	☐
• acid-base neutralization reactions?	☐	☐
• minerals?	☐	☐
• soil profile (horizons)?	☐	☐
• permafrost?	☐	☐
• watersheds?	☐	☐

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Name: ______________________ Group: ______________ **ST**

Planning the problem solving

I plan

1. Make a list of materials you will need to conduct your experiments.

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Planning the problem solving (*continued*)

2. Write out the protocol for the experiments. Remember to prepare control tests.

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Planning the problem solving (*continued*)

3. Prepare a table for recording your results and observations, and give it a title.

4. What safety rules should you follow during your experiments?

____

____

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____

Reflection

	Yes	No
Have I considered other approaches?	☐	☐

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Initiating the problem solving

I experiment

1. Conduct the experiments. Record your results and observations in the table you have prepared.

2. Did you alter your plan of action during the experiments? If so, explain your answer.

3. Did you work safely during the experiments? Justify your answer with at least two examples of safety-conscious behaviour.

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Reflection

	Yes	No
Did I record and justify each of the changes I made to my plan of action?	☐	☐

Name: ____________________ Group: __________ ST

Analyzing results and drawing conclusions

I analyze my results

1. Which substances neutralized the acid? Explain your answer.

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Analyzing results and drawing conclusions (*continued*)

2. What are the advantages of each of the neutralizing substances you used in your experiments?

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Name: ______________________ Group: ______________ **ST**

Analyzing results and drawing conclusions *(continued)*

3. What are the disadvantages of each of the neutralizing substances you used in your experiments?

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Analyzing results and drawing conclusions (*continued*)

4. What factors did you take into account to ensure that your experimental results were reliable?

5. What are the possible sources of error in your experiments? Suggest a way to eliminate them.

6. Would you have obtained the same results if you had conducted your tests in the field? Explain your answer.

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Analyzing results and drawing conclusions (*continued*)

I draw my conclusions

7. Draw a conclusion from your experiments. Which substance would you recommend for neutralizing the spilled acid? Write a short text to justify your recommendation.

8. Based on your knowledge of watersheds, which areas are most at risk from the acid spill? Explain your answer.

9. Was your hypothesis confirmed or not? Explain your answer.

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Name: ______________________ Group: ____________ **ST**

My evaluation

Use the evaluation grid on the following page to evaluate yourself. Write A, B, C, D or E in the "Me" column of the chart below.

SSC1—Seeks answers or solutions to scientific or technological problems				
Criteria*	Observable indicators	Me	Teacher	Comments
1	**Creating the context** Definition of the goal and formulation of the hypothesis		☐ With help	
2	**Planning the problem solving** Relevance of the elements of the plan of action: materials and procedure		☐ With help	
3	**Initiating the problem solving** Accuracy of the results and observations; compliance with safety rules		☐ With help	
4	**Analyzing results and drawing conclusions** Analysis of the results and conclusion		☐ With help	

*** Evaluation criteria**

1 Appropriate representation of the situation
2 Development of a suitable plan of action for the situation
3 Appropriate implementation of the plan of action
4 Development of relevant conclusions, explanations or solutions

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Name: ______________________ Group: ____________ **ST**

Evaluation grid

SSC1 Seeks answers or solutions to scientific or technological problems

Criteria*	Observable indicators	A	B	C	D	E
1	**Creating the context** Definition of the goal and formulation of the hypothesis	The goal and hypothesis are very clearly defined and relevant to the problem to be solved.	The goal and hypothesis are clearly defined and relevant to the problem to be solved.	The goal and hypothesis are not very clearly defined or are irrelevant to the problem to be solved.	The goal and hypothesis are not very clearly defined and are irrelevant to the problem to be solved.	The work must be done again.
2	**Planning the problem solving** Relevance of the elements of the plan of action: materials and procedure	The list of materials is complete. The procedure is relevant and very clear.	The list of materials is almost complete. The procedure is relevant and clear.	Many elements are missing from the list of materials, OR the procedure is not very relevant or clear.	Many elements are missing from the list of materials, AND the procedure is irrelevant or unclear.	The work must be done again.
3	**Initiating the problem solving** Accuracy of the results and observations; compliance with safety rules	All of the results and observations are accurately recorded and relevant, AND the experiment was conducted safely.	Most of the results and observations are accurately recorded and relevant, AND the experiment was conducted safely.	Some of the results and observations are accurately recorded and relevant, AND the experiment was conducted safely.	The results and observations are not accurately recorded and are irrelevant, OR the experiment was not conducted safely.	The work must be done again.
4	**Analyzing results and drawing conclusions** Analysis of the results and conclusion	The analysis of the results and the conclusion are very clear and relevant to the goal of the problem solving.	The analysis of the results and the conclusion are clear and relevant to the goal of the problem solving.	The analysis of the results and the conclusion are not very clear OR are not very relevant to the goal of the problem solving.	The analysis of the results and the conclusion are not very clear AND are not very relevant to the goal of the problem solving.	The work must be done again.

* Evaluation criteria

1 Appropriate representation of the situation
2 Development of a suitable plan of action for the situation
3 Appropriate implementation of the plan of action
4 Development of relevant conclusions, explanations or solutions

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Acid/base concept

by Fred Scaffidi, chemist

The corrosivity of a material, that is, the ability for a chemical to cause visible destruction to skin and other tissues is an important parameter in emergency response. The acids are well known for their ability to corrode. A splash of acid on the skin may cause a severe burn and scarring. Though highly dangerous, these materials are used in many industrial processes on a huge scale and are found in just about every household (for example, cleaners). What makes a material acidic (or basic)? What are the common approaches to dealing with these chemicals in a spill scenario?

Recall from your early chemistry: Acidic materials dissolve in water to produce a net surplus of hydrogen ions [H^+], ions being electrically charged chemicals in water. Basic materials also dissolve in water and produce hydroxyl ions [OH^-]. It is the concentration of these ions which determines the strength of an acid or a base. Strong acids produce higher concentrations of H+ than weak acids (similarly for bases). We can generalize and say that most common acids have a high solubility in water, i.e. you can put them in water, dissolve them and generate ions in solution; they are not flammable, although some highly concentrated acids may ignite other materials; acids react with metals, sometimes slowly, to produce flammable and explosive hydrogen gas; acids neutralize bases, in other words, hydrogen ions react with hydroxyl ions to produce water and resultant heat:

ACID + BASE → a salt + water + heat

Caustic soda (a base, chemical formula NaOH) will neutralize a spill of hydrochloric acid (acid, chemical formula HCl). The reaction would produce considerable heat and fumes.

The presence of water is critical to the acid/base concept. One might consider adding water to acids and bases in order to dilute them and hence make them less concentrated, less hazardous. One rule of thumb in the chemical laboratory is that acid is always added to water, never water to acid. Addition of water to concentrated acid, the only way to combine the two in a spill situation, can cause splashing and bubbling of acid. Dilution may also cause the solution to heat up (heat of dilution), which will reduce the solubility of the acid in water and generate acid fumes.

A 1-L spill of a strong acid (pH=1) would require 10 000 L of water to be diluted to pH=5. Dilution to neutral pH would require 1 000 000 L of water (although this wouldn't be necessary as pH=5 would represent a low hazard for skin contact). Addition of water has the added drawback of spreading the spill around.

Abrupt addition of neutralizing agents to concentrated acids in a spill situation will cause fuming and boiling. Neutralization is normally done in a laboratory under highly controlled conditions. Consider that some neutralizing agents can be just as hazardous as the original acid. One would have to add just enough neutralizer to do the job, and no more than that, as one could pass the endpoint and turn the solution into a strong base. A concentrated sulphuric acid spill can be neutralized using sodium bicarbonate (baking soda) fairly safely, while neutralizing with caustic soda could produce a lot of heat and fumes. Sodium bicarbonate has a lower heat of reaction; however, it will cause fierce bubbling due to the production of carbon dioxide gas. Sodium bicarbonate is not a particularly hazardous material, and an excess may be added without concern. Crushed limestone is also an excellent choice; however, the heat of reaction will be higher and hence greater fuming. Neutralization of a large quantity of acid at the site would require the presence of personnel very familiar with this procedure. It is recommended that recovery of as much spilled material as possible should be done prior to neutralization.

Clearly there are several chemical properties attributable to acids in general. The release of acid fumes due to neutralization or dilution seems to be the most grave concern.

Source: Fred Scaffidi, “Acid/base concept” [online article], Transport Canada, 1995 (accessed May 20, 2009).

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Hervey-Jonction, Québec: Train derailment, January 21, 1995

Incident overview

On January 21, 1995, a train travelling through central Québec derailed from a broken section of track. Twenty-eight of the forty-four tank cars on the train went off the track and spilled a total of 255 000 gallons [1 159 000 L] of concentrated sulphuric acid. The majority of the product entered Lac Masketsi and the Rivière Tawachiche, northeast of Trois-Rivières. In order to neutralize the acid, three truckloads (170 tonnes) of powdered limestone were poured into the lake. Due to residual contamination, Lac Masketsi has been closed for recreational use until the year 2003, and the Rivière Tawachiche until the year 2000.

Agencies on site collectively agreed to the following strategy for recovery and subsequent remediation.

Recovery of tank cars

- Undamaged rail cars were lifted back onto the track and brought to Hervey-Jonction to be off-loaded. Several half-full cars were pumped out first, then returned to the track.
- Holes were drilled on the tops of several carriages in order to evacuate any hydrogen gas that might have accumulated within.

Neutralization of acid

- 170 tonnes of limestone were poured into the lake in an effort to neutralize the acid. This was unsuccessful.
- A slurry of limestone and sodium hydroxide was then used to accelerate neutralization of acid pockets in the lake.
- Soda ash (sodium carbonate) was applied to the ditch under the rail cars to neutralize the acid in the soil.
- Large limestone blocks were placed at the mouth of the river in order to neutralize any remaining acid in the waterway.

Follow-up activities

- removal of lime build-up at spill site
- monitoring of brook trout spawning habitat
- replenishment of brook and lake trout populations

Human impact

The spill occurred in a remote, sparsely populated region, and no injuries were reported by response personnel.

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Hervey-Jonction, Québec Train derailment, January 21, 1995 (*continued*)

Incident overview (*continued*)

Environmental damage

The freshwater ecosystems affected by the spill were a spawning ground for certain species of protected fish, notably the gray trout and tommycod. As a result of the incident, these species may now be in danger of perishing in this area. The majority of aquatic populations along 13 km of the river were destroyed by the acid influx.

Actions taken by Environment Canada at time of incident

- collected and analyzed soil samples
- took aquatic pH readings
- determined the sulphate and sulphuric acid content of samples
- analyzed the acid concentration in tank cars
- advised other agencies regarding physical/chemical properties of sulphuric acid
- provided advice on site restoration options
- performed an environmental impact assessment

Lessons learned

- Bottom unloading tank cars are reliable during a derailment.
- Tank car weaknesses are mainly at dome level, at the unloading pipe, and with the safety disk set.
- Thorough emergency-response training for contractors should be provided.
- Vacuum truck usage for off-loading tank cars is safe as long as proper procedures are followed.
- Temperate water must be available for emergency showers for decontamination, particularly during the winter months.
- Further collaboration between carriers and shippers of dangerous goods needs to be established.
- An accurate definition of jurisdictions for the different intervening parties and organizations on the emergency site should be available from the onset of work.
- When establishing the clean-up plan of action, multi-party coordination is essential.

Source: Environment Canada, Environmental Emergencies Program, *Summary of Spill Events in Canada: 1984–1995* [PDF document], 1998 (accessed May 20, 2009).

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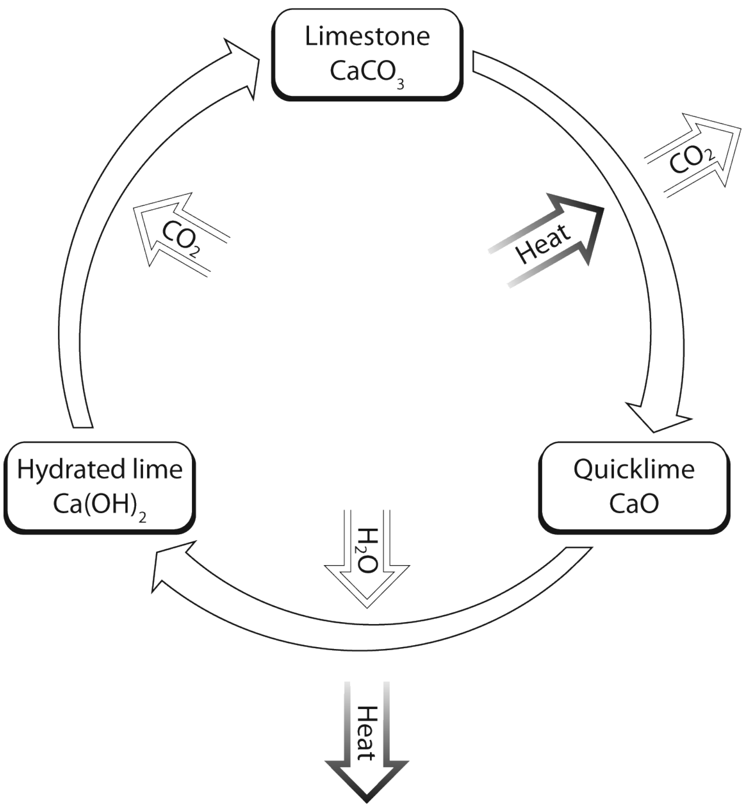
Lime

Limestone is a sedimentary rock found in large quantities all over the Earth. It is composed mainly of calcium carbonate or magnesium. The products derived from this rock are called *lime*.

The lime cycle

Products derived from limestone—especially quicklime, hydrated lime and hydraulic lime have the ability to transform and then return to their original form. The lime cycle involves the following stages:

1. Limestone ($CaCO_3$) is burnt to produce quicklime (CaO).
2. Water is added to the quicklime to obtain hydrated lime ($Ca(OH)_2$).
3. Carbon dioxide in the atmosphere reacts with the hydrated lime to produce limestone.



Uses of limestone

Limestone is extracted from quarries or mines for a variety of purposes, such as:

- manufacturing cement or concrete
- manufacturing glass, pulp and paper
- adjusting the pH of farmland
- treating water
- melting metals

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The toxicity of various products

Calcium hydroxide
This product is corrosive. It can irritate the skin (rash, swelling, ulcers) and affect the eyes (opacification of the cornea) and the respiratory and digestive tracts. The seriousness of the symptoms may vary depending on the conditions of exposure (length, product concentration, etc.). Exposure to calcium hydroxide dust particles causes irritation to the eyes and respiratory tract. If contact with this product is repeated or prolonged, an irritant contact dermatitis can develop. If the product is swallowed, it can cause pain, vomiting, diarrhea and circulatory collapse.

Calcium carbonate
Calcium carbonate is added to many everyday products without actually being an active ingredient. It is a filler material used in the manufacture of paints, toothpaste, ceramics, putty, polishing paste, insecticides, ink, shoe polish, paper, adhesives, matches, pencils, linoleum, insulation compounds, welding rods, plastics and synthetic rubber. The dust from this product can cause mechanical irritation to the eyes and respiratory tract.

Sodium hydroxide
This product is corrosive. It can irritate the skin (serious burns with deep ulcers), affect the eyes (disintegration and scarring of the conjunctiva and cornea, accompanied by swelling, ulceration and the possibility of permanent opacification of the cornea) and damage the respiratory and digestive tracts. The seriousness of the symptoms may vary depending on the conditions of exposure (length, product concentration, etc.). If the product is swallowed, it may cause corrosion of the digestive tract, accompanied by intense pain, vomiting blood (with mucosal shreds), diarrhea and inflammation of the larynx (risk of suffocation). Esophageal or gastric perforations are also possible, and even circulatory collapse and death.

Sodium bicarbonate
Although it may cause a slight irritation of the eyes, this product does not irritate the skin. Scientific journals report no irritating effects associated with the inhalation of sodium bicarbonate dust or mist particles.

Source: Adapted from Commission de la santé et de la sécurité du travail, Service du répertoire toxicologique, “Les produits” [online catalogue] (accessed April 7, 2009). *[Translation]*

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The lethal dose of various products

The lethal dose can be used to compare the toxicity of different products. It represents the amount of a substance, administered in a single dose, that causes death among 50 percent of individuals of the same species.

Product	Lethal dose (LD_{50})
Calcium hydroxide	7340 mg/kg orally in rats
Calcium carbonate	6450 mg/kg orally in rats
Sodium hydroxide	40 mg/kg orally in mice
Sodium bicarbonate	8290 mg/kg orally in rats