EDVO-Kit: AP02

Mathematical Modeling: Hardy-Weinberg

See Page 3 for storage instructions.

EXPERIMENT OBJECTIVE:

In this experiment, students will examine the effects of mutations, genetic drift and natural selection on gene frequency in a population by the Hardy-Weinberg law of genetic equilibrium. Using computer and Internet access, students will explore how a hypothetical gene pool changes from one generation to the next.
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All components are intended for educational research only. They are not to be used for diagnostic or drug purposes, nor administered to or consumed by humans or animals.

THIS EXPERIMENT DOES NOT CONTAIN HUMAN DNA. None of the experiment components are derived from human sources.

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Experiment Components

- PTC taste paper
- Control taste paper

Requirements

- Computer with spreadsheet software (Microsoft® Excel)
Background Information

Population genetics deals with analysis of gene frequencies in a population over many generations. The concept of describing frequencies of inherited traits owes its origin to scientific works published at the beginning of the 20th century. A 1908 paper, “Mendelian Proportions in a Mixed Population” published in Science 28 (49-50) by British mathematician G.H. Hardy, and a separate independent study also published in 1908 by the German physician W. Weinberg, both suggested that gene frequencies were not dependent upon dominance or recessiveness but may remain unchanged from one generation to the next under a set of “idealized conditions.” These classic papers describe an equation which has come to be called the Hardy-Weinberg theorem of genetic equilibrium. This theorem has become the basis for population genetics.

The Hardy-Weinberg theorem is used to determine the frequencies of individual alleles of a pair of genes, and the frequency of heterozygotes and homozygotes in the population. The theorem states that in the absence of outside forces such as mutation, selection, random genetic drift, and migration, gene frequencies remain constant over many generations in a large population. It is important to remember that in natural populations, events such as gene mutation, selection of genotypes which confer enhanced viability, presence of lethal homozygous recessive genes, nonrandom mate selection, and immigration and emigration of individuals of a population, are events that do occur. Nevertheless, the Hardy-Weinberg theorem is useful since unexpected deviations can point to the occurrence of evolutionary significant events such as speciation.

Distribution frequencies of two alleles for a given gene at a single locus, one being dominant, the other recessive, will follow a binomial distribution in the population. Consider the case of two alleles for a gene, one dominant and the other recessive.

Let \( p \) = the frequency of one allele and \( q \) = the frequency of the other. If gene frequencies are expressed as decimals, the following must be true,

\[
\begin{align*}
\text{Equation \#1:} \quad p + q &= 1 \\
\text{and,} \\
\text{Equation \#1a:} \quad p &= 1 - q \\
\text{therefore,} \\
\text{Equation \#2:} \quad (p + q)^2 &= 1.
\end{align*}
\]

Expanding equation \#2 generates,

\[
\begin{align*}
\text{Equation \#3:} \quad p^2 + 2pq + q^2 &= 1.
\end{align*}
\]

When equation 3 is applied to an ideal population, it follows that the frequency of homozygous dominant individuals is \( p^2 \), the frequency of the heterozygotes is \( 2pq \), and the frequency of homozygous recessives is \( q^2 \).
Mathematical Modeling: Hardy-Weinberg

Background Information

As an example, consider the following hypothetical situation. The famous European geneticist, Professor Ed V. Otek, tested his rather large genetics class for the ability to taste the chemical phenylthiocarbamide, PTC. He knew that the gene for this ability to taste PTC had two alleles, the dominant allele for tasting called T, and the recessive allele called t. He found that out of 1000 students, there were 700 students with the ability to taste PTC and 300 who lacked the ability to taste PTC. He used the Hardy-Weinberg equation to determine the gene frequencies for the T and t alleles of the gene for the ability to taste PTC. His notes show the following analysis:

A Converted raw data to decimals.
   • Frequency of two genotypes for tasting, TT and Tt, was 700/1000 = 0.7.
   • Frequency of genotype for inability to taste PTC, tt, was 300/1000 = 0.3.

B Determined gene frequency of the unique allele.
   • From the Hardy-Weinberg equation # 3, \(p^2 + 2pq + q^2 = 1\), the frequency of non-tasters, \(tt = 0.3 = q^2\).  
   • Taking the square root of 0.3, \(q = 0.5477\), and 0.5477 is the frequency of the t allele in Dr. Otek’s student population.

C Determined gene frequency of other allele, p:
   From equation # 1a, \(p = 1-q\), the frequency of p is 0.4523.

D. Determined frequency of homozygous TT and heterozygous Tt individuals in the population. Using equation #3:
   \[p^2 + 2pq + q^2 = 1,\]
   \[(0.4523)^2 + 2(0.4523 \times 0.5477) + (0.5477)^2 = 1\]
   • The frequency of homozygous tasters is, \(TT = p^2 = 0.4523^2 = 0.2046\).
   • The frequency of heterozygous tasters is \(Tt = 2pq = 2 (0.4523 \times 0.5477) = 0.4954\).

A computer spreadsheet allows students to build and test their own models to see how a gene pool of a population changes over time. Most spreadsheets have a “Random” function that can generate random numbers to model stochastic events. The computer can generate thousands of samples in a very short time. In this investigation, students will build a spreadsheet that models how a hypothetical gene pool changes from one generation to the next. Students will utilize the Hardy-Weinberg equation to analyze population data from the class.
Experiment Overview and General Instructions

EXPERIMENT OBJECTIVE

In this experiment, students will examine the effects of mutations, genetic drift and natural selection on gene frequency in a population by the Hardy-Weinberg law of genetic equilibrium. Using computer and Internet access, students will explore how a hypothetical gene pool changes from one generation to the next.

WORKING HYPOTHESIS

If there is no selection for any allele in a large randomly-mating population, then the gene frequencies will remain constant over many generations. However, if there are outside forces such as selection for an allele, heterozygote advantage, and genetic drift working in a population, then the gene frequencies will change over time.

LABORATORY SAFETY GUIDELINES

1. Wear gloves and goggles while working in the laboratory.
2. Exercise caution when working in the laboratory – you will be using equipment that can be dangerous if used incorrectly.
3. DO NOT MOUTH PIPET REAGENTS - USE PIPET PUMPS.
4. Always wash hands thoroughly with soap and water after working in the laboratory.
5. If you are unsure of something, ASK YOUR INSTRUCTOR!

LABORATORY NOTEBOOKS:

Scientists document everything that happens during an experiment, including experimental conditions, thoughts and observations while conducting the experiment, and, of course, any data collected. Today, you’ll be documenting your experiment in a laboratory notebook or on a separate worksheet.

Before starting the Experiment:
• Carefully read the introduction and the protocol. Use this information to form a hypothesis for this experiment.
• Predict the results of your experiment.

During the Experiment:
• Record your observations.

After the Experiment:
• Interpret the results – does your data support or contradict your hypothesis?
• If you repeated this experiment, what would you change? Revise your hypothesis to reflect this change.
Investigation I:  
Estimation of Gene Frequency for the Trait to Taste PTC Within a Small Sample Population

This experiment deals with the determination of the gene frequency of a human trait amongst students with no known selective advantage. The ability to taste the chemical phenylthiocarbamide, PTC, is one such human trait.

The ability to taste PTC is due to the presence of a dominant allele, T. Therefore, all tasters will either be homozygous, TT, or heterozygous, Tt. Non-tasters will be homozygous for the recessive gene, tt.

1. Students groups should obtain a PTC taste strip and a control strip.

2. Every member of the group should first taste the control strip of paper.

3. Every person should taste the PTC impregnated strip of paper. Compare the taste of the control and the PTC paper.

   If you are a taster, the PTC paper strip will be bitter. Non-tasters will not notice a difference between either strip of paper.

4. For the class, record the total number of tasters and the total number of non-tasters on the blackboard. Also record the results in your lab notebook.

5. Determine decimal value by division for tasters (p^2 + 2pq), and likewise the decimal value for non-tasters (q^2).

   • For example, there are 100 people in your class. 25 are non-tasters and 75 are tasters.
   • Then 25/100, or 0.25, is the frequency of non-tasters, and 75/100, or 0.75, is the frequency of tasters.

6. Record your values in Table 1. Use Hardy-Weinberg as described above to determine the value of p and q for your class.

<table>
<thead>
<tr>
<th>CLASS POPULATION</th>
<th>ALLELE FREQUENCY CALCULATED BY THE HARDY WEINBERG EQUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>p^2 + 2pq</td>
</tr>
<tr>
<td>NORTH AMERICAN POPULATION</td>
<td>0.55</td>
</tr>
</tbody>
</table>

**TABLE 1: Phenotypes and Gene Frequencies for Trait to Taste PTC**
Investigation II:
Building a Simple Mathematical Spreadsheet

A. Getting to know Microsoft® Excel

In this investigation, you will create a computer spreadsheet using Microsoft® Excel which will model the changes in a hypothetical gene pool from one generation to explore how allele frequencies change in populations of organisms.

Some important tips to remember when creating your computer spreadsheet are as follows:

• If you are not familiar with Microsoft® Excel, type “How to Use Excel video” in your search engine. The results include several step-by-step instructions or videos that will help you familiarize yourself with the software.
• Do not forget to save your work periodically in case the program closes unexpectedly.
• If you have difficulty refining your spreadsheet, consider using pencil and paper to archive and graph the results.

B. Building the mathematical spreadsheet once you have become familiar with Microsoft® Excel

1. Define the following:
   \( p \) = the frequency of the \( A \) allele and
   \( q \) = the frequency of the \( B \) allele.

2. Open the spreadsheet on your computer. The examples here are based on Microsoft® Excel.

3. First create the blue zone from A2 to D3 by highlighting the cells. Go to “Format”, then “Cells” and “Fill” the highlighted cells with a light blue color. This blue zone represents the gene pool.
Investigation II:
Building a Simple Mathematical Spreadsheet, continued

4. Enter the value for \( p \) in cell “D2” (for example, 0.6) and the value for \( q \) is calculated by a formula in cell “D3.”

   \[ \text{Question 1: What is the formula you need to enter to calculate the value for } q \text{?} \]

5. According to our model, the selection for gametes for the next generation is assumed to be random. We’ll use the RANDOM function for our purposes. Enter the following function in a nearby empty cell = Rand0.

6. a. Press enter and record the number you obtain.
   
   b. Hit \( F9 \) key several times if you are using a PC.
      
      Hit \( \text{Cmd} + \) if you are using a Mac.

   c. Record the number you get each time (those numbers should be random and are between 0 and 1). Our entire model is based on this RANDOM function. Delete the RANDOM function in the cell you entered.
Investigation II: Building a Simple Mathematical Spreadsheet, continued

7. a. Label cell E4 “Gamete.” Then in cell E5, enter =IF(RAND()<=D$2,”A”, ”B”) and press ENTER.

b. Create a similar formula in cell F5.

c. Press the “F9” or “Cmd +” key to force a recalculation of your spreadsheet. If you have entered the functions correctly in the two cells you should see changing values in the two cells randomly.

Question 2: What is the meaning of the function you have entered in cells E5 and F5?
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Mathematical Modeling: Hardy-Weinberg

Investigation II:
Building a Simple Mathematical Spreadsheet, continued

8. a. Copy these two formulas down for a total of 20 rows that will represent 20 offspring for this generation. (To copy the formulas, click on the bottom right-hand corner of the cell and drag the cell downward. Your finger should press down on the mouse the entire time.)

b. Then, highlight all 20 rows in columns E and F in green.

9. a. Label cell G4 as “Zygote.” The zygote is a combination of the two randomly selected gametes. In cell “G5” enter the function: =CONCATENATE(E5,F5) and press Enter.
Investigation II: Building a Simple Mathematical Spreadsheet, continued

9. b. Copy this formula as far down as you have gametes for a total of 20. Highlight the Zygote column in yellow.
Investigation II:
Building a Simple Mathematical Spreadsheet, continued

10. a. Label cells H4, I4, and J4 as “AA”, “AB”, “BB” respectively. These 3 columns are for keeping track of the numbers of each zygote’s genotype.

b. Enter the following function in cell “H5”: $$=IF(G5="AA",1,0)$$ and press ENTER.

   **Question 3:** Can you interpret this formula?

c. In cell “I5” enter the nested function: $$=IF(G5="AB",1,(IF(G5="BA",1,0)))$$ and press ENTER.

   **Question 4:** Can you interpret this formula?

d. In cell “J5” enter the following function: $$=IF(G5="BB",1,0)$$ and press ENTER.

   **Question 5:** Can you interpret this formula?
Investigation II: Building a Simple Mathematical Spreadsheet, continued

e. Copy these three formulas down for a total of 20 rows.

11. Press “F9” or Cmd + key to force a recalculation of your spreadsheet. If you have entered the functions correctly in the three cells you should see random values (either 1 or 0) in the three cells.

12. a. Label cell A26 “Sum of each Genotype.” Use the SUM function to calculate the number of each Genotypes in H, I and J.

b. Label cell A29 “Number of each allele in next generation.” Use the SUM function to calculate the number of each alleles in next generation.

c. Label cell A31 “Gene frequency in next generation.” Use the SUM function to calculate the Gene frequency in next generation.

Question 6: How did you formulate the SUM functions to calculate the number of each Genotypes, the number of each alleles, and the gene frequency in the next generation?
Investigation II:
Building a Simple Mathematical Spreadsheet, continued

13. Try recalculating a few times to make sure the spreadsheet is working as expected by pressing the “F9” or Cmd + key.

This model will help you explore how allele frequencies behave and change from generation to generation.

14. Make a histogram from the data you have obtained using the chart tool.

   a. Label the independent variable (horizontal x-axis).
   b. Label the dependent variable (vertical y-axis).
   c. Title the Graph

Question 7: How did you graph the histogram?

Question 8: What did your final spreadsheet look like?
Investigation III:
Testing Your Mathematical Model to Explore the Behavior of Allele Frequencies from Generation to Generation

1. Behavior of allele frequencies in multiple generations.

To observe how allele frequencies change in multiple generations, try adding additional generations to your model. To do this, use your newly recalculated p and q values from the previous generation to seed the next generation. Each new generation determines the new p and q values for the next.

2. Effects the size of the population on the gene frequencies in the next generation.

To observe the effects of a population sizes on gene frequency, insert or delete new rows into your spreadsheet.

Try recalculating every time to make sure the spreadsheet is working as expected by pressing the “F9” or Cmd + key. You should notice the changes in the worksheet every time you recalculate.
Experimental Results and Study Questions

Address and record the following in your laboratory notebook or on a separate worksheet.

Before starting the experiment:

- Write a hypothesis that reflects the experiment.
- Predict experimental outcomes.

During the Experiment:

- Record (draw) your observations, or save the results on your computer or flash drive.

Following the Experiment:

- Formulate an explanation from the results.
- Determine what could be changed in the experiment if the experiment were repeated.
- Write a hypothesis that would reflect this change.
Experimental Results and Study Questions

STUDY QUESTIONS

Answer the following study questions in your laboratory notebook or on a separate worksheet.

Investigation I: Estimation of Gene Frequency for the Trait to Taste PTC Within a Small Sample Population

1. What is the frequency of homozygous tasters, $p^2$, in your classroom?
2. What is the frequency of heterozygous tasters, $2pq$, in your classroom?
3. What is the frequency of homozygous non-tasters in your classroom?
4. Determine the percentage of the three genotypes TT, Tt, and tt in your classroom.
   Hint: multiply the values obtained for question 1, 2, and 3 by 100.

Investigation II: Building a Simple Mathematical Spreadsheet

Question 1: What is the formula you need to enter to calculate the value for $q$?
Question 2: What is the meaning of the function you have entered in cells E5 and F5?
Question 3: Can you interpret function in cell “H5”: =IF($G5$=“AA”,1,0)?
Question 4: Can you interpret the nested function: =IF($G5$=“AB”,1,(IF($G5$=“BA”,1,0)))?
Question 5: Can you interpret the function in cell “J5”: =IF($G5$=“BB”),1,0)?
Question 6: How did you formulate the SUM functions to calculate the number of each Genotypes, the number of each alleles, and the gene frequency in the next generation?
Question 7: How did you graph the histogram?
Question 8: What did your final spreadsheet look like?
Instructor’s Guide

Notes to the Instructor & Pre-Lab Preparations

OVERVIEW OF LABORATORY INVESTIGATIONS

The “hands-on” laboratory experience is a very important component of science courses. Laboratory experiment activities allow students to identify assumptions, use critical and logical thinking, and consider alternative explanations, as well as help apply themes and concepts to biological processes.

EDVOTEK experiments have been designed to provide students the opportunity to learn very important concepts and techniques used by scientists in laboratories conducting biotechnology research. Some of the experimental procedures may have been modified or adapted to minimize equipment requirements and to emphasize safety in the classroom, but do not compromise the educational experience for the student. The experiments have been tested repeatedly to maximize a successful transition from the laboratory to the classroom setting. Furthermore, the experiments allow teachers and students the flexibility to further modify and adapt procedures for laboratory extensions or alternative inquiry-based investigations.

ORGANIZING AND IMPLEMENTING THE EXPERIMENT

Class size, length of laboratory sessions, and availability of equipment are factors which must be considered in the planning and the implementation of this experiment with your students. These guidelines can be adapted to fit your specific set of circumstances.

If you do not find the answers to your questions in this section, a variety of resources are continuously being added to the EDVOTEK web site.

www.edvotek.com

In addition, Technical Service is available from 9:00 am to 6:00 pm, Eastern time zone. Call for help from our knowledgeable technical staff at 1-800-EDVOTEK (1-800-338-6835).

Visit our web site for information about EDVOTEK’s complete line of experiments for biotechnology and biology education.

Visit the EDVOTEK web site often for updated information.
Pre-Lab Preparations

1. Each student group should receive the following:
   a. PTC tasting strips for each student
   b. Control taste strips for each student

2. Each student group should have access to computers with spreadsheet software (Microsoft® Excel).
Expected (SAMPLE CASE) Results and Selected Answers

Investigation I: Estimation of Gene Frequency for the Trait to Taste PTC Within a Small Sample Population

1. What is the frequency of homozygous tasters, $p^2$, in your classroom?
   
   Refer to your results.

2. What is the frequency of heterozygous tasters, $2pq$, in your classroom?
   
   Refer to your results.

3. What is the frequency of homozygous non-tasters in your classroom?
   
   Refer to your results.

4. Determine the percentage of the three genotypes TT, Tt, and tt in your classroom.
   Hint: multiply the values obtained for question 1, 2, and 3 by 100.
   
   Use your results.

Investigation II: Building a Simple Mathematical Spreadsheet

Question 1: What is the formula you need to enter to calculate the value for $q$?

Answer: To calculate the value of $q$, in cell “D3” enter $(1-D2)$ and press enter.

Question 2: What is the meaning of the function you have entered in cells E5 and F5?

Answer: The formula $=IF(RAND()<=D2, "A", "B")$ means that if a random number between 0 and 1 is less than or equal to the value of $p$ then put an “A” gamete in this cell or if it is not less than or equal to the value of $p$ put an “B” gamete in this cell.

Question 3: Can you interpret function in cell “H5”: $=IF(G5="AA",1,0)$?

Answer: If the value in cell “G5” is “AA” then put a 1 in this cell, if not then put a 0.

Question 4: Can you interpret the nested function: $=IF(G5="AB",1,(IF(G5="BA",1,0))))$?

Answer: If the value in cell “G5” is exactly equal to “AB” then put a 1; if not then if the value in cell “G5” is exactly “BA” then put a one; if it is neither then put a 0 in this cell.

Question 5: Can you interpret the function in cell “J5”: $=IF(G5="BB",1,0)$?

Answer: If the value in cell “G5” is “BB” then put a 1 in this cell, if not then put a 0.
Expected (SAMPLE CASE) Results and Selected Answers

Question 6: How did you formulate the SUM functions to calculate the number of each Genotypes, the number of each alleles, and the gene frequency in the next generation?

Answer:

- Enter function =SUM(H5:H24) in cell H26 to calculate the number of “AA” genotype. Enter a similar function in cells I26, and J26 to calculate the number of “AB” and “BB” genotype, respectively.

- Enter function =SUM(H26+H26+I26) in cell H29 to calculate the number of “A” allele in the next generation.

- Enter function =SUM(I26+J26+J26) in cell J29 to calculate the number of “B” allele in the next generation.

- Enter function =(H29/40) in cell H31 to calculate the gene frequency for “A” allele in the next generation.

- Enter function =(J29/40) in cell J31 to calculate the gene frequency for “B” allele in the next generation.

Question 7: Graphing the Histogram

Every time students try recalculating the values, a different graph will be generated.

Below is an example of the graph.

a. Label the independent variable (horizontal x-axis) as Genotypes
b. Label the dependent variable (vertical y-axis) as Number of Offspring
c. Title the Graph: Genotype Frequency in Next Generation
Expected (SAMPLE CASE) Results and Selected Answers

Question 8: What did your final spreadsheet look like?

Below is an example of the final spreadsheet.
**Material Safety Data Sheet**

**IDENTITY (As Used on Label and List)**

| Note: Blank spaces are not permitted. If any item is not applicable or no information is available, the space must be marked to indicate this. |

**Section I**

**Manufacturer's Name**

EDVOTEK, Inc.

**Address**

1121 5th Street NW

Washington DC 20001

**Emergency Telephone Number**

202-370-1500

**Telephone Number for Information**

202-370-1500

**Date Prepared**

6-12-12

**Signature of Preparer (optional)**


**Section II - Hazardous Ingredients/Identify Information**

**Hazardous Components**

<table>
<thead>
<tr>
<th>Specific Chemical Identity; Common Name(s)</th>
<th>OSHA PEL</th>
<th>ACGIH TLV</th>
<th>Other Limits</th>
<th>Recommended % (Optional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenyliothiourea, 1-Phenyl-2-thiourea, Phenylthiocarbamide</td>
<td>NO data</td>
<td>NO data</td>
<td>NO data</td>
<td>NO data</td>
</tr>
</tbody>
</table>

**Section III - Physical/Chemical Characteristics**

**Boiling Point**

NO data

**Specific Gravity (H 2O = 1)**

NO data

**Vapor Pressure (mm Hg.)**

NO data

**Vapor Density (AIR = 1)**

NO data

**Solubility in Water**

Soluble

**Appearance and Odor**

Non toxic paper strip

**Section IV - Physical/Chemical Characteristics**

**Flash Point (Method Used)**

NO data

**LEL**

NO data

**UEL**

NO data

**Extinguishing Media**

Use media suitable to extinguish surrounding fire

**Special Fire Fighting Procedures**

Firefighters should wear full protective equipment and NIOSH breathing apparatus

**Unusual Fire and Explosion Hazards**

Thermal decomposition or contact with acids or acid fumes produces toxic fumes.

**Section V - Reactivity Data**

**Stability**

Unstable

**Conditions to Avoid**

Heat, acid, or acid fumes

**Incompatibility (Acids)**


**Section VI - Health Hazard Data**

**Routes of Entry:**

<table>
<thead>
<tr>
<th>Inhalation?</th>
<th>Ingestion?</th>
<th>Skin?</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Health Hazards (Acute and Chronic)**

Ingesting copious amounts of the chemical can be harmful or fatal.

**Carcinogenicity**

<table>
<thead>
<tr>
<th>NTP</th>
<th>ACGIH Monographs</th>
<th>OSHA Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Data</td>
<td>No data</td>
<td>No data</td>
</tr>
</tbody>
</table>

**Signs and Symptoms of Exposure**

Skin irritation. Ingesting copious amounts of the chemical will cause gastrointestinal discomfort.

**Medical Conditions Generally Aggravated by Exposure**

None noted

**Emergency First Aid Procedures**

Skin: Wash exposed area for 15 minutes. Seek medical attention if irritation persists.

If copious amounts of the chemical are ingested, immediately call poison control center. Induce vomiting.

**Section VII - Precautions for Safe Handling and Use**

**Steps to Be Taken in Case Material Is Released for Spilled**

NA

**Waste Disposal Method**

Observe all federal, state, and local regulations.

**Precautions to Be Taken in Handling and Storage**

Avoid skin contact. Avoid heat, acid or acid fumes. Keep in a cool, dry place.

**Other Precautions**

Do not ingest more than the one taste strip provided by your instructor.

**Section VIII - Control Measures**

**Respiratory Protection (Specify Type)**

None needed under normal conditions with adequate ventilation.

**Ventilation**

<table>
<thead>
<tr>
<th>Local Exhaust</th>
<th>Mechanical (General)</th>
<th>Eye Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Splash-proof goggles</td>
</tr>
</tbody>
</table>

**Protective Gloves**

Impervious clothing to prevent skin contact

**Work/Hygienic Practices**

Impervious clothing to prevent skin contact