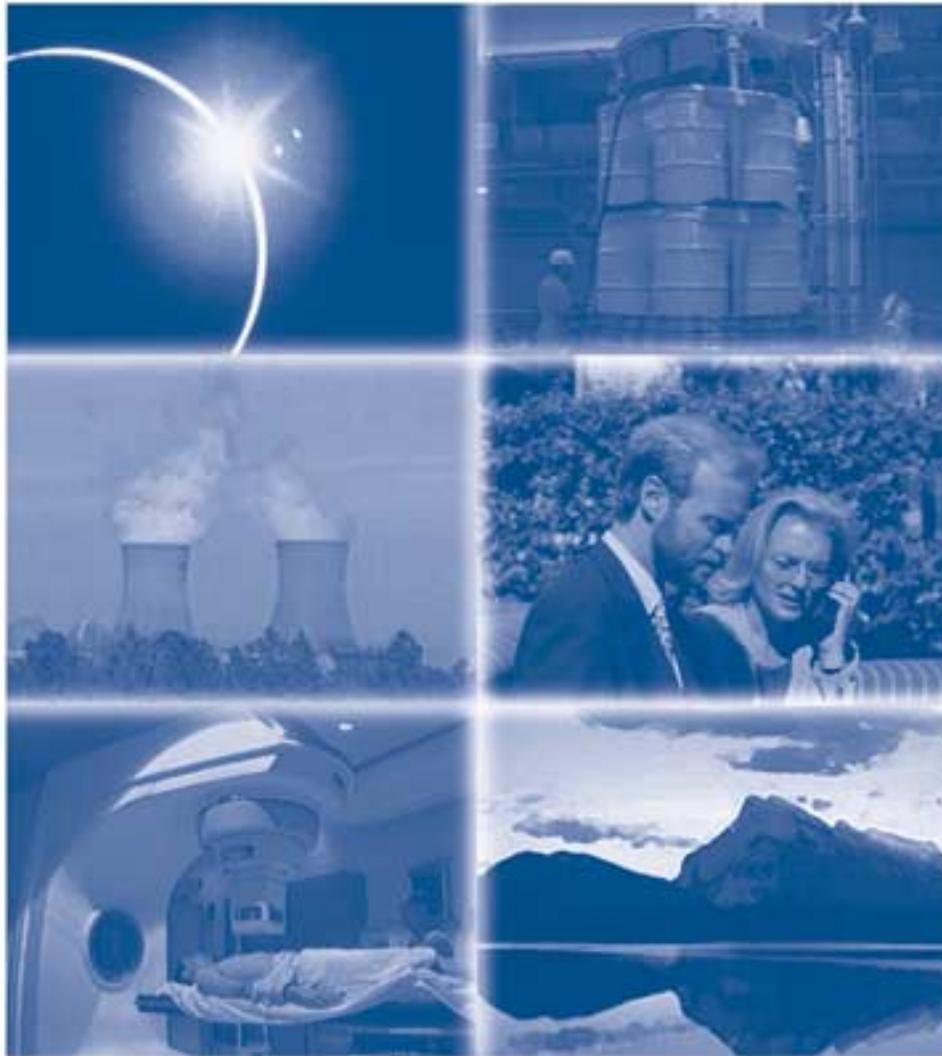


UNDERSTANDING RADIATION IN OUR WORLD



A COMPANION GUIDE FOR TEACHERS

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A COMPANION GUIDE FOR TEACHERS

National Safety Council's Environmental Health Center

1025 Connecticut Ave., NW Suite 1200

Washington, DC 20036

202/293-2270

<http://www.nsc.org/ehc.htm>

A Publication of the
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**Part I:
Activities for Each
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Understanding Radiation
in Our World**

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Introduction

This document is intended to serve as a classroom companion guide to the National Safety Council's book, *Understanding Radiation in Our World*. The science content is targeted at grades 9-12, although many of the classroom resources included could be adapted to lower grades.

This companion guide is designed to mirror the content of the chapters in the book, *Understanding Radiation in Our World*. For each chapter in the book, we have identified lesson plans/classroom activities that correspond to the topics in the chapter and that are available to any educator via the world-wide web. For chapter three, "What are the Benefits and Risks of Ionizing Radiation?," we have designed an original curriculum piece on risk analysis. This is the only part of the companion guide that is intended to be followed in a step by step sequence of instruction.

The remainder of the guide is intended for teachers to pick and choose the resources that are most suitable for their instructional objectives in teaching about radiation topics. The companion guide is designed to reflect this purpose. Each chapter in the book, *Understanding Radiation in Our World*, has a corresponding three-part section in the companion guide. The three parts are:

1. **Chapter Contents:** This is a copy of the table of contents for each chapter in the book. Teachers can refer to this to identify where they can find information in the book to help them prepare for the topics they plan to teach, as well as to identify where they might find lesson plans related to those topics.
2. **Lesson Plans and Activities:** This is a list of web sites and a description of the lesson plans and other classroom resources they contain that correspond to the topics in the chapter.
3. **National Content Standards:** This is a list of 9-12 science education standards that describe the key scientific learning goals that correspond to the topics in the chapter. The standard statements are taken from the following national standards documents:
 - American Association for the Advancement of Science's (AAAS) Benchmarks for Science Literacy
 - National Research Council's National Science Education Standards (NSES)

A note on teaching the standards...

In teaching about radiation, we encourage teachers to select learning goals from these national content standards. Upon selecting a learning goal, the teacher can tailor the lesson plans suggested in this guide to help students learn these important ideas.

In writing our curriculum piece on risk analysis, we have made an attempt to align instruction with learning goals defined from the national standards. Nevertheless, it is important that teachers use this curriculum piece and any others with a mind to improve upon it by inventing new strategies to align instruction with learning goals. We invite feedback on any strategies you use or revisions you make to improve upon our curriculum piece or any others in this guide (email to cohend@nsc.org).

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Activities for Chapter 1 of Understanding Radiation in Our World: What is the Nature of Radiation?

Chapter Contents

Energy
Types of Radiation
 Nonionizing Radiation
 Ionizing Radiation
Radioactive Decay
Half-life
Types and Sources of Ionizing
 Radiation

Lesson Plans and Activities

A. The ABC's of Nuclear Science;
Lawrence Berkeley National Laboratory
and the Contemporary Physics Education
Project. <http://www.lbl.gov/abc>

The "ABC's of Nuclear Science" is a brief introduction to Nuclear Science. It includes a "Nuclear Science Wall Chart," a "Teacher's Guide to the Nuclear Science Wall Chart," and nine experiments. (Note: a copy of the Wall Chart is included in this *Understanding Radiation* kit.)

1. *The Inverse Square*: Students explore and calculate the relationship (if any) between the distance from radioactive sources and the intensity of beta radiation.
2. *Alpha Please Leave Home*: The purpose of this experiment is to find the range of alpha particles and determine if the inverse square law applies.
3. *Stop That Gamma*: The purpose of this experiment is to find the range of gamma rays and determine if the inverse square law applies.
4. *Penetrating Power*: The purpose of this

experiment is to demonstrate the interactions of alpha, beta, and gamma radiation with matter.

5. *Radiography*: Students investigate the intensity of beta particles on photographic film.
6. *Half-life*: Students determine the half-life of Barium-137m.
7. *Magnetic Deflection of Beta Rays*: Students deflect the path of beta radiation by means of magnetism.
8. *Radiation Makes House Calls*: The purpose of this experiment is to demonstrate to the student that some household items are radioactive.
9. *It's In The Clouds*: Students create condensation trails in a cloud chamber which are evidence of the passage of alpha particles.

B. Maths300; Curriculum Corporation,
Victoria, Australia
<http://www.curriculum.edu.au/maths300/download/m300bits/007pradi.htm>

Maths300 is a web-based service that aims to support teachers in the delivery of excellent mathematics education. This lesson addresses radioactive waste and the concept of a half-life and exponential decay functions. All radioactive material is described in terms of its half-life. In this activity students 'pretend' to be uranium atoms and model the decay process. A computer simulation then provides an investigative tool to explore the underlying concepts of 'half-life' and exponential decay. Students discover just how long some of this material can stay in the environment.

Activities for
Understanding
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Our World

Chapter 1

1

Activities for Understanding Radiation in Our World

Chapter 1

C. On-line Technical Training Classroom; Institute for Energy and Environmental Research

<http://www.ieer.org/clsroom/index.html>

The Institute for Energy and Environmental Research's (IEER) on-line technical training classroom is designed to give you answers to some basic questions concerning nuclear issues without all the jargon. Worksheets accompany most of the following mini-lessons:

1. *Avoiding Conversion Aversion: Conversion of Familiar Units*
2. *All About Prefixes: No, the "nano" and the "pico" were not two ships sailed by Columbus!*
3. *I've Got Logarithms...Who Could Ask for Anything More?: Reading a logarithmic scale.*
4. *Why not just write ".0000000000 000000001?": All about Scientific Notation*
5. *Pull up a Chair (or a Web Browser) to the Periodic Table!:* Choose your favorite on-line periodic table and click away! (You can also view a periodic at <http://www.ieer.org/periodic.gif>)
6. *Putting it All Together: Factsheet on the Basics of Nuclear Physics and Fission*
7. *Jargon, Jargon, Jargon!: An Egghead's Glossary of Nuclear Terms*
8. *Yet More Jargon!:* Glossary of Radiation-Related Terms
9. *Einsteinium was a Germanium who worked in Americium: Those Confusing Chemical Element Names and their Symbols*
10. *Low-level waste, high-level waste...what does it all mean?: Classifications of Radioactive Waste*
11. *Afraid to Ask what a Fast Breeder Reactor Does?: Summary and Basic Characteristics of Nuclear Reactors.*
12. *The Rest of the Reactor Story: Table of Reactor Accidents*
13. *Plutonium Properties: Sorry, these don't refer to the waterfront variety, but they are still valuable*
14. *One Kind of Yellowcake Betty Crocker Never Made: Uses and Hazards of Uranium*
15. *Gray is not just a color and Rem is not only a*

rock group: Measuring Radiation: Terms and Units

16. *Scintillating!:* Measuring Radiation: Devices and Methods

D. Lesson Plan for Teachers: Nuclear Energy; Nuclear Regulatory Commission

<http://www.nrc.gov/NRC/PUBLIC/LESSON/905.html>

The Nuclear Regulatory Commission (NRC) has an instructional website with five units. The first unit is called Radiation and is designed around three activities:

1. *The Cloud Chamber:* While radiation cannot be seen, the cloud chamber allows you to see the tracks it leaves in a dense gas.
2. *Using a Geiger Counter* to answer the question: How radioactive are different materials?
3. *Personal Radiation Dose:* Students calculate their annual exposure to radiation.

E. Science, Society, and America's Nuclear Waste; U.S. Department of Energy

http://www.rw.doe.gov/progdocs/edresource/unit_2_toc/unit_2_toc.htm

Department Of Energy's Office of Civilian Radioactive Waste Management (OCRWM) has a resource curriculum called "Science, Society, and America's Nuclear Waste," which consists of four units. The second unit focuses on the topic of ionizing radiation and includes the following lesson plans:

1. The Cloud Chamber
2. Ionizing Radiation: Sources and Exposures
3. Pennium-123
4. Half-Lives
5. Atoms and Isotopes Review
6. Biological Effects of Ionizing Radiation
7. Radioactive Decay Series
8. Some Important Transitions in Spent Fuel
9. Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore

F. Activities For Teaching Fundamental Concepts of Nuclear Energy and Related Topics; Amarillo National Resource Center for Plutonium

<http://208.200.37.252/pdf/A00163.pdf>

“Activities For Teaching Fundamental Concepts of Nuclear Energy and Related Topics” is a collection of activities designed to assist middle school teachers in introducing into their classrooms topics relating to atomic structure, radioactivity, nuclear reactions, nuclear wastes, the environment and environmental recovery. Many of the activities can be easily adapted to high school level. The activities are arranged by general topic.

Activities that involve *Radiation Topics* include:

1. Student Radiation Survey
2. Adult Radiation Survey
3. Data Analysis
4. What is radiation?
5. Seeing the Invisible (Cloud Chamber)
6. How Do We Recognize Radiation?
7. Personal Radiation
8. UV Light and Mutations
9. Mutations and UV Light I
10. Mutations and UV Light II

Activities that relate to *Atomic Structure* include:

11. Background for Isotopes
12. Composition of Atoms
13. Isotopes I
14. Isotopes II

Activities that relate to *Radioactivity* include:

15. Background for Radioactivity
16. Time Line for Radioactivity Discoveries
17. Time Line Jeopardy
18. Preparing a Special Edition of a Newspaper
19. Reading and Writing Nuclear Chemistry
20. Alpha Decay
21. Beta Decay
22. Radioactive Decay
23. Radioactive Shielding
24. Half Life I
25. Half Life II

National Content Standards

The nucleus of a radioactive isotope is unstable and spontaneously decays, emitting particles and/or wavelike radiation. It cannot be predicted exactly when, if ever, an unstable nucleus will decay, but a large group of identical nuclei will decay at a predictable rate. This predictability of decay rate allows radioactivity to be used for

estimating the age of materials that contain radioactive substances. (AAAS, 80)

Energy is released whenever the nuclei of very heavy atoms, such as uranium or plutonium, split into middleweight ones, or when very light nuclei, such as those of hydrogen and helium, combine into heavier ones. The energy released in each nuclear reaction is very much greater than the energy given off in each chemical reaction. (AAAS, 86)

The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fission is the splitting of a large nucleus into smaller pieces. Fusion is the joining of two nuclei at extremely high temperature and pressure, and is the process responsible for the energy of the sun and other stars. (NSES, 178)

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Activities for Understanding Radiation in Our World

Chapter 1

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Activities for Chapter 2 of *Understanding Radiation in Our World:* Where Does Radiation Come From?

Chapter Contents

Sources of Ionizing Radiation

Natural and Manmade Radiation
Measuring Radiation Exposure
Manmade Sources

Sources of Nonionizing Radiation

Hazards of Nonionizing Radiation
Electric and Magnetic Fields
Radio-Frequency (RF) and Cellular Phones

Lesson Plans and Activities

A. Control the Nuclear Power Plant;

Dept. of Computer and Information
Science, Linköping University
<http://www.ida.liu.se/~her/npp/description.html>

This site, called “Control the Nuclear Power Plant,” uses an applet program (a program designed to be executed from within another application) to provide a rough simulation of a nuclear power plant and its safety systems. This power plant consists of three major components: the *reactor*, *turbine*, and *condenser*. Additionally, there are three *pumps*, four *valves*, and one *turbine*. The reactor boils the water and the steam generated drives the turbine. After the turbine, the condenser cools the steam. In turn, external cooling water cools the condenser. The cooling pumps transport the water from the condenser tank back to the reactor tank.

The simulator calculates values for reactor-tank pressure, condenser-tank pressure, water levels, and so on, and displays them graphically. When components fail, the simulator calculates and displays the consequences for the power plant system. For instance, if a cooling pump fails and the corresponding valve is not closed, water may flow backwards from the reactor tank to the

condenser tank. This process will then drain the reactor tank and expose the reactor core.

B. Solar Lesson Plan; The Why Files, University of Wisconsin

Why Files (an online resource for students and teachers that explores the science behind current news) has a lesson plan on solar energy which includes the following activities related to solar radiation:

1. Build a device to measure solar radiation
2. Collect data on solar radiation in your locale with your device
3. Discover the effect that certain variables have on solar radiation
4. Compare data on solar radiation with that collected at a distant site

<http://whyfiles.org/004antarctic/teacher4/solar.html>

C. Learn Not to Burn; Center for Research on Parallel Computation, Rice University <http://www.crpc.rice.edu/CRPC/GT/lee/burlesson.html>

In this lesson on the effects and health risks of solar radiation, students:

1. Observe the effect of different filter thickness on ultraviolet radiation.
2. The affects of ultraviolet radiation on UV Frisbees and Tonic water.
3. U.V. radiation is necessary for the production and destruction of ozone.

D. Nuclear Reactors/Energy Generation; Nuclear Regulatory Commission (NRC) <http://www.nrc.gov/NRC/PUBLIC/LESSON/905.html>

NRC has an instructional website with five units. The second unit is called Nuclear Reactors/Energy Generation and is designed

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Chapter 2

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Chapter 2

around a series of graphics showing the parts and mechanics of different types of nuclear reactors. The following activities require students to identify the parts of a reactor and indicate the pathways of substances in the reactors:

1. Powerplant Diagram – Boiling Water Reactor (BWR)
2. Powerplant Diagram – Pressurized Water Reactor (PWR)

E. Activities For Teaching Fundamental Concepts of Nuclear Energy and Related Topics; Amarillo National Resource Center for Plutonium

<http://208.200.37.252/pdf/A00163.pdf>

“Activities For Teaching Fundamental Concepts of Nuclear Energy and Related Topics” is a collection of activities designed to assist middle school teachers in introducing into their classrooms topics relating to atomic structure, radioactivity, nuclear reactions, nuclear wastes, the environment and environmental recovery. Many of the activities can be easily adapted to high school level. The activities are arranged by general topic. Activities that relate to *Nuclear Reactions* include:

1. Background for Nuclear Reactions
2. Simulating Fission
3. Nuclear Fission
4. Chain Reactions
5. Critical Mass
6. The Ethics of Science
7. Nuclear Reactors
8. Fusion: Energy of the Future
9. Fission vs. Fusion
10. Nuclear Gin Rummy

National Content Standards

Nuclear reactions release energy without the combustion products of burning fuels, but the radioactivity of fuels and by-products poses other risks, which may last for thousands of years. (AAAS, 195)

Activities for Chapter 3 of *Understanding Radiation in Our World:* What are the Benefits and Risks of Ionizing Radiation?

Chapter Contents

Benefits of Ionizing Radiation

Medical Uses
Industry
Nuclear Power
Agriculture
Food Irradiation
Consumer Products
The Space Program
Sea Power
Research

The Risks of Ionizing Radiation

Measuring Human Exposure
Studying Radiation's Effects on Humans
Human Health Effects of Ionizing Radiation
Health Effects of Radon
Radiation-Related Health Effects from Living
Near Nuclear Power Plants
Accidental Releases

Determining Your Exposure

Determining Levels of Risk

Balancing the Benefits and Risks of Radiation

Governmental Risk Assessments and
Standards
Individual Judgements
Society's Judgements, Pro and Con
Future Prospects for Nuclear Power

Lesson Plans and Activities

A. Risk Analysis Lesson Plan; National Safety Council

See page 25 of this guide.

B. Science, Society, and America's Nuclear Waste; U.S. Department of Energy

http://www.rw.doe.gov/progdocs/edresource/unit_3_toc/unit_3_toc.htm

DOE's Office of Civilian Radioactive Waste Management (OCRWM) has a resource curriculum called *Science, "Society, and America's Nuclear Waste,"* which consists of four units. The third unit includes the topic of Risk

Assessment and includes the following lesson plans:

1. Risk Perception and Judgement
2. Probability: The Language of Risk Assessment
3. Factors Affecting Risk Judgement

C. Understanding Risk; Sandia National Laboratories

<http://education3.ca.sandia.gov/risk/index.las>

Sandia National Laboratories has a tutorial called Understanding Risk that contains mostly information, but also includes the following worksheet activities:

1. Worksheet 1 – Assessing Everyday Risks
2. Worksheet 2 – Probability and Numbers of Deaths

D. Risk Assessment for Kids and Educators; California EPA's Office of Environmental Health Hazard Assessment (OEHHA)

<http://www.oehha.org/education/risk/index.html>

OEHHA has an online tutorial called Risk Assessment for Kids and Educators. Most of the activity is conveying information. Part of the activity illustrates dose-response with an example of eating cookies, which is targeted at a lower grade level audience, but the ideas are relevant to understanding quantitative risk analysis.

E. Radiation Reassessed; The Why Files, University of Wisconsin

<http://whyfiles.org/020radiation/>

The Why Files (an online resource for students and teachers that explores the science behind current news) has an in-depth report called "Radiation Reassessed" that has a lot of data and information about issues and expert opinions regarding risks and benefits of radiation tai-

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Chapter 3

3

Activities for Understanding Radiation in Our World

Chapter 3

lored to a student audience. It does not have lesson plans.

F. Radium: Narrative of a Moral Dilemma;

Access Excellence

<http://www.accessexcellence.org/21st/SER/BE/radium.html>

An educational site called ScienceNetLinks has a lesson plan to examine the history of the splitting of the atom. An extension to this lesson plan is a writing project in which the student plays the role of a character in an ethical real life dilemma faced by medical researchers and patients which involves the historical use of radium as a procedure to cure disease. This writing project illuminates the importance of balancing the benefits and risks whenever there is a breakthrough in the development of a procedure or drug to cure a disease.

G. Environmental Risk Assessment Unit;

Penn State Berks-Lehigh Valley College

<http://www.bk.psu.edu/academic/sts/SylRisk.htm>

Here is an excellent simulation on assessing environmental risk created by a professor at Penn State Berks-Lehigh Valley College. In this scenario, there has been a chemical leak from a manufacturing company. Students take on the role of different special interest groups. They are given details of the chemical and some evaluative criteria. Each group's task is to rate the importance of the criteria on a scale of 1 to 10. In other words, they must define which of the ways of looking at the situation are most important to them. Next, each group analyzes some data and rates the scientific risk on a scale of 1 to 10. Students then multiply the number they assigned the criteria for importance by the number they assigned to represent risk for each area to calculate the total perceived risk score for their interest group.

National Content Standards

The value of any given technology may be different for different groups of people and at different points in time. (AAAS, 52)

Risk analysis is used to minimize the likelihood of unwanted side effects of a new technology. The public perception of risk may depend, however, on psychological factors as well as scientific ones. (AAAS, 52)

In deciding on proposals to introduce new technologies or to curtail existing ones, some key

questions arise concerning alternatives, risks, costs, and benefits. What alternative ways are there to achieve the same ends, and how do the alternatives compare to the plan being put forward? Who benefits and who suffers? What are the financial and social costs, do they change over time, and who bears them? What are the risks associated with using (or not using) the new technology, how serious are they, and who is in jeopardy? What human, material, and energy resources will be needed to build, install, operate, maintain, and replace the new technology, and where will they come from? How will the new technology and its waste products be disposed of and at what costs? (AAAS, 57)

At present, all fuels have advantages and disadvantages so that society must consider the trade-offs among them. (AAAS, 195)

Industrialization brings an increased demand for and use of energy. Such usage contributes to the high standard of living in the industrially developing nations but also leads to more rapid depletion of the earth's energy resources and to environmental risks associated with the use of fossil and nuclear fuels. (AAAS, 195)

Radioactivity has many uses other than generating energy, including in medicine, industry, and scientific research in many different fields. (AAAS, 253)

View science and technology thoughtfully, being neither categorically antagonistic nor uncritically positive. (AAAS, 287)

Insist that the critical assumptions behind any line of reasoning be made explicit so that the validity of the position being taken—whether one's own or that of others—can be judged. (AAAS, 300)

Be aware, when considering claims, that when people try to prove a point, they may select only the data that support it and ignore any that would contradict it. (AAAS, 300)

Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems.

Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations.

Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world. (NSES, 193)

Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards – ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and the accuracy with which scientists and engineers can (and cannot) predict events are important considerations. (NSES, 199)

Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges. (NSES, 199)

Progress in science and technology can be affected by social issues and challenges. Funding priorities for specific health problems serve as examples of ways that social issues influence science and technology. (NSES, 199)

Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions—“What can happen?”—“What are the odds?”—and “How do scientists and engineers know what will happen?” (NSES, 199)

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Activities for Understanding Radiation in Our World

Chapter 3

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Activities for Chapter 4 of *Understanding Radiation in Our World*: How are Radioactive Wastes Managed?

Chapter Contents

Radioactive Waste Disposal
Types of Radioactive Waste
Sites and Methods of Waste Disposal
The Search for Permanent Disposal
Proposed High-Level Waste
Permanent Disposal Site
Public Concerns about Permanent Disposal
Options
Radioactive Waste Cleanup
Nuclear Weapons Waste
Nuclear Reactor Waste
Low-Level Radioactive Waste
Orphaned Sources and Contaminated
Scrap Metal
Naturally Occurring Radioactive Materials
Transporting Radioactive Waste

Lesson Plans and Activities

A. Nuclear Waste Cube; Nuclear Regulatory Commission (NRC)
<http://www.nrc.gov/NRC/PUBLIC/LESSON/905.html>

NRC has an instructional website with five units. The third unit is called Radioactive Waste and mainly tells students the distinction between high- and low-level radioactive waste. The fourth unit deals with the Transportation of Radioactive Materials. It includes information in the form of text and graphics, but no classroom activities.

B. Activities For Teaching Fundamental Concepts of Nuclear Energy and Related Topics; Amarillo National Resource Center for Plutonium
<http://208.200.37.252/pdf/A00163.pdf>

This is a collection of activities designed to assist middle school teachers in introducing into their classrooms topics relating to atomic structure, radioactivity, nuclear reactions, nuclear wastes, the environment and environmental recovery. Many of the activities can be easily adapted to high school level. The activities are arranged by general topic.

Activities that involve *Nuclear Waste* include:

1. Nuclear Waste: What Is It? Where Is It?
2. Inventories of Spent Fuels
3. Low Level Waste
4. Low Level Waste Disposal
5. Change the Rules

Activities that relate to *Nuclear Waste and the Environment*

6. Permeability and the Porosity of Soils I
7. Permeability and the Porosity of Soils II
8. Groundwater
9. Water-Logged
10. Water Contamination
11. Who Is the Guilty Party?
12. Zeolites Simulation
13. Biodegradability of Solid Waste
14. Mapping Radon Gas in Texas
15. Risk Analysis
16. Seismic Risk Map of Texas

Activities that relate to Transporting Nuclear Wastes

17. Safely Shipping Nuclear Waste
18. Designing for Safety I
19. Designing for Safety II
20. Analyzing State Highway Maps
21. Planning Hazardous Materials Shipment Routes

Activities that relate to *Pollution Cleanup*

22. Hazardous Waste

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Chapter 4

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Chapter 4

C. Science, Society, and America's Nuclear Waste; DOE Office of Civilian Radioactive Waste Management (OCRWM)

http://www.rw.doe.gov/progdocs/edresource/unit_4_toc/unit_4_toc.htm

OCRWM has a resource curriculum called "Science, Society, and America's Nuclear Waste," which consists of four units. The fourth unit is called The Waste Management System and includes the following lesson plans:

1. What Measures Ensure Safe Transportation of High-Level Nuclear Waste?
2. What Will A Geologic Repository Be Like?
3. The Role of the Multi-Purpose Canister in the Waste Management System
4. Designing for Safety
5. Transporting Hazardous Materials
6. Rock Characteristics Important in Repository Siting
7. Porosity and Permeability
8. Solubility
9. Mineral Solubility
10. Thermal Stability
11. Ion Exchange and Zeolites
12. Topographic Map Skills
13. Topography of the Yucca Mountain Site
14. Considerations for Siting the High-Level Nuclear Waste Repository

D. Transporting Radioactive Waste: An Engineering Activity; DOE Center for Environmental Management

<http://www.em.doe.gov/teacher/trwaea.html>

The Center's teacher website provides a lesson plan called "Transporting Radioactive Waste: An Engineering Activity," in which students design and test containers to contain waste and consider factors such as accidents, leaks, and ease of transport.

National Content Standards

Technological problems often create a demand for new scientific knowledge, and new technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research. The availability of new technology itself often sparks scientific advances. (AAAS, 47)

Industrialization brings an increased demand for and use of energy. Such usage contributes to the high standard of living in the industrially devel-

oping nations but also leads to more rapid depletion of the earth's energy resources and to environmental risks associated with the use of fossil and nuclear fuels. (AAAS, 195)

Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world. (NSES, 193)

Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change. (NSES, 199)

Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions – "What can happen?" – "What are the odds?" – and "How do scientists and engineers know what will happen?" (NSES, 199)

Activities for Chapter 5 of *Understanding Radiation in Our World:* How Is The Public Protected From Radiation?

Chapter Contents

- Government Responsibilities in Protecting the Public
 - Controlling Risks of Exposure to Radiation: Federal and Individual Roles*
 - How You Can Limit Your Radiation Exposure*
- Government Controls on Exposure to Radiation
 - Controlling Radiation in the Air*
 - Controlling Radiation in Water*
 - Controlling Medical Exposures*
 - Controlling Exposure to Radon*
 - Monitoring Radiation Levels in the Environment*
 - Controlling UV Radiation Exposure*
 - Controlling Occupational Exposures*
 - Major Federal Legislation Governing Radiation*
- Responsible Federal Agencies
 - The Nuclear Regulatory Commission (NRC)*
 - The Department of Energy (DOE)*
 - The Environmental Protection Agency (EPA)*
 - The Department of Defense (DOD)*
 - The Department of Transportation (DOT)*
 - The Department of Health and Human Services (HHS)*
 - The Occupational Safety and Health Administration (OSHA)*
 - The National Academy of Sciences (NAS)*
 - The National Council on Radiation Protection and Measurements (NCRP)*
- Federal, State and Local Government Functions
 - Responding to Emergencies*
 - Setting Standards*
 - Issuing Guidance*
 - Conducting Site Cleanup*
- Other Roles in Managing Radiation
 - The Role of the States and Native American Tribes*
 - The Role of International Organizations*
 - Your Role as a Citizen*

Lesson Plans and Activities

- A. Science, Society, and America's Nuclear Waste;** DOE Office of Civilian Radioactive Waste Management (OCRWM)
http://www.rw.doe.gov/progdocs/edresource/unit_3_toc/unit_3_toc.htm
OCRWM has a resource curriculum called "Science, Society, and America's Nuclear Waste," which consists of four units. The third unit is called The Nuclear Waste Policy Act and includes the following lesson plans:
1. The Nuclear Waste Policy Act
 2. Approaching a Complex Task
 3. Nuclear Waste Challenges and Solutions

- B. Critical Thinking Curriculum Model;** Los Alamos National Laboratory
<http://set.lanl.gov/programs/cif/>
The "Critical Thinking Curriculum Model," which includes five areas focusing on the nuclear world. Each curriculum area addresses several topics in the form of assignment "tasks" that engage the student/teacher teams in research, critical thinking, communicating thoughts, and making connections. For each task, there are "Suggested Classroom Activities" which provide additional opportunities for students to demonstrate what they have learned by completing the task.

- The curriculum area dealing with The Storage and Disposition of Radioactive Materials includes the following topics:
1. Use of Radioactive Materials
 2. Types of Radioactive Waste
 3. Issues and Concerns
 4. Laws and Regulations
 5. Options
 6. Student Conference on the Nuclear World

Activities for
Understanding
Radiation in
Our World

Chapter 5

5 Activities for Understanding Radiation in Our World

Chapter 5

The curriculum area called The Future of the Nuclear World includes the following topics:

1. Current Nuclear Events
2. Future World Environments in General
3. Future World Environments, specifically energy
4. Role of Things Nuclear in Future World Environments, specifically weapons
5. Role of Things Nuclear in Future World Environments, specifically medical, industrial, and other applications
6. Public Attitudes and Institutional Responses to Technology in the Future with Emphasis on Nuclear Things

National Content Standards

Technological problems often create a demand for new scientific knowledge, and new technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research. The availability of new technology itself often sparks scientific advances. (AAAS, 47)

Decisions to slow the depletion of energy sources through efficient technology can be made at many levels, from personal to national, and they always involve trade-offs of economic costs and social values. (AAAS, 195)

A massive effort went into developing the technology for the two nuclear fission bombs used on Japan in World War II, nuclear fusion weapons that followed, and reactors for the controlled conversion of nuclear energy into electric energy. Nuclear weapons and energy remain matters of public concern and controversy. (AAAS, 253)

Insist that the critical assumptions behind any line of reasoning be made explicit so that the validity of the position being taken—whether one’s own or that of others—can be judged. (AAAS, 300)

Be aware, when considering claims, that when people try to prove a point, they may select only the data that support it and ignore any that would contradict it. (AAAS, 300)

Personal choice concerning fitness and health involves multiple factors. Personal goals, peer and social pressures, ethnic and religious beliefs,

and understanding of biological consequences can all influence decisions about health practices. (NSES, 197)

Progress in science and technology can be affected by social issues and challenges. Funding priorities for specific health problems serve as examples of ways that social issues influence science and technology. (NSES, 199)

Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions—“What can happen?”—“What are the odds?”—and “How do scientists and engineers know what will happen?” (NSES, 199)

**Section II:
Risk Analysis
Lesson Plan**

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Introduction

Estimated Time:

4 - 6 hours (over 5 days)

Understanding sought:

Risk analysis is used to minimize the likelihood of unwanted side effects of a new technology. The public perception of risk may depend, however, on psychological as well as scientific factors. (Benchmarks for Science Literacy, page 52)

Natural and human induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and tradeoffs of various hazards – ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and accuracy with which scientists and engineers can and cannot predict events are important considerations. (National Science Education Standards, page 199)

Individuals and society must decide upon proposals involving new research and the introduction of new technologies into society. Decisions involving assessment of alternatives, risks, costs, and benefits, and consideration of who benefits and who suffers, who pays and who gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions – “What can happen” – “What are the odds” – and “How do scientists and engineers know what will happen?” (National Science Education Standards, page 199)

View science and technology thoughtfully, being neither categorically antagonistic nor uncritically positive. (Benchmarks for Science Literacy, page 287)

What students are doing and why:

Students learn how scientists measure risk by estimating both the probability and consequences of an event or technology. Students then make the distinction between quantitative estimates of risk and estimates based upon psychological factors. Upon making this distinction, students practice calculating risks and viewing familiar risks by comparing quantitative estimates against their personal assessments of risk. The purpose of this is to provide students with a new tool in which to evaluate risk. Students then examine the topic of radiation and nuclear energy through risk analysis. Students will apply their understanding of quantitative and psychological dimensions of risk analysis to communicate the risk of operating a nuclear power plant to the public impacted by it.

Note on commonly held student ideas:

A bit of probing may reveal that students' knowledge of risk is highly subjective, and that students probably do not rate risk in the same way as experts in the field of probabilistic risk analysis. Expert assessment of the risks associated with various activities and technologies correlate highly with statistical frequencies of death; students' judgements often incorporate considerations other than annual fatalities. In the case of nuclear power plants, factors such as whether the technology could have catastrophic consequences or whether the technology is unfamiliar potentially influence students' judgements of risk. The challenge, then, is to make students aware of the psychological factors that shape their perceptions of risk and weigh those perceptions against a scientific approach to risk assessment. The goal is to have students demonstrate this understanding by being able to communicate a rational risk assessment in a simulated debate over nuclear power.

Risk
Analysis
Lesson
Plan

Introduction

**Risk
Analysis
Lesson Plan**

Introduction

Objective:

Students will be able to complete a risk analysis about nuclear power using a quantitative viewpoint of risk provided by scientific data and considering public perceptions of risk that are shaped by subjective judgements.

Advance Preparation:

Duplicate handouts and make overheads. Distribute copies of handout, RISK COMMUNICATION: FACING PUBLIC OUTRAGE, and assign students to read it as homework before the class.

Handouts:

- "RISK COMMUNICATION: FACING PUBLIC OUTRAGE" (Article by Peter M. Sandman, published in EPA Journal, Nov. 1987, pp.21-22.)
- SAMPLE SITUATIONS FOR RISK DISCUSSION
- RISK PERCEPTION WORKSHEET
- EXPRESSING RISK DATA (from "A Fistful of Risks." Discover 17 (5), 82-83, May 1996)
- ENERGY ALTERNATIVES (data from Nuclear Electricity, 6th edition, Uranium Information Centre Ltd., <http://www.uic.com.au/ne6.htm>)
- ALL ABOUT RADON (National Safety Council)
- INTERPRETING THE BEIR-V REPORT
- NUCLEAR ACCIDENT SCENARIO
- THREE-MILE ISLAND CONSEQUENCES
- RISK ANALYSIS INSTITUTE
- PRO AND CON STATEMENTS ON NUCLEAR POWER
- RISK ANALYSIS ASSESSMENT
- A PRESENTATION PLANNER (Agency for Toxic Substances and Disease Registry, www.atsdr.cdc.gov/HEC/primer.html)
- AVOIDING PRESENTATION PITFALLS (Agency for Toxic Substances and Disease Registry, www.atsdr.cdc.gov/HEC/primer.html)

Overheads:

- COMPARISON OF TWO EVENTS WITH EQUAL RISK (Sandia National Laboratories, <http://ttd.sandia.gov/risk/riskasmt>)
- CARTOON (A Steve Kelly cartoon, Copley News Service)

- RISK STATISTICS (from "A Fistful of Risks." Discover 17 (5), 82-83, May 1996)
- WHAT IS RISK?
- CALCULATING RISK (from ChemCom, 2nd Edition, American Chemical Society, p.317)
- EXPRESSING RISK
- COMPARING RISKS (University of Michigan, <http://www.umich.edu/~radinfo/introduction/risk.html>; adapted from *Radiobiology for the Radiologist*, Fourth Edition; Eric Hall 1994, J.B. Lippincott Company.)
- REM VS. MILLIREM (Nuclear Regulatory Commission, <http://www.nrc.gov/NRC/EDUCATE/REACTOR/05/fig013.html>)
- SOURCES OF RADIATION EXPOSURE TO THE US POPULATION (National Council on Radiation Protection and Measurements)
- RADON RISK EVALUATION CHARTS (From "Citizen's Guide to Radon," U.S. Environmental Protection Agency, 1994)
- HISTORY OF RADIATION RISK ESTIMATE (Nuclear Regulatory Commission, www.nrc.gov/NRC/NUREGS/SR1437/V2/sr1437v2.html)
- LINEAR NO-THRESHOLD RISK MODEL (Nuclear Regulatory Commission, www.nrc.gov/NRC/EDUCATE/REACTOR/09/fig006.html)
- RADIATION-RELATED HEALTH EFFECTS FROM LIVING NEAR NUCLEAR POWER PLANTS
- NUCLEAR POWER PLANT ACCIDENT PROBABILITIES AND CONSEQUENCES
- POTENTIAL CONSEQUENCES OF NUCLEAR POWER PLANT ACCIDENTS (From U.S. House of Representatives, Committee on Interior and Insular Affairs Subcommittee on Oversight and Investigations, "Calculation of Reactor Accident Consequences (CRAC2) for US Nuclear Power Plants (Health Effects and Costs) Conditional on an 'SST1' release," November 1, 1982.)
- MEETING NOTICE

What Is Risk?

Risk Analysis Lesson Plan

A. What is Risk?

ASSIGNMENT prior to class: Distribute the handout RISK COMMUNICATION: FACING PUBLIC OUTRAGE and ask students to read prior to class.

1. Scientific factors

(Adapted from “Nuclear Plant Risks Studies: Failing the Grade,” Union of Concerned Scientists.)

SAY: Consider an event (defined scenario) that occurs, on average, once a decade and kills 40 people when it happens. Consider another event that happens every other year and kills 8 people each time. (Display these statistics in view of all students) You can only spend \$1 million dollars and totally eliminate the chance of one of these events from occurring again. Faced with this decision, you want to spend the money where it will do the most good.

ASK: Would you eliminate the first event because it injures 40 people as opposed to 8 people? Or would you eliminate the second event because it happens more often?

Present the following two options:

Option one:
Eliminate the first event because it injures 40 people as opposed to 8 people.

Option two :
Eliminate the second event because it happens more often.

SAY: In making your decision, consider if one event has more risk than the other. Justify your decision.

Elicit responses. Students should conclude that the risk for both events is the same. You can explain this interpretation in the following way.

SAY: In this case you can't lose. The elimination of either event prevents it from killing an average of four people per year.

Display the following:

1 event every 10 years killing 40 people per event averages 4 fatalities/year
1 event every 2 years killing 8 people per event averages 4 fatalities/year.

SAY: These two events have exactly the same risk, even though they have different probabilities and consequences. But what if the second event killed 10 people each time it happened? How many fatalities per year would result?

Display the following:

1 event every 2 years killing 10 people per event averages 5 fatalities/year.

SAY: It might be tempting to spend the money on the first event because it causes 40 fatalities, but it would be wiser to eliminate the second event because it ultimately injures more people and thus poses greater risk. This exercise shows how critical it is when evaluating risk, to consider both the probability of an event and the consequences from that event.

(Display the COMPARISON OF TWO EVENTS WITH EQUAL RISK overhead.)

2. Psychological factors

Display or read the following:

“The values to society of risks and benefits, as perceived by the people in that society, are not the sums of the values to the individuals affected. The catastrophe that kills 1,000 people in a whack is perceived as far more threatening – that is, has far more negative value – than 1,000 single fatality auto wrecks.”

—Stephen H. Hanauer, Nuclear Regulatory Commission, 1975

Elicit discussion of this statement by having students provide examples of real world scenarios that support or refute this opinion.

ASK: Do you generally approach risk more rationally or more emotionally? Elicit examples.

(The following activity is based upon the assigned reading entitled RISK COMMUNICATION: FACING PUBLIC OUTRAGE .)

SAY: In preparation for class today, you read an article entitled RISK COMMUNICATION: FACING PUBLIC OUTRAGE.

ASK: What does the author mean by “outrage factors”? What does the article say are some outrage factors that influence people’s feelings about risk? Can you think of any others?

SAY: We are going to do an activity in which we evaluate comments with regards to risk. Your task is to determine which outrage factors are evident in each of the following situations.

Distribute the SAMPLE SITUATIONS FOR RISK DISCUSSION handout. Review and discuss each of the situations.

Situation #1 – facts

The average American has a 1 in 250,000 chance of dying in an airplane crash.

The average American has a 1 in 45 chance of dying in an auto accident.

The average American has a 1 in 160,000 chance of choking to death on food.

Situation #2 – discussion

Q: Do you think that if someone in the industry said they found a safe way to store this waste, would you feel comfortable with that?

A: No. I would like to have some independent verification of that. When someone’s personal or corporate financial interest is at stake, and they set forth a bold new announcement that the following issues have been satisfactorily resolved and there are no public health or other concerns that need now to be addressed, they’ve all been satisfactorily settled, I’d like independent verification of those kinds of things...

Situation #3 – comment on studies

“...the most recent study that came out (we’re talking August of ‘96), that took the figures from the Columbia health study. And the Columbia health study said, ‘Look, there’s elevated levels of cancer, but we’re reluctant to attribute it to Three Mile Island.’ Well, the University of North Carolina, Chapel Hill, their Department of Public Health looked at the data and said, ‘Look, between ‘75 and ‘85 in the Three Mile Island area, there was a five to ten times increase of lung cancer and leukemia.’ I mean, clearly, it depends on who’s doing the study and who has what to gain from the study.”

Situation #4 – comment

“There are energy ‘haves’ around the world, like the United States, and there are energy ‘have nots.’ Every country has got to find some source of energy, or they’re just going to sit in the Middle Ages. If they’re going to do that, they’re going to find energy somewhere – or import it. The Japanese, of course, were highly dependent on oil. We all know that’s about the only thing we go to war for, really, is to protect the oil. And so the Japanese know they can’t be dependent on oil. They’ve gone big time into the nuclear program. The Chinese have a lot of coal, and they’ll start with coal. They’ll move to nuclear power very quickly, because they have an educated, skilled group of people that can do that. The only energy policy that I’ve seen our government really support is the fact that we will go to war to protect our sources of oil.”

Risk Analysis Lesson Plan

A. What is Risk?

Situation #5 – discussion

Person A (a toxicologist): What might be a life-threatening hazard is not perceived that way, either by the public or the press. But if we say, “We have some TCE in the groundwater, but we are going to deal with something else,” the people with the TCE in their water go nuts. A public official can’t say “You have a one-in-a-million risk, what’s the big deal?”

Person B: He should say it while he is drinking some of that water. Is there a more user-friendly way to define risk, a way that would be more communicative? When you say “one in a million,” the public thinks “I don’t want to be that one.”

Person A: We have also learned in my field that the public seems to divide risk regardless of how you describe it statistically: risk is either/or. Is it something I have to worry about or not? Do I take an umbrella to work or not?

Person B: We hear “one in a million” risk of cancer as being a criteria for making decisions. Is anyone looking at other health effects that might be caused by TCE?

Person A: Absolutely. That is a pet peeve of mine as a toxicologist. I think it is remiss to focus on theoretical one-in-a-million cancer risks and ignore subtle nervous system and developmental problems. We have a tremendously high miscarriage rate in this country, and not a whole lot of research is going into why. We should research these things, de-emphasize the big “C” and start thinking about what is more important in terms of public health. Not that cancer isn’t. I mean one in three of us will suffer some kind of cancer in our lifetime. Cancer is an epidemic. I am just saying that addressing environmental risk at a “one in a million” risk level doesn’t make much sense to me as a toxicologist.

One in a million chance of death is equal to smoking 1.4 cigarettes, traveling six minutes by canoe or 10 miles by bicycle, driving 300 miles in a car or flying 1,000 miles by jet. There is another number you may know. Somewhere between two and three, maybe as much as four, percent of cancers are attributable to what we would call environmental causes. So, if we cleaned up everything, we would still only reduce cancer rates by four percent.

Person B: Whether it is important depends on whether you are in that four percent. To me, we don’t look at cost/benefit enough. To what levels do you clean? Do you clean up something for the sake of it and not look at the benefit. That seems to be a major problem.

Situation #6 – cartoon

(Display the CARTOON overhead.)

ASK: How does the author propose we can get political leaders, government agencies, and citizens to be more rational decision-makers with respect to risk?

3. Risk definition

As a class, formulate a working definition of risk. Compare your definitions to the following expert definitions.

(Display the “WHAT IS RISK?” overhead.)

ASK: What elements does our definition have in common with their definitions?

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Calculating Risk

Risk
Analysis
Lesson
Plan

B. Calculating
Risk

1. Risk statistics

SAY: The common rule used by regulators in determining human health risks associated with new technology is “One in a million.” That is, the new technology is safe if it does not increase the risk of fatality to the population to more than one in a million. Risky activities are often expressed in terms of their mortality rate.

ASK: When we say, “one in a million,” what is that called? (a probability) If I flip a coin, what is the probability that it will come up heads? (50% or one out of two times). In the language of probability, we say the probability is 0.5. What does it mean if the probability of a coin coming up heads is 0.0? (the coin will never be heads) What does it mean if the probability is 1.0? (the coin will always come up heads)

ASSIGNMENT: Distribute the RISK PERCEPTION WORKSHEET handout. Instruct students to rank the events from most risky (1) to least risky (16) and then guess the probability of that event occurring. After allowing approximately ten minutes for students to complete the chart, ask a few students to offer their most risky and least risky choices and explain their rationale for ranking.

(Display the RISK STATISTICS overhead.)

SAY: If your judgements about what is most risky and least risky differ from the data, then you based your judgement on something other than statistical evidence.

ASK: Without the data, how did you measure risk?

ASK: Which of those risks could be reduced? Which of those risks could you live with?

SAY: Reducing risks has benefits and costs.

ASSIGNMENT: You are charged with the task of reducing one of those risks. You can do so by making one law or regulation. State your law or regulation. Explain how your law or regulation would reduce the risk. Then explain the costs of reducing this risk. (Do not limit your definition of cost to money. Consider such things as societal and environmental costs, too.)

(end day one)

2. Calculating risk

(Adapted from [ChemCom](#), 2nd Edition, American Chemical Society, page 317.)

SAY: You are taking a trip to a place 500 miles away. You want to travel by the safest means. Which mode of travel would you choose? Rank the following modes from safest to least safe:

- Bicycle
- Auto
- Commercial Airline
- Train
- Bus

(Display the CALCULATING RISK overhead.)

Mode of Travel	Distance
Bicycle	10 miles
Auto	100 miles
Commercial Airline	1,000 miles
Train	1,200 miles
Bus	2,800 miles

SAY: Another way of saying this is that if you take a 10 mile bike ride, you are increasing your chance of dying by one millionth. To calculate the risk of dying by taking a 500-mile bike ride, risk analysts use the following formula:

Risk of Fatality = Probability X Consequence

SAY: We said the “Probability” of death by bike is one in a million per 10 miles.

one in a million = $1/1,000,000$ = one millionth = 0.000001

SAY: Consequences can include fatalities, monetary-costs, a quantity, or, in this case, a magnitude.

0.000001			
10 miles	X	500 miles	= 0.000005 or 5.0×10^{-6}
Probability	X	Consequence (Magnitude)	= Risk of Fatality

SAY: Calculate the risk of dying if you take your 500-mile trip by other modes of travel.

Auto $\frac{0.000001}{100 \text{ miles}}$ X 500 miles = 0.000005 or 5.0×10^{-6}

Airline $\frac{0.000001}{1000 \text{ miles}}$ X 500 miles = 0.0000005 or 5.0×10^{-7}

Train $\frac{0.000001}{1200 \text{ miles}}$ X 500 miles = 4.17×10^{-7}

Bus $\frac{0.000001}{2800 \text{ miles}}$ X 500 miles = 1.79×10^{-7}

(Display “WHAT IS RISK?” overhead.)

SAY: Now let’s return to our expert’s definitions of risk.

ASK: How are these definitions reflected in the risk data of the activity we just did? Review of how to express risk data

SAY: No matter how risks are defined or quantified, they are usually expressed as a probability of adverse effects associated with a particular activity. Risk is expressed as a fraction, with units from 0.0 to 1.0, where at one there is absolute certainty that risk will occur. Scientific notation is generally used to present quantitative risk information.

(Display EXPRESSING RISK overhead.)

Actual Number	Scientific Notation	Read as
.1	1×10^{-1}	One in ten
.01	1×10^{-2}	One in a hundred
.001	1×10^{-3}	One in a thousand
.0001	1×10^{-4}	One in ten thousand
.00001	1×10^{-5}	One in a hundred thousand
.000001	1×10^{-6}	One in a million
.0000001	1×10^{-7}	One in ten million

ASSIGNMENT: Distribute EXPRESSING RISK DATA worksheet. Assign students to convert the probability for each event into a decimal and scientific notation.

3. Comparing risks

SAY: Individuals have different perceptions of risk. Consider the risks associated with smoking, driving, and medical procedures using radiation.

ASK: Which do you perceive as more risky? Which do perceive as acceptable? Now consider the following data comparing these risks.

(Display COMPARING RISKS overhead.)

ASK: Based upon this risk analysis, which risk do you perceive as more risky? Which do you perceive as acceptable?

SAY: While the definition of risk is fairly straightforward, the term “risky” can be harder to define. What’s unacceptably

Risk Analysis Lesson Plan

B. Calculating Risk

risky to one person may be merely an adrenaline rush to another. It's important to realize that people do not evaluate risks solely by comparing numbers. Perceptions of risk, whether based on fact or not, frequently are people's sole means of evaluating risk. As Supreme Court justice Oliver Wendell Holmes put it: "Most people think dramatically, not quantitatively."

ASK: How did your perceptions of the risks associated with smoking, driving, and medical procedures using radiation compare to the quantitative data? Do you tend to evaluate risks in your life more "quantitatively or dramatically."

SAY: So what's the best way of evaluating everyday risks you encounter? In many cases, all you've had time for is a snap decision based on minimal information and a gut feeling. In other cases, you may want to invest more time and effort before making a particularly risky choice that could have a major impact on your life. To be able to make rational, informed decisions about risks, we need to understand some basic concepts of risk analysis and decision making.

4. Practice calculating risks

SAY: We are going to do an activity in which we compare risks of energy production. Let's return to our expert's definitions of risk.

(Display WHAT IS RISK? overhead.)

ASK: What are the two factors we must take into account when calculating risk quantitatively?

Answer: Probability that an event will occur and the consequence if the event were to occur. Risk = Probability X Consequence

ASSIGNMENT: Distribute ENERGY ALTERNATIVES handout. When students have had time to complete this hypothetical scenario have them share their answers with the class.

(end day two)

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Radiation and Risk



Risk Analysis Lesson Plan

C. Radiation and Risk

1. Perceptions of radiation

SAY: I'm going to say a few words and I want you to write down the first word that comes into your head in response.

**Radiology
Radiation
Nuclear**

Analyze the associations. Do they reflect benefits or risks? Group responses accordingly.

Watch the ten-minute video, "A Look at Radiation." Instruct students to add to the lists based upon the information in the video.

SAY: Let's review two important terms in the video that will help us be able to talk about your radiation exposure and risk. The first term is the millirem. A person's exposure to radiation is measured in units called millirem. A millirem measures the effects of radiation on the human body much as degrees measure temperature. There are 1,000 millirems in one rem. There are other units used to measure radiation, but for our purposes we will use millirem.

(Display REM vs. MILLIREM overhead.)

SAY: The second term is average annual exposure. In the United States, a person's average exposure to radiation is about 360 millirem per year. Roughly 300 millirem come from natural sources of radiation, and 60 millirem come from man-made sources, primarily medical procedures. This means that every day, every minute of our lives, we are all subject to the constant bombardment of radiation produced in our natural environment,

even from radionuclides in our own bodies, and from manmade sources of radiation.

ASK: What do you predict is your largest source of exposure?

(Display SOURCES OF RADIATION EXPOSURE TO US POPULATION overhead.)

SAY: Radon is a radioactive gas that has been found in homes all over the United States. It comes from the natural breakdown of uranium in soil, rock and water, and gets into the air you breathe. Radon typically moves up through the ground to the air above and into your home through cracks and other holes in the foundation. You cannot see, smell, or taste it. When you breathe air containing radon, you increase your risk of getting lung cancer. In fact, the U.S. Surgeon General has warned that radon is the second leading cause of lung cancer in the United States today. If your house is tested and is found to have excessive levels of radon, it can be fixed. But even if your house has no radon, you are still likely to be exposed to it somewhere you go every day.

SAY: Consider the following discussion (from the PBS *Frontline* program titled "Nuclear Reaction: Why Do Americans Fear Nuclear Power?" <http://www.pbs.org/wgbh/pages/frontline/shows/reaction/interviews>)

Question: This area has a very high concentration of radon, are you concerned?

Answer: Radon has always been here. The homes have always been here. Even

**Risk
Analysis
Lesson Plan**

**C. Radiation
and Risk**

though the newer homes are being built more air-tight, radon has always been here. I really think radon is a minor problem, compared with the routine releases from a nuclear power plant. Most of the radon goes up through the dirt and out into the air. Some of it is trapped into homes. But there are methods in place now where people can alleviate all of that. But a routine operating power plant releases approximately 1,000 curies a month – that is not trivial. And you multiply that times every nuclear power plant in this country or in the world, and you get massive doses. And one of the highest things that is released on a routine basis is krypton-85. And the worldwide levels of krypton-85 are increasing horrendously and exponentially.

ASK: What psychological factors seem to shape this person's perception of risk?

(Display RADON RISK EVALUATION CHART overhead.)

Distribute the ALL ABOUT RADON handout.

SAY: Let's look at some ways to boost your average annual exposure.

A person taking a cross-country flight would receive about two to five additional millirem of radiation per roundtrip, depending on flight altitude and shielding on the airplane. Due to the thinner atmosphere at the altitudes involved in cross-country flights, a traveler is exposed to more cosmic radiation. Because of their occupations, airline pilots and flight attendants routinely are exposed to higher levels of radiation than many other workers. Airline crew members and frequent flyers receive annual doses on the order of between 500 and 600 millirem.

A person undergoing a full set of dental X-rays would receive about 10-39 additional millirem per set of X-rays.

A person working in a nuclear power plant would receive approximately 300 additional mil-

lirem per year. (The Nuclear Regulatory Commission's limit is 5,000 millirem per year for occupational exposures).

A person living within 50 miles of a nuclear power facility would receive approximately one additional millirem per year from the facility. (The Nuclear Regulatory Commission's limit is 25 millirem per year for public exposures)

2. Radiation and its effects on humans

(From Los Alamos Science, Number 23 1995, pages 91-92)

SAY: Radiation and its effects on humans, may be one of the most studied, most regulated, and most feared of the physical, chemical and biological insults to which we are exposed. Some scientists believe that, because biological organisms evolved in the presence of low levels of ionizing radiation, we and other life forms must have developed effective mechanisms to repair the damage caused by low levels of exposure. Other scientists contend that even the lowest levels of radiation have the potential to cause serious biological effects, such as cancer.

In fact, no one knows for sure if low doses of ionizing radiation can cause cancer. What we do know is that high doses of radiation can cause cancer, and the risks can be quantified. This data generally comes from four sources: Japanese atomic-bomb survivors, Chernobyl and other radiation accidents, occupational exposures, and medical exposures. The following table is a summary of the radiation risk estimates used by federal agencies following the publication of the documents shown.

(Display HISTORY OF RADIATION RISK ESTIMATE overhead.)

SAY: Note the year each report was published. Then note the increase in fatality estimates over time. What do the changes in these official risk estimates over the years indicate?

Help students see how the data reflects the delayed effects of cancer following the initial exposure of Japanese atomic bomb survivors. Premature evaluations of the delayed effects of radiation among the Japanese survivors, as well as an over reliance on animal data to predict radiation effects in humans, lead to early risk estimates. Risk estimates had to be revised as the appearance of long delayed excess cancer cases among the Japanese survivor population arose.

SAY: Because the rate at which radiation causes cancer is quite low, it is very difficult to detect statistically significant increases in cancer mortality caused by radiation unless the population is very large. Consequently, risk based estimates for radiation induced cancer are primarily based on data from the Japanese atomic bomb survivors.

SAY: The real question is how much radiation exposure will increase your chances of cancer death over your lifetime. We are going to do an exercise where we calculate the risks of cancer from increased radiation exposure.

3. The risk of cancer from increased radiation exposure

Pass around a hat with a (for example) poker chip for each student. Twenty percent of the poker chips should be a different color (red, for example) than the other chips. One or two chips should be another color (purple, for example). Have each student randomly pick a chip out of the hat. Explain that the red chips represent the rate of cancer mortality in the United States. On average, one in five people, 20%, die of cancer. The purple chips represent excess cancer deaths above the normal rate.

ASK: How do we know if these excess cancer deaths among you are caused by radiation exposure and if so are they statistically significant?

ASSIGNMENT: Distribute copies of INTERPRETING THE BEIR-V handout. When most of the students have had time to complete the problem set, have them share their answers with a neighbor. Then ask some students to share their answers with the class.

(end day three)

4. The linear no-threshold model

SAY: Because exposure to high levels of ionizing radiation is known to cause cancer and other health problems, public

Publication	Excess cancer fatalities among 100,000 people receiving instantaneous external radiation doses of 10 rem
1972 BEIR-I report (Biological Effects of Radiation)	100
1977 ICRP Publication 26 (International Commission on Radiological Protection)	200
1980 BEIR-III report	200
1990 RERF publication (Radiation Effects Research Foundation)	400-500
1990 BEIR-V report	800

health regulators extrapolate from these known risks at high doses to estimate risks for low doses. These extrapolations from high doses to low doses are based on theory rather than hard human data. What is thought to be a more cautious, conservative approach assumes that any exposure could cause similar effects. Here is how it looks on paper.

(Display LINEAR NO-THRESHOLD RISK MODEL overhead.)

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SAY: Let's start at the high-dose/high-risk end of the graph, since this is where we have hard human data.

ASK: How would you describe this line (It's straight) What does a straight line mean?

Guide students to look at how the line was created with the data. For each dose there is a risk. Help students see that each decrease in dose has an exactly proportional decrease in risk.

SAY: That type of relationship between dose and risk creates a line and we call this graph "Linear." Notice that the risk does not start at 0 because there is some risk of cancer, even with no additional exposure. The slope of the line just means that a person that receives 5 rems in a year incurs 10 times as much risk as a person that receives 0.5 rems in a year.

ASK: According to this graph, is there a dose after which there is no risk?

(Any dose, no matter how small, produces some risk.)

SAY: We say there is "no-threshold" below which there is no risk. This model is, therefore, called the "Linear No-Threshold Model." Exposure to radiation is not a guarantee of harm. However, because of the linear, no-threshold model, more exposure means more risk, and there is no dose of radiation so small that it will not have some effect. Much of the current controversy surrounding radiation is based on whether we should assume low doses also cause harmful health affects.

Making Decisions Based Upon Calculation Of Risk

Risk Analysis Lesson Plan

D. Making Decisions Based Upon Calculation of Risk

1. Background

Many people worry about the risks of radiation not so much because of routine, low-level exposures, but because of the possibility of an accident. For many people, nuclear power plants have this stigma attached to them.

In September 1994, *The Los Angeles Times* conveyed the findings of a University of Oregon study in which members of various American populations had been asked to rank various technologies, pursuits, and habits according to how risky they thought they were. Respondents among college students and respondents among members of the League of Women Voters had ranked nuclear energy production as the top hazard – riskier, for example, than habitual cigarette smoking or working as a police officer. In contrast, respondents who were scientists had given nuclear energy production the 20th rank and had ranked bicycling, swimming, and undergoing an X-ray exam as more hazardous.

The public perception of nuclear power has changed over time. *The Los Angeles Times* article reported that, in 1971, 58 percent of Americans polled in a survey had said they would be agreeable to having a nuclear power plant in their respective communities. According to a later survey, however, only 28 percent said they would be agreeable to such, and 63 percent said they'd be averse to having a nuclear power plant around.

People living near nuclear power plants are exposed to very small amounts of radiation from the plants, generally less than one millirem per year. In the United States, EPA sets strict standards governing radiation emissions, enforced by the Nuclear Regulatory Commission. Radiation levels at every plant are monitored

24-hours-a-day. The following are some data on the radiation health effects of people living near Nuclear Power Plants.

(Display RADIATION-RELATED HEALTH EFFECTS FROM LIVING NEAR NUCLEAR POWER PLANTS overhead.)

The NRC: "...the risk of early and latent fatalities from individual nuclear power plants is small. It represents only a small fraction of the risk to which the public is exposed from other sources. Even if the predicted early and latent fatalities from all 118 plants were considered (that is, the risk to the population of the United States from all 118 nuclear power plants), this would only result in a predicted risk of approximately one additional early fatality per year and approximately 30 additional latent fatalities per year, which is still a small fraction of the approximately 100,000 early and 500,000 latent cancer fatalities per year from other sources."

In 1990, the National Cancer Institute (NCI) of the National Institutes of Health released the results of a two-year study of cancer data in 107 U.S. counties that contained, or were adjacent to, major nuclear facilities that had started up before 1982. The study, which compared cancer mortality rates in the 107 counties with rates in counties with no nuclear facilities, found no increased cancer mortality for people living near the nuclear installations.

[Note: As of early 2001, 104 nuclear power plants were operating in the United States.]

SAY: But what if an explosion or meltdown at a nuclear power plant suddenly released deadly amounts of radiation or radioactive materials into the environment. Even the most adamant nuclear proponent must admit that a major reactor accident cannot be ruled out for the nuclear plants operating today. The key questions are when will the next reactor accident occur and where will it occur?

(Display NUCLEAR POWER PLANT ACCIDENT PROBABILITIES AND CONSEQUENCES overhead.)

The NRC told the U.S. Congress in April 1985 that: "The most complete and recent probabilistic risk assessments suggest core melt frequencies in the range of [one in one thousand] per reactor year to [one in ten thousand] per reactor year. A typical value is [three in ten thousand]. Were this the industry average, then in a population of 100 reactors operating over a period of 20 years, the crude cumulative probability of [a severe reactor] accident would be 45%."

A 1982 Congressional study estimated the potential consequences from reactor accidents that release large amounts of radiation in the atmosphere. They assumed that the reactor core damage occurred (i.e. meltdown) and that the containment buildings failed to prevent the release of radiation. The study estimated how many Americans would die and be injured within the first year due to their radiation exposure following a major accident. For example, the study concluded that an accident at the Limerick nuclear plant outside Philadelphia could kill 74,000 people within the first year and cause 34,000 subsequent cancer deaths. Another 610,000 people could experience radiation-related injuries such as cataracts, temporary sterility, and thyroid nodules. The study estimated that an accident at Limerick could cost \$200 billion for lost wages, relocation expenses, and decontamination efforts.

SAY: The following table provides a summary of the results.

(Display POTENTIAL CONSEQUENCES OF NUCLEAR POWER PLANT ACCIDENTS overhead.)

SAY: The consequences vary because larger plants can release more radiation than smaller plants, because some plants are located near large population centers, and because different engineered safety systems may perform differently.

2. Nuclear Accident Scenario

SAY: We are going to do a decision-making exercise based on a nuclear power plant accident scenario. I want you to make your decisions and justify them solely upon the information provided to you in the handout.

ASK: What are the factors we must take into account when calculating risk quantitatively?

Answer: Probability that an event will occur and the consequence if the event were to occur.
Risk = Probability X Consequence.

ASSIGNMENT: Distribute copies of NUCLEAR ACCIDENT SCENARIO handout. When students have had time to complete the scenario, have them share their answers with a neighbor. Then ask some students to share their answers with the class.

ASK: In the event of an accident that could potentially pose a threat to you, what other factors would you take into account when determining our risk? Recall the quote by Supreme Court justice Oliver Wendell Holmes: "Most people think dramatically, not quantitatively."

Answer: Information from media sources, experts, etc; our gut instincts.

(end day four)

3. Three-Mile Island

SAY: This scenario is based upon an actual event that occurred at the Three-Mile Island Nuclear Power Plant near Harrisburg, Pennsylvania on March 28, 1979. Other than the quantitative risk data, the information, while not directly

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D. Making Decisions Based Upon Calculation of Risk

quoted, reflects what the public was exposed to during the Three-Mile Island accident. Of the approximately 300,000 people impacted, half evacuated, half stayed. As a result, public anxiety about nuclear power was heightened. In the next activity, we are going to examine the aftermath of TMI.

ASSIGNMENT: Distribute copies of THREE-MILE ISLAND CONSEQUENCES handout. When students have had time to complete the assignment, have them share their answers with a neighbor. Then ask some students to share their answers with the class.

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Risk Analysis Culminating Activity

(Display the MEETING NOTICE overhead at the beginning of class.)

MEETING NOTICE

There will be a meeting of government regulators next Monday. The purpose of this meeting is to gather information for or against the application to build nuclear power plants in our town. The application has been made by the Yourtown Power Company. All interested parties are invited.

SAY: The local power company has filed an application with the federal government to build a nuclear power plant in your town. Federal regulators have called a hearing to gather information on the application. You represent an independent, nongovernmental agency called the Risk Analysis Institute. You have been hired by the city to provide the residents with credible, trustworthy guidance on the risks associated with operating a nuclear power plant. Your goal is not to recommend a position for or against the nuclear power plant, but to guide citizens to make that decision based upon fact rather than based upon fear. To fulfill your contract, you must complete the following two tasks:

1. Design a pamphlet that can be distributed to every resident. You must be able to communicate quantitative risk information, as well as address psychological factors that shape people's perceptions of the risk.
2. Prepare an opening presentation for the public meeting. Merely disseminating information without regard for communicating the complexities and uncertainties of risk does not necessarily ensure effective risk communication. Well-managed efforts

will help ensure that your messages are constructively formulated, transmitted, and received and that they result in meaningful actions.

SAY: Although your work at the Risk Analysis Institute is to provide credible, trustworthy guidance on the risks associated with operating a nuclear power plant, you are not sheltered from the influence of public opinion. You will receive letters, press releases, and reports from organizations advocating positions for and against nuclear power. Your job is to separate facts from fears and present the information provided in a rational manner.

(Distribute the PRO AND CON STATEMENTS ON NUCLEAR POWER handouts.)

NOTE TO TEACHER: You may choose to use all these documents or to only select a few of these documents for students to consider. Perhaps you may choose to distribute the documents gradually as daily news releases, rather than all at once. Use your discretion here. In addition to the information provided, please do not hesitate to supplement or substitute the documents provided with other sources and other media to clarify positions for and against nuclear power.

NOTE TO TEACHER: This project is designed as a collaborative effort for up to four students per group. The following rubric suggests how you might evaluate students on their collaborative effort:

1. Student willingly participates in group activity, volunteers for active roles, encourages sharing of ideas and opinions.

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2. Student needs encouragement to participate, stays on task, accepts role within group, shares ideas with others.
3. Student requires prompting to work with the group, must be reminded to stay on task, accepts team role, grudgingly shares ideas.
4. Student is uninvolved with the efforts of the group, does not focus on the task, refuses to accept role within the group, does not share ideas.

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The content of the students' work should be evaluated based upon the guidelines set forth in the assignment handout.

ASSIGNMENT: Distribute copies of RISK ANALYSIS INSTITUTE handout.

NOTE TO TEACHER: The handout A PRESENTATION PRIMER serves as a useful tool for evaluating the group presentations. If you choose to use it, distribute it to students ahead of time so that they are clear about how they will be evaluated.

NOTE TO TEACHER: After groups have given their presentations, compare and contrast approaches used by the groups. Determine if some approaches were more successful than others. Ask the students to generate a "do" and "don't" list when communicating risk to the public. Compare students' responses to those addressed in the handout AVOIDING PRESENTATION PITFALLS. Of the many "pitfalls" mentioned, address those most relevant to the students' work.

(end day five)

Assessment

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F. Assessment

ASSIGNMENT: Distribute copies of the RISK ANALYSIS ASSESSMENT handout. Relate the following statements to what you have learned about assessing risks associated with nuclear power and radiation. For each statement, write a short essay. Use specific examples from activities that we did in class and from your own research outside of class.

1. Risk analysis is used to minimize the likelihood of unwanted side effects of a new technology. The public perception of risk may depend, however, on psychological as well as scientific factors. (Benchmarks for Science Literacy, page 52)
2. Natural and human induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and tradeoffs of various hazards – ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and accuracy with which scientists and engineers can and cannot predict events are important considerations. (National Science Education Standards, page 199)
3. Individuals and society must decide upon proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits, and consideration of who benefits and who suffers, who pays and who gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions – “What can happen” –

“What are the odds” – and “How do scientists and engineers know what will happen?” (National Science Education Standards, page 199)

4. View science and technology thoughtfully, being neither categorically antagonistic nor uncritically positive. (Benchmarks for Science Literacy, page 287)

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Appendices

Appendix A: Additional Suggestions for Classroom Activities

- **Introduce radiation and discuss students' perceptions.** Write "Radiation" on the blackboard and ask the students to say or write down (anonymously) on an index card what they think of when they think of radiation, what they think it means. Write down some of the answers or collect the cards and read some out loud and discuss the students' perceptions.
- **Discuss health effects of radiation.** Discuss some of the health effects from radiation including effects from acute high-dose exposure and low-dose exposure. Examine some of the results of long-term studies of victims of the Hiroshima and Nagasaki bombings or of workers in nuclear weapons facilities in the United States. Invite a health physicist or doctor to speak.
- **Discuss professions that involve the use of radiation.** Briefly discuss (or review) some of the uses of radiation (power generation, medicine, industry, national security) and then introduce a more specific discussion of professions involving the use of radiation. (See Appendix B.) Ask the students to research careers through some of the professional associations. Invite professionals working in these areas to come to class to discuss their jobs and their careers.
- **Discuss some of the uses of radiation in industry and consumer products.** Begin with a discussion of some of the uses of radiation that students may be more familiar with such as medical and dental X-rays. Also discuss some of the uses that may be less familiar such as in exit signs and smoke detectors or in industry to identify defects in airplane equipment, to manufacture Teflon coated pans, and to ensure consistent size of sheets of various materials and consistent amount of contents of beverage cans.
- **Locate nuclear power plants near you.** Identify nuclear power plants in your region and discuss issues such as: How much of the area's energy do they provide? What type of reactors are used? How long has it been operating? How long is it expected to continue operating? If possible, visit the facility or invite a representative to speak to the class. A listing of plants is available from the Department of Energy's Energy Information Administration at <http://www.eia.doe.gov/fuelnuclear.html>. Maps and detailed information are available through the Nuclear Energy Institute at <http://www.nei.org/doc.asp?catnum=2&catid=93>.
- **Have a debate on the pros and cons of nuclear power.** Have the students research and analyze various aspects of nuclear power versus other sources of energy including such things as cost (including decommissioning and decontamination of nuclear plants and nuclear waste disposal), potential risk, environmental impact, public acceptability, and sustainability.
- **Conduct research on incidents of accidental releases.** Assign the students a research activity to study incidents of accidental release of radiation. Have them prepare a report on the history, immediate effects, repairs, long-term consequences (for individuals and for society), etc. of the incident(s). Invite a local firefighter or emergency response professional to discuss how the local community prepares to respond to potential radiological emergencies.

Appendix A: Additional Suggestions for Classroom Activities

Appendix B: Examples of Careers that Involve the Use of Radiation

Health Physicist: This term originated during the Manhattan Project—the United States’ effort to develop the atomic bomb during World War II. Most of the scientists involved in that project were physicists. Those physicists responsible for health and safety concerns were called health physicists. Today health physicists can be found at work at nuclear power plants, on military submarines, in hospitals (where they are called medical physicists), and at research universities, to name just a few. Health physics provides the practical means for protecting workers, the general public, and the environment from harmful radiation exposures.

Health physicists work in a variety of disciplines, including research, industry, education, environmental protection, and enforcement of government regulations. Some examples follow.

- In research, health physicists investigate principles by which radiation interacts with matter and living systems. Health physicists also study environmental levels of radioactivity and the effects of radiation on biological systems on earth and in space.
- Industrial or applied health physicists make recommendations to management regarding methods and equipment for use in radiation work.
- Health physicists working in education develop training programs for and instruct future health physicists. They also provide training for radiation workers and the general public.
- Health physicists also help develop and enforce government regulations.
- Medical health physicists work wherever radiation sources are used such as hospitals, clinics, and laboratories. They help ensure proper and safe working conditions for both patients and medical staff.
- Nuclear weapons health physicists are responsible for radiation safety at defense sites that store and assemble nuclear weapons. Their responsibilities include measuring and calculating radiation dose

rates from nuclear weapons, identifying appropriate personal protective equipment (e.g., lead aprons, lead-lined gloves) for weapons technicians and ensuring that sufficient shielding is provided in the workplace for technicians.

- Environmental health physicists work to protect the public and environment from unnecessary exposure to manmade and technologically enhanced naturally occurring radioactivity. Activities include environmental monitoring for radioactivity.

Radiobiologist: Radiobiologists work in a specialized branch of biology that studies the effects of ionizing radiation on cells and organisms. The work of radiobiologists contributes significantly to our understanding of how radiation can cause cancer, genetic effects, and damage to fetuses.

Radiochemist: Radiochemists practice a branch of chemistry that uses a combination of standard analytical techniques ("wet chemistry") along with sophisticated radiation measurement techniques to understand chemical reactions and the structure of chemical compounds.

Radioecologist: Radioecologists and other environmental scientists help determine how radioactive material is transported through the physical environment (i.e., ground, water, and air) and through ecosystems (e.g., through bioaccumulation). The information they provide can be critical in setting safe clean-up levels at contaminated sites and protective public health standards.

Nuclear Physician: Nuclear physicians usually work in universities or hospitals, or both, and have limited involvement in direct patient care. Nuclear medicine physicians assist with patient diagnoses and treatment, when the use of radiological examination and treatments are appropriate.

Nuclear Medicine Technologist: The nuclear medicine technologist is a specialized healthcare professional who works directly with patients during an imaging procedure and works closely with the nuclear medicine physician.

Nuclear Pharmacist: A nuclear pharmacist specializes in the procurement, compounding, quality control testing, dispensing, distribution, and monitoring of radiopharmaceuticals. They also provide consultation regarding health and safety issues as well as the use of non-radioactive drugs and patient care.

Appendix B:

Examples of Careers that Involve the Use of Radiation

Radiation Protection Technologist: A radiation protection technologist engages in the operational aspects of providing radiation protection. This individual is concerned with the basic understanding of the mechanisms of radiation damage, with the methods and procedures necessary to evaluate hazards and with providing protection to man and his environment from unwarranted radiation exposure.

Emergency Response Professional: Many emergency response professionals (including fire fighters and hazmat responders) are specifically trained and prepared to respond to radiological emergencies.

Nuclear Power Plant Professional: There are numerous careers involved with the operation and management of nuclear power facilities:

- *Nuclear Engineers* work to ensure that the reactor core is configured and assembled correctly—according to the laws of reactor physics and heat transfer fluid dynamics—to use the nuclear fuel most efficiently and safely while producing energy.
- *Mechanical Engineers* monitor and supervise systems areas involving heat transfer and fluid flow including supervising the design of machinery.
- *Electrical Engineers* oversee the electrical systems in the plant and the operation of the turbine generators which convert energy to electric power that will be transmitted to customers.
- *Chemical Engineers/Chemists* are responsible for maintaining the proper chemistry of the primary system—water flowing through the reactor—and other cooling and heat removal systems so that corrosion is kept to a minimum.
- *Civil/Structural Engineers* ensure the physical integrity of the plant structures, including the containment building and radiation shielding for the nuclear reactor.
- *Power Reactor Health Physicists* are responsible for all phases of radiation protection at a reactor site. Selecting, purchasing, and maintaining radiation protection, laboratory, and detection equipment are some of their responsibilities.
- *Reactor Operators* are licensed operators who are responsible for operating a reactor's

controls. Qualifying as a reactor operator usually requires five years experience as a non-licensed operator, one year of training, and successful completion of a NRC exam.

- *Operations Engineers* analyze plant performance and prepare operating procedures for the plant's components, systems and reactor.
- *Maintenance Engineers* keep plant machinery in optimal condition to ensure reliable plant operation. They also conduct equipment failure analysis and recommend corrective actions to improve reliability.
- *Information Systems Professionals* oversee the computer operations support for a nuclear power plant. The computer operations at a nuclear plant are the most complicated of any electricity generating facility.

Sources:

Health Physics Society – <http://www.hps.org/publicinformation/hpcareers.html>
Nuclear Energy Institute – www.nei.org
Society of Nuclear Medicine's – <http://www.snm.org/education/index.html>
U.S. Environmental Protection Agency – <http://www.epa.gov/radiation/students/index.html>

Appendix B:

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Examples of
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Involve the Use
of Radiation

National Safety Council's Environmental Health Center

1025 Connecticut Ave., NW Suite 1200

Washington, DC 20036

202/293-2270

<http://www.nsc.org/ehc.htm>