Debatable Issues: A STUDENT'S GUIDE TO EARTH SCIENCE, Volume 4

Creative Media Applications

GREENWOOD PRESS

Debatable Issues

Titles in the series

Words *and* Terms

Important People

Developments *and* Discoveries

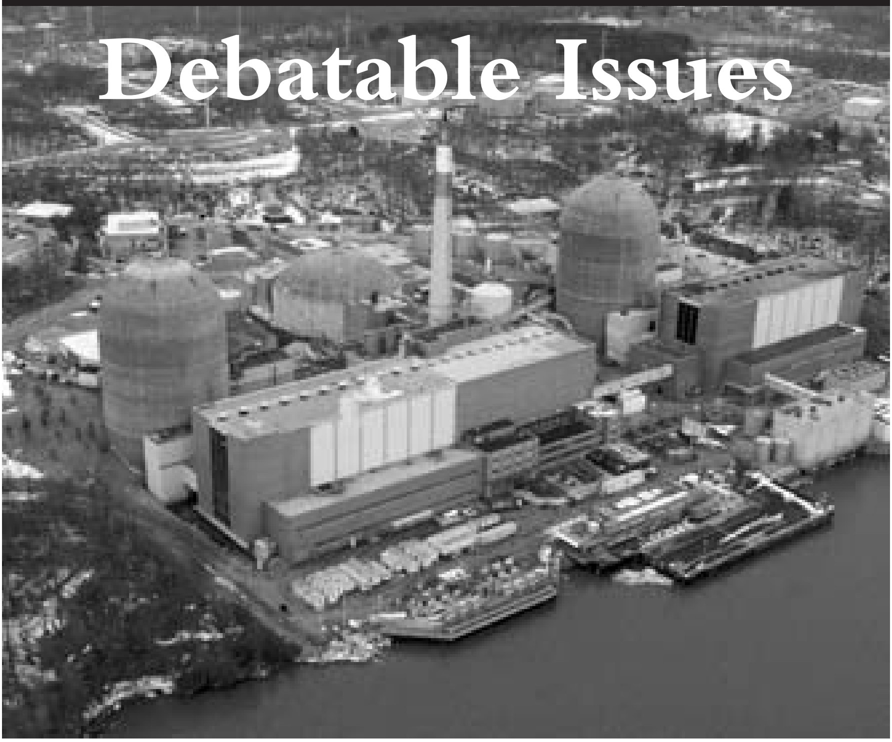
Debatable Issues

A STUDENT'S GUIDE TO

earth science

VOLUME 4

Debatable Issues



GREENWOOD PRESS
Westport, Connecticut · London

Library of Congress Cataloging-in-Publication Data

A student's guide to earth science / by Creative Media Applications.
p. cm.
Includes bibliographical references and index.
Contents: v. 1. Words and terms — v. 2. Important people — v. 3. Developments and discoveries — v. 4. Debatable issues.
ISBN 0–313–32901–X (set: alk. paper) — ISBN 0–313–32902–8 (v. 1: alk. paper) — ISBN 0–313–32903–6 (v. 2: alk. paper) — ISBN 0–313–32904–4 (v. 3: alk. paper) — ISBN 0–313–32905–2 (v. 4: alk. paper)
1. Earth sciences. I. Creative Media Applications.
QE26.3.S78 2004
550 — dc22 2003068634

British Library Cataloguing in Publication Data is available.

Library of Congress Catalog Card Number: 2003068634
ISBN: 0–313–32901–X (set)
0–313–32902–8 (Vol. 1)
0–313–32903–6 (Vol. 2)
0–313–32904–4 (Vol. 3)
0–313–32905–2 (Vol. 4)

First published in 2004

Greenwood Press, 88 Post Road West, Westport, CT 06881
An imprint of Greenwood Publishing Group, Inc.
www.greenwood.com

Printed in the United States of America

The paper used in this book complies with the Permanent Paper Standard issued by the National Information Standards Organization (Z39.48–1984).

10 9 8 7 6 5 4 3 2 1

A Creative Media Applications, Inc. Production
WRITER: Kris Harper
DESIGN AND PRODUCTION: Alan Barnett, Inc.
EDITOR: Matt Levine
COPYEDITOR: Laurie Lieb
PROOFREADER: Jennifer Rose
INDEXER: Nara Wood
ASSOCIATED PRESS PHOTO RESEARCHER: Yvette Reyes

PHOTO CREDITS:
AP/Wide World Photographs pages: iii, 4, 7, 8, 11, 12, 21, 22, 25, 27, 32, 35, 37, 38, 40, 47, 48, 55, 57, 58, 61, 67, 68, 71, 73, 74, 77, 85, 89, 95, 96, 99, 100, 106, 114, 118
© James A. Sugar/CORBIS page: 18
© Schenectady Museum; Hall of Electrical History Foundation/CORBIS page: 82
© National Center for Atmospheric Research page: 86
© Roger Ressmeyer/CORBIS pages: 109, 110
© CORBIS page: 113
© Bettmann/CORBIS pages: 121, 122, 123, 124

Table of Contents

Introduction

Research and discoveries by earth scientists give information about many different issues of interest to scientists in other fields, to governmental leaders, and to the general public. Although most new scientific discoveries or ideas do not inspire much discussion, some of them lead to intense controversy. When this happens, scientists on each side of the debate continue along different research paths, publishing their results and engaging their colleagues in conversation about their ideas. Some of these debates can go on for years—others are settled in a few months. These scientific debates, which take place in universities and in laboratories, are usually not known to the general public.

Other debates that involve earth scientists and their work are carried out among policy makers. Policy makers are generally governmental or industry leaders who support their position on a particular policy—for example, how to deal with global warming—by gathering around them scientific experts who agree with them. In this case, there may be very little debate going on among most scientists—who might already agree on the scientific findings—but a huge debate going on between politicians looking for public support. When very large sums of money are involved, the debate tends to be political, not scientific.

A third kind of debate related to earth science involves the general population. This often happens when a policy decision might affect the lives of average citizens or some ideal about which they have strong feelings. For example, although very few people in the United States live near the Arctic National Wildlife Refuge in Alaska, many citizens across the country feel very strongly that there should be no oil drilling in the refuge so that the natural beauty and wilderness quality of the area might be protected. Politicians are also involved in this debate. However, as with global warming, most scientists agree that drilling would cause substantial risk to the environment. Therefore, earth scientists are no longer debating this issue, although some are still debating how much oil is actually under the refuge waiting to be pumped out.

A number of important issues currently being debated either by scientists, politicians, or the general public are related to the earth science fields of geology (jee-AHL-uh-jee), meteorology (meet-ee-uh-RAHL-uh-jee), oceanography (oh-shuh-NAHG-ruh-fee), or planetary astronomy (uh-STRAH-nuh-mee). This volume presents some of those issues in a debate style. Each chapter covers a key issue in one or more of the earth sciences. For each controversial issue, you will find a brief introduction. This will be followed by arguments presented by fictitious scientists, political leaders, or average citizens who are actively concerned with the issue presented. One argument will support the issue and one will oppose it. An in-depth discussion of the science and related considerations behind the issue follows the two arguments. At the end of each chapter are questions to consider. They will help you to form your own ideas about the issue.

Pronunciation

You will notice that in the pronunciation guides, the words are not broken into syllables. Rather, they are sectioned off by the way that they sound so you can figure out how to say them. The piece of each word in CAPITAL LETTERS is where you put the emphasis. That means it is the part you pronounce slightly louder.

Note: All metric conversions in this book are approximate.

CHAPTER 1

Should Radioactive Waste Be Buried for Safekeeping?

Radioactive elements, like uranium (yuh-RAY-nee-um), emit a tremendous amount of energy. Power companies use uranium in nuclear fission reactions to produce energy that creates electricity for millions of customers in the United States.

Spent uranium fuel—called *radioactive waste*—remains dangerous to living things for 10,000 years. If radioactive waste comes in contact with living things, it causes damage to cells. Cells are the smallest living parts of all plants and animals. If cells are badly damaged, the plant or animal may die. In animals, including humans, the result may be cancers. For that reason, radioactive waste must be handled very carefully. If it is not, many people could become extremely sick and die.

Nuclear power plants store radioactive waste in special pools of water built near the plants. In the 1980s, nuclear power plants started to run out of space in the pools, which are expensive to build and maintain. Since the waste must be safely stored for about 10,000 years, building more pools—at best a temporary solution—does not solve the waste disposal problem. Therefore, in 1983, the U.S. government decided that the best option for the safe disposal of radioactive waste would be to bury it. The debate's intensity increased when the government decided to bury all of the country's radioactive waste at one location: Yucca Mountain, a rocky ridge about 100 miles (160 kilometers) northwest of Las Vegas, Nevada. Some geologists (jee-AHL-uh-justs) argue that the site isn't geologically (jee-uh-LAHJ-ih-kul-ee) stable enough to prevent radioactive waste from leaking into the environment over the next 10,000 years. The people and government of Nevada argue that radioactive waste doesn't belong in their state. In the meantime, the radioactive waste keeps piling up, and the U.S. government wants it safely buried.

Yes

I am a geologist working for the U.S. Department of Energy. I have been working on the radioactive waste disposal problem for the government for over twenty years. It is not a good idea to have nuclear waste scattered all over the country. All those sites would need a lot of security to make sure that no one who wishes to harm our country had the opportunity to get the spent uranium fuel. The way to handle the problem is to bury all the radioactive waste in one secure place.

My colleagues and I agree that the safest place to store the radioactive waste is under Yucca Mountain in southern Nevada. Yucca Mountain is close to the U.S. Nuclear Weapons Testing Site, so it is already an area that has been sealed off and secured by the military services. Furthermore, although Yucca Mountain itself is just a ridge 6 miles (9.6 kilometers) long that stands only 1,000 to 1,500 feet (300 to 450 meters) high, the volcanic rock within it extends down 6,500 feet (1,950 meters) into the ground. We plan to dig out a hole under the mountain that will be able to hold 70,000 tons (63,000 metric tons) of waste. It will be 1,000 feet (300 meters) under the ground. Because the water level is 700 to 1,400 feet (210 to 420 meters) below where the waste will be, we don't have to worry about the waste being dissolved in water and then leaking away.

Although the containers that hold the waste will eventually rust and let the waste out, not enough of the radioactive atoms will reach the environment outside the mountain to be dangerous. I am convinced that Yucca Mountain can keep this radioactive waste from harming living things for the next 10,000 years. Putting the nation's radioactive waste under Yucca Mountain is a wise decision.

No

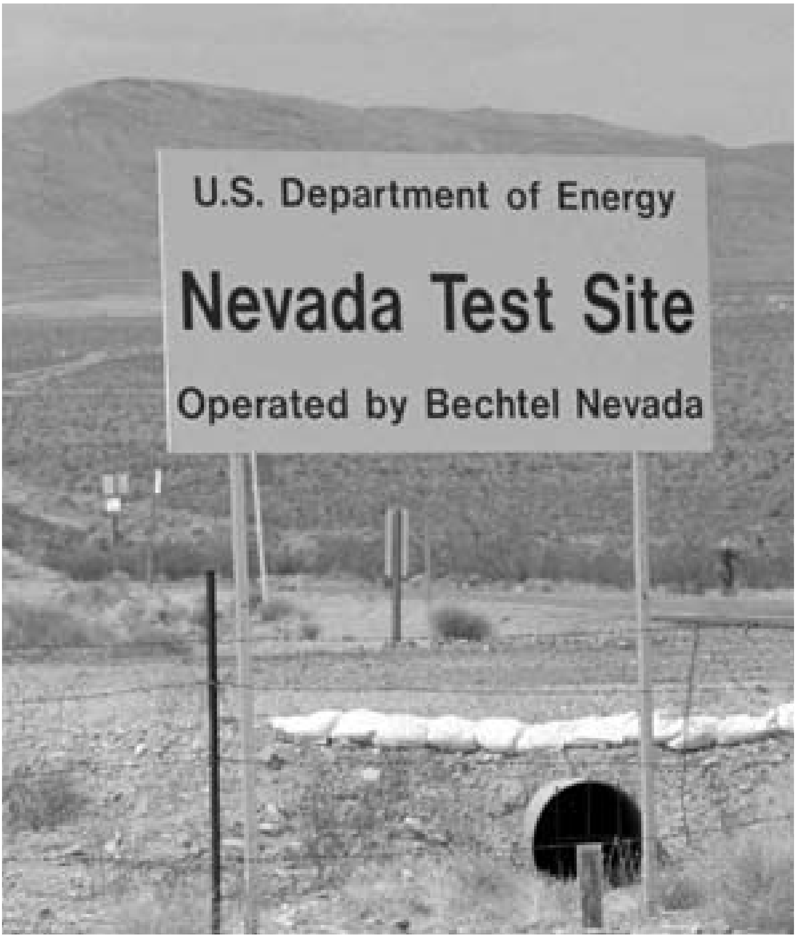
I have lived in Nevada my whole life. It is bad enough that we have the U.S. Nuclear Weapons Testing Site here. Now the U.S. government wants to store radioactive waste from all over the nation in my state. I think that's wrong. If energy companies want to produce electricity from nuclear power, that's fine. Let them figure out a way to store the resulting radioactive waste in their states, not mine.

The scientists working for the government maintain that Yucca Mountain is a safe place for the radioactive waste. Nevada is a dry place with not much rain, so the scientists say there is no worry that the waste will be dissolved by rain that moves down through the rock. Well, it may be dry now, but will it be dry in 10,000 years? I won't be here, but someone else probably will. Meteorologists (meet-ee-uh-RAHL-uh-justs) can't predict the weather a week from now, so how can they predict what the climate will be in 10,000 years? Furthermore, even though this isn't an area that is usually affected by earthquakes, what happens if a major earthquake is centered near Yucca Mountain and the rocks move? What happens to the waste then?

Even if Yucca Mountain is safe, the radioactive waste must be moved here by trucks or on trains from all over the United States. If there is an accident while the waste is being unloaded and moved into the storage facility, harmful radiation could be released. I think that the government picked Yucca Mountain because Nevada has relatively few people and not much political power. My state is being used as a large dump for the rest of the country, and I'm very angry.

Discussion

Radioactive waste disposal is a topic that concerns all countries that use nuclear power or have nuclear weapons. However, in the United States, the people most concerned with the reality of radioactive waste storage are the citizens of Nevada. Yucca Mountain—located in the southern tip of Nevada, near the U.S. Nuclear Weapons Test Site—has been chosen as the storage facility for all the waste created by civilian nuclear power plants and nuclear research activities.



This road, 100 miles (160 kilometers) northwest of Las Vegas, Nevada, leads to Yucca Mountain. The proposed nuclear waste repository could begin accepting waste by 2010, if it can meet Environmental Protection Agency standards. The site sits above an aquifer that provides drinking water and irrigation to the people of Nye County.

While government scientists maintain that the site is perfectly safe and that there will be no adverse effects on Nevada's citizens, others are not so sure. While the site might be safe now, it needs to remain safe for at least 10,000 years. Changes in climate or geological (jee-uh-LAHJ-ih-kul) stability of the region could make it less safe in the future. Consequently, the future of the Yucca Mountain site—and of the burial of radioactive waste—remains an emotionally charged issue.

A Long-Term Question

The debate over the appropriate disposal of radioactive waste from nuclear power plants is not new. It has been going on since the 1950s, when the first nuclear power plants were built in the United States. At that time, engineers recommended that the spent fuel be burned in other reactors. This technique, known as reprocessing, was adopted by nuclear power plant operators in other countries, including France and Japan. However, the U.S. government refused to allow this option for nuclear waste disposal because reprocessing of spent uranium fuel rods leads to the production of plutonium—an element that is usable in dangerous weapons. The government feared that enemies of the United States could steal the plutonium and use it to attack the country.

Therefore, the United States decided that the only safe way to dispose of spent fuel rods was to bury them and leave them buried forever. In 1982, electric power industry executives signed agreements with the U.S. government that obligated the government to receive shipments of nuclear waste from the power plants, starting in January 1998. The cost of the new storage facility would be funded by a surcharge placed on electricity customers. In the meantime, power plants would store the spent fuel rods themselves in specially constructed pools of water where they would be safe.

Although the decision to bury the waste was made in 1982, it took five years of congressional investigations and debates before a decision was reached on where the burial site would be located. In 1987, Congress selected Yucca Mountain. (Two other sites—one in Texas and one in the state of Washington—had been considered.) The controversy surrounding this decision was immediate and intense. The federal government pointed to the dry climate, the stable geological formations, the remoteness of the site, and the fact that it was right next to a large desert already contaminated from years of nuclear weapons testing. Nevadans pointed out that they didn't even have any nuclear power plants in their state. Placing the spent fuel at the Yucca Mountain site essentially meant that Nevada was becoming a dumping ground for the nuclear waste produced by the rest of the country.

Since the answer to the nuclear waste disposal problem is largely dependent upon a scientific and technological solution, it might seem as if earth science research could solve it. However, there are earth scientists on both sides of this debatable issue. Each side claims that science supports its view.

Science for Yucca Mountain

Government scientists have been examining conditions at the Yucca Mountain site in detail since the 1987 congressional decision to make it the country's only nuclear waste repository. The government has spent over $3 billion studying the acceptability of the site.

Yucca Mountain stands in an arid wasteland where there are almost no living things. Workers at the site claim that they have never seen a lizard, a bird, or another animal since their arrival. Department of Energy (DOE) scientists, in cooperation with other federal agencies, have removed 18,000 geological and water samples for analysis. They have also taken 75,000 feet (22,500 meters) of core samples

Construction is under way on Yucca Mountain. The Department of Energy estimates that the overall cost of the program will be $34.7 billion. Proponents of the project insist that generators of the waste will pay the costs, but skeptics argue that American taxpayers will get hit with a large part of the bill.

(obtained when hollow tubes are drilled into the ground, filled with rock, and then removed for examination). Geologists conducted studies to determine the relative risk of earthquakes and volcanic eruptions in the area. *Hydrologists* (hye-DRAHL-uh-justs)—who study the availability and transportation of fresh water—observed the movement of water through and below Yucca Mountain. Geochemists (jee-oh-KEM-usts) studied how the radioactive material would react with the Yucca Mountain rock known as tuff—a type of volcanic rock made of compacted ash between 8 million and 16 million years ago.

Since no one has actually observed what happens after radioactive waste sits in a repository like Yucca Mountain for 10,000 years, scientists have relied on computer-generated

An aboveground picture of the Yucca Mountain Nuclear Waste Dump at Mercury, Nevada. For now, spent fuel rods, which emit dangerous levels of radiation, are kept at 131 power plants around the country. Although President George W. Bush approved the plan for Yucca Mountain in 2002, there are many appeals to go through before it is put into effect.

predictions of how the radioactive waste will behave. In January 2002, convinced that the threats from earthquakes, volcanoes, rising groundwater, and breaches of the mountain itself by radioactive waste would be remote, the DOE recommended to the administration of President George W. Bush that the development of the Yucca Mountain site move forward.

Science against Yucca Mountain

There are a number of scientific arguments against the development of the Yucca Mountain site as a burial ground for over 70,000 tons (63,000 metric tons) of radioactive waste. Geologist Eugene Smith of the University of Nevada, Las Vegas, has pointed out that the site lies between two volcanic fields. DOE researchers maintain that the chances of an eruption are slim, but Smith argues that only the volcanoes within 6.2 miles (10 kilometers) of Yucca Mountain were examined. Although those volcanoes only erupt four to twelve times every million years, another group of volcanoes about 62.5 miles (100 kilometers) to the north tends to erupt between eleven and fifteen times per million years. Smith notes that there are periods of time when both fields might be likely to erupt. Unfortunately, it is impossible to know if one of those periods is coming soon. Since the site needs to stay sealed for 10,000 years, it is important to find out if the volcanoes are likely to erupt during that time. Smith suggests that research should be done to explore how the volcanic fields are connected and what might trigger their eruption.

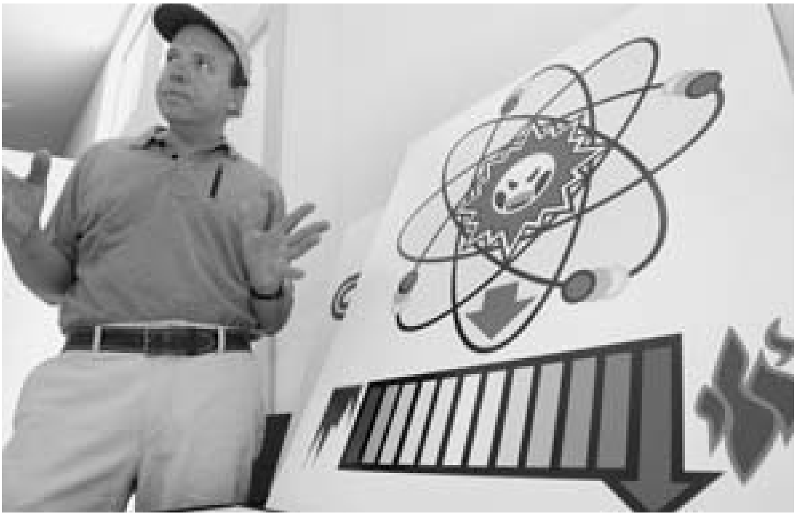
A team of geologists and geophysicists (jee-uh-FIZ-uh-susts) led by Brian Wernicke of the California Institute of Technology and James Davis of the Harvard-Smithsonian Center for Astrophysics (ass-truh-FIZ-iks) started surveying the area in 1991 using a global positioning system (GPS)—a system that uses satellites (SAT-uh-lytez) to determine exact locations on Earth's surface. By the time that they published their results in 1998, they had discovered that Earth's crust is stretching at a rate ten times faster than it has in the recent past near the Yucca Mountain site. That deformation in the crust could mean that the area is at a higher risk for earthquakes and volcanic eruptions than had been previously thought. Indeed, in June 2002, an earthquake of magnitude 4.4 on the Richter scale occurred near Yucca Mountain.

Despite these arguments about a possible increased risk of earthquake or volcanic eruptions, government researchers continue to stand by their earlier conclusions. They argue that the values being measured on Earth's crust are so small that they could fall within the margin of error that always occurs when using measurement instruments like GPS. Researchers outside of government will continue their work to see if the changes persist.

There are also questions about the future impact of water flowing through the site. Originally, government scientists had thought that in the arid climate, any precipitation (prih-sip-uh-TAY-shun) that fell would just run off the side of the mountain, penetrating only a few inches at most. Since the water table is hundreds of feet below the proposed repository, it was assumed that there was no danger of water getting into the storage chamber. However, critics have pointed out that the water table level could change if the climate became markedly different over the next 10,000 years.

The canisters that will store the waste will not last forever. Since no one has ever tried to store radioactive waste for long periods before, no one really knows how long the canisters will last before the waste eats through them. However, the best estimates are only 300 to 1,000 years. Therefore, government scientists are counting on the fact that it will take a very long time—over 10,000 years—for the leaching waste to move through tiny cracks in the rock and arrive at the water table, where it could be carried for long distances. However, to avoid the leakage problem, a new canister design has been proposed. It would feature a thick outer layer of carbon steel that would resist rust, and an inner layer of a high-nickel alloy that would resist corrosion from the waste itself.

Another part of the plan—to store the waste so that it would create heat above the boiling point in the storage chamber, thus evaporating (ih-VAP-uh-rayt-ing) any water that happened to enter—has also come under attack from a



The curator of the Desert Space Foundation, Joshua Abbey, presents one of the designs for a universal warning sign for Yucca Mountain, to be shown in a month-long exhibition. The purpose of the warning sign is to discourage interference, deliberate or otherwise, at the nuclear repository site.

panel of six experts hired by the government to check over the original scientific studies. The experts were not impressed with the computer models that were used to calculate the success of the so-called "hot design," pointing out that the assumptions made in the model undermined its effectiveness.

Scientists continue to point out that no one really knows what will happen. No one has ever built any kind of facility that has lasted for 10,000 years—particularly one holding dangerous radioactive waste. Therefore, there is no way to accurately predict the risks involved.

The Political Questions

Besides the scientific issues, plenty of political issues must be dealt with concerning the Yucca Mountain project. The government made a binding commitment to the nuclear power industry to take its waste starting in 1998. In the meantime, nuclear power plants are running out of room to store spent fuel rods. Failure to find a safe home for them could result in the plants losing their licenses to operate. This would be an unfortunate consequence for the people and businesses that rely on nuclear energy. In fact, 23 percent of the electricity used in the United States comes from nuclear power plants. Shutting those facilities down due to lack of storage for their waste would cause severe economic problems.

The worst commercial nuclear accident in history took place when Three Mile Island nuclear plant experienced a partial meltdown in 1979. Thousands of people living near Middletown, Pennsylvania, claim they have been harmed by the radiation released during the accident.

To counter the argument that keeping all of the country's nuclear waste at one location is inherently dangerous, proponents of the plan argue that having that waste scattered at the 131 current sites is even worse. Proponents of the Yucca Mountain repository maintain that it will be much easier to secure the waste on a government reservation that is already protected by the military. It would be very difficult, they say, for terrorists to break through the multiple layers of security, reach the burial chamber, grab the radioactive waste, and then escape with it.

A problem related to the storage issue is the transportation of the radioactive waste from all over the country to the Yucca Mountain site. Despite assurances that the only danger from an accident would come from having a container holding the waste crush whatever it landed on, critics are not so sure. The movement of all the radioactive waste to Yucca Mountain will require over 100,000 shipments by both truck and train over the next thirty years. Over 50 million people live within 0.5 miles (0.8 kilometers) of the transportation routes. A leak in a canister along the way, especially in an urban area, critics argue, could result in radioactive poisoning of many thousands of people.

A Decision to Proceed

On July 9, 2002, the U.S. Senate voted sixty to thirty-nine to approve the Bush administration's plan to proceed with the waste repository. The House of Representatives had already voted to approve the plan in May. On July 23, President Bush signed Joint House Resolution 87, which allowed the DOE to prepare an application for a license from the Nuclear Regulatory Commission to proceed with construction at Yucca Mountain. In the meantime, the state of Nevada will continue to fight the dumping of radioactive waste in its "backyard."

Questions to Consider

1. Earth scientists are being asked to predict the future at Yucca Mountain. Is it the role of science to make predictions? Why or why not?
2. Do you think people should have the right to block the disposal of radioactive waste in their states? Why or why not?
3. Are radioactive wastes safer stored next to the plants that produce them across the country or located all in one place? Explain your answer?

CHAPTER 2

Do Greenhouse Gases Cause Global Warming?

Earth has experienced an overall warming trend since the middle of the nineteenth century. Reasonably good weather records started to be kept then and thus can be compared with current temperature data. Scientists all agree that Earth is warmer now by about 1.8 degrees Fahrenheit (1 degree Celsius) than it was 150 years ago. They don't all agree on *why* the temperature is warmer.

Over the course of its 4.5-billion-year existence, Earth has experienced periods that were much warmer than they are today—and periods that were much colder. Indeed, just a scant 11,000 years ago—yesterday, in geologic (jee-uh-LAHJ-ik) time—Earth was just coming out of an extended ice age in which glaciers (GLAY-shurz) extended down into the northern part of what would become the United States. Therefore, scientists are in agreement that Earth's temperature has changed both up and down over the millennia.

What distinguishes this current warming period from the others is that, this time, Earth is inhabited by over 6 billion people—people who drive cars that emit exhaust, work in factories that emit polluting gases and aerosols, and cut down vast forests and burn the wood. Some of the resulting pollutants (carbon dioxide, methane, water vapor) are called *greenhouse gases.* At issue is whether Earth's warming is primarily caused by these gases, by something else, or by a complex combination of factors.

Yes

There is no doubt in my mind that humans and the huge amounts of greenhouse gases that their cars, factories, and home heating methods are pumping into the atmosphere (AT-muh-sfeer) *every day are the reason that Earth is warming up. As an atmospheric* (at-muh-SFEER-ik) *scientist, I find the evidence that greenhouse gases cause global warming to be overwhelming.*

The amount of carbon dioxide in the atmosphere has been steadily increasing over the last fifty years. No one can argue with that—the scientific measurements are rock solid. Some scientists maintain that this warming is just part of a naturally occurring cycle. However, Earth experienced a 0.72 degree Fahrenheit (0.4 degree Celsius) increase in 1988 alone. There is almost no chance that such an increase could be caused by any factors other than greenhouse gases.

Computer models have been used for years to show the effects of the increase in greenhouse gases on temperature. Some of the early models weren't very reliable—I'll agree with that—but the latest models are much more finely tuned. These models not only predict future temperatures, they have been successfully used to show how and why temperatures increased in the past. Analyses of tree ring data, sediment deposits, and glaciers all show that the twentieth century was the warmest in the last 1,000 years. Those high temperatures, which occurred at the same time that people were burning more fossil fuels than ever before (gasoline in cars, oil and natural gas for heating, and oil and coal for industry), tell me that human actions produce the carbon dioxide that threatens to warm our planet even more.

No

As an earth scientist, I just can't accept the argument that greenhouse gases created by human civilization are the cause of the current warming period on Earth. I agree that the amount of those gases—in particular, carbon dioxide—has steadily increased since continuous measurements started being made in the 1950s. However, there is just no proof that increased carbon dioxide causes global warming.

Earth has been warmer in the past than it is now. In fact, just 1,000 years ago (a time called the Medieval Warm Period), the temperatures were at least as warm as they are today—maybe even warmer. In the year 1000 C.E., there were only 300 million people on Earth, there were no cars, and there were no big factories. There is no way that those 300 million people could have been producing the amount of greenhouse gases that over 6 billion people produce today. There must have been another reason for the warming.

In fact, there are several possible reasons why Earth could be warmer now. Measurements show that the Sun has been emitting larger amounts of radiation in the last twenty-four years. That could certainly make a difference. Earth's path around the Sun is not constant. As it changes, the amount of radiation that Earth receives changes, too.

Furthermore, while the carbon dioxide readings have been steadily increasing, Earth's temperature has not followed with a steady increase of its own. In fact, from the 1940s to the late 1960s, Earth was actually cooling down! There are just too many uncertainties. I want to see a lot more research and solid evidence of a connection between greenhouse gases and temperature increases before I'll accept that those gases cause global warming.

Discussion

The effect of greenhouse gases like carbon dioxide, methane, and water vapor on Earth's climate has been a topic of serious discussion in atmospheric science circles since at least the 1950s. However, the debate intensified in 1988 when James Hansen, a climate expert at the Goddard Institute of Space Studies of the National Aeronautics (ayr-uh-NAWT-iks) and Space Administration (NASA) in New York City, testified before a U.S. Senate energy committee. Hansen told the senators that between 1950 and 1980, temperatures had only varied 0.23 degrees Fahrenheit (0.13 degrees Celsius) from the average. However, in the first three months of 1988, the temperatures had risen 0.72 degrees Fahrenheit (0.4 degrees Celsius) compared to the average. Because the only atmospheric variable that had changed during the same period was the amount of greenhouses gases, Hansen explained to the senators, he was 99 percent sure that greenhouse gases were responsible for the temperature increase.

Not so fast, said climatologist Syukuro Manabe of the Princeton, New Jersey, office of the National Oceanic and

Dr. Syukuro Manabe, a climatologist, helped create the first model exploring the greenhouse effect. Dr. Manabe acknowledges that any model is flawed by not being able to take into account unpredictable weather patterns, such as the recent El Niño currents that warmed the Eastern Pacific Ocean.

Atmospheric Administration (NOAA). A *climatologist* (klye-muh-TAHL-uh-just) is a scientist who studies climate. Manabe also testified at the hearing. He pointed out that while the slow increase in temperature over the past 100 years did match a corresponding increase in greenhouse gases, those increases were still within Earth's natural climate variability.

Since 1988, more data, additional research, and better computer models have led most atmospheric scientists to accept that greenhouse gases have caused global warming. However, a few scientists still do not agree. These scientists claim that the debate over global warming is really about politics—not about science.

Carbon Dioxide—A Greenhouse Gas

Nobel Prize–winning Swedish chemist Svante Arrhenius (uh-REE-nee-uss) (1859–1927) was one of the first scientists to recognize that humans might be influencing the greenhouse effect. (The *greenhouse effect* is the name given to the warming effect of carbon dioxide and water vapor in the atmosphere on Earth. These greenhouse gases absorb radiation emitted from Earth and radiate it back to the surface. Earth would be a very cold place if there were no carbon dioxide or water vapor in the atmosphere.) In 1896, Arrhenius wrote that each year people were burning more coal and oil than the year before. When *fossil fuels* (coal, oil, natural gas) are burned, they give off carbon dioxide gas as a by-product. Therefore, Arrhenius argued, the carbon dioxide level in the atmosphere was increasing and would continue to increase. He estimated that a doubling of the carbon dioxide level would result in a 9 to 11 degrees Fahrenheit (5 to 6 degrees Celsius) increase in surface temperature. Scientists generally ignored Arrhenius's work. They thought that the carbon dioxide would accumulate very slowly and that most of it would be absorbed by the oceans anyway. (The oceans contain fifty to sixty times as much carbon as the atmosphere.)

Fifty years later, U.S. oceanographer (oh-shuh-NAHG-ruh-fer) Roger Revelle (1909–1991) of the Scripps Institution of Oceanography in San Diego, California, published research showing that the oceans actually did not absorb most of the carbon dioxide that was streaming into the atmosphere. Revelle had encouraged a young scientist named Charles Keeling (1928–) to set up a monitoring station for atmospheric carbon dioxide on the top of Mauna Loa (a mountain in Hawaii) as part of the worldwide observations of the International Geophysical (jee-uh-FIZ-ih-kul) Year (IGY).

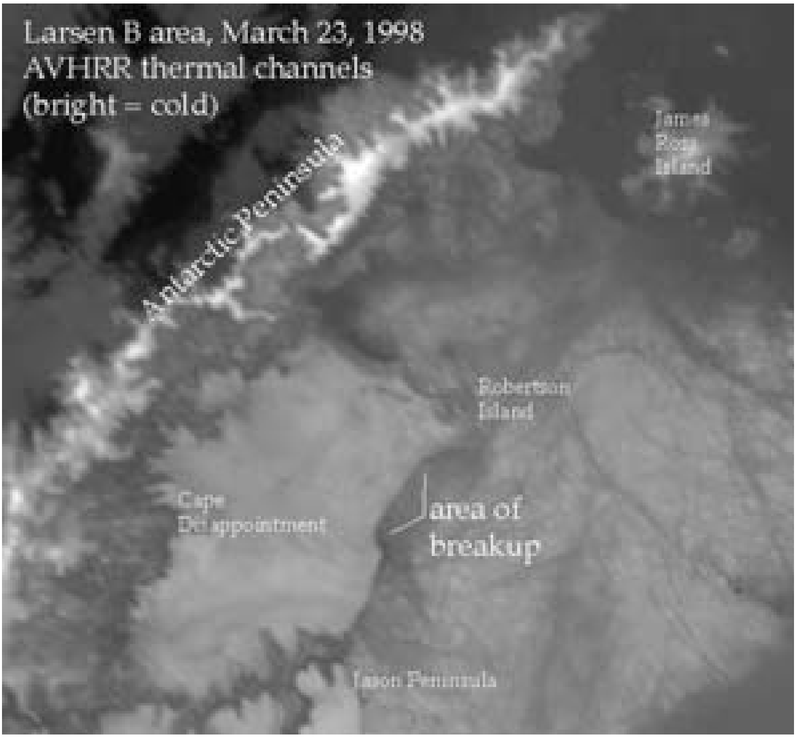
The results—plotted on what has come to be known as the Keeling Curve—show that the level of carbon dioxide in the atmosphere has increased from 315 parts per million to 355 parts per million since 1958. By boring glacier ice cores from Greenland and Antarctica and checking the amount of carbon dioxide, scientists were able to determine that before the world became heavily industrialized about 200 years ago, the amount of atmospheric carbon dioxide was stable at 280 parts per million. (Air trapped between fallen snowflakes remains even after it has been pressed into ice over hundreds of years. When scientists examine glacier cores from deep in the ice, they can perform chemical analyses that reveal the amount of carbon dioxide that was in the atmosphere at earlier times.) At that point, it was clear to researchers that the 25 percent increase in carbon dioxide over the past 200 years was due to people burning fossil fuels.

More recent cutting and burning of tropical rain forests have also contributed to the increase in carbon dioxide. Trees take carbon dioxide out of the atmosphere and give off oxygen. Now, without the trees, less carbon dioxide is being used. The rate at which carbon dioxide is being pumped into the atmosphere is greater than the rate at which it is being removed. Therefore, the amount of carbon dioxide is increasing and will continue to increase unless there is a reduction in emissions.

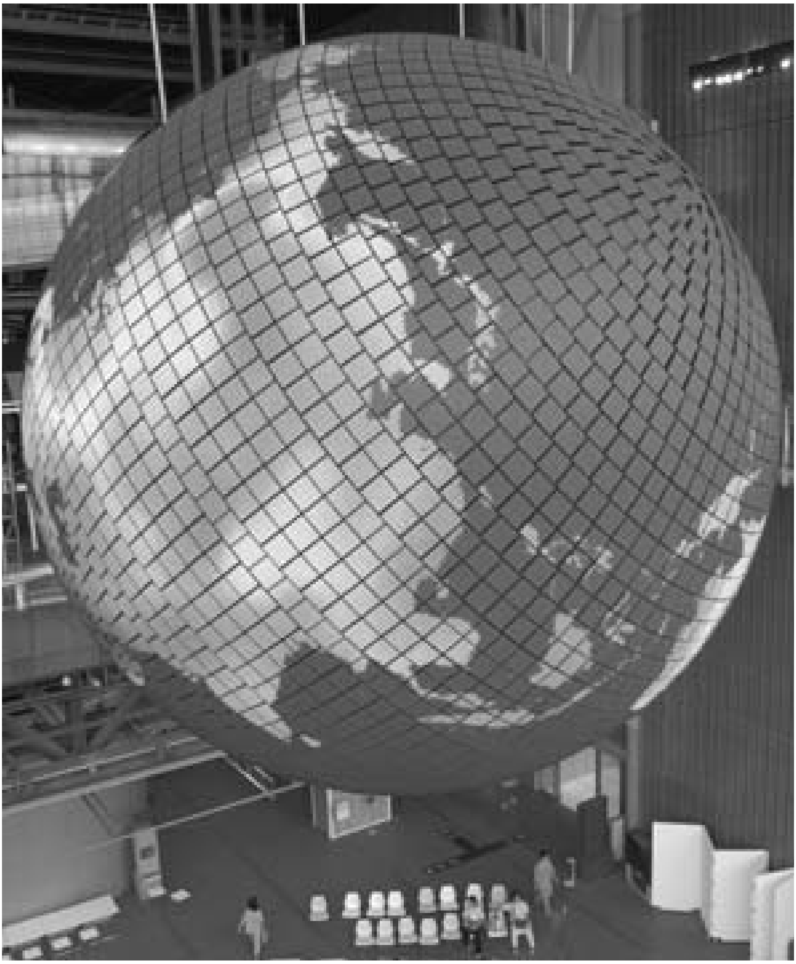
Temperature Trends

Scientists need good records of past temperatures to compute temperature *trends*—that is, whether the temperature is increasing or decreasing over time. Accurate, continuous temperature records have been maintained by meteorological (meet-ee-uh-ruh-LAHJ-ih-kul) observers for only the past 120 years or so. In some places, there has been virtually no change. In others, there have been significant changes—usually because a city grew up around the weather station and the additional concrete and asphalt in buildings and roads caused the readings to be higher than in the past.

However, when dealing with *global* warming, scientists can't just look at a handful of reports across America, Europe, or Asia. Scientists need to be able to sample temperatures from



This satellite photograph shows the Larsen B ice shelf on the Antarctic Peninsula. Ice shelves are thick plates of ice that float on the ocean around Antarctica or the Arctic. This area became of particular interest to scientists in 1998, when a 75-square-mile (195-square kilometer) chunk of the ice shelf snapped off.



The Geo-Cosmos, a globe 70 feet (21 meters) in diameter, located at the National Museum of Emerging Science and Innovation in Tokyo, shows real-time weather conditions updated every hour. The Geo-Cosmos simulates today's global warming trends.

all over the world. This is not an easy task. Over 70 percent of Earth is covered by water, and temperature observations are not usually taken out in the middle of the ocean. Therefore, most of the data have come from land stations. Climatologists have analyzed thousands of temperature measurements dating back to the nineteenth century. What they have found is that temperatures increased from the end of the nineteenth century to 1940. For the next thirty years, temperatures held steady or decreased slightly. Then, starting in 1970, temperatures started to rise again, and they started to show an even greater increase in the early 1990s (with the exception of cooling from the effects of the Mount Pinatubo volcanic eruption in 1991).

Before the mid-nineteenth century, weather records were scarce. There were very few accurate thermometers and even fewer dedicated weather observatories. To determine the relationship between temperature and atmospheric content in the past, *paleoclimatologists* (pay-lee-oh-klye-muh-TAHL-uh-justs)—scientists who study past climates—have studied ice cores that date back 160,000 years. By looking for the presence or absence of a heavier form of oxygen called oxygen-18 (which has eight protons and ten neutrons, instead of the normal eight protons and eight neutrons) in the ice, the scientists can determine whether temperatures were higher or lower than they are now. (There is less oxygen-18 in the ice when temperatures are colder.) Then the scientists check for the amount of carbon dioxide in the trapped air. This research has shown that in the past, warm temperatures and higher amounts of carbon dioxide occurred at the same time. This does not mean that the carbon dioxide levels *caused* the higher temperatures, but it is an indication of a possible cause.

Even taking into account higher temperatures from city-based observation stations, scientists are now convinced that in the last 100 years, the average global temperature has increased by 1.08 degrees Fahrenheit (0.6 degrees Celsius). That may not seem like much, but scientists say that an increase that large in so short a time is outside the range of natural variability. This means that people have contributed, at least in part, to the increase.

It turns out that people have also contributed pollutants that quite possibly have kept the increase smaller than it would have been. Another pollutant emitted as the result of burning fossil fuels is sulfur dioxide. Sulfur dioxide undergoes a chemical reaction with other elements in the atmosphere to produce small particles called *aerosols* (AYR-uh-sahlz). These aerosols have a temporary cooling effect because they reflect radiation from the Sun, but they don't stay in the atmosphere very long—just a few days.

Other factors in warming occur naturally. One concerns the amount of radiation that the Sun emits. The Sun's radiative energy does change over time, so it can contribute to either warming or cooling—warming as it increases, cooling as it decreases. Another natural contributor to temperature trends is the level of volcanic eruptions. Large eruptions throw into the sky enormous amounts of dust and ash that are rapidly pulled into the air moving around the earth. Because the particles are small and the air is moving quickly, they remain suspended for a year or two before completely falling out. During that time, they reflect energy from the Sun and prevent it from reaching Earth's surface; cooling results.

All these factors can enhance or offset each other. For example, during the cooling trend from 1940 to 1970, carbon dioxide concentrations were rising, but the Sun's radiation was temporarily reduced. As a result, the temperature trend stabilized and decreased slightly. The rapid increase in warmth after 1970 seems to have been accompanied by a reduction in sulfur dioxide emissions that had previously led to cooling, as well as by an increase in solar output; this was in addition to the increased carbon dioxide.

Most scientists agree that these temperature trends are evidence of warming and can be accepted as fact. A few do not. The most prominent of these is S. Fred Singer (1924–), the president of the Science and Environmental Policy Project (SEPP). The SEPP is a *think tank*—a group of researchers who work together to consider problems and questions of particular interest to them. Singer disputes that there is a warming trend. Instead of looking at surface temperatures, which he considers to be suspect because of urban development, he has considered only temperatures measured remotely from satellite sensors or from weather balloons. Based on these measurements, Singer claims that the atmosphere has actually *cooled* slightly and that there is no credible evidence that temperatures have been increasing. The majority of scientists dispute Singer's conclusion, saying that he has focused on only a few readings instead of a global trend.

Climate Models

Since it is impossible to know exactly what will happen if the percentage of greenhouse gases in the atmosphere continues to rise, climate scientists have turned to *climate models* to determine how the climate will be changed in the future. These climate models are special versions of the computer programs that predict the weather. The models take into consideration the location of land, water, and ice on the globe, the extent of

The star of the U.S. television show Bill Nye the Science Guy *creates a simple climate model illustrating how carbon dioxide retains heat better than air inside an aquarium. Nye broadcast daily reports of the discussions held during a two-week-long world conference on global warming held in The Hague, Netherlands, in 2000.*

cloud cover, and the combination of gases forming the atmosphere. The climate modelers can then change any of the parameters and let the model calculate what the temperature would be decades or centuries into the future. No model is perfect. However, climate models have improved tremendously over the last two decades, and climatologists are confident that they are getting good predictions from the models. They can test the models by putting in the factors that existed in 1900 and then seeing what the model predicts for the year 2000. If the result is close to what has been observed, then the model would appear to produce an accurate representation of future climate conditions.

By modifying the greenhouse gas amounts in the models, scientists have determined that as greenhouse gases increase, the temperature will continue to increase. Indeed, because of the greenhouse gases that have already accumulated in the atmosphere, the temperature will increase even if greenhouse gas emissions remain steady or are reduced in the future.

The Scientific Debate

The very public scientific controversy over global warming due to greenhouse gas increases has, for the most part, been settled. The vast majority of scientists accept that there has been an increase in temperatures and that at least 70 percent of that increase is due to human action—the burning of fossil fuels. In the fall of 1995, the Intergovernmental Panel on Climate Change (IPCC) published a report that had received the support of 2,500 international climate scientists. Their conclusion: "The balance of evidence suggests that there is a discernible human influence on global climate." Then in January 2001, the IPCC made an even firmer statement that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." In the years between the reports, additional data gath-

Dr. Robert Watson (in the foreground), the former chair of the Intergovernmental Panel on Climate Change, is one of the world's most outspoken scientists on the issue of global warming. He believes that human activity is contributing to climate change at dangerously high levels.

ered from tree-ring measurements showed that the twentieth century experienced the greatest warming trend in the past 1,000 years. That, says U.S. IPCC delegate Daniel Albritton of NOAA's office in Boulder, Colorado, is not likely to have been a natural occurrence.

The Political Debate

While most scientists agree, many political leaders do not. The Kyoto Protocol of 1997—an international agreement sponsored by the United Nations (UN)—called on developed nations to reduce their greenhouse emissions in an attempt to reduce future global warming. The Protocol has yet to be ratified by the U.S. Senate. Because there were no curbs placed on developing countries—which would not have to abide by the emission reductions—federal leaders balked at placing the United States under the provisions of the treaty. They have argued that participating in the treaty will ruin America's economy, which depends on the burning of fossil fuels, while other economies—in particular, China's—would not be so restricted. A variety of interests, including the petroleum industry, have heavily lobbied the Senate to prevent a positive vote on this matter. As of 2004, it does not appear that the treaty will be ratified. In any case, the Kyoto Protocol would not reduce the level of greenhouse gases in the atmosphere. It would just reduce the rate at which they accumulate while scientists continue to collect evidence of global warming.

Questions to Consider

1. Do you think that there is sufficient scientific data that greenhouses gases cause global warming? Why or why not?
2. Should governments be responsible for enforcing reductions in greenhouse gas emissions? Why or why not?
3. Would you be willing to reduce your dependence on the automobile as a preferred method of transportation if it would reduce greenhouse gas emissions? Why or why not?

CHAPTER 3

Should Oil Drilling Be Allowed in Sensitive Areas?

The United States has more cars than licensed drivers, millions of homes that use heating and air-conditioning, and a well-developed industrial economy. Therefore, the country and its people are extremely dependent on petroleum products (oil and natural gas) to meet those demands. Having used up much of its own oil reserves during the twentieth century, the United States has come to rely on imports of oil from foreign countries in order to maintain its high standard of living.

In 1973, the Organization of Petroleum Exporting Countries (OPEC), a group of primarily Arab oil-producing nations, *embargoed* (did not release for sale) oil destined for countries that supported Israel. The United States and many Western European nations that depended on OPEC oil were hit with severe shortages. Drivers sat in their cars for hours, waiting for their turn to purchase a few gallons of gasoline. *Brownouts* (periods when not enough electricity was available for everyone) became common. People were very concerned. Something needed to be done, Americans said, so that the United States would not be dependent on oil from other countries.

Oil companies were quick to point out that there was no shortage of oil under U.S. territory. The continental (kahnt-un-NENT-ul) shelf—that strip of land just off the coast of the continent (KAHNT-un-unt)—holds billions of gallons of oil that could be pumped out in the future. Likewise, there were billions of gallons to be had in Alaska. All the oil companies had to do was to build oil platforms in the ocean and drilling fields in the frozen north. Not everyone agreed. Environmentalists who were concerned about possible damage to nature from oil drilling and spills objected to these attempts to pump oil at any price. The debate continues in the twenty-first century.

Yes

America is too dependent upon foreign oil. First the OPEC oil embargo in 1973 led to long lines at gas stations and large price increases. Then in the early 1980s, the revolution in Iran and the Iran-Iraq War (1980–1988) disrupted oil flow from the Middle East even more. Ten years later, when Iraq invaded Kuwait, oil supplies were slowed again. After the terrorist attacks of September 11, 2001, and the U.S. war in Iraq (2003), it is apparent that now is not the time to be looking to foreign producers for the oil that the United States needs.

As a petroleum geologist, I know that there are potential gas- and oil-producing fields located in the Gulf of Mexico coast, off the California coast, off the coast of Alaska, and under the Arctic National Wildlife Refuge (ANWR) in Alaska. All we need to do is go in, drill the wells, and pump out the oil. We have been doing it for years in some of the gulf coast fields without any problems at all. We have also been doing it near Alaska's Prudhoe Bay for thirty years. In fact, the Prudhoe Bay field has been a major U.S. oil producer during that period. It provided 25 percent of the total U.S. oil output during its peak years in the 1980s.

After years of pumping, the 12 billion barrels of recoverable oil that we found there are almost gone. We need to be looking elsewhere. Environmentalists claim that if we drill in the ANWR, we'll disrupt the lives of the caribou that raise their young in this area. That is ridiculous. First, we are very careful not to disturb the environment when we drill. Second, even if a few caribou were inconvenienced, what are they compared to the national security of the United States and all its citizens? If this country runs out of energy sources, it runs the risk of being held hostage to nations that have such sources.

No

America doesn't have too little oil—it has too much usage. Americans drive just a few blocks to the store when they could walk or ride bikes. They drive huge gas-guzzling trucks and sport utility vehicles instead of small, fuel-efficient cars. Instead of conserving what they have, they use up what they don't have, so they have become dependent upon foreign oil. After the terrorist attacks of September 11, 2001, political leaders said that oil was no longer just something we needed to support our high standard of living. Oil was directly related to our national security. The oil companies' solution: Drill for oil and natural gas in environmentally sensitive areas like the ANWR or the continental shelf just off the coast of California.

As an environmentalist with a national conservation organization, I know that the ANWR is one of the best examples of natural wilderness left on Earth. There are many more different kinds of wildlife there than in any other protected area in the Arctic. No matter what the oil companies say, it is impossible to drill for oil without causing some damage. The oil companies will have to do seismic tests in advance of drilling to determine the threat from possible earthquakes or other ground movements. That will damage the surface where the tests are done. The area where they want to drill is the calving area (the place where young are born) for the native herd of Porcupine caribou—animals that native people depend upon for food. Disturbing the calving area may mean the end of this valuable herd.

Even if the caribou aren't disturbed, there is always the risk of an oil spill, which would permanently damage the ANWR. No cleanup will ever bring it back. Ruining the refuge for a little bit of oil? It's just not worth it.

Discussion

The United States hasn't always been dependent upon foreign oil. In the middle of the twentieth century, it was a major world producer. In 1950, it produced 52 percent of the world's crude oil. By 1997, however, the United States was only producing 10 percent of the world's crude oil. The oil fields in the

This oil, known as the Lucas Gusher, erupted from a well on a hill known as Spindletop in southeastern Texas in 1901. Before the discovery of oil in this region, Pennsylvania had produced more oil than any other state in the country. The Lucas Gusher blew over 150 feet (45 meters) into the air for nine days, losing oil that would equal a loss today of $17 million.

continental United States were largely depleted. In the meantime, oil-producing countries in the Middle East significantly increased their crude oil production. Since it was cheaper for the United States to purchase oil from overseas than to drill for it at home, the percentage of imported oil continued to increase. By the end of the twentieth century, almost half of all oil consumed in the United States was imported from abroad. However, the imported oil comes from a politically unstable region. When the OPEC countries experience internal problems or are fighting with each other, oil supplies can quickly be reduced. The realization that it might not be wise to be so dependent on foreign oil led to recommendations for additional oil exploration in the United States.

Actually, the U.S. government, oil companies, and petroleum geologists started looking offshore at oil and natural gas fields located beneath the continental shelf to fill wartime requirements in the 1940s. Although the technology for drilling was primitive, it rapidly improved. The calm waters of the Gulf of Mexico covered significant natural gas reserves—soon, drilling platforms sprang up like a sparse forest throughout the shallow gulf, despite annual threats from passing hurricanes (HUR-uh-kaynz) and high seas. Although there wasn't much of an outcry from conservationists then, the next place that looked attractive for oil exploration created concern. The potential natural gas fields were under the continental shelf off the coast of California.

The Impact of Offshore Drilling

North America has more offshore drilling platforms than any other region of the world—a little over 3,000. Because of concerns over the impact of petroleum leaks and spills, the number of offshore platforms has actually been declining. As the drilling platforms empty the fields of oil and gas, they are no longer useful and are shut down. Most platforms are now found in the Gulf of Mexico—where they have been for over fifty years—and in Alaska's Prudhoe Bay, on its north coast.

The first major debate over offshore drilling was sparked by a huge oil spill off the coast of Santa Barbara, California, on January 29, 1969. Oil workers stationed on a platform about 6 miles (9.6 kilometers) off the coast had drilled a well 3,500 feet (1,050 meters) below the ocean floor. As they were replacing a drill bit, the well suffered a natural gas "blowout." While the workers struggled to cap the well, the pressure built up below the ocean floor. Oil and gas burst through five breaks in a fault that snaked across the seafloor. In the eleven days that it took to cap the rupture, over 200,000 gallons of crude oil bubbled out of the ground, floated to the surface of the ocean, and created an oil slick covering 800 square miles (2,080 square kilometers). The incoming tides brought thick tar to a 35-mile (56-kilometer) stretch of Southern California beaches. Seals and dolphins were hard hit by the oil, and many of their dead bodies washed up on the beach. Despite the efforts of rescue workers, over 3,500 birds also died after coming into contact with the oil.

People across the nation were outraged by the damage to the ecosystem. Within days, concerned citizens founded an organization called Get Oil Out (GOO). GOO volunteers collected over 100,000 signatures on petitions demanding the end to offshore oil drilling. Although drilling was halted temporarily, it continued once laws were passed to strengthen regulations that would have prevented the Santa Barbara spill.

In the 1980s, Californians were so concerned about offshore drilling that voters in twenty-six different communities passed initiatives that prevented companies wanting to pursue offshore drilling from operating in their towns. The state of California later passed a law that prevented all offshore drilling except for areas that were covered by previously existing legal agreements.

In June 1990, President George Bush imposed a moratorium (a halt) on oil drilling until 2002. In 1998, President Bill Clinton extended the moratorium for another ten years and

This offshore drilling unit is currently operating in the Gulf of Mexico. The semisubmersible unit, owned by ENSCO, a science, engineering, and technology company, can drill to a depth of 30,000 feet (9,000 meters) and operate in waters up to 8,000 feet (2,400 meters).

applied it to virtually every part of the U.S. coastline. Although conservationists pushed Clinton to make the ban permanent, Clinton argued that the additional ten years would provide the government enough time to examine the matter as science and technology advanced.

Oil from Prudhoe Bay

The Prudhoe Bay oil fields, on the north coast of Alaska, were discovered in 1968. They are the largest oil fields in North America—over 13 billion barrels of oil have been pumped from nineteen separate fields since 1977. Once the oil is pumped out, it leaves Prudhoe Bay for the 800-mile (1,280-kilometer) trip through the Trans-Alaska Pipeline System to Valdez, the northernmost ice-free port in Alaska. The pipeline, which is 4 feet (1.2 meters) in diameter, snakes across three mountain ranges and 800 rivers and streams. Started on March 27, 1975, it was completed on May 31, 1977, and the first oil moved through the pipeline three weeks later. Once the oil arrives at Valdez, it is loaded onto oil tankers for the trip to oil refineries in the lower forty-eight states. The first tanker-load of crude oil left Valdez on August 1, 1977, and over 17,000 tanker-loads of oil have been shipped out since then.

The Prudhoe Bay fields and the pipeline system have not moved all of this oil without causing any damage. The entire system has averaged 400 spills annually since 1995—spilling a total of 1.5 million gallons (5.7 million liters) of oil. Compared with initial estimates in the U.S. Department of the Interior's 1972 Environmental Impact Statement (EIS), five times as many wells have been drilled and twice the mileage of roads have been constructed through the tundra. Caribou herds that live in the area have been affected by the pipeline system. Wildlife biologists note a reduction in the birthrate among the caribou, and they are known to keep clear of the pipeline and related oil-drilling activities.

The oil-laden beaches of Prince William Sound mobilized thousands of workers in a cleanup effort after the Exxon Valdez *accident. Ongoing research citing the resiliency and regeneration of the area's ecosystem is seen, by some, as damaging to the argument opposing offshore drilling.*

Critics of drilling in sensitive regions argue that even if the drilling itself does no damage, the potential exists for an accident to happen throughout the process of drilling and delivering the oil to the refinery. They point to the grounding of the oil tanker *Exxon Valdez* on March 24, 1989. The spill dumped 257,000 barrels of crude oil (enough to fill 125 Olympic-sized swimming pools) into the water. Wind and waves eventually spread the oil along 1,300 miles (2,080 kilometers) of coastline, with 200 miles (320 kilometers) suffering serious damage. The Exxon Company spent $2.1 billion on the cleanup effort, which extended over four summers before it was called off. Not all of the oiled beaches were cleaned—some are still lightly oiled. There is no way to know exactly how many animals died, but the best estimates are 250,000 seabirds, 2,800 sea otters, 300 harbor seals, 250 bald eagles, and up to 22 killer whales; billions of salmon and herring eggs were also destroyed. The damage created by the grounding of the *Exxon Valdez* has given conservation groups a lot of reasons to oppose the proposed drilling in the ANWR.

The Trans-Alaska pipeline begins in Prudhoe Bay on Alaska's North Slope and ends 800 miles (1,280 kilometers) away in Valdez, the northernmost ice-free port in North America. The pipeline started transporting oil in 1977, and over 13 billion barrels of oil have already moved through its pipes.

Why the ANWR?

In order to reduce America's dependence on foreign oil, the administration of President George W. Bush has been working to open up Alaska's ANWR to oil exploration. Although it is a refuge area, it can be opened for oil exploration as long as Congress approves. On July 17, 2001, the House Resources Committee approved a bill that would allow oil exploration to begin. Expecting significant opposition from environmentalists, supporters of the bill suggested that drilling for oil in the ANWR was a requirement for national security, in order to keep the United States independent of foreign oil supplies. According to Alaska senator Frank Murkowski, the refuge possibly contained more oil than Prudhoe Bay, which would be enough to replace all the oil that the United States currently imports from Saudi Arabia for thirty years. Within days of the September 11, 2001, terrorist attacks, the U.S. Senate began to consider the drilling bill as part of the national security agenda.

Besides citing the possible damage to the refuge, opponents wanted to know if the estimates of large amounts of oil were really true. A number of studies have been made of the refuge and each has come to a different conclusion. The Alaskan Bureau of Land Management's 1987 report determined that there is only a 19 percent chance that there is any oil at all in the refuge. Others studies have concluded that there is oil there, but estimates of amounts range from 1 billion to over 7 billion barrels of recoverable oil. (*Recoverable oil* is oil that can actually be pumped out of the oil field. Since the oil is trapped between sand grains, there may be, under some conditions, a lot of oil in a field, none of which can be removed, or recovered.)

The U.S. Geological Survey (USGS) concluded its study in 1998. The agency estimated that the refuge may contain between 11.6 and 31.5 billion barrels of oil, with between 4.3 and 11.8 billion barrels recoverable. Compared to the 13 billion

Conservationists were victorious in March 2003, when the Senate voted to block oil development in the Arctic National Wildlife Refuge. It is assumed, however, that this is merely a reprieve for the refuge and that the oil industry will continue to fight for drilling rights well into the future.

barrels that have already come out of the Prudhoe Bay fields, the ANWR would not be very productive. However, some petroleum geologists remain convinced that the ANWR is America's best chance for finding a giant, productive oil field.

Whether there is any oil there or not, at 19 million acres (7.6 million hectares), the ANWR is the nation's northernmost wildlife refuge. It is also one of the largest. The 1980 Alaska National Interest Lands Conservation Act set aside 8 million acres (3.2 million hectares) of the ANWR as wilderness. In particular, it called for the protection of the Porcupine caribou herd. The caribou, used by native peoples for food, graze within the refuge, and the cows give birth to their calves along one section of the coastal plain during the spring. It is in this special calving area that oil exploration would have the greatest impact. If it disrupted the reproduction of the caribou herds, the native peoples—known as the Gwich'in Athabascan (GWICH-in ath-uh-BASS-kan)—could find their way of life destroyed. Although the state of Alaska—and hence the citizens of Alaska—would receive funds for the sale of the oil—the Gwich'in maintain that the money will eventually run out and that, in the meantime, their ability to live on their land will be gone. They point out that the ANWR represents only 5 percent of the area that is open for oil exploration in Alaska. That small amount will make no difference to America's oil supply over time. If the drilling does take place, plants and animals will be adversely affected.

Environmental groups and the National of Academy of Sciences agree that oil drilling in Alaska has already harmed the environment upon which the plants and animals in the state depend. Indeed, a random poll of Americans showed that 62 percent of them oppose drilling in the refuge. While the Senate rejected the proposal, the House of Representatives voted in favor of the proposal in April 2003 to open the ANWR for oil exploration. For now, oil exploration in the refuge remains on hold.

Questions to Consider

1. Do you support the Bush administration's efforts to open the ANWR to oil exploration? Why or why not?

2. Environmentalists argue that instead of spending large amounts of money to drill for oil in sensitive ecological areas, Americans would be better off making the oil that they have last longer by conserving fuel (for example, driving smaller, fuel-efficient cars and using more public transportation). Do you agree? Why or why not?

3. Supporters of offshore drilling maintain that hazards to the environment from drilling are small compared to the benefits of having plenty of oil. Do you agree? Why or why not?

CHAPTER 4

Does Enough Fossil Fuel Exist to Meet Future Needs?

Fossil fuels—oil, natural gas, coal—exist in finite amounts. Some 200 to 500 million years ago, fossil fuels started as remains of plants and animals that were covered by layer after layer of sand and sediment. Under intense pressure and high temperatures, the remains were crushed, and converted into oil, gas, and coal. Once these fuels are pumped or dug out of the ground, they will be gone forever. Fossil fuels are a *nonrenewable* source of energy. Since they can't be renewed, scientists, government leaders, and average citizens need to be aware of how many years' worth of fossil fuels are left to be mined. The United States's economy and way of life—and those of other countries around the world—largely depend on the availability of fossil fuels.

Despite the cost of getting them out of the ground, fossil fuels produce the most energy for the least amount of money. There has therefore been little motivation to exploit other types of energy. A few nuclear power plants exist, but they come with their own sets of problems. Wind energy is being harnessed by large "windmill farms" in some places, but that is a fairly new technology. Solar energy—collecting energy from the Sun and using it to generate electricity or heat water—has also been tried on a limited basis. However, none of these methods is very useful for powering automobiles. Almost 98 percent of transportation in the United States is powered by oil.

Scientists estimate that there are fifty years' worth of oil and about sixty-five years' worth of natural gas left in the world. Coal, on the other hand, is abundant. The United States alone is reported to have enough coal to last for 1,500 years, but that is only if consumption stays the same. If it increases at 5 percent per year, the coal will only last eighty-six years. If consumption increases at a faster rate, the supply won't last even that long.

Yes

I am a petroleum geologist. I have spent my life exploring for oil and natural gas. Some people think that our supplies of fossil fuels are going to run out in the twenty-first century. I can accept that the easy-to-find oil and natural gas may run out in the next fifty years—although I really think that they will last at least until the end of this century—but there is still more to find out there.

What these people never discuss is the huge amount of shale oil deposits that exist in the United States. These deposits are found in southwest Wyoming, eastern Utah, and western Colorado. Shale oil contains a substance called kerogen (KER-uh-jun). *By burning kerogen, it is possible to turn it into fuel products. While we have 24 billion barrels of oil left (more or less) in U.S. oil reserves, we have at least ten times as much oil as that in oil shale, the rock in which the shale oil is found. Do the math. If we have fifty years' worth of oil left, and oil shale contains ten times as much oil as we'll use in fifty years, then we really have 500 years of oil left.*

By my calculations, if we have 500 years of oil left and 1,500 years of coal left, people will have figured out another type of energy by that time, right? People who talk about conservation all the time are just underestimating the amount of fuel that is out there. They are trying to scare others into thinking that their quality of life is going to go down. I am not worried about it. I'll never see a time when there won't be enough fuel, and my children and grandchildren will have plenty of fuel, too. All we have to do is look for it and, when we find it, be smart about the way that we take it out of the ground.

No

There is only one possible way that I can be confident that the fossil fuels we'll need in the future will be there. The way to continued use of fossil fuels is to conserve what we have. As long as oil and other fossil fuels remain inexpensive in the United States, we will continue to use them at a high rate. I don't know of anyone who thinks that cheap oil will last forever—not even the oil companies believe that.

I am a conservationist, not a geologist, but I have been trained in the sciences, and I have taken enough courses in economics to be able to do the math on energy consumption. People are more likely to be wasteful with energy sources when they are cheap. One reason that nuclear, wind, and solar power have not caught on in this country is that they cost more than fossil fuels do to produce the same amount of energy. Therefore, we have not actively worked to make those energy sources more efficient and less expensive. Since we have failed to do that, we will use up our oil and natural gas reserves even faster than we would have if we had been using other sources also.

Another reason that we will run out is that the remaining oil reserves will be harder to tap. They will be under the ocean or under wildlife areas that we would like to preserve. Will it be worth polluting the oceans and special places like the ANWR just to get more oil to burn in our automobiles—which use way too much fuel anyway? What kind of people would we be if we decided not to spoil our beaches but were willing to help other countries—which may need the money that oil would bring—to spoil theirs? The way that things are going, my children will find themselves out of fossil fuels during their lifetime. I hope the world has discovered a new, inexpensive source of fuel by then.

Discussion

The question of whether we will have enough fossil fuel for the foreseeable future involves two factors. First, geologists need to have a good idea of how much fossil fuel is left. Since they have been working to estimate the amount of oil, natural gas, and coal for many years, and since they know under what kinds of conditions these fossil fuels are found, most geologists are fairly confident that they know how much remains to be pumped out or dug up. Second, national leaders who are involved in making policy decisions about the use of fossil fuels need to know how quickly they are being used up. The rate at which fuel is used for energy depends on the number of people who live in a given country and what that country's per person consumption rate is. The larger the consumption rate per person and the more people there are, the faster the fossil fuels will be used up.

For example, oil produces 38 percent of the energy used in the United States. Each American uses, on average, almost 1,000 gallons (3,800 liters) of oil per year. That oil is used for transportation, heating, cooking, and running factories in which people work. How long will the oil last? At the highest rates of production and current rates of use, most scientists think that the oil (at least the oil that is easily pumped out) will be gone by the middle of the twenty-first century. If the production drops and consumption increases, it will last a shorter time. Most current estimates show that by the year 2010, world demand will exceed world production of oil. The oil reserves and how they are used would then become influenced by supply and demand. As the supply drops and the demand increases, the price of each gallon of oil will rise. When that happens, demand will probably decrease unless people are willing to spend a larger amount of their income for gasoline and heat. If the demand were to drop off rapidly, and if other sources of cheap energy were developed quickly, then the oil would possibly last longer than the next fifty years.

Natural Gas—More Years Left

The natural gas situation is a little better than that for oil. Natural gas provides 24 percent of America's energy needs. Based on its own natural gas reserves, and if consumption continues at its current rate, the United States would have fifty years of its own supplies left. Again, if consumption increases as the population increases, the natural gas will last for less time. If the price goes up and consumption drops, then it will last longer. The world reserves are about four times bigger than the U.S. reserves, so there is a considerable amount of natural gas

In 2002, the energy company BP began operations on an $86 million experimental natural gas plant in Alaska. Its goal, to convert natural gas into a liquid form, could theoretically turn the massive amounts of natural gas currently located on the North Slope of Alaska into crude oil that would be pumped through the Trans-Alaska pipeline.

available. However, it would be expensive to transport the gas across oceans to the United States to generate electricity or use for home heating. Therefore, Americans will probably run out of natural gas before the end of this century.

Plenty of Coal out There

Coal is a completely different story. The United States uses coal to produce about 22 percent of all the energy that it uses. For the most part, utilities burn coal to generate electricity. Coal production has continued to increase, particularly as oil supplies have dwindled, but pollution from coal-burning plants—which contributes to global warming and acid rain—makes it a less desirable fuel than clean-burning natural gas.

The United States alone has about 1,500 years of coal left, if it continues to use it at the current rate. However, if technology improves so that coal can burn without polluting the atmosphere, that rate will probably go up sharply, and the number of years of useful coal remaining will decrease. If such

Coal production may see even more of an increase in the next decade as tensions in the Middle East threaten our ability to obtain oil from overseas. In this open pit coal mine in Illinois, large chunks of coal are dug out from more than 70 feet (21 meters) below the earth's surface.

technology is not forthcoming, Earth might become so badly polluted by the gases emitted from burning coal that life on Earth would end before the 1,500 years were up. Consequently, it is safe to assume that for the foreseeable future, there will be plenty of inexpensive coal available, but whether people will choose to use it for energy or not is another debatable issue.

Potential Fossil Fuels

Another form of fossil fuel that has not been exploited is called *shale oil*. Shale oil forms when organic material accumulates at the bottom of lakes, is mixed with mud, and then sits for hundreds of millions of years. The Green River Formation, in the U.S. Rocky Mountains, contains between 0.6 and 2 *trillion* barrels of oil. That is a lot of oil. However, removing oil from oil shale is a very expensive process. Unless the cost of recovering the oil comes down below the cost of other fuels, shale oil is not likely to be viewed as a viable energy source. However, the supply will last for a long time.

Tar sands are another fossil fuel source. Tar sands contain a hydrocarbon (HYE-druh-kahr-bun) called bitumen (buh-TYOO-mun), which can be burned. There are large amounts of tar sands waiting to be tapped—one deposit alone, located in Alberta, Canada, is reported to contain about 300 billion barrels of oil—but there are problems with mining tar sands. To begin with, it takes more energy to extract the oil from the tar sands than the oil taken from the tar sands produces. (The tar is stuck to the sand and must be "unstuck" to make oil.) Mining, extracting, and refining tar sands produce more greenhouse gases (which contribute to global warming) than coal. Unlike oil and natural gas wells that pump fuel out of the ground, tar sands are strip-mined—a very large hole remains in the ground after the mine operators take away the plants, trees, and fertile topsoil to expose the bitumen, which is 40 feet (12 meters) down in the ground. This ruins wildlife habitat and destroys water sources. Tar sands may be an option in the future, and indeed, there is some tar-sand mining going on now, but it is still limited, because of cost and pollution problems.

Making It Last

Fossil fuels will only last as long as people work at conserving them. Possible ways of conserving fossil fuels include developing and using more energy-efficient modes of transportation, setting thermostats to use the least amount of fuel while maintaining a comfortable living atmosphere, and building more efficient electric plants that will burn fuel more cleanly. Another option is exploiting renewable energy sources, such as wind and solar power, which would allow for a decreased consumption of fossil fuels. All these factors will help to determine how many years of fossil fuel use the world has left.

Questions to Consider

1. Do you think that your children will use fossil fuels for their transportation, heating, and electricity needs? Why or why not?
2. There may come a time when people will need to decide whether they want cheap fuel and polluted air or more expensive fuel and cleaner air. If these were your only two choices, which would you choose? Why?
3. Conservation of fossil fuels may become a requirement before the end of this century. How do you think that reductions in the amount of energy you could use would affect your way of life? Why?

CHAPTER 5

Should Desert Cities That Lack Water Be Allowed to Expand?

Water is a necessity of life. Arid regions that typically receive less than 10 inches (25 centimeters) of rain per year must carefully manage their water resources in order to support the personal needs of growing populations, as well as industrial and agricultural needs. The desert Southwest is the driest region in the United States. It also has the fastest-growing population.

In the past ninety years, the population of the United States has grown 225 percent. During the same period, the population of the southwestern United States increased by almost 1,500 percent. Of the Southwestern states, Arizona and Nevada have experienced the greatest growth: 2,880 percent and 2,840 percent respectively. While that is certainly a tremendous increase, the population of one city and its associated county—Las Vegas and Clark County, Nevada—has experienced explosive growth, increasing from a population of 3,248 people in 1900, to 741,459 in 1990, to 1,036,180 in 1995 (an increase of 31,902 percent)! City officials project that the greater Las Vegas area will have a population of more than 2 million people by 2005. In fact, the population of just the city of Las Vegas doubled between 1985 and 1995.

The water supply, however, is no greater now than when the city was first incorporated in 1905. Although there is a better system of piping to bring water from the Colorado River to the city than there was in 1905, the river itself carries less water than it did 100 years ago. As cities and agricultural demands increased upriver, less and less water came downstream, and yet the city of Las Vegas continues to grow rapidly.

Yes

Las Vegas is a great place to live. We have something for everyone here. The climate is absolutely the best—warm and dry. Hoover Dam and the Lake Mead recreational area are close by. There are places to hike, swim, and boat. We have plenty of golf courses—and of course, we have the world famous Las Vegas strip, which is lined with hotels and resorts that cater to millions of tourists every year.

As a business leader in Las Vegas, I am proud of the way my city has grown in the last few decades. In fact, the Las Vegas area is the fastest-growing region in the United States and has been for several years. The number of hotel rooms increases by 4 percent a year, and we have plenty of jobs for newcomers. In the past few years, the number of jobs has increased by 9 percent each year. Single-family housing units, apartments, and condominiums are being built all over the city. If Las Vegas weren't such a wonderful place to live, people wouldn't move here from all over the country.

Some people say that all these people shouldn't be allowed to move to Las Vegas. They would like to see us restrict the building permits that allow builders to add housing developments, schools, medical clinics, and shopping areas. They are concerned that there isn't enough water to support everyone in this desert. I disagree. We have always had a sufficient water supply here. Lake Mead collects water from the Colorado River, and we are entitled to use that water. Sure, we use a lot of water—grass doesn't grow in a desert without it—and people need water, too. If we're smart and conserve what we have, we'll do just fine. Our economic prosperity depends on continued growth. The water problem will work itself out—it always has.

No

I was born and raised in Las Vegas, unlike most of the people who live here. Did you know that Las Vegas is nine times bigger now than it was in 1960? Nine times! Most of those new people weren't born here—they moved here because the weather here is a lot better than wherever they came from. There are a lot of jobs, too. I am sure some of the people come because of the jobs.

While the city has grown and the houses have multiplied, the water supply is the same as it's always been. That is a huge problem, and it's getting bigger. We have had drought conditions for several years. The water level in Lake Mead is the lowest that it has been in more than thirty years. If the global warming experts are right, as the temperature increases, the amount of rainfall will continue to decrease. That will mean even lower water levels in Lake Mead. At the same time, we have uncontrolled growth in the city. The mayor says that he is not concerned about the water—that the city will be able to figure out a solution. What solution? We'll conserve by taking only two-minute showers and flushing our toilets only a couple of times a day? Our gardens will only be allowed to have native plants? We'll drink only bottled water that's shipped into the state from someplace else?

I don't buy it. I say that this explosive growth will strain the water supply to the breaking point one of these days. When that happens, millions of people will be looking for water in their taps, and it isn't going to be there.

Discussion

The desert Southwest of the United States has become an attractive destination for people from around the country in the last forty years. Most new residents are attracted by the warm, dry winters and the many opportunities for outdoor activities—including golfing and water sports. The winters are followed by very hot, dry summers. Although seasonal rains called monsoons do occur during the summer as moist air is pulled in from the Gulf of California, these storms often bring brief, heavy rain that causes localized flooding as it runs off the parched ground. It does not soak into the ground to replenish the groundwater supply that eventually flows into surface streams. Water supplies for the region are drawn from naturally occurring underground water storage features called *aquifers* (AK-wuh-furz), from moving groundwater, and from large rivers. As the population grows, demand for water from all three of these sources increases. However, the water resources themselves are finite. While the population increases, the water supply essentially stays the same.

Cities versus Agriculture

The desert Southwest has been experiencing drought conditions for most of the last decade. This has put a severe strain on the water that is available. Eighty-five percent of all water in the United States is used for irrigating farms and ranches, and most of that irrigation occurs in the desert Southwest—an area that blooms as long as there is sufficient water. The other 15 percent of the fresh water supply is used by people. Those people aren't necessarily distributed where the water is. Indeed, they are increasingly moving to where the water isn't.

One of the nation's rivers in severe trouble due to overuse of water is the Rio Grande. The headwaters of the Rio Grande start in southern Colorado, and the river winds through New

Mexico and Texas, defining the boundary between the United States and Mexico, before entering the Gulf of Mexico near Brownsville, Texas. In 2001, the Rio Grande stopped flowing into the Gulf of Mexico. An accumulation of silt and weeds blocked the low flow. In the spring of 2003, stretches of the river within Big Bend National Park in west Texas were completely dry.

Where did the water go? The combination of below-normal rainfall and increased demand for water has literally drained parts of the river dry. Agricultural needs increase

The Rio Grande is one of the nation's ten most endangered waterways, according to the environmental group American Rivers. The river's banks were home to some of the earliest established Native American settlements in the United States. There is a concerted effort under way by private organizations and state, federal, and tribal governments to restore the river to health.

during droughts. Farmers and ranchers could lose their livelihoods if they can't draw on river water for irrigation. Likewise, cities along the full length of the Rio Grande have been concerned about the availability of water for the past two years. Water is being stored in reservoirs to ensure that there is sufficient fresh water, but conservation efforts are required. Residents of El Paso, Texas, had 43 percent less water available in 2003 than they had in a normal year. As a result, restrictions have been placed on lawn watering and other nonessential water use.

As Robert M. Hirsch, the associate director for water for the United States Geological Survey, has pointed out, most of the country has abundant water. However, the desert Southwest is not an abundant water region. The water supply cannot sustain the current rate of use.

Economic Disruption

The state of Texas found out the hard way what happens when the water stops flowing. In 1996, the state was struck by a major drought. Both agriculture and industry were hit hard. Little water was available to irrigate crops and keep livestock alive. Ranchers ran out of water and had to sell off their herds, taking an economic loss. Some major cities did not have enough water for both industry and their citizens. Manufacturers were forced to close their plants when the water was shut off. The total losses amounted to several billion dollars.

To avoid a similar catastrophe in the future, Texas created a comprehensive water plan, composed of detailed local water plans from over 2,200 cities and other water users. It is perhaps the most detailed water plan in the nation. The plan will be updated every five years in an effort to prevent another water emergency like the 1996 drought.

A local farmer and business owner in Presidio, Texas, points out some of the low points of the Rio Grande. Initiatives in the past to control flooding and maximize water sources for the area have had a backlash effect, altering and damaging the river's natural flow.

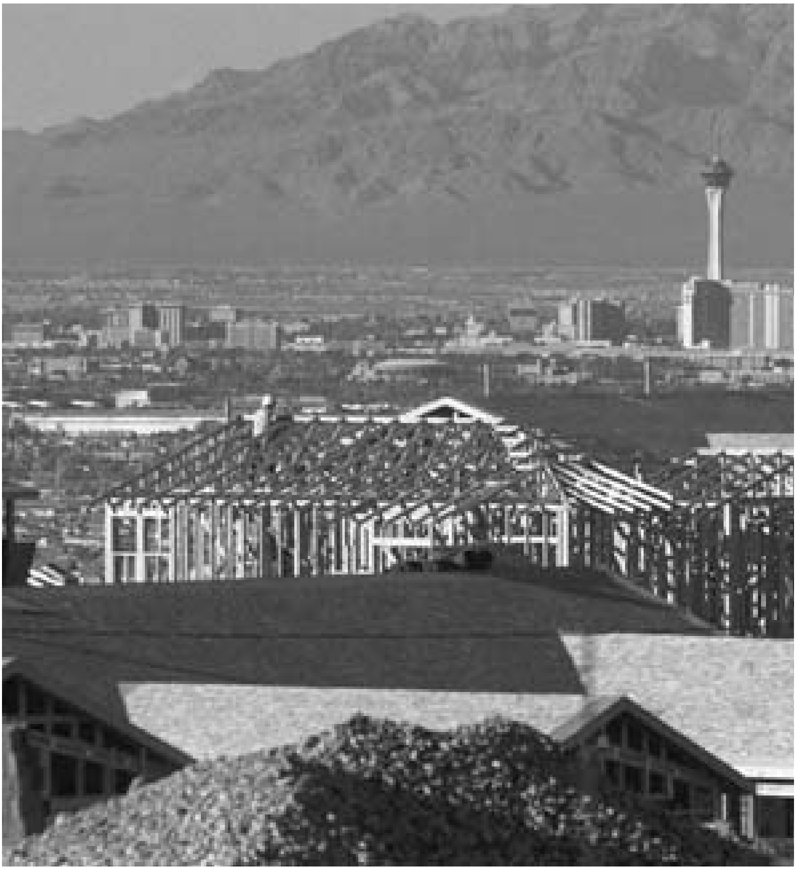
However, Texas projects that its population will double from 20 million to 40 million people by 2050. Based on its latest calculations, at least 900 cities in the state will not have enough water to support their increased populations. Looking ahead to meet this need, state water planners have recommended the addition of eight major reservoirs in the next few years. (The state currently has 200 major reservoirs.)

Although per person water usage has leveled off in the past few years, the demand for water will increase as the population grows. An increasing population requires an increased industrial base and more food to support it. Both industry and agriculture will require additional water to meet the need.

The Las Vegas Story

The fastest-growing region in the United States is the Las Vegas Valley of Nevada, which encompasses Clark County and its county seat, the city of Las Vegas. Las Vegas was just a small desert town of about 5,000 people until the construction of nearby Hoover Dam in 1931 brought an influx of new residents. During World War II (1939–1945), the military established bases in the area, drawn by the abundant water of the Colorado River and inexpensive power.

The city's fortunes changed significantly in the 1960s, when developers with plenty of cash moved into town and



Nevada has been the fastest growing state in the nation for thirteen straight years. The continuing commercial and residential development in Las Vegas has placed great strains on water supplies throughout the state.

started building fancy resort hotels and casinos, expanding the gaming and entertainment industries. Since then, Las Vegas has seen even greater growth—people are drawn by abundant jobs and a reasonable cost of living. By 1990, the number of new residents streaming into Las Vegas had outstripped the available water. Las Vegas was a city in trouble. Water resource personnel estimated that it would run out of water by the middle of the decade. If that happened, the city would not be able to survive.

Clearly something had to be done about the water supply. Eighty-eight percent of the water used in Las Vegas comes from the Colorado River. The rest of the water comes from wells that have been drilled into a large underground water basin. Since the amount of *recharging* (water returning to the basin underground) has been less than the amount pumped out, there are restrictions on pumping from the wells.

In 1991, the water and sewage agencies in the area joined together to form the Southern Nevada Water Authority (SNWA). The goal of the SNWA is to bring water to Las Vegas in the least expensive manner possible. By 1993, the leadership of the SNWA convinced the Nevada legislature to give three of seven seats on the Colorado River Commission to members representing the Las Vegas region. This had the effect of giving water districts within Las Vegas more control over the distribution of water within the entire state. The SNWA was able to make deals that brought additional water to the city from aquifers located north of Clark County. The additional water was stored at Lake Mead, and Las Vegas drew upon this water as needed.

While this seemed to be the answer to the city's supply problem, other areas in the state were adversely impacted. Northern Nevada lost water under this deal and found its agricultural and business interests with insufficient supplies. Even in Las Vegas, all was not well. A 2,000-acre (800-hectare) wetland associated with Lake Mead has been destroyed, and the water in the lake has become contaminated. In 1994, a serious outbreak of waterborne illness traced back to Lake Mead resulted in thirty-two deaths. Seventy-eight people were left seriously ill. Water quality is so poor that citizens of Las Vegas are discouraged from drinking tap water.

Nevadans aren't the only ones upset about Las Vegas's grab for water. As Las Vegas removes water from the Colorado River, it leaves less for downstream customers in Arizona and California. One idea under consideration would have Nevada build a desalination (dee-sal-uh-NAY-shun) plant on the California coast to meet part of that state's requirements. (*Desalination* is the process whereby salt is removed from ocean water to make fresh water for drinking.) Nevada, in turn, would be able to withdraw some of California's share of water stored in Lake Mead.

In the meantime, people living in Las Vegas are being encouraged to conserve water by taking shorter showers, using low-flow faucets, running full loads in dishwashers and clothes washers, and reducing the number of times that they flush toilets. They are also being asked to tear out water-thirsty plants in their gardens. While most people don't mind conserving water, they are irritated that more houses and apartments are springing up around the city. Large hotels and resorts continue to use large amounts of water in fancy fountains and pools that lose a significant amount of water to evaporation (ih-vap-uh-RAY-shun) in the dry desert air, and golf courses continue to use water to stay green.

The Federal Response

Interior Secretary Gale Norton unveiled the "Water 2025: Prevent Crisis and Conflict in the West" plan in the spring of 2003. This plan is an attempt to prevent future fights over limited water supplies. As Norton has noted, "Crisis management is not an effective solution for addressing long-term, systematic water supply problems." The plan would dedicate federal money and technical resources to ensuring the viability of

The ruins of the western town of St. Thomas, Nevada, hidden underneath Lake Mead for sixty-five years. The town was deliberately flooded in 1938 when the newly constructed Hoover Dam sent the waters of Lake Mead in its direction. The lake, at a thirty-year low, now reveals the long-lost town. Many see the shrinking lake as an example of what can happen when water sources are manipulated and left unchecked.

important watersheds (large areas that collect rainwater and snowmelt that ends up in rivers and aquifers) in the western United States. It would also support research in water conservation and desalination techniques.

The Bush administration will request $11 million in the 2004 budget to fund this effort. Not everyone thinks that is enough money. Nevada representative Shelley Berkley argues that it doesn't "take a rocket scientist to figure out we have major water issues in the United States and with the fastest-growing community located in Nevada, eleven million dollars is not adequate to help solve the crisis that is looming."

As Secretary Norton has pointed out, Las Vegas is only one of several cities facing serious water shortages in the near future. Carson City and Reno, Nevada; Albuquerque, New Mexico; Denver, Colorado; Houston, Texas; Salt Lake City, Utah; and Flagstaff, Arizona are all experiencing water shortages. Those shortages will increase, if the drought continues and populations grow. However, Norton is on record as saying that the federal government will not restrict population growth in these areas. Decisions about growth, Norton says, are best left to cities and states.

Questions to Consider

1. Should cities facing water problems be allowed to restrict new housing and businesses to prevent population growth? Why or why not?
2. Should water be set aside for cities, even if it means less water for agriculture? Why or why not?
3. If water is in short supply, should cities have the authority to restrict water use by residents? Why or why not?

CHAPTER 6

Should the U.S. Manned Space Program Be Continued?

The United States launched its first manned space flight on May 5, 1961. Astronaut Alan Shepard (1923–1998) rocketed off from Cape Canaveral, Florida, for a fifteen-minute, twenty-eight–second, suborbital flight aboard the *Freedom 7* space capsule. Since that time, the United States has sent individuals (Project Mercury), pairs (Project Gemini), and groups of three astronauts (Project Apollo) into orbit around Earth. These flights were followed by the Moon landing of *Apollo 11* astronauts Neil Armstrong (1930–) and Edwin "Buzz" Aldrin (1930–) on July 20, 1969.

On May 14, 1973, the United States launched its first space station, *Skylab 1*. Less than two weeks later, its first crew of astronauts arrived and remained onboard for twenty-eight days. (*Skylab* fell out of the sky—with no one on board—in 1979.)

The United States launched the first reusable manned spacecraft—the space shuttle *Columbia*—on April 12, 1981. Shuttle flights continued at regular intervals until January 28, 1986, when the shuttle *Challenger* exploded just seventy-three seconds after lifting off. All seven crew members were killed. It would be over two years before another shuttle was launched.

Shuttle flights then continued on a regular basis. The shuttle carried scientific experiments, launched satellites and the Hubble Space Telescope while in orbit, and delivered people and supplies to the International Space Station. On February 1, 2003, tragedy once again struck the shuttle program when the *Columbia* broke apart over the western United States during its return to Cape Canaveral. Once again, all seven astronauts were killed. The loss of a second shuttle and crew has provoked much discussion over the future of the manned space program.

Yes

I have been watching launches of U.S. manned space missions since I was a youngster forty years ago. My family lived in California, and that meant the rockets were launched from Florida at four o'clock in the morning, Pacific time. With our eyes riveted on the screen my dad and I would count down the seconds—five…four…three…two…one…liftoff! I'll never forget it.

The excitement of the manned space program was one reason that I majored in mathematics (math-uh-MAT-iks) *and minored in science while I was in college. I knew that I'd never be part of the space program—there weren't women astronauts, or even pilots, in the early 1960s—but I could be a part of the advance of science, just like they were.*

In the past forty years, manned space flight has become routine, and people take it for granted. My children can't remember a time that the space shuttle didn't fly. It's no big deal to them. However, the space program could be much more than a disintegrating shuttle fleet with not much purpose. I think that the manned space program should continue—it should continue on to Mars. We've learned a lot about Mars with unmanned flights and remote-controlled roving vehicles. We could learn much more by putting people on Mars and letting them explore the landscape. These astronauts would be carrying on in the tradition of Meriwether Lewis and William Clark, who explored the American West and contributed greatly to science during their trip to the Pacific Ocean 200 years ago. We need manned space flights to expand our scientific knowledge and inspire another group of young people to reach for the stars.

No

As a scientist, I think that there is only one reason to have a space program: to advance science. If the program doesn't advance science, then we need to scrap it and put the money into something else. As great as the manned space program has been, it has not paid off in scientific discoveries. There is nothing that people can do in space that cannot be accomplished with unmanned spacecraft.

Our manned space program has become not only terribly expensive, but also extremely deadly. Fourteen talented people—scientists, physicians (fuh-ZISH-unz), *pilots—have been killed in two catastrophic failures of the space shuttle. Fourteen irreplaceable people and $5 billion worth of hardware, lost.*

The shuttle was built for a number of reasons. One was as a platform for scientific experiments. Well, it turned out that industry wasn't much interested in space experiments, and consequently, there was no commercial interest. The experiments that did go up with the shuttle could have been sent up on unmanned rockets with the same results—and less expense. Yes, the shuttle launched the Hubble Space Telescope and some satellites, but they could have been more cheaply launched with regular rockets, too. Spending large sums of money on the shuttle fleet when just a fraction of that money could accomplish the same goals is a wasteful use of limited government funds. Sacrificing human lives can never be justified.

Discussion

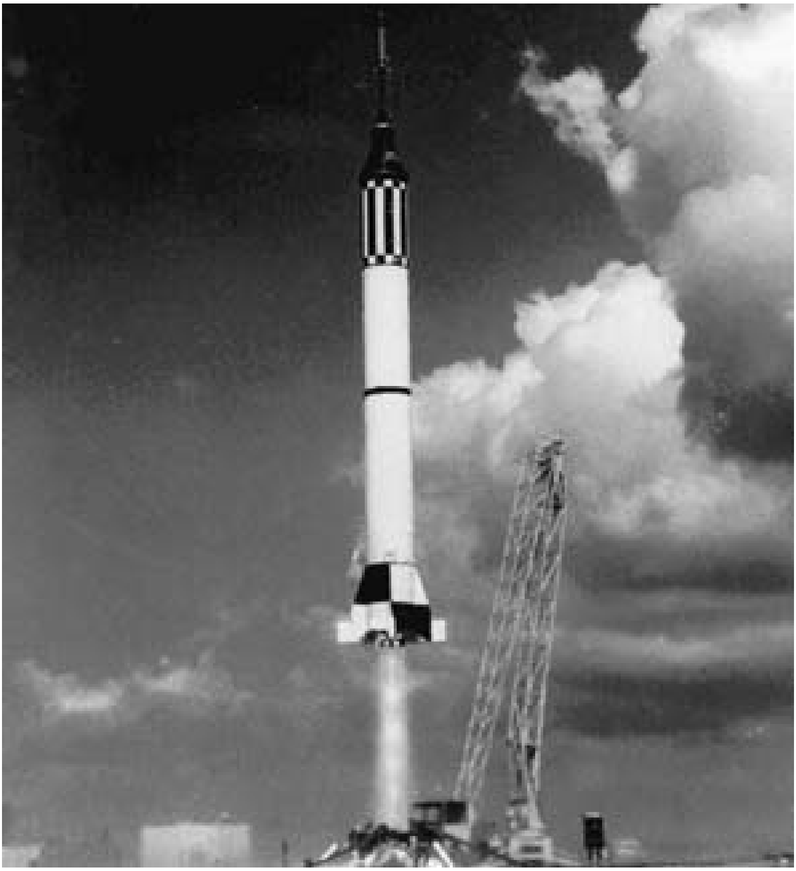
The race for space was sparked by the Soviet Union's launch of a 183-pound (82-kilogram), basketball-sized, spiked hunk of aluminum named *Sputnik* on October 4, 1957. This event was viewed with alarm in the United States. If the Soviets could launch a satellite into space, then they could presumably launch a rocket with a nuclear warhead that could strike anywhere on American soil. A U.S. team had also been working on a rocket to carry a satellite system into space, but it was only going to weigh 3.5 pounds (1.6 kilograms). In no way was the United States ready to launch a satellite on a par with *Sputnik*.

What was at stake was not just superiority in science and technology. This was the time of the Cold War, a war of ideas between the United States and the Soviet Union (present-day Russia) for influence around the world, which lasted from shortly after World War II to the early 1990s. In the Cold War, each side—Soviet and American—strove to demonstrate that its political system was superior to the other by showcasing achievements in science, technology, agriculture, the arts, and, of course, military hardware. It was within this context that America's manned space program was begun.

The U.S. manned space program was not about the advancement of science or even about the exploration of space. The advances in scientific knowledge and technological know-how that resulted from putting men on the Moon were just a by-product of the political goal of ensuring that the world looked upon the United States as a superpower. Indeed, scientists argued that it made more sense to put the money for the manned space program into unmanned spacecraft that could travel to the far reaches of the solar system, sending back information about planets, comets, and asteroids (ASS-tuh-roydz). In the twenty-first century, the debate over the usefulness of a manned space program continues.

Why Manned Space Flights?

After World War II, the U.S. Air Force took the lead in rocketry, examining the idea of putting humans into space. In military-based space programs, national defense was the first priority. In 1957, after the Soviets launched *Sputnik,* President Dwight D. Eisenhower ordered the creation of a civilian space agency, NASA. Eisenhower, who was not convinced of the value of manned space flights to begin with, wanted any manned missions to be under civilian control and wanted science to be NASA's first priority. Thus, NASA launched the first phase of the manned space program—Project Mercury.



The Redstone rocket blasts off in 1961, carrying astronaut Alan B. Shepard Jr. into space. This flight initiated the U.S. manned flight space program, which remains controversial to this day. Although the program helped establish the United States as a leading technological power, critics argue that the scientific research we do in space does not require manned spacecraft.

Although under civilian control, the Project Mercury astronauts were all military test pilots—the best that their services had to offer. Selected in 1959, the astronauts started training for the first flight—undertaken by Alan Shepard in 1961. The nation's intense interest in the astronauts and in manned space flights cannot be overstated. The entire country's attention was riveted on Shepard's suborbital flight and on all the Project Mercury flights that followed. Americans were filled with pride over the accomplishments of their astronauts.

There was no shortage of drama and human interest in these early space flights. At the end of the three-orbit flight taken in 1962 by John Glenn (1925–), problems with the heat

John Glenn, who in 1962 became the first American to orbit the earth, returned to space in 1998 as a member of the shuttle Discovery *crew. The national excitement over Glenn's trip into space at the age of seventy-seven mimicked the pride and enthusiasm Americans had for the space program when it began.*

shield during reentry left the country holding its collective breath to see if he was okay once communications were reestablished with his spaceship. Then there was the off-course flight of Scott Carpenter (1925–) in his space capsule *Aurora 7,* which landed 200 miles (320 kilometers) away from its target. The nation's attention was once again riveted as U.S. Navy search planes and helicopters combed the Pacific Ocean, looking for the bobbing capsule. The fascination with manned flight did not wane as NASA followed Project Mercury with the two-man capsules of Project Gemini and the three-man capsules of Project Apollo.

President Eisenhower's original goal was a science-oriented space program, but once President John F. Kennedy took office in January 1961, politics took on a greater role. Kennedy had been in office for only three months when Soviet cosmonaut Yuri Gagarin (guh-GAHR-un) (1934–1968) became the first human to orbit Earth in April 1961. With an intense desire to outclass the Soviets, Kennedy asked his advisers to propose a "space program which promises dramatic results in which we could win."

The proposal from NASA administrator James Webb and Secretary of Defense Robert McNamara was that the United States make landing men on the Moon a national goal. They reasoned that "it is man, not merely machines, in space that captures the imagination of the world." Such an achievement in space would "symbolize the technological power and organizing capacity of a nation." In other words, putting men on the Moon was not about science at all. It was about increasing the prestige of the nation. This idea has been central to U.S. efforts in space ever since. On July 20, 1969, when the United States became the first and only country so far to land men on the Moon, Neil Armstrong's "One small step for man—one giant leap for mankind" placed America ahead of the Soviet Union in the space race. As a group, Americans may never have been prouder than they were that day.

Scientific Missions

While the manned space program fascinated the nation—and the world—it was the unmanned missions that were providing scientific insight into the solar system. Unmanned missions have sent back detailed images and scientific information about every planet but Pluto, for which a mission is planned sometime in the future.

The first unmanned spacecraft to another planet was *Mariner 2,* which flew by Venus in 1962. *Mariner 5* (launched in 1967) and *Mariner 10* (launched in 1973) also went to Venus. *Mariner 10* sent back images of Venus's cloud tops before continuing on its way to Mercury. Two more sophisticated spacecraft—*Pioneer Venus 1* and *2*—were launched in 1978. *Pioneer Venus 1* was the first spacecraft to use radar to map a planetary surface, while *Pioneer Venus 2* dropped four probes to the planet's surface in parachutes. A little over a decade later, in 1989, the *Magellan* spacecraft took detailed images of Venus's surface.

The first mission to Mars—*Mariner 4*—left Earth on November 28, 1964. It was followed by *Mariner 6, 7,* and *9*—all of which sent back images that were carefully examined by scientists seeking information about Martian landforms. Then in 1975, *Viking 1* and *2* rocketed off to Mars. These spacecraft carried "landers" that were sent to the surface of Mars while the spacecraft orbited the planet overhead. The landers sent back images from the surface and took and analyzed soil samples, radioing the information back to Earth. *Viking 1* remained in orbit around Mars from June 1976 until its power was shut off in August 1980. *Viking 2* was in orbit from August 1976 until its power was cut in July 1978. Like the landers, the orbiters sent images of the Martian surface back to Earth.

There were several missions to Mars in the 1990s. The Mars *Pathfinder*, complete with its "rover"—a remote-controlled exploration vehicle that traveled over the Martian surface—landed on July 4, 1997. Shortly after, the *Mars Global*

The Mariner 2 *spacecraft launched in 1962 speeds toward Venus, improperly unfolding its solar panels in the process. The glitch didn't keep* Mariner 2 *from becoming the first spacecraft to fly by a planet or from sending back valuable information on the temperature of the clouds and surface of Venus.*

Surveyor entered into orbit around Mars. Its mission was to carry out six different scientific studies. While all of these missions were successes, there have been a few failures on the way to Mars. The *Mars Climate Orbiter,* launched in December 1998, and the *Mars Polar Lander,* launched in January 1999, both suffered from technical problems that ended their missions before the spacecraft collected any scientific data. The next two Mars rovers, dubbed *Spirit* and *Opportunity*, landed in January 2004. The rovers had been engineered to travel 330 feet (100 meters) per day across the surface, collecting information from the atmosphere, rocks, and soil.

Other very successful unmanned missions that returned large amounts of valuable scientific information were those that flew to Jupiter and Saturn—*Pioneer 11* (launched in April 1973) and *Voyager 1* (launched in September 1977). These missions sent back hundreds of images of both planets and provided detailed (and previously unknown) information about the planets, their moons, and Saturn's rings. *Voyager 1* also provided the first faint images of Jupiter's faint, narrow ring. *Voyager 2* (launched in August 1977) not only flew by Jupiter and Saturn, it continued on to Uranus and Neptune, returning thousands of images of all these planets. *Galileo* (gal-uh-LAY-oh)—a joint mission with the European Space Agency—left Earth in October 1989 and took six years to travel to Jupiter. Arriving in December 1995, it sent a space probe through Jupiter's atmosphere to collect information. *Galileo* then continued to orbit Jupiter, sending back images of the planet and its moons until NASA deliberately crashed the spacecraft into the planet on September 21, 2003. Before being permanently damaged by radiation in the planet's atmosphere, *Galileo* beamed information about the atmosphere back to Earth.

The *Cassini* (kuh-SEE-nee) spacecraft—launched in October 1997—is a project jointly sponsored by NASA, the European Space Agency, and the government of Italy. *Cassini* will arrive at its target planet, Saturn, in July 2004. Carrying twelve scientific experiments, *Cassini* will allow scientists to discover more about Saturn's atmosphere, rings, and moons.

Planets aren't the only heavenly bodies being investigated by unmanned spacecraft. The *Contour* mission left Earth in July 2002 with plans to visit three different comets between 2003 and 2008. The first encounter was with Comet Encke in November 2003, to be followed by Comet Schwassmann-Washmann-3 in June 2006 and, finally, Comet d'Arrest in August 2008. The *Contour* spacecraft will analyze the comets' nuclei, as well as the dust surrounding the comets. Although there haven't been specific missions to asteroids, missions to

Jupiter and Saturn have passed through the asteroid belt that lies between Mars and Jupiter. En route, those spacecraft have sent back images of the asteroids that were close by.

Unmanned spacecraft with robotic sensors and cameras have enabled earthbound scientists to make many discoveries about the solar system. The early manned space missions, as

The Cassini *spacecraft, launched in 1997, is said to have better senses than a human. It can see and feel light, energy, and magnetic fields that no human being could detect.* Cassini *is scheduled to reach Saturn in 2004 and will spend four years orbiting the planet and its moons, transmitting valuable data back to Earth.*

fascinating as they were to the general public, did not make significant contributions to the physical (FIZ-ih-kul) and earth sciences. They did contribute in small measure to the medical and life sciences, since specialists in those fields were able to monitor the effects of weightlessness and the stresses of space travel on astronauts. One reason that those early manned missions were short on scientific discoveries was that there was no space inside the capsules to conduct scientific experiments. That problem was to be solved with the development of NASA's space shuttle program.

The Space Shuttle: Promise and Reality

Project Apollo, which had taken men to the Moon, was a victim of its own success. Once the United States had won the space race with the Soviet Union, funding for NASA's next big manned mission—to Mars—dried up. Having shown the

The space shuttle Discovery *takes off from the launchpad in 1998. Despite the loss and tragedy of other shuttle missions, there have been a number of scientific discoveries that have practical applications here on Earth. Government and space officials must constantly weigh the human cost against the need for progress.*

world that America had the superior space program, and with no sign that the Soviet Union was in hot pursuit, the U.S. government saw no urgent need to continue the space race at breakneck speed. If manned spaceflight were to continue, it would have to do so on a smaller budget, and it would need to be more practical than just sending people up to orbit Earth or make yet another trip to the Moon.

Enter the space shuttle. In October 1969, a space shuttle symposium was held to discuss just what such a system might look like. The opening remarks set the theme. The idea was to reduce the cost per pound (0.45 kilograms) of *payload* (the spacecraft and whatever it would carry in orbit) from $1,000 to between $20 and $50. If this could be done, then there would be all sorts of opportunities to use the space shuttle to carry satellites for launching, for manufacturing processes for industries in space, and perhaps even as a hotel. (According to some accounts, the Hilton family offered to build a hotel in orbit if the cost dropped to less than five dollars per pound.) Indeed, Francis Clauser, chair of the college of engineering at the California Institute of Technology, envisioned low-orbit space travel so inexpensive that the average citizen would be able to afford a ticket for a flight into space. Aerospace industry leader Lockheed Corporation's Max Hunter envisioned as many as ninety-five space shuttle missions per year at a cost of around $350,000 each, or $7 per pound of payload delivered into orbit. As long as the cost were below $50 per pound, he said, Texas Instruments (a company that made calculators and other electronic gear) would be interested in moving some of its manufacturing operations to space. In space, weightlessness would aid in the creation of silicon chips and crystals for electronic equipment.

In other words, the symposium participants viewed the space shuttle as nothing more exciting than a space-going aircraft with regularly scheduled runs that would basically pay for themselves. NASA would provide the crews and the shuttles, while the companies would provide the payloads, for which they would foot the bill. The use of the space shuttle for scientific experiments didn't even come up.

The development of the shuttle went forward, but on a much-reduced budget. The first shuttle mission roared away from Cape Canaveral on April 12, 1981, for a two-day shakedown mission, successfully landing at Edwards Air Force Base in California on April 14. The next launch took place in November 1981. Although it was supposed to be a five-day trip, problems with a fuel cell cut it short to two days. Flights continued from then on, but in stark contrast to Hunter's vision of ninety-five flights per year, the shuttle typically made about five or six flights per year at a cost of over $500 million per flight.

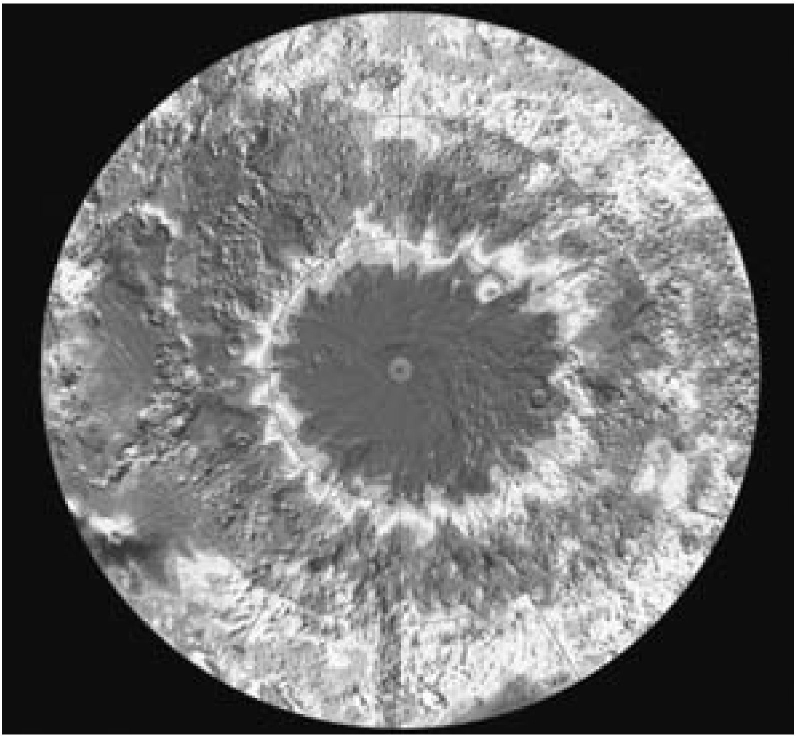
The shuttle crews deployed satellites and hauled up pieces of the International Space Station, but both tasks could have been accomplished by unmanned spacecraft. With improvements in robotic techniques, most of the scientific experiments on the space shuttle could have been performed by other means for much less money. In the meantime, the money that could have funded less expensive unmanned missions was being absorbed by the shuttle program.

The shuttle program continued with little public attention, despite the loss of the *Challenger* mission in 1986. However, with the loss of the *Columbia* and its crew of seven in 2003, some people began to question the need for manned space flight.

The Benefits of Manned Space Flight

Space shuttles have carried a variety of physical science, earth science, and life science experiments into space. For example, an experiment in growing cadmium zinc telluride crystals in space showed that the space-grown crystals were of higher quality than those grown on Earth and would improve the accuracy of electronic sensors, such as radiation detectors. The results of another experiment on the behavior of drops of liquid may be able to improve technologies used in the making of medicines and in chemical processing, as well as aiding the understanding of rain formation. Space shuttle experiments are welcomed by the scientific community because they eliminate the effects of gravity. (However, even though crystals grown in a weightless environment are better than those grown on Earth, it is unlikely that there will be widespread manufacturing in space until permanent colonies are established in space.)

If manned space flight isn't fundamentally about the advance of science, then what can justify the continued expense, and risk of life, that accompany it? Those who support the continuation of manned space flights point to the broader purposes that they serve. Even if these missions are not overtly scientific, they do serve to inspire another generation of students to seek careers in science and technology. It is



NASA's 2001 Mars Odyssey *spacecraft provided this view of the surface of Mars, indicating that much of the planet contains water, mixed as ice with the dirt, dust, and rock that form the planet's surface.*

scientific, engineering, and technological expertise that allows the United States to put people into space, whether aboard the space shuttle, on board the International Space Station, or perhaps on a spaceship to another planet sometime in the future. Manned spaceflight also serves as a symbol of American leadership in the world, while giving all Americans an achievement in which they can feel a sense of pride. If the human element is cut from the space program, it is likely that support for the space program itself will dwindle. Because it takes several years for space probes to reach their destination, the resulting photos aren't enough to keep the interest of most Americans. The technical details of discoveries about soil, rocks, or even ice on Mars is not going to stir pride in the space program.

Humans have always been explorers, seeking the next frontier across mountains, seas, and continents. Adventurers have always been drawn to leave the human community and go to places that no one has ever been before. Now, those places are out in space. Should the United States continue its manned space program to find them? The debate is unresolved.

Questions to Consider

1. Should the risk involved in human space travel determine whether the U.S. space program continues? Why or why not?

2. Does the possibility of human space travel to other planets influence your interest in a scientific career? Why or why not?

3. Each flight of the space shuttle costs taxpayers $500 million. Each shuttle costs $5 billion. Do the scientific results gained from the space shuttle flights justify the expense? Why or why not?

CHAPTER 7

Should Companies or Governments Try to Control the Weather?

In 1945, Vincent Schaefer (1891–1993) of General Electric Laboratories in Schenectady, New York, accidentally dropped tiny particles of dry ice (solid carbon dioxide) into a deep-freeze. Little snowflakes formed around the dry ice. Intrigued, Schaefer and his boss, Nobel Prize–winning chemist Irving Langmuir (1881–1957), decided to test their method on clouds in a nearby mountain area. Flying in a small plane, they dropped tiny particles of dry ice into the clouds. This technique, called *cloud seeding,* successfully produced precipitation. Langmuir soon secured government funding for additional trials to show that seeding clouds with either dry ice or silver iodide could make rain.

By the early 1950s, private consulting firms were offering to produce rain for farmers and hydroelectric (hye-droh-ih-LEK-trik) companies for a fee. The federal government, concerned about unregulated rainmaking, formed an advisory committee to investigate whether these techniques really produced "weather on demand." As a result of the committee's recommendations, the National Science Foundation (NSF) funded a five-year, $5 million research project on weather control starting in the late 1950s. By the 1960s, there were many more private weather control firms, and the government was spending millions of dollars every year on additional research. The military tried to use weather as a weapon in the Vietnam War (1964–1975) by producing rain over trails used by the North Vietnamese, despite protests from meteorologists and other scientists.

Although the peak years of government spending on weather control research ended in the 1980s, weather consulting companies continue to sell rainmaking services in parched Western states. The U.S. government still sponsors weather control research, but on a more limited basis than in the past.

Yes

I am a water resources official in a Western state that doesn't get much rain. In fact, over the past several years, my state has experienced a severe drought. Not only have we received limited rain, but the winter snows were extremely light. We depend on the winter snowpack to melt and provide water in rivers and streams for farmers and ranchers—not to mention for people in cities to drink—all during the summer. When the snows don't come year after year, it creates a great hardship for people.

It isn't like we don't have clouds floating overhead. We do. However, they don't rain or snow. Moisture in the sky doesn't do us a whole lot of good on the ground. For the past several years, we have contracted with a firm that makes rain. The firm's meteorologists keep track of where the clouds are and then launch their fleet of aircraft to seed the clouds with silver iodide. As a result, snowfall increased between 15 and 18 percent over what we would have gotten without seeding. That may not seem like much, but in a dry state like mine, it makes a huge difference. When the mountains get more snow, people come to ski. That pumps more money into the local economy. Then when the snow melts in the summer, the streams are full and the farmers and ranchers don't have to worry that there won't be sufficient water for their crops and animals. I know that some people think that we are playing God by squeezing rain out of these clouds, but having some control over the weather makes a big difference in the quality of life for all the people in my state.

No

As a state legislator working for the benefit of the people in my district, I have heard all the arguments for cloud seeding and weather control. The ski resorts say that they need the increased snow to attract more skiers and improve the local economy. They claim that seeding allows them to hire more people, which is important, since people are looking for jobs. The hydroelectric companies say that they need more snow to fall in the mountains so that there will be spring and summer runoff to generate cheap electricity. The farmers—who insist on trying to grow crops where there isn't enough water to begin with—claim that they need to seed the clouds to keep their farms going. However, I don't think it is right for people to try to control the weather.

Making rain for farmers and snow for ski areas is a good thing. So what happens when weather control is a bad thing? If one state seeds clouds to get the rain, what happens to the state that is farther downwind? Hasn't the first state "stolen" the rain that the next state would have gotten? That just doesn't seem fair.

Furthermore, governments have already tried to use weather as a weapon. During the Vietnam War, the United States had a secret plan to make rain in Vietnam and Laos. The idea was to make the trails muddy and keep the enemy's army from moving. The military might have thought it had control, but what if it rained more than they thought it would or in the wrong place? What if a government that didn't like our policies used weather control to try to prevent the United States from getting its normal rainfall? If we can do this sort of thing to other governments, can't they do it to us? It seems to me that we are playing God when we allow weather control.

Discussion

Weather control, also known as weather modification, has been practiced by individuals and companies promising to bring rain and snow to areas that needed it since the middle of the twentieth century in the United States. It has also been practiced by governments and companies around the world. In fact, weather control is a multimillion-dollar business.

The science behind weather control depends on a solid knowledge of cloud physics (FIZ-iks)—in other words, how clouds form and grow in the atmosphere. The first definitive studies were done by European meteorologists in the 1930s. Then weather control was taken up seriously in the late 1940s after the early work by Schaefer, Langmuir, and Bernard Vonnegut (1914–1997) at General Electric. The first major trial—called Project Cirrus—was a five-year field study funded by the Defense Department. The U.S. Weather Bureau conducted cloud physics studies in the late 1940s, and the air force and navy conducted their own field experiments on both *strat-*

Irving Langmuir (left) and Bernard Vonnegut look on as Vincent Schaefer exhales in an attempt to turn his breath into crystals. These early experiments, part of Project Cirrus, which was carried out by General Electric in the 1950s, led to weather control practices that raised legal, ethical, and economic issues for future policy makers.

iform (flat) clouds and *cumuliform* (puffy) clouds. However, results were mixed. It appeared that the seeding did have some effect on the growth of clouds, but researchers were unable to determine that seeding significantly increased the amount of precipitation. Other studies concentrated on clearing fog from airport runways—a critical issue for both commercial and military airfields.

Weather Wars

Commercial firms started actively marketing rainmaking services in the early 1950s. Although it might seem odd because of the large amount of rain and snow that falls naturally in the state, Washington's farmers and utilities were among those in the western United States contracting with rainmakers. The wheat farmers who lived in the eastern part of the state wanted the rainmakers to provide more than the 10 inches (25 centimeters) of rain that usually fell in a year. Ten inches is just barely enough to raise wheat. To insure the success of their crops, the farmers got together and paid rainmaking firms to seed clouds for them. Another group in Washington also wanted more precipitation: the hydroelectric companies. The more snow that fell in the mountains, the more cheap electricity they could produce as a result of the spring melt. In this case, rainmakers worked on seeding winter clouds. They set up "cannons" on the ground that fired silver iodide up into the clouds from below.

Unfortunately, some of the rain did not fall on the wheat farmers' fields. Instead, it fell in the hills that are home to cherry farmers. If rain falls when cherry trees are blooming, it knocks off the blossoms, and there is no crop. If rain falls when cherries are ripe and ready for harvesting, the cherries split and are ruined. Therefore, the cherry farmers fought back by hiring an "anti-rainmaker" to stop the rain from falling. Thus the desire of different groups to control the weather led to one of the first "weather wars."

In an attempt to keep the disputes over weather under control, the state of Washington held a number of hearings. Eventually, the state government established a special board to license firms desiring to do business in weather control. Additionally, efforts were made to keep one region's desired weather from injuring that of another region.

Weather as a Weapon

During the Cold War, one potential weapon that was attractive to both sides was the weather. Using weather as a weapon had a special attraction for the military. Nuclear weapons had residual problems. Once the bombs were dropped, the entire target area was contaminated for years, if not for decades. If weather were used as weapon, there would be no contamination problems. Furthermore, since severe weather can occur on its own without any help from people, it would be difficult to prove that another country had launched a weather weapon. Military planners envisioned making heavy rain to bog down enemy armies and their tanks, fogging in runways so that enemy aircraft couldn't take off or land, and inducing drought to seriously reduce the enemy's food production. Military weather controllers could also use the same techniques to clear fog from their own runways, move rain away from their armies and tanks, and provide the rain needed to grow crops to feed the troops. Both the United States and the Soviet Union pumped millions of dollars into classified programs on weather control.

Meteorologists in the United States were very much opposed to this manipulation of the weather for other than peaceful means. Advances in meteorology depend on all nations sharing information about their weather conditions with every other country. Meteorologists were concerned that focusing on weather control to inflict damage on other countries would ultimately ruin the spirit of scientific cooperation that existed among nations, even during the Cold War.

Preventing Hail Damage

It may be fun to watch small hail bounce along the ground during a thunderstorm, but hail that is even 0.25 inches (0.6 centimeters) in diameter can cause a lot of damage in farmers' fields. Golf-ball–sized hail can dent cars, break windows, and punch through house siding. In short, hailstorms can cause serious problems. On September 7, 1991, Calgary, Canada, was hit by a hailstorm that caused over $400 million in damage. Five years later, a group of insurance companies banded together to spend almost $2 million per year on a hail mitigation project dubbed the Alberta Hail Suppression Project. The

Hail damaged this house during a storm that lasted for forty-five minutes in Liberal, Kansas. Opponents of weather control believe that we need to make more timely and accurate weather predictions to protect ourselves, rather than trying to exercise human control over the unpredictability of nature.

idea was to seed thunderstorm cells (individual thunderclouds) with silver iodide and cause the growing crystals inside them to precipitate as rain before they could grow into larger—and more dangerous—hail.

So far seeding has worked fine for the insurance companies. They have saved $50 million in insurance claims since seeding started. The same technique has been used in Kansas for over twenty-five years. The Western Kansas Weather Modification Program has used seeding to reduce damage to the area's vast wheat fields. In 1994, the Kansas Water Office determined that for every dollar spent on cloud seeding, thirty-seven dollars was returned in higher crop yields. As a result, the program was expanded into nine additional northwestern Kansas counties.

A seeding apparatus is shown on the wing of this specialized plane flying over Mexico. Opponents of the project believe there is no conclusive evidence that manipulating weather patterns has long-term benefits for all.

Not everyone was happy with the results in Canada and Kansas. Farmers downwind from the Calgary seeding sites thought that they were being deprived of rain that they needed for the crops. Already stressed by several years of drought, these farmers remained unconvinced when the staff running the seeding program maintained that seeding did not remove significant amounts of moisture from the clouds before they continued east. Likewise, in Kansas, some farmers complained that the seeding was reducing the rainfall over their fields. A few threats were made to shoot down the aircraft seeding the clouds, and newspaper ads claimed that the silver iodide was dangerous. Voters decided to end the funding for the program not long afterward.

There are other concerns about seeding thunderstorm cells. One of those concerned is Chuck Doswell, now retired from a career studying severe storms at the University of Oklahoma. In 1999, while watching the seeding of a thunderstorm cell, he saw a tornado develop from it. Then in 2000, another seeded thunderstorm cell spawned a tornado that killed twelve people and injured 140 in Pine Lake, Alberta, Canada. However, there is no proof that seeding thunderstorm cells actually causes tornadoes, and seeding has continued. Doswell argues that it is unrealistic to expect that people can tamper with the weather without experiencing some kind of side effects.

Does It *Really* Work?

Despite the millions of dollars poured into research during the last half of the twentieth century, there is no conclusive evidence that weather control works. In October 2003, the National Research Council—the research arm of the National Academy of Sciences, an organization composed of the most outstanding scientists in the United States—issued a report titled *Critical Issues in Weather Modification Research*. The report stated, "Although there is physical evidence that seeding affects cloud processes, effective methods for significantly modifying the weather generally have not been demonstrated." The report does acknowledge that there are potential benefits from cloud seeding and that more research is needed.

Representatives of states that have purchased rainmaking services over the last forty years are already believers in weather control techniques. The city of Denver's water board spent $1.1 million dollars on cloud seeding in the early 2000s to offset the impact of several drought years. Water board members think that the money they have spent is a better, and cheaper, investment than trying to purchase additional water rights or stored water. If the seeding brings more rain and snow, then they are ahead of where they were. If it doesn't, they are not much worse off for the year. Purchasing water rights entails an ongoing expense that does not guarantee water, either, and very little water could have been purchased for the amount of money spent on seeding. By restricting water usage, the city can survive a year of low rainfall and wait to seed again the next year.

New Mexico is also running a trial program in the southeastern corner of the state. Nevada has seeded its mountain areas for the last thirty years to enhance the snowpack needed to replenish summer water supplies. According to the National Research Council, there are sixty-six similar projects going on across the United States. Twenty-four other countries also have weather control projects under way.

Not all states in the western United States are as supportive of weather control. In Montana, farmers and ranchers were so concerned that making rain in one area would rob others of rain that the legislature set higher standards for seeding than those in other states. As a result, no seeding has taken place in Montana since 1993.

The American Meteorological Society issued its latest policy statement on weather control in 1998. The society made it

The 1998 drought in Oklahoma damaged more crops than any other drought since the 1930s. Eighty-year-old farmer Archie Gottschall inspects corn that should have been 6 feet (1.8 meters) tall by that time in July. It is debatable whether manipulation of the weather could have positively affected a drought that severe.

clear that while there is some statistical evidence that increased precipitation occurs due to cloud seeding, atmospheric scientists have still not determined the cause-and-effect relationship between seeding and production of precipitation. In other words, the rainmaking services are available and they may or may not work, but the scientific reasons behind the process are still waiting to be determined.

Questions to Consider

1. Should companies be allowed to make rain even though scientists don't know exactly why this process works or doesn't work? Why or why not?

2. Do you think that restrictions should be placed on weather control efforts to prevent their use as a weapon? Why or why not?

3. If rainmaking resulted in a flood that damaged property and injured people, do you think that the company that seeded the clouds should be held responsible? Why or why not?

CHAPTER 8

Should People Be Allowed to Build in High-Risk Areas?

Low-lying Atlantic and gulf coast areas are at risk from flooding during the six-month-long Atlantic hurricane season, which runs from June 1 to November 30 each year. Although the risk for any given town is small, some towns are at greater risk than others. For example, in the Outer Banks of North Carolina, high walls of water called the *storm surge* can come ashore with hurricane-force winds of 75 miles (120 kilometers) per hour or more. When high water from the ocean is combined with several inches of rapidly falling precipitation, the fast-rising water can wipe out homes and businesses—not to mention roads, bridges, and water and sewer facilities.

Towns that sit along rivers in low-lying coastal areas are also at risk. Heavy rains that fall as a hurricane passes accumulate in rivers and streams that head back to the ocean. As the water rises, flooding can cause huge amounts of damage.

Hurricanes aren't the only natural disasters that raise questions about development. Almost all rivers will eventually flood. When large rivers like the Mississippi and Missouri flood, the waters spill out of the banks and spread over thousands of acres of flat bottomland. People who live on the floodplain may be flooded out again and again.

The U.S. government does not turn its back on disaster victims. The Federal Emergency Management Agency (FEMA) provides disaster relief, in the form of low-interest loans, to help people rebuild their homes and replace their belongings. However, when people continue to live in areas at high risk of being wiped out by flooding, the government may be placed in the position of rebuilding their homes or businesses again and again. Should people be required to relocate to higher ground and thus avoid flood conditions?

Yes

I have lived near the Mississippi River my whole life. My parents lived here. My grandparents, great-grandparents, and even my great-great-grandparents have all lived within 1 mile (1.6 kilometers) of where my house is right now. My children will live here after I'm gone. Everyone in my family has been flooded out at some time or another. It makes sense, actually. The Mississippi is only a couple of miles from here. Held back by levees, it pretty much stays where it is supposed to stay. Sometimes, though, the rains fall and fall, and then the river rises until it laps over the side of the levees. Sometimes, the levees break loose, and all the water floods out. It is so flat here that once the water breaks out of the levees, it flows for miles around, flooding homes, farms, and businesses. It is a real mess when that happens. Folks that live up on the hills do better—they usually don't get flooded out—but I've never lived on a hill and I don't intend to move now.

When the floods come and the president declares this a disaster area, we are eligible for disaster relief funds. We get low-interest loans that allow us to rebuild and continue to live where we have always lived. Some people say that we should just let the government buy us out and move the whole town up the side of the hill. I'll bet they wouldn't be happy if someone forced them to move their homes or towns away from where they have always lived. Well, I wouldn't be happy, either. If it has always been good enough for my family, it is good enough for me. This is a free country, and I should be able to live anywhere that I want to live.

No

Another hurricane just swept over North Carolina. Some 10 inches (25 centimeters) of rain fell in just a few hours. Not long after, the rivers started to rise. Those people were lucky to get out alive. Their houses were destroyed—again! Representatives from FEMA have been sent in to help. They'll arrange for low-interest loans so that those unfortunate folks can rebuild.

I think it's fine that the government helps out—but some of these people's homes have been replaced two or three times. Every time that a hurricane comes through, the river floods, and they lose their homes. Then they rebuild in exactly the same place. That makes no sense at all. If the river flooded once, it will certainly flood again.

In my opinion, unless the flood was truly due to a very unusual circumstance, people who live in flood-prone areas should be forced to move to safer areas. It costs the government—and that means the taxpayers—less to buy people's homes and property and help them to settle on higher ground than it does to rebuild the home several times. I am sympathetic to the problem, and I understand that people don't like to leave the places that they know best. However, there are better ways to spend my tax money than to bail out people who are irresponsibly building in the same disaster-prone places.

Discussion

Natural disasters are a fact of life everywhere in the world. The United States is a big country with thousands of miles of coastline, thousands of miles of rivers and streams, and a lot of opportunities every year to be struck by massive wildfires, hurricanes, tornadoes, blizzards, droughts, floods, and landslides. All are potential disasters that can cause property damage, injuries, and loss of life.

The U.S. government extends assistance to people who have just lived through a disaster. If the disaster is widespread—for example, if it affected most of a state or large parts of several states—the region is declared a disaster area. Low-interest loans are made available so that people can afford to rebuild their homes and businesses. It is not in the best interest of federal, state, or local governments to have large numbers of homeless people left without basic shelter and the ability to care for themselves. During a major disaster, the mess left behind is just too big for any one agency to handle by itself. It takes the cooperation of many groups of people with specialized abilities to get disaster victims and their communities back to being productive again.

Some people live in areas that are hit by disaster just once in a few hundred years. Others live in areas called *floodplains* that are wiped out by flooding every few years. Floodplains are flat areas that do not rise much above the level of the river that runs through them. After weeks of rain or even just a few days of extremely heavy rain, the ground can no longer absorb any more water. What is left on the surface flows into little creeks, which in turn flow into streams that feed into the river. When the river gets too full, the water flows out over the floodplain. If the floodplain is within a river valley, and the flat area is only a mile or two across between the hills, there is no place for the water to go. It just fills up the valley and washes away everything that is there.

After Disaster, Radical Measures

Sometimes, it takes several years of disasters. Sometimes, it takes just one big one. Either way, when people become discouraged by devastation today, they are increasingly seeking to avoid falling into the same situation again. They are agreeing to use federal emergency relief money managed by FEMA either to rebuild in a safer way or to relocate.

Much of the coastal land in North Carolina is carved up by rivers and streams that are prone to flooding. The land is, quite simply, swampy. Even though generations of families have lived in the same spot, many people in the area have finally decided to let the government buy them out and move to higher ground. Hundreds of people in the town of Tarboro decided to take the buyout and move to higher ground. Other towns have

Top officials from the National Hurricane Center in Miami remain in constant contact with Federal Emergency Management Agency (FEMA) teams. In 2002, Tropical Storm Isidore was tracked as it strengthened and weakened over a period of ten days.

In 2003, the damage caused by Hurricane Isabel is assessed by a FEMA official from a helicopter near Hartfield, Virginia. This hurricane caused loss of life and property in areas that aren't particularly prone to weather damage.

taken a different approach. The residents of Belhaven (population 2,300) decided to avoid another cycle of hurricane-created flooding by raising the elevation of their entire town by 10 feet (3 meters). The Charlotte City Council voted to require all new homes to be built so that their first floors were 6 feet (1.8 meters) higher than the 100-year flood line.

Obviously, not everyone is willing to move from their hometowns. Although FEMA officials asked the mayor of Princeville, North Carolina, to encourage residents to rebuild their historic town (the first to be chartered by African-Americans) a few miles away, where it would no longer be in danger of flooding, townspeople are concerned that if they leave, an important part of their history will be lost. They would rather stay, despite having been hit by floodwaters several times in the last 100 years.

If federal officials have their way, it will be harder for people to stay in flood-prone areas. When the same homes are flooded out time after time, the emergency relief money is expended over and over for the same buildings. People will have the option of not moving, of course, but they could find that the next time their homes flood, they will have to replace their homes and all their belongings without financial help from the government.

Tulsa—A City with a Plan

Unlike the small towns in North Carolina, Tulsa, Oklahoma, is a large city, covering almost 200 square miles (520 square kilometers), with about 375,000 residents. Although Oklahoma seems to be a rather dry state—certainly much drier than the swampy lowlands of North Carolina—Tulsa receives an average of 37 inches (94 centimeters) of rain a year. That would be fine, except that the rain tends to come all at once. Rainfalls of several inches in just a few hours are not odd occurrences in Tulsa. This severe storm pattern, combined with the way that the land is formed, makes it prone to flooding.

One reason that people settled in the Tulsa area in the 1800s was the availability of water from the Arkansas and Verdigris Rivers nearby. By 1882, Tulsa was a town of 800 people. It officially incorporated as the City of Tulsa in 1898. Oklahoma became a state in 1907. The discovery of oil near Tulsa in the early 1900s brought many more people to the city, which claimed to be the oil capital of the world.

Tulsa had oil, reasonably good soil, and plenty of water, but it was also built right in the middle of what meteorologists call "tornado alley." This band of land extending through Oklahoma and into Kansas frequently gets hit by violent thunderstorms that sometimes develop tornadoes during the springtime. With two rivers nearby, 10 to 15 percent of Tulsa lies in the floodplain—an area that is prone to flash floods that arrive with virtually no warning.

In the early part of the twentieth century, most of Tulsa's flood problems developed along the Arkansas River. The city was hit by devastating floods in 1908 and again in 1923. The 1923 flood wiped out its water plant, which the city wisely moved to higher ground before the next floods hit in the 1940s and 1950s. The city was somewhat protected from flooding when the U.S. Army Corps of Engineers built levees along the Arkansas River to keep the high water out. Then in 1964, the corps built the Keystone Dam on the Arkansas, upstream from Tulsa.

Tulsa continued to get bigger, building out onto low-lying lands with a network of interconnected streams and creeks that fed the Arkansas and Verdigris. When rain fell quickly, these networks of small creeks became flash-flood risks. Every few years from the 1960s through the 1980s, the city experienced floods that caused considerable damage to the buildings in the way.

Indeed, Tulsa became the perfect example of what happens when the geology and *hydrology* (hye-DRAHL-uh-jee)—the way that water flows through an area—are not taken into account when a city is built. The city was hit by major flooding in 1970, 1974, 1976, 1984, and 1986. The worst spot in town was the area drained by Mingo Creek. The overflowing Mingo accounted for two-thirds of the city's flood damage.

The city's response to the floods followed the prevailing view at the time. When the floods came, the city used emergency money from the federal government to help home owners and businesses rebuild in the same spots that had just been flooded, as if they would never flood again. The 1970 flood, which hit on Mother's Day, caused $1 million in damage. At that point, Tulsa entered the newly established National Flood Insurance Program. Residents could now purchase low-cost flood insurance that would cover their losses due to flooding. As a result, the city started to regulate where people could build.

Just four years later, in 1974, the city got hit again—this time with $18 million worth of damage—in the same area. City leaders debated plans to deal with flooding, but took little action. Unfortunately, two years later, on Memorial Day 1976, another flood struck Tulsa. This one did $34 million in damage and killed three people. Each flood was causing more damage, because the city kept getting bigger between floods. This time, city officials partnered with the Army Corps of Engineers to develop an alert system and drainage plan for Mingo Creek.

Severe flooding in Oklahoma in 1999 resulted in evacuations, road closures, and millions of dollars' worth of damage to property. This home, located south of Tonkawa, Oklahoma, became an island until waters from the Salt Fork of the Arkansas River receded.

In 1997, Minnesota governor Arne Carlson sought federal disaster relief after hundreds of houses were flooded by the waters of the Minnesota and Chippewa Rivers. City planners in high-risk areas can now take precautions by hiring hydrologists to recommend building sites and drainage areas to maximize development and minimize damage caused by severe flooding.

It still wasn't enough. Exactly eight years later, on Memorial Day 1984, Tulsa was struck by the worst flood of all. Fifteen inches (38 centimeters) of rain fell in six hours. This storm caused $180 million in damage, injured 228 people, and killed fourteen. The city had the dubious distinction of leading the nation in federally declared disaster floods, with nine in fifteen years. Shocked by the damage, the city finally sprang into action. It hired a team of consultants, headed by a hydrologist, who quickly mapped out the damaged areas and determined the paths through which water drained from the city. Using local and federal funds, Tulsa bought up 500 damaged homes and mobile homes and prevented rebuilding in the most seriously flooded area. It also bought up flooded houses and land near the Arkansas River. Areas that had previously flooded were turned into soccer and other sports fields that were dry most of the time, but provided space for floodwaters when the heavy rains came.

These efforts paid off. When the Arkansas River flooded again just two years later, the main part of the city suffered only $113,000 in damages. However, the small neighborhood of Garden City was wiped out and suffered $1.3 million in damage. Once again, the city bought out the home owners and moved them to higher ground. Since it was also an industrial area, the levee was rebuilt to protect manufacturers, but no homes were allowed to be rebuilt.

Will all these efforts prevent Tulsa from flooding again? No. However, they will lower the amount of property damage. On Mother's Day in 1993, Tulsa received approximately the same amount of rain under the same conditions that had triggered the 1970 Mother's Day flood. Almost no damage was reported—a considerable improvement over the $1 million in damage done in 1970, especially since Tulsa was a larger city twenty-three years later. Hydrologists believe that the city's new system of increased drainage, holding areas, and zoning that prevents building in flood-prone sections will reduce future damage. The houses that the city moved to higher ground have never flooded again.

Questions to Consider

1. Do you agree that home owners should always have the final decision on whether to rebuild their homes in the same spots despite repeated flooding? Why or why not?

2. Most of Tulsa's problems could have been prevented if city leaders had consulted hydrologists and water engineers as the city expanded in the early twentieth century. Why do you think that city leaders were reluctant to take action, even though their city was being badly damaged every few years?

3. Hurricanes have wiped out homes on the barrier islands off the southeastern Atlantic coast numerous times, and yet people continue to rebuild there. Many of those homes are large and expensive, because of their location near the beautiful beaches. Should there be zoning laws that restrict building on spits of sand that are vulnerable to erosion from large, hurricane-created waves? Why or why not?

CHAPTER 9

Did an Object from Space Kill the Dinosaurs?

For the last 100 years, *paleontologists* (pay-lee-un-TAHL-uh-justs)—scientists who study the fossils of plants and animals—have known that dinosaurs became extinct 65 million years ago. However, they didn't actively pursue the question, What killed the dinosaurs? Most accepted that the dinosaurs had died off when they became "less fit" to survive. Paleontologists did propose several reasons why the dinosaurs had become less fit animals. Some suggested that there had been a loss of dinosaur habitat. Without a proper place to live, the dinosaurs died. Others suggested that Earth had entered a period when many volcanoes were erupting at once. The dust and ash thrown high into the atmosphere would have been sufficient to prevent plants from growing properly, so the dinosaurs would have starved to death. Another group of scientists suggested that the volcanic debris in the atmosphere would have blocked the sunlight, leading to very cold temperatures that the dinosaurs could not adapt to. Yet there was not enough evidence to support any of these scientific ideas.

Then, in 1980, a team of four scientists startled the world with their explanation for the death of the dinosaurs. Earth, they said, had been hit by a very large meteorite (MEET-ee-uh-ryte). This impact so changed Earth's climate that the dinosaurs could not survive. This out-of-this-world theory immediately triggered a scientific controversy that is still being debated today.

Yes

As far as I'm concerned, the data are perfectly clear. The only realistic explanation for what killed the dinosaurs is the impact of a large meteorite or comet. Sixty-five million years ago, the dinosaurs just disappeared. It wasn't in the blink of an eye, of course—nothing happens that fast in geological time. Actually, they disappeared over a period of several thousand years—but considering that Earth is 4.5 billion years old, a few thousand years is a very short period in geological time. What else could have killed the dinosaurs that quickly?

Some scientists claim that when the sea level got lower, the dinosaur habitat disappeared and the dinosaurs died. But even if the sea level did decrease, it would have taken a lot longer than a few thousand years for the dinosaurs to disappear. The water didn't just drain off the land that *quickly. Other scientists claim that a lot of volcanoes threw ash up into the atmosphere, so the Sun's light was blocked, the temperature dropped, and the plants died. The dinosaurs starved, they say. That makes no sense to me. It would take a lot of volcanoes all erupting at once to do that much damage.*

On the other hand, during my geological field studies in Italy, I have found large quantities of the element iridium—an element that is rarely found in Earth's crust, but is found on meteorites—at the exact location in the rock layers that represents the boundary between the Cretaceous (krih-TAY-shuss) *and Tertiary* (TUR-shee-er-ee) *periods. This boundary in time was 65 million years ago, exactly the same time that the dinosaurs died. Other colleagues have even found where the meteorite landed: just off the Yucatan Peninsula in what is now Mexico. Only an impact from space would account for the rapid extinction of the dinosaurs.*

No

As a paleontologist, I refuse to accept that a meteorite—or any other object from space—landed on Earth and killed the dinosaurs. I have looked at the data and observed how geological processes work over time. Plants and animals go extinct every year. Did something land from space to make them extinct? Of course not. They became extinct because Earth no longer offered them a good place to live.

There are plenty of ways that Earth could have become less hospitable to the dinosaurs. At the boundary of the Cretaceous and Tertiary periods, 65 million years ago, the oceans (which had been very high and covered more land than they do now) started to recede. Marshy areas that produced a lot of large, healthy plants—which plant-eating dinosaurs liked to eat—started to dry up. Over a few thousand years, as their habitat disappeared, these dinosaurs were forced into smaller and smaller areas that were unable to provide enough food. Some starved. Some were eaten by meat-eating dinosaurs. Some became weak and died of disease. Finally, when their habitat totally disappeared, they all died out. As the plant-eating dinosaurs died, the meat-eating dinosaurs lost their source of food and died, as well.

Besides, if a meteorite or comet had hit Earth, wouldn't that have killed everything in the vicinity at that time? Not everything died. Not long after the dinosaurs disappeared, little mammals were found in great abundance, even in places near the impact site. They were doing just fine. I don't believe that a meteorite could have hit Earth and killed the dinosaurs but left all those little mammals alive and thriving.

Discussion

The discovery of radioactive dating (which uses the decay rate of radioactive elements to "tell time") in the early twentieth century enabled earth scientists to determine the ages of rock layers. Before this discovery, geologists only knew that some

This whale fossil, found by David Alexander (left) and Kim Scott in San Juan Capistrano, California, is estimated to be 5 to 7 million years old. Radioactive dating of fossils and rock layers is used by proponents of the meteorite theory to explain why the dinosaurs disappeared.

rocks were older than others, based on the fossils found with them or their relative positions—rocks near the surface were younger than rocks deep in the ground. Once geologists could determine the actual age of rock samples (in millions of years), they could assign absolute ages to the geologic time scale. The geologic time scale is the division of Earth's 4.5-billion-year history into distinct blocks of time.

Paleontologists were able to use the same technique to date the plant and animal fossils that they found buried in these same rock layers. Based on this new information, paleontologists determined that the dinosaurs died off—or became extinct—about 65 million years ago. This point in time was the boundary between two major geologic periods: the Cretaceous and the Tertiary. Geologists call this the K-T boundary.

It might seem logical for paleontologists to have then asked the question, Why did the dinosaurs die? However, paleontologists didn't ask this question, because they were more interested in the fact that dinosaurs were extinct than in why they were extinct. According to the theory of *natural selection* developed by Charles Darwin (1809–1882), only those plants and animals that were "most fit" for their environments would thrive. (A *theory* is a scientific explanation for why things happen as they do.) Therefore, the paleontologists thought that it was obvious that the dinosaurs died because they were no longer the fittest of animals.

Despite this lack of interest, paleontologists did develop what became the standard explanation of why the dinosaurs died off. The physical and biological environment that had kept dinosaurs flourishing for 140 million years gradually changed during the last five or ten years of the Cretaceous period. Finally, the environment was so changed that the last remaining dinosaurs were unable to survive. The primary culprit was the air temperature. During the course of the Cretaceous, the temperature cooled. Dinosaurs lived in warm areas of Earth, and those regions finally cooled to a level that could not sustain the creatures. Because they were not able to adapt to these new conditions quickly enough, they died. Indeed, based on the fossil evidence, paleontologists know that the number of different dinosaur species declined during the late Cretaceous period. By the end of the period, there may have been only twenty-five different types of dinosaurs (of about fifty types to begin with) walking the Earth.

This idea that the climate cooled and the environment was no longer hospitable to dinosaurs was certainly a possibility. Unfortunately, there was no solid proof for the theory. Just because the temperatures cooled at the same time that the dinosaurs were going extinct did not mean that the two events were related.

As the twenty-first century starts, paleontologists still do not know for sure what killed the dinosaurs. However, a discovery in 1980 led to the startling proposal that the dinosaur extinction was due to an extraterrestrial (ek-struh-tuh-RESS-tree-ul) object striking Earth at the time of the K-T boundary. That proposed theory sparked a huge controversy within the scientific community that is still ongoing today. When issues like dinosaur extinction become debates within the broader scientific community, they spark additional research, as scientists seek support for their own positions. Debatable issues in science lead to new scientific discoveries.

The Impact Hypothesis

In the late 1970s, geologist Walter Alvarez (1940–) was working in northern Italy on a thick section of sedimentary rock that had been laid down during the late Cretaceous and early Tertiary periods. Other geologists had determined the proper rock sequence years ago by looking at the fossil remains of animals trapped in the sediment. Alvarez wanted to know how long it had taken for each layer of limestone or clay to be laid down, so he could get a better idea about the length of the transition between the Cretaceous and Tertiary periods.

Alvarez could have analyzed many different samples for radioactive elements to get actual ages, but that would have been very expensive. So he and his father, Nobel Prize–winning physicist (FIZ-uh-sust) Luis Alvarez (1911–1988), came up with another technique. Knowing that tiny meteorites rain down on Earth all the time and that meteorites contain more of the element iridium than is found in Earth's crust, they

A star dome shows the orbits and locations relative to the Earth of stars and constellations. In the 1980s, the father-and-son research team of Luis and Walter Alvarez, using this information to understand how meteorites might travel, formulated their theory of dinosaur extinction.

checked the layers for iridium. The more iridium in the layer, the longer it had taken the layer to be laid down, assuming that the iridium was deposited at a constant rate.

With the help of chemists Frank Asaro and Helen Michel of the Lawrence Berkeley Laboratory, the Alvarezes found that

Luis (left) and Walter Alvarez view a sample of an iridium layer deposit. Luis Alvarez believed that researchers who disagreed with the Alvarezes' theory were misled by inconclusive evidence suggesting that mass extinctions took place over millions of years. Further study of fossil beds eventually proved that a population could die out in just a few years.

the K-T boundary layer had a much higher proportion of iridium than the layers above or below it. This result was not what they had expected. Many scientists might have just dropped the project at this point, thinking that an error in their methodology had given them a wildly incorrect reading, but the Alvarezes didn't give up. Careful analysis revealed that the values were correct. There could be only one explanation: A very large meteorite had struck Earth 65 million years ago. When it did, it threw up such a large quantity of dust and debris that the Sun's rays were blocked, plants died, the temperature plummeted, and the dinosaurs died. A meteorite impact had been responsible for the death of the dinosaurs.

Controversy Erupts

The article that explained the Alvarezes' findings appeared in the prestigious scientific journal *Science* on June 6, 1980. They had already given an oral presentation of their results at a meeting of the American Association for the Advancement of Science (AAAS), but in scientific circles, the published paper is most important. Unlike articles in a magazine such as *Time* or *Newsweek,* articles in scientific journals must be reviewed by other scientists before they are published. If the other scientists question the validity of the study or the data that were used—and the authors cannot provide satisfactory answers—the article is not printed. If the article does appear, therefore, it almost always means that the authors used excellent research techniques and have come to valid conclusions.

The paper spurred much discussion among paleontologists, geologists, and biologists who had studied the dinosaur extinction. The discussion was almost all negative. Opponents of the meteorite impact theory argued that there was absolutely no reason to look to extraterrestrial sources to explain problems on Earth. Further, scientists did not know enough about the geological chemistry of iridium to come to the conclusion that a meteorite had caused the iridium deposits found by Walter Alvarez.

Some scientists argued that intense volcanic eruptions could also produce large amounts of iridium. Others argued that scientists needed to analyze the entire geologic column—all of the rock layers down to the mantle—to see if there were indications of other unusual iridium deposits. Perhaps such deposits occurred on a regular basis and were not just a one-time event caused by a meteorite. Still other critics pointed out that something was missing: the crater. If a meteorite estimated to be 6 miles (9.6 kilometers) in diameter (based on the size needed to produce the thin layer of iridium around Earth at the K-T boundary) had struck Earth, shouldn't there be a big crater someplace? The paleontologists pointed out that no one on the Alvarez team was a paleontologist. Therefore, they did not have the authority to discuss mass extinctions. Still others argued that if a big cloud of dust had blotted out the Sun, why hadn't every plant and animal died along with the dinosaurs?

Clearly, the scientific community was stirred up by the idea that a meteorite impact killed the dinosaurs. Newspapers and magazines picked up the story as the scientists debated the issue. Research teams started going over old data to see whether they supported the meteorite theory or not. Other teams of scientists headed out into the field to look for additional evidence that would answer the question, What killed the dinosaurs?

The Chicxulub Crater

Paleontologists continued to scoff at the impact theory through the 1980s. They maintained that gradual cooling of Earth's surface, perhaps due to a period of increased volcanic activity, was the likely cause of the dinosaur extinction. In the recent past, the ash and dust thrown into the atmosphere by

This radar image shows the Chicxulub crater on the Yucatan Peninsula in Mexico. The discovery of this crater, or impact site, gave great weight to the Alvarezes' theory that the mass extinction of the dinosaurs was caused by a meteorite. However, with only twenty years of impact research to review, the scientific community is still far from a conclusive answer.

the eruption of just one volcano—the Philippines' Mount Pinatubo in 1991—were responsible for lowering the average air temperature at Earth's surface by 0.72 degrees Fahrenheit (0.4 degrees Celsius) for the two years following the eruption. The enormous eruption and explosion of the Indonesian vol-

An extraordinarily well-preserved fossil of a previously unknown dinosaur, Scipionyx samniticus, *was discovered in Italy in the 1980s. The scientific community is constantly uncovering new information that challenges existing theories and leads to new ideas about dinosaur life and death.*

cano Krakatau (Krakatoa) in 1883 lowered atmospheric temperature by 2.7 degrees Fahrenheit (1.5 degrees Celsius). Normal temperatures did not return until 1888. Therefore, if many large volcanoes had erupted within a few years of each other, they could have triggered a significant cooling trend—enough to kill the dinosaurs.

Then a new discovery in 1990 changed the picture once more. Scientists discovered a crater 125 to 188 miles (200 to 300 kilometers) wide, lying under 3,700 feet (1,100 meters) of limestone deposits, near the town of Chicxulub (CHEEK-shoo-loob) on Mexico's Yucatan Peninsula. The geologic structure of this crater—which is not visible on the surface—had attracted the attention of Petroleos Mexicanos (Mexican Petroleum, or Pemex—an oil company) in the 1950s. Petroleum geologists looking for oil had drilled a number of test wells and studied the rock that had come up with the drills. The rock was quite unusual, because it gave evidence of *shock metamorphism* (met-uh-MORF-iz-um)—the modification of rock due to heat and pressure caused by a large impact. By 1990, teams of scientists from both the United States and Mexico had ruled out the possibility that a large volcano had created the crater. This was just the evidence that the supporters of the impact theory needed. When they checked the age of the rock at the impact level, they found that it was 65 million years old. They had found a crater at the K-T boundary.

Additional research showed that over 47,600 cubic miles (200,000 cubic kilometers) of Earth's crust (along with the meteorite itself) were ejected, melted, or vaporized in an instant. Ejected material from this site has been found throughout North America at the K-T boundary layer. Furthermore, the materials that the meteorite struck (calcium carbonate and calcium sulfate) produce carbon dioxide gas and sulfate particles when heated to high temperatures. Thus, when the meteorite hit, the resulting heat threw these materials into the air, which, when combined with water, produced acid rain.

Acid rain in turn destroyed plant life. So not only would the dust and ash have blocked the sunlight to lower temperatures and harm plant life, but the resulting rains would have harmed plants, and thus animals, too.

Clouds of Sulfuric Acid?

Yet another twist to the impact theory appeared in 1995. Scientists at NASA reported that the rocks near the impact site contained unusually large amounts of sulfur. When the meteorite struck, they said, the resulting blast vaporized about 100 billion tons (90 billion metric tons) of sulfur into the atmosphere. When it combined with water vapor, it created drops of sulfuric acid. So much airborne sulfuric acid would have been carried around the globe by upper-level winds that a barrier to sunlight would have formed quickly. Airborne sulfuric acid is a reflector, so the incoming sunlight would have been reflected back into space, and the temperature at Earth's surface would have plunged past the freezing point. This globe-covering sulfuric acid cloud could have remained airborne for up to a century, according to NASA atmospheric scientist Kevin Baines, although a period of twenty to forty years is more likely. He maintains that if the meteorite had landed somewhere else on terrain with a lower sulfur content, the dinosaurs would still be lumbering around on Earth.

NASA planetary scientist Owen Toon isn't so sure. He sees no evidence that sulfuric acid actually filled the air. However, there is another possibility for what occurred after the meteorite struck. The billions of tons of debris ejected by the impact would have been moving fast enough to escape Earth's atmosphere, but not fast enough to escape Earth's gravitational attraction. Within an hour of the impact, all this debris would have reentered Earth's atmosphere, burning up as it returned. Toon argues that the sky would have become a "glowing sheet of rock" and that the resulting heat would have started global wildfires and killed exposed animals immediately. Once the airborne rock cooled, the black soot left behind would have blocked sunlight for up to a year. Any sulfuric acid would have added to the blackout. Earth's temperature would have dropped significantly for about a decade. Then, Toon says, the temperature would have risen for the next fifty to a hundred years because of the additional carbon dioxide in the atmosphere—also a result of the impact. The combination of low temperatures followed by high temperatures would have so stressed the dinosaurs that they could not have survived. Other scientists dispute the warming trend, saying that carbon dioxide levels would not have been sufficient to cause a significant temperature increase.

The "Double Whammy" Theory

Also in 1995, scientist Jon Hagstrum of the United States Geological Survey (USGS) proposed another theory about dinosaur extinction. In his "double whammy" theory, Hagstrum argued that a large meteorite impact on one side of Earth could have triggered massive volcanoes on the other side of the planet. This would have ensured significant death and destruction on both sides of the world. Unfortunately, evidence for such a volcanic reaction is unavailable. As Hagstrum pointed out, the location that would have been exactly opposite the Chicxulub site at the time has long since been destroyed by the movement of Earth's crustal plates.

Extinction Alternatives

Although astronomers (uh-STRAHN-uh-merz), physicists, and chemists may be convinced of the impact theory, not all paleontologists accept it. They point out that the dinosaurs were in decline in the last years of the Cretaceous anyway—

Found by farmers in northeast China, this 130-million-year-old fossil of a rare bird was brought to New York City in 1993. Dinosaur research remains hampered because many important fossils found by amateurs have not been properly studied.

therefore, a catastrophic impact was unnecessary to eliminate them from Earth's face. Furthermore, the geologic evidence points to other causes that could just as easily have contributed to dinosaur extinction.

Besides the cooling trend of the Cretaceous, in those final millions of years, Earth's oceans started to recede, and as a result, more land was exposed. For example, an ocean that had divided North America into two pieces drained away, leaving an entire continent. The land bridge that connected North America with Asia also appeared. The low-lying, swampy areas that had provided the habitat for the dinosaurs dried up. Meanwhile, as the dinosaurs moved to the few remaining areas that would support them, the temperature dropped—further stressing their bodies. Scientists point to multiple locations around the world today where animals are becoming extinct due to loss of habitat. As more and more animals looking for food are crowded into smaller and smaller areas, the resulting collapse of the ecosystem leads to their extinction.

There are other arguments against any theory that bases the extinction on one cause. French geophysicist Vincent Courtillot has argued that hundreds of thousands of years of volcanic eruptions could have put enough gases into the air to poison the dinosaurs. As evidence, he points to the massive eruptions of basaltic lava (called the Deccan Traps) on the Indian subcontinent. San Diego State University biologist J. David Archibald opposes the single-cause scenario for different reasons. Why, Archibald wants to know, were the dinosaurs wiped out, but the turtles weren't? Why did the dinosaurs die, while only half of the mammals did? To him, a meteorite impact would seem to be an "equal opportunity" killer. The fossil record shows that it was not.

It has been over twenty years since solid evidence of an extraterrestrial impact was offered to explain the dinosaur extinction at the K-T boundary. Today, scientists are still debating the question, What killed the dinosaurs?

Questions to Consider

1. How might additional evidence change the debate surrounding the death of the dinosaurs? What additional evidence might be needed before people agree on what killed the dinosaurs?

2. Does the debate over the possible loss of dinosaur habitat as a cause of their extinction influence the debate today over the preservation of endangered species? Why or why not?

3. Some scientists claim that changes in the atmosphere, due to the release of gases from volcanic eruptions, could have killed the dinosaurs. How is this theory related to today's concerns over air pollution and its effects on Earth's life?

Timeline of Earth Science

DATE	EVENT
2296 B.C.E.	The Chinese record the earliest comet sighting.
2000 B.C.E.	Chinese discover magnetic attraction.
600–350 B.C.E.	Greek philosophers develop a geocentric cosmology that places a perfectly spherical Earth at the center of a spherical universe in which the other planets, the Moon, and the Sun all orbit Earth.
334 B.C.E.	Aristotle (384–322 B.C.E.) produces his *Meteorologica,* the first work on the atmospheric sciences. It includes his studies on comets, shooting stars, and rainbows. Most of the meteorology is incorrect, but it remains the accepted information about weather until the fifteenth century.
330 B.C.E.	Greek geographer and explorer Pytheas (c. 350–c. 300 B.C.E.) proposes that tides are caused by the Moon. His observation of the spring tides occurring during a new or full Moon led him to conclude that the position of the Moon was connected to the height of the tides.
240 B.C.E.	Greek astronomer Eratosthenes of Cyrene (c. 275–c. 195 B.C.E.) becomes the first person to accurately measure the circumference of Earth.
A.D. 132	The Chinese astronomer royal, Zhang Heng (78–139), invents the world's first seismograph. The seismograph consisted of a case with eight bronze dragons' heads around the top. Each dragon held a bronze ball in its mouth. When an earthquake hit, the ball sitting in the opposite direction from the source of the earthquake would fall into the mouth of a bronze toad at the bottom of the case, making a loud ring. Chinese officials thus knew in which direction to go to find the area affected by the earthquake.
140	Greek astronomer Claudius Ptolemy (c. 90–c. 170) defines the universe mathematically. Ptolemy uses the data that had been collected since the time of the Babylonians to create a mathematical model that accounts for the positions of the planets and predicts their future positions.

1517 Italian physician and scholar Girolamo Fracastoro (1478–1553) describes the remains of ancient organisms that we now call fossils. At about this same time, Italian inventor and artist Leonardo da Vinci (1452–1519) concludes that fossils are the remains of animals that had once been alive. By 1546, Georgius Agricola (1494–1555) of Saxony (now part of Germany) has applied the term *fossil* to any nonliving thing dug up from the ground in his book *On the Nature of Fossils*.

1543 Polish astronomer Nicolaus Copernicus publishes his book, *The Revolution of the Heavenly Spheres,* which proposes a heliocentric view of the solar system.

1608 Dutch spectacle-maker Hans Lippershey (1570–1619) is the first person to apply for a patent on a telescope. Exactly who invented the telescope is still unknown. Italian astronomer and physicist Galileo Galilei (1564–1642), who is often given the credit for being the telescope's inventor, did not invent it. However, he did improve the design.

1609 German astronomer and physicist Johannes Kepler proposes the first of his laws of planetary motion: Planets have an elliptical orbit around the Sun.

1611 Galileo and several others discover sunspots.

1643 Evangelista Torricelli (1608–1647), an Italian mathematician and student of Galileo, creates the first mercury barometer.

1703 The first modern seismograph is invented by French scientist Abbé Paul Gabriel de Hautefeuille (1647–1724).

1801 Italian astronomer Giuseppe Piazzi (1746–1826) becomes the first person to discover an asteroid, Ceres.

1804 French chemist J.L. Gay-Lussac (1778–1850) and physicist Jean Biot (1774–1862) make the first manned balloon exploration of the atmosphere. They take meteorological measurements up to a height of 3 miles (4.8 kilometers). Gay-Lussac makes a second flight alone to a height of 4.2 miles (6.7 kilometers) and determines that the composition of air does not change with height.

1837 Swiss-born U.S. naturalist and glaciologist Jean Louis Agassiz (1807–1873) proposes that ice had covered much of Earth in the past during what he called ice ages.

1840s U.S. Navy lieutenant and oceanographer Matthew Fontaine Maury (1806–1873) begins the first organized collection of information about the ocean's winds and currents. Maury creates pilot charts that shorten the time it takes for ships to cross the oceans.

1856 American meteorologist William Ferrell (1817–1891) proposes that the general circulation of the atmosphere can be divided up into six separate circulation cells (three for each hemisphere). Ferrell's idea explains the presence of the trade winds in the band between the equator and 30 degrees latitude and the generally west-to-east movement of storms in the mid-latitudes, between 30 and 60 degrees.

1904 Norwegian meteorologist Vilhelm Firman Bjerknes (1862–1951) sets out his ideas for a mathematical basis for meteorology.

1906 British seismologist Richard Dixon Oldham (1858–1936) discovers that the compressional waves of earthquakes arrive on the opposite side of Earth later than expected when compared with the arrival times at other points on the surface. From this information, he correctly deduces that Earth's core has to be much denser than the mantle, since the waves travel more slowly through denser material.

1907 American radiochemist Bertram Boltwood (1870–1927), who played an important role in advancing the understanding of the radioactive decay of uranium, first uses uranium to date rocks.

1912 German meteorologist and geophysicist Alfred Wegener (1880–1930) proposes his theory of continental drift.

1920 Vilhelm Bjerknes, his son Jacob (1897–1975), and others develop their theory of polar fronts. They successfully show that the atmosphere is divided into distinct air masses. Frontal analysis is slowly introduced and adopted worldwide.

1927 Belgian priest and astronomer Georges Lemaître (1894–1966) proposes the big bang theory of the universe. Evidence to support it comes in 1929 from U.S. astronomer and galaxy specialist Edwin Powell Hubble (1889–1953). Hubble observes that the galaxies are moving apart, thereby supporting the theory of an expanding universe.

1935 American seismologist Charles Richter (1900–1985) develops his scale of earthquake strength. Richter's scale is based on the maximum height of the mark made by the pen on an earthquake seismograph.

1946 Vincent J. Schaefer (1891–1993) at General Electric discovers that dry ice causes supercooled water to turn to snow. This leads to a rush to develop weather modification techniques for clearing fog, increasing rainfall, and preventing damage from hail.

1950 U.S. astronomer Fred Lawrence Whipple (1906–) proposes that comets are composed of ice, dust, dry ice, methane, and ammonia. This becomes known as the "dirty snowball" theory of comets. Dutch astronomer Jan Oort (1900–1992) proposes that comets originate in a sphere that contains the ingredients to create them. This comet "nursery" is now known as the Oort Cloud.

1954–1955 The first operational weather maps created by numerical weather prediction techniques on a computer are produced at the Swedish Meteorological and Hydrographic Institute in Stockholm, Sweden, and at the Joint Numerical Weather Prediction Unit in Suitland, Maryland.

1957 The Soviet Union launches the first spacecraft and artificial satellite, called *Sputnik,* and thus begins the space age.

1957–1958 The International Geophysical Year (IGY) is launched in July 1957 as an eighteen-month period devoted to observing geophysical phenomena and taking measurements of Earth and the atmosphere. Sixty-seven nations share information and work together on the project.

1962 American Harry Hammond Hess (1906–1969) proposes seafloor spreading as the mechanism that explains the presence of the mid-ocean ridges. Within a few years, the theory of plate tectonics would become the fundamental theory underlying all geology.

1965 Astrophysicist Arno Penzias (1933–) and physicist Robert Wilson (1936–) discover the radio waves left over from the big bang. This discovery provides additional evidence supporting the idea of a steadily expanding universe.

1969 American astronauts Neil A. Armstrong (1930–) and Edwin "Buzz" Aldrin (1930–) become the first humans to land on the Moon.

1974 Mario J. Molina (1943–) and F. Sherwood Rowland (1927–) warn of the threat of chlorofluorocarbons (CFCs) to the stratospheric ozone layer. Within four years, the United States bans the presence of CFCs in aerosol cans.

1975 The United States launches the first Geostationary Operational Environmental Satellite (GOES). The United States has two GOES satellites that send back images of the United States and adjacent ocean waters to aid meteorologists.

1980 U.S. physicist Luis Walter Alvarez (1911–1988) and his son, geologist Walter Alvarez (1940–), propose that Earth was hit by a comet or asteroid some 65 million years ago, which had led to the extinction of the dinosaurs.

1990 The first optical telescope in space, the Hubble Space Telescope, is placed into orbit. The Hubble can see farther into the universe and beam back images that are clearer than ever before possible.

1992 Studies of ice cores from Greenland show that it is possible for the climate to change very suddenly, perhaps in as little as one to two years. This is a significantly different view of climate change, which had been seen as a very slow process.

1994 Fragments of the comet Shoemaker-Levy 9 strike the planet Jupiter. This is the first time that astronomers are able to predict that a comet would strike another planet and to watch the collision.

1997 Negotiations are completed on the Kyoto Protocol, which commits industrialized countries to reducing emissions of greenhouse gases. The United States, citing inconclusive evidence on the accuracy of global warming predictions, declines to sign the treaty.

2000 Ice cores from a Himalayan glacier confirm that the decade from 1990 to 1999 was the warmest in the last 1,000 years.

2001 Scientists suggest that Pluto is not a planet but a large piece of ice from the Kuiper Belt, a location of many comets. Other scientists disagree and remain convinced that Pluto is the solar system's ninth planet.

2003 A team of astronomers discovers a planet about twice as big as Jupiter that is orbiting a star in the constellation Puppis. The astronomers call this proof of the existence of another solar system in the universe.

Glossary

aquifer—a stratum of rock, sand, or gravel bearing water that can be pumped out

cloud seeding—the distributing of minute particles of a water-attracting substance such as dry ice or silver iodide into a nonprecipitating cloud to promote condensation and rain or snow

crust—the thin, outer layer of Earth and all nongaseous planets

floodplain—the flat area that extends out on both sides of a river

fossil fuels—fuels, like gas and coal, that form from dead plants and animals that have been trapped in sediment for millions of years

greenhouse gases—gases such as carbon dioxide, methane, and water vapor that trap heat radiated by Earth and radiate it back down to Earth

nuclear energy—energy released from the splitting of atoms, known as nuclear fission

radioactive elements—elements such as uranium that decay (lose electrons) over a given period of time and become new elements; they can be used to determine an exact age for rocks and fossils

storm surge—the unusually high sea level near a coastline caused by extremely high winds blowing toward the shore, especially during hurricanes

tuff—a type of volcanic rock made of ash compacted 8 million to 16 million years ago

water table—the level under the ground where all the open spaces between tiny bits of rock are filled with water

Bibliography

Books

Campbell, C.J. *The Coming Oil Crisis.* Essex, England: Multi-Science Publishing, 1997.

Keller, Edward. *Environmental Geology.* 7th ed. Upper Saddle River, NJ: Prentice Hall, 1996.

Miller, Clark A., and Paul N. Edwards, eds. *Changing the Atmosphere: Expert Knowledge and Environmental Governance.* Cambridge, MA: MIT Press, 2001.

Nese, Jon M., Lee M. Grenci, Timothy W. Owen, and David J. Mornhinweg. *A World of Weather: Fundamentals of Meteorology.* Dubuque, IA: Kendall/Hunt, 1996.

Raup, David M. *The Nemesis Affair: A Story of the Death of Dinosaurs and the Ways of Science.* New York: W.W. Norton, 1999.

Web Sites

American Rivers *www.amrivers.org*

Federal Emergency Management Agency (FEMA) *www.fema.gov*

National Aeronautics and Space Administration (NASA) *www.nasa.gov*

The Royal Institution of Great Britain—Science Inside Out: Discover Energy: Power Up *http://insideout.rigb.org/insideout/energy/power_up*

U.S. Department of Energy (DOE) *www.doe.gov*

U.S. Department of Energy (DOE) Smart Communities Network—Creating Energy Smart Communities *www.sustainable.doe.gov*

U.S. Fish & Wildlife Service (USFWS)—Arctic National Wildlife Refuge *arctic.fws.gov*

Cumulative Index

Note: Page numbers in *italics* indicate illustrations and captions.