EDUCATOR'S GUIDE

Nuclear Energy: The Costs and Benefits of Alternative Choices

Disney Presents the Eyes of Nye

For six seasons, millions of students came to understand, appreciate and enjoy the exploration of science through the series, *Bill Nye the Science Guy*. Bill returns with *The Eyes of Nye*, a more in-depth look at science subjects making news, changing lives, and impacting policy. From the future of alternate fuel sources and genetic engineering to population growth trends and issues of race, Bill and his expert cohorts bring science to life right in your classroom, helping you **Motivate** investigation; **Assess** available information; and **Propose** lines of argumentation.

This Educator's Guide includes:

- An **Introduction** that clearly defines the subject and offers an overview of the issue objectives of the guide; how it relates to science from both a social and personal perspective; as well as pertinent questions and insights regarding the topic.
- A listing of all **National Science Education Standards Addressed**.
- Detailed procedures highlighted in the MAP Framework (**Motivate, Assess, Propose**).
- Illustrative **Video Clips** from *The Eyes Of Nye* DVDs with pinpoint chapter cues.
- **Web Site Resources** to help students further investigate and locate research, charts, data as well as experts featured in the program material.
- Easily downloadable **Support Materials** that include articles, transparencies, charts, and much more.

Introduction:

"Nuclear energy" refers to production of energy by means of fission, or the splitting of subatomic particles. *The Eyes of Nye - Nuclear Energy: The Costs and Benefits of Alternative Choices* describes the process and particularly the problems posed in storing the waste that results from society's production of energy through such means.

The issue of nuclear energy has been around for some time—it went from the post-WWII poster child of efficiency to a 1960s symbol of death and gloom, Three Mile Island and Chernobyl, with continued use in 104 nuclear power-producing plants today in the U.S. alone. Newer, however, is the issue only predicted in the past—over 300,000 tons of high-level nuclear waste sits in storage around the world. What students will encounter early in their adult lives—and what this guide addresses—is what to do about the situation, what

*Check the **MAP Teaching and Learning Framework** to explore the phases (motivate, assess, and propose) used in this guide.*

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must be understood about nuclear energy production and waste storage in order to make that decision, and what trade-offs societies locally and around the world must consider in so doing.

National Science Education Standards Addressed

Science As Inquiry

- Abilities necessary to do scientific inquiry
    - Identify questions and concepts that guide scientific investigations.
    - Recognize and analyze alternative explanations and models.
    - Communicate and defend a scientific argument.
- Understanding about scientific inquiry

Physical Science

- Structure of atoms
- Chemical reactions

Earth and Space Science

- Energy in the earth system

Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

On the DVD:

Nuclear Energy – Chapters

Chapter 1: *Nuclear Energy Preview*
Beginning through 2:14
Ends with title screen.

Chapter 2: *Generating Power: Then and Now*
2:37—6:13
Starts with "Our Friend the Atom."

Chapter 3: *Waste Production and Containment*
6:13—9:58
Starts with Bill saying, "A nuclear power plant can generate a lot of electricity…"

Chapter 4: *Yucca Mountain: Pros and Cons*
9:59—15:45
Starts with Bill asking, "What if you had your way?"

Chapter 5: *A Problem for the Ages…and Growing*
15:46—19:20
Starts with Bill saying, "We measure radioactivity in what's called half-lives."

Chapter 6: *Searching for Solutions*
19:22 through end of program.
Starts with Bill saying, "300,000 tons and growing."

Nuclear Energy – Activity Clips

The Dry Cask Storage
7:16—8:19
(referenced in Educator's Guide step 3)
Starts with introduction of Larry Linik. Ends with Larry saying, "No, they're not."

Reactors and Reactions
4:00—6:13
(referenced in Educator's Guide step 5)
Starts with Bill saying, "This is the Columbia Generating Station… " Ends with Bill saying, "That's a lot of juice."

Containing Ionizing Radiation
8:19—9:31
(referenced in Educator's Guide step 6)
Starts with Bill saying,"Radiation is technically any energy that radiates.
" Ends with Bill saying,"See, in this game, rock beats paper."

The Half-Life Problem
15:46—17:01
(referenced in Educator's Guide step 7)
Starts with Bill saying,"We measure radioactivity in what's called half-lives."
Ends with Bill saying,"That's not even half of a half-life."

Yucca: The Perfect Hiding Place
10:21—12:34
(referenced in Educator's Guide step 8)
Starts with Bill saying,"Look out there." Ends with Dr. Gil saying "…to come in contact with the public."

Worst Mistake Our Species Ever Made
14:08—15:45
(referenced in Educator's Guide step 9)
Starts with Bill asking,"So is Yucca Mountain a good idea?" Ends with Hirsch saying "…and it has a 24,000-year half-life."

The Struggle
17:01—18:04
(referenced in Educator's Guide step 10)
Starts with the posted text info on the lawsuits filed by Nevada and environmental groups. Ends with Hirsch saying "…a species less capable of handling that danger."

The Potential of Transmutation
21:06—23:06
(referenced in Educator's Guide step 14)
Starts with Bill saying,"Now, what is this business of transmuting?" Ends with posted data on amount currently being spent on transmutation research.

Procedure: Motivate Phase

1) Ask students to suggest forms of energy commonly used to provide for industrial and residential needs. Most have heard of petroleum, coal, wind, hydroelectric (water), and nuclear energy. Explain each requires the conversion of renewable or nonrenewable resources into power or energy and some by-product or waste is produced in the process. Tell them we will primarily focus on nuclear energy and the waste or by-product of nuclear energy production.

2) Describe the potency of small amounts of plutonium (below), which along with uranium is used to produce nuclear energy. Explain even though nuclear power produces a small *volume* of waste compared to other means of producing energy, the damage a tiny amount can cause can be alarming. Suggest because it remains dangerous for thousands of years, and we've been storing it up for so long, we now have quite a quantity of radioactive nuclear waste to deal with (below).

> *"If inhaled, a millionth of an ounce of plutonium (the size of a speck of dust) can cause lung cancer. A few pounds (the size of a grapefruit you can hold in your hand) can bring down a city if used in a nuclear weapon."*
>
> \- **Dan Hirsch**, *Committee to Bridge the Gap*
>
> *Since 1945 the world has stored nearly 300,000 tons of high-level nuclear waste.*
>
> ***- World Nuclear Associates***

3) Ask students what comes to mind when they think of storage of nuclear waste. Most will have only general ideas. Tell them to note the most common form of storage presently used as you play ***"The Dry Cask Storage."*** Review and ask students to suggest possible present or future problems with this mode of storage. Some may simply suggest we stop using nuclear energy. Remind them of the amount of nuclear waste already in storage. Tell them we can't just make it disappear.

4) Play ***"Chapter 1: Nuclear Energy Preview"*** In addition to the problem posed by waste storage, explain we are still *generating* waste (at 104 facilities in the U.S. alone), and some people and countries feel they have little recourse—recall the quantity of coal it takes to power a conventional plant. Ask students to consider the broad question posed, "Do science and society have an answer for this problem?" and construct at least two scientific and one social question to focus investigation of the nuclear waste issue.

Potential scientific questions

a) How is nuclear energy produced and waste presently stored?

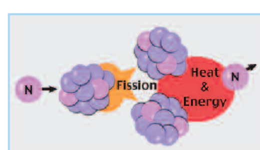
b) What are presently considered the best options for storing nuclear waste and the advantages and disadvantages of these options?

Potential social question

c) What must societies in the U.S. and across the world consider when exploring options to nuclear energy and storage of nuclear waste?

Procedure: Assess Phase

5) Recall various means of producing energy and explain there are aspects of nuclear energy production that distinguish it from other methods, most notably the energy is produced by *fission* and a given mass of nuclear fuel (e.g., uranium or plutonium) produces more energy than other fuels. Ask students to note the scope of a nuclear facility and the proximity of the reactor, generator,



See **The Eyes of Nye** Issue Support ***Nuclear Energy: The Process***

and cooling towers as you play ***"Reactors and Reactions,"*** in which Bill first visits the Columbia Generating Station and then demonstrates the fission chain reaction that produces nuclear energy. Use "Nuclear Energy: The Process" to point out components of the system that work in tandem, the common fuel used, and the fission process and chain reaction initiated by neutron bombardment. Note as well the security mentioned in the segment above, and point out the containment encasing the entire system—an added form of security.

6) Describe two basic "levels" of waste and two forms of storage (below), and note the emphasis placed on containment of high-level waste. Recall structural aspects of the containment (concrete and steel) explained above as well as in the segment on the dry cask, and the measurement of "radiation" being emitted from the material. Review general aspects of radiation or provide an overview (below). State, though we realize the material is dangerous, explaining *why* such extraordinary means are necessary is more difficult. Play ***"Containing Ionizing Radiation,"*** comparing ionizing radiation with other forms of radiation, and describing the safety issues involved. Ask students to consider why the material emits ionizing radiation.

Explore and compare characteristics of radiation and various health hazards posed by high energy, short wavelength radiation. Two types of waste: low- and high-level. Two types of storage for high-level waste: on-site cooling pools and off-site dry cask storage.

7) Recall the wastes remain hazardous for many years and suggest that given the hazards just discussed we should explore why they remain so potent so long. Explain plutonium-239 (Pu-239), the most common result of fission, will begin to "decay" or lose its radioactivity at a certain rate. Introduce the "half-life" as the time taken for Pu-239 to lose half of its radioactivity. Discuss "Half-Life" (right) and explain the half-life of the Pu-239 present in nuclear waste is 24,100 years, and it continuously emits ionizing radiation throughout that time. Play "The Half-Life Problem," and explain that, significantly, the U.S. government has established nuclear waste containment must be capable of remaining intact for 10,000 years. Ask if this target is realistic given what we know about the half-life of this material. Note we have been using the dry cask method since 1986. Ask students if they feel we should be looking into other storage options, and note we *have* done just that—starting in 1987.

Teacher Note: *This guide introduces general concepts at a level sufficient for understanding the issue of nuclear energy and waste disposal. Students may investigate further details as you wish.*

As students explore options (second question), examples (e.g., Yucca mountain storage, coal power production) are used to illustrate trade-offs that must be considered in determining solutions. You may wish students to factor in other options for power production and storage. Consider the quantity first, however, and ensure the number of options addressed does not preclude students' abilities to assess, weigh, and think critically about trade-offs. The students' goal is to acquire skills they can transfer and develop more deeply as they mature. Excess data at too early an age can interfere with acquisition and compromise this goal.

For more, go to eyesofnye.org.

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How long?? Explore the half-life of Pu-239!

*See **The Eyes of Nye** Issue Support **Half-Life***

8) Introduce Yucca Mountain (below) from a geographical perspective, and explain, since 1987, the U.S. Department of Energy has been planning and conducting tests to make Yucca the U.S. repository for high-level nuclear waste. Play ***"Yucca: The Perfect Hiding Place,"*** in which Dr. April Gil discusses the reasons for its selection—large enough capacity, stability of the rock, distance from population centers, and most importantly, its dryness. Ask students if they would be ready to act on this plan. Follow by asking why we have not acted, after almost 20 years. Ask if we have simply been very thorough in testing, or there are things we don't know about Yucca. Tell them some would say the latter.

View Yucca Mountain and the characteristics considered conducive to waste storage.

9) Recall Dan Hirsch (Committee to Bridge the Gap) and the data discussed in step 2, and play ***"Worst Mistake Our Species Ever Made."*** Ask students to note the claims Mr. Hirsch makes regarding high levels of moisture in Yucca, and the Department of Energy's penchant for changing findings to suit their needs. Ask them to also note the newspapers flashing in the background, and that Yucca has indeed become a big struggle. Review "Yucca: Claims and Counterclaims" (right), but suggest when we say "no" to something it helps to have another suggestion—that at some point we must say "yes" to something, and we would hope we could influence that decision, as Mr. Hirsch does.

What are the goals of conflicting groups?
Explore opponent's claims and Department of Energy responses.
For more on exploring claims and claimants, go to eyesofnye.org

10) Play ***"The Struggle"*** and point out Bill's question "So what would you do?" Ask if Hirsch's idea to leave the waste at the reactor facilities (recall cooling pools in step 6) is a good one. Explain some believe there is sufficient space and security to do so. Others believe our ability to monitor the waste is greatly enhanced at a central off-site location, and on-site storage space will soon be at capacity (right). Ask students consider the potential trade-off between less on-site security and regular transport of waste to another location. Ask if we can afford to wait and find a better alternative—Hirsch's suggestion—or ultimately, if we can afford *not* to.

Procedure: Propose Phase

11) Based on their present views, ask each student to select one of three stances—for, against, or undecided—on:

- continuing with the Yucca mountain storage plan
- continuing with the use of nuclear energy

Ask them to individually construct one good reason for each decision in writing.

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the Eyes of Nye

See ***The Eyes of Nye*** *Issue Support*
Yucca: Claims and Counterclaims
Yucca: The U.S. Containment Goal

View projections of on-site storage capacity.
See ***The Eyes of Nye*** *Issue Support*
Nuclear Fuel Pool Capacity

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12) Divide the class into nine groups based on their responses, one for each permutation. For instance, one group should include those "for" going ahead with Yucca Mountain and "against" continuing nuclear energy, and so forth. Ask students to share their reasons for their similar stances within their groups, and together devise two more reasons they feel support each stance taken, or decided against taking in the case of those who are unsure.

13) Remind students of the nearly 300,000 tons of waste in storage around the world, and that about 70,000 tons of that is in the U.S. Suggest our study of pros and cons related to storage options such as Yucca, as well as the question to use nuclear energy, still applies when viewed from a global perspective. Allow groups to select any country and consider themselves citizens. Provide one period for them to access and study related information on their country—% reliance on nuclear energy, access to other forms of energy, amounts of resources available for production (or export). Ask students in each group to consider the stances they took in step 11, and describe changes (if any) in either stance. Where changes occur, students should also describe the reason. Ask each group to present briefly their original stances and reasons, their new country, and changes (and reasons) in stances they chose to make as a result of their new perspective.

Viewpoints can be uniquely modified or sometimes reinforced by exploring an issue from a very different perspective—as a citizen of a country who is a principal exporter of uranium or has no access to other forms of energy, or conversely, as a citizen of a country bordering a rogue nation.

Alternatively…*ask each group to construct and present a position paper based on their step 12 stance on use of nuclear energy and storage of waste at Yucca Mountain.*

14) Discuss the ramifications of errors in decisions that deal with nuclear energy. Tell students to imagine their decision will go into effect. Ask them what information they would most want to know before finalizing that important decision. Discuss responses. Close by informing students Nevada's challenge to the Yucca plan succeeded, but only in part. In July 2004, one of 12 courts has required that before storage can go forward, the 10,000-year target must be adjusted to a more appropriate figure. Tell students to keep themselves apprised—the nuclear issue will be awaiting new, hopeful solutions in the near future.

Final Teacher Note: *Extending the exploration to include global perspectives poses some difficulty in that an already stretched quantity of detail is further pressed. Given this, you may choose to remain focused on national and local considerations—the stipulated learning goals will still be met. However, the decision to consider the global outlook for this particular issue provides a certain realism. Countries' dual collaborative and competitive concerns, both economic and political, are of paramount importance to any lasting solution to the question of nuclear energy. The role of other forms of energy—and access or lack of access to those alternatives—is similarly unavoidable. As the* National Science Education Standards *emphasize, assessment of risks, benefits, and alternatives also involves decisions of who pays, who gains, and who bears the risks.*
For more, go to eyesofnye.org.

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Check out a promising new possibility. Play ***"The Potential of Transmutation."***

Further Research

Investigating the Issue: Nuclear Energy

The issue of whether to use nuclear energy and how to store the waste stands out from many other issues in three ways. *First*, there is the requirement we say "yes" to something—we must have some form of energy, and our exploration of trade-offs associated with nuclear energy must coincide with a similar exploration of benefits and costs of other forms of energy. *Second*, the consequences of our decisions regarding nuclear energy are monumental—few issues carry with them the potential for the destruction of our species in the event a poor choice is made. *Third*, without proper perspective, we can make the right choices at "home" and win the battle in our own backyard, yet lose the war abroad—nuclear energy is an issue worldwide.

In addition to information and claims presented in *The Eyes of Nye - Nuclear Energy*, there are a wide variety of resources students can access to learn more about nuclear energy production, security, regulation, licensing, waste storage, environmental effects, and transportation of waste materials, as well as solid numerical data and projections, trends, and extrapolations built from that data.

Exploring Nuclear Energy

Students should obtain information from the following groups/agencies.

The ***U.S. Nuclear Regulatory Commission*** provides information related to storage of spent nuclear fuel, including regulations, licensing, and oversight efforts. Access at: http://www.nrc.gov

The ***Nuclear Energy Institute***, a principal policy organization of the nuclear energy industry, provides—in addition to a wealth of policy-related materials—a wide range of technical and descriptive materials related to production of nuclear energy, modes of storage, and plans and processes for safe use and disposal. Access at: http://www.nei.org

The ***U.S. Environmental Protection Agency*** provides an assortment of materials and links of interest especially related to various means of energy production and their potential effect on the environment. Students should use the search feature on the home page. Access at: http://www.epa.gov

The ***U.S. Department of Energy*** likewise provides a range of resources related to nuclear and other forms of energy, including sources/resources to drive the production, costs (economic), health and safety, and national security. Access at: http://www.doe.gov

Exploring Nuclear Energy Claims and Claimants

An important aspect of dealing with the socio-scientific issue of nuclear energy involves looking beneath the evidence and viewpoints expressed by acquiring additional information on the experts themselves as well as the organizations with whom they are affiliated. Through such exploration, students are better able to infer social (contextual) factors that may influence the claims. In *The Eyes of Nye - Nuclear Energy*, many individuals are interviewed—each is provided below. Teachers may

encourage students to conduct open-ended searches for this type of information, or direct students to the names and institutions below.

Suzie Kroma, refuel coordinator	Columbia Generating Station
Larry Linik, spent fuel coordinator	Columbia Generating Station
Dr. April Gil, geologist	Yucca Mountain, Nevada
Bruce Reinert, engineer	Yucca Mountain, Nevada
Dan Hirsch, president	Committee to Bridge the Gap
Dr. Gary Cerefice, research scientist	Harry Reid Center University of Nevada, Las Vegas

ISSUES SUPPORT MATERIAL

Nuclear Energy: The Costs and Benefits of Alternative Choices

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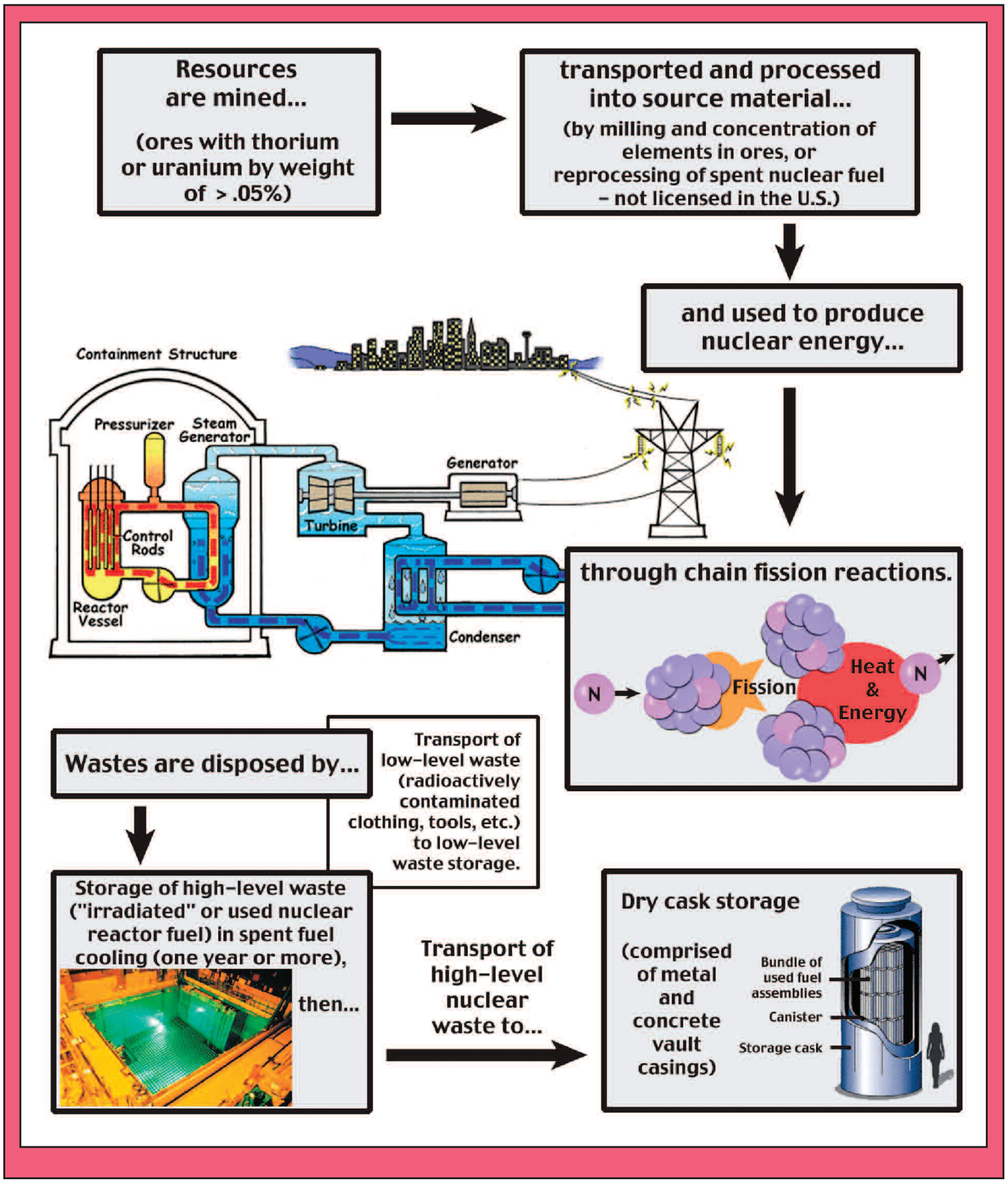
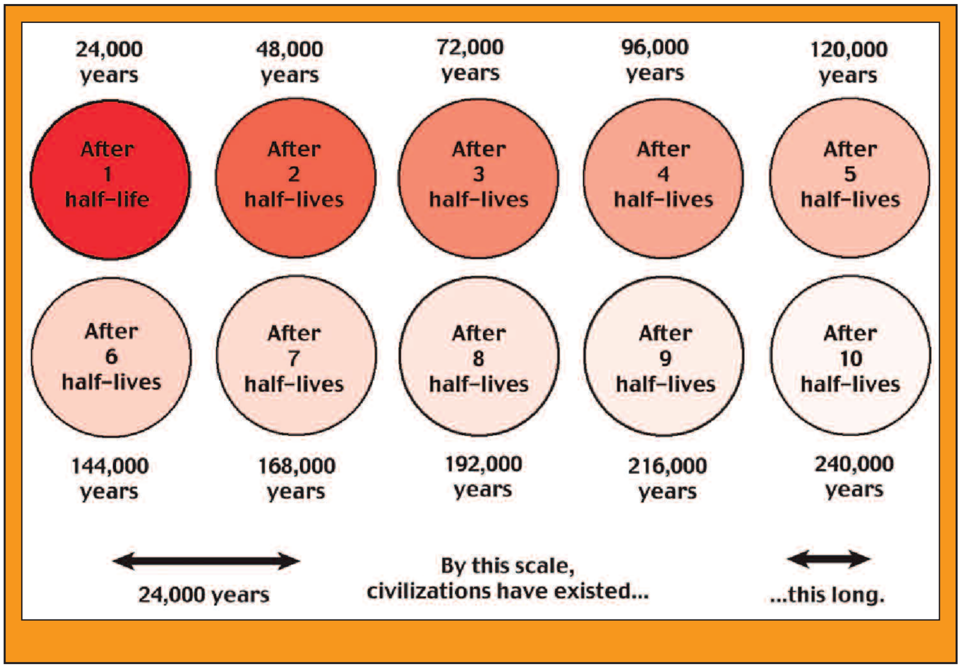
Nuclear Energy: The Process



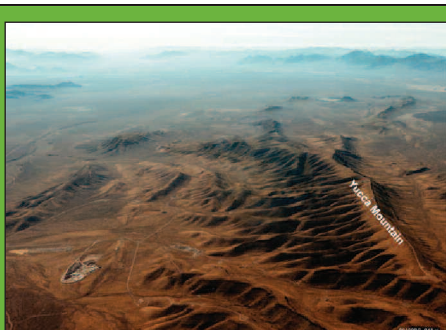
Power generator, cooling pool and dry cask image elements courtesy of the U.S. Nuclear Regulatory Commission.

Half-Life

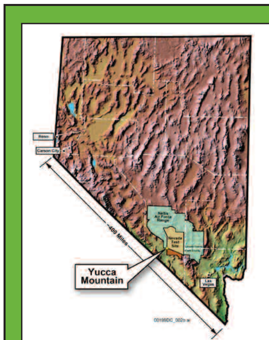
The element Plutonium-239 (Pu-239); half-life of 24,100 years



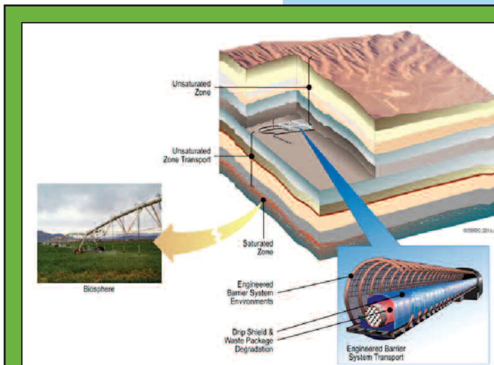
Yucca: The U.S. Containment Goal



Yucca aerial view.



Nevada state map.



Natural and engineered barriers of Yucca.

Yucca from aerial view (top left), and on Nevada state map (top middle). Around 100 miles from the closest population center (Las Vegas).

Natural and engineered barriers of Yucca (top right).

- Impermeable rock above and below.
- Situated far above water table.

Source: Nuclear Energy Institute

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Yucca: Claims and Counterclaims

The following are the most frequently cited objections to the Yucca Mountain project and the response based on scientific analysis.

Scientific bias-

Concern:

DOE skews scientific results to make the repository look OK.

Answer:

- An independent Inspector General's investigation, completed in April 2001, found no evidence of pro-repository bias in DOE's scientific program.
- DOE science is the product of thousands of respected scientists and organizations.
- DOE's scientific methods are backed by strong international consensus.
- DOE has taken a conservative approach in areas of scientific uncertainty.
- DOE's scientific results have been subjected to and withstood critical review from organizations such as the International Atomic Energy Agency and the Nuclear Waste Technical Review Board.

Upwelling of groundwater -

Concern:

Geothermal processes could force up the water table from 1000' below the repository to flood the waste emplacement area.

Answer:

- Multiple studies at the National Academy of Sciences, University of Nevada at Las Vegas, Nuclear Waste Technical Review Board, U.S. Geologic Service, and Virginia Polytechnic University have completely debunked this theory.

Corrosion -

Concern:

Water will degrade the waste package containers.

Answer:

- Very little water falls on Yucca; most of what does runs off. Scientists have modeled possible water infiltration and designed corrosion resistant containers.
- Natural analogues—objects not protected by advanced materials—have survived thousands of years in the environment under similar or less favorable conditions.

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Earthquakes -

Concern:

It is not safe to bury nuclear waste in a seismically active area.

Answer:

- The seismicity of Yucca Mountain is well known and understood.
- Repository surface and operating facilities will be designed to withstand quakes.
- The occurrence of earthquakes has been considered in repository design and long-term performance assessments. The waste containers themselves will be designed to withstand worst-case earthquakes and falling rocks.
- The repository layout will avoid well-characterized fault lines.
- Earthquakes release most of their destructive force at the surface.

Volcanoes (igneous activity) -

Concern:

A volcano could erupt through the repository.

Answer:

- A volcanic eruption that affects the repository is a highly improbable event.
- There has not been a volcanic eruption through Yucca in 10 million years.
- Millions of years of history shows the region surrounding Yucca Mountain is becoming less volcanically active with time.
- Nevertheless, NRC is requiring that DOE analyze the consequences of such an event and include this analysis in the repository performance assessment.
- The Volcano itself is likely to cause more harm than any radiation it might release.

Transportation is too risky -

Concern:

Moving used fuel along road & rail threatens millions of homes.

Answer:

- Used nuclear fuel transportation has a well-established safety record.
- Used nuclear fuel transportation is regulated and carried out with precautions.
- Used nuclear fuel shipping containers are designed to withstand accidents.
- Highly improbable (non-credible) accident release scenarios have

been analyzed and can be mitigated; emergency responders will be prepared if they happen.

Human intrusion -

Concern:

Future residents of Yucca Mountain may inadvertently mine into the repository.

Answer:

- It is difficult to believe that future populations will lose knowledge of or ability to detect the repository yet retain the technology to drill through and/or mine into it.
- High ground in a resource barren area is an unlikely drilling/mining location.
- Nevertheless, NRC will require DOE to evaluate a human intrusion scenario and demonstrate that consequences to the public would be within safety limits.

Climate change -

Concern:

Yucca will not be as dry in 1000s of years as it is today.

Answer:

- Past climate change patterns have been evaluated. If Yucca gets wetter, it won't get that much wetter.
- DOE conservatively assumes a wetter climate in its performance assessment.

Surface flooding -

Concern:

Flash floods could inundate the surface facilities during repository operations, causing release of radioactive materials.

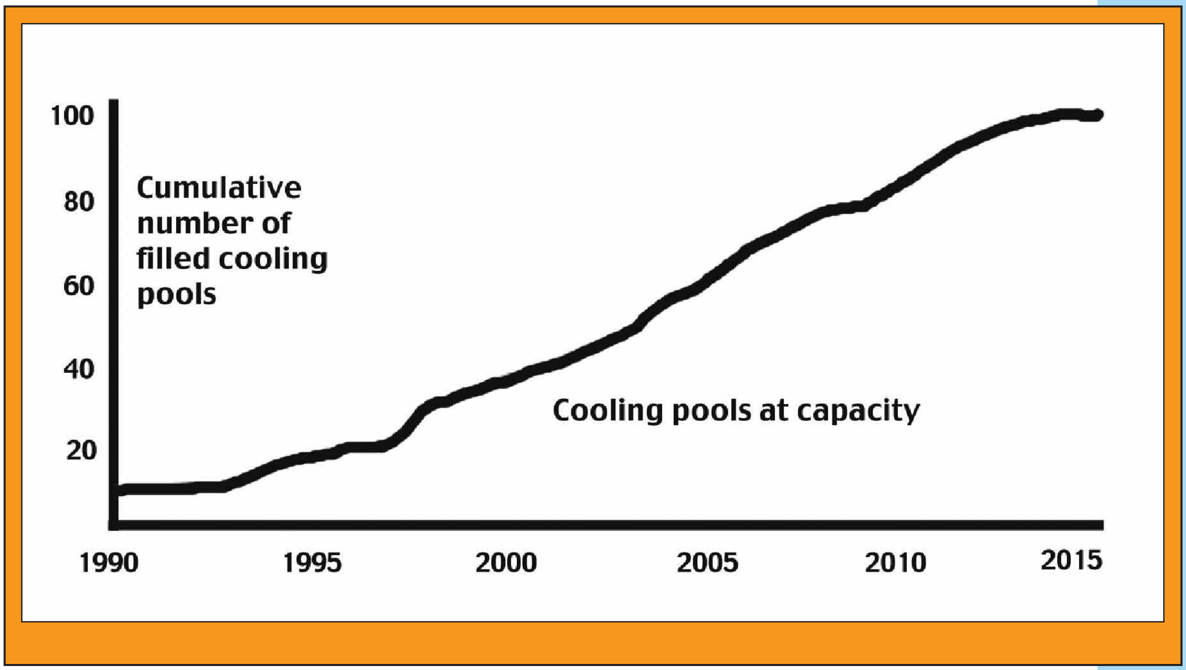
Answer:

- The surface facilities will be designed to withstand worst-case floods.
- Transportation and storage casks are designed to withstand submersion.
- Nevada has flooding when it rains because the ground does not absorb water well. Ground that doesn't like to absorb water is a good thing above a repository.

Site is not large enough -

Concern:

The nuclear waste storage facility at Yucca Mountain as planned is not large enough to store all of the used nuclear fuel and defense-related waste.



Source: Energy Resource International and DOE/RW-0431 - Revision 1