Department of Environmental and Occupational Health Sciences, University of Washington

Is Nuclear Power Green?

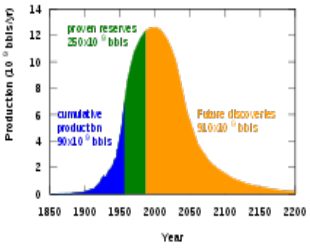
University of Washington >
School of Public Health & Community Medicine >
Department of Environmental & Occupational Health Sciences

Overview

- **Why is nuclear power being considered, again**
- **History of nuclear power in the US and world**
- **How do nuclear power plants work**
- **Pros and Cons of nuclear power**
- **Where does nuclear power fit into the US energy profile**

Hubbert Curve (1956)

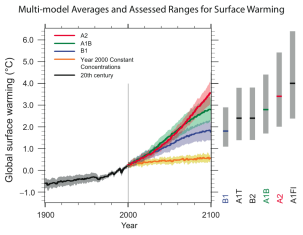
- M. King Hubbert, PhD
  - Shell Oil; USGS
- Non-market method to account for energy production
- Prediction of oil & gas reserves
- Advocated for renewables & nuclear
- Method applied to fisheries



21st Century Global Warming

Projected range of global-scale warming by the 2090s:
3.2°F-7.2°F

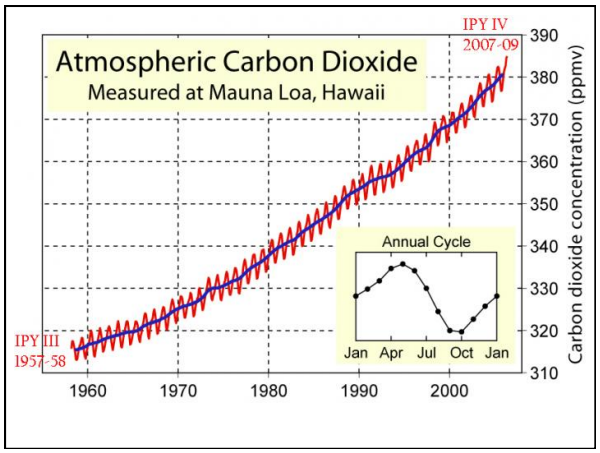
Warming expected through 21st century *even if CO2 emissions end today* due to persistence of greenhouse gases.

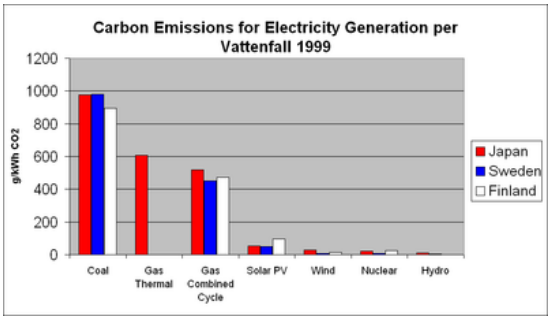


Estimated atmospheric lifetime of major greenhouse gas (per molecule)

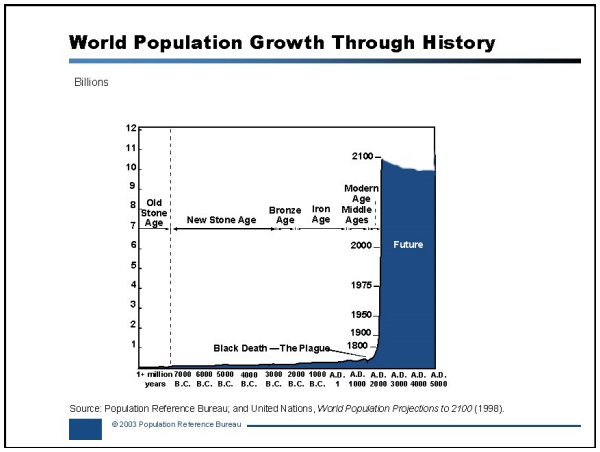
Carbon Dioxide	~60% of warming from GHG	5 to 200 years
Methane	~20% of warming from GHG	8 to 12 years
Nitrous Oxide	~6% of warming from GHG	~120 years
CF4 (Perfluoromethane)		>50,000 years

Data source: IPCC 2001



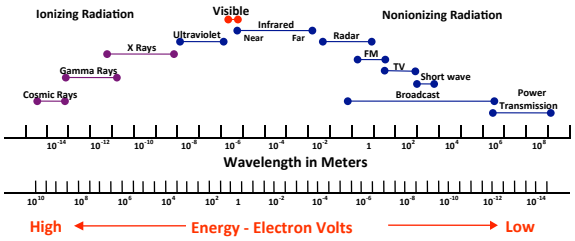


Greenhouse Emissions by generation source



So what about Nuclear?

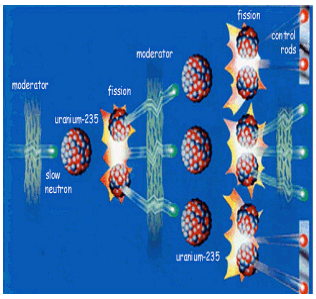
Electromagnetic Spectrum



Half life: the time for half the nuclei in a radioactive substance to decay

Nuclear Fission

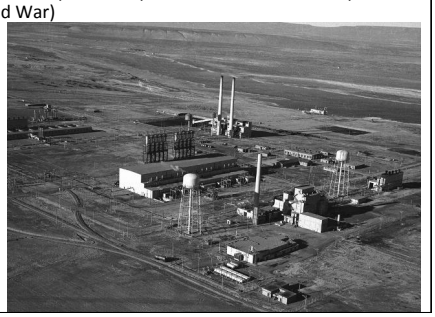
- U-235 atom absorbs slow-moving (thermal) neutron
- Atom becomes excited and splits, producing
  - Pair of fission fragments
  - 2-3 additional fast neutrons
  - Heat
- Fast neutrons are thermalized in the moderator and go on to split more U-235 atoms in a chain reaction
- And so on, and so on, and so on…



History of nuclear power in the US

Manhattan Project

Hanford B reactor produced plutonium for atomic weapons (WW 2; Cold War)



History of nuclear power in the US

"Atoms for Peace"

The first commercial pressurized water reactor (PWR)

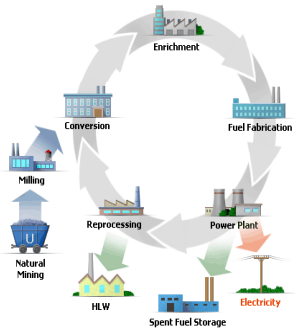
Westinghouse
Yankee Row (1960 – 1992)

Boiling water reactor (BWR) was developed

Argonne National Laboratory
A prototype BWR, Vallecitos, ran from 1957 to 1963.
First commercial plant, Dresden 1
designed by General Electric (1960).

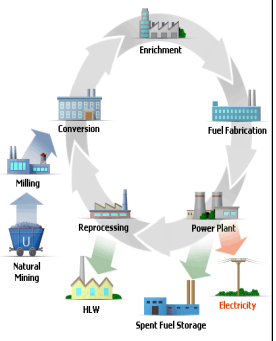
Nuclear Fuel Cycle

- Uranium Mining & Milling
- Conversion
  - Separates fissile U-235 present in uranium ore from more abundant, non-fissile U-238
- Enrichment
  - Further distills U-238, increasing U-235 percentage
- Fuel Fabrication

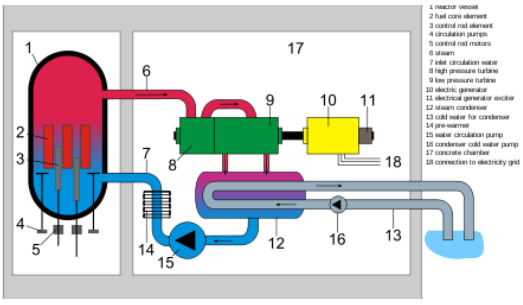


Nuclear Fuel Cycle

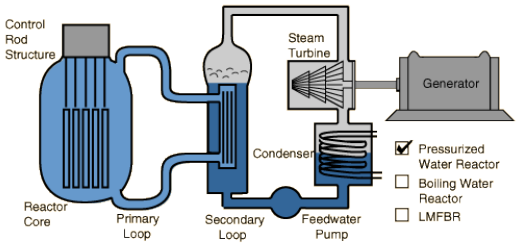
- Power Generation
  - Reaction controlled by control rods made with neutron-absorbing elements, slows or stops reaction
- Reprocessing (not done much in the US)
  - Pu-239, U-235, and U-238 recovered from waste and reclaimed for additional fuel
- Nuclear Waste
  - Low-level waste
  - Current on-site storage for high level waste (water/dry cask)



Boiling Water Reactor (BWR)

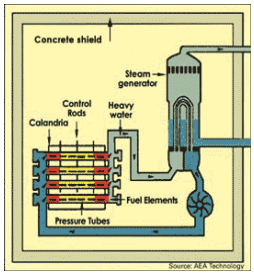


Pressurized Water Reactors (PWR)

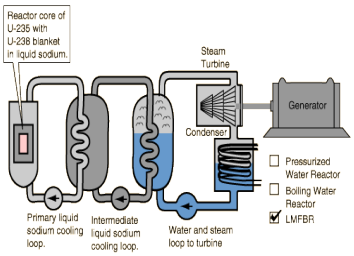


Canada Deuterium Uranium (CANDU)

- Heavy water flows over horizontal non-enriched fuel elements
- Sustained chain reaction due to additional neutrons in D2O
- Cost of producing heavy water offset by savings in uranium conversion



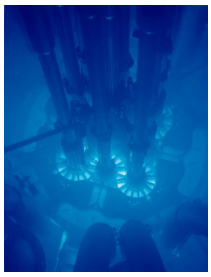
Fast Breeder Reactor



- "Breeds" more fuel than consumed in sustained chain reaction
- Initial fuel Pu-239, creates additional Pu-239 from non-fissile U-238
- Liquid sodium coolant, no moderator necessary
- Reprocessing recovers Pu-239 from U-238 blanket

Mini "backyard" reactors

- Modular design
- Smaller scale, less material present in enclosed reactor vessel, smaller components
- Intended for use in remote locations, small communities (20,000 homes)
- Underground installation, low maintenance
- Long fuel cycles possible (40+ years per fuel container)



Radiation Units of Measure

Curie (Ci) or becquerel (Bq) = Radiation emitted by radioactive material

- **Joule of energy in one kg of matter**
- **expresses the number of disintegrations of radioactivity**

Rad (radiation absorbed dose) or Gray (Gy) = Absorbed Dose

- **amount of energy deposited per unit of weight of human tissue**

Rem or Sievert (Sv) = equivalent dose

- **measure of biological risk of adverse health effects**
- **makes different types of radiation equivalent**
- **1 SV = 100 REM**

Health Effects of Ionizing Radiation

Alpha particle: helium nuclei consisting of two protons and two neutron
- Are emitted from naturally-occurring heavy elements such as uranium and radium
- Cannot penetrate the skin, so are dangerous only if emitted inside the body.

Beta particles: fast-moving electrons
- Emitted by many radioactive element
- More penetrating than alpha particles, but easily shield
- Exposure produces an effect like sunburn, but which is slower to heal.

Gamma rays: high-energy beams (similar to X-rays)
- emitted in many radioactive decays and are very penetrating
- Damages or kills cells

Neutrons: released by nuclear fission
- Fast neutrons can be very destructive to human tissue.

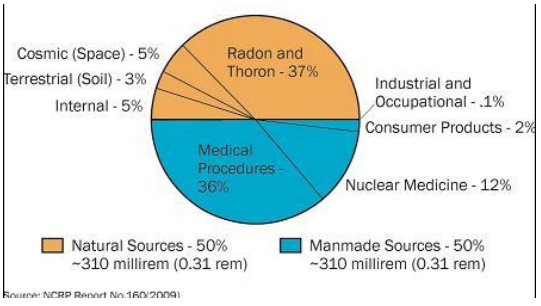
Examples of Tissue Sensitivity

Very High	White blood cells (bone marrow) Intestinal epithelium Reproductive cells
High	Optic lens epithelium Esophageal epithelium Mucous membranes
Medium	Brain – Glial cells Lung, kidney, liver, thyroid, pancreatic epithelium
Low	Mature red blood cells Muscle cells Mature bone and cartilage

Dose Response

Dose (Sv)	Effects / organ	Time to death	Death (%)
1-2	Bone marrow	Months	0-10
2-10	Bone marrow	Weeks	0-90
10-15	Diarrhea, fever	2 weeks	90-100
>50	Neurological	1- 4 hrs	100

Sources of Radiation



Exposure Standard

Occupational Exposure Guidelines (USA)
variable by body part
whole body: annual limit 0.05 Sv (5 rem)
lens of eye: annual limit 0.15 Sv (15 rem)

Background about 2 - 3 mSv/year
earth, cosmic radiation, coal fired power plants
medical tests (.4 - 1 mSv/year)
5 uSv from nuclear weapons testing and use

Japanese standard: 0.10 Sv ; 0.25 Sv (emergencies)

Reducing Exposure

- Time
  - Reduce the spent near the source of radiation
- Distance
  - Increase the distance from the source of radiation.
- Shielding
  - Place shielding material between you and the source of radiation.

Government efforts

Huge Taxpayer investments from the beginning

Initial effort with the Manhattan project
US Army Corp of Engineers

Peacetime use of atomic energy
Nuclear power
Atomic Energy Act of 1946 and 1954 = Atomic Energy Commission
AEC responsible for **supporting** the industry & protect the public
AEC abolished 1974 >> Nuclear Regulatory Commission in 1975

Nuclear Regulatory Commission
Radiation protection (standards to protect public & workers)
Reactor Safety (prevent accidents, releases)
Regulate Nuclear Materials (relicensing, licensing, waste waste)

1977 Carter executive order banning reprocessing nuclear fuel

Government activities continue

1979 Three Mile Island accident (near Harrisburg PA)
partial core meltdown of a PWR
resulted in no new construction starts since 1977

Nuclear Waste Policy Act of 1982
plan for storage of highly-radioactive material and military waste

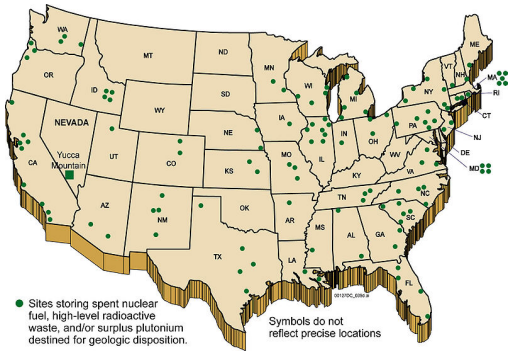
1987 Yucca Mountain designated primary site (one of 10)

1992 Energy Policy Act

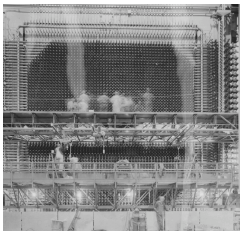
2009 proposed elimination of Yucca Mt repository

Nuclear Waste

- Low-level radioactive waste
- High-level waste
- Waste Processing
  - Compaction and burial
  - Solidification
  - Incineration
  - Vitrification
  - Reprocessing/'recycling'
- Burial sites
  - Yucca Mountain?
  - Barnwell, SC
  - Hanford



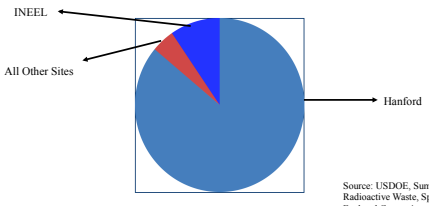
Hanford



- Additional plants built for power generation, all shut down by 1971
- Eventual 'discovery' of levels of environmental contamination
- Led to largest cleanup effort in history
- Currently removing contaminants from groundwater, recovering waste from underground tanks, vitrifying high-level waste, and burying LLRW in ERDF facility

Hanford's Environmental Legacy

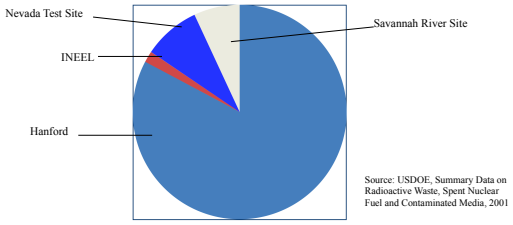
- Hanford has over 80 percent of DOE's highly radioactive spent reactor fuel (2,100 tons).



Source: USDOE, Summary Data on Radioactive Waste, Spent Nuclear Fuel and Contaminated Media, 2001

Hanford's Environmental Legacy

- Hanford has the largest amount of contaminated soil and groundwater.



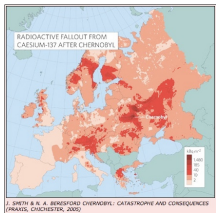
Source: USDOE, Summary Data on Radioactive Waste, Spent Nuclear Fuel and Contaminated Media, 2001

Yucca Mountain

- Nuclear Waste Policy Act 1982
  - Created timetable for establishment of permanent underground repository
  - Sites examined on multiple criteria for storage of spent fuel and other high-level waste
  - Yucca Mountain site selected in 1987, license application submitted by Dept. of Energy (DOE) in 2008
  - No funding for Yucca Mountain in 2010 federal budget, site "no longer an option."
  - DOE files a motion with NRC to withdraw its license application, faces multiple lawsuits as a result

- Blue Ribbon Commission to explore alternative waste disposal

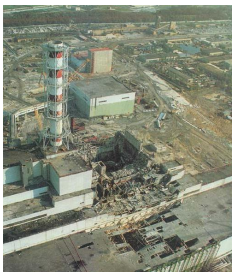
Nuclear Accidents



A Few Problems

- Three Mile Island
  - 1979 partial meltdown due to misinterpretation of equipment functioning
  - Release of 13M curies of radioactive material
  - Reactor building cleanup
- Aftermath
  - No injury or deaths, 'small' dose to the public
  - Fear of worse outcomes prompted increased oversight and regulation throughout industry

More Problems: Chernobyl



- 1986 steam explosion of reactor core at Chernobyl plant
- Plant design contributed to magnitude of disaster
- Fire with large release of radioactive material prompted area evacuation (81M Ci cesium)
- Over 100 deaths due to radiation exposure during initial response
- 200,000 radiation-linked CA fatalities
- 30 km no-go zone 25 yrs later

And More Problems: Fukushima

- BWR
- March 11, 2011 9.0 earthquake; tsunami >> damage & power loss
- 30 workers >100mSv
- >200,000 evacuated (12 mi)
- I131 & Cs 137 > Chernobyl

Nuclear Energy Current Status

There are **430 operating nuclear power plants in the world**, providing 15% of the worlds electricity (2007)

- France: 77% of the country's electricity is from nuclear power
- Lithuania: 65% of the country's electricity is from nuclear power
- US: 20% of the country's electricity is from nuclear power
  - **104 power plants**
    - 30% of the nuclear power generated in world
    - built between 1967 and 2007 (permitted before 1977)
    - 31 states, operated by 30 different power companies.

4-6 new units may come on line by 2018

- in process since 2007

Government subsidies necessary for continued reactor development and operations (loan guarantees; liability)

Pros and Cons of Nuclear Power

PROS

Doesn't use fossil fuel (coal or oil) so no CO2

Releases less radioactivity than a coal-fired power plant

Renewable energy will not supply even a small percentage of the worldwide electricity need.

CONS

Mining and purifying uranium - carbon emissions, worker health

A nuclear power plant generates 20 metric tons **radioactive waste**.

No long term waste repository or method identified

Increased amount of plutonium – '**proliferation**' AKA terrorist threat

Accidents can be catastrophic

The Seattle Times

"Safe, secure nuclear energy must be part of climate change solution"

Paul Dickerson and Adam Grosser
Seattle Times, April 19, 2010