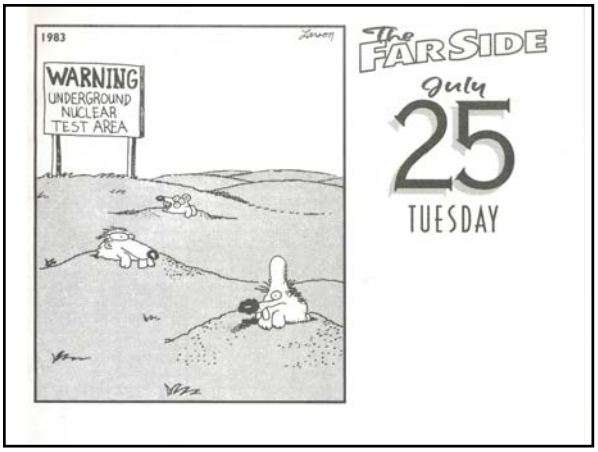
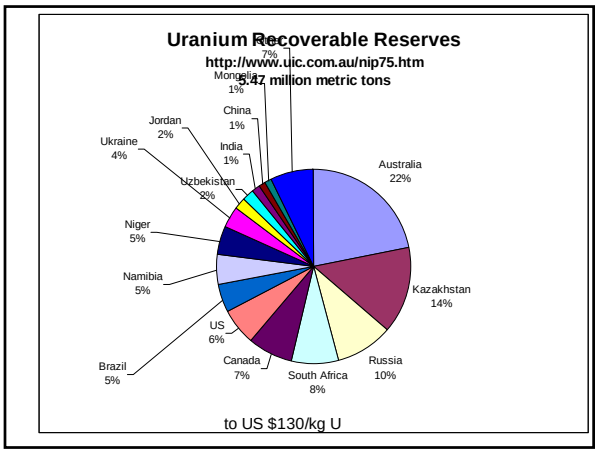
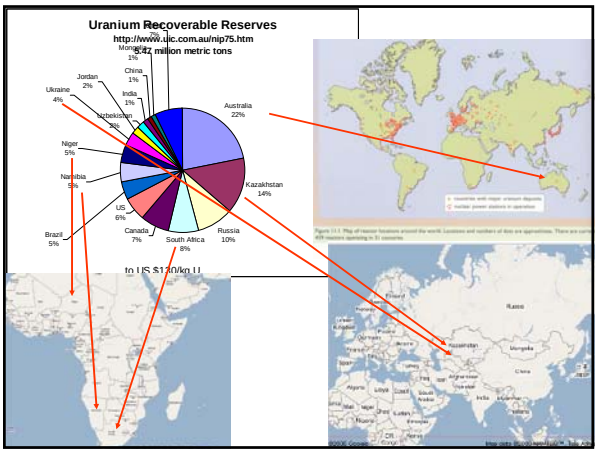
Nevada Test Site



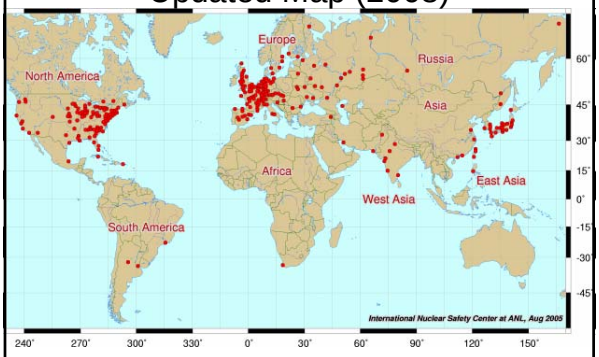
Occurrence of U

• **Very high-grade ore (Canada) - 20% U**	200,000 ppm U
• **High-grade ore - 2% U,**	20,000 ppm U
• **Low-grade ore - 0.1% U,**	1,000 ppm U
• **Very low-grade ore* (Namibia) - 0.01% U**	100 ppm U
• **Granite**	4-5 ppm U
• **Sedimentary rock**	2 ppm U
• **Earth's continental crust (av)**	2.8 ppm U
• **Seawater**	0.003 ppm U

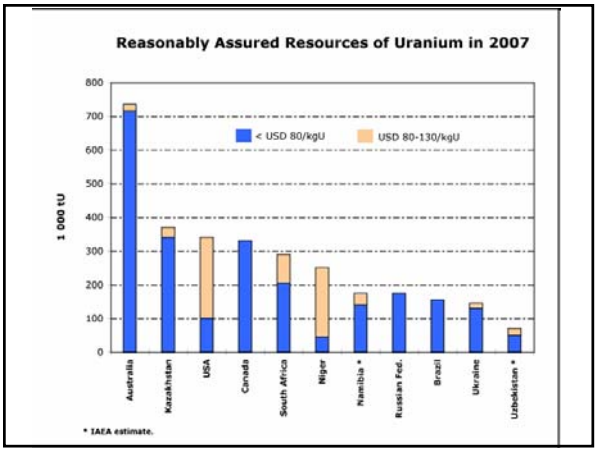




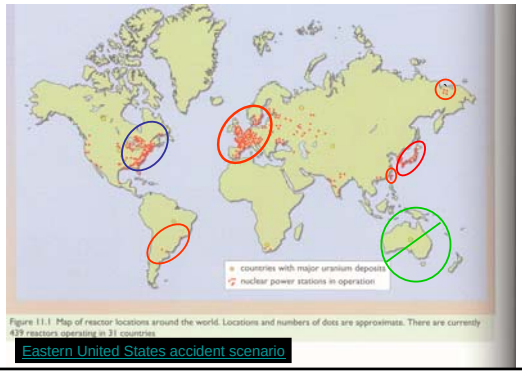
Updated Map (2008)



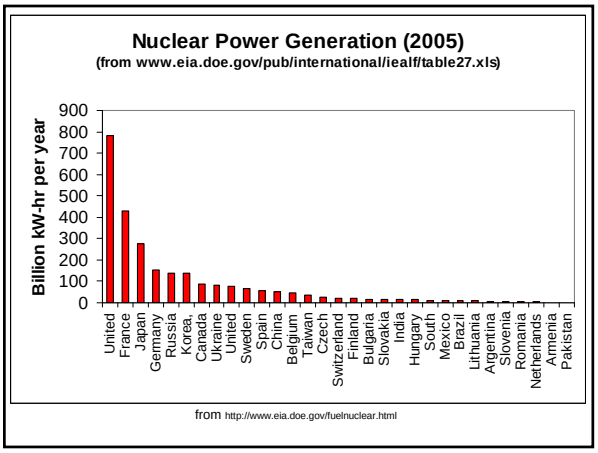
http://www.insc.anl.gov/pwrmaps/map/world_map.html



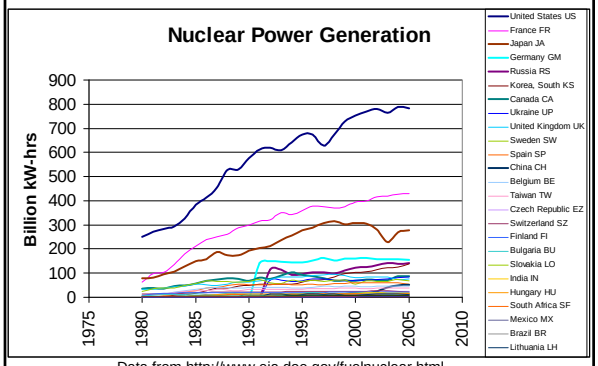
Location of Nuclear Plants



Eastern United States accident scenario



from http://www.eia.doe.gov/fuelnuclear.html



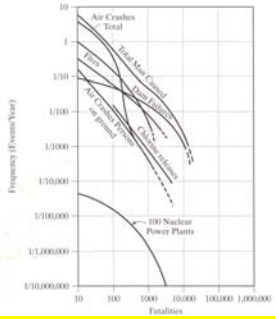
Data from http://www.eia.doe.gov/fuelnuclear.html

Why Not Nuclear?

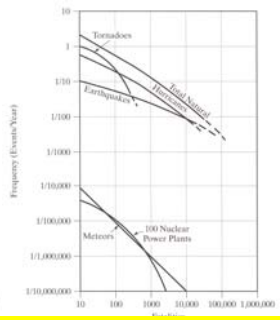
- Accidents
- Disposal
- Economics

Risk vs. Probability

Human-Caused Events



Natural Events



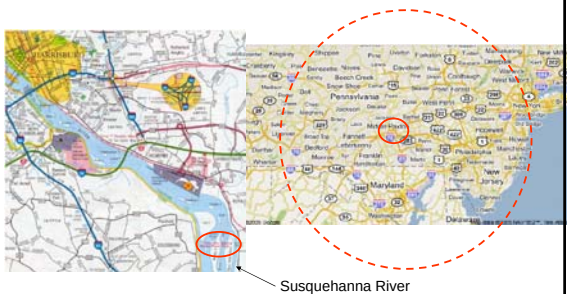
This is a good attempt (from Rasmussen report), but does not consider all possibilities

From Energy, Physical, Environmental, and Social Impact, G. J. Aubrecht (2006)

Nuclear Units

1 Curie (Ci) =	3.7×10^{10} becquerel (Bq) (measures emission)
1 Gray (gy) =	1 J of absorbed energy per kg
1 rad =	0.01 gray (gy)
1 Sievert (Sv) =	Dose equivalent (J/kg, adjusted for type of radiation)
1 rem =	0.01 Sievert

Three Mile Island
(location)



Chain of Events

- Minor problem in secondary cooling circuit caused shutdown
- Relief valve on pressurizer opened for 10 seconds, but failed to close
- Water and steam escaped from secondary cooling system, lowering pressure
- Operators had signal saying valve was closed
- Makeup water automatically added to secondary cooling
- Operators saw rise in water level in pressurizer, and decreased water flow
- Less cooling caused high temperatures in core, boiling water and damaging core
- Subsequent attempts to add water to primary hampered by gas bubble
- Some release of radioactive gases to relieve gas pressure
- Average dose within 10 mile radius was 0.08 mSv, highest dose 1 mSv
  - 0.08 mSv = 1 chest X-Ray
  - 1 mSv = 1/3 of annual background radiation received in U.S.)

Pressurized Water Reactor (PWR)

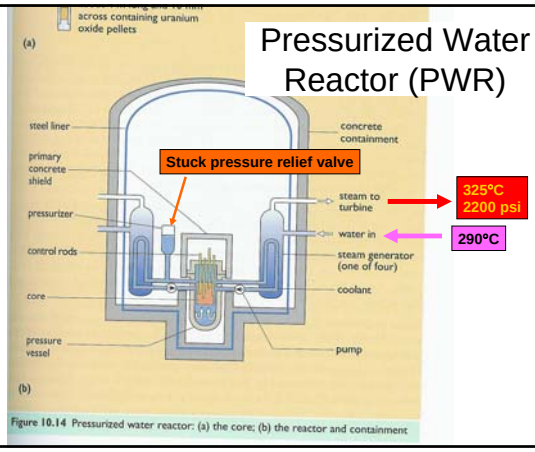


Figure 10.14 Pressurized water reactor: (a) the core; (b) the reactor and containment

Chernobyl

1 of 4 RBMK reactors in northern Ukraine

Chernobyl Chain of Events

- Reactor test at low power setting (known to be unstable at these conditions)
- Automatic shutdown systems disabled for test
- As coolant decreased, power increased
- Dramatic power surge occurred due to design of RBMK reactors
- Fuel elements ruptured
  - Resultant explosive force of steam lifted off the cover plate of the reactor
  - Fission products released to atmosphere
- Second explosion threw out fragments of burning fuel and graphite from the core
  - Air rushed in, causing the graphite moderator to burst into flames
  - Graphite burned for nine days (main cause of radioactive release to atmosphere)
- 12 x 10^{18} Bq of radioactivity was released
  - 5% of reactor core released to atmosphere
  - 5000 tonnes of boron, dolomite, sand, clay and lead were dropped on to the burning core by helicopter

- 45,000 people evacuated
- Most deaths among initial firefighters
  - Doses of 20,000 mSv received
- Health effects exaggerated to gain more aid
- Large areas still evacuated (except for squatters)

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- **The Chernobyl accident in 1986 was the result of a flawed reactor design that was operated with inadequately trained personnel and without proper regard for safety.**
- **The resulting steam explosion and fire released at least five percent of the radioactive reactor core into the atmosphere and downwind.**
- **28 people died within four months from radiation or thermal burns, 19 have subsequently died, and there have been around nine deaths from thyroid cancer apparently due to the accident: total 56 fatalities as of 2004.**
- **An authoritative UN report in 2000 concluded that there is no scientific evidence of any significant radiation-related health effects to most people exposed. This was confirmed in a very thorough 2005-06 study.**

http://www.uic.com.au/nip22.htm

Dosages

360 millirem (3.6 mSv)	Average annual U.S. dosage from ambient
1 Sv, or 100 rem (short term dose)	Temporary radiation sickness
10 Sv (1000 rem)	Fatal
6-60 mSv (600 to 6000 mrem)	10-yr dose near Chernobyl
5 Sv (500 rem)	Received by fatalities in a few days at Chernobyl
3-4 Sv (300-400 rem)	Acute radiation sickness at Chernobyl

Cost Comparison

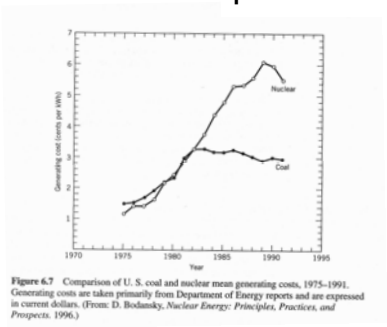
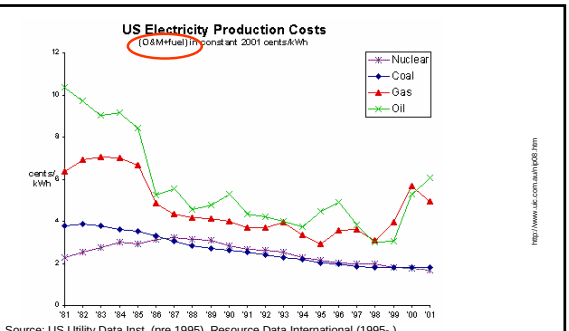


Figure 6.7 Comparison of U. S. coal and nuclear mean generating costs, 1975–1991. Generating costs are taken primarily from Department of Energy reports and are expressed in current dollars. (From: D. Bodansky, *Nuclear Energy: Principles, Practices, and Prospects*, 1996.)

From Energy and the Environment, by Ristinen and Kraushaar



Source: US Utility Data Inst. (pre 1995), Resource Data International (1995-)
Note: the above data refer to fuel plus operation and maintenance costs only, they exclude capital, since this varies greatly among utilities and states, as well as with the age of the plant. On the basis of the OECD projections opposite, capital costs in USA are 55% of total for nuclear, 45% of total for coal and 16% of total for gas.

Total gross costs on this basis for 2001 gives 3.73 c/kWh for nuclear, 3.27 c/kWh for coal and 5.87 c/kWh for gas.

So How Much Uranium Is There?

- Price dependent
  - Only low-cost, concentrated ore is now used
  - Doubling of price could yield 10-fold increase in amount
- http://www.uic.com.au/nip75.htm
  - 70 years without breeder reactors – depends on price
- http://www.americanenergyindependence.com/uranium.html
  - No worries – we'll find more, just like oil
  - 50 years, then breeder reactors will become "economical"
- Certainly breeder technology will extend life of nuclear fuel up to ~1000 years instead of ~50-70 years

Future Considerations

- Cost
- Supply (imports?)
- Waste Disposal & Plant Decommissioning
- Safety
- Security
- Importance of CO_2 emissions