Resources:  
Nuclear power

Reading:  
Ch 14 p338-348

Alternative energy sources  
i.e. non-fossil fuels

Power consumption is increasing  
Fossil fuels provide 85% of global power  
Oil and gas supplies not expected to last more than a few decades...  
→ we need alternative energy sources

Generating electricity  
Most electricity is generated in the same way...  

Nuclear fuel  
The energy released by nuclear fuel is the product of converting mass to energy

Einstein's famous equation:  

\[ E = mc^2 \]

E is the energy released  
m is the mass converted  
c is the speed of light  
\( (3x10^8 \text{ m/s}) \)
Fission and Fusion

**FISSION**
- splitting large nuclei
- the energy source for nuclear power stations

**FUSION**
- joining small nuclei
- not currently a viable energy source (remember cold fusion?)

In each of these reactions there is a small loss of mass resulting in energy release.

Uranium isotopes

**238U:** The most abundant isotope of uranium
- 92 protons
- 146 neutrons
- lighter and more active
- spontaneously splits
- the fuel for nuclear reactors

**235U:** Only 0.7% of natural uranium
- 92 protons
- 143 neutrons
- not currently a viable energy source (remember cold fusion?)

Uranium deposits

Most U.S. deposits are in sandstones
- U dissolved out of crustal rocks by O-rich waters
- Fluids precipitate the U in O-poor environments
- resulting in concentrations of U

Also found in granites within last crystals to form - fractionation
And carbonates precipitated from water

Extraction

1. Extraction from mine
2. Crushing, grinding and adding water to form a slurry
3. Leaching with sulfuric acid to extract $U_3O_8$
4. Chemical precipitation dried and packed

Processed "yellowcake"
- > 99% pure $U_3O_8$

Only mildly radioactive: 1 m away it is half as radioactive as cosmic radiation on a plane
- need to enrich for power plants
**Enrichment**

Need to increase the 0.77% $^{235}\text{U}$ to 3-5% for nuclear reactors

First convert $\text{U}_3\text{O}_8$ to $\text{UF}_6$ (uranium hexafluoride)

1. **Gaseous diffusion**
   - U.S. method of choice

2. **Gas centrifuge**
   - European approach

- Lighter $^{238}\text{U}$ preferentially escapes through porous membrane
- Heavier $^{235}\text{U}$ forced to the outside of a rotating cylinder and separated

**Control of a chain reaction**

Each $^{235}\text{U}$ that splits generates another 3 neutrons that could split another $^{235}\text{U}$

- Chain reaction
- Nuclear exposition

Control rods absorb neutrons to stop the chain reaction

**Nuclear power**

Containment Structure

- Reactor Vessel
- Control Rods
- Generator
- Turbine
- Condenser

**Uranium reserves**

<table>
<thead>
<tr>
<th>Known Recoverable Resources of Uranium</th>
<th>tonne $\text{U}_3\text{O}_8$</th>
<th>percent of world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>164,000</td>
<td>24%</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>472,000</td>
<td>18%</td>
</tr>
<tr>
<td>Canada</td>
<td>437,000</td>
<td>14%</td>
</tr>
<tr>
<td>South Africa</td>
<td>286,000</td>
<td>8%</td>
</tr>
<tr>
<td>Argentina</td>
<td>215,000</td>
<td>0%</td>
</tr>
<tr>
<td>Brazil</td>
<td>167,000</td>
<td>6%</td>
</tr>
<tr>
<td>Russian Fed.</td>
<td>121,000</td>
<td>4%</td>
</tr>
<tr>
<td>USA</td>
<td>104,000</td>
<td>3%</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>135,000</td>
<td>2%</td>
</tr>
<tr>
<td>World total</td>
<td>3,107,000</td>
<td>100%</td>
</tr>
</tbody>
</table>

Increasing nuclear power production by more than a factor of four would cause significant U shortages in the U.S.

An increase by a factor of four would still only supply less than 15% of U.S. energy needs

Other safety concerns are preventing an increase in the use of nuclear power anyway
Breeder reactors
Generating power AND more fuel
This would reduce the pressure on the supply of uranium

A "spare" neutron can convert $^{238}\text{U}$ to $^{239}\text{Pu}$:

- $T_1 = 2.38 \text{ yrs}$
- $T_2 = 2.35 \text{ yrs}$
- $T_3 = 2.44 \times 10^8 \text{ yrs}$

which is fissile.

The reactors required are more expensive as they cannot use a water coolant, they use liquid metal sodium instead.

There are no commercial breeder reactors in the US and little interest in pursuing the nuclear option.

Commercial reactors in the U.S.

This is an aging population, most were built in the 1970's

Three Mile Island, PA, 1979
Core meltdown

The drastic effect of a highly unlikely accident is the reason nuclear power is going out of favor

Remains of fuel rods within reactor core

For more information about the Three Mile Island incident: http://www.pbs.org/wgbh/amex/three/sfeature/tmihow.html
April 1986

Chernobyl

Test to see how long the turbines would spin given a loss of power, many safety systems disabled
Flow of coolant reduced followed by power spike which caused the fuel rods to rupture and an explosion which lifted the reactor cover plate releasing radiation

Second explosion threw out fragments of the core, air rushed in and the graphite core started to burn
Core burned for 9 days releasing radiation

Chernobyl

Graphite moderated reactors

Moderators:
- the neutrons need to be slowed down before they can interact with $^{235}$U

Chernobyl-type reactor
- graphite moderator remains solid and effective up to high temperatures

Water reactors
- water is used as a moderator in most U.S. reactors
- if a water-moderated core becomes too hot the water becomes steam which is not a moderator and the reaction stops

Chernobyl release

The reactor core was exposed to the atmosphere as it burned for nine days
Boron, dolomite, sand, clay and lead were dropped on to the burning core by helicopter

Most radiation released collected around the reactor but small increases were detected across much of Europe

Eventually the reactor was encapsulated

Chernobyl

20 years on

Most recent UN report (2000): no scientific evidence of any significant radiation-related health effects to most people exposed to the Chernobyl disaster.
One exception: Increase in thyroid cancer among children from the region, ~1000 cases

Most of the radioactive material remains inside the ruins

The hope is that this can be moved to a permanent storage site within the lifetime of the new shelter: 100 years

Environmental Geology - Nuclear Power