Lec #25: Fission & Fusion in our Future?

LAST TIME: Fundamentals of Nuclear Physics & Reactors

TODAY: 1) Issues for Future of Nuclear Power
2) Is there Fusion in our Future?
3) Introduction to Renewables

NEXT 3 Classes: Renewable Energy

Reactor Operation and Safety

- much less than critical mass; not highly enriched
  - core can NOT explode!
- control rods absorb neutrons, K<1 when they are in
- walls, moderator also absorb neutrons
- thermal energy continually produced w/ K=1
  - temperature will go up unless energy is carried away
  - water very effective, but w/out it, core can melt
  - LOCA very bad --> need backups and failsafes
  - also need confinement vessels
- most reactors are inherently stable
  - if Temp goes up, moderator effectiveness goes down, so K goes down, so reaction slows down
  - there are some designs (breeders, for example) that are not inherently stable, but they are not used in power plants

Special Concerns

- want to release only heat (hot water a/o steam) to environment
- some gas build up is inevitable; can include radioactive gasses; must be released (hydrogen is worst case scenario)
- radiation damage to "plumbing" in primary loop (or entire turbine for BWR)
- radiation, neutron bombardment of container
- highly radioactive waste left over in spent fuel rods
- can produce more fissile material in reactor (e.g. Plutonium), which can be
  - useful if put back in a reactor or
  - harmful if it can be extracted, b/c it can be bomb-grade

Nuclear Power: Where We Stand

- Nature stores most of its energy in nuclei
- If we want LARGE quantities of energy w/o disrupting natural balances, nuclear is probably the only way
- Relative to coal, the lack of combustion, lack of greenhouse gas emissions, and small waste stream are very attractive
- The technology for power production is well developed, but getting antiquated. We could do even better now.
- With reprocessing and breeding, nuclear fission can provide large quantities of electrical power for a very long time
- Still, it's very controversial, and there are unresolved issues
- Nuclear power itself is relatively "safe", but what about the byproducts?

Some Unresolved Issues

- Reactor design/capital costs:
  - cheap to operate, but very expensive to build
  - in large part, this is due to very strict environmental impact laws and litigation costs
  - amortization and stranded costs must be addressed
- High-Level Waste Disposal
  - US has been unable to come to grips with this
  - Current methods are unacceptable
  - "Permanent" solutions have problems
    - transportation of waste to storage facility
    - tracking of fissile material (can be used to make bombs)
    - tracking of toxic material (can be used in dirty bombs)

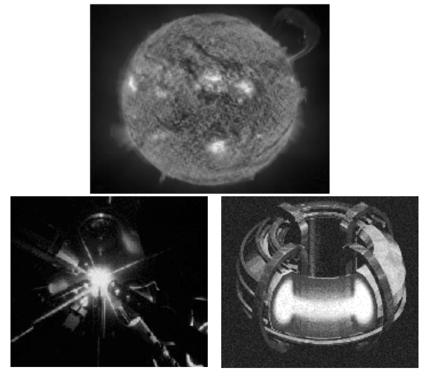
Some Unresolved Issues (cont.)

- Proliferation
  - reactor fuel is only slightly enriched; nowhere near "bomb grade"
  - spent fuel contains plutonium and other fissile material
  - when extracted, it is already enriched
  - but extraction is very difficult and expensive; not likely to be done by terrorists or rogue nations
  - however, the more enriched material there is to keep track of, the more likely some will be "lost"
  - it doesn't take very much to make a bomb
  - we have measures in place to safeguard against this, but it will be more difficult to enforce is nuclear power is expanded

Status and Future of Nuclear Power

- TMI, Chernobyl. and Fukushima affected public attitudes, but environmental groups are taking a second look.
- High-Level waste disposal problem
  - WIPP
  - Yucca Mountain
- High capital costs (billions to build)
- Relicensing
- Restructuring
- New designs; cheaper, smaller, faster, safer
- Proliferation of bomb-grade material a problem
  - N. Korea; Iran
  - terrorism
- Global Warming much more of an issue now

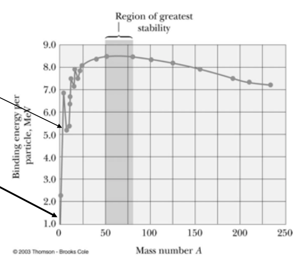
Fusion Power?



Fusion: Two light nuclei form a heavier nucleus.

Slightly heavior nuclei is about 5 MeV per nucleon.

light nucleus is about 1.5 MeV per nucleon



$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ deuterium (^{2}H) and tritium (^{3}T) nuclei

More mass/nucleon → Less mass/nucleon + E

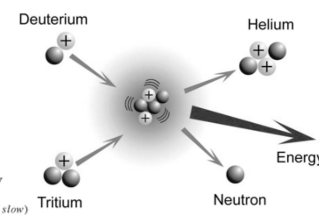
The difference in the masses is converted to the *kinetic energy* of the emerging particles...

Deuterium: about 1 part in 5000 of the hydrogen in seawater is deuterium.

Tritium must be bred from Lithium:

$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{4}_{2}He + ^{3}_{1}H + 4.8MeV$

$^{1}_{0}n(fast) + ^{7}_{3}Li \rightarrow ^{3}_{1}H + ^{3}_{2}He + ^{1}_{0}n(slow)$



Both nuclei are positively charged, so they have to be travelling really fast in order to collide/stick together.

This only happens at VERY high temperature (and/or density).

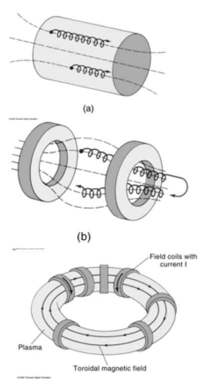
Nuclear Fusion

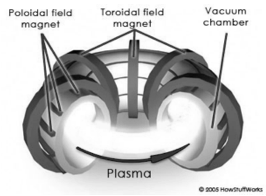
- Energy is released by reactions that "fuse" light nuclei
- This is how the Sun produces its energy, so it is the source of most of the Earth's energy
- Positively charged nuclei repel, so they must collide with very high kinetic energy (very high temperature)
- Such temperatures would vaporize/ionize any container we put it in (Sun uses gravity to confine material)
- We know how to make it work in an explosive way
- In a reactor, there will be no danger of uncontrolled energy release, and waste stream will be tiny and not long-lived
- Fuel can be extracted from seawater, so it's virtually infinite!

How to Make Fusion Practical?

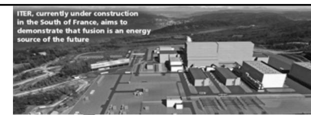
- Fusion reactions can release much more energy than fission reactions
- Sustainable energy source
- No combustion or emissions; no greenhouse gasses
- No risk of serious accident
- No long-lived radioactive waste (really easy to shut down)
- Basic physics very well understood (because these are the processes that fuel stars and nuclear bombs).
- Requires very high temperatures to activate. How do we confine material at high temperature? Has proven to be technically very difficult, time-consuming, and expensive.
- Material will be plasma. Can it be confined well enough with magnetic fields? Lasers?

Magnetic Confinement: Tokamak





Leakage of plasma through the ends can be eliminated by joining the ends.
Toroidal or doughnut-shaped magnetic field



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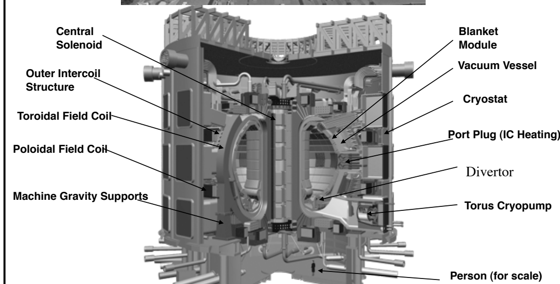
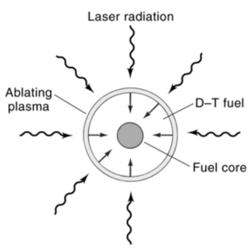
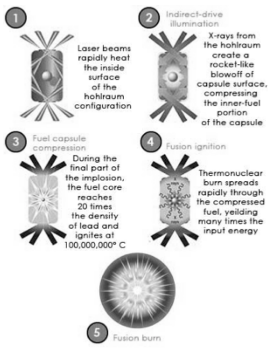


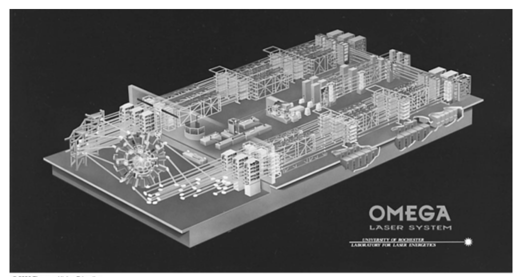
Inertial Confinement

Laser-induced implosion of small (3mm) solid deuterium–tritium pellets





National Ignition Facility (Lawrence Livermore)



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30,000J UV Laser (60 beams)
The size of football field