Lecture 5:
The Fukushima disaster

Today's song:
Nuclear - Ryan Adams
Practicalities

- **Thursday reading:** Chapter 6 of lecture notes
- **Peer review** due at 5pm today
- **We will post our comments on your draft in the next few days.** *(Comments may be based on your draft as it was last Monday)*
- **Final draft** due next Monday
What is the role of the control rods?

A. Slowing down the neutrons, to prevent the chain reaction from dying
B. Measure how fast the chain reaction is occurring
C. Regulate the speed of the chain reaction by absorbing neutrons
D. Start up the chain reaction
E. They are just there to produce that spooky blue shine
A. Slowing down the neutrons, to prevent the chain reaction from dying
B. Measure how fast the chain reaction is occurring
C. Regulate the speed of the chain reaction by absorbing neutrons
D. Start up the chain reaction
E. They are just there to produce that spooky blue shine
Radioactive fall-out is ...

A. ... the same as radioactivity
B. ... the same as radiation
C. ... dust blown in the air containing radioactive particles
D. ... radiation blown into the air
E. ... a video game
Radioactive fall-out is ...

A. ... the same as radioactivity
B. ... the same as radiation
C. ... dust blown in the air containing radioactive particles
D. ... radiation blown into the air
E. ... a video game
Last time you learned...
Last time you learned...

- **Radioactivity** is an example of a process in which radiation is emitted.
- We each receive radiation all the time.
- Most radiation is not dangerous.
- The *half-life* is the time after which half of the nuclei have decayed. This implies that the intensity of the radiation emitted has also halved.
The plan of action

Lecture 1: Intro to Quantum Mechanics

Lecture 2: Quantum Mechanics & Uncertainty

Lecture 3: $E=mc^2$ & the atomic bomb

Workshop: Radioactivity

Lecture 4: The Fukushima disaster

Lecture 5: Intro to modern Particle Physics
Applications of $E=mc^2$

- Radioactivity
- Nuclear weapons
- Nuclear power
- Energy production in stars
- Supernovas
Cooling towers

H$_2$O vapor

Connection to the grid

Reactor buildings
Major difference: Type of fuel being used

Coal plant
(45% of electricity production, by 1436 plants)

Nuclear plant
(20% of electricity production, by 104 plants)
Fossil fuel

~ millions years

need ~ 1000 tons a week

Chemical energy

Nuclear fuel

~ billions years

need ~ 10 tons a year

Mass
The reactor itself

Goal: sustain a **stable** chain reaction

Build a “slow” nuclear bomb

Control rods: absorb some of the neutrons
(To prevent run away chain reaction, which would lead to nuclear explosion)

Moderator: slows down the neutrons
Why do we need a moderator to slow down the neutrons?

A. If the neutrons move too fast, they form a health hazard for the staff in the power plant

B. If the neutrons move too fast, the chain reaction will occur too fast, resulting in an explosion

C. If the neutrons move too fast, they will won’t hit a Uranium nucleus and no chain reaction will occur. Therefore the reactor will not produce any energy.

D. Fast neutrons can damage the reactor

E. Fast neutrons can’t get free drinks
Why do we need a moderator to slow down the neutrons?

A. If the neutrons move too fast, they form a health hazard for the staff in the power plant

B. If the neutrons move too fast, the chain reaction will occur too fast, resulting in an explosion

C. If the neutrons move too fast, they will won’t hit a Uranium nucleus and no chain reaction will occur. Therefore the reactor will not produce any energy.

D. Fast neutrons can damage the reactor

E. Fast neutrons can’t get free drinks
Penn State nuclear reactor
The spent fuel pool

- Storage of spent fuel rods
- Usually on reactor site
- Fuel must be cooled continuously
What is the blue stuff?

Just blue light!

Cherenkov effect

Remember: Ionizing radiation is always invisible!
What’s wrong with this picture?
Nuclear Meltdown

Radioactive

Produce heat, even after chain reaction is stopped

Melt if not cooled adequately
No China syndrome has ever occurred
<table>
<thead>
<tr>
<th>Year</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>Lucens reactor, Switzerland</td>
</tr>
<tr>
<td>1979</td>
<td>Three Mile Island, Pennsylvania</td>
</tr>
<tr>
<td>1986</td>
<td>Chernobyl, Ukraine</td>
</tr>
<tr>
<td>2011</td>
<td>Fukushima I, Japan</td>
</tr>
</tbody>
</table>
The pacific ring of fire

- Earthquakes
- Volcanos
Tectonic convection

Tension builds up, until the plate snaps

Earthquake
55 reactors on the Ring of Fire

- Tectonic theory accepted in USA & Europe
- Japan constructs reactors
- '70': Tectonic theory accepted in Japan
- '80': Tectonic theory accepted in Japan
March 11th 2011, 2:46 pm

Japan moved 8 feet closer to the United States
Tokyo
Fukushima Daiichi,
March 11th 2011, 2:46 pm

Emergency system triggered

Control rods fully inserted automatically

Chain reaction interrupted within a second after the first shocks
(Never any danger for nuclear explosion)

Earthquake also knocked out external power supply

Backup diesel generators take over
Even after the nuclear chain reaction has stopped, the fuel remains extremely hot for a long time. Why is this?

A. The fuel was just very hot to begin with, and it cools only very slowly

B. The chain reaction never fully stops, and keeps producing some heat

C. The daughter nuclei from the splitting are radioactive, and their decays keep produce heat long after there nuclear splittings have stopped

D. It depends on the design of the reactor and only occurs for old reactors

E. Seriously, bring on those superpowers...
Even after the nuclear chain reaction has stopped, the fuel remains extremely hot for a long time. Why is this?

A. The fuel was just very hot to begin with, and it cools only very slowly

B. The chain reaction never fully stops, and keeps producing some heat

C. The daughter nuclei from the splitting are radioactive, and their decays keep producing heat long after the nuclear splittings have stopped

D. It depends on the design of the reactor and only occurs for old reactors

E. Seriously, bring on those superpowers...
The weak spot of every nuclear power plant

**External power supply**

- External power supply cut
- Emergency power supply keeps cooling the fuel rods
- If Emergency power supply fails, cooling liquid starts to evaporate

Must continue to cool fuel rods, even after the chain reaction has stopped

Fuel rods melt: Meltdown
March 11th 2011, 3:01 pm

Tsunami destroys the emergency diesel generators that prevent the meltdown

Second emergency power system (batteries) takes over

March 11th 2011, 7:30 pm

Government declares nuclear emergency and instates 2 mile evacuation zone
(Later extended to 12 miles)
March 12th 2011, morning

Emergency batteries have died, cooling liquid starts to evaporate

Temperature and pressure rise rapidly in reactors 1, 2 and 3

build up of $\text{H}_2$ gas

explosive!
March 12th 2011, 3:30 pm

Hydrogen explosion at reactor 1
(but containment vessel believed to have remained intact)
March 13th 2011

Start to cool the reactors with sea water
large amounts of radioactivity leak back into the sea

March 14th 2011

Hydrogen explosion in reactor 3

March 16th 2011

Hydrogen explosion and fire near the spent fuel pool of reactor 4
Trouble for spent fuel pool of reactor 4
Cooling the spent fuel pool of reactor 4
Summer 2011

Purification system installed, reduced contamination of sea water

December 2011

Cold shut down, no more danger for meltdown
Comparison with Chernobyl disaster

- Triggered by human error
- Nuclear explosion
- Extremely acute crisis
- Dubious response from the government
Immediate Aftermath

- 6 deaths during disaster or attempts to get the plant under control (non relate to radiation effects)
- 20 mile evacuation zone around the plant
- Radioactive fall-out in large area

**Fall-out**

Radioactive fall-out or fall-out are the radioactive dust particles that are blown into the air when a nuclear incident occurs. When it rains they come down to the soil.
Radioactivity ≠ Fall-Out

Radioactivity = Process in which a nucleus emits radiation

Fall-Out = Radioactive dust

Often we say: “...x amount of radioactivity was released in the air...”

It should be: “...x amount of Fall-Out was released in the air...”
Why is this person wearing a this special suit?

A. To protect himself from radiation
B. To prevent contact of radioactive particles with his skin
C. To prevent spreading around radioactive dust that would otherwise attach to his clothing
D. Both B and C
E. For better recognition by civilians
Why is this person wearing a this special suit?

A. To protect himself from radiation
B. To prevent contact of radioactive particles with his skin
C. To prevent spreading around radioactive dust that would otherwise attach to his clothing
D. Both B and C
E. For better recognition by civilians
Fallout in USA?

400 rads: acute radiation sickness
>1000 rads: fatal

HOAX!!
How dangerous is radioactive Fall-Out?

As always, the answer is it depends...

• Radiation from outside the human body not that harmful, unless in extreme dose

• Radiation from inside the human body potentially (very) harmful

Contamination of the food chain is most important concern
Food chain contamination

The fall-out is spread out by the wind over a large area, so the concentration is rather low...

... but the concentration in food (animal) products can still be high!

Most important contaminants:
- Cesium - 137 ($^{137}$Cs)
- Iodine - 131 ($^{131}$I)
- Srontium - 90 ($^{90}$Sr)
Example 1: $^{131}$I

$\beta$ decay
half life: 8 days

Yellow: Adults (19–34)
Blue: Adolescents (15–18)
Red: Children (0–14)
Example 2: $^{90}\text{Sr}$

$\beta$ decay  
half life: 29 years

Absorbed in bones, can cause leukemia
Future action in Japan

Long terms health effects uncertain

What can the government do?

- Further secure existing plants
- Training of the population
- Monitor food circuit
- Maintain the safety perimeter

A silver lining?

Worldwide awareness and increased security measures for nuclear plants
Nuclear power plants in the USA

<table>
<thead>
<tr>
<th>Age (in years)</th>
<th>Number of power stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>0</td>
</tr>
<tr>
<td>10-19</td>
<td>3</td>
</tr>
<tr>
<td>20-29</td>
<td>48</td>
</tr>
<tr>
<td>29-30</td>
<td>46</td>
</tr>
<tr>
<td>40 plus</td>
<td>7</td>
</tr>
</tbody>
</table>

2010 data
Nuclear power plants in New Jersey

- Susquehanna: 36 years old
- Indian Point: 44 years old (Scheduled for shut down in 2019)
- Three Mile Island: 44 years old
- Limerick: 27 years old
- Oyster Creek: 36 years old
- Hope Creek: 27 years old
- Peach Bottom: 36 years old
Questions for the future

Decommissioning of old nuclear plants?

Construct new ones?

Storage of nuclear waste?

Risk management?

Invest in research and development?

How to meet our energy needs without nuclear energy?

How to further fight global warming without nuclear energy?
On Thursday:
To the frontier!

Introduction to Modern Particle Physics