Understanding the radioactivity at Fukushima

A physics and engineering perspective

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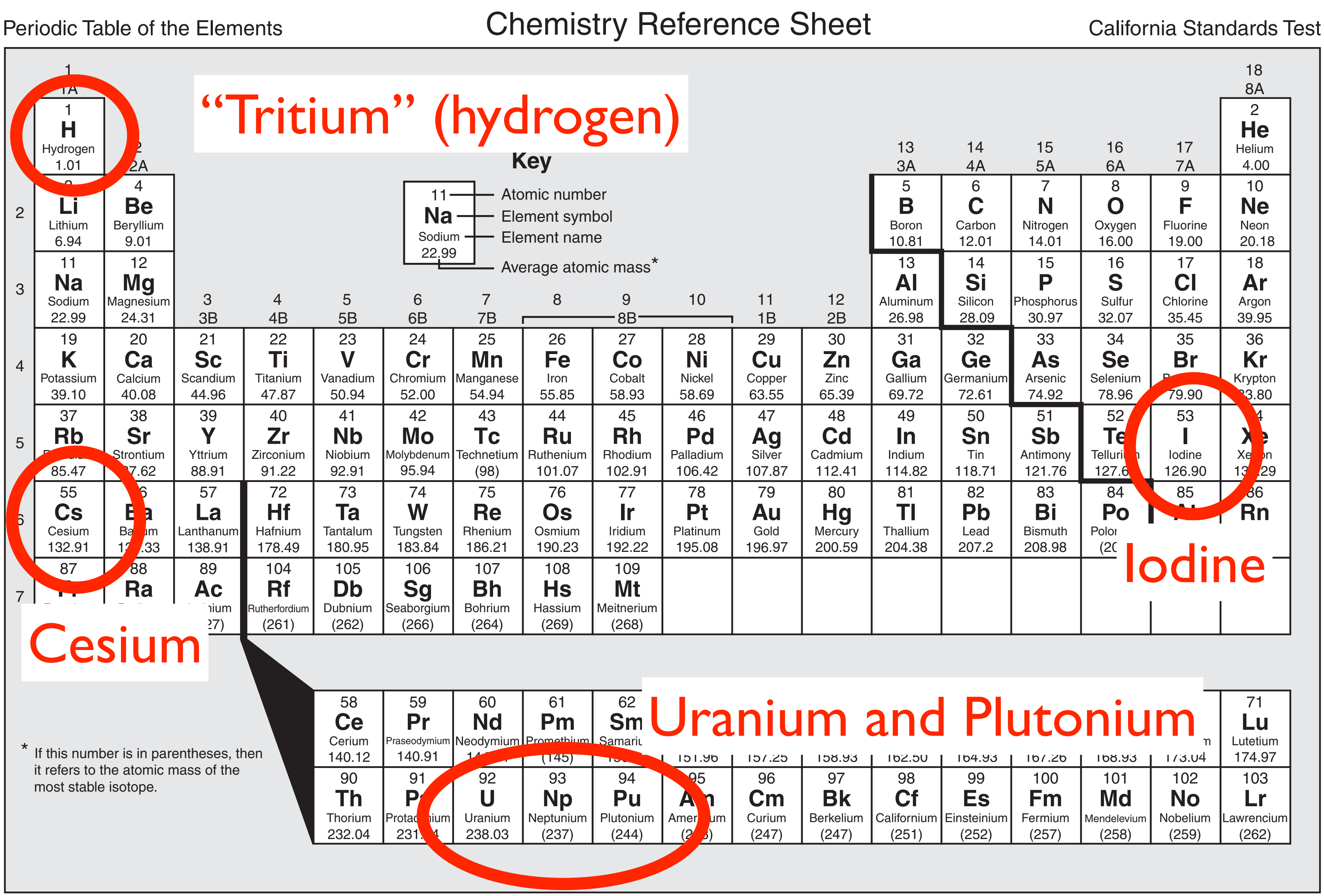
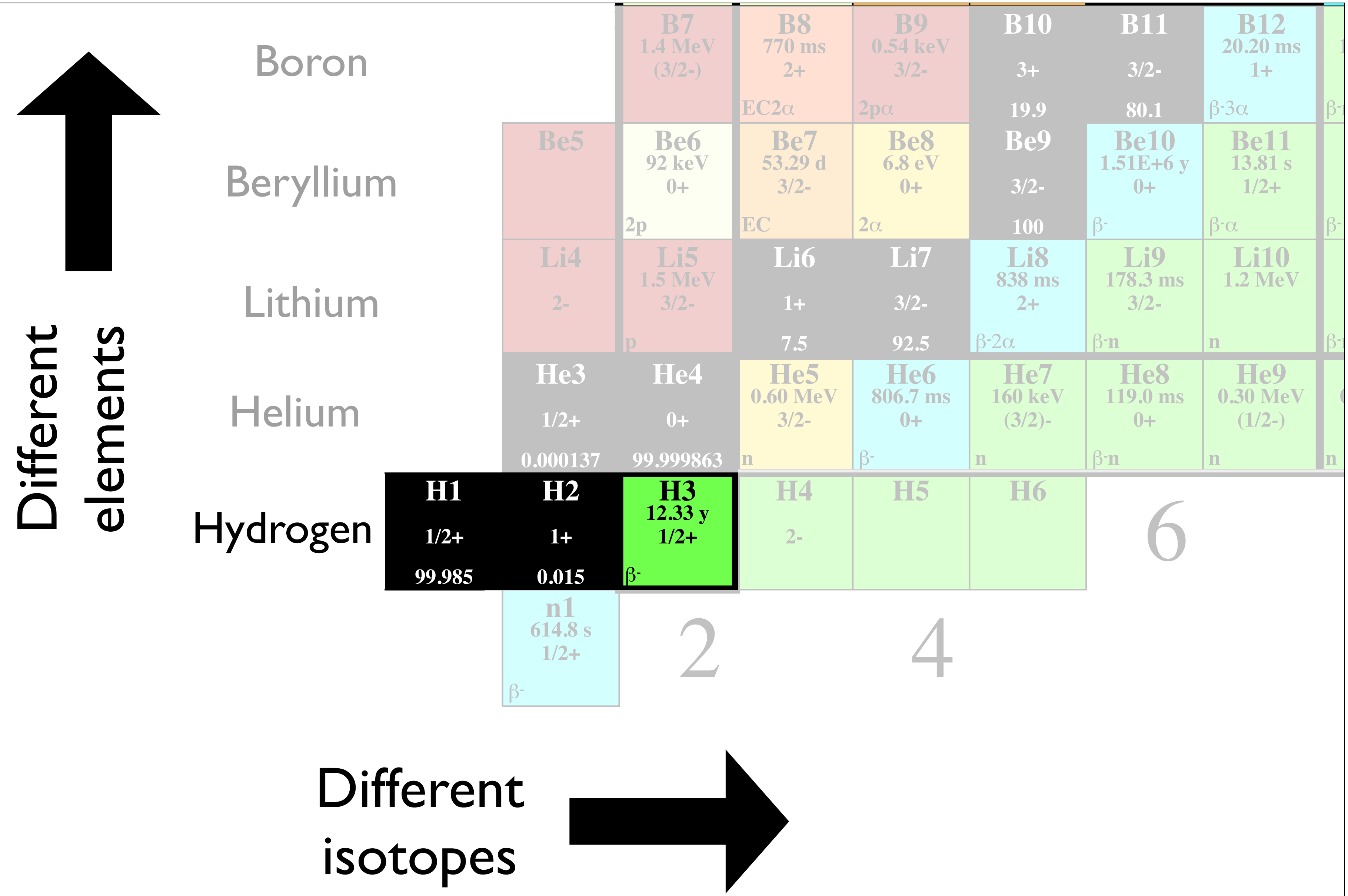
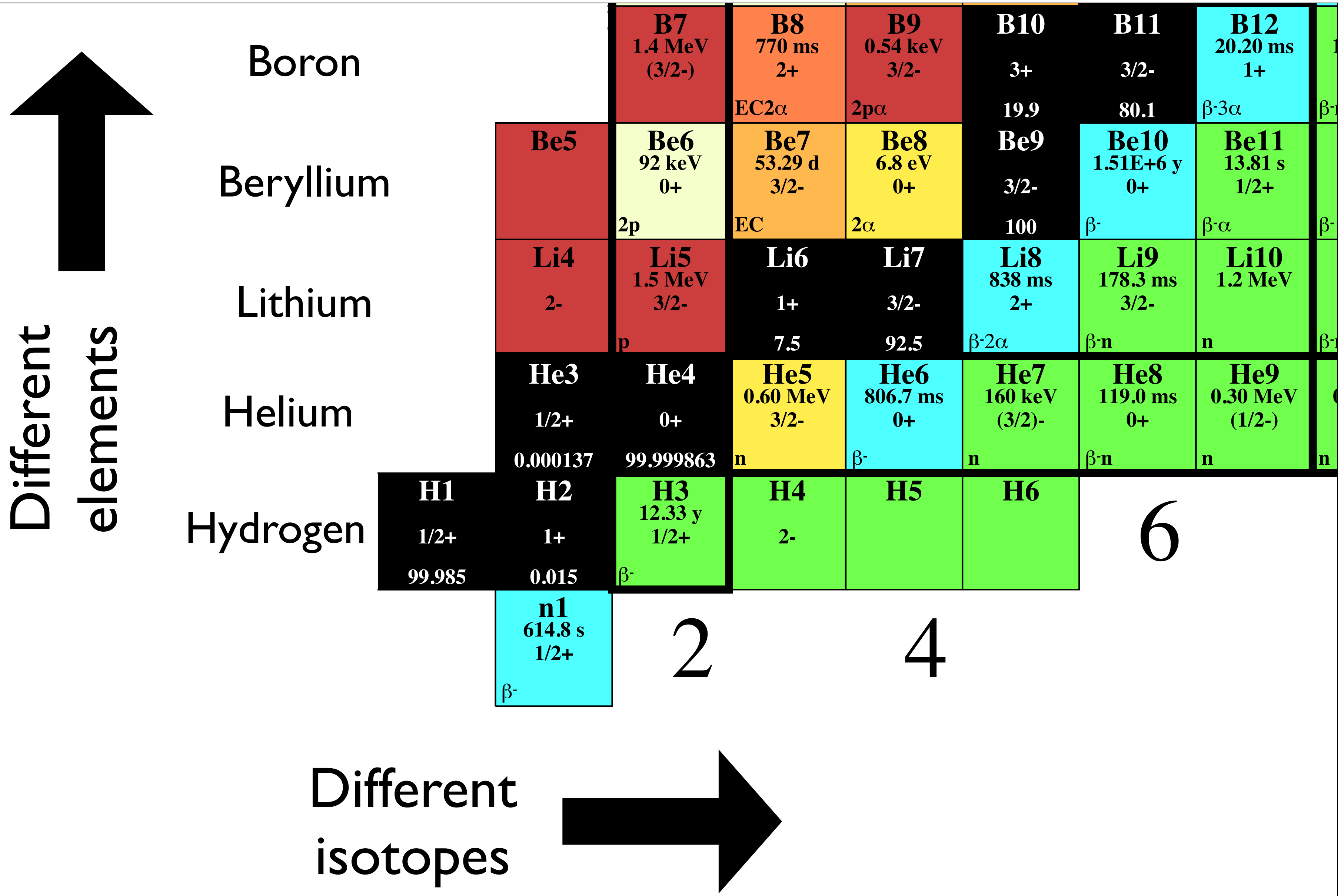
Q&A Panel:
Ben Monreal
Prof. Theo Theofanous, UCSB Chem E.
Prof. Patrick McCray, UCSB History

- Introduction to radioactivity
- Radiation hazards and health
- What escapes in a meltdown?
- Where does it go?
- How worried should we be?


Periodic Table of the Elements
Chemistry Reference Sheet
California Standards Test
“Tritium” (hydrogen)
Cesium
Iodine
Uranium and Plutonium
Key
Atomic number
Element symbol
Element name
Average atomic mass*
* If this number is in parentheses, then it refers to the atomic mass of the most stable isotope.



http://nndc.lbl.gov



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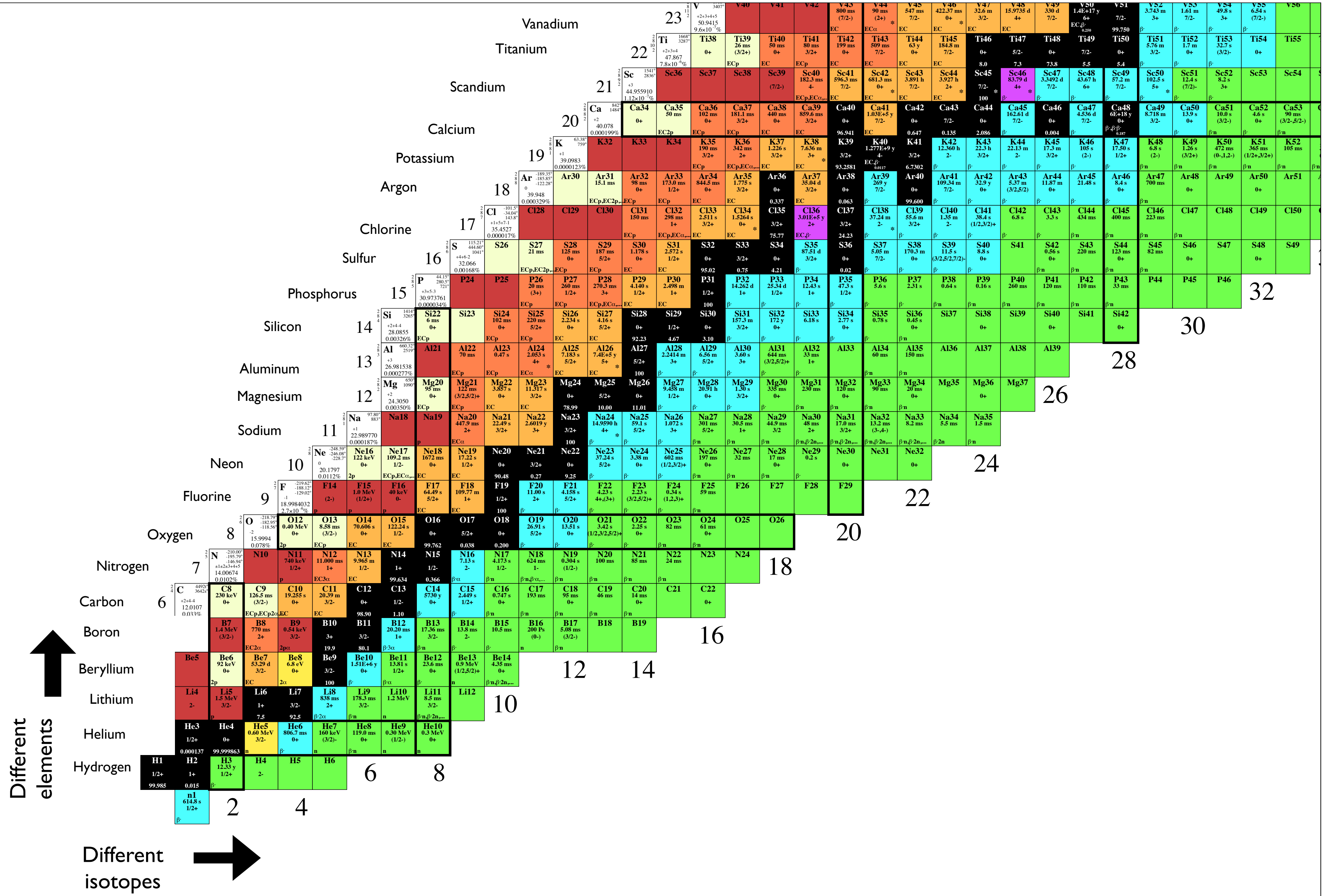

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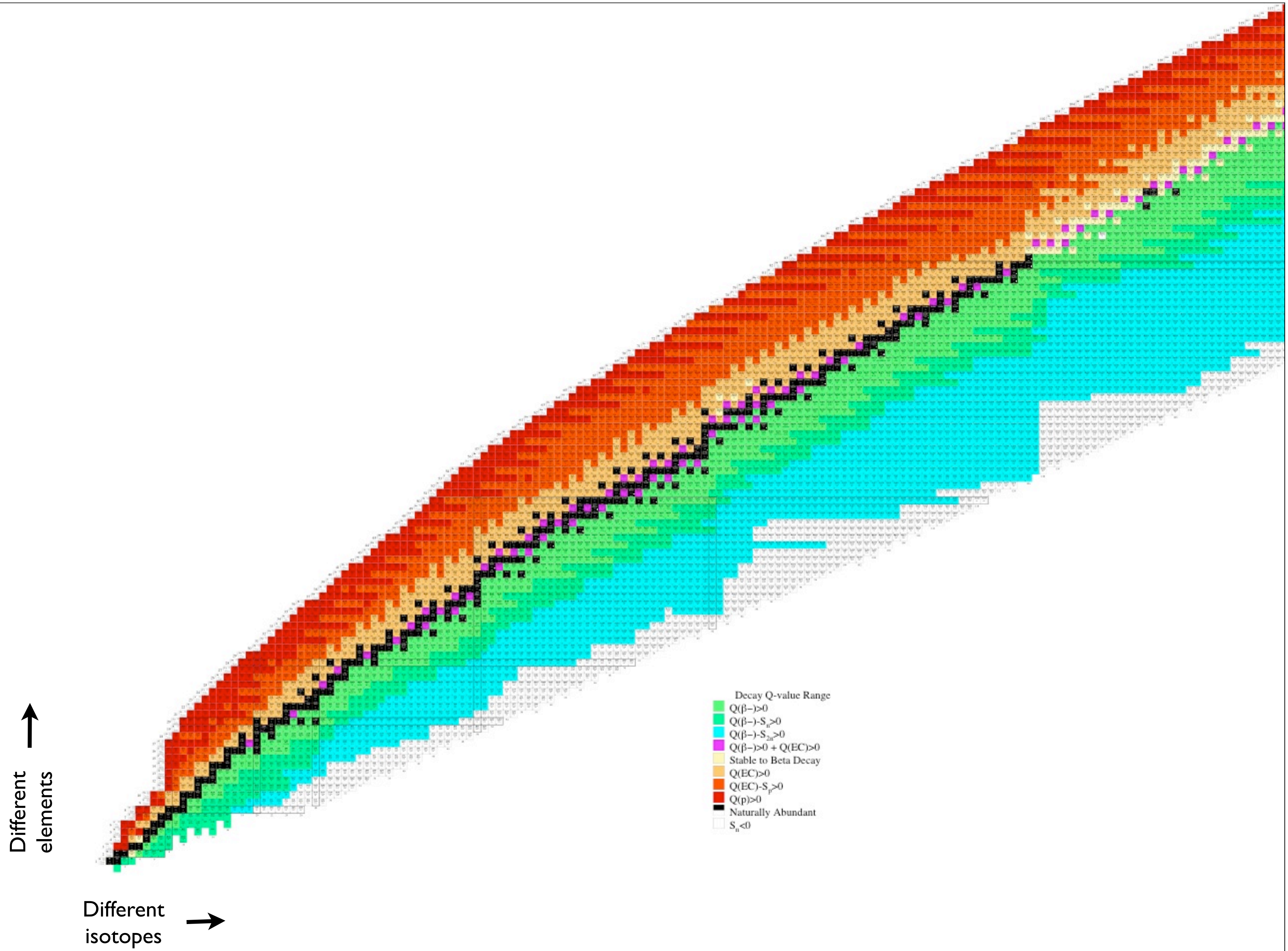
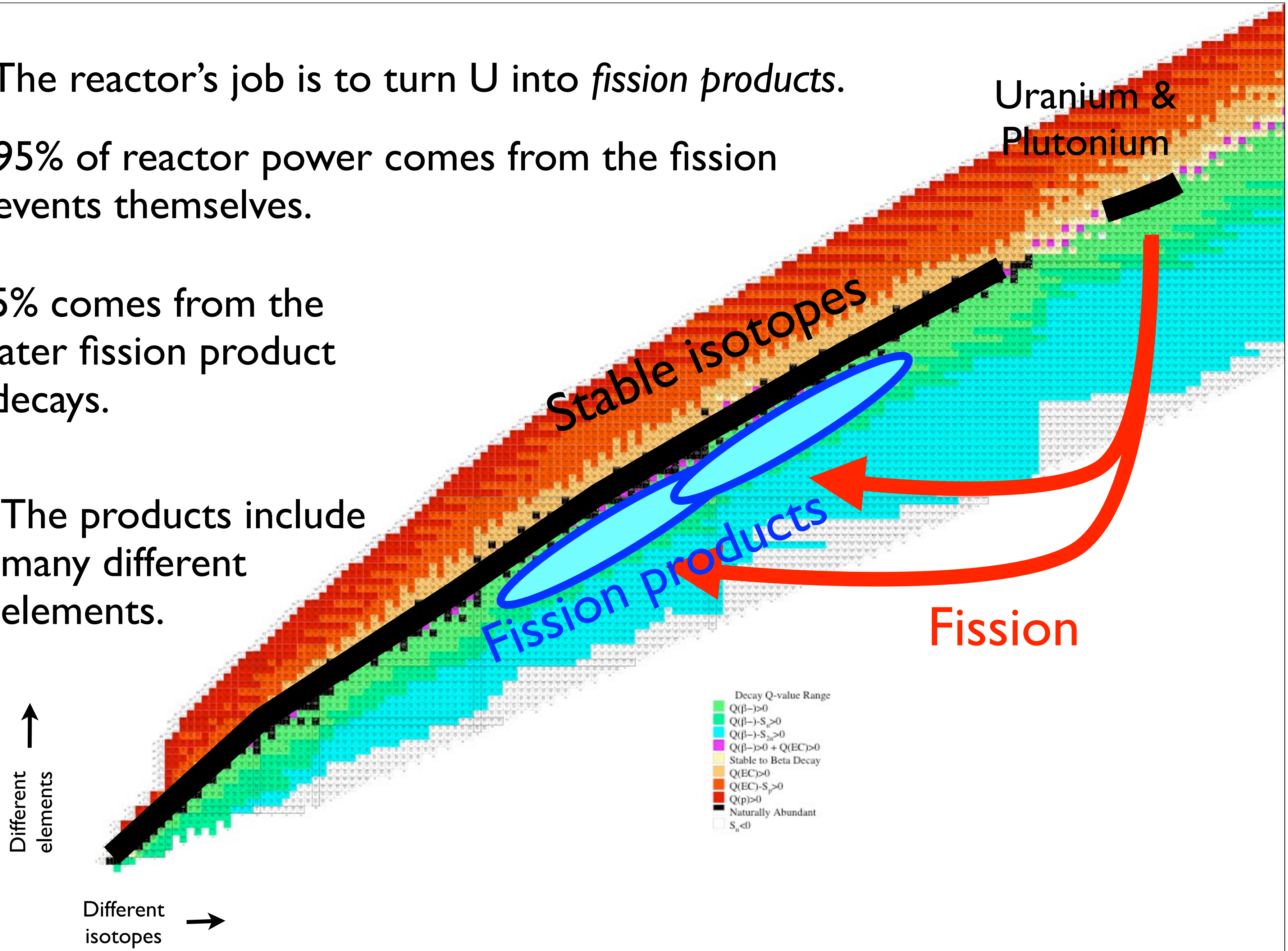

Decay Q-value Range
$Q(\beta-)>0$
$Q(\beta-)-S_n>0$
$Q(\beta-)-S_{2n}>0$
$Q(\beta-)>0 + Q(EC)>0$
Stable to Beta Decay
$Q(EC)>0$
$Q(EC)-S_p>0$
$Q(p)>0$
Naturally Abundant
$S_n<0$
Different elements
Different isotopes

The reactor’s job is to turn U into *fission products*.

95% of reactor power comes from the fission events themselves.

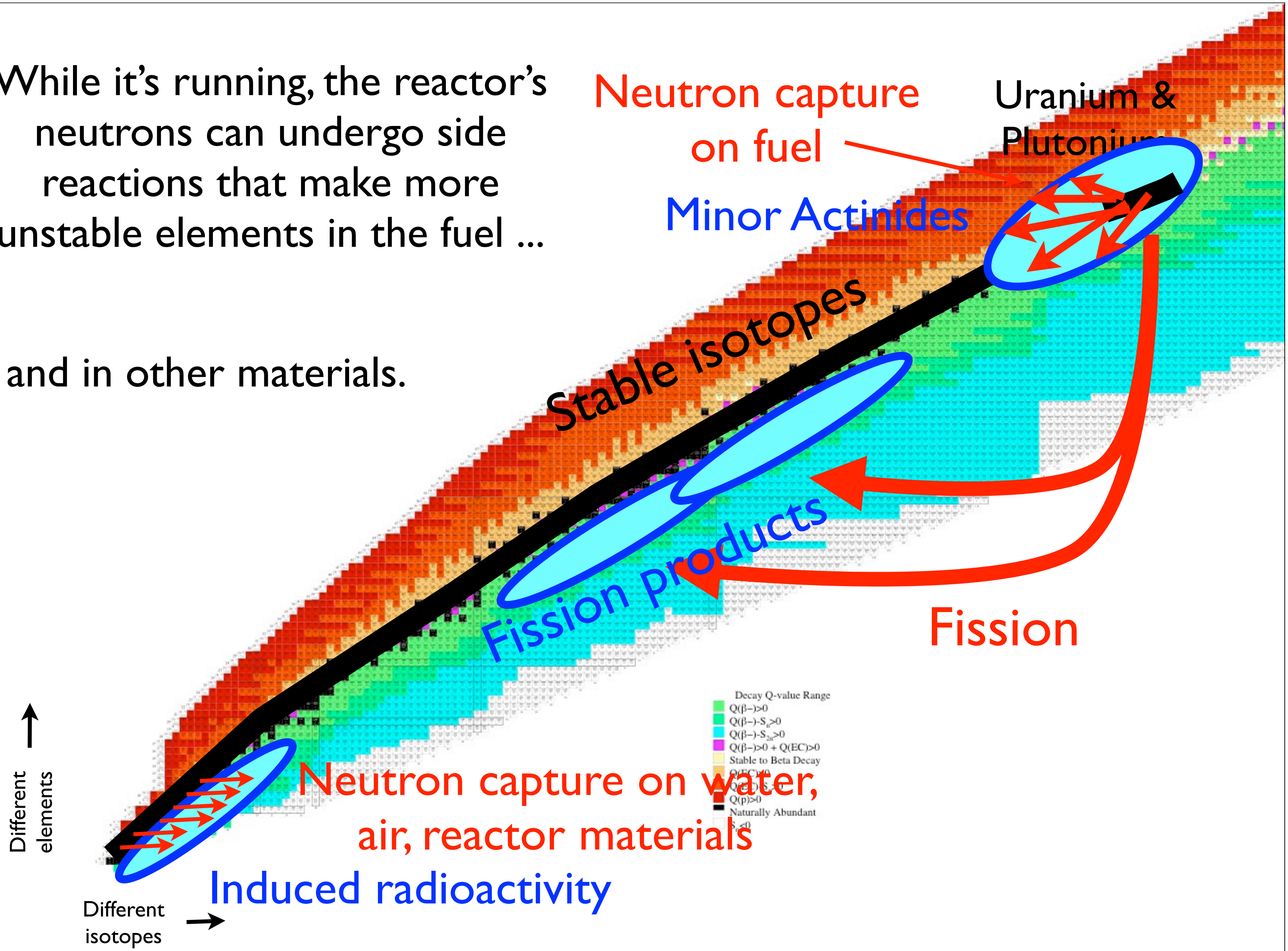
5% comes from the later fission product decays.

The products include many different elements.



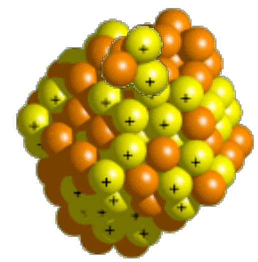
While it's running, the reactor's neutrons can undergo side reactions that make more unstable elements in the fuel ...

and in other materials.



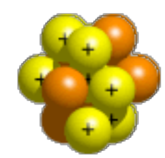
Radiation damage

Alpha decay: common in minor actinides (damages every 10th atom it passes.)



$^{222}\mathrm{Rn} \rightarrow {}^{218}\mathrm{Po} + {}^{4}\mathrm{He}$

Beta & gamma decay: fission products (damages every 3000th atom it passes.)



$^{14}\mathrm{C} \rightarrow {}^{14}\mathrm{N} + e^{-} + \nu$

http://education.jlab.org

How much damage?

- One **becquerel** = 1 decay per second
- One **curie** = 37 billion decays per second.
  - A measure of amount, as in “There are 20 million curies of ^{137}Cs in the fuel pond”

- One **gray** = absorbing 1 billion ^{238}U decays, or 10 billion ^{137}Cs decays, per gram of body mass

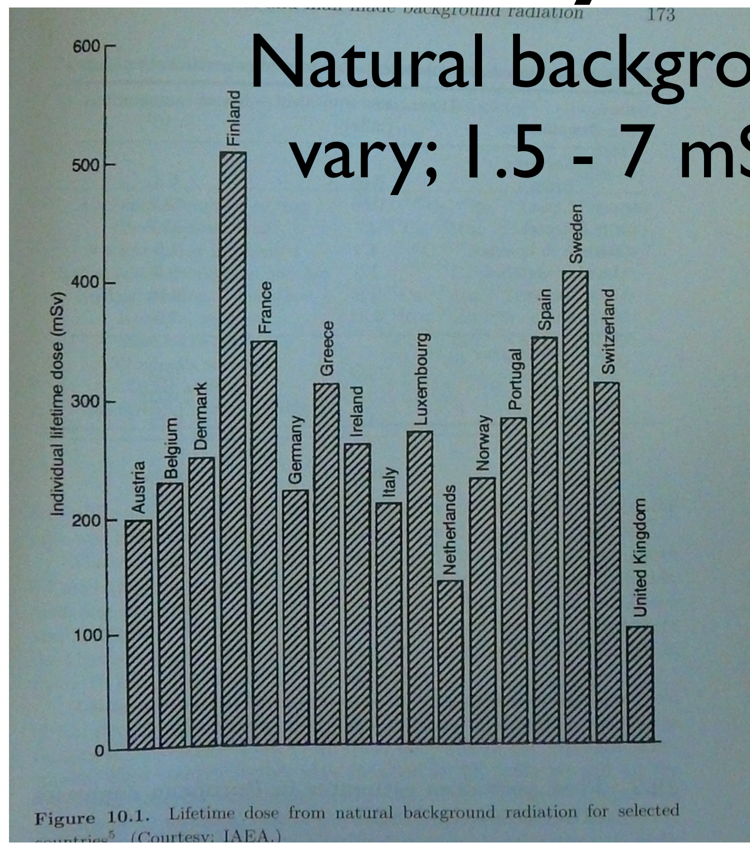
One **sievert** = absorbing 0.05B ^{238}U decays, or 10B of ^{137}Cs, per gram of body mass

  - A measure of “dose” = fraction of body’s chemical bonds damaged.

For fission products, gray = sievert

Radiation numeracy

- You are all getting irradiated right now.
  - natural ^{40}K in your body: ~0.2 mSv/yr.
  - natural ^{222}Rn in the air: ~1 mSv/yr.
- Moving to Denver? Add ~1 mSv/yr.
- Are you a flight attendant? Add ~few mSv/yr.



Natural backgrounds vary; 1.5 - 7 mSv/y

Lesson: *a few milliSieverts dose is not worth worrying about at all. (but mSv/h rate can add up.)*

"Chernobyl Record" R.F. Mould, IOP 2000

Radiation and cancer

Ionization ≈ DNA damage *(rarely)*

DNA damage ≈ changed cells *(rarely)*

changed cells ≈ cancer *(rarely)*

Type of cancer	Extra cases per 10000 people with 1000mSv doses
Leukemia	3
Breast	7
Thyroid	1.6
Lung	4
Stomach	5
Colon	2

Lesson: *1 Sv = 1000 mSv is a risk you would go out of your way to avoid, like texting while driving.*

From John D. Boice, Natl. Cancer Institute
in "Health Effects from Exposure to Low-Level Ionizing Radiation", IOP 1996

Acute radiation sickness

Lesson: >*5 Sv = run for your life*

- *Extraordinarily rare.*
  - "Slotin Incident": 21 Sv, victim died 9 d later
  - "Daghlian incident": 5 Sv, victim died 1 month later
  - Goiania accident: 5 Sv/hr medical source got loose. 4 dead (all > 5 Sv), 15 hospitalized (all betwen 0.5 and 5 Sv).
  - Chernobyl first-responders: dose rates of 10 Sv/hr in many areas; 30 dead, 200 hospitalized
  - Many victims of Hiroshima and Nagasaki

Units in the news

The New York Times

Last Defense at Troubled Reactors: 50 Japanese Workers

Radiation close to the reactors was reported to reach 400 millisieverts per hour on Tuesday after a blast inside reactor No. 2 and fire at reactor No. 4, but has since dropped back to as low as 0.6 millisieverts at the plant gate.

← we know 5000 mSv = fatal
so 400 mSv/hr for would be fatal
if you had 5000/400 = 12 hours

← 0.6 mSv per hour
1000 mSv = texting while driving
1000/0.6 = two months

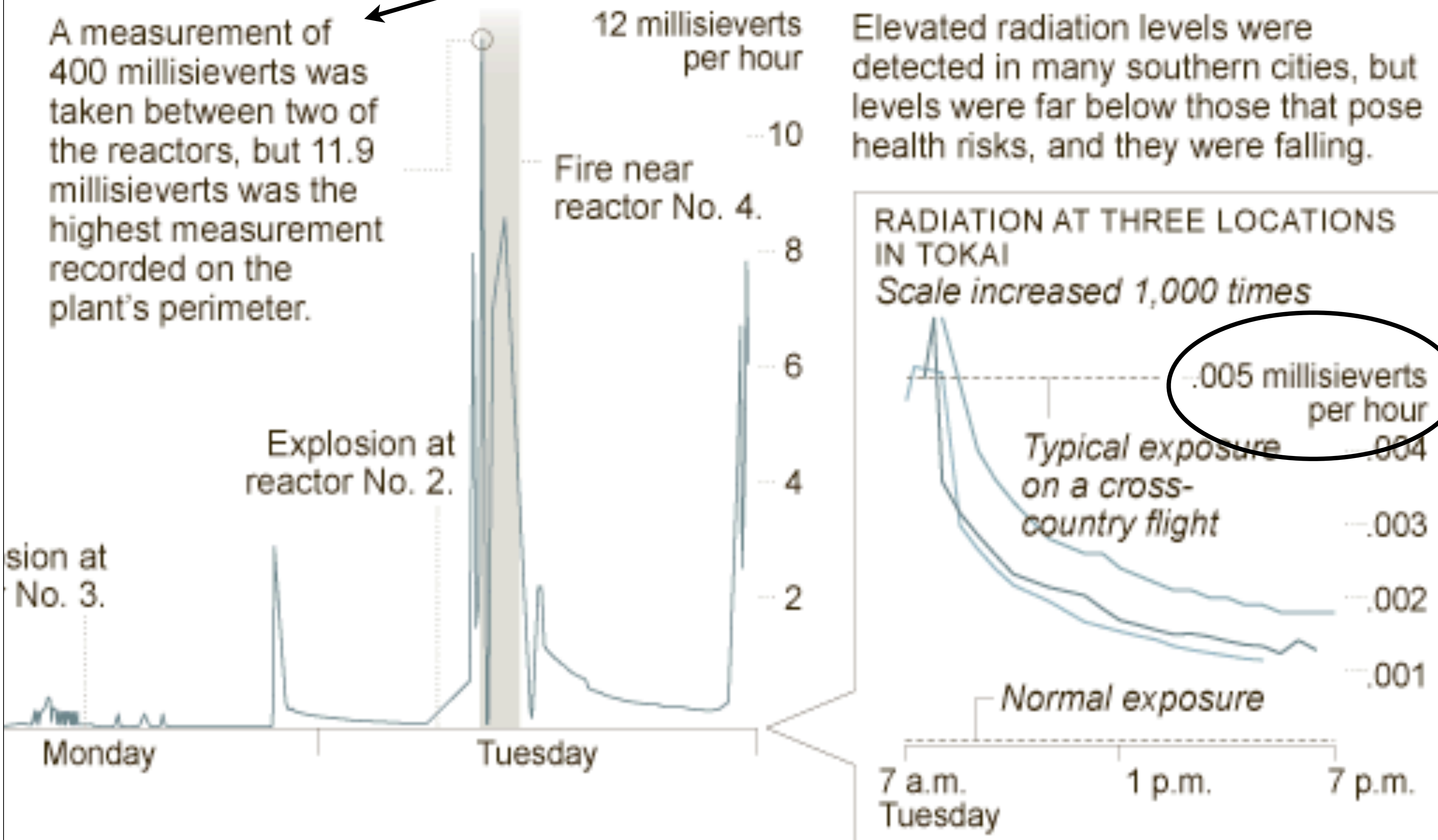
wnn
world nuclear news

Radiation levels on the edge of the plant compound briefly spiked at 8217 microsieverts per hour but later fell to about a third that.

← 8000 μSv/hr = 8 mSv/hr

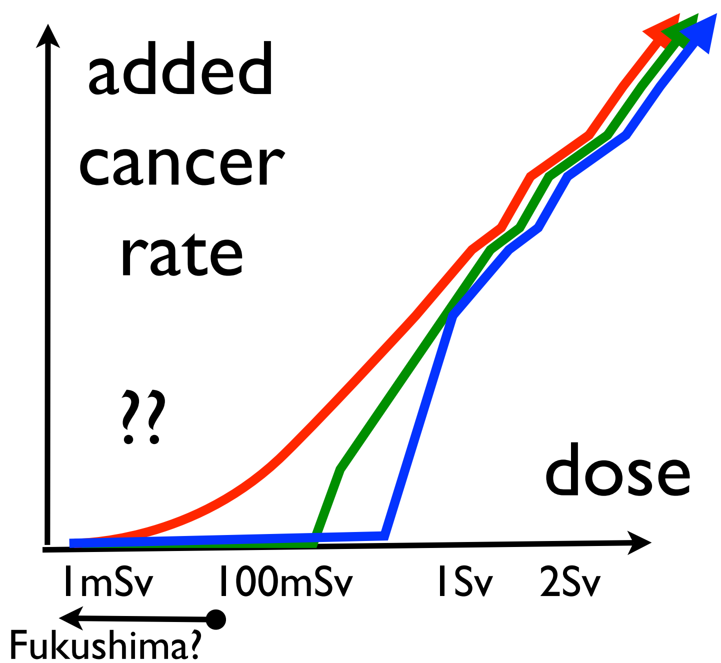
They meant "millisieverts *per hour*"

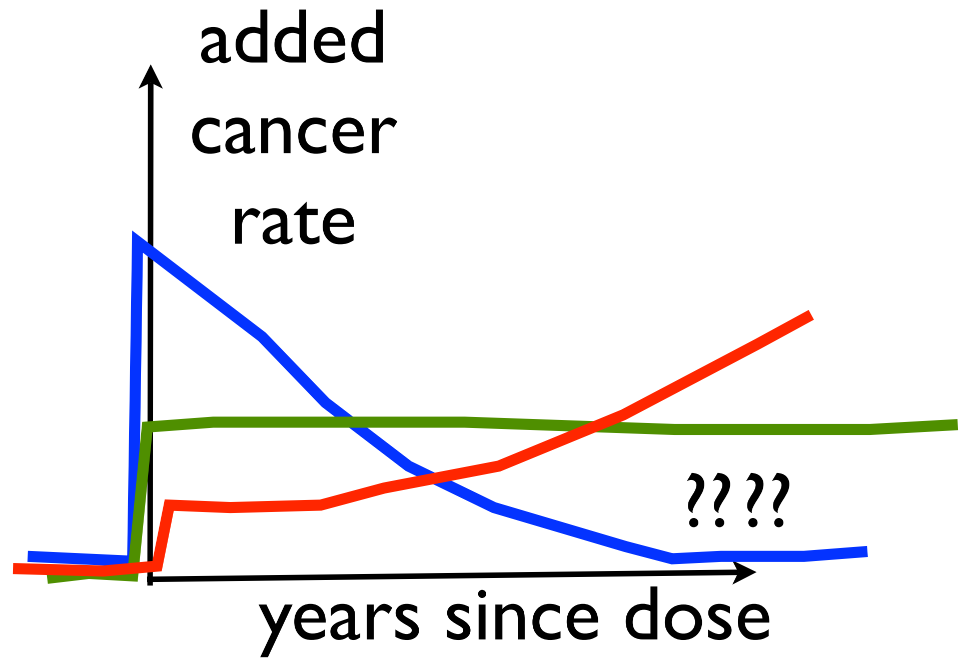
NYTimes.com



Are low doses proportionally dangerous?

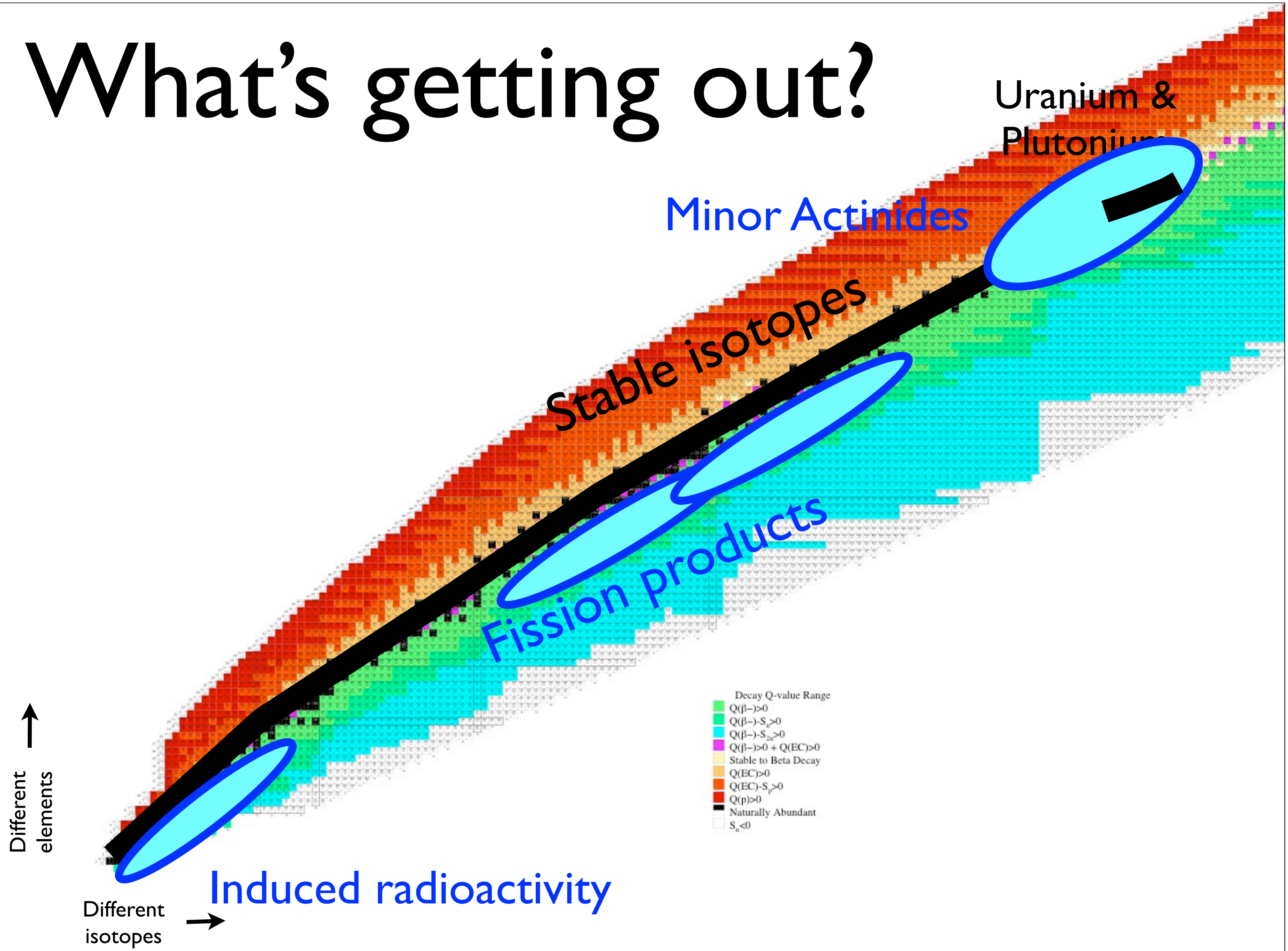
- Probably?? There is no case where a small extra risk was *detectable*. (Chernobyl area: thyroid cancer at 100 mSv)





“Health effects of low-level exposure to ionizing radiation”, ed. Hendee & Edwards, IoP 1996

What’s getting out?



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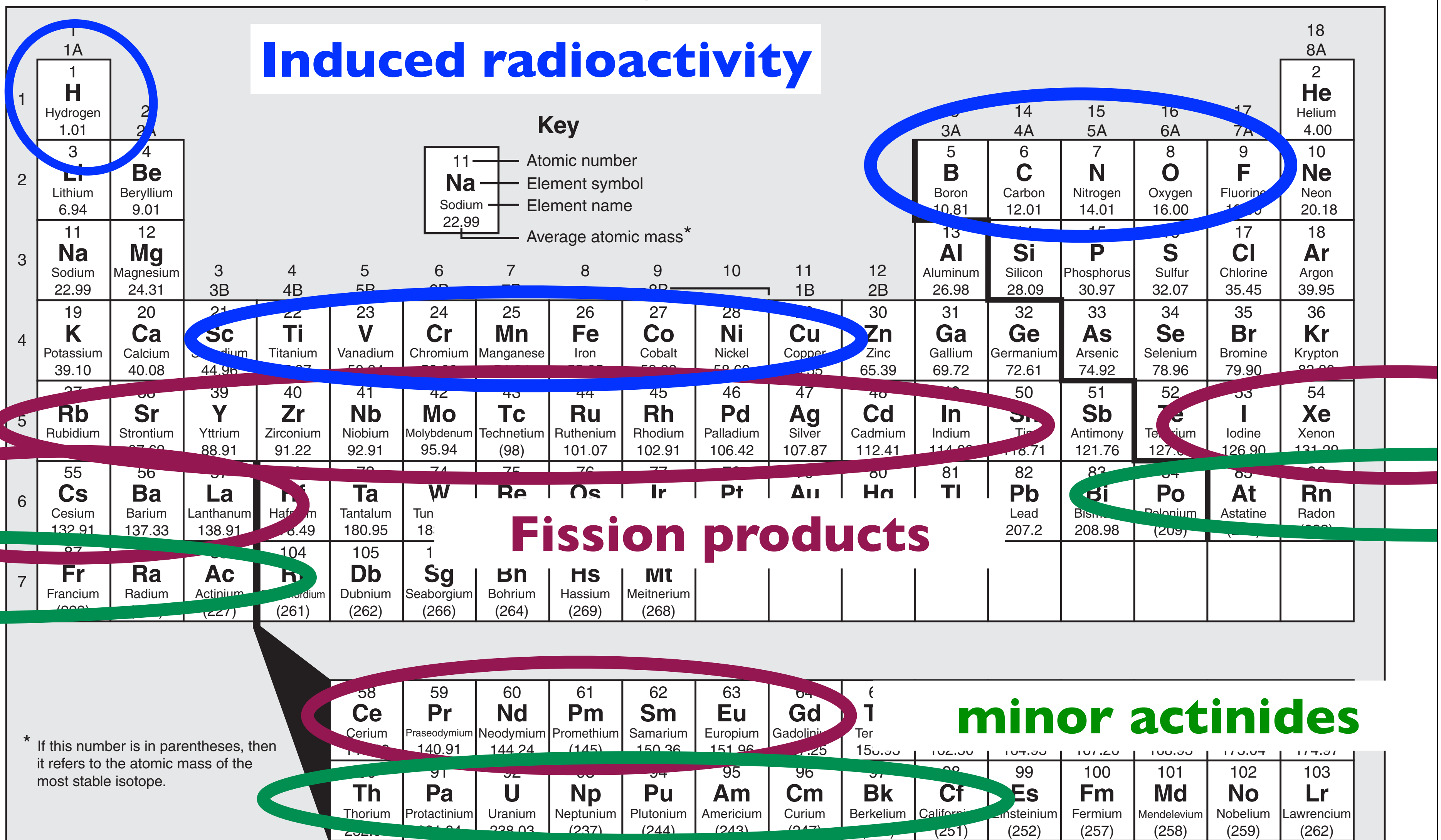

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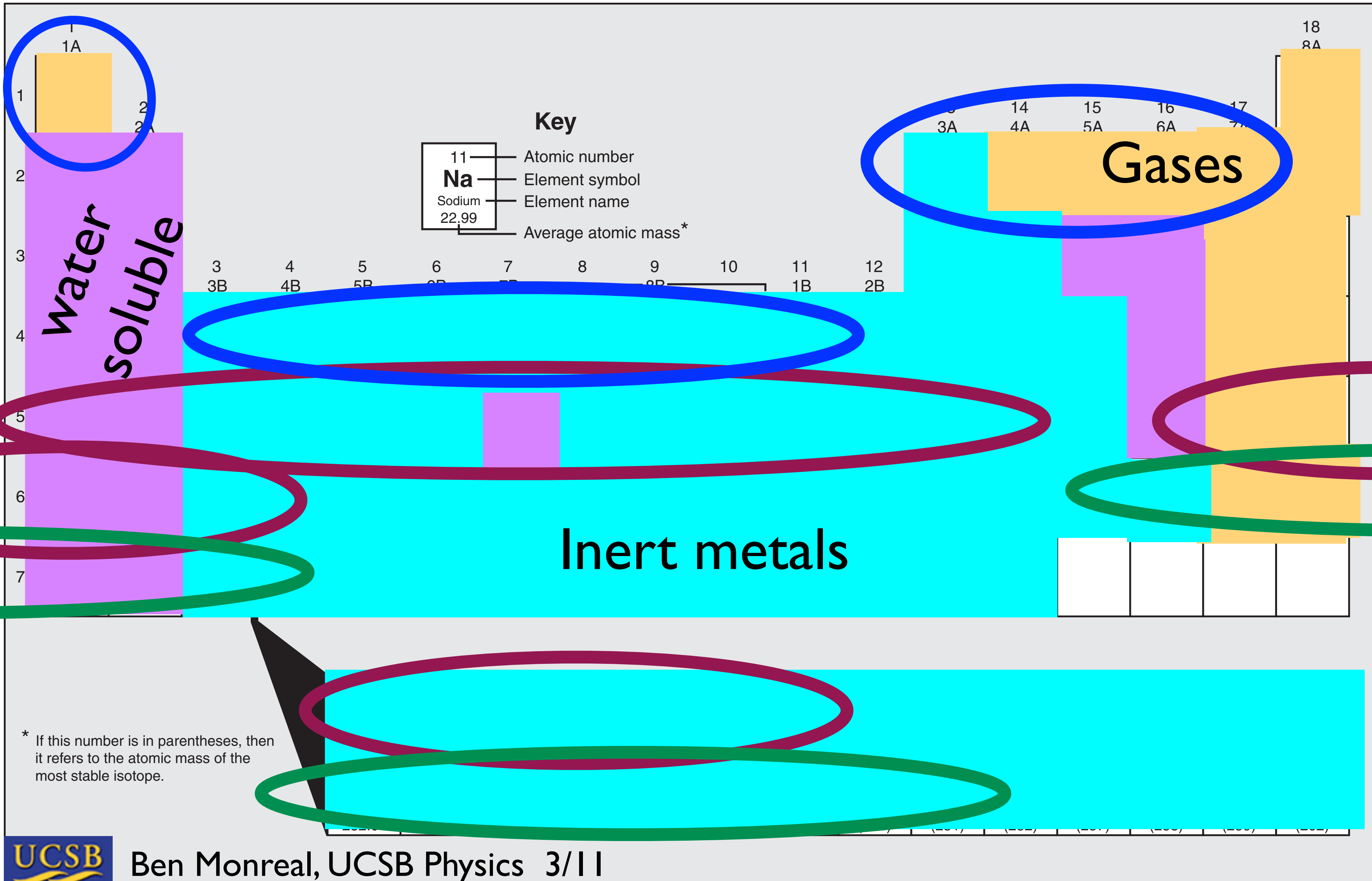

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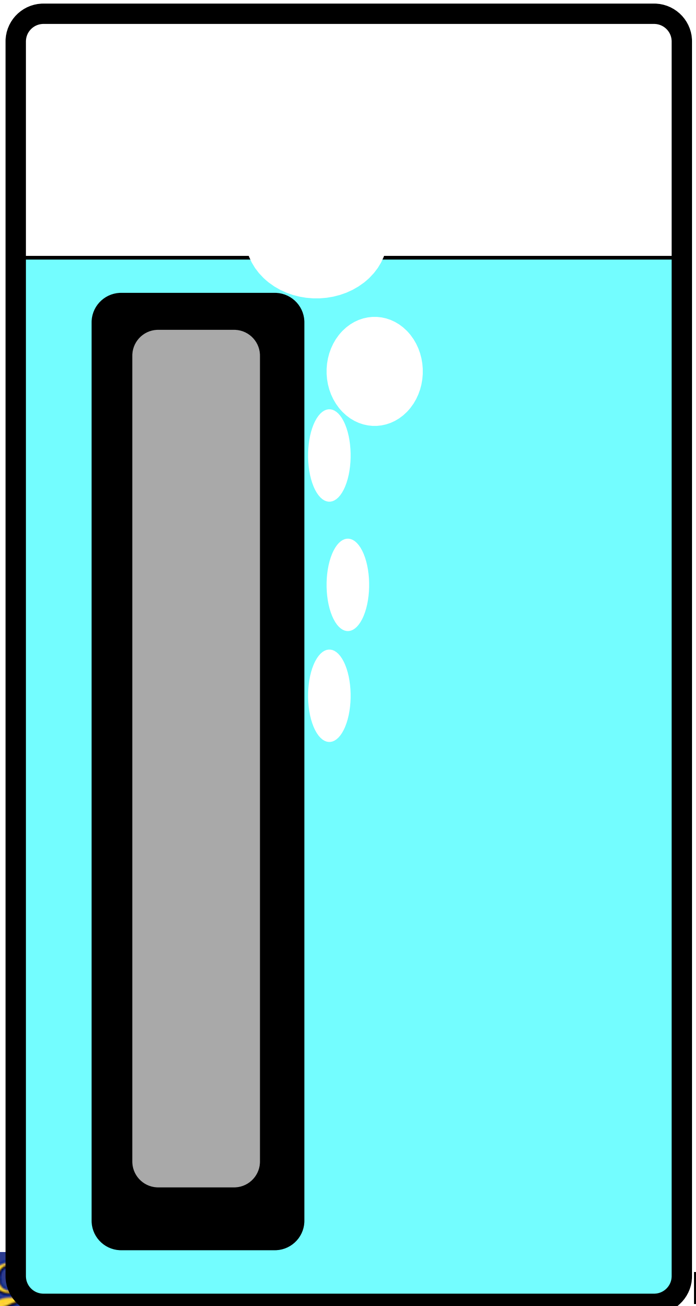


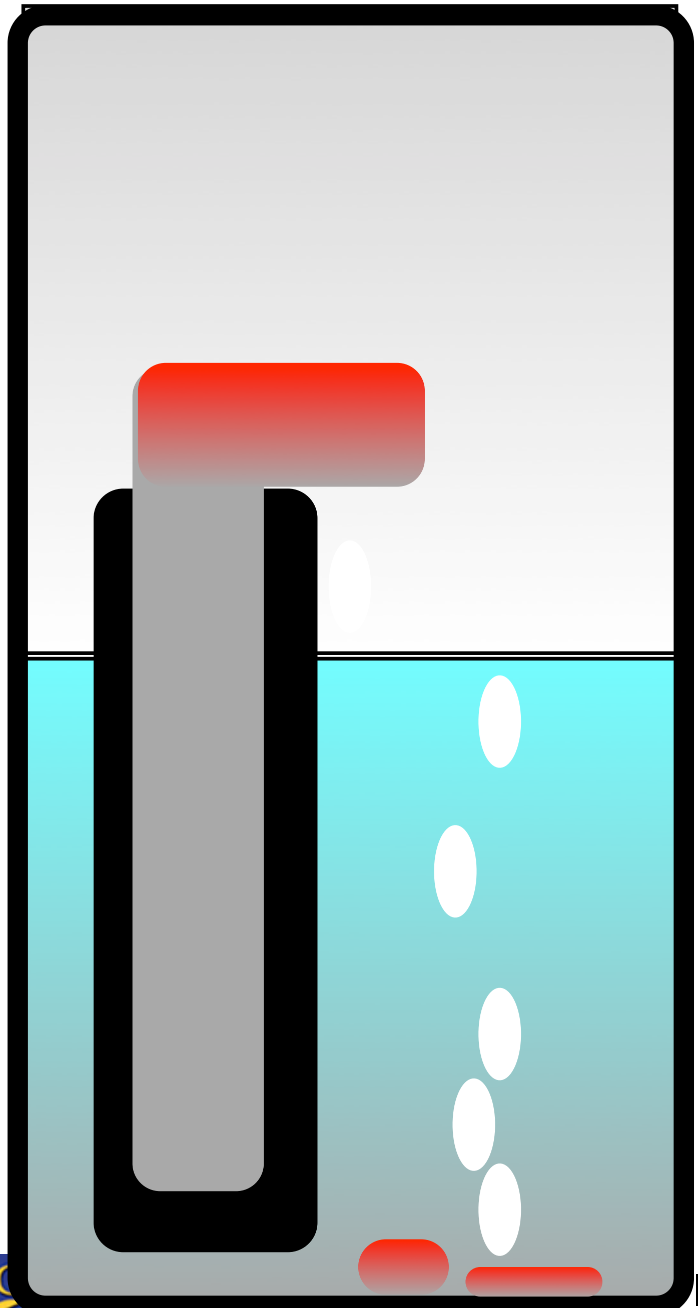
Healthy reactor:

In Zircalloy casing:
fuel + fission products + actinides

In cooling water:
activation products

In steam:
activation products

In environment:
practically nothing



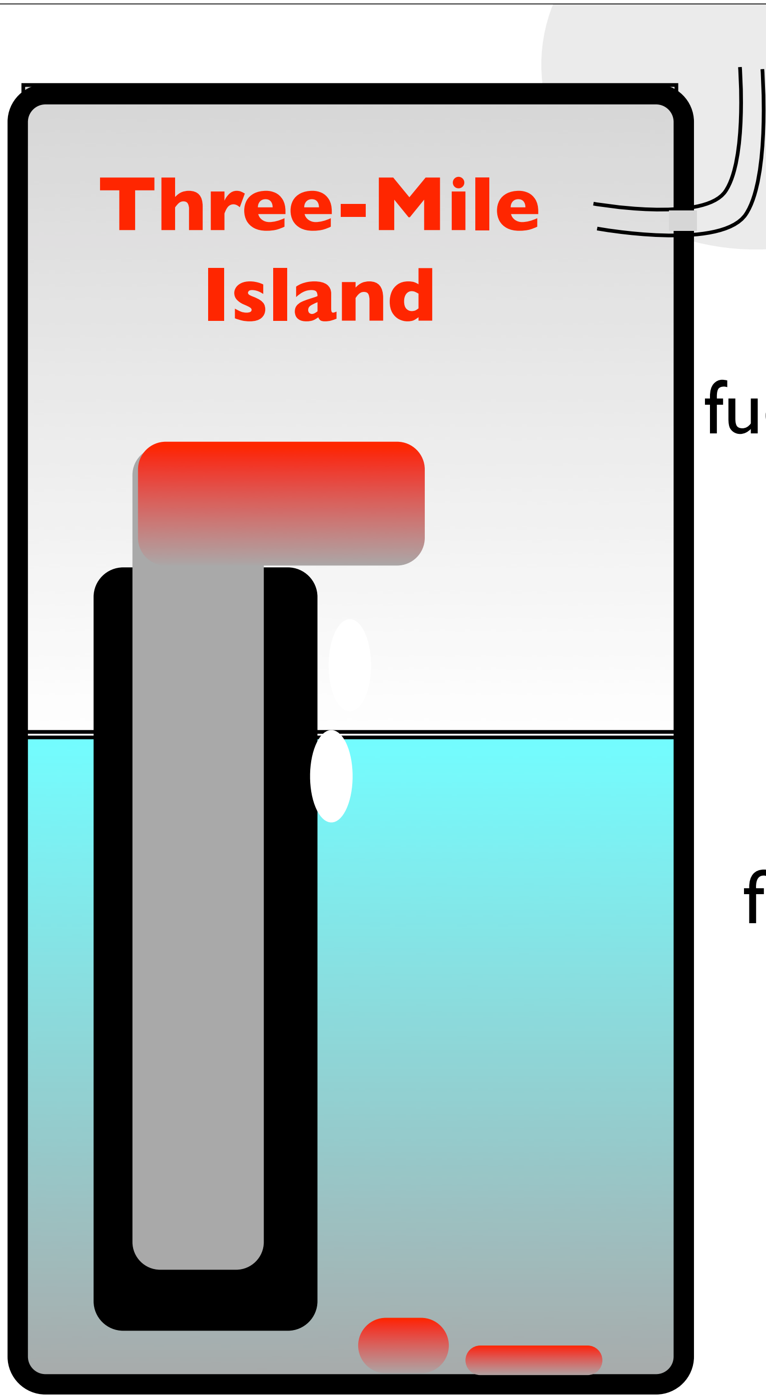
Meltdown:

In Zircalloy casing:
fuel + fission products + actinides

In cooling water:
fission products like Cs, I, Tc

In steam:
fission products like Xe, Kr, Rn

In environment:
practically nothing



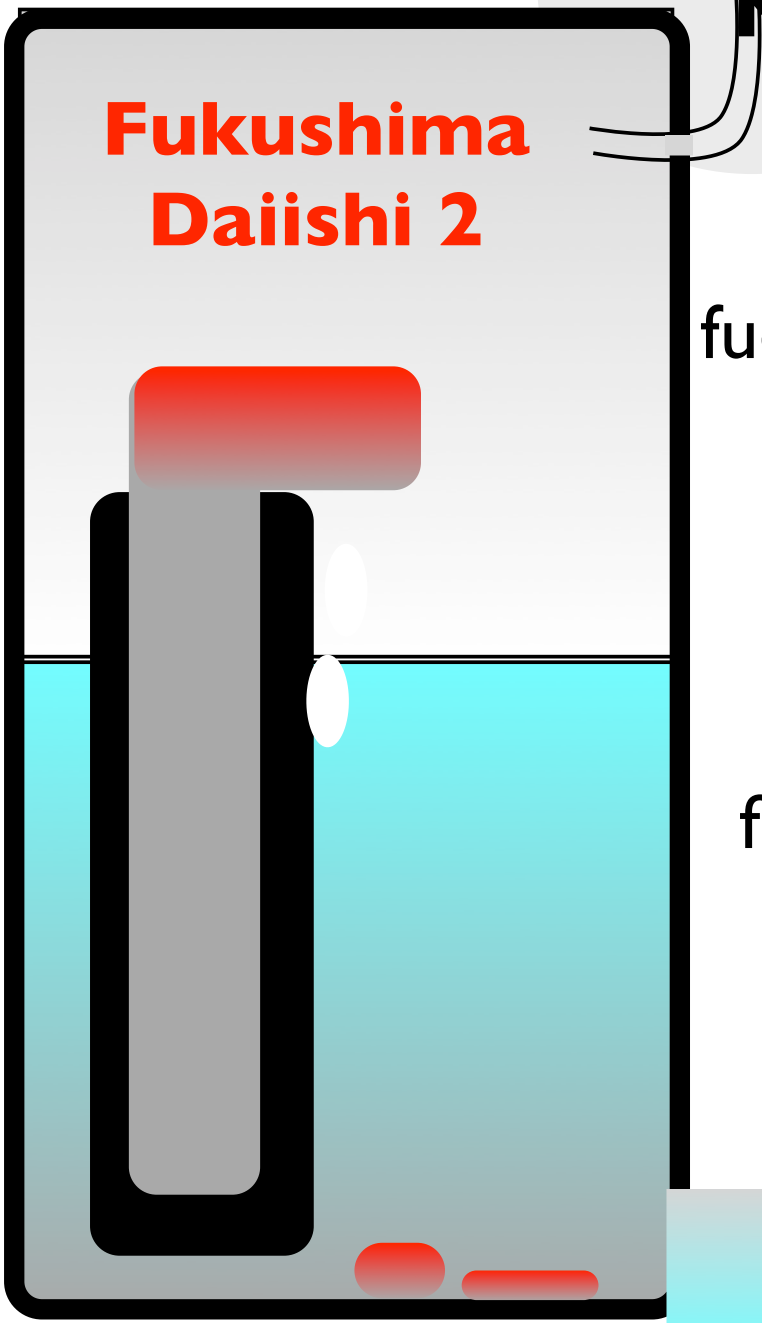
Meltdown + emergency venting:

In Zircalloy casing:
fuel + fission products + actinides

In cooling water:
fission products like Cs, I, Tc

In steam:
fission products like Xe, Kr, Rn

In environment:
practically nothing
Xe, Kr, Rn



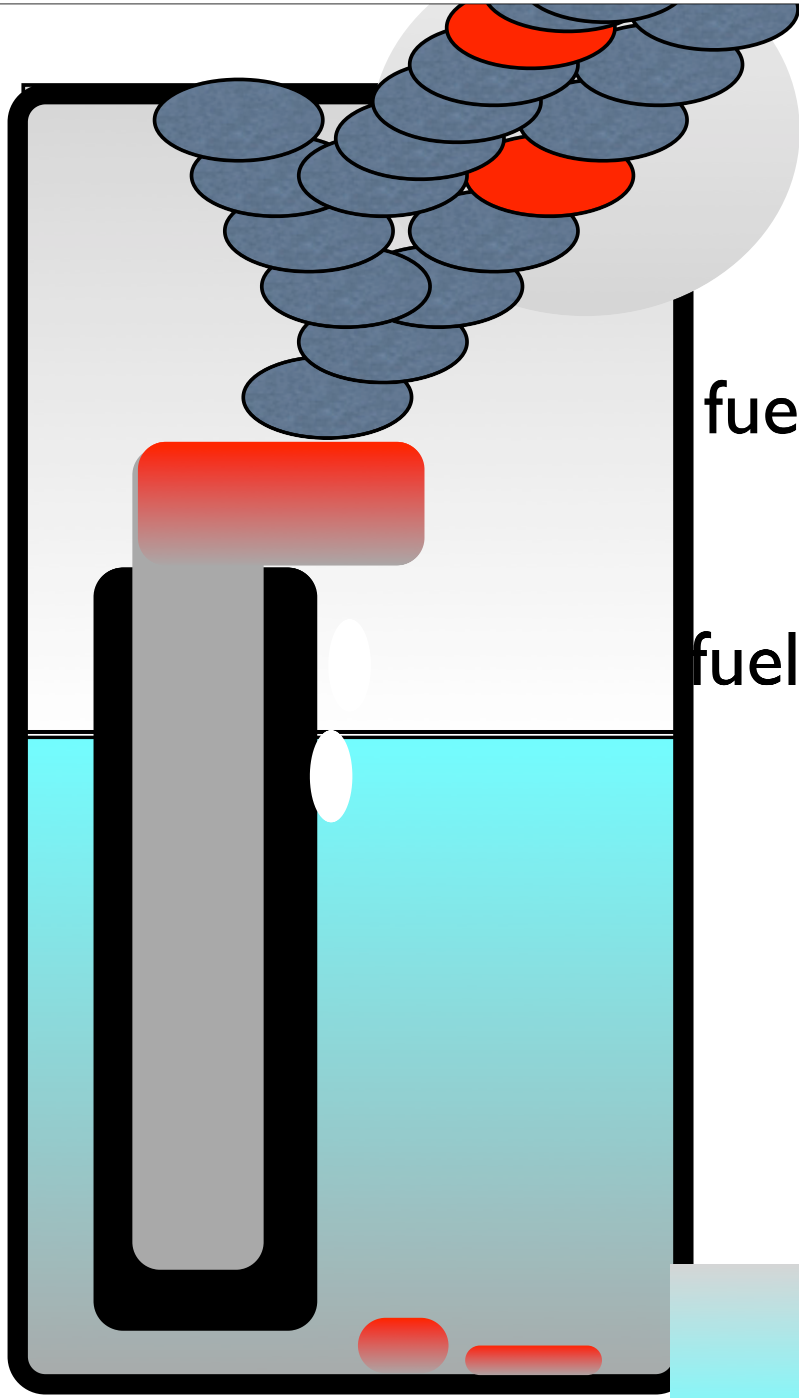
Meltdown + containment failure:

In Zircalloy casing:
fuel + fission products + actinides

In cooling water:
fission products like Cs, I, Tc

In steam:
fission products like Xe, Kr, Rn

In environment:
Xe, Kr, Rn, Cs, I, Tc



Meltdown + fuel fire

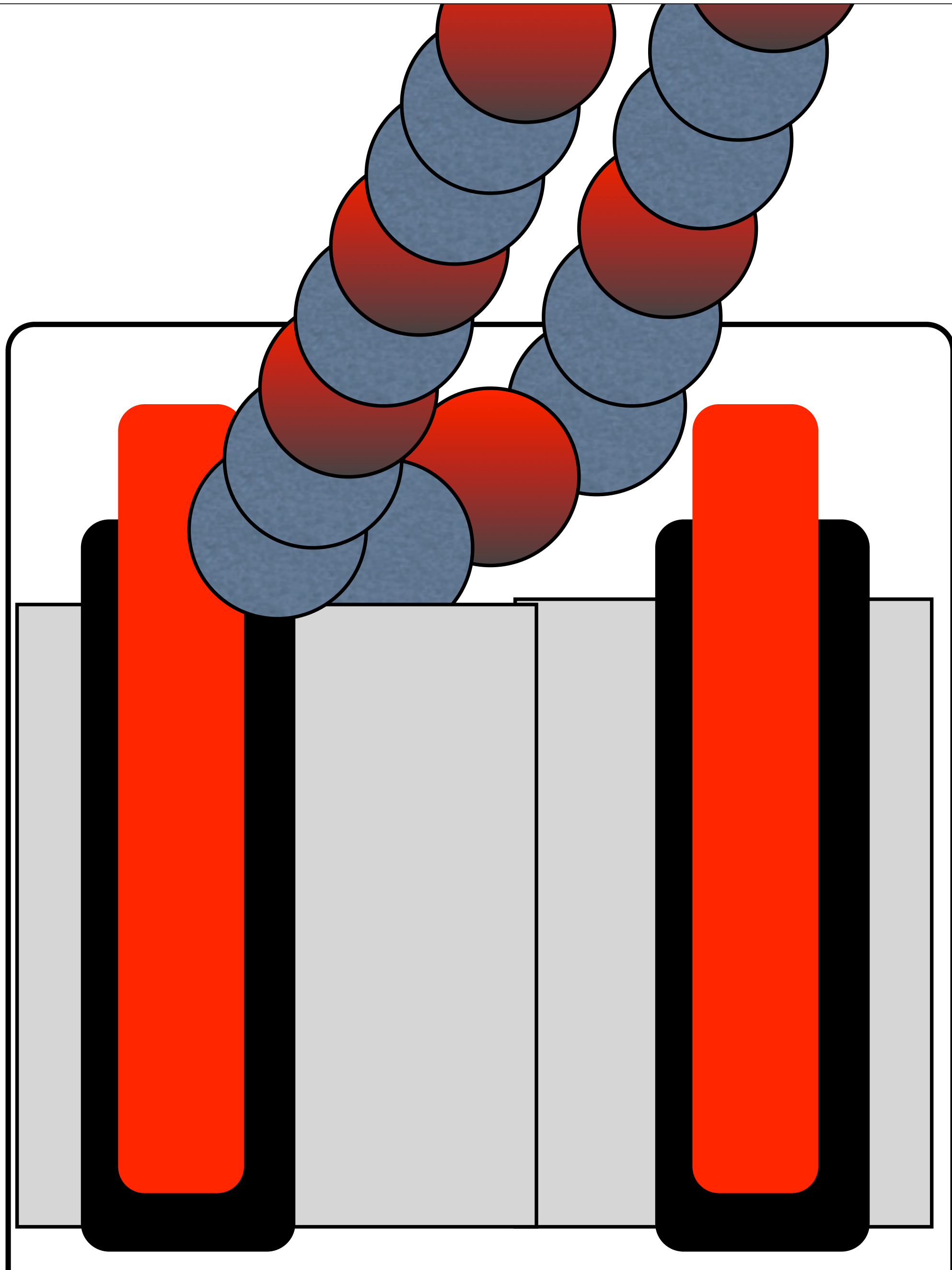
In Zircalloy casing:
fuel + fission products + actinides

In environment:
fuel + fission products + actinides

Briefly happened at Fukushima spent-fuel pools? (reports vary?)

This is very bad but
still not as bad as Chernobyl

Chernobyl

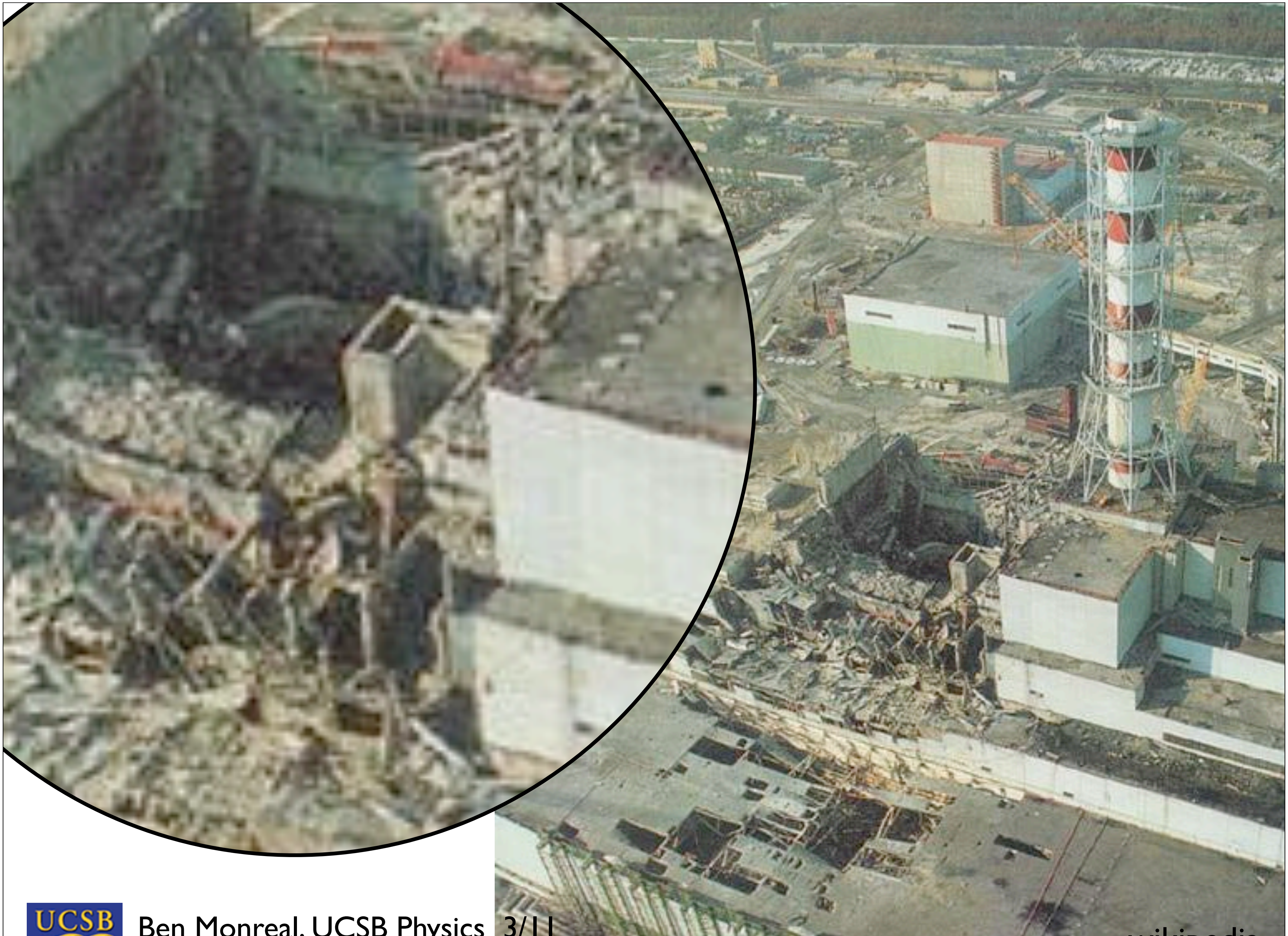


no real "containment vessel"

Core filled with graphite (fuel for huge fire)

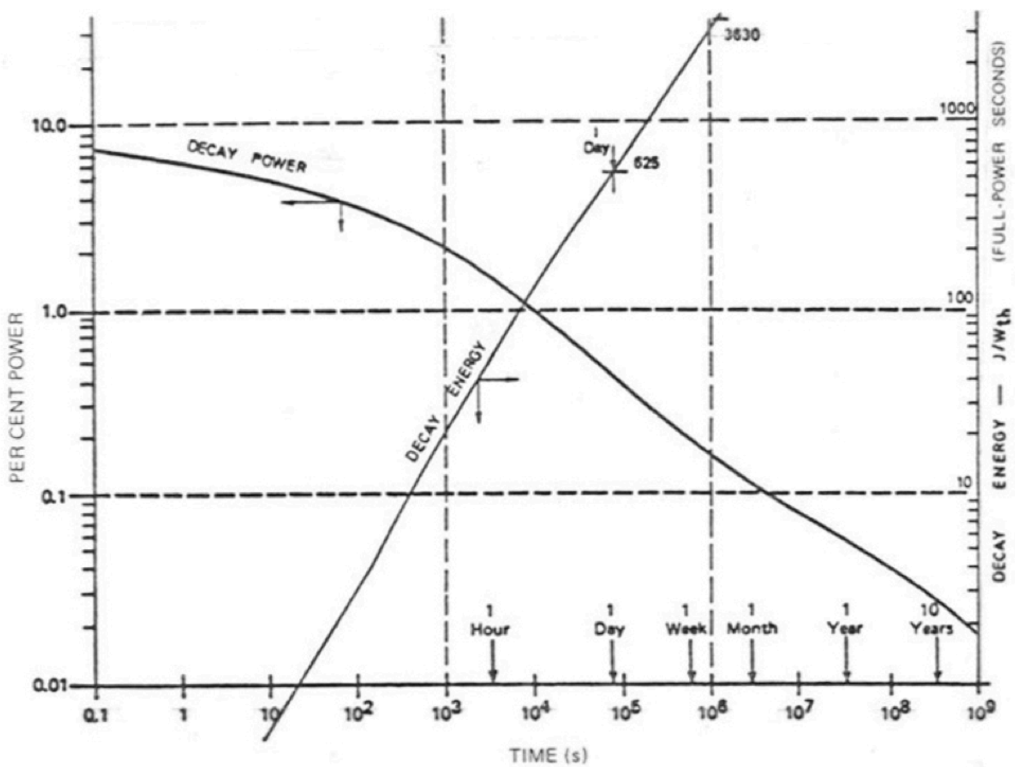
Reactor *fissioning during explosions and fire*

(Fukushima reactors have now been "off" for 5 days)



wikipedia

Saving graces at Fukushima



- *Reactor survived earthquake intact (!!!!!)*
- Shut down properly
- First hour of containment saved factor of 5x
- First day: factor 20x
- Evacuation
- Biggest fire risk is 100-day-old spent fuel, i.e. 100x less radioactive than Chernobyl material

Nuclides to watch

Nuclide	Half-life	Effect at Chernobyl
^{131}Iodine	8 days	quick ~0.5 mSv dose to everyone in Eastern Europe
^{137}Cesium	30 years	Additional ~1 mSv over 30y
^{90}Strontium	30 years	Lower amount than Cs, but accumulates in bone
^{241}Plutonium	9 years	Large doses near reactor site; easier to decontaminate

Cooper, Randle, and Sokhi, Wiley 2003

In case of fire ... soot

Nuclide	Half-life
^{95}Zirconium	60 days
^{99}Molybdenum	3 days
^{103}Ruthenium	40 days
^{141}Cerium	30 days
^{140}Barium	14 days

- Worst concern to first responders. Weather may move soot plumes around (Chernobyl: bad plumes to 60km)
- *This is what the "stay indoors" advisories are talking about. Soot in your driveway doesn't dose you; soot on your clothes does.*
- Can be cleaned from streets/buildings. Agriculture, fisheries have to wait it out (or remove top 10cm soil)

Conclusions

- The worst general-public effects of Chernobyl were *stress/fear;* HUGE education/communication failure
  - You have the information: count the millisieverts and decide how to respond
- My feeling: the worst-case radiation hazards from Fukushima are mitigatable and local
  - (early evacuation + controls on ^{131}I in food)
- My feeling: the global radiation hazard is nil.
  - The best way to reduce worldwide low-level radiation releases is ... stop burning coal
- Save your energy for those affected by the tsunami and "50 plant workers" at Fukushima