# HOW MANY BANANAS IS A TRANS-ATLANTIC FLIGHT :

## WHY NUCLEAR POWER WON'T KILL YOU


Salvatore Rappoccio, PhD
Physics Department at UB
Professional atom smasher

My policy statement is here:

http://www.acsu.buffalo.edu/~srrappoc/NuclearPower.html

University at Buffalo The State University of New York

[Humans] have now all but destroyed this once salubrious planet as a life-support system in fewer than 200 years, mainly by making thermodynamic whoopee with fossil fuels.

-- Kurt Vonnegut

# IPPC Statement

The report finds that limiting global warming to 1.5°C would require “rapid and far-reaching” transitions in land, energy, industry, buildings, transport, and cities. Global net human-caused emissions of carbon dioxide (CO2) would need to fall by about **45 percent from 2010 levels by 2030**, reaching **‘net zero’ around 2050**. This means that any remaining emissions would need to be balanced by removing CO2 from the air.

We need to do SOMETHING

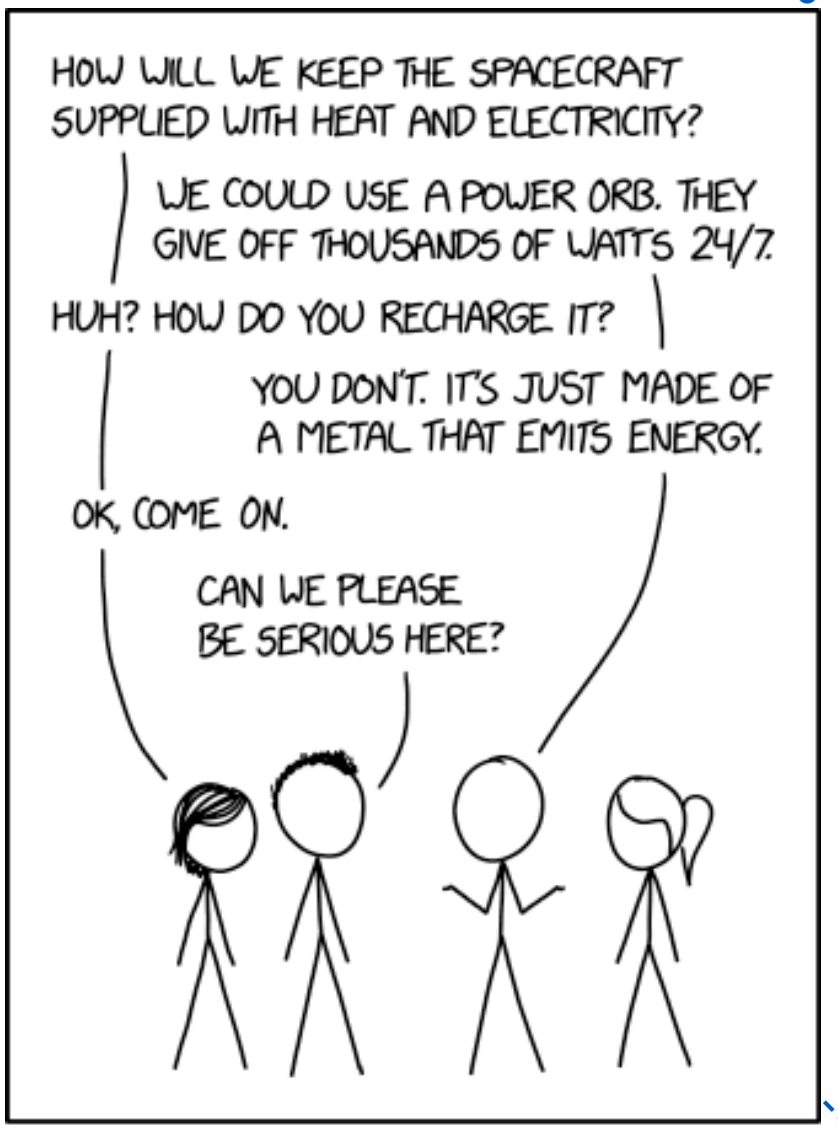
http://www.ipcc.ch/news_and_events/pr_181008_P48_spm.shtml

# How to stop making thermodynamic whoopee: The Green New Deal

- The most serious plan any politician currently has. 😀
- It probably won't work without nuclear power. ☹️

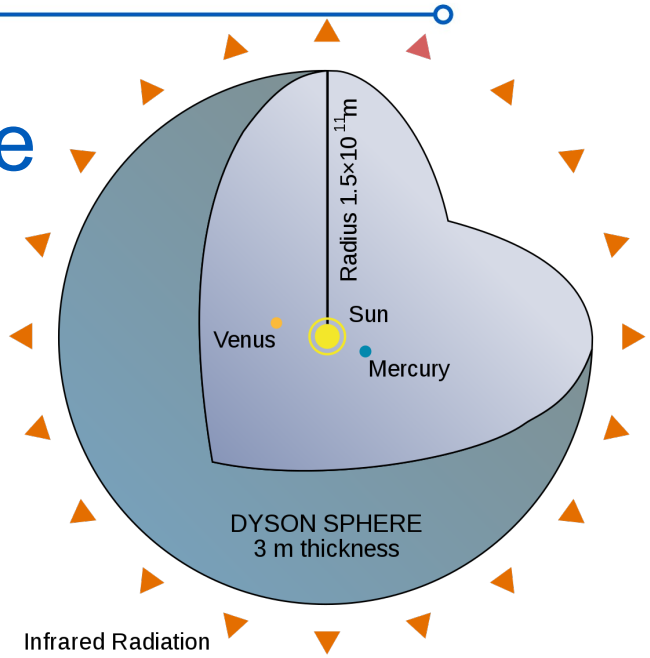
https://xkcd.com/2115/

Why?
Because nuclear power is like magic.



# Challenges facing energy storage

- No problem with electricity generation
-




We get 174,000 times as much energy as we use here on earth

# Challenges facing energy storage

- No problem with electricity generation

- Problem with energy STORAGE
  - Store <1% of energy produced in the grid

| | |
|---|---|
| US Stored energy / day: | 828000000000000 J |
| US use / day: | 10000000000000000000 J |

**Every joule of energy you use needs to be produced instantaneously**

https://www.eia.gov/energyexplained/?page=us_energy_home
https://www.ucsusa.org/clean-energy/how-energy-storage-works#bf-toc-1

https://en.wikipedia.org/wiki/Grid_energy_storage

# Challenges facing energy storage

- No problem with electricity generation

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- Options:
  - Mechanical
  - Chemical
  - Electromagnetic
  - Nuclear
-

Convert kinetic energy to potential energy, then release it

Examples:
Moving water uphill, letting it fall.
Moving heavy rocks uphill, letting them fall.
Gigantic windup toys.
Moving squirrels uphill, letting them fall.

https://en.wikipedia.org/wiki/Grid_energy_storage

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These three are real ideas

This one isn't

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-

Convert to chemical energy (from kinetic or electric)

Current state of art:
Lithium ion batteries
(13.5 kW-hr, $5.9k)
Other ideas: make hydrogen

Can supply a suburban family of 4 for ~8-12 hrs (~overnight)

Still some way to go technologically

What about the equity of this solution?
We need #EnergyJusticeForAll, not just wealthy homeowners.

https://en.wikipedia.org/wiki/Grid_energy_storage

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  - Mechanical
  - Chemical
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  - Nuclear

Currently nothing deployed.

Options:
- Giant capacitors
- Giant electromagnets (superconducting?)

Extremely expensive.
Extremely dangerous.


Damage from superconducting magnet destroying steel at the LHC

https://en.wikipedia.org/wiki/Grid_energy_storage

# Challenges facing energy storage

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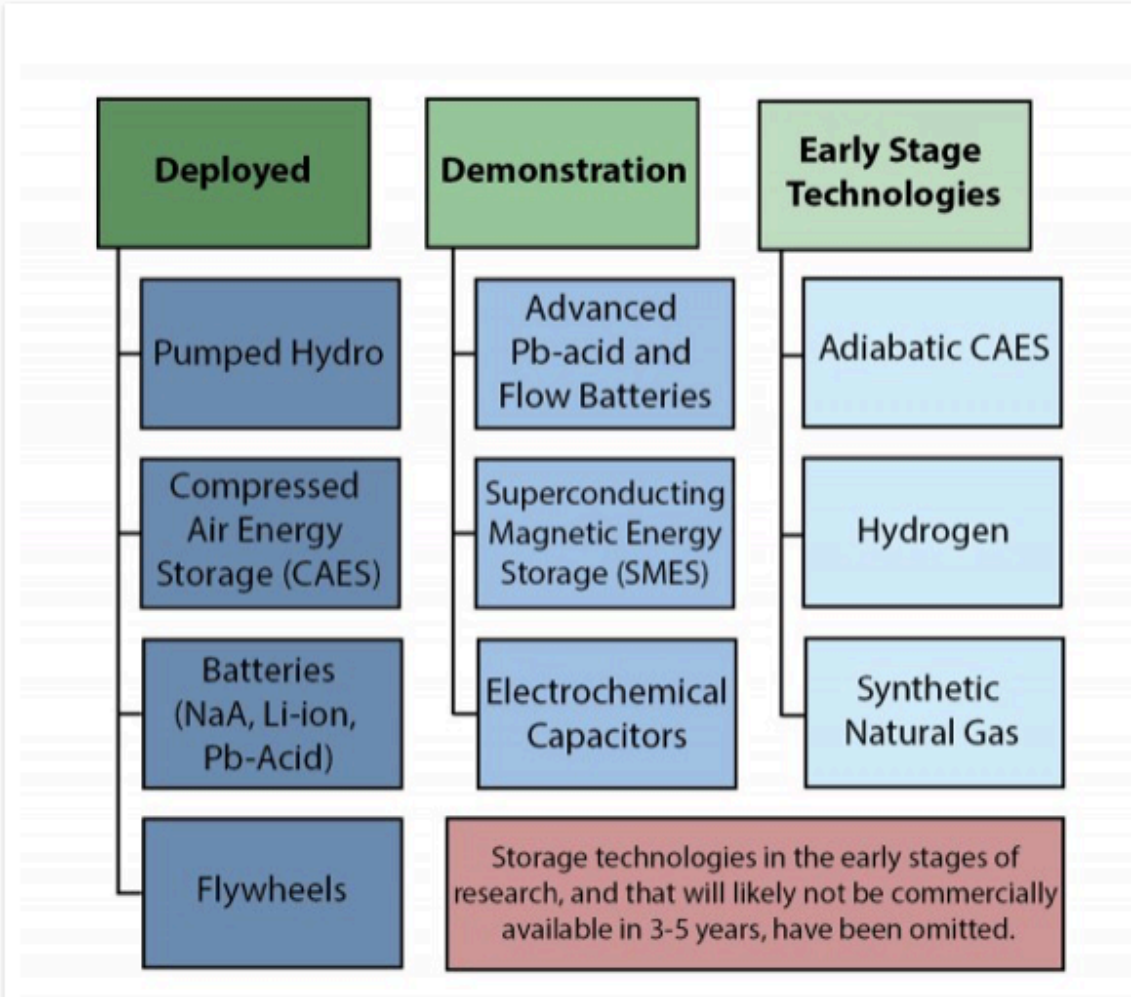
- Options:
  - Mechanical
  - Chemical
  - Electromagnetic
  - Nuclear

Nuclear storage is stupid, because nuclear power generation is like magic.

http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

# Challenges facing energy storage



http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

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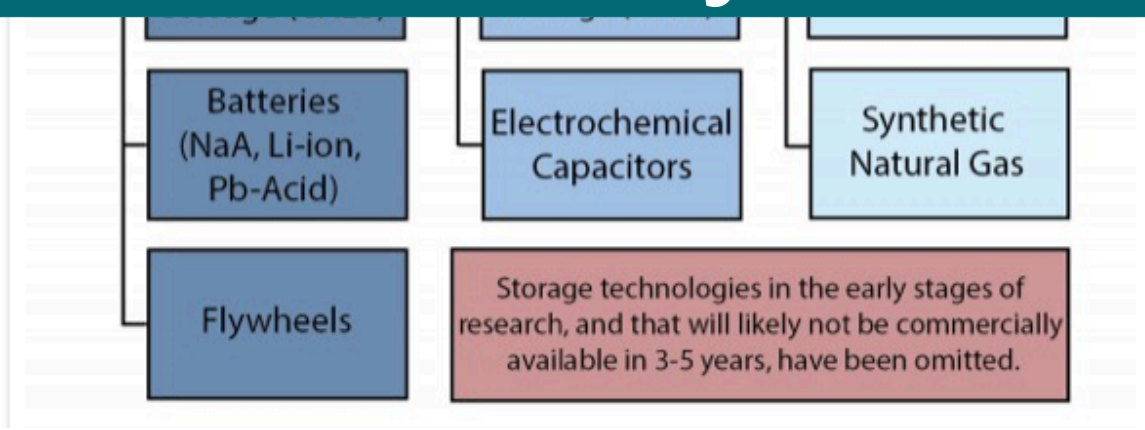
# Energy storage isn't sufficient and is not going to solve the problem in 12 years



https://en.wikipedia.org/wiki/Capacity_factor

# Quantify this: Capacity factor

$$C = \frac{\text{Actual energy output}}{\text{Total possible energy output}}$$

To solve climate change, we need high-capacity solutions deployable within 12 years

# Capacity factor : how often can it run?

| Source | Capacity factor (%) |
|---|---|
| Nuclear | 92.2 |
| Geothermal | 76.4 |
| Hydro | 45.2 |
| Wind | 36.7 |
| Solar PV | 27.0 |
| Solar CSP | 21.8 |
| Biomass + wood | 50.7 |
| Landfill | 70.9 |
| Natural Gas (CC) | 53.5 |
| Petroleum Liquids | 13.0 |

Almost always runs

Good idea! Requires large open space

Not everyone lives near Niagara Falls

Wind doesn't always blow

Sun doesn't always shine

Plant, burn, capture: can REDUCE CO2

Dumpster fire

Thermodynamic whoopee

UUgggghhhh

https://en.wikipedia.org/wiki/Capacity_factor

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Almost always runs

Good idea! Requires large open space

Falls

CE CO2

UUgggghhhh

**Nuclear power is the only zero-carbon source with >90% capacity**

https://en.wikipedia.org/wiki/Capacity_factor

# But Chernobyl! But Fukushima!

https://en.wikipedia.org/wiki/Chernobyl_(miniseries)

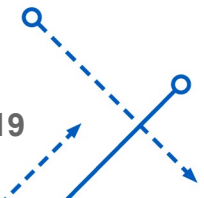
"the true story of one of the worst man-made catastrophes in history"

Godzilla will come from Chernobyl!

# Nuclear Power versus Nuclear Weapons

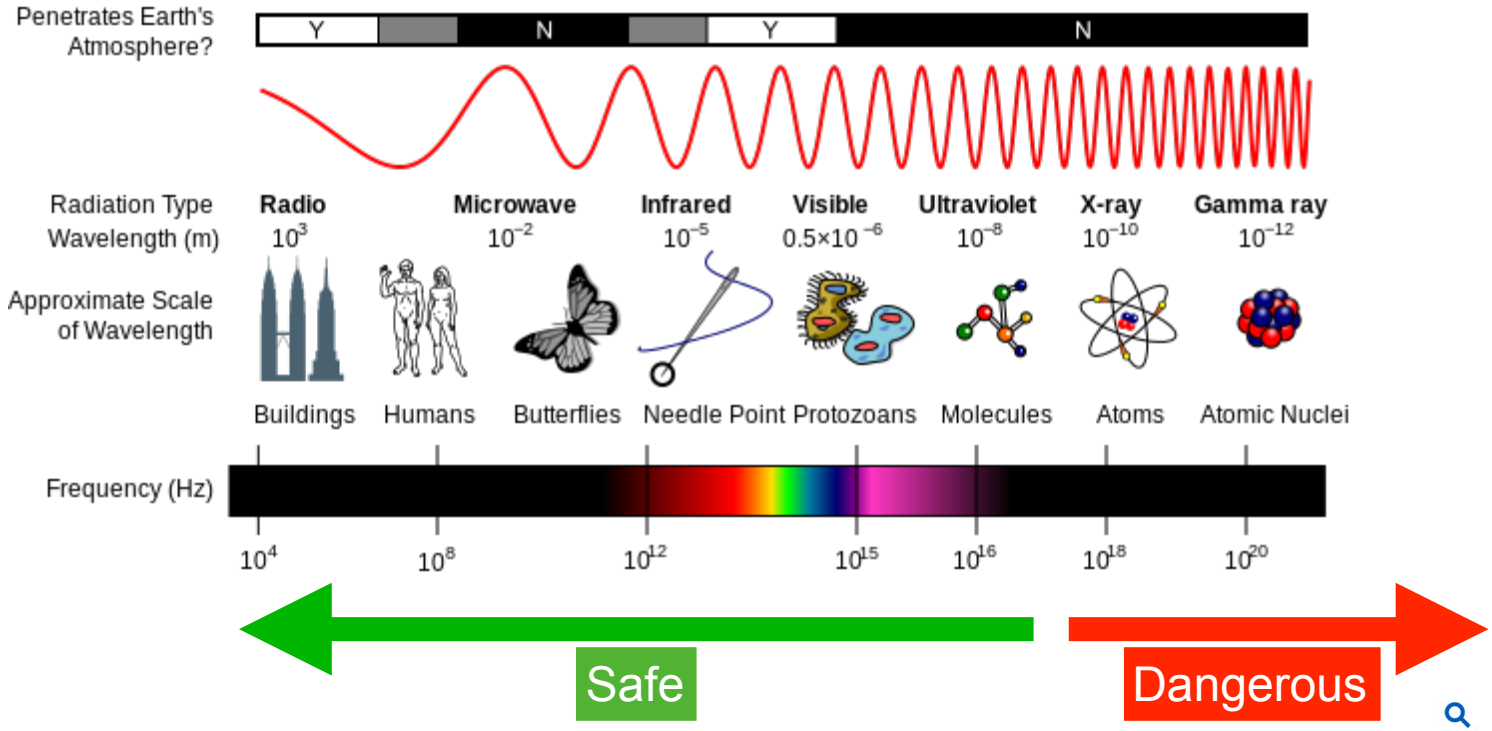
Not Scary

Scary



# What is radiation?

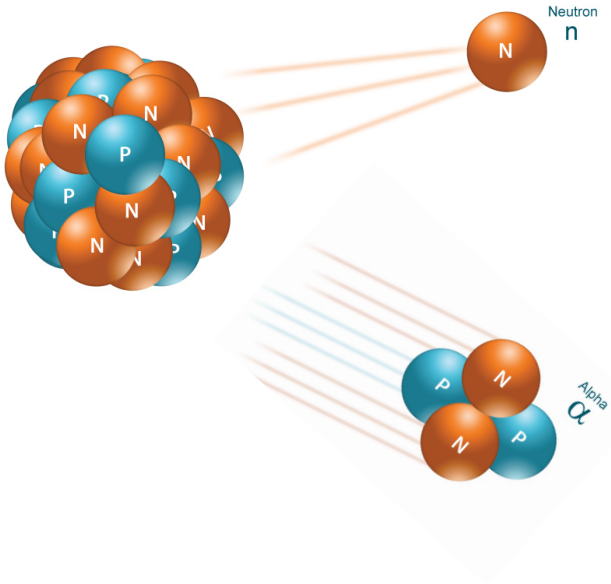
- Particles moving through space
  - Example: Photons




https://en.wikipedia.org/wiki/Radiation

# What is radiation?

- Particles moving through space
  - Other types: Positrons (beta particles, like electrons). neutrons. helium nuclei (alpha

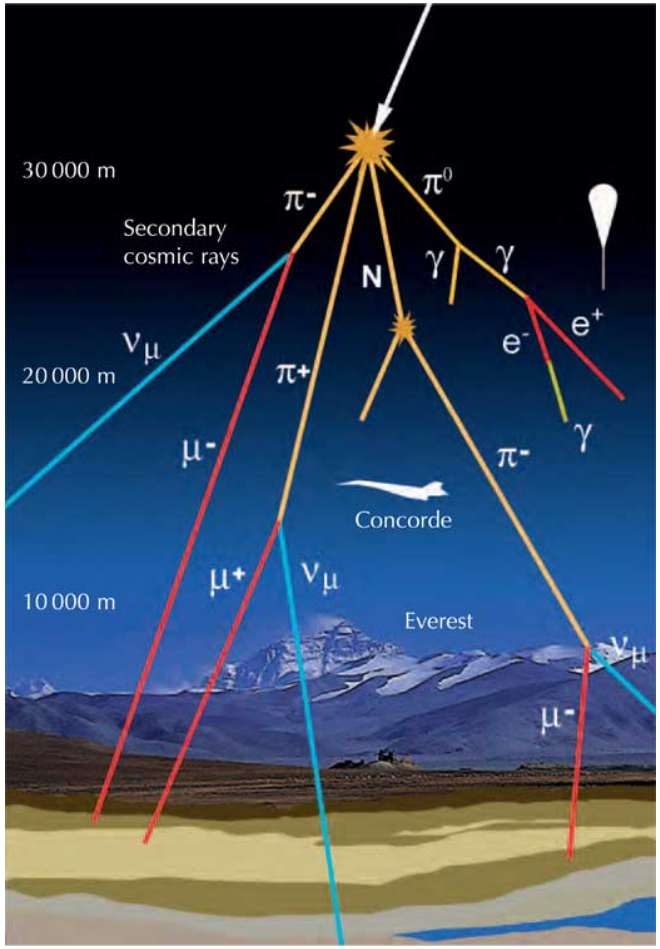



Nuclei emit particles via radioactive decay
(from the weak interaction!)

https://imnh.iri.isu.edu/digitalatlas/clima/atmosph/rad.htm

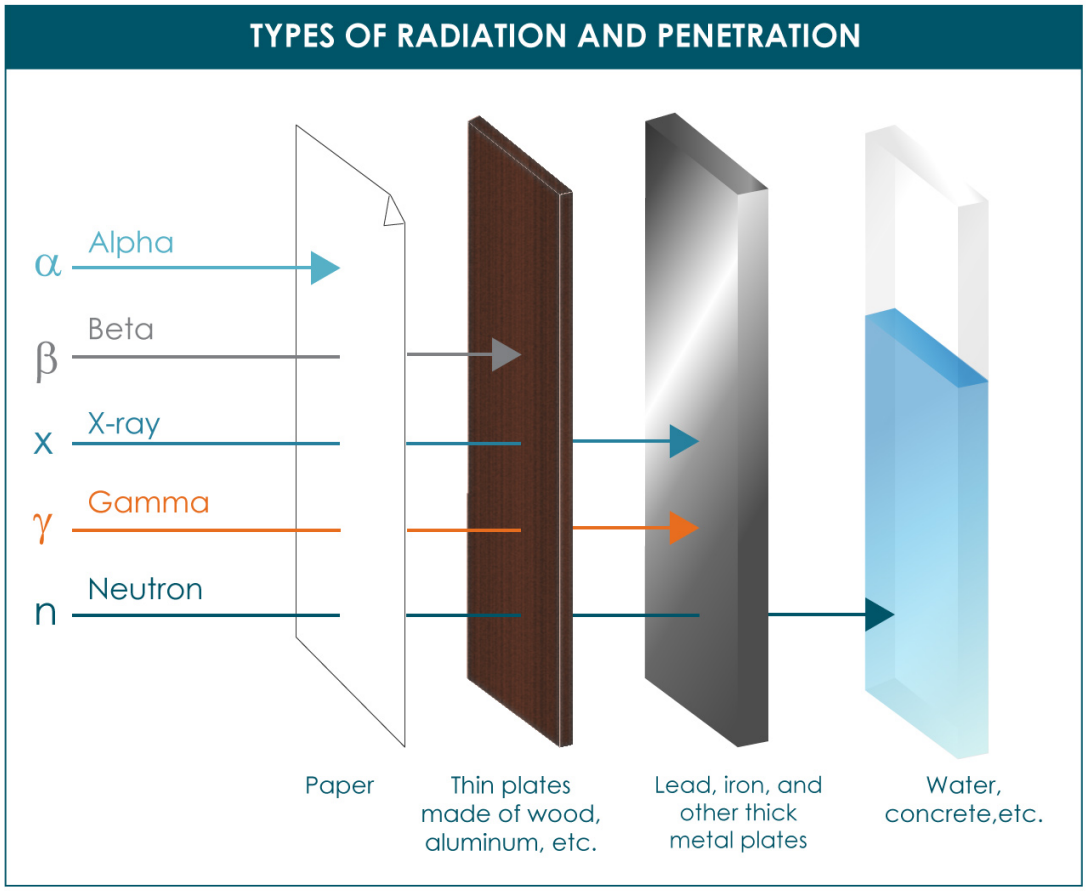
# What is radiation?

- Particles moving through space
  - Exotic types:
    - Muons (heavy electrons)
    - Pions (like a proton/neutron)
    - Neutrinos
    - Dark matter (yep, 4x more abundant than normal matter)




https://imnh.iri.isu.edu/digitalatlas/clima/atmosph/rad.htm

# Protection: distance and shielding

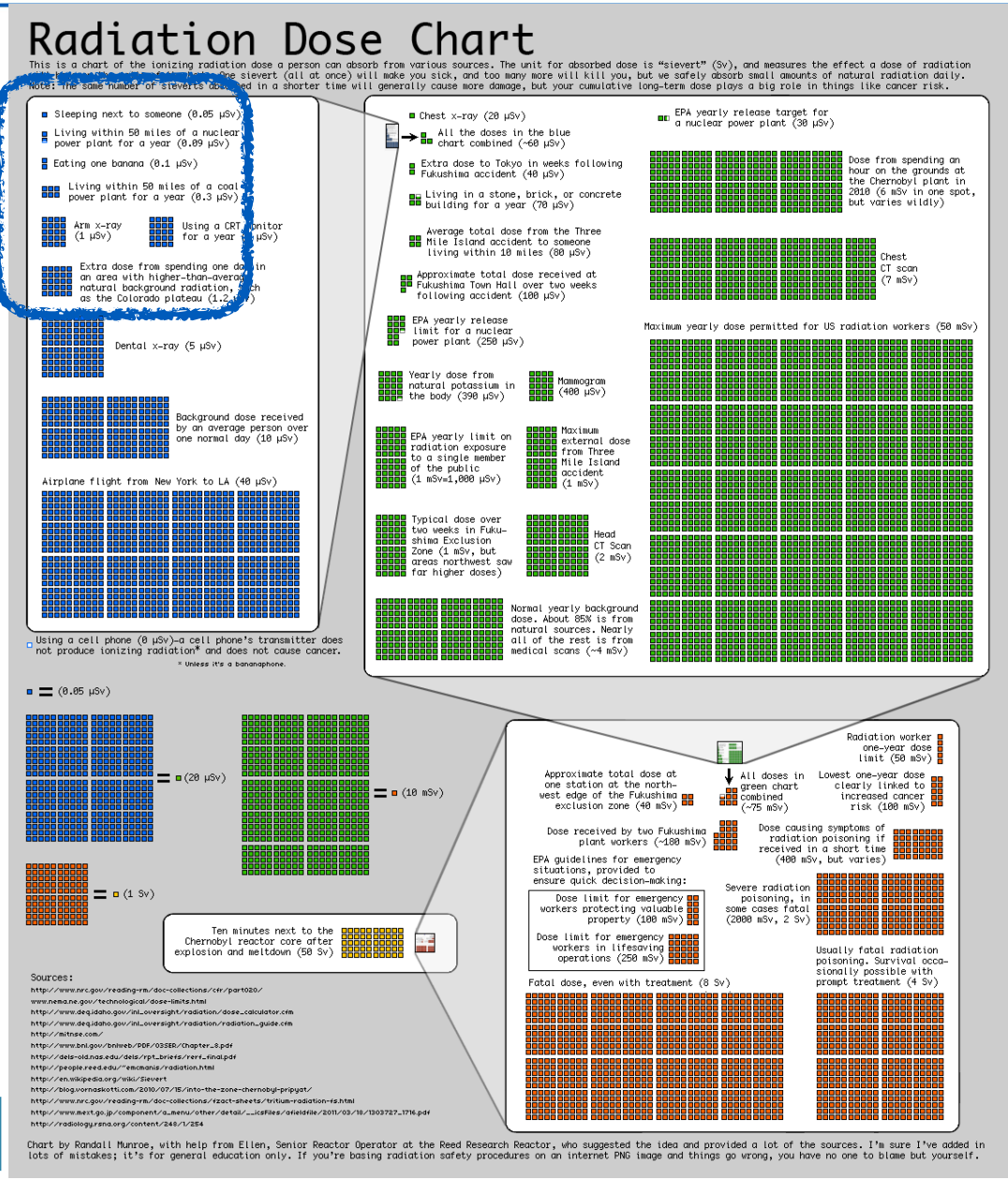



Protection against all radiation:

Hide behind ~1m of concrete or dirt

https://www.mirion.com/introduction-to-radiation-safety/types-of-ionizing-radiation/

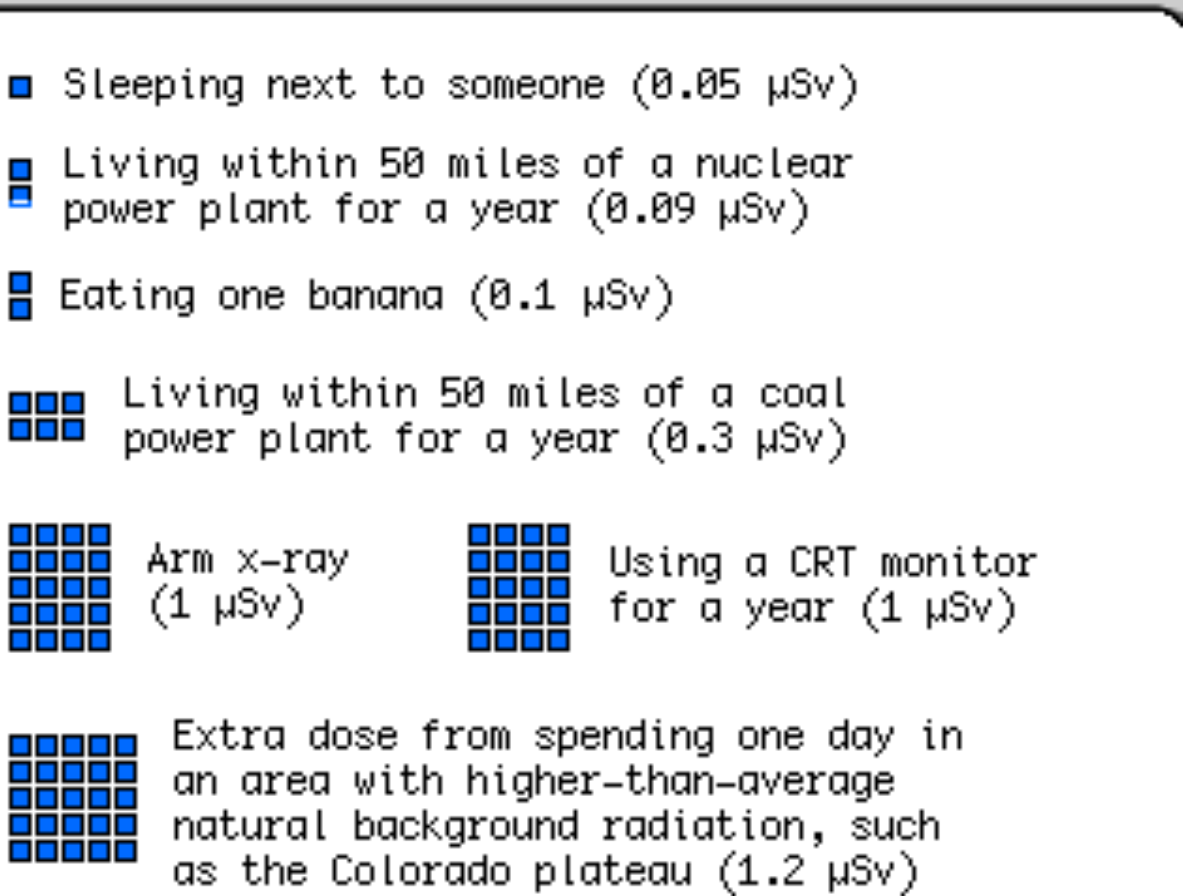
Zoom in




https://xkcd.com/radiation/

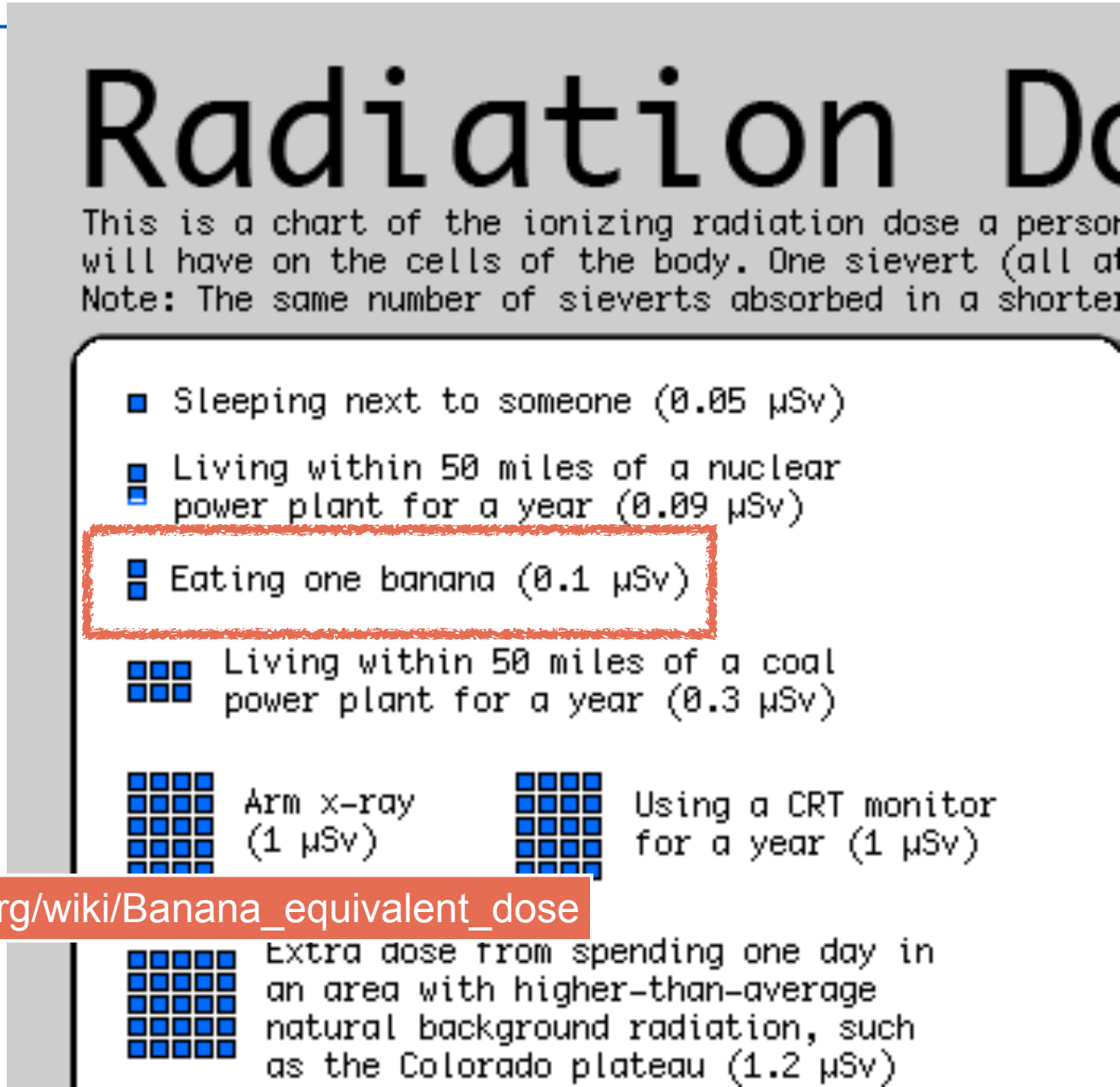
# Radiation Do

This is a chart of the ionizing radiation dose a person will have on the cells of the body. One sievert (all at
Note: The same number of sieverts absorbed in a shorter

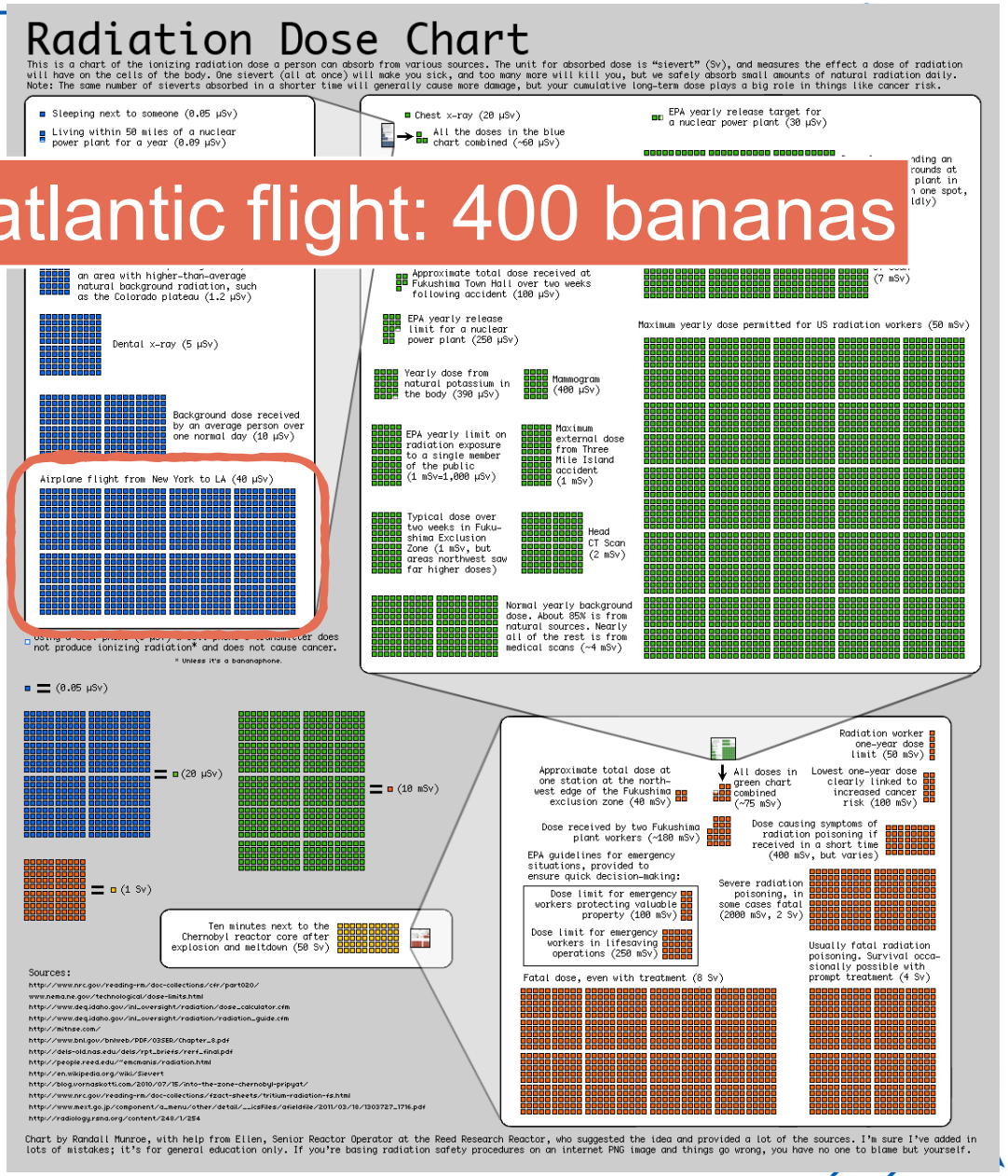


Yeah, you're getting irradiated right now.

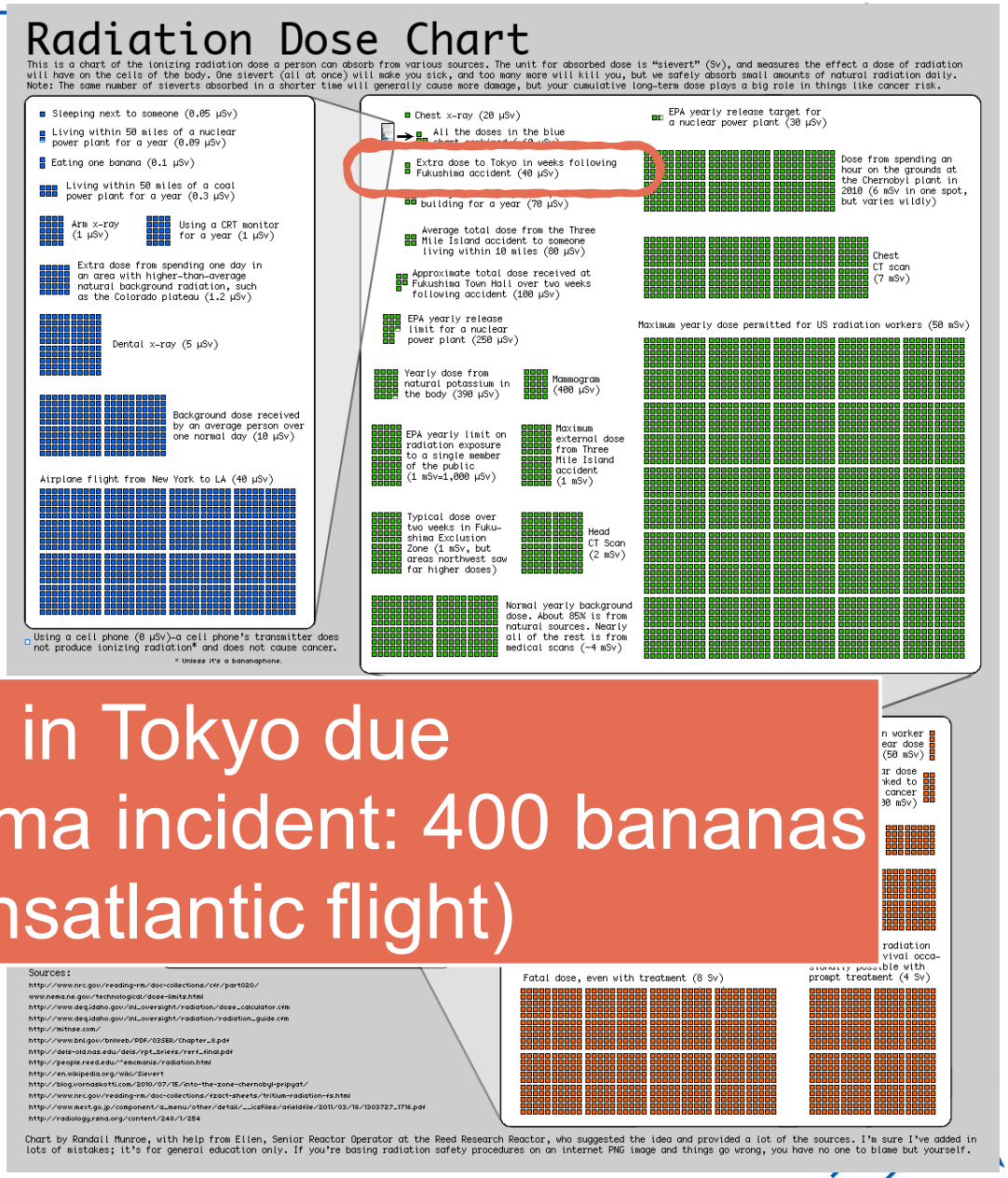
Let's use "one banana" as a radiation unit.



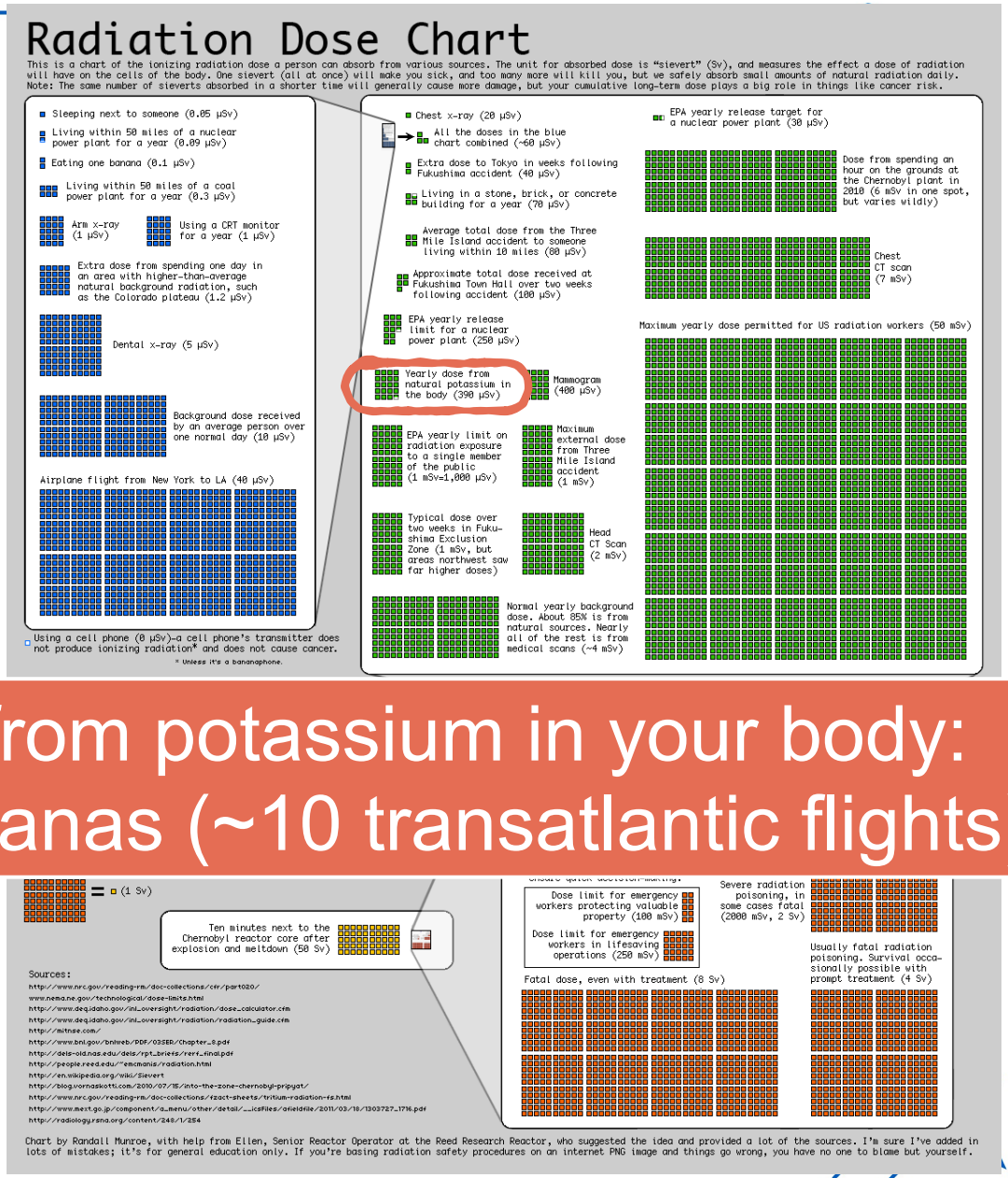

https://en.wikipedia.org/wiki/Banana_equivalent_dose



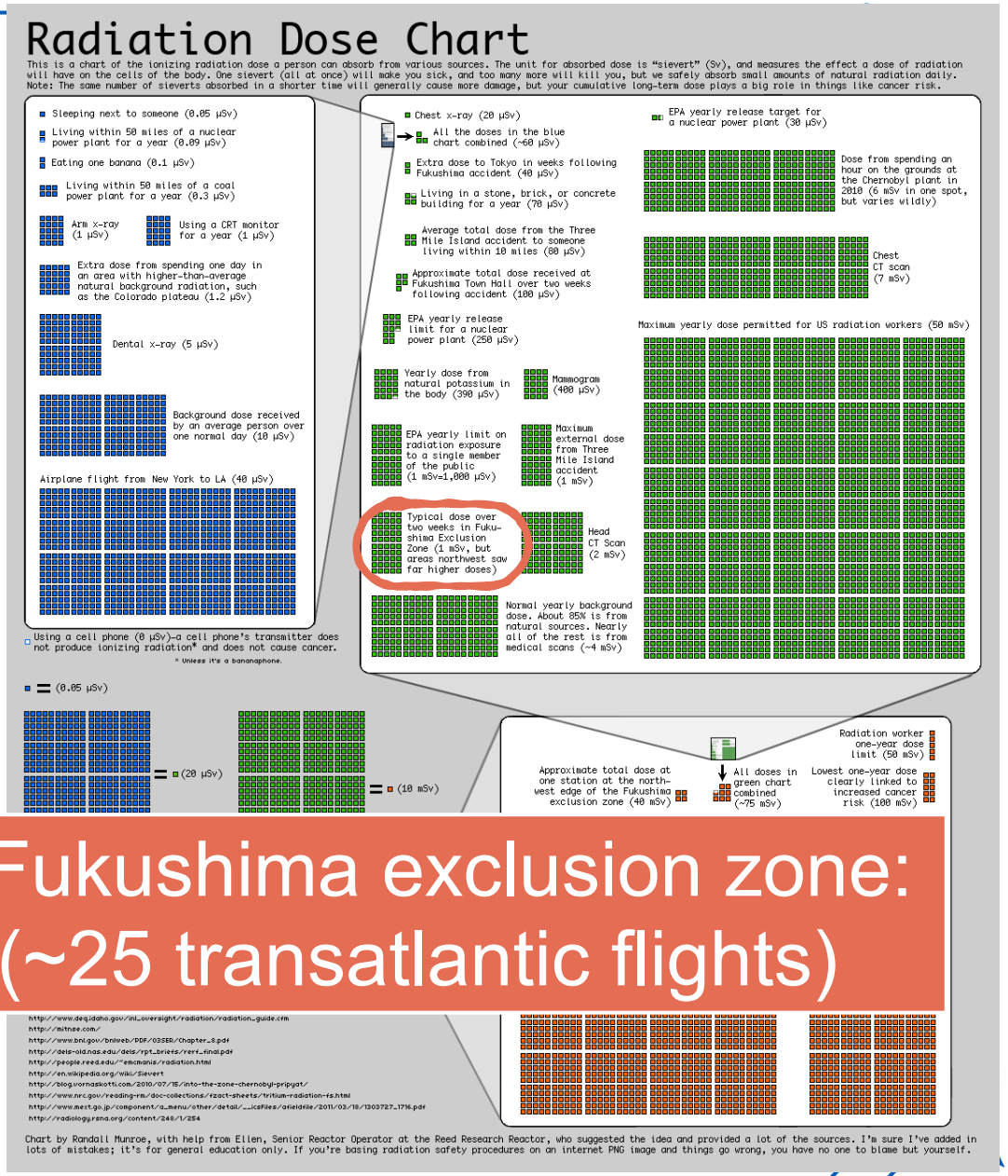

# Transatlantic flight: 400 bananas



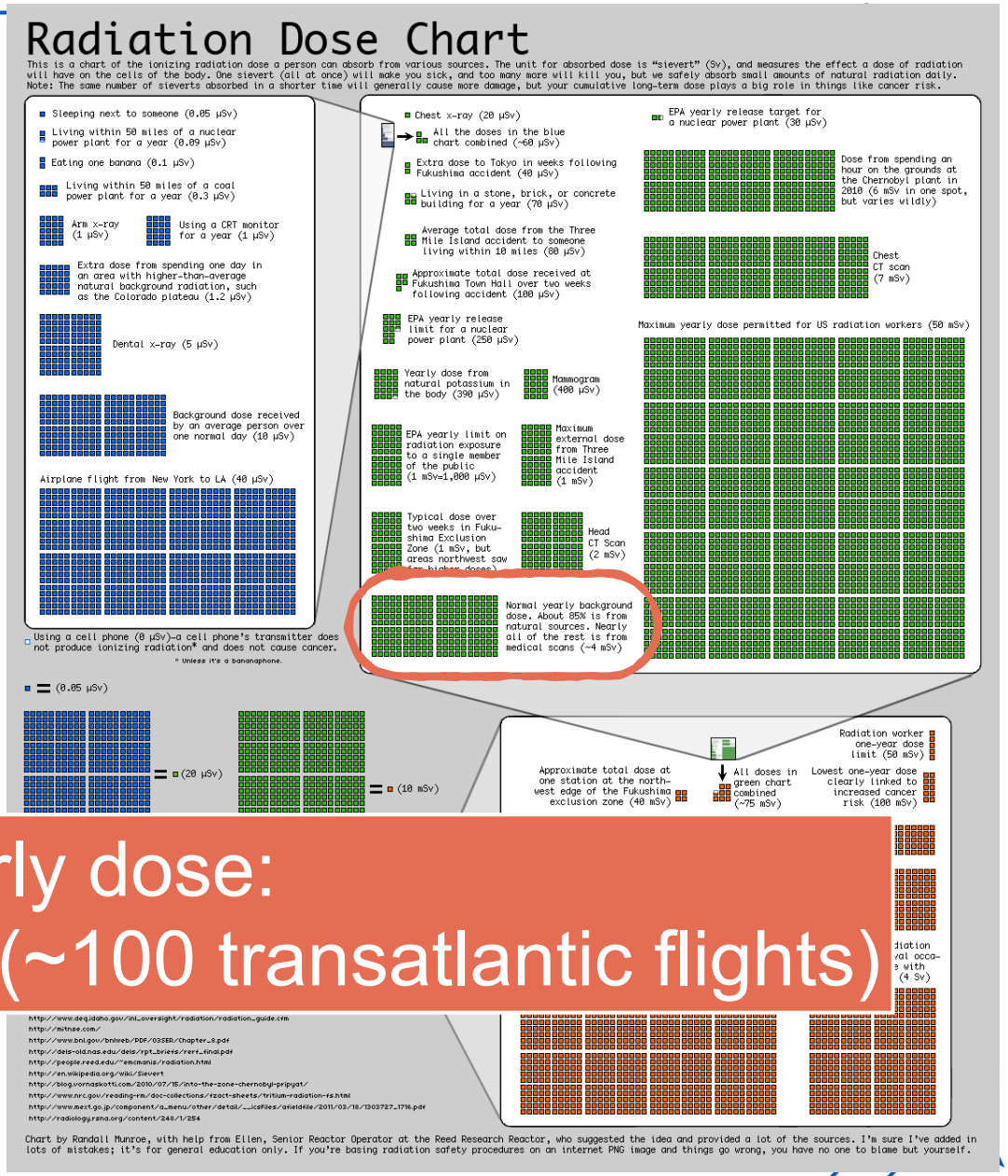

Extra dose in Tokyo due to Fukushima incident: 400 bananas (i.e. ~1 transatlantic flight)



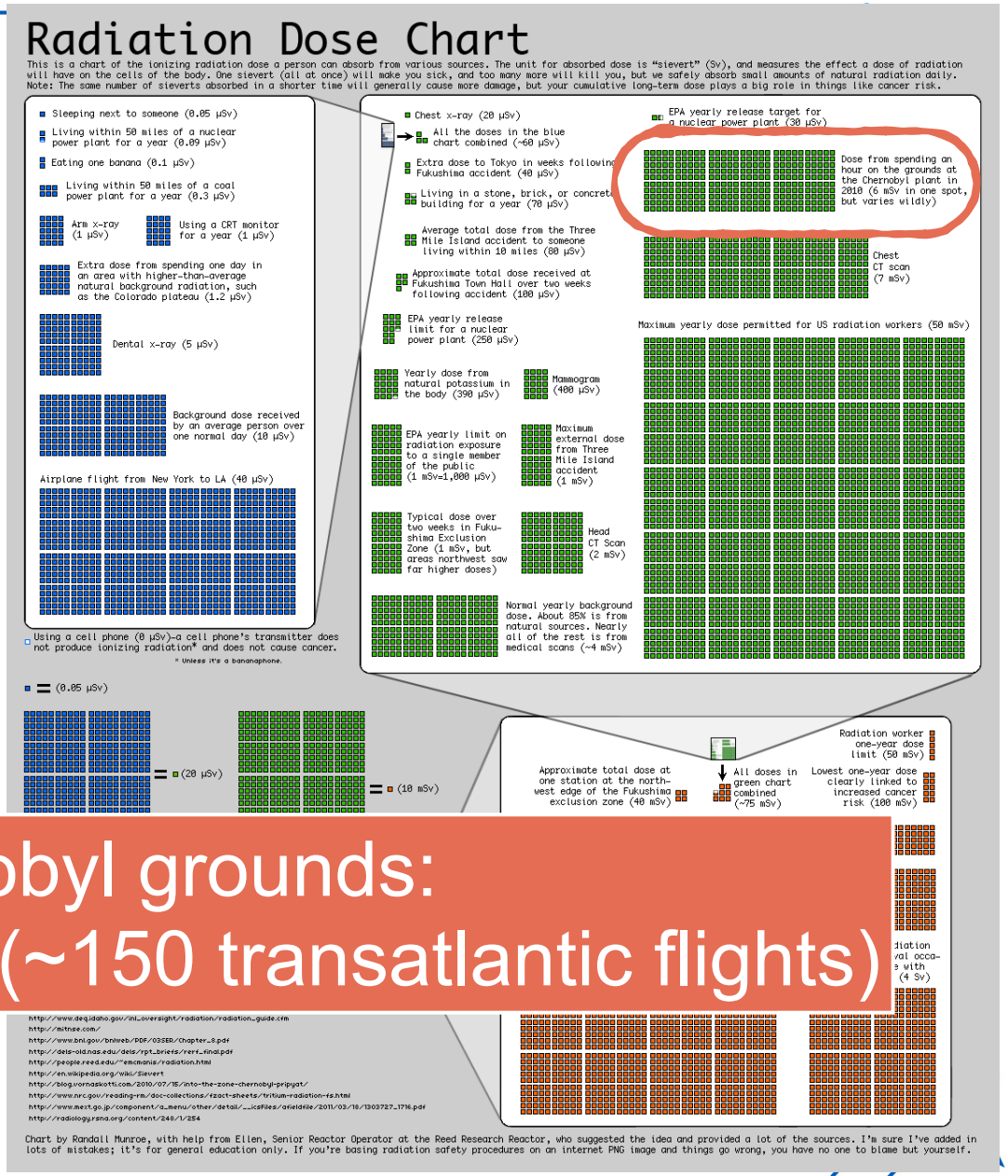

# Radiation from potassium in your body: ~4000 bananas (~10 transatlantic flights)



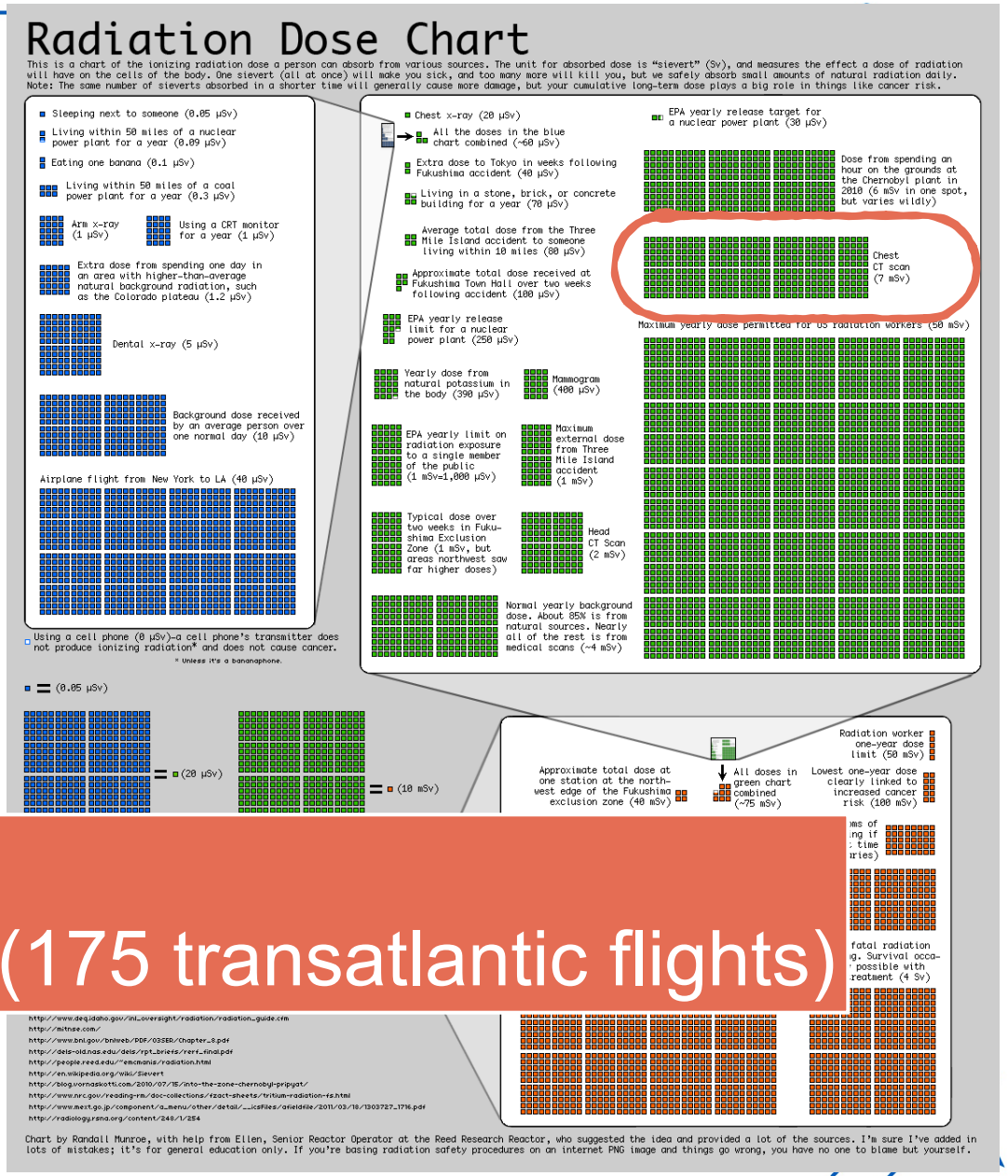

# 2-week dose in Fukushima exclusion zone: 10000 bananas (~25 transatlantic flights)



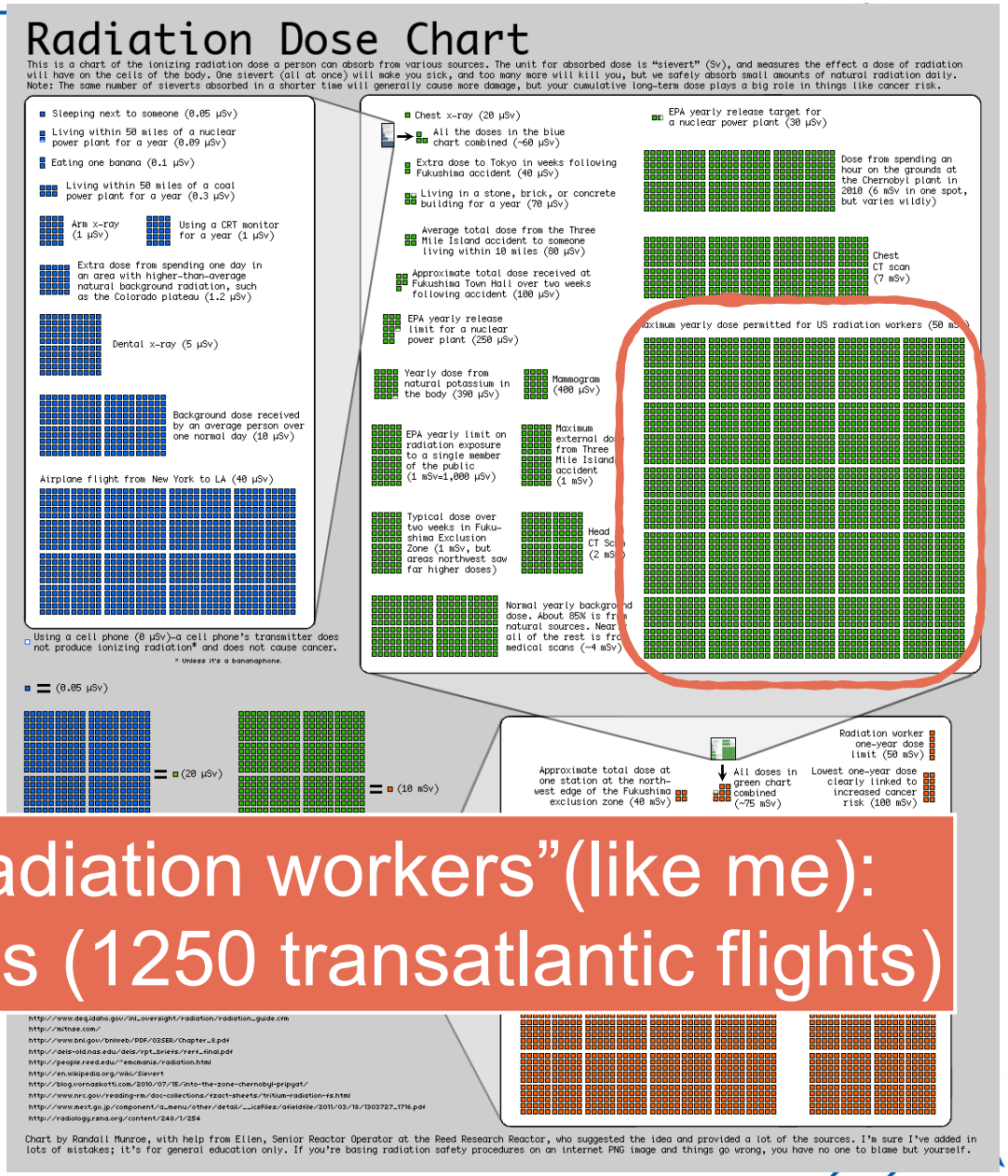

# Your typical yearly dose:
# 40000 bananas (~100 transatlantic flights)



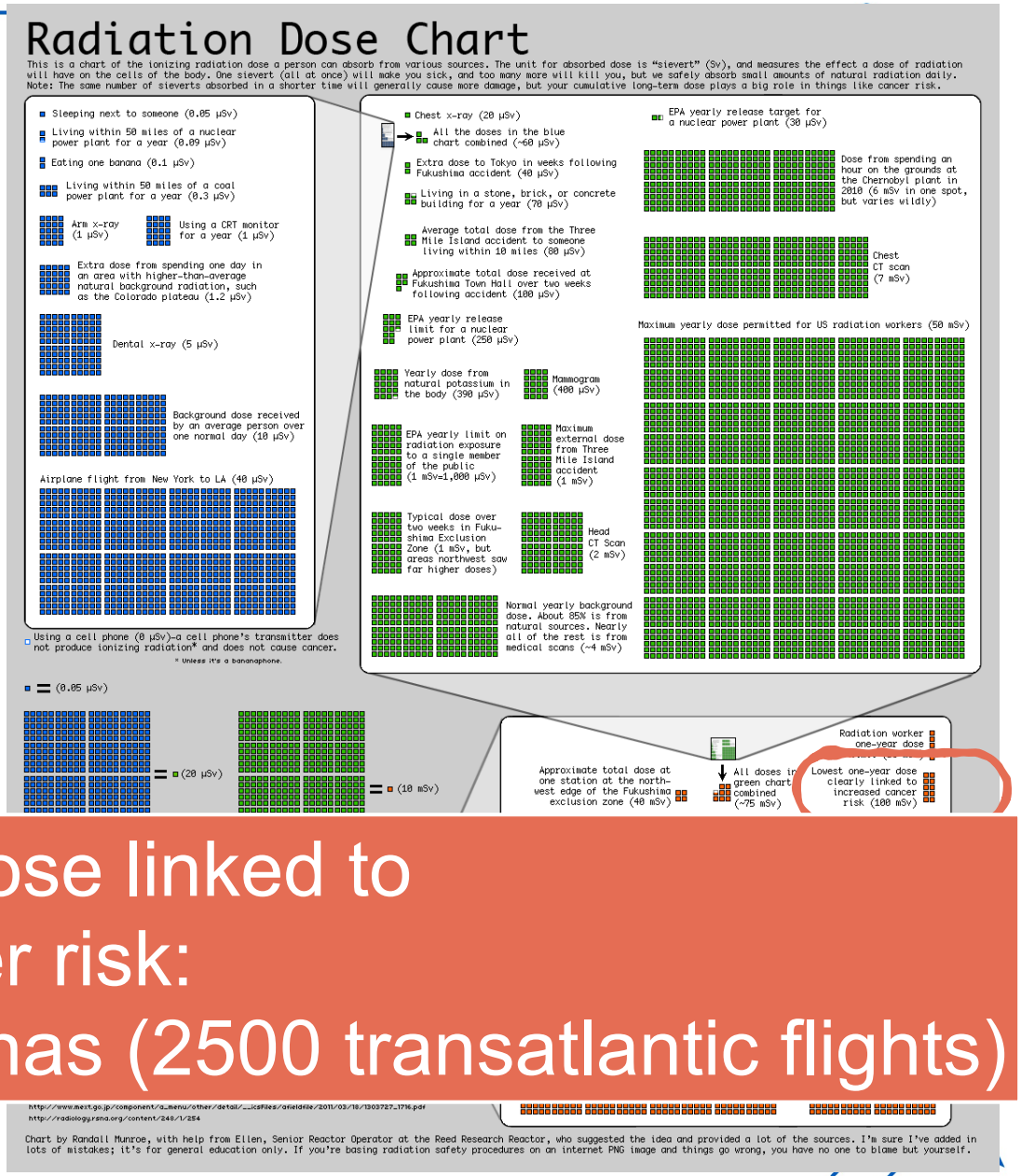

1 hour in Chernobyl grounds:
60000 bananas (~150 transatlantic flights)



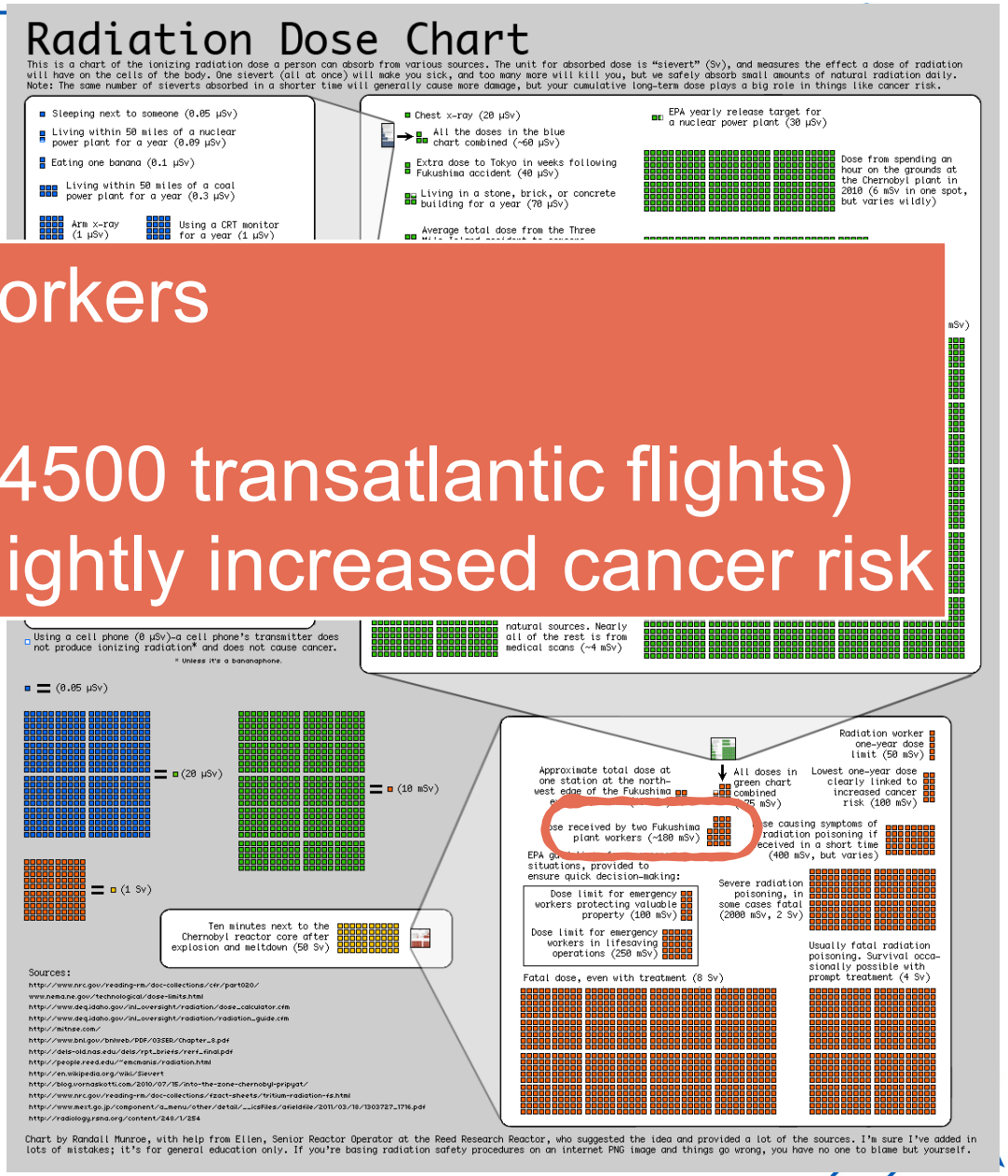

# Chest CT scan:
# 70000 bananas (175 transatlantic flights)



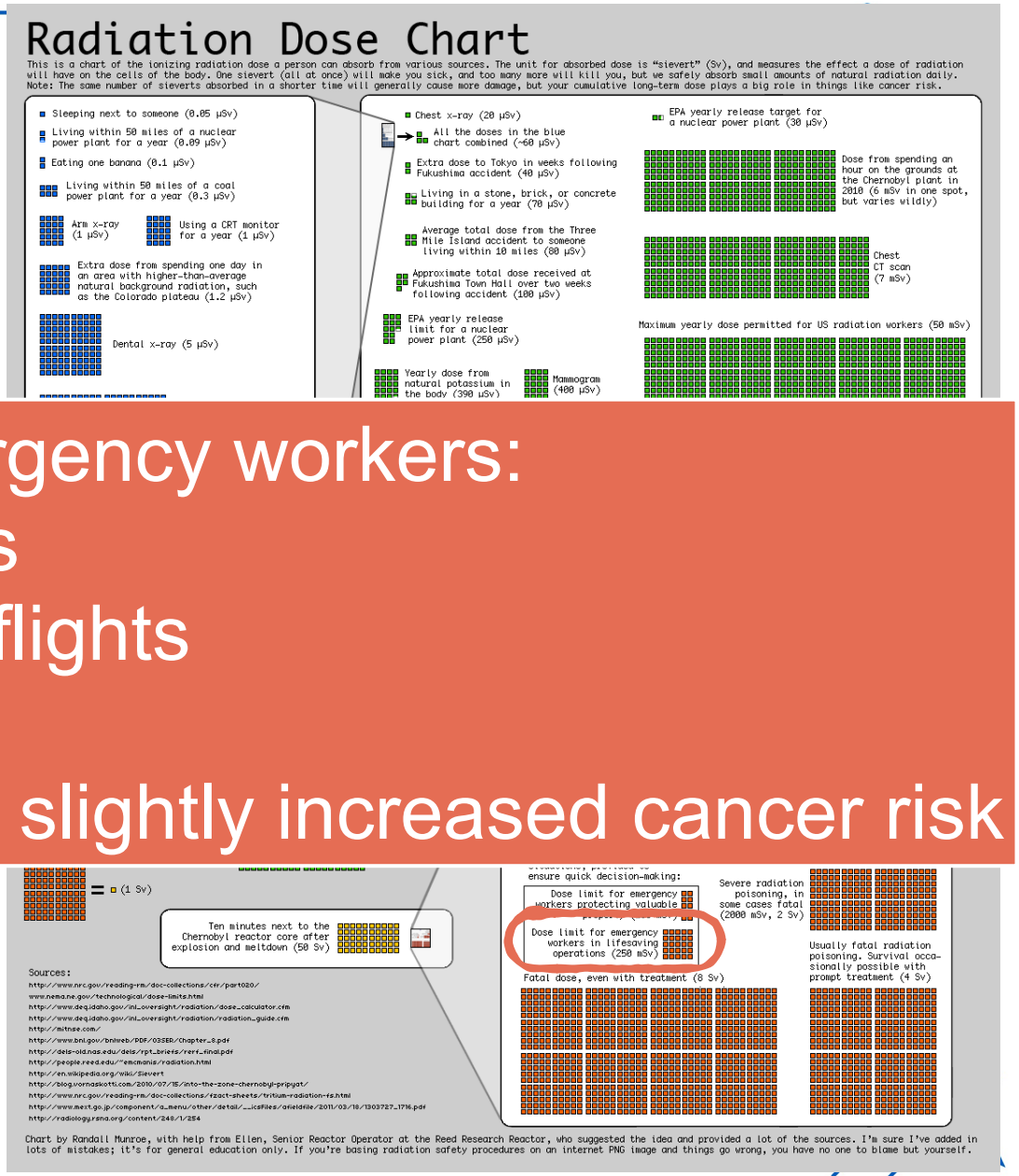

# Safe dose for "radiation workers"(like me): 500,000 bananas (1250 transatlantic flights)



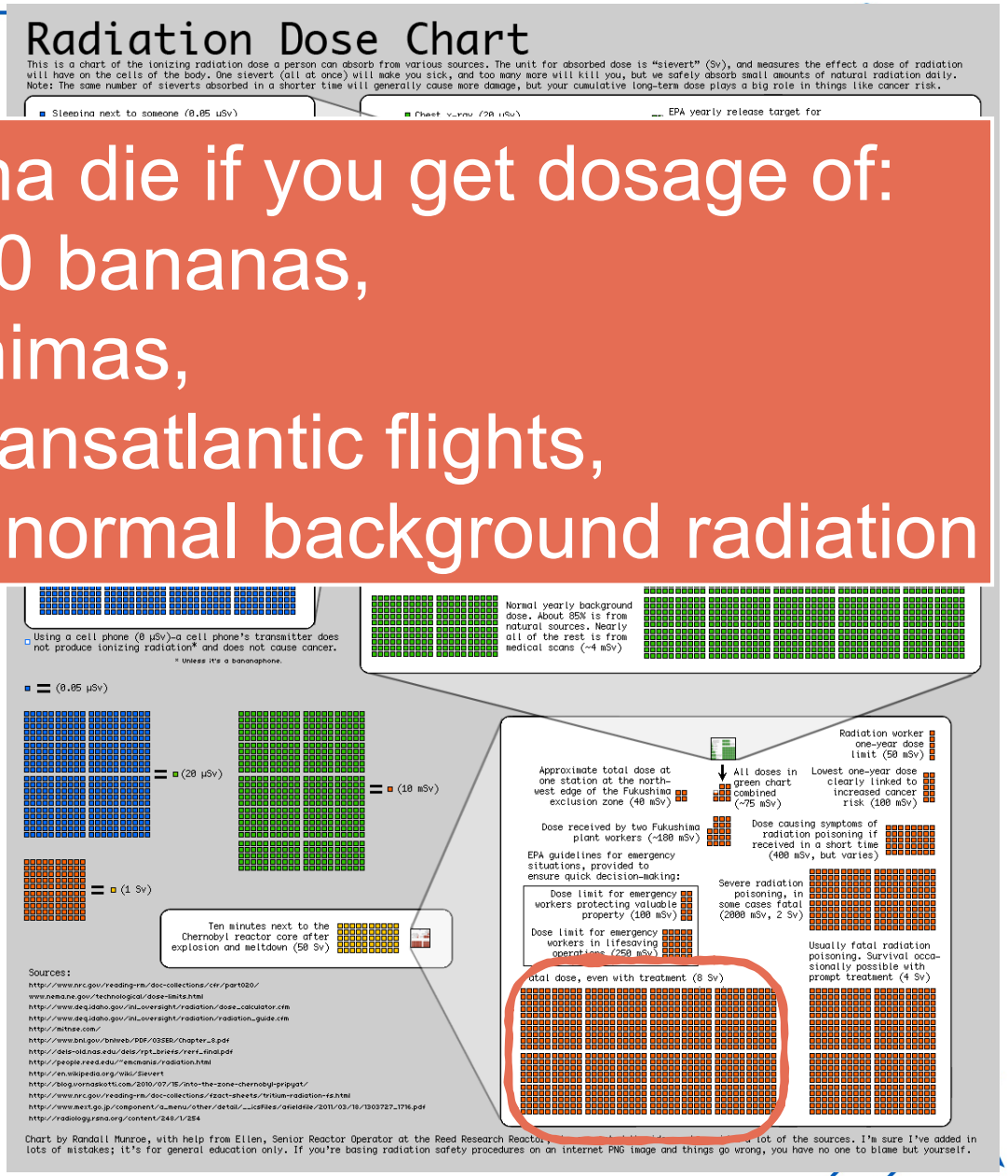

# Lowest yearly dose linked to increased cancer risk: 1,000,000 bananas (2500 transatlantic flights)




2 Fukushima plant workers
were exposed to
1,800,000 bananas (4500 transatlantic flights)
1.8 lowest level for slightly increased cancer risk




Dose limit for emergency workers:
2,500,000 bananas
6250 transatlantic flights
1.4 Fukushimas
2.5 lowest level for slightly increased cancer risk




You're gonna die if you get dosage of:

80,000,000 bananas,

32 Fukushimas,

200,000 transatlantic flights,

133 times normal background radiation

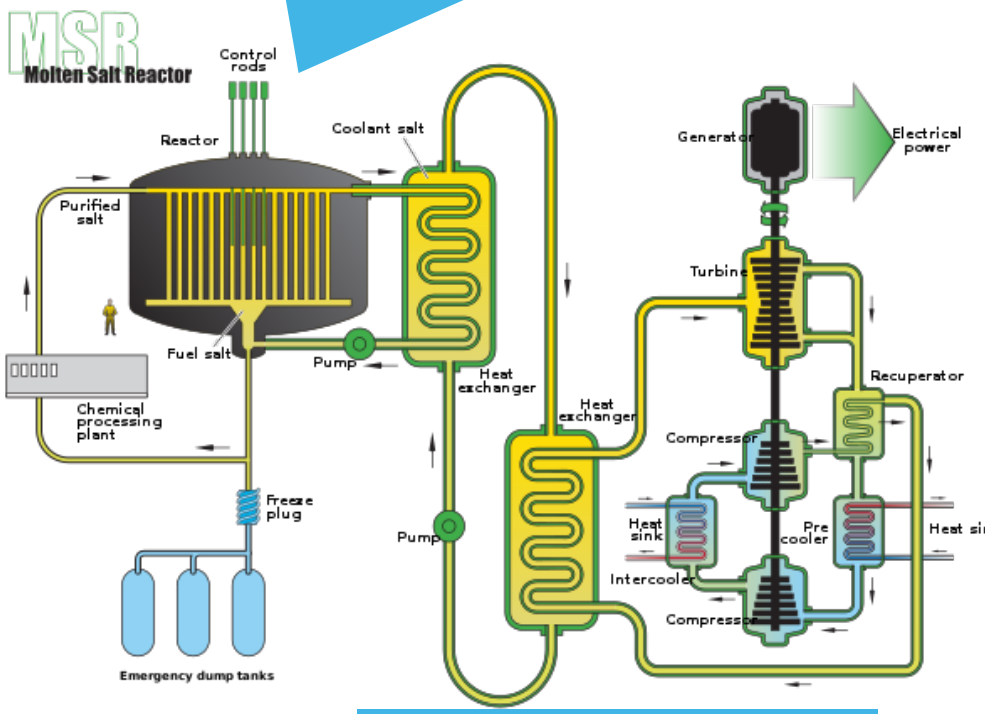
# What about waste or meltdown?

If something bad happens, reaction stops

- Nasty stuff, but frankly easy to contain:
  - Encase it in glass, and bury it.
  - We HAVE a perfect place to store it (Yucca Mountain) but we stopped in 2011 for political reasons and store it on sites now

OR (better) :

- Build Gen 4 nuclear plants to CONSUME existing nuclear waste




Can use thorium (closed cycle, consume previous waste)

https://en.wikipedia.org/wiki/Generation_IV_reactor

# So How Deadly Is your Kilowatt?

https://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/#5e5c94f9709b

1 trillion kWh powers planet for ~2.7 days

| Mortality Rate : deaths / trillion kWhr | | |
|---|---|---|
| Coal – global average | 100,000 | (41% global electricity) |
| Coal – U.S. | 10,000 | (32% U.S. electricity) |
| Natural Gas | 4,000 | (22% global electricity) |
| Solar (rooftop) | 440 | (< 1% global electricity) |
| Wind | 150 | (2% global electricity) |
| Hydro – global average | 1,400 | (16% global electricity) |
| Hydro – U.S. | 5 | (6% U.S. electricity) |

Air pollution

Falling off roofs

Catastrophic dam collapse

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Place your bets:

- Nuclear— global average:
- Nuclear — U.S.:

(Includes Chernobyl and Fukoshima)

(Includes nuclear waste)

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Place your bets:

| | | |
|---|---|---|
| Nuclear— global average: | 90 | (11% global electricity) |
| Nuclear — U.S.: | 0.1 | (19% U.S. electricity) |

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- Mortality Rate : deaths / trillion kWhr
- Coal – global average 100,000 (41% global electricity)
- Coal – U.S. 10,000 (32% U.S. electricity)

**Nuclear power is, by far, the safest form of electricity**

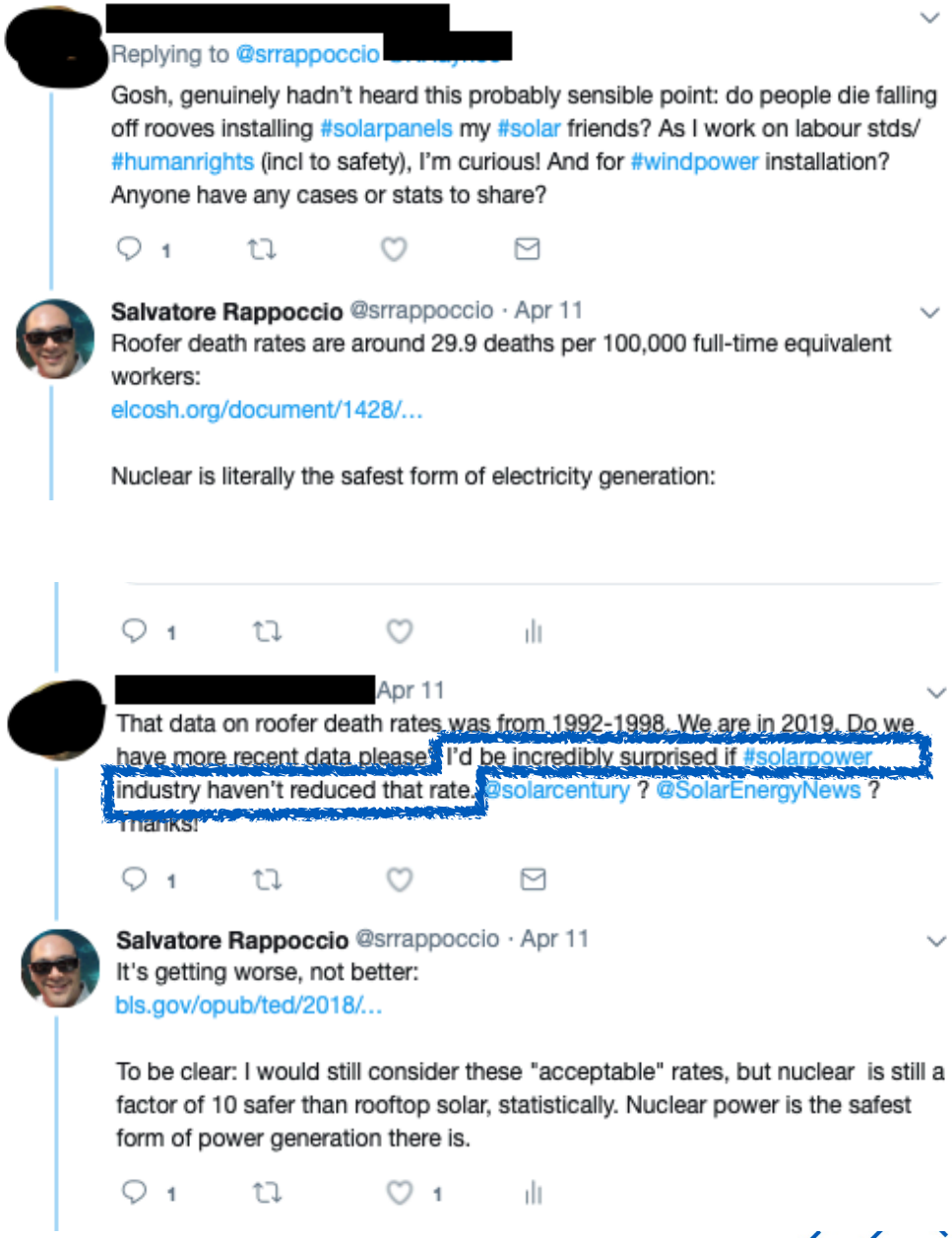
- Hydro – Global 1,400 (6% Global electricity)

Place your bets:

- Nuclear— global average: 90 (11% global electricity)
- Nuclear — U.S.: 0.1 (19% U.S. electricity)

# This blows people's minds. Even when faced with data they find it almost impossible to accept.

"I'd be incredibly surprised if #solarpower industry haven't reduced that rate."



University at Buffalo The State University of New York

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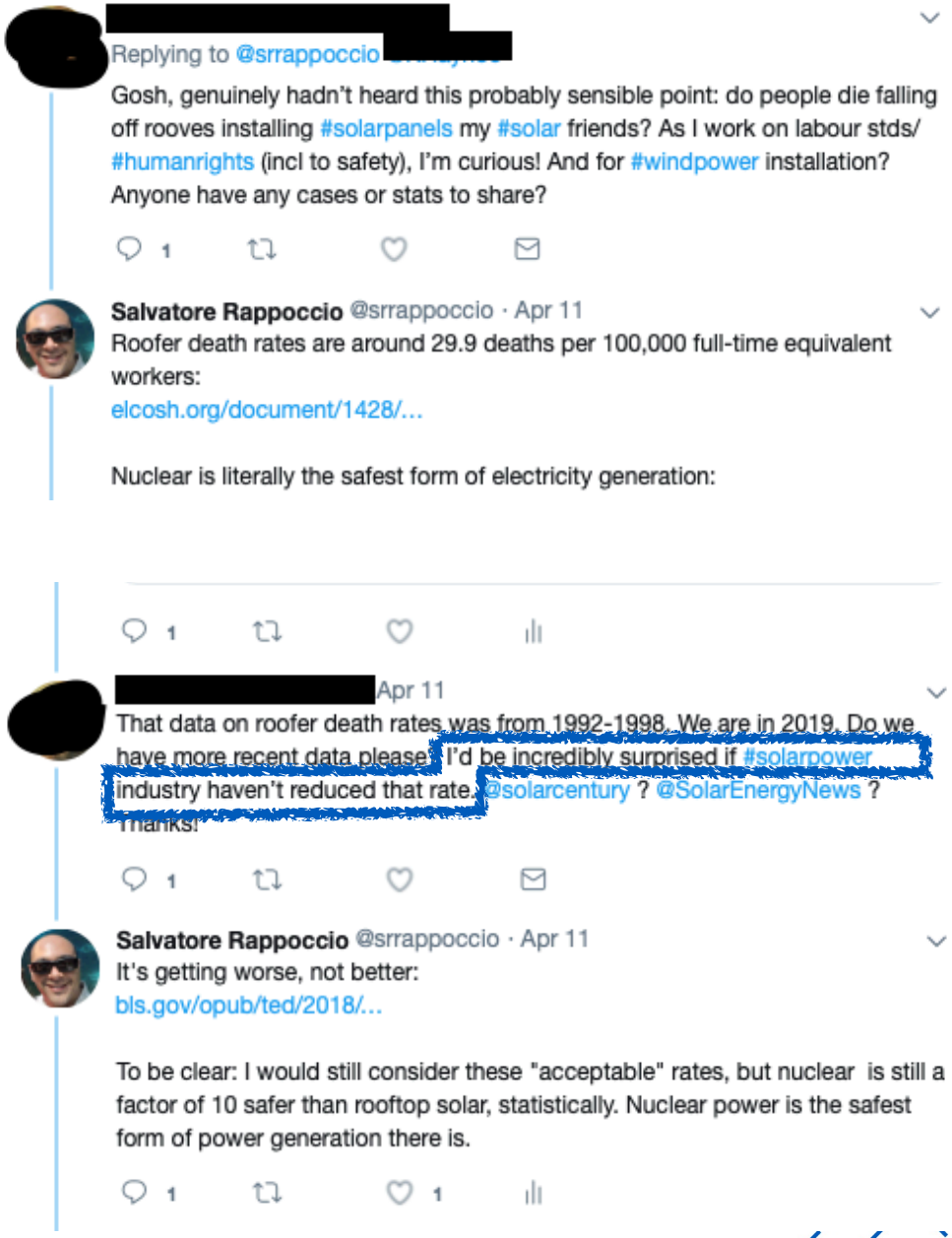
"I'd be incredibly surprised if #solarpower industry haven't reduced that rate."

This person is expecting technological advances in FALLING DOWN.



# So what about that fear mongering?

"the true story of one of the worst man-made catastrophes in history"

Chernobyl:

Immediate deaths from radiation: 49 people

Increased cancer risk: 6000 cases of thyroid cancer

Fukushima:

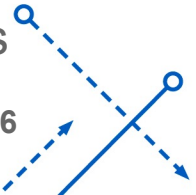
Immediate deaths from radiation: 1 person

Increased cancer risk: 2 people

Other human-driven catastrophes:

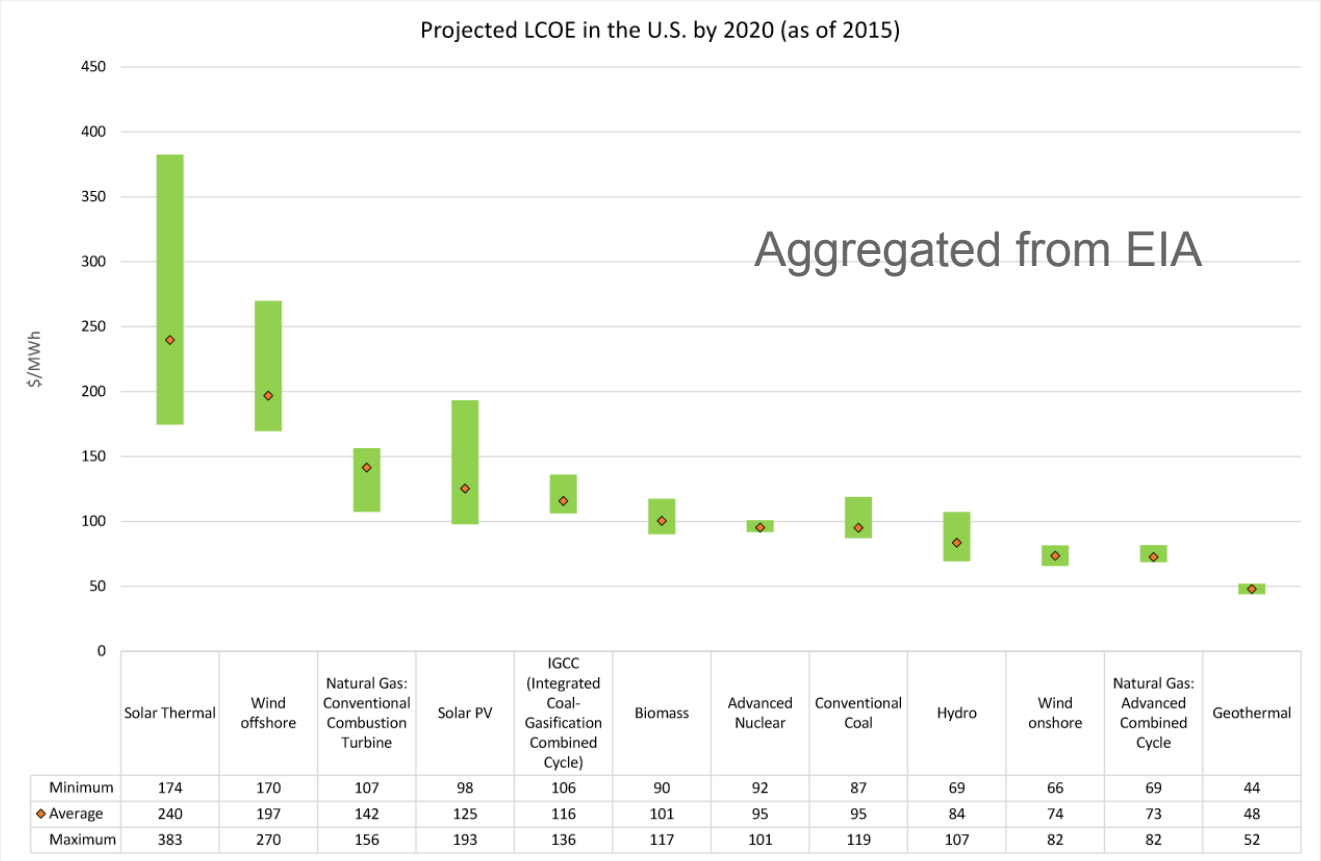
| | |
|---|---|
| Auto fatalities / year: | 1250000000 |
| Drunk driving fatalities / year: | 10,497 |
| Toddlers shooting people / year: | 13 |

https://en.wikipedia.org/wiki/Deaths_due_to_the_Chernobyl_disaster
https://en.wikipedia.org/wiki/Fukushima_Daiichi_nuclear_disaster_casualties
https://www.snopes.com/fact-check/toddlers-killed-americans-terrorists/



# Cost: How much will we pay?

- Levelized cost of energy (LCOE):




| | Solar Thermal | Wind offshore | Natural Gas: Conventional Combustion Turbine | Solar PV | IGCC (Integrated Coal-Gasification Combined Cycle) | Biomass | Advanced Nuclear | Conventional Coal | Hydro | Wind onshore | Natural Gas: Advanced Combined Cycle | Geothermal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 174 | 170 | 107 | 98 | 106 | 90 | 92 | 87 | 69 | 66 | 69 | 44 |
| ◆ Average | 240 | 197 | 142 | 125 | 116 | 101 | 95 | 95 | 84 | 74 | 73 | 48 |
| Maximum | 383 | 270 | 156 | 193 | 136 | 117 | 101 | 119 | 107 | 82 | 82 | 52 |

https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

https://en.wikipedia.org/wiki/Cost_of_electricity_by_source

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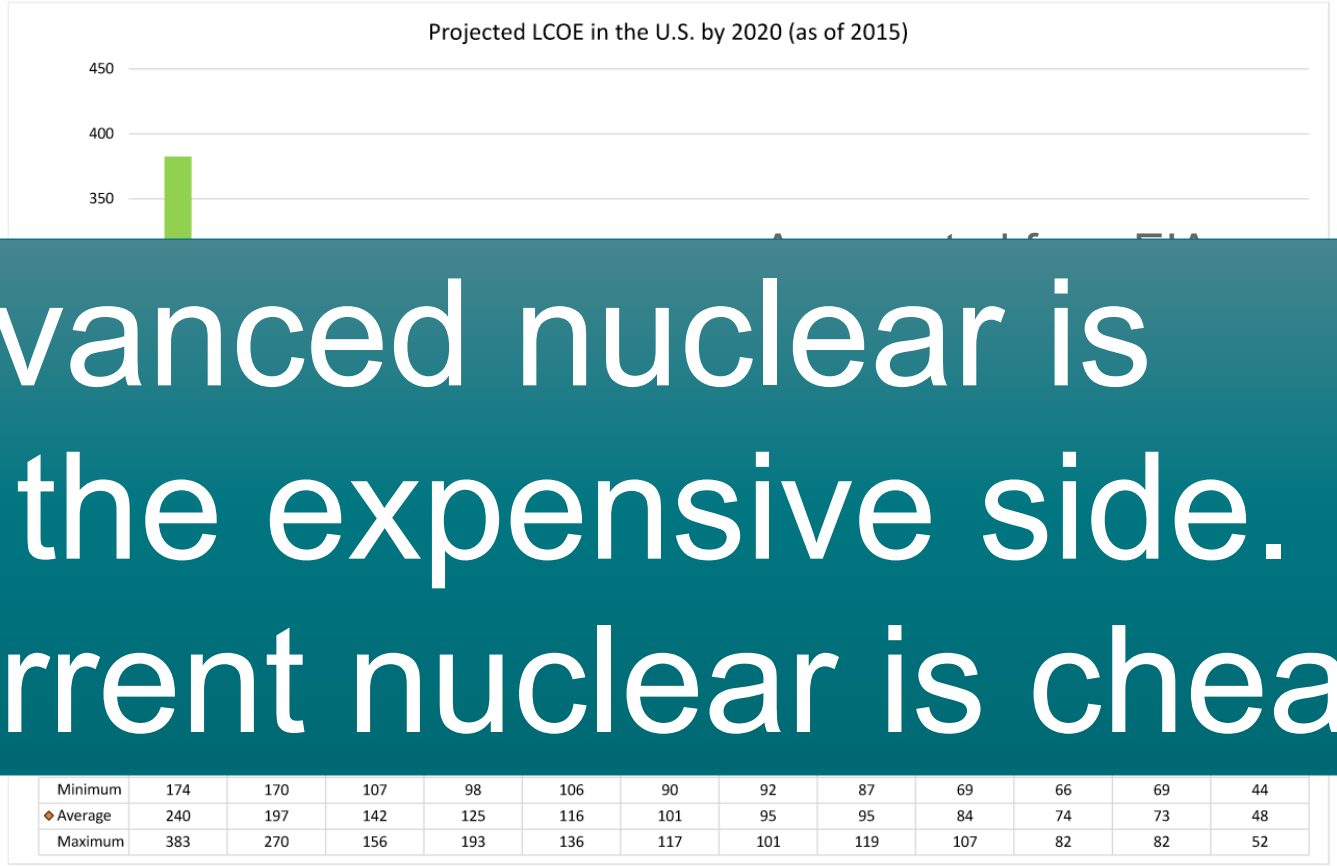



| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 174 | 170 | 107 | 98 | 106 | 90 | 92 | 87 | 69 | 66 | 69 | 44 |
| Average | 240 | 197 | 142 | 125 | 116 | 101 | 95 | 95 | 84 | 74 | 73 | 48 |
| Maximum | 383 | 270 | 156 | 193 | 136 | 117 | 101 | 119 | 107 | 82 | 82 | 52 |

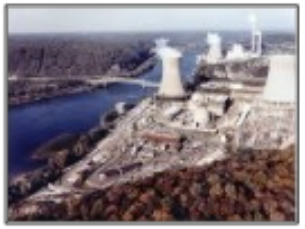
**Advanced nuclear is on the expensive side. Current nuclear is cheaper.**

https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf
https://en.wikipedia.org/wiki/Cost_of_electricity_by_source

# Advanced Nuclear : worth the cost

Generation I

Early Prototype Reactors



- Shippingport
- Dresden, Fermi I
- Magnox

Generation II

Commercial Power Reactors

- LWR–PWR, BWR
- CANDU
- VVER/RBMK

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- EPR

Near-Term Deployment

Generation III+ Evolutionary Designs Offering Improved Economics

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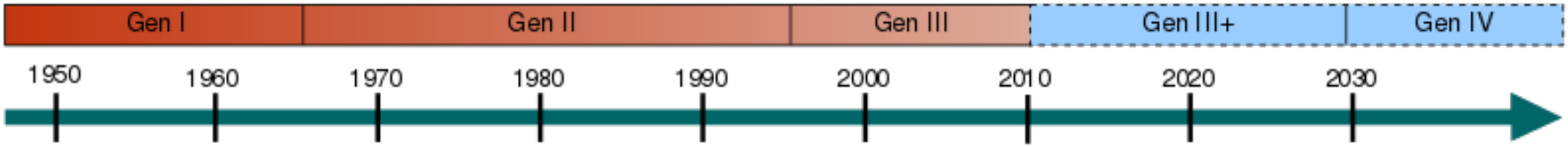
Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant




http://large.stanford.edu/courses/2016/ph241/xue2/docs/gif-002-00.pdf

http://large.stanford.edu/courses/2016/ph241/xue2/

https://en.wikipedia.org/wiki/Generation_IV_reactor

# Advanced Nuclear Options

- Gas-cooled fast reactor
- Lead-cooled fast reactor
- Molten salt reactor
- Sodium-cooled fast reactor
- Supercritical water-cooled reactor
- Very high-temperature gas reactor

**Generation IV reactor designs under development by GIF**

| | Neutron spectrum (fast/thermal) | Coolant | Temperature (°C) | Pressure* | Fuel | Fuel cycle | Size (MWe) | Use |
|---|---|---|---|---|---|---|---|---|
| Gas-cooled fast reactors | fast | helium | 850 | high | U-238 + | closed, on site | 1200 | electricity & hydrogen |
| Lead-cooled fast reactors | fast | lead or Pb-Bi | 480-570 | low | U-238 + | closed, regional | 20-180** 300-1200 600-1000 | electricity & hydrogen |
| Molten salt fast reactors | fast | fluoride salts | 700-800 | low | UF in salt | closed | 1000 | electricity & hydrogen |
| Molten salt reactor - **advanced high-temperature reactors** | thermal | fluoride salts | 750-1000 | | $UO_2$ particles in prism | open | 1000-1500 | hydrogen |
| Sodium-cooled fast reactors | fast | sodium | 500-550 | low | U-238 & MOX | closed | 50-150 600-1500 | electricity |
| Supercritical water-cooled reactors | thermal or fast | water | 510-625 | very high | $UO_2$ | open (thermal) closed (fast) | 300-700 1000-1500 | electricity |
| Very high temperature gas reactors | thermal | helium | 900-1000 | high | $UO_2$ prism or pebbles | open | 250-300 | hydrogen & electricity |

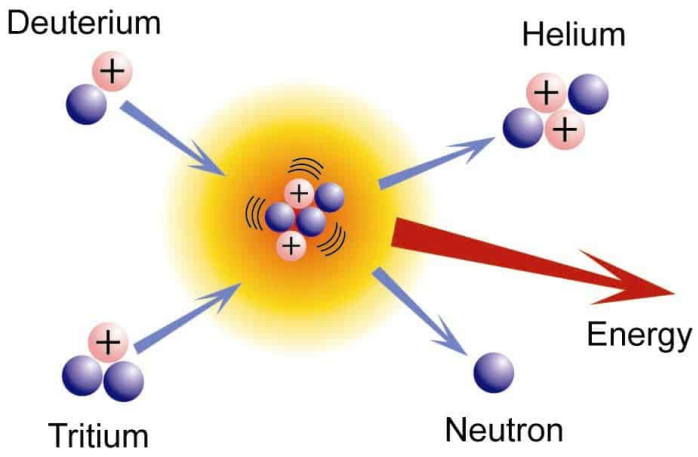
* high = 7-15 MPa

+ = with some U-235 or Pu-239

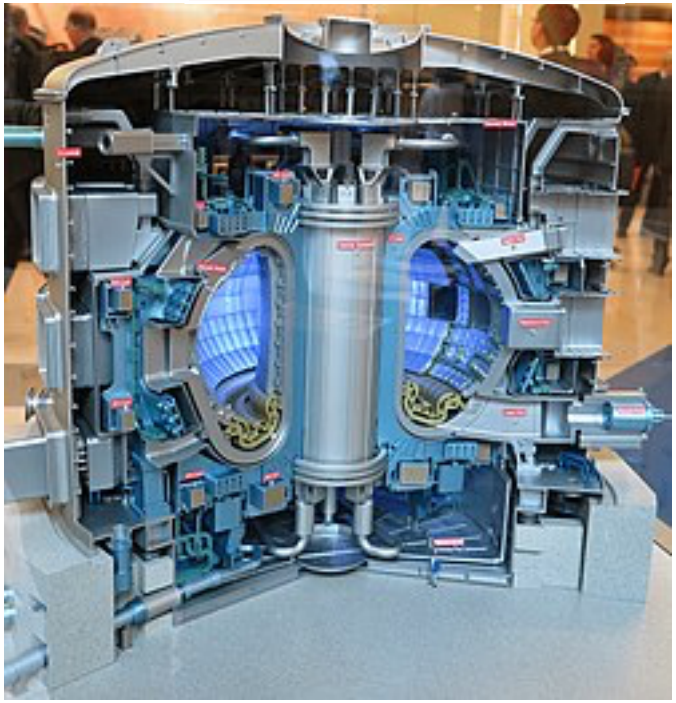
** 'battery' model with long cassette core life (15-20 yr) or replaceable reactor module.

http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-

# Nuclear fusion?




ITER Reactor:
Tokamak generator



https://www.nuclear-power.net/nuclear-power/nuclear-fusion/

https://en.wikipedia.org/wiki/ITER

# Nuclear fusion?


ITER Reactor:
Tokamak generator

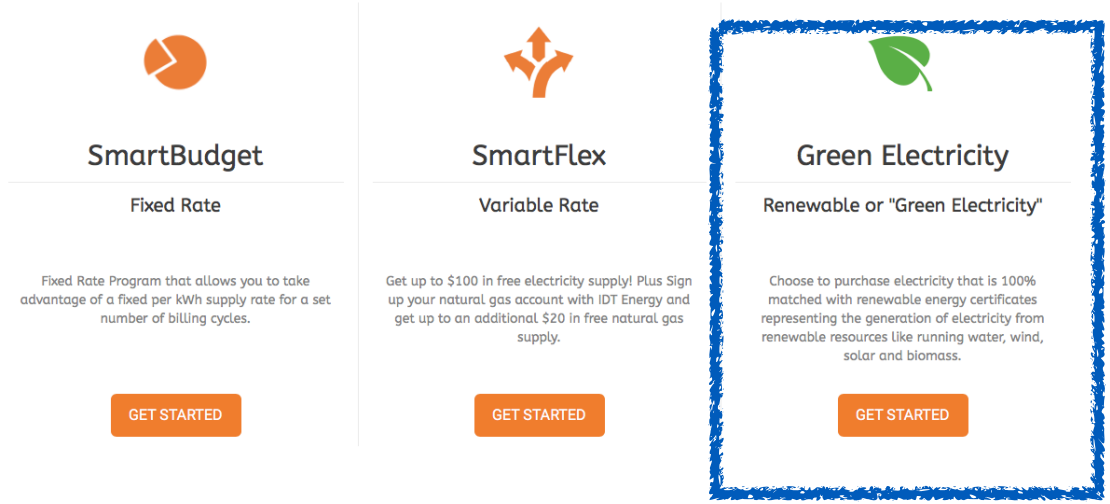
**Promising progress, but we can't rely on this in the immediate future.**

https://www.nuclear-power.net/nuclear-power/nuclear-fusion/

https://en.wikipedia.org/wiki/ITER

# Tonight: Go carbon free

- Many solutions to go 100% carbon free for your electric needs… today.
  - Example: https://idtenergy.com/what-we-do/green-energy/
    - https://idtenergy.com/what-we-do/your-choice/




For your phone:

About 12% higher cost than natural gas
Zero guilt about leaving your lights on a bit longer.


Can use the higher capacity factors of nuclear power and geothermal to supplement wind, solar, and hydro

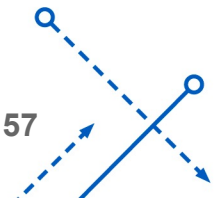
# Summary:

- We need to stop thermodynamic whoopee… NOW… or many/all of us are gonna die
- Nuclear power is safe and effective
  - 100% necessary to achieve climate change goals
- Options:
  - Wind?
  - Solar?
  - Nuclear?
  - Geothermal?
  - All of the above?

Go carbon free tonight, please!

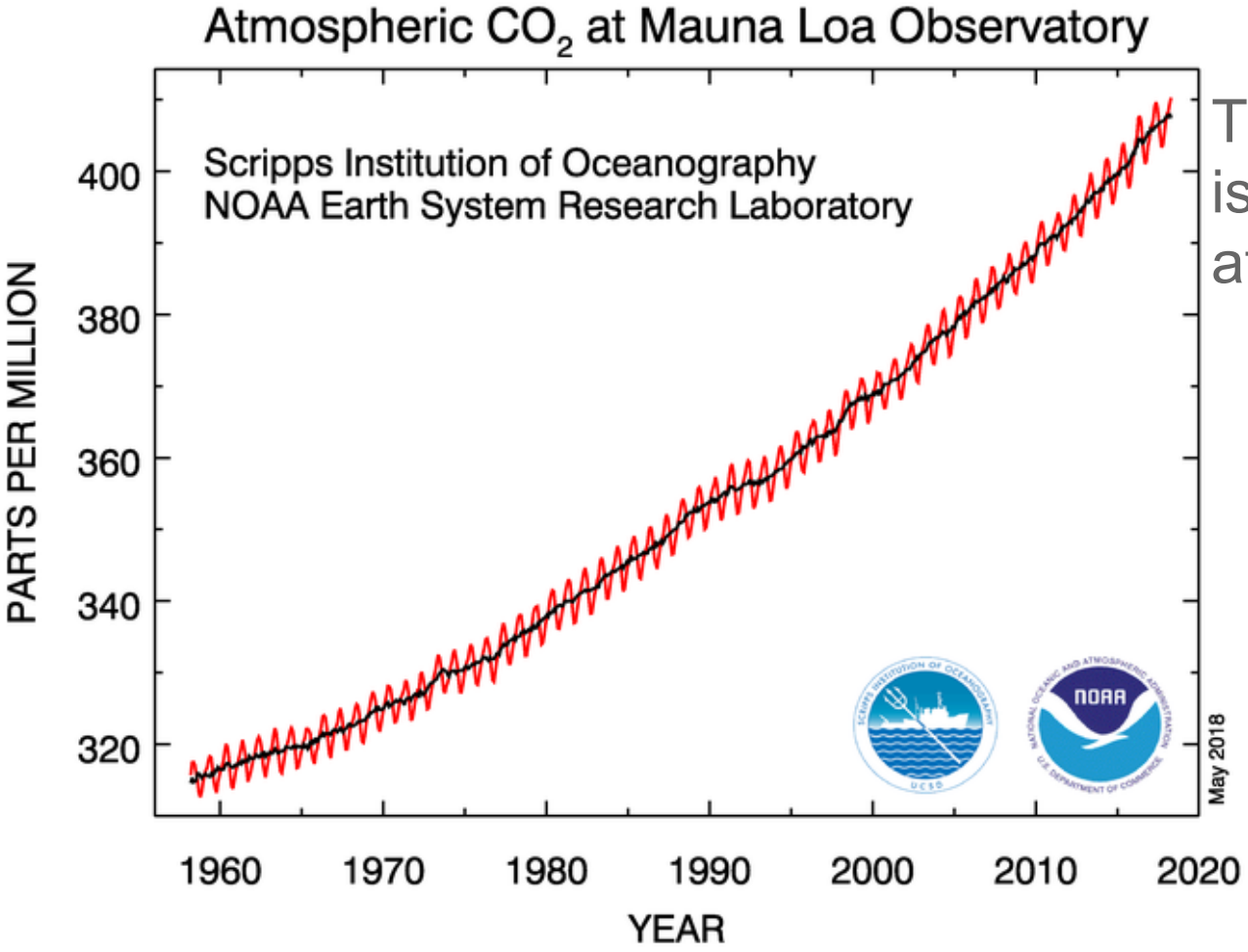
We need a complete solution to climate change. That includes renewables, storage improvements, and nuclear power.

# Backups



# Why we are all going to die* if we keep making thermodynamic whoopee

https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html

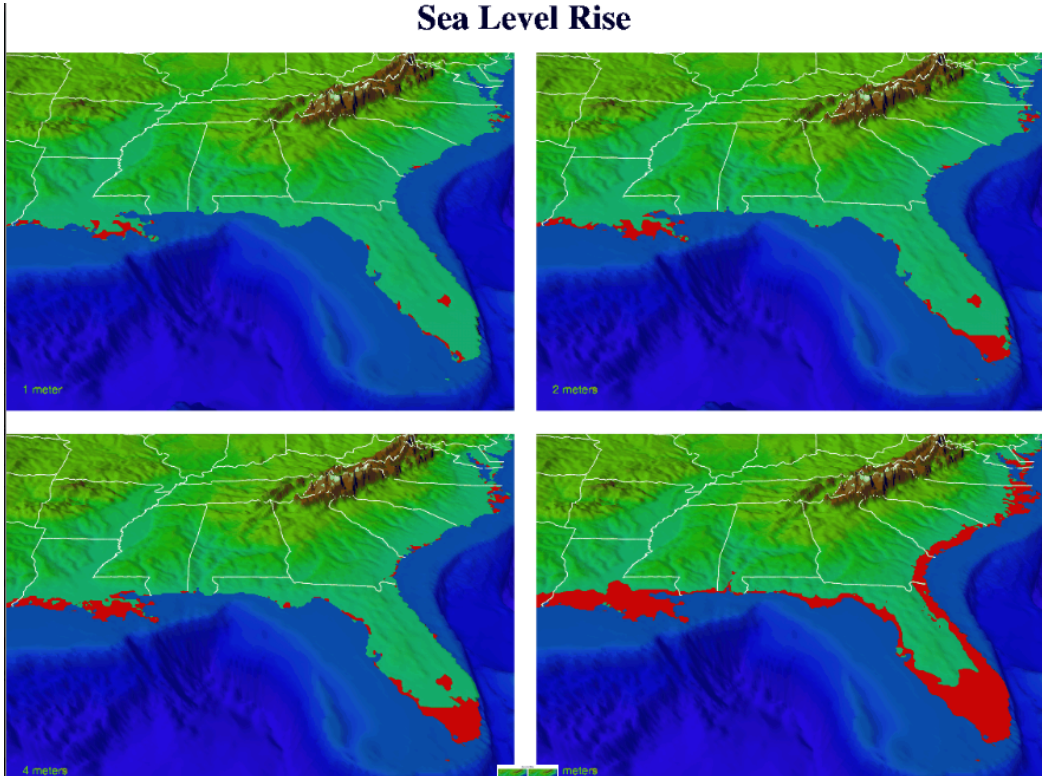



The CO2 concentration is toxic to human life at 50,000 ppm

Extend this plot:
All life stops around year 3700 CE

*This won't really happen, we won't have enough carbon to burn… I think.

# Why many are going to die* MUCH FASTER if we keep making thermodynamic whoopee




https://web.whoi.edu/coastal-group/primers/sea-level-rise/#

"Limiting global warming to 1.5°C would require rapid, far-reaching and unprecedented changes in all aspects of society."

— Intergovernmental Panel on Climate Change

http://www.ipcc.ch/news_and_events/pr_181008_P48_spm.shtml

* : Caveat: We're not ALL gonna die in 2030. We'll just be severely INCONVENIENCED and just a LOT of people will die.