

Neutrinos and Nuclear Non-Proliferation

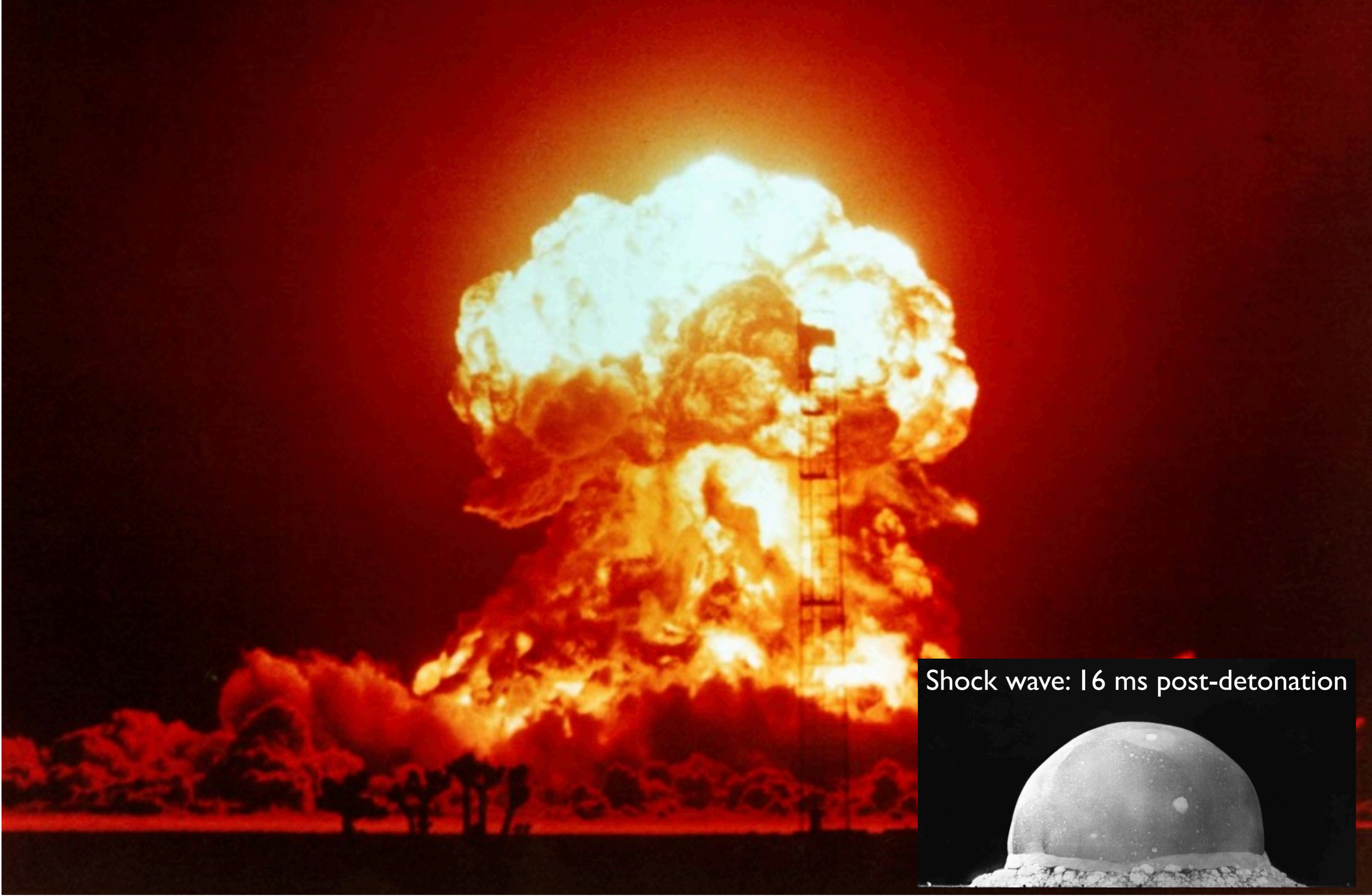
August 12, 2019

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Trinity: Alamagordo, NM, USA, 1945

22kT TNT, ^{239}Pu implosion device



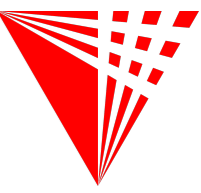
Shock wave: 16 ms post-detonation



Trinity: Alamagordo, New Mexico, USA

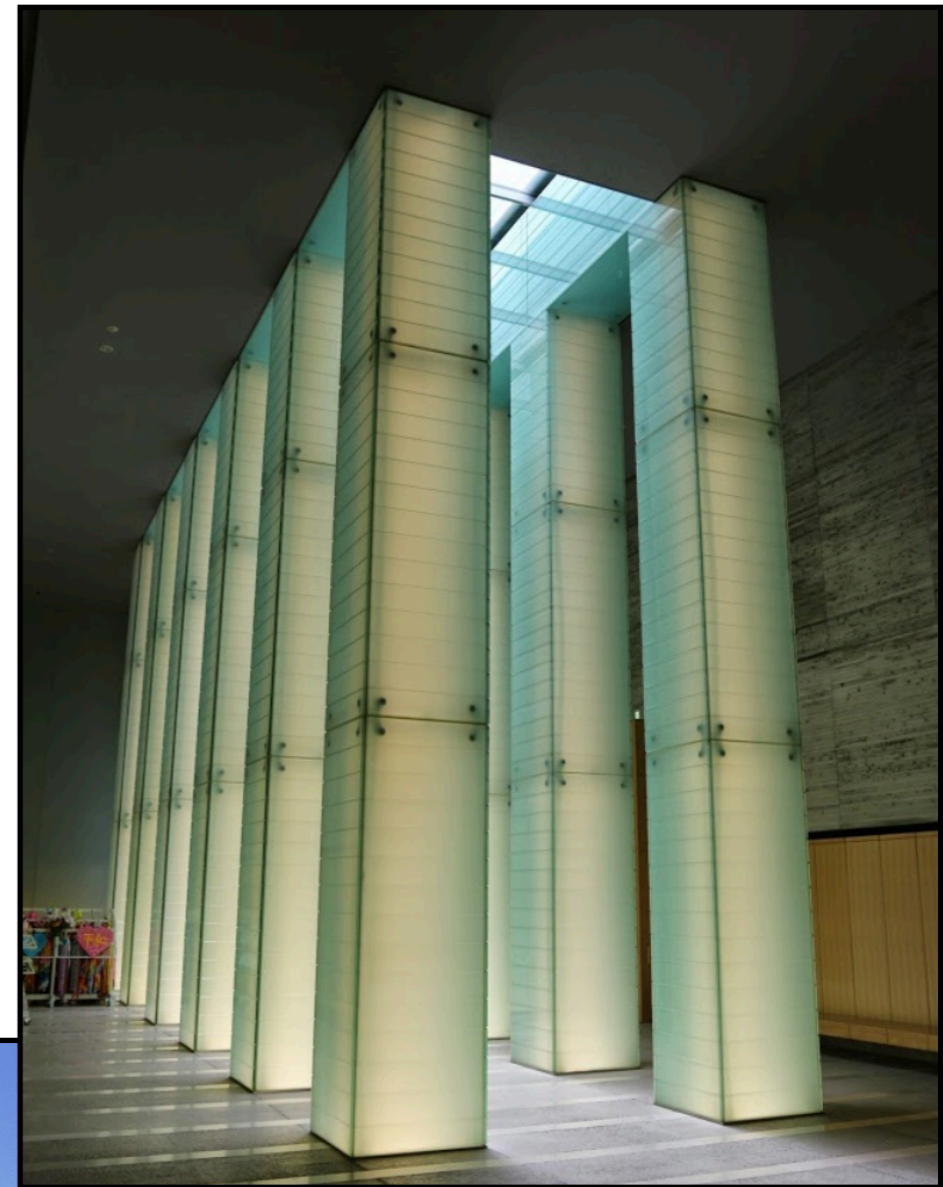


Hiroshima and Nagasaki, Japan, 1945



- Over 100,000 men, women and children lost their lives in the first nuclear attack at Hiroshima
- Over 50,000 lost in the subsequent Nagasaki attack

Remembrance Hall, Nagasaki

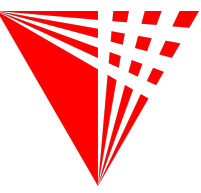


Genbaku (A-Bomb) Dome, Hiroshima Peace Memorial Park



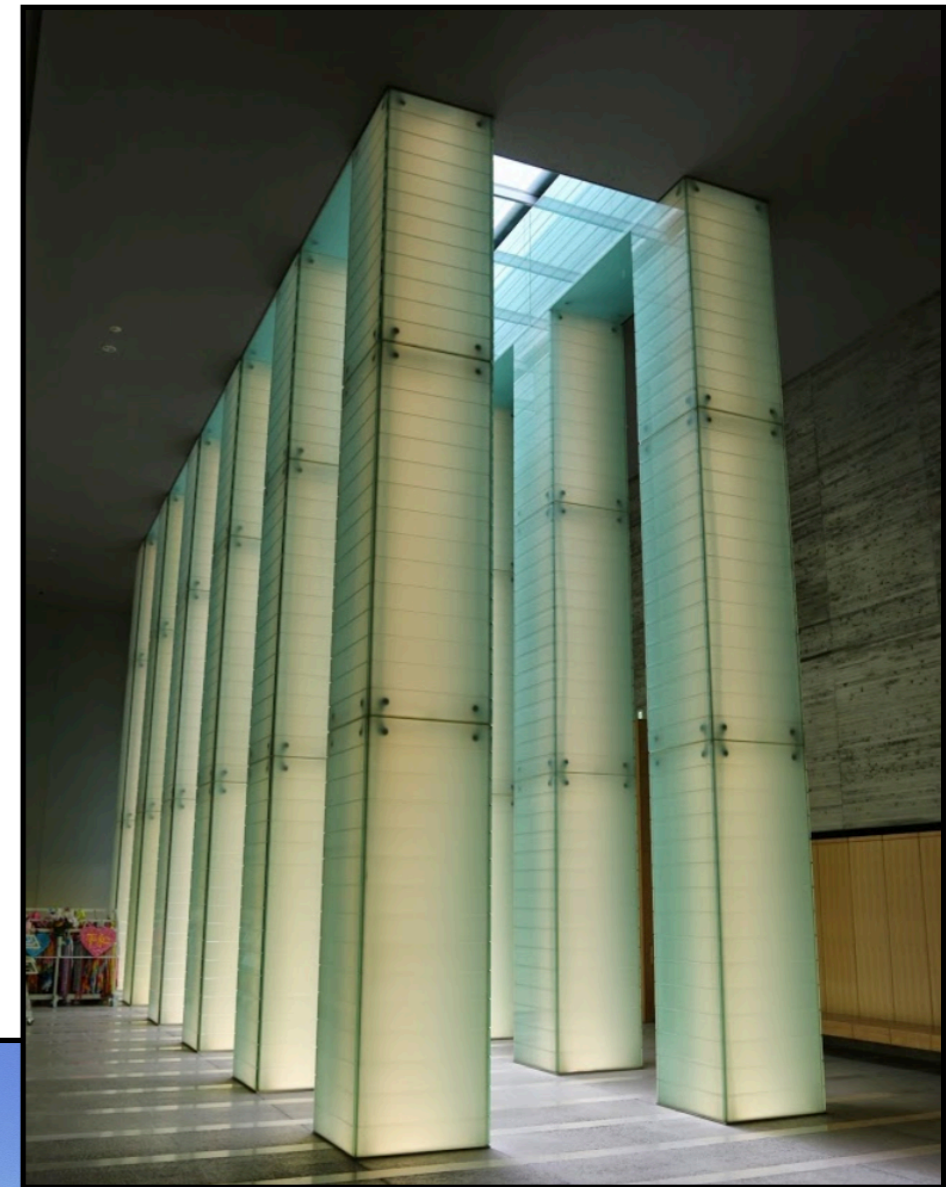
Hiroshima Peace Memorial Park

Hiroshima and Nagasaki, Japan, 1945



- Over 100,000 men, women and children lost their lives in the first nuclear attack at Hiroshima
 - ^{235}U gun design: 15kT
- Over 50,000 lost in the subsequent Nagasaki attack
 - ^{239}Pu implosion device similar to Trinity: 20kT

Remembrance Hall, Nagasaki

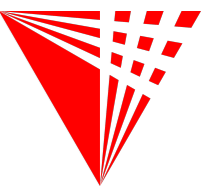


Genbaku (A-Bomb) Dome, Hiroshima Peace Memorial Park

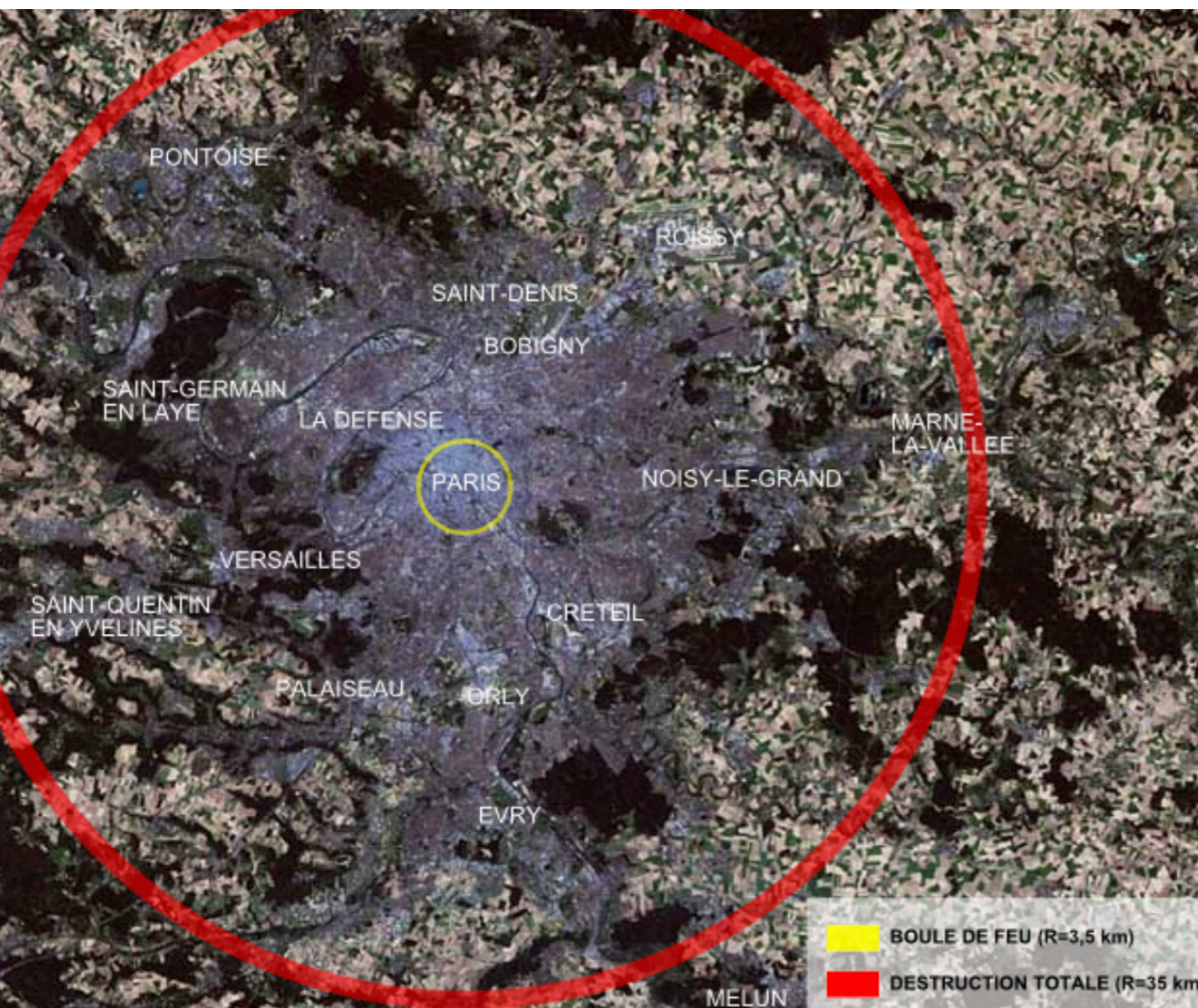


Hiroshima Peace Memorial Park

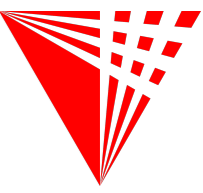
Tsar Bomba: Severny Island, Russia, 1961



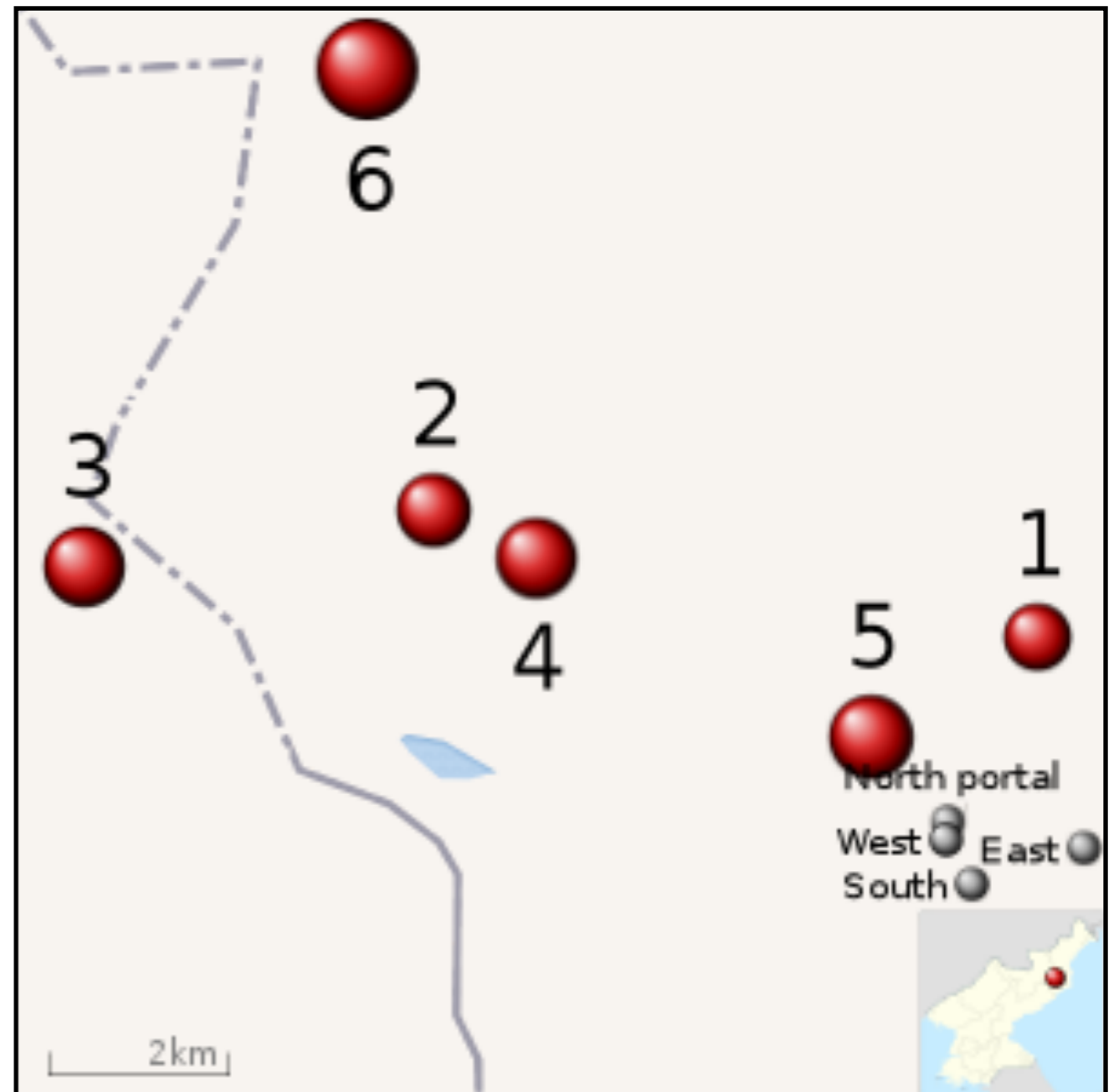
- 50 MT multi-stage thermonuclear (fusion) device
- 10x more energetic than all explosives used in World War II
 - 1500x more powerful than Hiroshima/Nagasaki a-bombs
- Total destruction radius (red) compared to Paris (yellow)



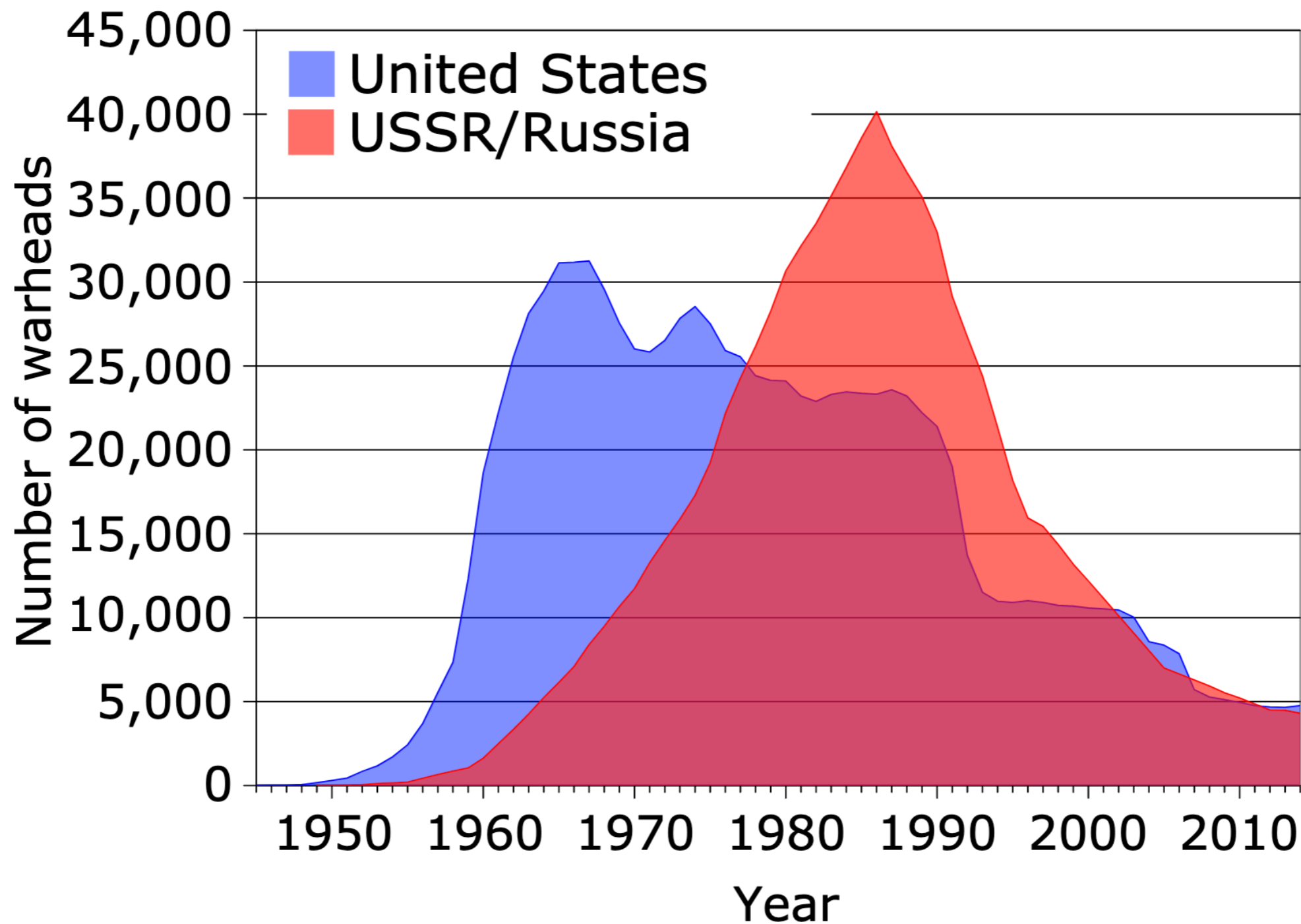
Punggye-ri, North Korea, 2017



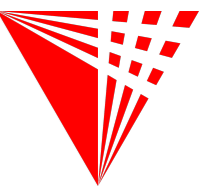
- Underground explosion estimated at 70-280 kT
 - At least $>4x$ more powerful than Hiroshima device
 - Thought to be a fusion-boosted fission device
- Most recent of 6 North Korean device tests
 - Some successfully tested devices are rocket-mountable



Nuclear Stockpiles



- We know that a single nuclear weapon is capable of causing a humanitarian catastrophe



The Point of All That

- Nuclear non-proliferation is more than an academic exercise
- Lives have been lost or changed forever from use of nuclear weapons; lives currently are at risk.
- Fundamental science permits functional nuclear weapons
- Can science also help to control/monitor them?

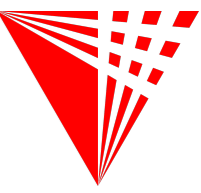


Hibakusha: Hiroshima and Nagasaki survivors

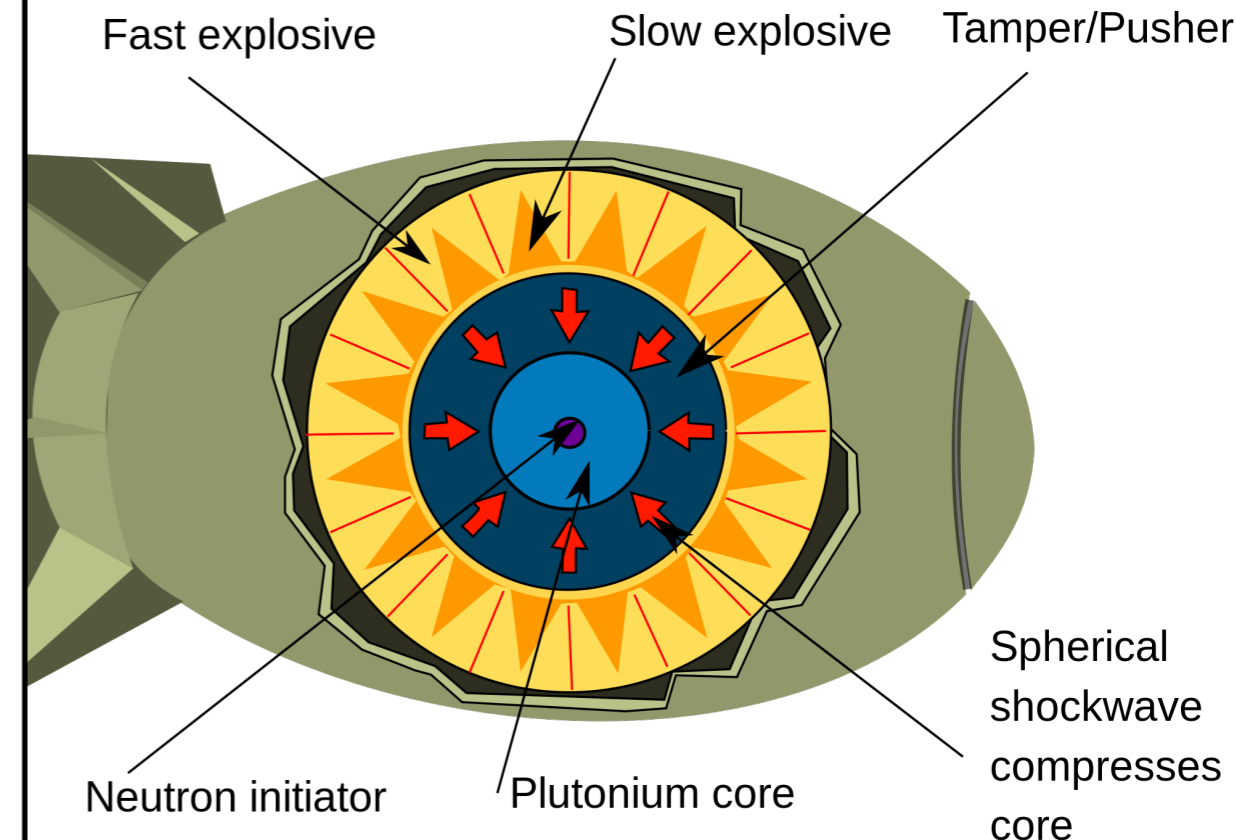
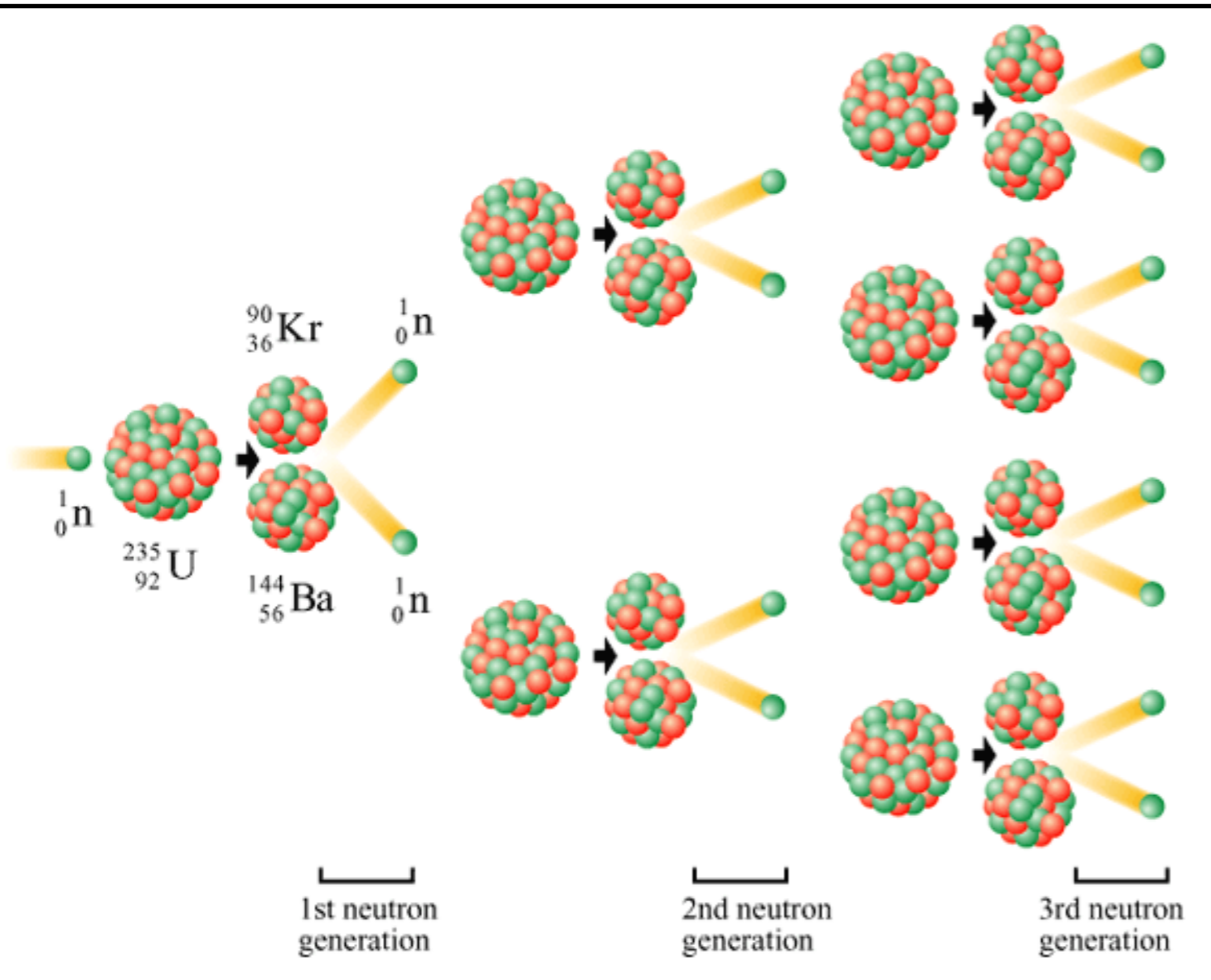


Peace Bell, Hiroshima Peace Park

Nuclear Explosion Concepts



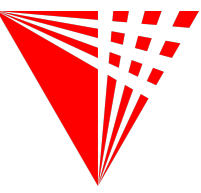
- Neutron-induced fission chain reactions



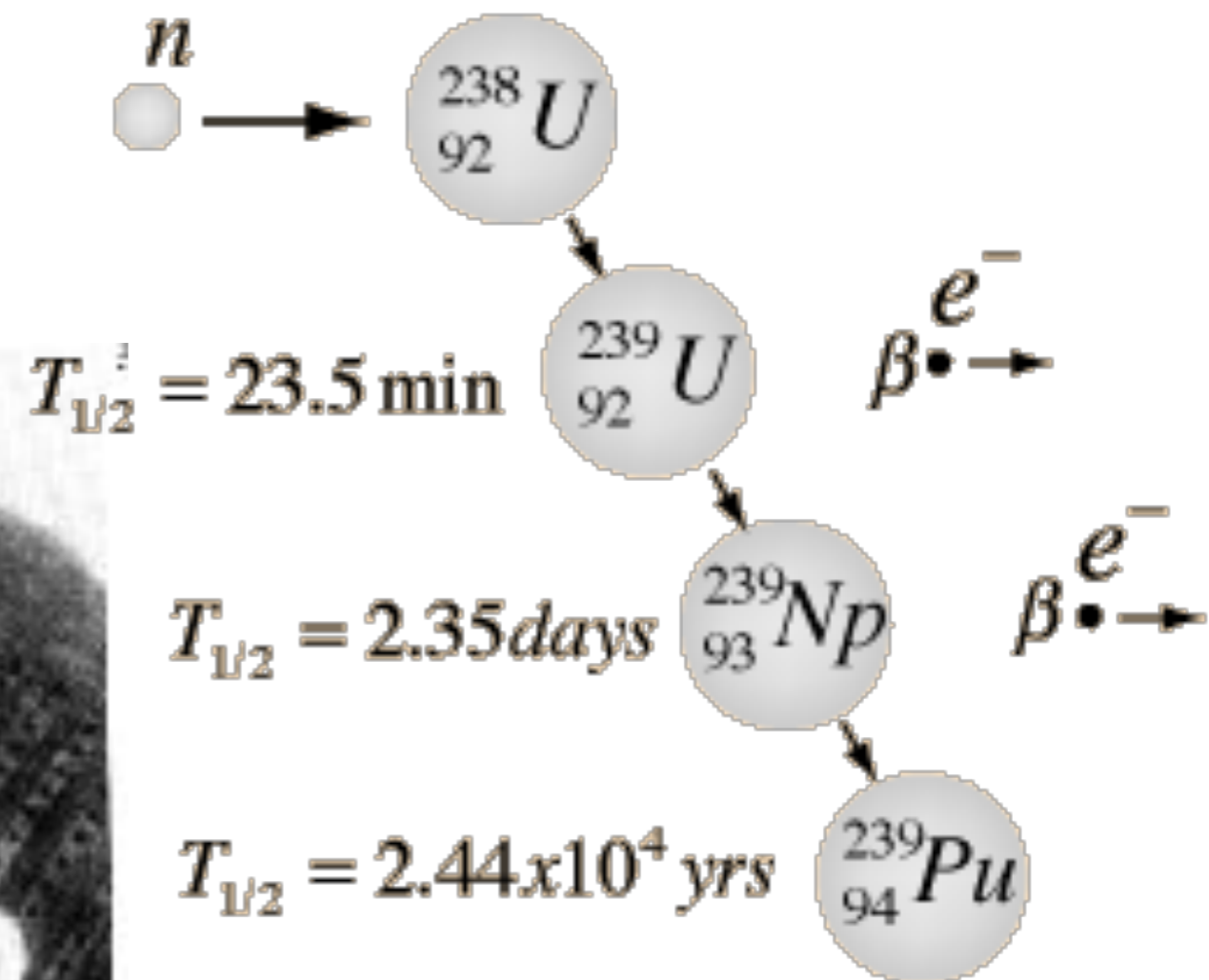
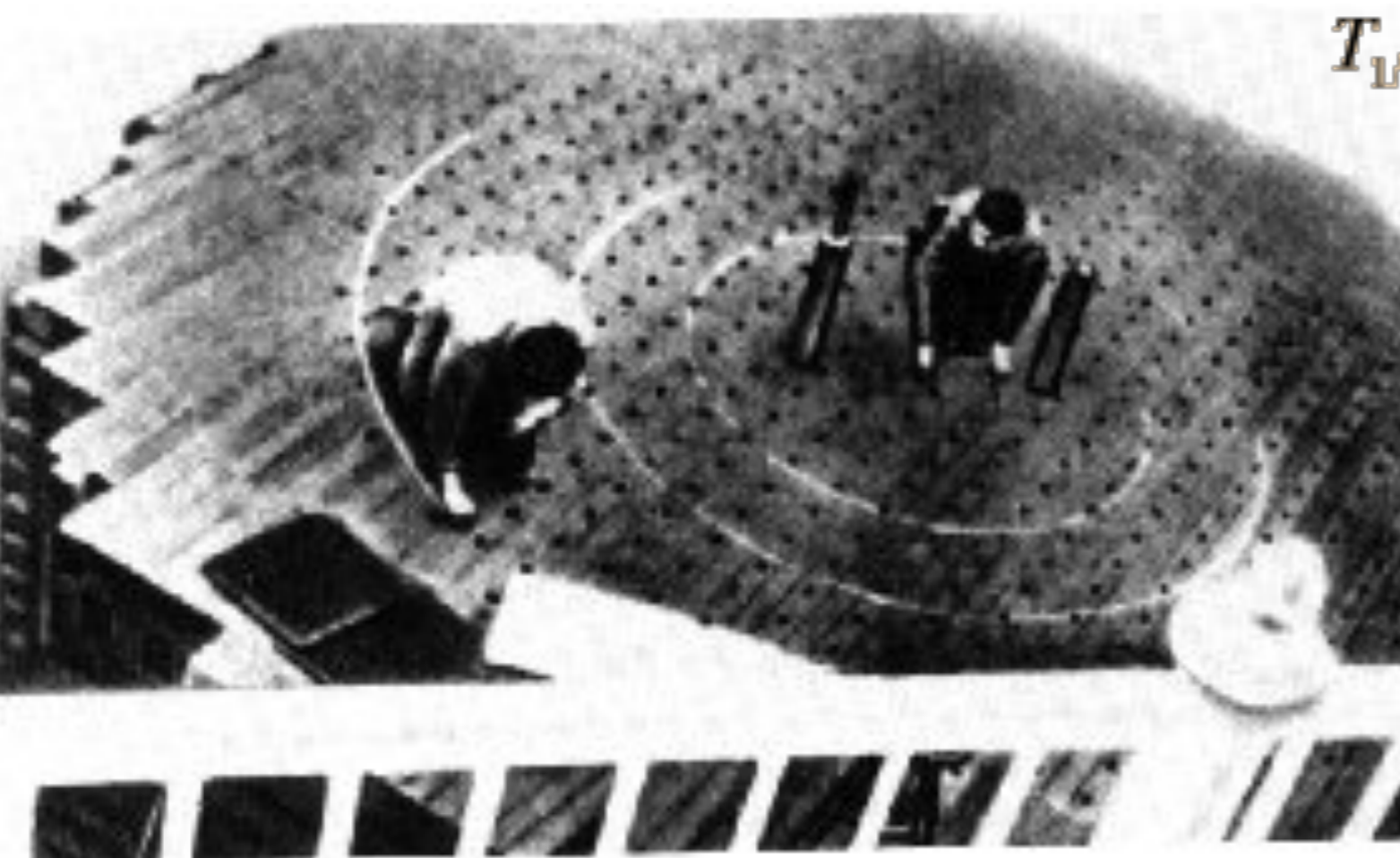
- Absolutely essential ingredients: ^{235}U or ^{239}Pu

- Nearby neutron likely to cause fission and release >1 neutron as a product
- These isotopes aren't found in enriched form in nature

Nuclear Control



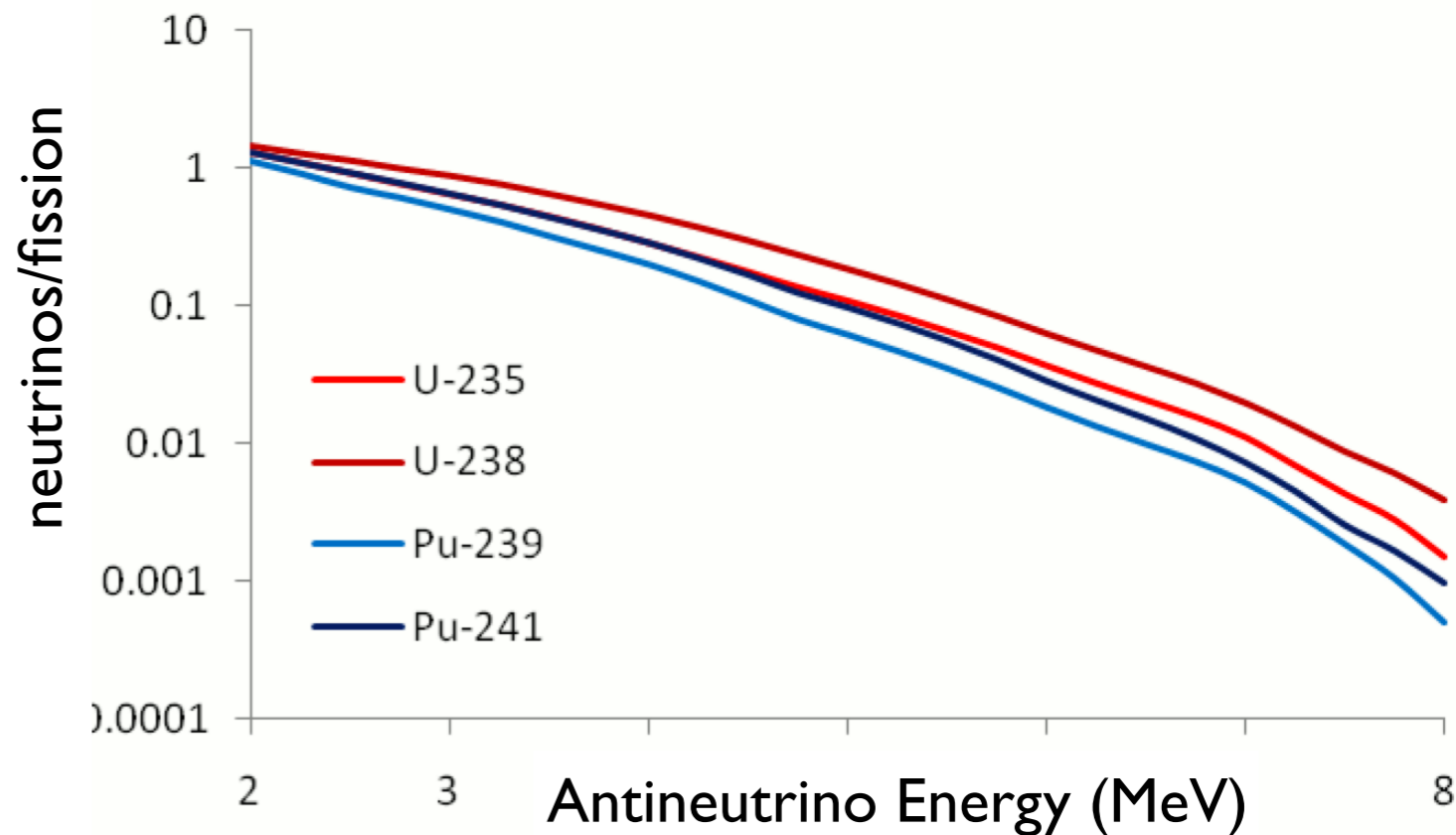
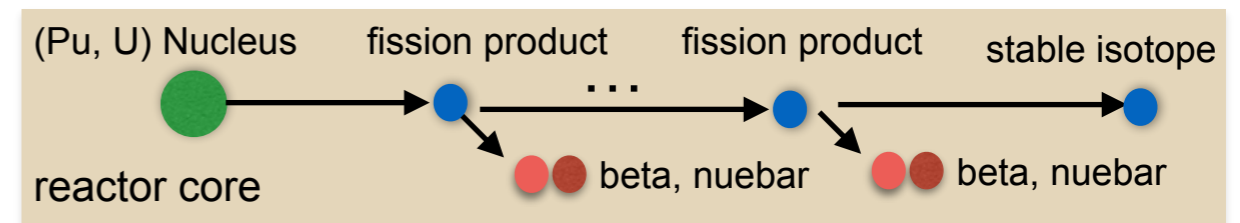
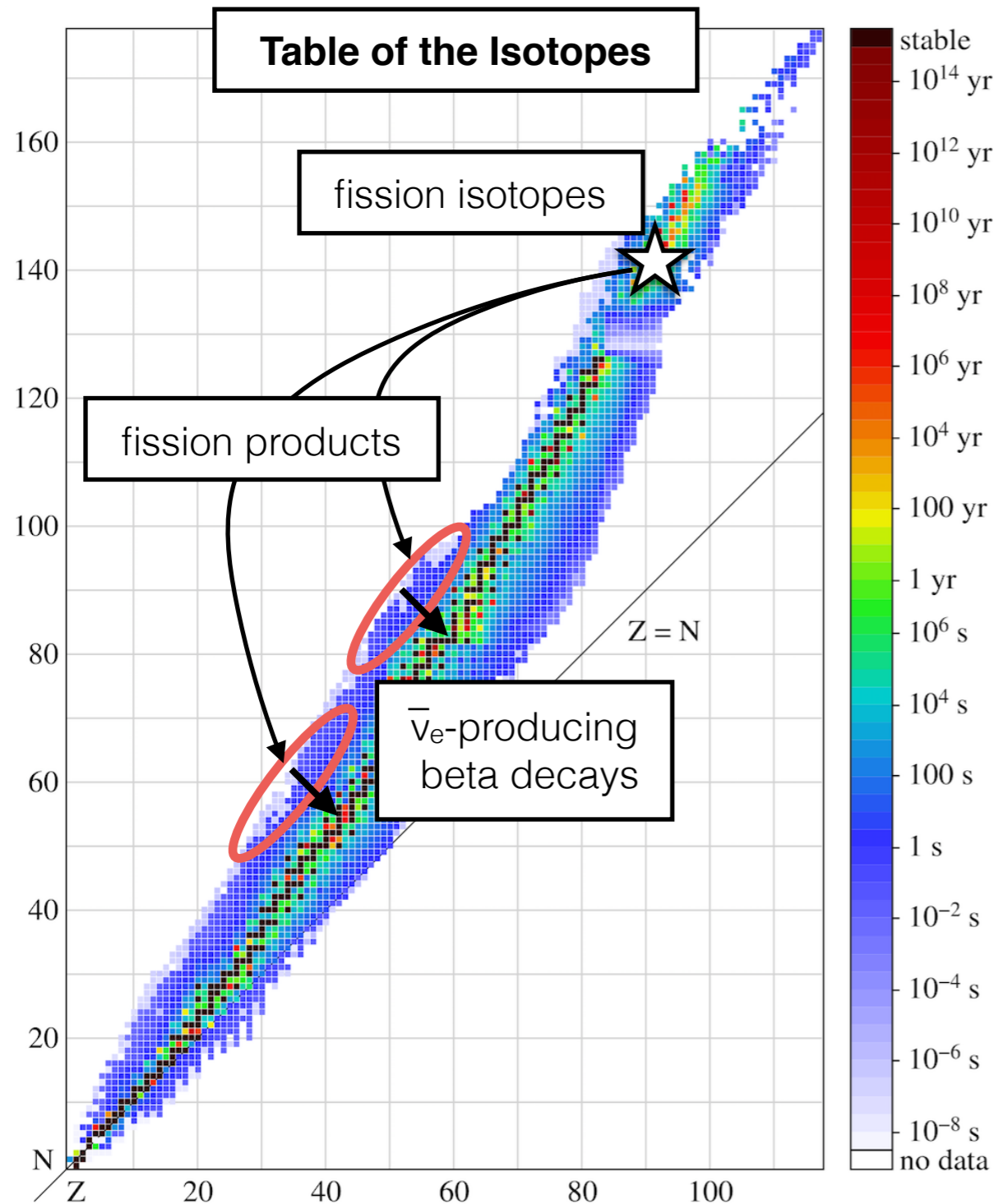
- To control nuclear weapons, control/catalog ^{235}U and ^{239}Pu
- Control/monitor reactor operation = ^{239}Pu control/monitoring
- ALL reactors make ^{239}Pu ; some better than others



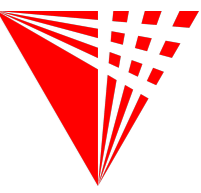
Reactor Antineutrino Production



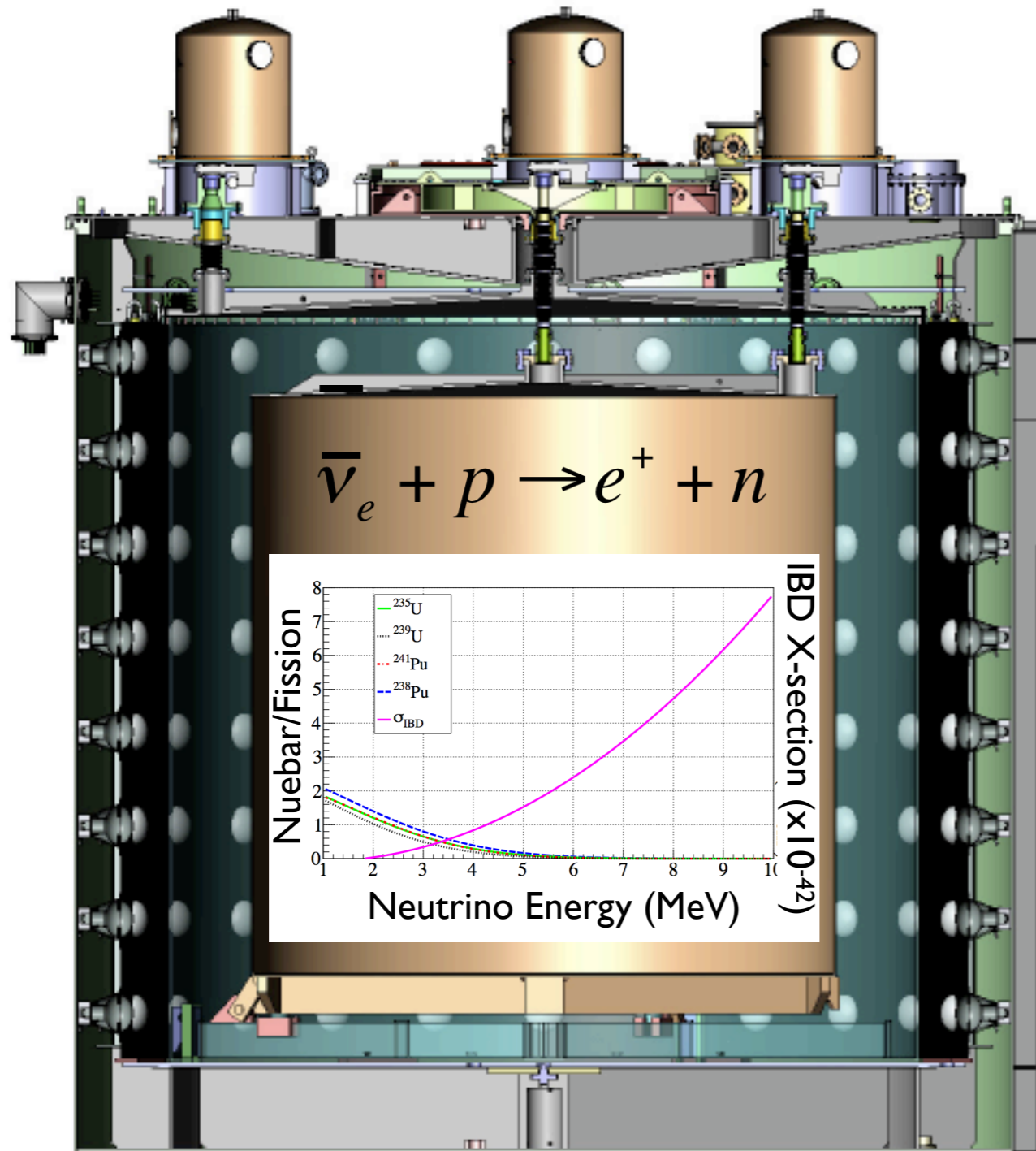
- Reactor $\bar{\nu}_e$: made in beta-decay of ^{239}Pu , ^{235}U fission products
- Each isotope: different branches, so different neutrino energies (slightly)



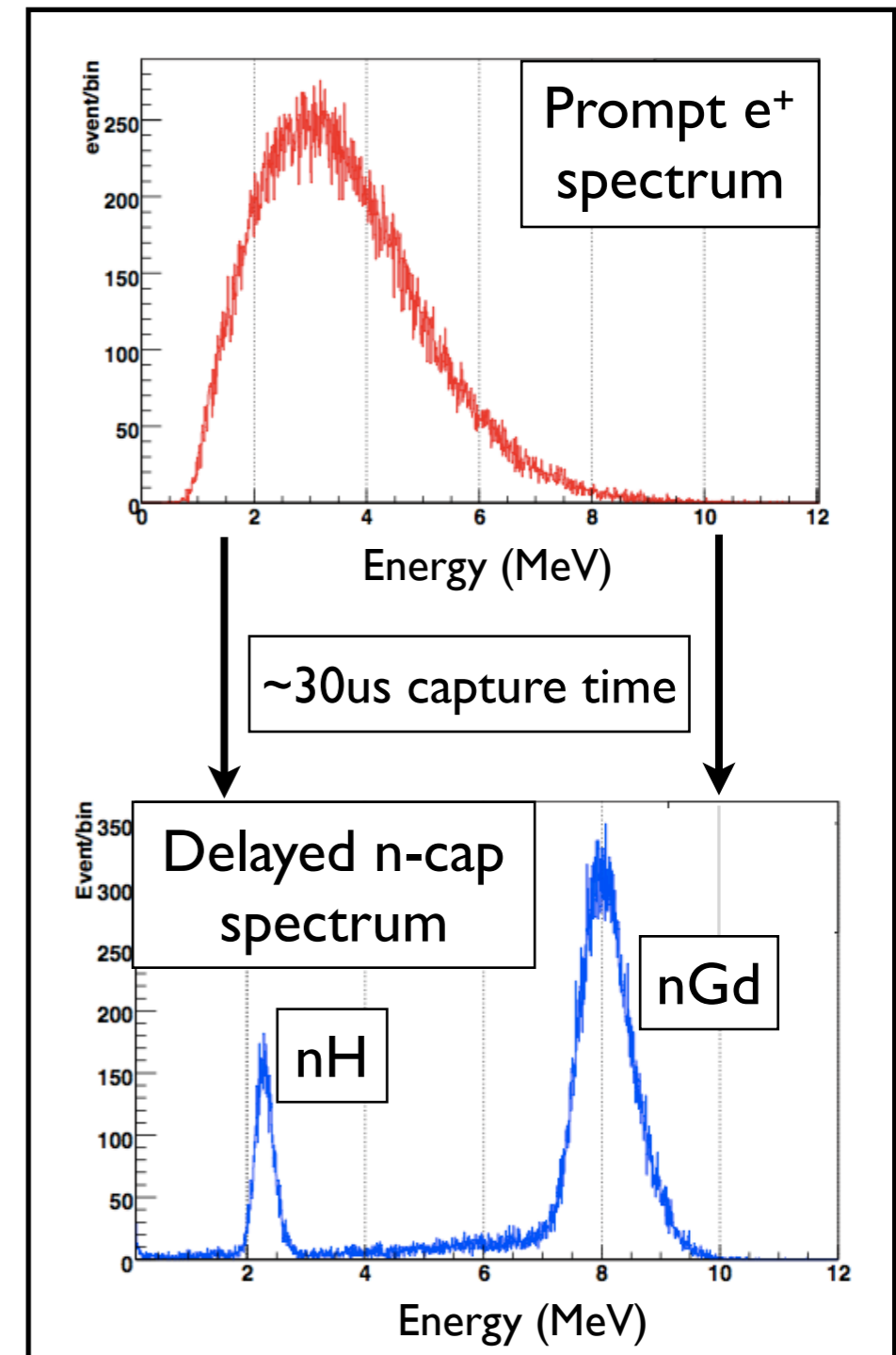
Reactor Antineutrino Detection



- Detect inverse beta decay with liquid or solid scintillator, PMTs
- IBD e^+ is direct proxy for antineutrino energy



Example: Daya Bay Detector

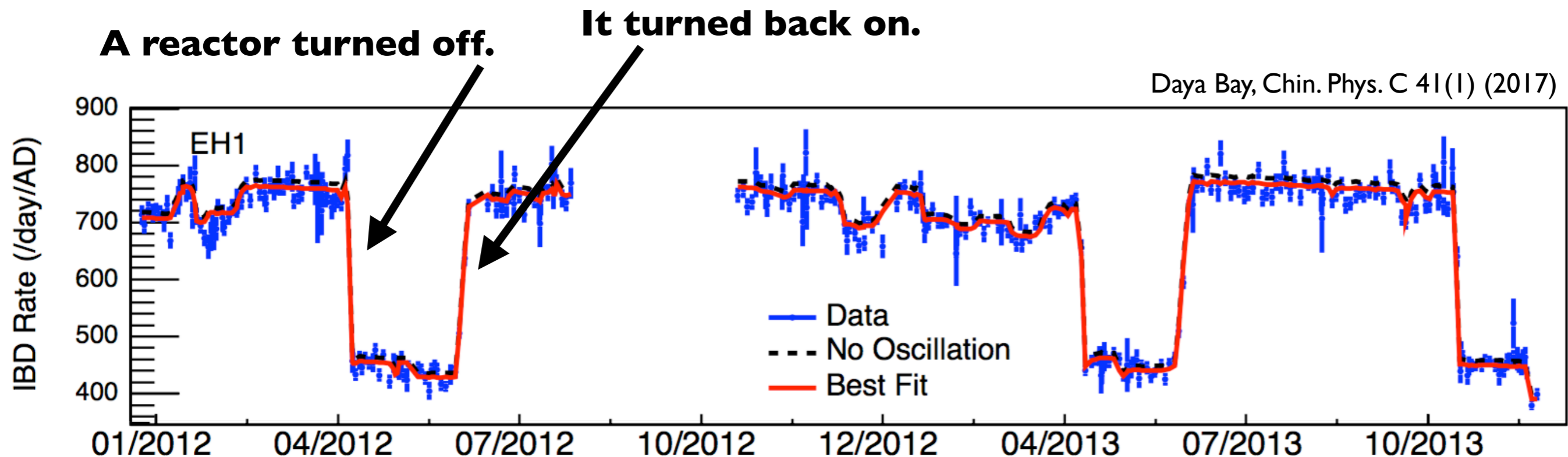


Daya Bay Monte Carlo Data

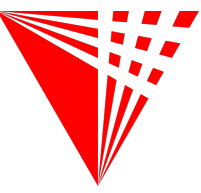
Reactor Power Monitoring



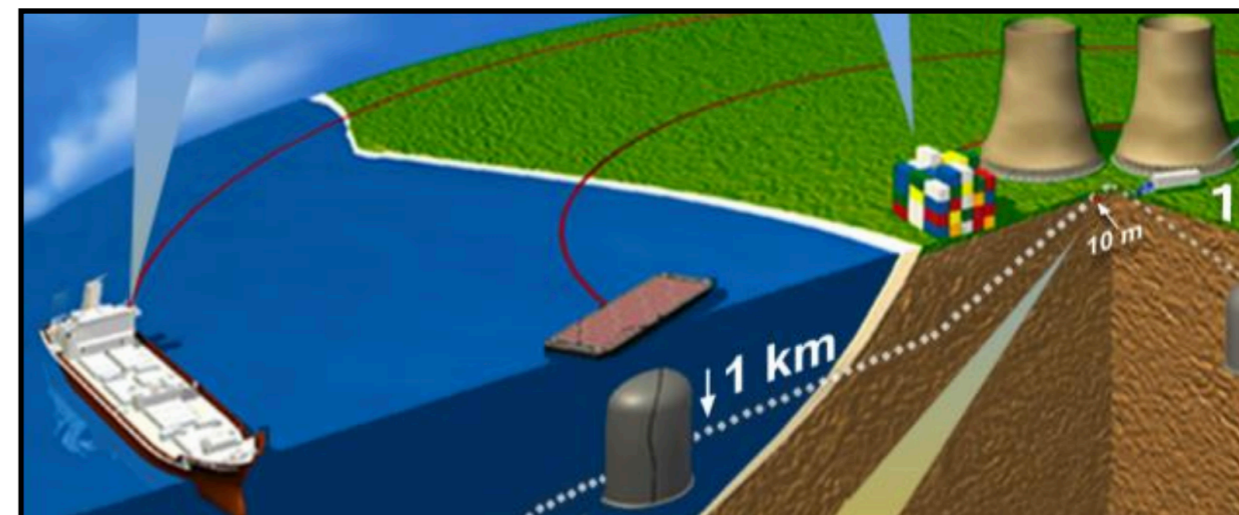
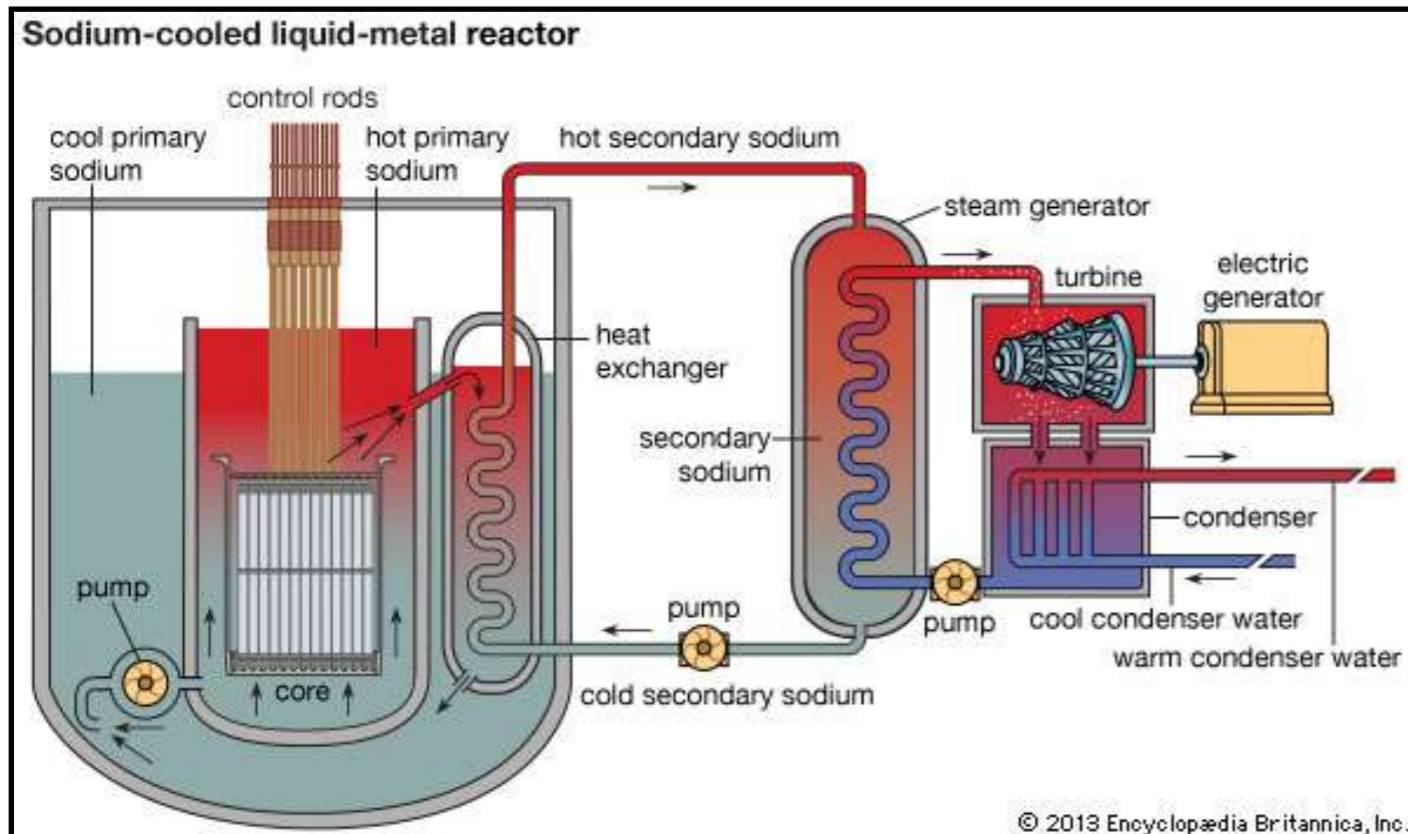
- Fissions make both neutrinos AND energy
 - More power made = more neutrinos released
- An IBD-based ex-situ reactor power monitor
 - Achieved already in numerous reactor experiments up to >km distances

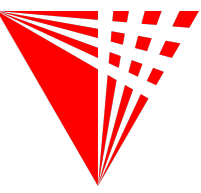


Reactor Power Monitoring



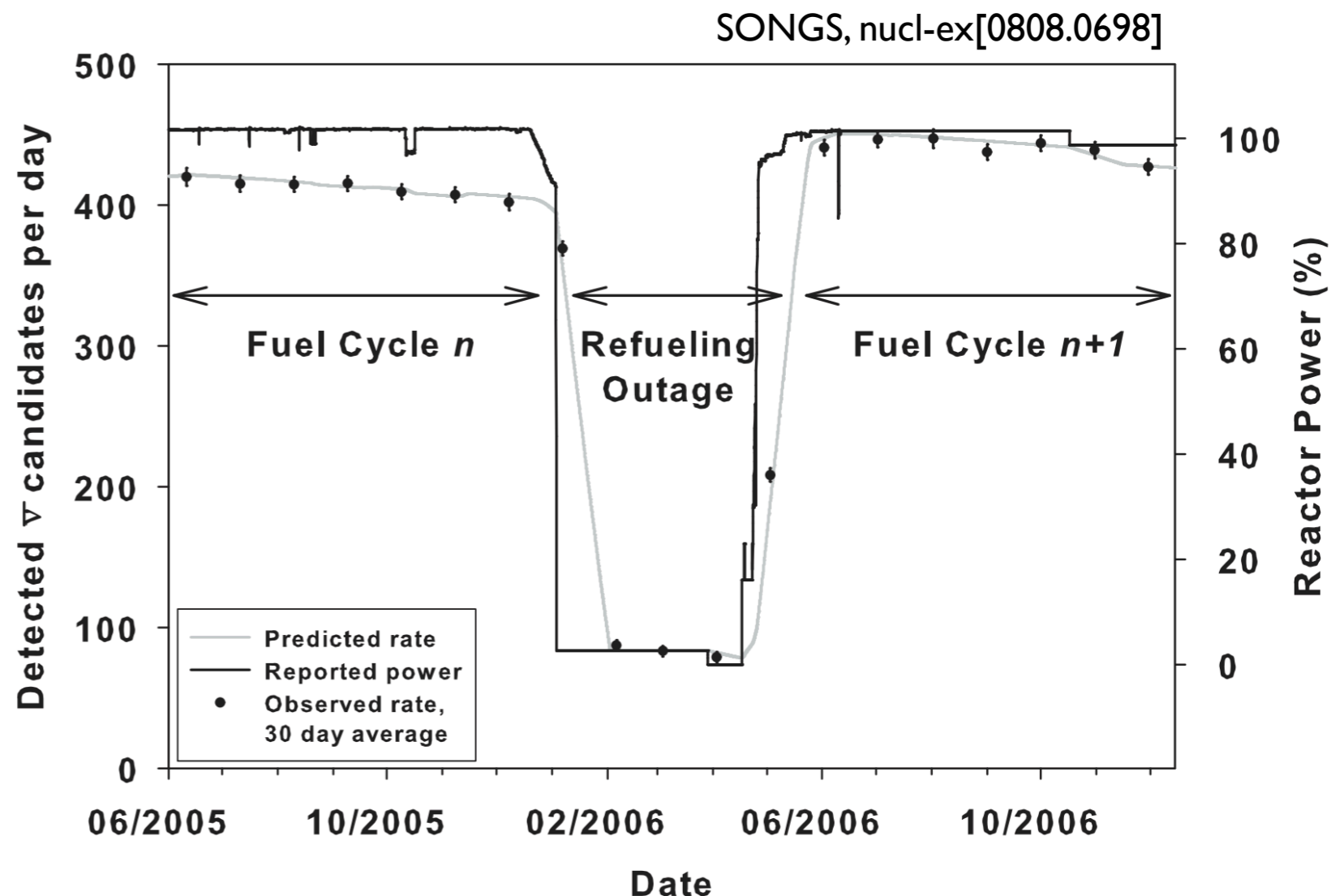
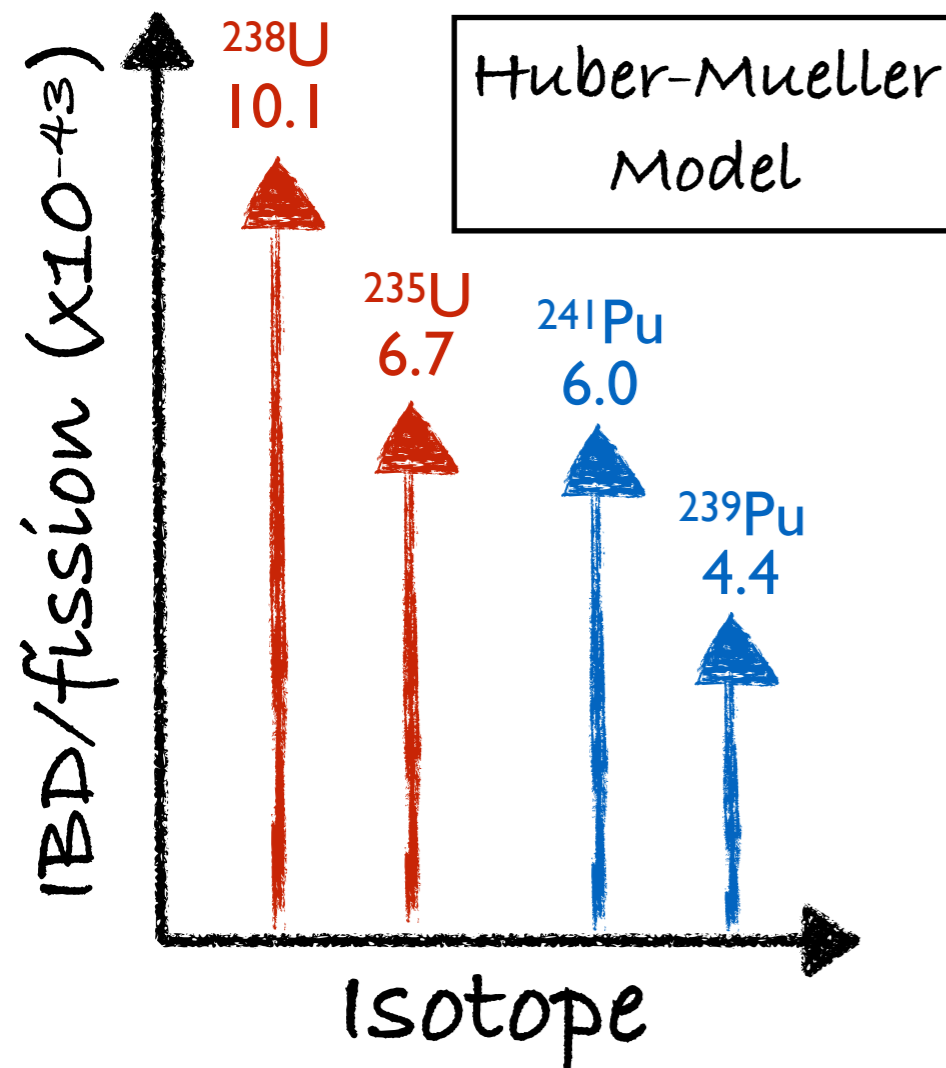
- Fissions make both neutrinos AND energy
 - More power made = more neutrinos released
- An IBD-based ex-situ reactor power monitor
 - Know power without any in-core instruments (good for sodium reactors)
 - Discover reactor or monitor operational status very far away (50+ km)
 - None have been explicitly implemented as monitoring sub-systems





Rate-Based ^{239}Pu Monitoring

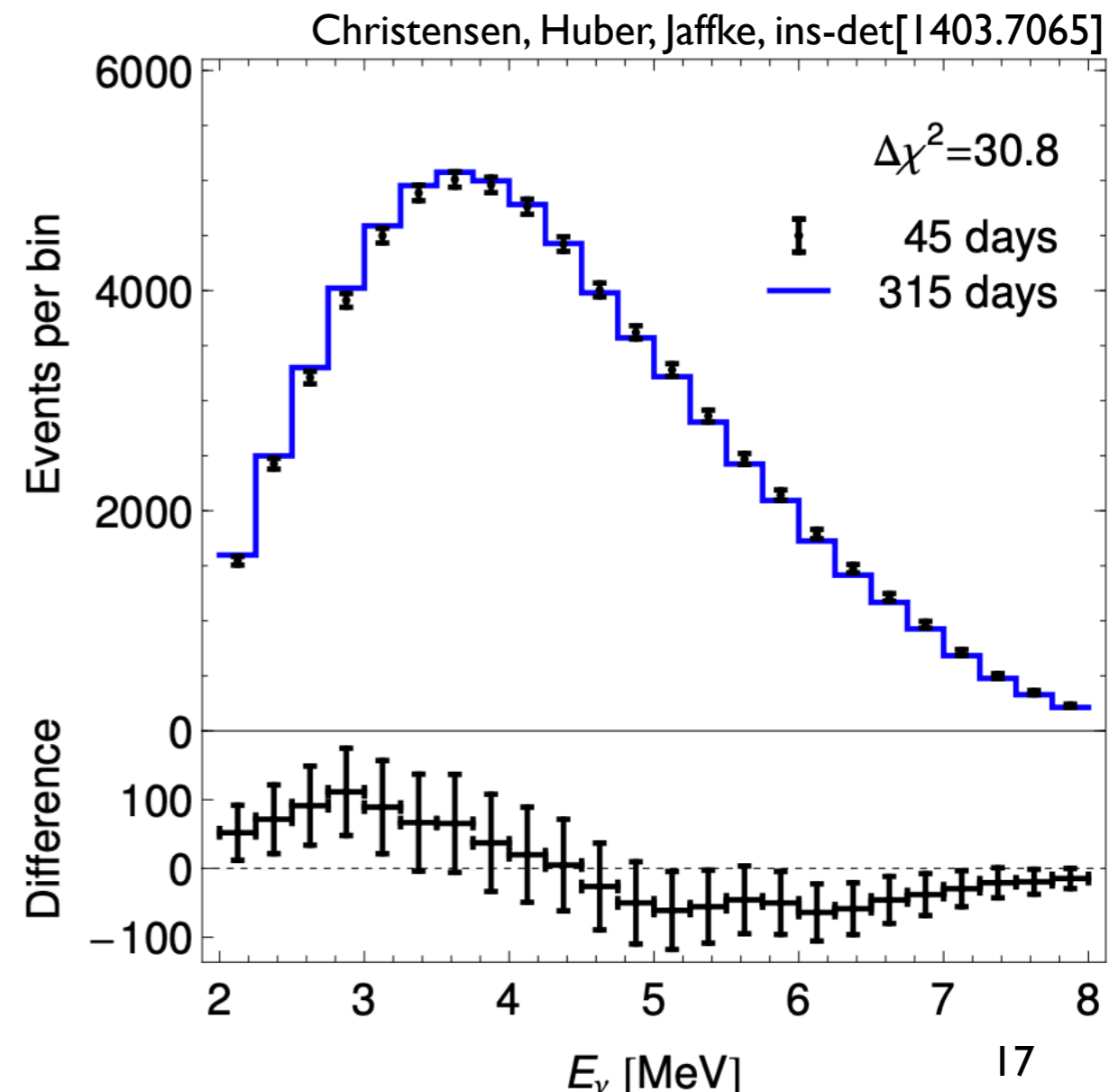
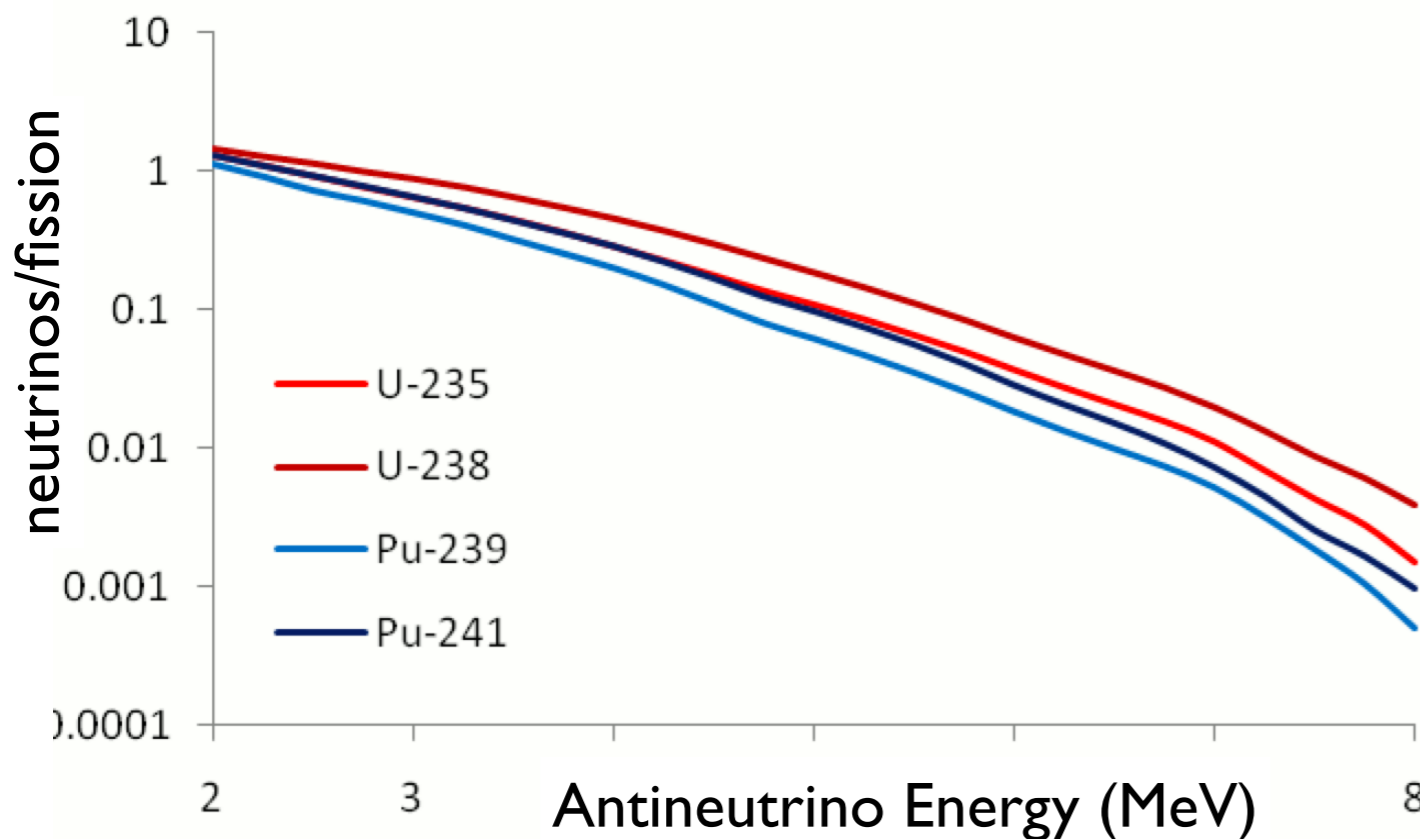
- We know ^{239}Pu makes fewer neutrinos than ^{235}U
 - Change in IBD/day is a direct measure of kg of ^{239}Pu bred into fuel
 - Numerous IBD experiments have seen reduction in IBD/day over fuel cycle
 - Drawback: degeneracy between power and ^{239}Pu content



Energy-Based ^{239}Pu Monitoring



- We know ^{239}Pu makes lower energy neutrinos than ^{235}U
- IBD prompt energy is a direct measure of kg of ^{239}Pu bred into fuel
- Daya Bay has observed this change in spectrum
- Power (IBD rate) and ^{239}Pu (IBD energy) can be independently monitored



QUESTIONS?

