

Chernobyl, Three Mile Island, and the Manhattan Project

Dr. Steve Goetsch

1. Nuclear Fission in Center of Earth?
 - a. YES! According to neutrino measurements announced in 2011
 - b. **Nuclear fission** contributes **20 terawatts** of heat (nearly twice what humans generate)
 - c. Decaying **potassium** contributes **4 terawatts** of heat
 - d. This keeps earth's mostly iron core molten and able to spin (geomagneto)
 - e. Without this heat, earth's magnetic field would end
 - f. Surface of earth would look like surface of moon or mars: blasted by solar and interstellar radiation
2. Radioactive Isotopes in Earth's Core
 - a. Four major isotopes:
 - i. **Uranium-235**, half-life of 0.703 billion years
 - ii. **Potassium-40**, half-life of 1.277 billion years
 - iii. **Uranium-238**, half-life of 4.468 billion years
 - iv. **Thorium-232**, half-life of 14.056 billion years
3. Earth is not very old compared to these decay schemes
 - a. Note: U-235 concentration at time of earth's formation would have been 30% of natural uranium (now 0.7%)
4. The Oklo Phenomenon
 - a. The Belgian Congo is an important source of uranium: this was part of Einstein's concern in famous 1940 letter to President Roosevelt
 - b. **Oklo, Gabon, West Africa**: in 1972 uranium mines were fueling French civilian nuclear reactors
 - c. Chemists in Paris found uranium ore depleted in U-235 (fissionable isotope). Samples had **0.717% U-235** instead of **0.720%**. Where did the rest go?
 - d. Examination of the mines found concentrations decreased toward a geometric center: a **nuclear reactor** was operating there about 1.7 billion years ago! U-235 concentration would have been **3.6%** 2 billion years ago
 - e. Fulfilled prediction of UCLA professor George Wetherill in 1953
5. History of Oklo Light Water Reactor
 - a. **Seventeen** different known sites in Oklo region
 - b. Fired up 1.8 billion years ago
 - c. Water moderated neutrons, reactor switched **ON** for 30 minutes, boiled away water, **OFF** for 2 ½ hours
 - d. Generated 100 kilowatts of power, consumed 6 tons of uranium
 - i. Ran for hundreds of thousands of years (up to 1 million yrs)
 - e. Fission products still entombed at the site (neodymium)
 - i. Treasure trove for nuclear reactor physicists and engineers
6. Manmade Nuclear Reactors
 - a. Late 19th and early 20th century physics was repeatedly rocked by disruptive discoveries: X-rays, radioactivity, atomic theory, photoelectric effect, special and general relativity, quantum mechanics
 - b. But **Lise Meitner** (working w Otto Hahn) correctly explained the destruction of the uranium nucleus when bombarded by neutrons as "**fission**" (term borrowed from biology)
 - c. Now Einstein's equation **E = mc²** became reality
7. The Race for Nuclear Power
 - i. Chancellor Adolf Hitler's increasingly anti-Semitic virulence drove many world-class physicists and chemists out of Europe

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- b. **Albert Einstein** left Germany in 1933
 - c. In 1938 **Leo Szilard** persuaded him to sign a letter to President Franklin Roosevelt, warning him of the terrifying possibility of a nuclear weapon:
 - i. ***“it is conceivable that extremely powerful bombs of a new type may thus be constructed”***
 - d. Roosevelt appointed the Advisory Committee on Uranium
- 8. The Manhattan Project**
- a. Enrico Fermi and CP-1: Dec. 2, 1942
 - b. First Nuclear Weapons: 1945
 - c. Hiroshima: August 6, 1945
 - d. Hanford “F” Nuclear Reactor
One of 9 plutonium breeders
1945-1965
 - e. Hydrogen Bomb: The “Super”
9. Origin of Civilian Nuclear Power
- a. **Lewis Strauss**, Chairman of US Atomic Energy Commission, promised that nuclear reactors would provide electric power “too cheap to meter” in a 1954 speech. Later became infamous for persecution of Robert Oppenheimer
 - b. **Argonne National Laboratories** built 28 test reactors
 - c. The **Shippingport, PA** Atomic Power Station went online Dec. 2, 1957. First civilian nuclear power station in the world. It produced 60 Megawatts of electric power. Ceased operation in 1982 after 25 years and was decommissioned
10. Civilian Nuclear Power Reactors
- a. **United States: 98** currently operating power units at 59 plants. Peaked at 104 reactors, 7 now decommissioned
 - i. Construction underway on 2 new reactors in US and 50 more in 15 other countries
 - ii. Provides about 20% of total US electrical power: 98.62 GW (Total grid: 1100 GW)
 - iii. Typical size: 1000 to 1100 megawatts
 - b. **China** has 46 reactors, 11 more under construction
 - c. 450 nuclear reactors worldwide
11. Types of Nuclear Reactors
- a. **Enrico Fermi** design (1942) was spherical, w **pure graphite** interlaced w **natural uranium**
 - b. **Control rods** killed the reaction until slowly withdrawn
 - c. Exact same design for first Russian reactor (based on espionage data)
 - d. Similar design for **Windscale Reactor** in England, which caught fire and burned in 1956. Graphite burns!!
 - e. Soviet **RBMK** reactor design very similar, with cooling water circulating to remove heat. 15 units were built, 9 more under construction were cancelled after Chernobyl accident
12. Soviet RBMK reactor design
- a. Pressurized Water Reactor (PWR)
 - b. Boiling Water Reactor (BWR)
13. International Nuclear Event Scale
- a. Scale goes from 0 thru 7
 - i. Level 7: Chernobyl, Fukushima Daiichi
 - ii. Level 6: Kyshtym waste explosion
 - iii. Level 5: Windscale Fire, Chalk River (1952), Three Mile Island, Lucens, Switzerland (1969)
 - iv. Level 4: SL-1 accident
14. Kyshtym, Russia Waste Explosion Sep 29, 1957

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15. Three Mile Island: March 28, 1979
 - a. Two-unit plant PWR, 852MWe capacity
 - b. TMI-2 suffered a catastrophic meltdown
 - c. Resulted in complete loss of unit
 - d. \$1 billion cleanup cost
 - e. Took until 1993
 - f. Unit TMI-1 still operating
16. 1986: Consequences of Chernobyl explosion
 - a. 31 immediate deaths, 33 later (UNSCEAR)
 - b. **500,000** emergency workers affected
 - c. Contamination over most of Europe, some lingering to this day
 - d. Town of Pripyat (50,000) abandoned permanently
 - e. Exclusion zone: 1,000 square miles
 - f. Reactor entombed in unstable “sarcophagus” in 1986
 - g. Radiation levels up to 20,000 R/hr
 - h. **\$235 billion** cleanup cost (so far)
 - i. Cs-137 Contamination
17. Follow-up to Catastrophe
 - a. **Six people placed on trial:** chief and two others sentenced to 10 years in prison, other 3 received 5-year sentence. NEVER told about previous accidents
 - b. Small physics group kept exploring the “**Sarcophagus**”
 - c. Fuel melted thru 3 levels of concrete!
 - d. **China Syndrome**
 - e. New Safe Confinement
18. Consequences of Great Japanese Earthquake of 2011
 - a. 9.0 earthquake followed by tsunami up to 15 meters high
 - b. Tsunami killed electric power and flooded backup generators
 - c. Units #1, 2 and 3 over-heated and melted down
 - d. Hydrogen caused explosions, blowing structures apart
 - e. 940 PetaBQ (mostly I-131) emitted
 - f. Over 100,000 people evacuated
 - g. \$13.5 billion spent on decontamination so far
 - h. Millions of tons of contaminated soil
19. US Congress “Nuclear Waste Policy Act” of 1987 that nation’s spent fuel (from nuclear reactors) must be put in a repository
 - a. Yucca Mountain in Nevada was agreed on but never opened
 - b. President Jimmy Carter gave up on “breeder reactor” which would have operated on PWR and BWR spent fuel
 - c. Now it has to be disposed of: US has 61,000 tons in storage
 - d. Mostly stored on site at operating nuclear reactors
 - e. Spent fuel repository has never been opened
20. Last US Nuclear Weapons Test, Sep 23, 1992
 - a. Trans Atomic Power: Waste Annihilating Molten Salt Reactor (Lesley Dewan, MIT)
 - b. San Onofre Nuclear Generating Station (SONGS)
21. San Diego Union Tribune, Aug 28, 2017
 - a. The operators of the [San Onofre Nuclear Generating Station](#) (SONGS) promised Monday to make a good faith effort to find a location to move the [3.55 million pounds](#) of nuclear waste that has accumulated on the plant’s premises, between the Pacific Ocean and one of the busiest freeways in the country.

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22. [Southern California Edison](#) (SCE) made the announcement in an [out-of-court settlement filed](#) in San Diego between the utility and a pair of San Diego-area plaintiffs who sued after the California Coastal Commission in 2015 [approved a 20-year permit](#) for Edison to expand a storage system to place the plant's spent nuclear fuel placed into heavy, dry casks.