Nuclear Energy Overview

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In 2010, nuclear provided almost 14 percent of the entire California power mix (which included out of state imports). As of mid-2012, California had one operating nuclear power plant: Diablo Canyon (2,160 megawatts), near San Luis Obispo. In 2017, in-state power generation was 206,336 gigawatt-hours (GWh), nuclear accounted for ~11.5% of the total in-state electric generation.[1]

There are two fundamental ways to release energy from nuclear reactions: fission and fusion of atomic nuclei. Nuclear fission is a nuclear reaction or a radioactive decay process in which the atomic nucleus splits into lighter nuclei, releasing some combination of particles and energy.[2] Nuclear fusion is a reaction in which multiple atomic nuclei combine to form a combination of new atomic nuclei and subatomic particles with the resulting mass difference manifesting as either an absorption or release of energy.[3] Electricity generating technologies based on fission are commercially available, whereas fusion is still in the stages of research and development.

Nuclear Fission

Of the several types of fission reactors, the most common type in the United States are light water reactors[4], normal water is used to cool the reactor core, based on pressurized water reactor (PWR) and boiling water reactor (BWR) technology.[5] U.S. commercial rectors use uranium-235, a naturally occurring radioactive isotope of uranium, as the nuclear fuel. In a PWR or BWR reactor, the overwhelming majority of fission events are induced by bombardment with another particle, a neutron, which is itself produced by prior fission events. The uranium-235 fission event is a bimodal process, resulting in the release of energy, different atomic nuclei, and extra neutrons. The free neutrons bombard adjacent uranium-235 atoms, creating a fission chain reaction that releases more energy and byproducts.

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[1] Sector-specific summaries of California's progress toward a cleaner energy future, with links to additional resources. Information and metrics are updated regularly. Available at https://www.energy.ca.gov/renewables/tracking_progress/index.html.

[2] Nuclear fission, https://en.wikipedia.org/wiki/Nuclear_fission.

[3] Nuclear fusion, https://en.wikipedia.org/wiki/Nuclear_fusion.

[4] "Light" water is composed of oxygen and hydrogen while "heavy" water replaces the hydrogen with the isotope deuterium, hydrogen atoms with an additional neutron in the nucleus.

[5] Pressurized water reactor, https://en.wikipedia.org/wiki/Pressurized_water_reactor. Boiling water reactor, https://en.wikipedia.org/wiki/Boiling_water_reactor.

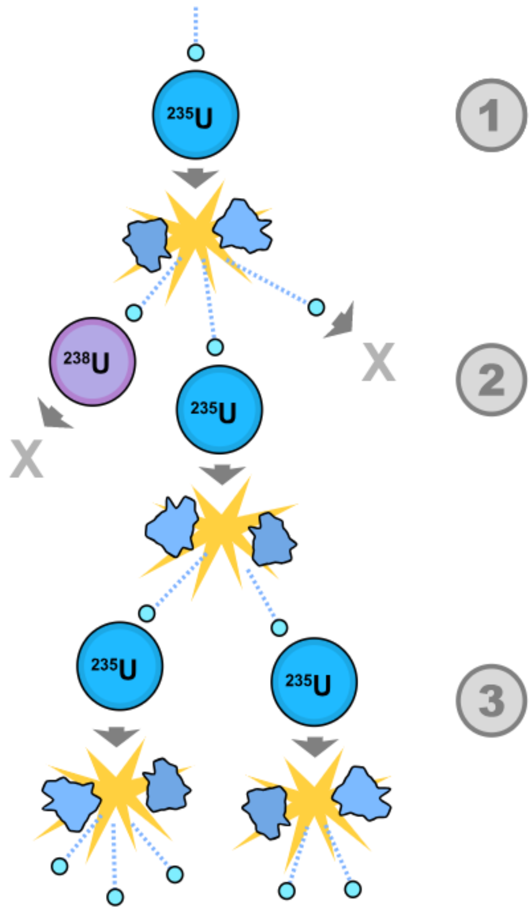

Figure 1: A schematic of a nuclear fission chain reaction. **(1)** A uranium-235 atom absorbs a neutron and fissions into two new atoms (fission fragments), releasing three new neutrons and energy. **(2)** One neutron is absorbed by an atom of uranium-238 and does not continue the chain reaction. Another neutron is simply lost and does not collide with anything, also ending a potential chain reaction. However, one neutron does collide with an atom of uranium-235, which then fissions and releases two neutrons and energy. **(3)** Both neutrons collide with uranium-235 atoms, each of which fissions and releases between one and three neutrons, which propagates the chain reaction.[6]

The Diablo Canyon Nuclear Power Plant, the last operating nuclear reactor in California, consists of two PWR units. Nuclear fission in the reactor vessel produces heat. This heat is absorbed by pressurized water in the primary coolant loop. The primary coolant loop is isolated in order to contain radiation released during the fission and decay process. The super-heated

[6] Figure 1 Source: By User: Fastfission - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=522592

water in the primary coolant is routed through hundreds or thousands of pipes, which transfer heat to the secondary coolant loop. Water in the secondary coolant loop is converted to high-pressure steam that is used to spin the turbines that generate electricity.

There are several alternative reactor designs and advanced reactor power plant designs being developed in the U.S. and over-seas. Information on these systems can be found on reputable web sites such as the World Nuclear Association website, http://www.world-nuclear.org/.

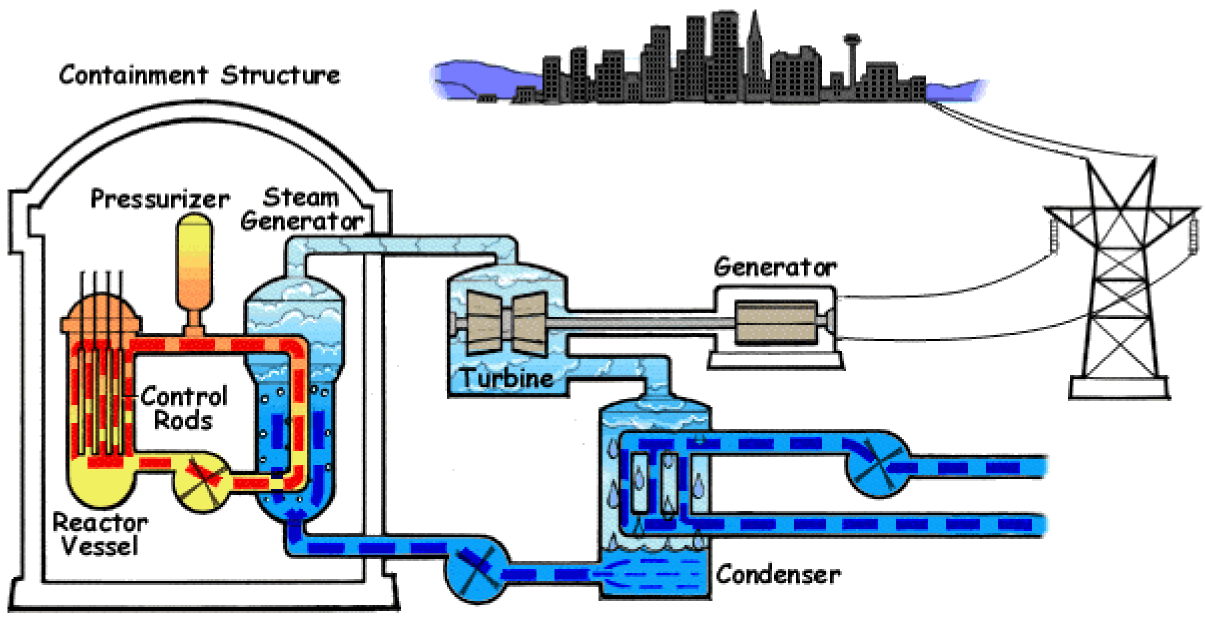

Figure 2: Pictorial explanation of power transfer in a pressurized water reactor. Primary coolant is in orange and the secondary coolant (steam and feed water) is in blue.[7]

Issues for Fission Power Plants

Some of the issues associated with commercial nuclear power plants include:

- Economic feasibility of new and existing plants in the United States
- Need for a spent fuel disposal facility and a decommissioning plan
- Use of large amounts of water for cooling purposes (if wet cooling towers are used)
- Biological impacts on the ocean due to thermal discharge (if seawater cooling is used)
- Seismic safety concerns
- Public safety concerns

[7] Figure 2 Source: By U.S. NRC, http://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2320214

- Transportation issues associated with emergency evacuation and the disposal of radiological waste
- Changes in visual quality due to the power plant structures, including the reactor vessel containment structure, and associated structures
- Land usage and contamination
- Public perception

Nuclear Fusion

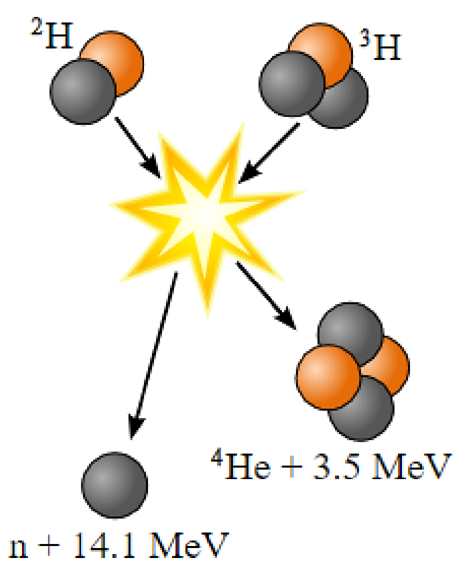

Figure 3: Fusion of deuterium, helium-2, with tritium, helium-3, creating helium-4, freeing a neutron, and releasing 17.59 MeV as kinetic energy of the products while a corresponding amount of mass disappears, in agreement with *kinetic E*= Δmc^2, where Δm is the decrease in the total rest mass of particles.[8]

A fusion reaction occurs when atomic nuclei, such as hydrogen and its isotopes (deuterium and tritium), are forced together (conditions require some combination of extremely high temperature, pressure, or velocity to overcome the Coulomb force) until they fuse into a nuclei of a heavier element. The fusion process releases a combination of particles and kinetic energy proportional to the difference in mass. There are multiple fusion methods that are currently being pursued for use in a commercial reactor system.[9]

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[8] By Wykis (talk · contribs) - This file was derived from: D-t-fusion.png:, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2069575
[9] Figure 3 Source: Fusion Power https://en.wikipedia.org/wiki/Fusion_power

To generate commercial energy from fusion, the released energy would be converted to heat, which in turn is converted to electricity via a conventional generator cycle. Although the fusion reaction does not produce significant or long-lived radioactive byproducts, the high-energy particles irradiate the surrounding reactor vessel and associated components. The irradiated material could pose potential disposal problems similar to those for the irradiated fission reactor vessel. The reasons fusion continues to be actively pursued is that unlike nuclear fission, there is less waste products, no risk of a nuclear melt down (the reactor vessel could explode but this would be comparable to a conventional gas plant accident), and fusion power provides more energy for a given weight of fuel than any fuel-consuming energy source currently in use.