Safer Fission Reactors

By John Suchocki © 2019

The designs for nuclear power plants have progressed over the years. The earliest designs, from the 1950s through the 1980s, are called the Generation I and II reactors. The safety systems of these reactors are “active,” in that they rely on a series of active measures, such as water pumps, that come into play to keep the reactor core cool in the event of an accident. The problem with this is that the active measure itself may fail in the event of a crisis.

Notably, active safety measures failed when the Generation II Fukushima Daiichi nuclear plant of Japan was hit by the powerful tsunami of 2011. In this case, the water pumps could not operate because the electric generators designed to power these pumps where destroyed by seawater.

The Generation III reactors, built in the 1990s, are more economical to build, operate, and maintain. These reactors, however, still rely on active safety measures.

While not yet operational, the latest Generation IV nuclear reactors have fundamentally different reactor designs. Importantly, they incorporate passive safety measures that will cause the reactor to cool down by itself in the event of an emergency. For example, as the fuel gets hotter, it expands, which leads to a decrease in the rate of fission.

The fuel source for a Generation IV reactor may be the depleted uranium stockpiled from earlier-generation reactors. Designs will also allow for the formation of hydrogen fuel from water. Furthermore, these reactors can be built as small modular units generating between 150 and 600 megawatts of power rather than the 1500 megawatts that is the usual output of today’s reactors. Smaller reactors are easier to manage and can be used in tandem to build a generating capacity suited to the community being served.

The Generation IV International Forum (gen-4.org) aims to have Generation IV power plants operating by the 2030s. Some of these Generation IV power plants may employ the element thorium as the primary fuel.

The Thorium Reactor

It is well known that uranium and plutonium have fissionable isotopes, U-235 and Pu-239. These isotopes are historic in that they comprised the two nuclear bombs that ended World War II, and were favored in nuclear power reactors that followed. But there is a third isotope that is fissionable, which is the less well-known U-233.

U-233 does not occur naturally on Earth, but is produced in specially designed reactors where thorium-232 captures a neutron to form Th-233, which beta decays into U-233. Thorium is about four times more abundant in Earth’s crust than uranium, and most thorium is the needed Th-232 isotope. So, the world already has an abundant supply of this fuel.

The thorium is first blended with fluoride salts to bring the melting point to a relatively cool 360°C. To initiate the fission chain reaction, neutron-releasing isotopes of uranium or plutonium are mixed into a molten blend of thorium and fluoride salts. This leads to the formation of U-233, which upon fission releases more neutrons making the chain reaction self-sustaining while also creating more U-233 from Th-232, as shown in Figure 1. With a higher temperature, the liquid mixture flows through a heat exchanger where it causes a turbine to generate electricity. This system is called a Liquid Fluoride Thorium Reactor, LFTR.

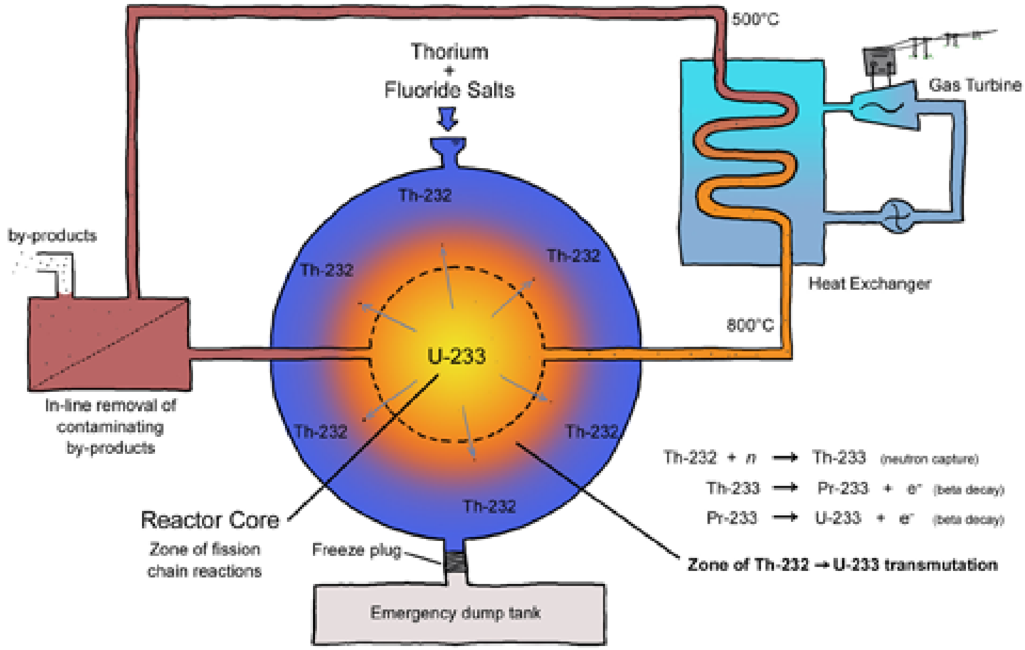


Figure 1 Diagram of a thorium reactor. Fissionable U-233 is produced as the thorium is exposed to neutrons. Because of its liquid phase, the fuel mixture itself can be passed through the heat exchanger and then treated for the removal of contaminating by-products.

Nuclear power plants using U-235 or Pu-239 as a fuel are prone to explosive accidents because they operate at extremely high pressures. The LFTR, by contrast, operates near atmospheric pressure, which translates to greater safety. And whereas the fuel in conventional nuclear power plants invariable leads to the creation of plutonium, production of this toxic element in the LFTR is low enough to be retained and controlled within the molten mixture. The LFTR also has inherent passive safety mechanisms that prevent a meltdown scenario.

Conventional nuclear power plants have to be shut down once every 18 months for replacement of solid fuel pellets. The LFTR, however, can function continuously for years using liquid fuel in which by-products can be removed by distillation or electrolysis. Furthermore, most of the by-products isolated from the LFTR have short half-lives that decay within a matter of hours or days. Its longest-lived isotope Cs-137 requires only decades of safe storage (rather than the hundreds of millennia with plutonium reactors).

Bomb technology has historically avoided the fissionable isotope U-233, mainly because a dangerous by-product is the thallium-208 isotope, which is a powerful gamma ray emitter. Nuclear bombs built of U-233 were impracticable because the gamma rays from residual thallium-208 would fry the detonation circuitry making a bomb “temperamental.” The resultant Tl-208 isotope produced within the LFTR, however, can simply remain within the molten mixture to provide additional energy. And indeed, the presence of the pesky Tl-208 isotope provides a great deterrent against anyone trying to extract U-233 for clandestine nuclear bomb making.

With a growing awareness of the dangers posed by greenhouse gases, more attention is being given to the potential benefits of next-generation nuclear technology. Japan, China, the UK and India are all sponsoring research into the LFTR as well as private companies in the US, Czech Republic, Canada, and Australia. Check online for the latest developments.

Concept Check
Thorium-232 is not fissionable. How then can this common isotope be used as a fuel for nuclear fission?

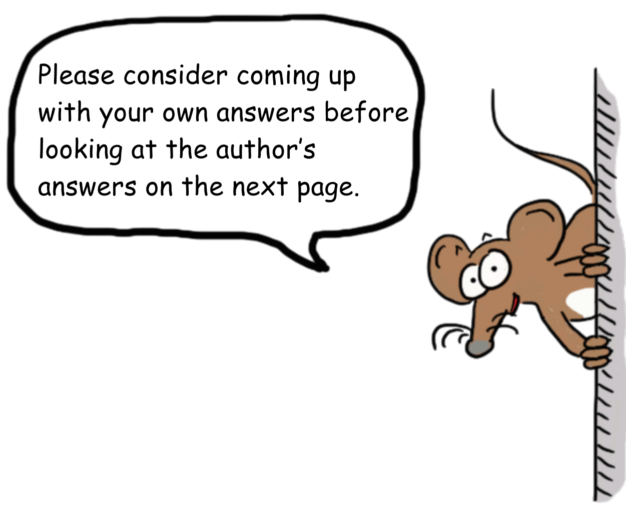
Check Your Answer
The Th-232 isotope transforms into Th-233 upon capturing a neutron. The Th-233 isotope then undergoes two beta decays to form the fissionable U-233 isotope.

Think and Discuss

1. The United States has an abundant supply of coal and natural gas. To what extent does this affect the reluctance of Americans to accept nuclear power as a means of generating electricity?

2. Rank the following issues in order of importance for the implementation of nuclear power: (a) Sustainable supply of fuel, (b) Management of nuclear wastes, (c) Remaining economically competitive, (d) Safe operation of the nuclear power plant, (e) Reducing risk of weapons proliferation.

3. Describe how each of these might be a threat or salvation to human existence: nuclear-fired power plants, coal-fired power plants, no power plants.



Think and Discuss (Answers)

1. The United States has an abundant supply of coal and natural gas. To what extent does this affect the reluctance of Americans to accept nuclear power as a means of generating electricity?
1. The reluctance of Americans toward nuclear energy has many causes, most notably safety issues and the association of nuclear technology with nuclear bombs. Americans can supply most all of their electrical needs through coal and gas fired powered plants, which is to say that nuclear power plants are not so essential. In all, only about 20% of electricity in the United States is generated by nuclear power. France, by contrast, relies on imported fossil fuels. In all, over 70% of electricity in France is generated by nuclear power.

2. Rank the following issues in order of importance for the implementation of nuclear power: (a) Sustainable supply of fuel, (b) Management of nuclear wastes, (c) Remaining economically competitive, (d) Safe operation of the nuclear power plant, (e) Reducing risk of weapons proliferation.
2. It is vitally important that each one of these issues be addressed.

3. Describe how each of these might be a threat or salvation to human existence: nuclear-fired power plants, coal-fired power plants, no power plants.
3. The fissionable isotopes from a nuclear power plant could potentially be concentrated sufficiently to make a nuclear weapon. If such a nuclear weapon were used, it could potentially set off a nuclear war in which already made nuclear bombs are set off. In addition to killing millions of people, a "prolonged" nuclear war could set of a "nuclear winter" in which residuals from these bombs reflect sunlight creating a feedback loop in which the planet plunges into an ice age. Nuclear power plants, by contrast, generate no greenhouse gases. If they were used to substitute for coal-fired power plants, then this would dramatically lower our carbon dioxide emissions. A great disadvantage of coal-fired power plants is the they produce significant amounts of carbon dioxide, a potent greenhouse gas. Excessive reliance on coal-fired power plants could lead to a devastating global climate change. Coal, however, is abundant and therefore relatively cheap. The energy we get from coal-fired power plants helps our economy. With a strong economy we're in a better position to offer assistance in times of crises as they happen. If all power plants were to suddenly shut down, so would our electricity dependent society leading to much chaos. There would be a strong push, however, toward decentralized power, such as solar panels or wind turbines at every home. Such technology could easily be exported to developing countries who already lack centralized power. This, in turn, would minimize the global output of greenhouse gases.