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Alexander Gaskins
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Dr. Edward Friedman

The Rise of Sodium Fast Reactors

The age of Generation IV nuclear reactors is upon us, with energy efficiency being among the most important focuses as new nuclear reactor models are experimented with. In Generation III, safety was the biggest concern, offering reactors designed with the goal of being "passively safe" in the event of a problem. While the Generation III reactor designs have proven their ability to keep up with traditional fossil fuel energy production, there is room for improvement. When it comes to energy generation, boiling water to spin a magnetic turbine is a common concept that has been used for decades, but its efficiency is limited by the chemistry involved. A formula for heat energy efficiency (E) was derived from Sadi Carnot's work in the 1820's, showing that $E = 1 - \frac{T_C}{T_H}$, where T_C is the coldest temperature during the heat cycle, and T_H is the maximum temperature reached by the gas, such as steam in many traditional generators. From the equation, we see that in order to increase efficiency, $\frac{T_C}{T_H}$ needs to be closer to 0, requiring T_H to be larger. As a result, Generation IV reactors are designed to function at higher temperatures. A popular Gen IV reactor design is the Sodium-Cooled Fast Reactor (SFR), which encompasses a fast neutron reactor that is cooled by liquid sodium. This technology has already been used by several countries, such as France and Russia. The reactor is fuelled by a recycled actinide radioactive decay chain with two possible design methods depending on the reactor size. One is an intermediate-size (150–600 MWe) sodium-cooled reactor with uranium-plutonium minor actinide-zirconium metal alloy fuel, and the other is a medium to large (500–1,500 MWe) sodium-cooled reactor with mixed uranium-plutonium oxide fuel, supported by a fuel cycle based upon advanced aqueous processing at a central location serving multiple reactors.

There are many advantages to the SFR design, including the fact that the fast neutron design allows for fission to occur almost flawlessly, with a small chance of being captured by uranium and plutonium, and still resulting in fission even when they are captured. This generic fast reactor trait is vital, as it prevents the generation of any transuranic waste. Because metal atoms, such as sodium, are much heavier than hydrogen atoms, they are weak neutron moderators. This is yet another advantage to the SFR, as much less energy is lost due to collisions with lighter atoms. In accordance with the aforementioned heat energy efficiency objective, using liquid sodium as a coolant provides a much higher temperature range, with a melting point of 371 K and a boiling point of 1156 K, providing a range of approximately 785 K between the two phases, compared to the roughly 100 K range of water, which allows it to absorb a much greater amount of heat in comparison. The sodium also protects steel reactor parts from corrosion, unlike water, which can contribute to corrosion. However, there is some danger involved with the SFR model, particularly due to its chemical reactivity. Unfortunately, due to its chemical properties, it is prone to exploding when it comes in contact with water. This is because when sodium comes into contact with water it reacts to produce sodium hydroxide and hydrogen, and the hydrogen burns in contact with air, which can be disastrous, as exemplified from the Monju Nuclear Power Plant accident, which involved a sodium leak as result of violent vibrations. Thankfully, the leak was not radioactive, as it took place in the secondary cooling system, but nonetheless presented the ability of the sodium to burn when in contact with air. All in all, with proper leakage prevention methods and maintenance, the many advantages of the SFR design definitely outweigh the few flaws that can be easily controlled.