

Nukes Part 8 - Fast Breeders

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January 2024

1. Introduction

*How the old is new—a paradoxical dance,
Time's waltz, a cosmic romance.
Eons whisper secrets, ancient and wise,
Echoes of yesteryears, under celestial skies...*

- *Microsoft Bing Generative AI*

Many times, I thought I had left my history in the dust, only to have a new team bring it back to me. In case you are wondering about the title of this paper, it is a type of nuclear fission reactor that was in my deep past.

I graduated from college (BSEE) in 1975. My first job out of college was with Rockwell Atomics International. The projects I worked on there all involved a type of reactor called a Liquid Metal Fast Breeder Reactor or LMFBR.

The “Liquid Metal was the heat transfer fluid: either liquid sodium or a sodium-potassium alloy (NaK). “Fast” refers to the neutrons emitted by the nuclear reaction that are “fast” (high-energy), and remain fast until they undergo an additional reaction. In a standard water-cooled fission reactor, the neutrons are moderated (have their energy reduced). Breeder means that the LMFBR breeds its own fuel in a breeder blanket of fertile material (usually the most common isotope of uranium, U-238, a.k.a. depleted uranium).

1.1. LMFBRs

At Atomics International we were mostly working on the Clinch River Breeder Reactor, which was never built. We used the experience of a highly successful previous LMFBR, Experimental Breeder Reactor-II (EBR-II), which first achieved criticality in the summer of 1964. We also were watching the Fast Flux Test Facility (FFTF). This was a 400 MW thermal, liquid sodium cooled, nuclear test reactor, which was then under construction, and achieved criticality in 1980. At that time (in the late 70s), FFTF was bringing its subsystems on line in preparation for criticality. The insider joke at the time was that FFTF really stood for “Fabulously Funded Test Facility.”

1.2. EBR-II

EBR-II was a tremendous success, having achieved a number of major advancements:

- *Sodium coolant— A key issue for a fast reactor is cooling. Although sodium reacts violently with water, EBR-II engineers chose it because it has a number of attractive features. In addition to having minimal interaction with neutrons, it has a high thermal conductivity, is noncorrosive with steel construction material, and has a high boiling point, which avoids safety issues that come with using a pressurized vessel.¹*

¹ Catherine Westfall, Nuclear News, “Vision and Reality: The EBR-II Story,” Feb 2004, <https://www.ne.anl.gov/About/reactors/EBR2-NN-2004-2-2.pdf>

- *Pool-type configuration of primary system— One of the distinctive features of EBR-II was that the primary system (the reactor vessel and core, pumps for pumping sodium, and an intermediate heat exchanger) was put into a one tank.*

This is instead of using a series of connected pipes. This arrangement did pose the complication that components were not out in the open to maintain. However, it offered many advantages. Because sodium becomes radioactive due to neutron absorption when pumped through the reactor to the heat exchanger, by using the pool design, EBR-II designers avoided the problem of radioactive sodium leaks that would have plagued a loop system. EBR II could also have a simple piping system instead of the elaborate measures that are necessary in an open system. The enclosed system also made it easy to keep sodium in the molten state needed for circulation.

- *Closed fuel cycle—A hallmark feature of EBR-II was that it had a closed fuel cycle. That is, as anticipated from the beginning of the project, the fuel would be recycled using a separate fuel cycle facility. Plans were thus made to take fuel/breeder elements out of the reactor, reprocess them (in the process removing fission products), then refabricate fuel elements. Since fuel would be continuously reprocessed, EBR-II had the potential not only to make extra fuel, but also could exploit the full potential of the uranium. An additional advantage of this approach was that the fuel remained highly radioactive and therefore would be harder to steal; that is, it was proliferation-resistant.*
- *Fuel handling innovations—Fuel handling was complicated by a number of factors. For one thing, EBR-II engineers needed to recycle fuel quickly to keep the total fuel cycle working inventory low so that the reactor could be operated economically. Also, fuel and breeder components consisted of subassemblies that were totally submerged in sodium in the primary tank and therefore were not visible during refueling operations. In addition, designers wanted to store fuel for fission-product decay-heat removal while the reactor was in operation. Extracting the fuel, transferring it first out of the reactor to a fuel storage rack and then out of the primary tank and then to the fuel cycle facility, then reprocessing and refabricating the fuel elements and transferring them back into place, was accomplished with a series of cleverly designed, meticulously engineered remote handling devices— grippers, a hold-down mechanism, and a transfer arm, as well as specialized devices for fabrication and for transferring the highly radioactive elements safely in and out of the sodium environment.*

Author's comment: When I worked at Atomic International, I was the control and instrumentation engineer for several Clinch River subsystems. One of these was the sodium-removal and decontamination subsystem.

This subsystem took the fuel / breeder elements (and potentially other components) after they had been removed from the LMFBR primary system and first removed the sodium coating using nitrogen and water vapor. This process-gas slowly reacted sodium into sodium hydroxide, Then the sodium hydroxide was washed off with water. Then the surfaces of the components were acid-etched to remove the most radioactive outer-layer (most highly-activated).

The way we detected when all of the sodium-coating had been converted to sodium hydroxide was to monitor the process-gas hydrogen content (hydrogen evolved as the sodium reacted). FFTF had an operating sodium removal and decontamination system like ours and at one point had a pretty significant explosion (they called it a high-pressure transient) which blew a sizable hole in a quarter inch thick plate of stainless-steel. The transient occurred when the processing vessel was flooded with water. We were really pushing the state-of-the-art technique for measuring part-per-million hydrogen in our nitrogen-water-vapor process-gas and thus detect the smallest pockets of still-reacting sodium. There is a saying in engineering, first the theory, then the design, then the explosion, then the new theory and redesign...

2. Oklo

Oklo's technology has been built and operated before. Our fast reactor design benefits from robust inherent safety performance. The reactor is self-stabilizing, self-controlling, and cooled by natural forces. This means the plant is walk-away safe and the technology that enables this has been demonstrated at scale.²

- **Proven technology:** Over 400 operating-years of experience
- **Cutting edge innovation:** Uniquely able to recycle used nuclear fuel
- **Cost-competitive power**

There are many amazing advanced nuclear technologies, but Oklo wanted to focus on the technology with the most demonstration history, with inherent safety, while having the capability to use waste as fuel.

By far, liquid-metal-cooled, metal-fueled fast reactors have the most demonstration history of the advanced fission technologies at over 400 reactor-years of operating experience worldwide.

In fact, the very first power plant to produce useful electrical power from fission was a liquid-metal-cooled, fast reactor – the Experimental Breeder Reactor-I (EBR-I). It's successor, the Experimental Breeder Reactor-II (EBR-II), operated for decades and showed that it could easily remain safe during challenges as severe as those that led to the Fukushima accident. The tests done with EBR-II showed that the coolant could be shut off and all shutdown systems removed, and the reactor would naturally stabilize and shut itself down without damage.

² Oklo Web Site, Technology Page, <https://oklo.com/technology/default.aspx>



Starting in 1964, the Experimental Breeder Reactor-II proved the concept of fuel recycling and passive plant safety characteristics.

Only fast reactors can use waste as fuel, and in fact, this capability was demonstrated already with EBR-II. Oklo is currently doing work with the Idaho National Laboratory to take the waste fuel from EBR-II and use it for our very first Aurora Powerhouse.

EBR-II was a fast reactor that produced about 20 MW of electric power and operated for 30 years. During its illustrious history, EBR-II and its on-site facilities recycled its used fuel, demonstrated inherent safety, achieved superior operating and maintenance characteristics compared to commercial light water reactors, and sold power to the grid.

Oklo obtained a site use permit from the U.S. Department of Energy in 2019, was awarded fuel for its first reactor from Idaho National Laboratory, and has significant regulatory traction to date, including having submitted a license application to build and operate its first plant. Oklo is on track to bring its first plant online before the end of the decade.

The Aurora powerhouse is a very unusual design (see next page). Go to the Oklo home page (link below) for more details.

<https://oklo.com/energy/default.aspx>

