The Molten Salt Reactor: Nuclear Energy Without Fear?

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If he were alive today, Dr. Alvin W. Weinberg would likely be feeling a certain bitter satisfaction. The reason? The unfolding calamity at the Fukushima-Daiichi nuclear complex in Japan. As with the previous disasters at Three Mile Island in 1979 and Chernobyl in 1986, Weinberg would know that, if his concerns about nuclear safety had been listened to decades ago, none of this had to happen.

Weinberg was a brilliant nuclear physicist/engineer who worked on the atomic bomb during World War II. In 1948 he went to Oak Ridge National Laboratory (ORNL) in Tennessee, where he became one of the mid-wives at the birth of civilian nuclear power. His favorite baby was always the molten salt reactor (MSR). In his book, *The First Nuclear Era*, Weinberg refers to "ORNL's twenty-five-year love affair with the molten fluorides,"[1] referring to the molten fuel/salt technology that gave his favorite baby its name. He spent his career promoting MSR technology, but, sadly, in vain. One of the results of his failure to be heard is the visceral fear many people feel today on the subject of nuclear power.

In his book, Weinberg writes that he ". . .(B)ecame obsessed with the idea that mankind's whole future depended on the breeder,"[2] a nuclear reactor that creates more fuel than it burns. The MSR is just such a reactor. While there are various reasons beyond the scope of this article why the MSR never became the future of energy envisioned and tirelessly pursued by Weinberg, it appears there was one thing that precipitated the sealing of the fate of the MSR and, ultimately, his own fate. That one thing was Weinberg's concern about nuclear safety.

In his book, Weinberg recounts that, in 1972, while discussing safety issues with Rep. Chet Holifield, Chairman of the Congressional Joint Committee on Atomic Energy, the Representative blurted out, "Alvin, if you are concerned about the safety of reactors, then I think it may be time for you to leave nuclear energy."[3] It was clear to Weinberg that his attitude and concerns about the future of nuclear power embodied in the uranium solid fuel pressurized water reactor (PWR), on which he was the co-owner of the patent, both as to safety issues and his promotion of alternative MSR technology, were no longer in tune with the powers within the Atomic Energy Commission or the Congress. Sure enough, later that year, after 29 years at Oak Ridge, 18 as director, he was fired by the Nixon administration. A few years after that, the MSR was put on the shelf at Oak Ridge, where it remains.

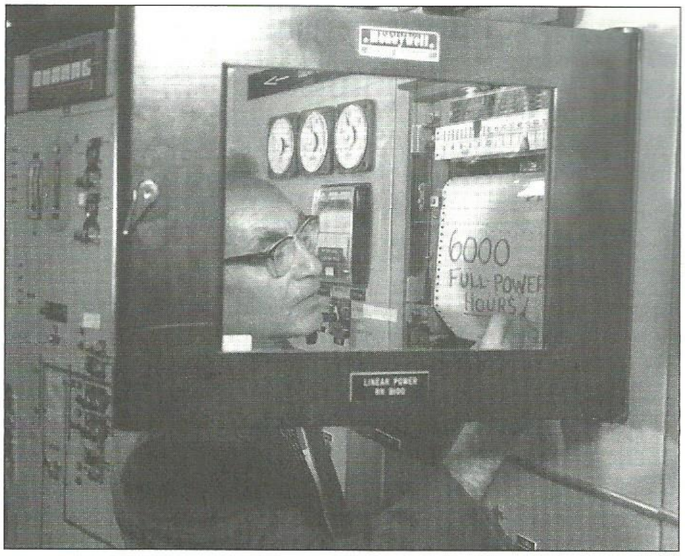
What is it about the molten fuel/salt reactor that makes it so much safer than the solid fuel uranium PWR? The answer is in the question: It is the physical state of the fuel. One is liquid and the other is solid. The solid nuclear fuel in a typical PWR is enriched uranium oxide pellets encased in zirconium alloy rods surrounded by water. If something goes wrong, that solid fuel can boil away the water and melt down. In contrast, the nuclear fuel in the MSR is dissolved in a mixture of molten lithium and beryllium salts. The whole nuclear process takes place in that liquid, which is extremely hot but very stable. By definition, therefore, the molten salt reactor cannot "melt down"; it is designed to function in a molten state.

The molten fuel/salt mixture operates at close to atmospheric pressure. In dramatic contrast, as its name implies, the pressurized water reactor must operate at extremely high pressure in order to keep the water surrounding the fuel rods from boiling, turning to steam and exploding. Every student knows that water boils at 212°F at atmospheric pressure. To keep water at 540°F in the PWR from boiling, it must be maintained at around 2250 pounds per square inch pressure (PSI). For reference, the air in your tires is 35 PSI. The whole system, by design, is one huge pressure cooker, with extremely hot water straining at all times to flash to steam and explode.

This pressure cooker design means that if there is ever a breech anywhere in the system, even a small one, pressure will drop and the water circulating at 540°F will flash to steam and instantly explode. To protect against that constant risk, the PWR must be enclosed inside a huge, and hugely expensive, steel reinforced concrete containment structure with walls many feet thick. Likewise, all plumbing and fixtures must be able to withstand the extremely high pressure. In contrast, because there is no water anywhere in the MSR, there is no risk of a steam explosion. Accordingly, it needs no such expensive containment structure or high pressure plumbing.

The use of water in the PWR process presents additional risks. If there is a power failure and pumps cannot furnish cooling water to the reactor, there is nothing to keep the fuel rods cool. As already mentioned, the inevitable result is unleashed steam, even before actual melt down. The excess heat and steam, together with the zirconium cladding of the uranium oxide fuel rods, produce hydrogen, a gas that is very explosive. In fact, at Fukushima, the loss of power caused by the tsunami resulted in overheating and the creation of hydrogen which then led to the explosions we saw on television. The hydrogen explosions blew radioactive material into the air, necessitating widespread evacuations. Because there is no water in the MSR, the risk of steam explosion or hydrogen production is non-existent.

Proponents of the molten salt reactor describe it as "walk-away safe."[4] Beneath the reactor vessel is a drain pipe. The pipe is stopped with a plug of frozen salt, the same mixture as is in the reactor. The plug is kept frozen solid by a device no more complicated than an electric fan. If there is a power failure, the fan stops and the heat of the molten salt in the reactor will quickly melt the frozen drain plug. In that event, the liquid contents of the reactor, by gravity, will drain into underground containment vessels, instantly stopping the reaction. Now safely underground, the molten fuel/salt mixture will passively cool and solidify, like candle wax on your



ORNL director Alvin Weinberg notes the 6,000th hour of molten salt reactor experiment full-power operation.

dining room table, into a substance resembling colored glass.

This glass-like solid substance is radioactive but it is safely contained. In the unlikely event of a rupture in the containment vessel, the now solidified fuel/salt mixture will stay where it is. It cannot get into the air or the water table. When power is restored, the tank's heaters melt the frozen mixture and pumps return it back into the reactor, where the reaction will automatically start up again.

These "walk-away safe" features of the MSR would have prevented Three Mile Island, Chernobyl and, now, Fukushima.

There is another safety contrast between the solid fuel PWR and the MSR—the vexing problem of nuclear waste. The uranium fuel PWR is incredibly inefficient. After only 3-5% of its fuel has been consumed in the reactor, fission products (mostly xenon-135) begin to contaminate and slow the reaction. The only solution is to shut the reactor down, remove the contaminated fuel and replace it with fresh fuel. This is an expensive process that must be done once about every 18 months to three years. Because the MSR fuel is in a liquid state, its fission products can be removed by simple chemical processes without shutting the reactor down.

The nuclear material that must be removed periodically from the solid fuel reactor is called spent fuel. This is the nuclear waste, some 70,000 tons of it now stored at nuclear power plants in the U.S. today, the disposal of which has proven to be, as yet, an unsolved problem.

The MSR burns very close to 100% of its fuel. The minimal waste that is left over measures in hundreds of pounds rather than thousands of tons for a reactor that would power a city of a million people for a year. Around 83% of that tiny amount of waste will become harmless in as little as ten years, the rest in several hundred years. The thousands of tons of spent fuel produced by the uranium solid fuel PWRs is dangerously radioactive and must be safely stored for tens of thousands of years.

Enter the MSR again. It can help solve the spent fuel waste problem created by today's solid fuel pressurized water reactors. Existing spent solid fuel is not really "spent." It still contains 95% or more of its energy. The MSR can burn all kinds of nuclear fuel—uranium, plutonium and thorium, a natural element in the earth's crust about four times more abundant than uranium. The spent fuel left over from PWRs can be added to the liquid molten fuel/salt mixture in the MSR, rather like adding more beef to the beef stew simmering on your stove. The same is true for plutonium from nuclear weapons decommissioned pursuant to international disarmament treaties. The perfect way to turn megatons into megawatts.

There is still a final safety advantage, a very important one, that molten salt technology enjoys over existing solid fuel technology, an advantage that can contribute to world security by solving the frightening problem of the threat of nuclear weapons proliferation. MSR produces almost no nuclear waste and can turn existing waste into electricity. In addition, if terrorists somehow broke into a MSR to steal, what would they find? They would find a reactor vessel filled with a mixture of molten fuel and fluoride salts, all at a temperature above 1500°F.

Even cooled, the glass-like solid would not easily yield its nuclear fuel, which is a very poor substance for use in a weapon in any case.

The fuel in a MSR is denatured with a form of uranium which emits powerful gamma radiation that would, in a short time, prove fatal to the unprotected terrorists handling it. Under ordinary operating conditions, that radiation is safely contained within the reactor vessel or underground drain tanks. But if terrorists somehow figured a way to remove the red-hot liquid fuel from a MSR plant, its radiation would easily be detectable, even from long distances. In such an unlikely situation, if they were not already sick, or even dead, from exposure to gamma radiation, the terrorists and their stolen nuclear fuel would very quickly be detected and captured.

Dr. Weinberg died in 2006, his dream of a future powered by clean, abundant, affordable and, most important, safe electric power provided by the MSR unfulfilled. But it is not too late. All of the multiple benefits of the MSR, especially its inherent safety, developed and proven over 60 years ago at Oak Ridge, are still there, on the shelf, ready and available today for additional research and development.

So the answer to my opening question is a resounding yes—the molten salt reactor can give humanity all of the benefits of nuclear energy, safely and without fear. But as long as our fear exceeds our courage and foresight, the molten salt reactor will remain on the shelf at Oak Ridge.

References

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3. *Ibid.*, 199.
4. Thompson, K. 2011. "Concepts and Prototypes: Two Next-Gen Nukes," *Popular Science*, quoting John Kutsch, Executive Director, Thorium Energy Alliance.

About the Author

Robert Orr, Jr. is recently retired from a 35-year career as an attorney. In May 2011, he addressed the President's Blue Ribbon Commission on America's Nuclear Future.

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