Thorium may be the key to the second nuclear era

(As published in The Oak Ridger's Historically Speaking column the week of April 9, 2018)

This is the third in a series of articles by Carolyn Krause on the history of the molten salt reactor developed at the Oak Ridge National Laboratory.

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Alvin Weinberg, former director of Oak Ridge National Laboratory and later of the Institute for Energy Analysis at Oak Ridge Associated Universities, was an animated speaker.

But in the original European documentary "Thorium: The Far Side of Nuclear Power," directed by Myriam Tonelotto of France, Weinberg appears as a French-speaking animated character. The film is dedicated in memoriam to Alvin Weinberg (1915-2006). I watched the French version and read the English subtitles.

Others with an Oak Ridge connection who speak in English (with French voiceovers) in the documentary are Alvin's son Rick Weinberg, retired ORNL engineer Syd Ball, and the late Dick Engel, who spent much of his career at ORNL developing the molten salt reactor (MSR), the film's subject.

The documentary's first U. S. showing was last spring at the New York International Film Festival, where it won a silver medal in the documentary category. The version with English voiceovers will be shown in March 2018 at the Oak Ridge Institute for Continuous Learning at Roane State Community College.

The educational and entertaining film also shows animated characters in a casino playing "nuclear poker" with cards and chips, suggesting that investing in the development and commercialization of passively safe MSRs is a gamble that could have big rewards. Here are some of the film's highlights.

The fuel source for MSRs could be thorium, which is found all over the world as a waste product from mining rare earths, iron and uranium. No country can monopolize this resource, discovered in 1828 in Norway and named after Thor, the Norse god of thunder; there will not be an OPEC of thorium, as there is for oil. When thorium-232 is bombarded with neutrons in a reactor, it turns into uranium-233, a fissionable fuel not found in nature. ORNL proved in 1968 that the MSR can operate on U-233 fuel. Weinberg said that U-233 would not make an effective bomb material for terrorists to steal "because it explodes too soon." Also, it must be separated from U-232, which is dangerously radioactive.

Reactors that are cooled by water or liquid metal have been used to produce both power and plutonium (for nuclear weapons). MSRs cannot generate good material for bombs, possibly explaining why the U.S. government gave MSR development lower priority.

Molten salts, Weinberg said, have many advantages over water, gas or liquid metal in a reactor. They can be used as a coolant and as a fluid fuel. Uranium and thorium in a compound of fluorine or chlorine dissolve easily in salts. Molten salts are stable under conditions of high levels of heat and radioactivity. Salts circulating in plumbing made of nickel-based alloys do not attack the material. They transfer heat very well and have high boiling points.

Pressurized-water reactors (PWRs) that produce electricity all over the world are less efficient than MSRs would be because MSRs can operate at much higher temperatures, but with lower pressures – normal atmospheric pressure. Because water is used to cool the PWRs' solid fuel – transferring heat from uranium pellets stacked in hollow rods to a steam generator – the water is kept under high pressure to prevent it from boiling off and to keep it liquid long enough in the core to effectively remove the heat. The higher pressures in a PWR raise the risk of a steam explosion.

In 1946 Weinberg and a colleague wrote a paper promoting the pressurized-water reactor Weinberg helped develop. Lieutenant Commander Hyman Rickover got the message from Weinberg that a compact, water-cooled reactor would be ideal for propelling a submarine. When Rickover worked for both the Navy and the Atomic Energy Commission, he influenced the decision to use PWRs and other light-water reactors (LWRs) in the first land-based nuclear power stations in the U.S.

As LWRs became larger in the 1970s, they were more likely to have an accident, as Weinberg predicted. In the early 1970s, ORNL researchers were asked to testify at an AEC hearing on reactor safety issues. They presented evidence

that solid-fuel cladding can become brittle, and if overheated in a loss-of-coolant accident, the zirconium in the cladding alloy can react with steam, producing zirconium oxide and hydrogen, Engel said. The resulting hydrogen gas "bubble" caused a hydrogen burn in the Three Mile Island (1979) nuclear power plant accident and explosions in the Fukushima (2011) accident.

Weinberg encouraged his researchers to tell the truth about LWRs' safety issues. Chet Holifield, chair of the Joint Committee on Atomic Energy, said, "Alvin, if you are concerned about the safety of reactors, then I think it's time you leave nuclear energy." "So in 1973, to put it bluntly, I was fired as director of ORNL," Weinberg said. His son Rick added, **"** I was a hippie and the Vietnam war was on and [many of us hated our] parents. But even then I was proud of him for getting fired for that reason."

What are the passive safety features of the molten salt reactor? Alvin and Syd Ball noted in the film that if the molten salt gets hotter, it expands and the distances between uranium nuclei increase, making them less likely to capture neutrons, slowing the chain reaction rate. Also, if electrical power is lost, a salt-containing "freeze valve" mechanism thaws, allowing the fuel salt to drain safely into tanks that shut down the nuclear reaction and passively discharge the afterheat. If radioactive molten salt starts to leak from a pipe, the liquid solidifies, sealing the crack.

In China at least 10,000 people a day are dying from fossil fuel pollution, and scientists are concerned that increased burning of fossil fuels worldwide could bring a global climate catastrophe in 100 to 200 years. Yet building new LWRs, and especially building new types of reactors such as MSRs, for nuclear power, has been meeting with resistance.

Today's nuclear industry tends to focus on short-term profits, including selling LWR solid nuclear fuels to vendors. One objection to MSRs would be that they don't require purchases of nuclear fuel rods or the return of spent fuel for processing. Also, utilities seem to prefer refurbishing older power plant reactors to extend their lives rather than buying new ones.

Even though ORNL has solved most of the structural materials and tritium release problems in the MSR, advocates for the reactor acknowledge that at least $2 billion is needed to further develop, test and commercialize MSRs of several different types. "But in the economy we are dealing with, that's not much at all," said Ball. "Goldman Sachs, the company that was instrumental in destroying the world economy in 2008, paid their employees bonuses of $16 billion in 2010. That would have been sufficient to build several large reactors, producing clean energy for 60 years and employing hundreds of people."

One type of MSR design could be a modular reactor manufactured in a factory and shipped by truck or ship to an approved power plant site, rather than being built onsite. Another type could be built as a backup to intermittent energy sources such as wind and solar power; the MSR, like its predecessor the Aircraft Reactor Experiment, could be quickly maneuvered to provide power as needed.

The animated character of Weinberg predicted that "there will be enthusiastic, younger engineers who will shape a second nuclear era." Quoting from his 1994 book "The First Nuclear Era," he concluded, "My only regret is that I shall not be here to witness their success."

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I hope you have enjoyed Carolyn Krause's excellent history of the Molten Salt Reactor. Alvin Weinberg is an Oak Ridge Icon and was a great scientist. I am proud to be a part of the Children's Museum of Oak Ridge's recent effort to digitize the Weinberg Papers that he left with Selma Shapiro http://www.oakridger.com/news/20180220/weinberg--papers-to-be-digitized-for-public--at-museum .

To make a donation to the Alvin Weinberg Papers Archive Project, send checks to the Children's Museum, 461 West Outer Drive, Oak Ridge, TN 37830. Please write Weinberg Project in the memo line. Visit the Children's Museum of Oak Ridge website at http://childrensmuseumofoakridge.org.

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This film crew led by French film director Myriam Tonelotto made the European documentary "Thorium: The Far Side of Nuclear Power"

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Dick Engel, with French film director Myriam Tonelotto

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Syd Ball, with French film director Myriam Tonelotto