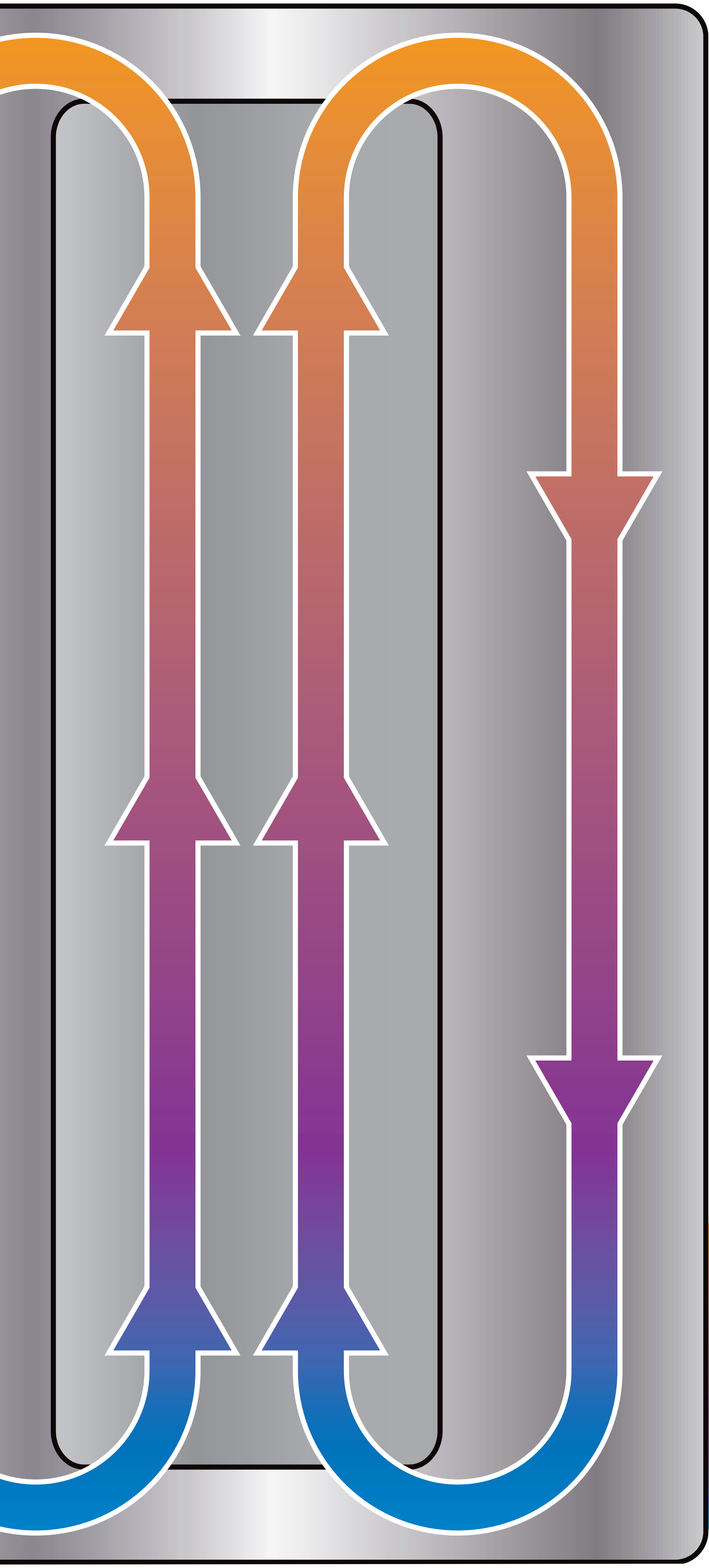

INTRODUCING THE MOLTEN SALT NUCLEAR BATTERY

Molten salt reactor technology first gained popularity in the 1960s, through the Molten Salt Reactor Experiment program at Oak Ridge National Laboratory. Now, decades later, a technology known as the molten salt nuclear battery (MsNB) is being developed to support the growing need for carbon-free, reliable, independent, and compact sources of small-scale heat and electrical power.

By Paul Marotta, Richard Christensen, and Piyush Sabharwall

Applications for the MsNB are numerous, and initial units are targeted to support locations such as sensitive Department of Defense bases or installations, which often require frequent shipments of fossil fuels to meet baseload energy demands. Other early applications include facilities that are not connected to a wide electrical grid, such as islands and off-grid industrial sites. A microreactor such as the MsNB can meet this energy demand with long-term reliable thermal and electric power. More specifically, the MsNB microreactor is currently designed to operate continuously for up to a decade.

The MsNB is a microscale nuclear fission heat source capable of providing heat to power a small commercial gas turbine on the order of 5–10 MWe. The MsNB is novel because it is a natural-circulation molten salt reactor that requires no pumps or valves. Natural-circulation power reactors have been already proven in other reactor designs. Feasibility analysis, scaled experiments, theoretical studies, and computational modeling have shown that the MsNB can provide power reliably, is radiologically safe, and as designed can provide 10 MWe of power for up to 10 years. The MsNB itself is small (a 3-meter-diameter by 3-meter-height right cylinder), transportable, and self-contained—all desirable parameters for remote and critical infrastructure use.

Development of a novel reactor design is a significant effort. The creative engineers working on the MsNB design, led by the authors and with the help of various student design projects and theses, have recently developed a new testing device that physically validates the MsNB as an improved, more reliable, and cost-effective molten salt reactor for its ability to naturally circulate liquid fuel. The device projects to save millions of dollars in testing costs and may cut up to two years off the MsNB's development timeline.

The testing device has a cylinder-within-a-cylinder configuration and uses ohmic heating to evenly heat liquid via an electric current and volumetric heating. It acts as a reactor surrogate, duplicating the internal heat generation that would occur within a reactor through fission of fuel dissolved within the molten salt. In the ohmically heated device, heat released during the ohmic heating testing process causes the salt solution within the battery surrogate to rise in the central cylinder. Once at the top, the fuel moves to a heat exchanger, where it is cooled and falls back down the space between the inner and outer cylinders. This natural circulation eliminates the need for valves and pumps, improving the reliability and simplicity of the reactor design.

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Fig. 1. Fountain test.

In a natural-circulation system, the flow is driven by the density difference resulting from the temperature variance between T_{hot} and T_{cold}. This "thermal driving head" is primarily a function of the temperature difference, not the specific temperature of the fluid. This provides the opportunity to physically validate computer simulations using low system temperatures in an environment that is not radiologically burdensome, eliminating the needs for high-temperature-alloy materials and high energy input, thus dramatically reducing overall testing cost. A patent is being filed on the concept's application to natural circulation for nuclear power plants.

Several tests have been conducted using the ohmic heating concept in a phased approach, starting with the fountain test illustrated in Fig. 1. The purpose of this initial testing was to demonstrate the ohmic heating process using saturated salt water and a welder. This was not a flowing system and generated boiling-water conditions (creating a fountain) within 20 minutes.

The next phase of testing was focused on generating naturally circulating flow within an ohmically heated flow circuit with heat input and cooling. The loop test rig was designed, built, and tested to demonstrate flow as presented in Fig. 2. Note the similar electrodes for energy input into the system near the bottom of the test rig and the cooling loop at the top left. Natural circulation was directly observed in the pipe opening at the top right of the test rig.

The next two test rigs were designed as surrogates for the MsNB with the intended objective of validating the thermal hydraulics code calculations performed with molten salt for the MsNB. The ohmically heated full-height reactor surrogate was constructed by contractor Premier Technology Inc. The visible test reactor was constructed using clear PVC material, with testing for both being conducted at Premier Technology's facility. Both units are shown in

Fig. 2. Loop test rig.

Fig. 3. Left: full-height reactor; center: a cutaway view of the full-height reactor; right: visible test reactor.

Fig. 3. All of the tests used a homogeneous, aqueous, 25 percent salt (NaCl) working fluid system and were built using the same general geometry used in several other systems designed as part of this overall program.

The temperature profiles from two sequential test runs of the full-height reactor simulator are illustrated in Fig. 4. In both plots, the T_{hot} and T_{cold} of the reactor are represented by the top two traces, and the coolant T_{in} and T_{out} are the lower two traces.

The startup case (Fig. 4, left) illustrates the development of the temperature difference across the core that, after an initial heat-up phase, decreases and becomes stable as steady-state natural-circulation flow is established. An increase in input power (Fig. 4, right) illustrates an increased temperature difference, as expected. Since natural circulation had already been established, steady state at the higher power level was established very quickly. The test system provides the opportunity to gather required data and validate both steady-state and transient modeling solutions.

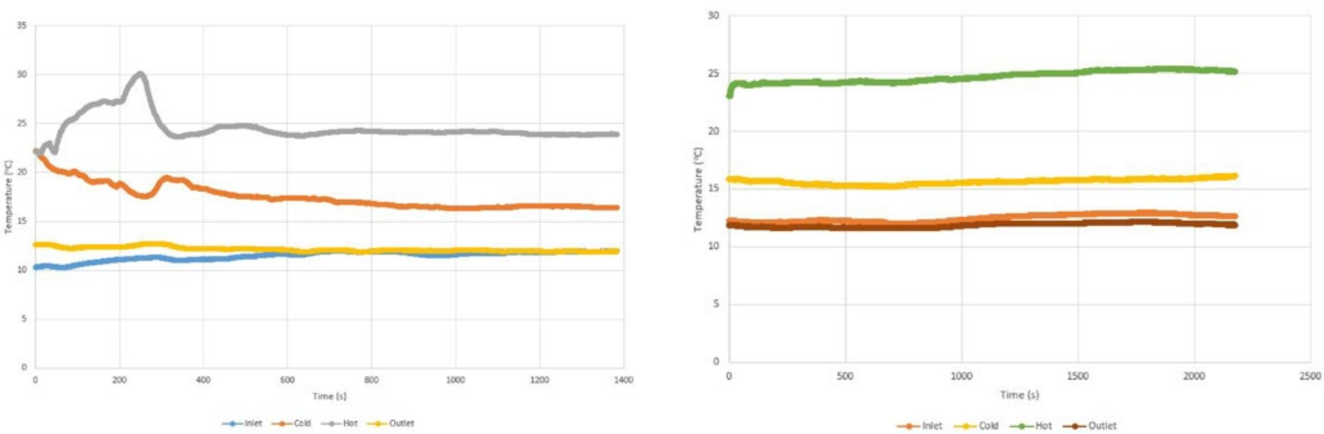

Fig. 4. Left: 40-amp-power run from startup; right: 75-amp-power run.

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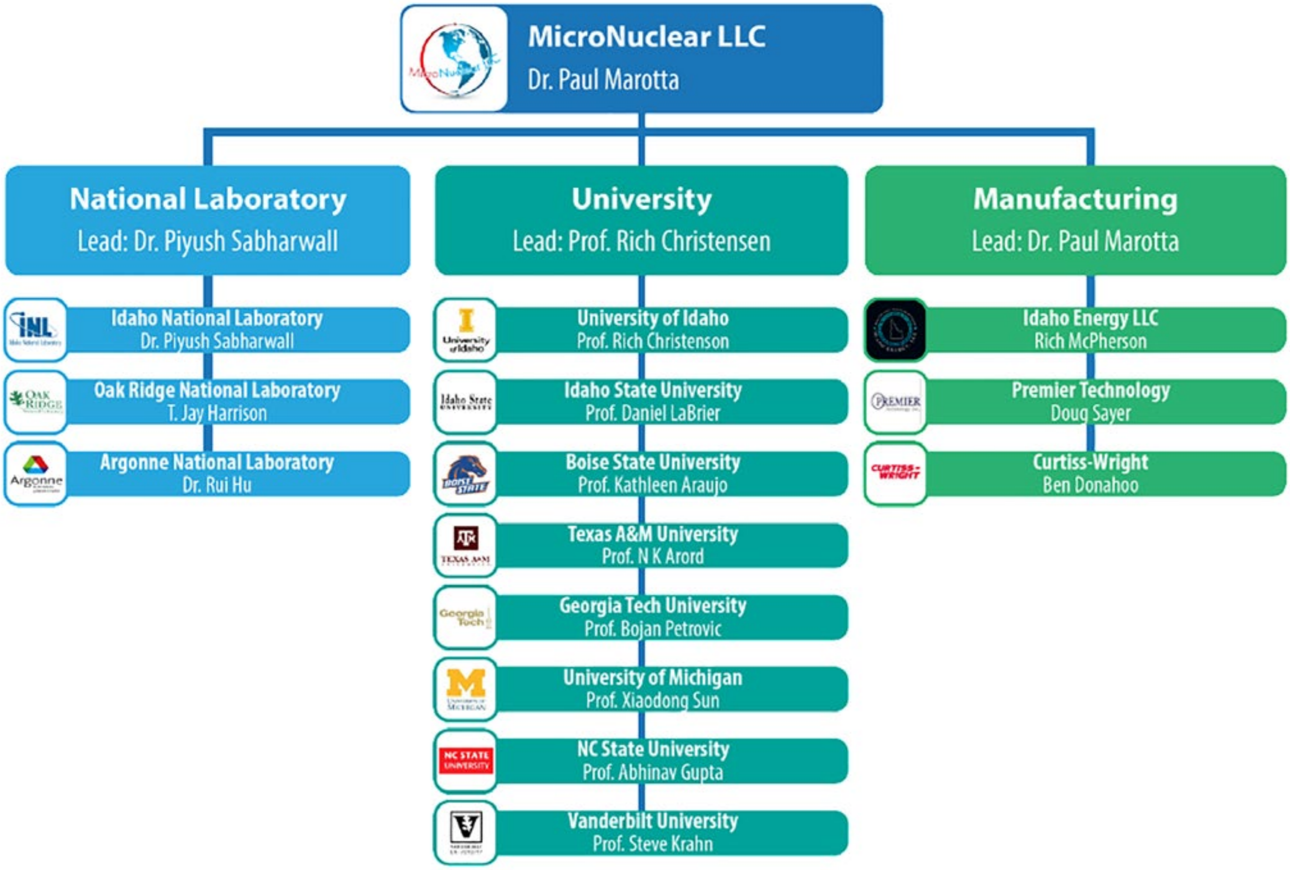

Fig. 5. MsNB project consortium.

MicroNuclear LLC plans to continue MsNB development with the support of several team members from the consortium illustrated in Fig. 5. We at MicroNuclear would like to acknowledge all the excellent supporting work conducted by students under the guidance of the University of Idaho and other supportive professionals passionate about the development of advanced nuclear energy. ⌧

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