

Nuclear Advocacy, an Independent Assessment

Gary J. Duarte, Director
US Nuclear Energy Foundation
www.usnuclearenergy.org

“Nuclear Advocacy Through Grassroots Education”

Molten Salt Reactors

**Some slides are provided with permission
from the source companies below.**



MOLTON SALT REACTORS

The Molten Salt Reactor (MSR) system produces fission power in a circulating molten salt fuel mixture with an epithermal-spectrum reactor and a full actinide recycle fuel cycle.

In the MSR system, the fuel is a circulating liquid mixture of sodium, zirconium, and uranium fluorides. The molten salt fuel flows through graphite core channels, producing an epithermal spectrum. The heat generated in the molten salt is transferred to a secondary coolant system through an intermediate heat exchanger, and then through a tertiary (3rd order) heat exchanger to the power conversion system. The reference plant has a power level of 1,000 MWe. The system has a coolant outlet temperature of 700 degrees Celsius, possibly ranging up to 800 degrees Celsius, affording improved thermal efficiency.

Molten salt reactors operated in the 1960s. *(Updated December 2018)*

They are seen as a promising technology today principally as a thorium fuel cycle prospect or for using spent LWR fuel.

A variety of designs is being developed, some as fast neutron types. Global research is currently led by China.

Some have solid fuel similar to HTR fuel, others have fuel dissolved in the molten salt coolant.

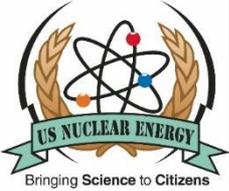
Molten salt reactors (MSRs) use molten fluoride salts as primary coolant, at low pressure. This itself is not a radical departure when the fuel is solid and fixed. But extending the concept to dissolving the fissile and fertile fuel in the salt certainly represents a leap in lateral thinking relative to nearly every reactor operated so far. However, the concept is not new, as outlined below.

MSRs may operate with epithermal or fast neutron spectrums, and with a variety of fuels. Much of the interest today in reviving the MSR concept relates to using thorium (to breed fissile uranium-233), where an initial source of fissile material such as plutonium-239 needs to be provided. There are a number of different MSR design concepts, and a number of interesting challenges in the commercialization of many, especially with thorium.

The salts concerned as primary coolant, mostly lithium-beryllium fluoride and lithium fluoride, remain liquid without pressurization from about 500°C up to about 1400°C, in marked contrast to a PWR which operates at about 315°C under 150 atmospheres pressure.

The main MSR concept is to have the fuel dissolved in the coolant as fuel salt, and ultimately to reprocess that online. Thorium, uranium, and plutonium all form suitable fluoride salts that readily dissolve in the LiF-BeF₂ (FLiBe) mixture, and thorium and uranium can be easily separated from one another in fluoride form. Batch reprocessing is likely in the short term, and fuel life is quoted at 4-7 years, with high burn-up. Intermediate designs and the AHTR have fuel particles in solid graphite and have less potential for thorium use. Graphite as moderator is chemically compatible with the fluoride salts.

Background: During the 1960s, the USA developed the molten salt breeder reactor concept at the Oak Ridge National Laboratory, Tennessee (built as part of the wartime Manhattan Project). It was the primary back-up option for the fast breeder reactor (cooled by liquid metal) and a small prototype 8 MWt Molten Salt Reactor Experiment (MSRE) operated at Oak Ridge over four years to 1969 (the MSR program ran 1957-1976). In the first campaign (1965-68), uranium-235 tetrafluoride (UF₄) enriched to 33% was dissolved in molten lithium, beryllium and zirconium fluorides at 600-700°C which flowed through a graphite moderator at ambient pressure. The fuel comprised about one percent of the fluid

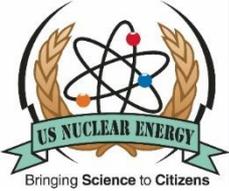


Future of nuclear will be **driven** by **grassroots education**

The design concepts for MSRs have been available since the 60s.

- We must continue bridging the gap between science, citizens & politics.
- Industry must participate in the grassroots education of the public.
- Personal discernment must help us separate truth, integrity & character from political correctness.

The future of nuclear energy will include **“Molten Salt Reactors”**



Are we politically correct but publicly inept?

US Nuclear Energy Foundation

The TRUTH about nuclear technology, must challenge politically correct.

- Nuclear has been misrepresented and demonized for so many years, the nuclear industry, agencies, groups and foundations must work to **REBRAND** nuclear for the grassroots public.
- Industry, labs, agencies and associations are reluctant support grassroots education unless they “control” the message to remain politically correct, but, this does not provide the public message.

The majority of scientists & engineers support nuclear.

Integral MSR: Canada-based Terrestrial Energy has designed the Integral MSR. This simplified MSR integrates the primary reactor components, including primary heat exchangers to secondary clean salt circuit, in a sealed and replaceable core vessel that has a projected life of seven years. The IMSR will operate at 600-700°C, which can support many industrial process heat applications. It operates in the thermal neutron spectrum with a hexagonal arrangement of graphite elements forming the moderator. The fuel-salt is a eutectic of low-enriched (2-4%) uranium-235 fuel (as UF₄) and a fluoride carrier salt – likely sodium rubidium fluoride with potential to change to FLiBe – at atmospheric pressure. Secondary loop coolant salt is ZrF₄-KF. Multiple pumps and six heat exchangers allow for redundancy. Emergency cooling and residual heat removal are passive. When the sealed core is replaced after seven years, it is then left for fission products to decay. Each plant would have space for two reactors, allowing seven-year changeover, with the used unit removed for off-site reprocessing when it has cooled.

The IMSR is designed in three sizes: 80 MWt (32.5 MWe), 300 MWt, and 600 MWt. The total levelized cost of electricity from the largest is projected to be competitive with natural gas. The smallest is designed for off-grid, remote power applications, and as a prototype. The company completed the first of three phases in the Canadian Nuclear Safety Commission's pre-licensing vendor design review in October 2018. It aims to have the first IMSRs in operation before 2030.

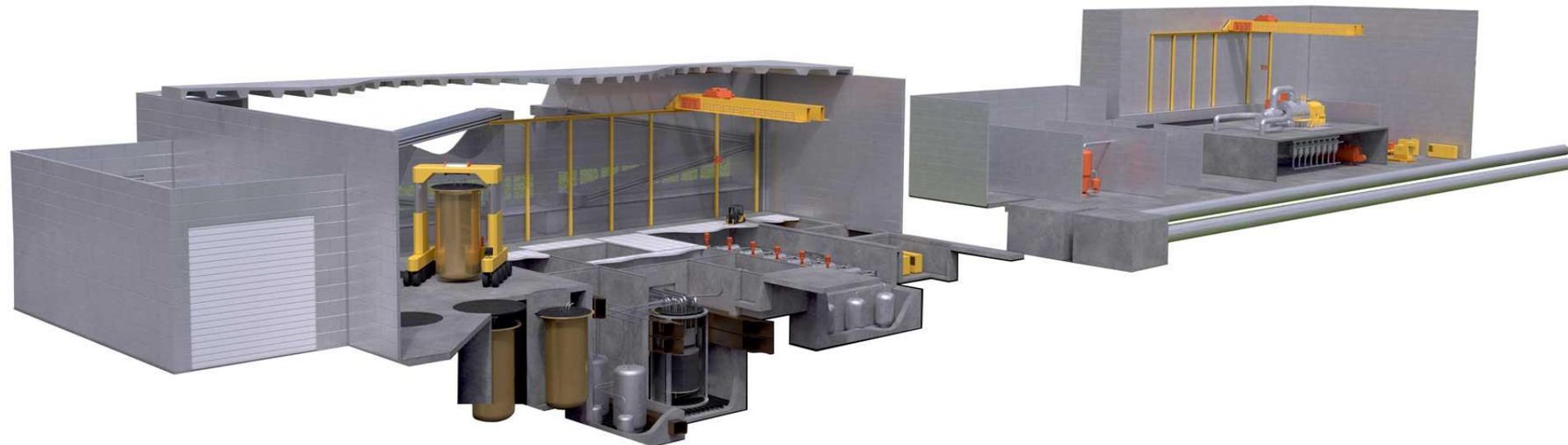


IMSR Integrated Molten Salt Reactor

Terrestrial Energy's IMSR[®]

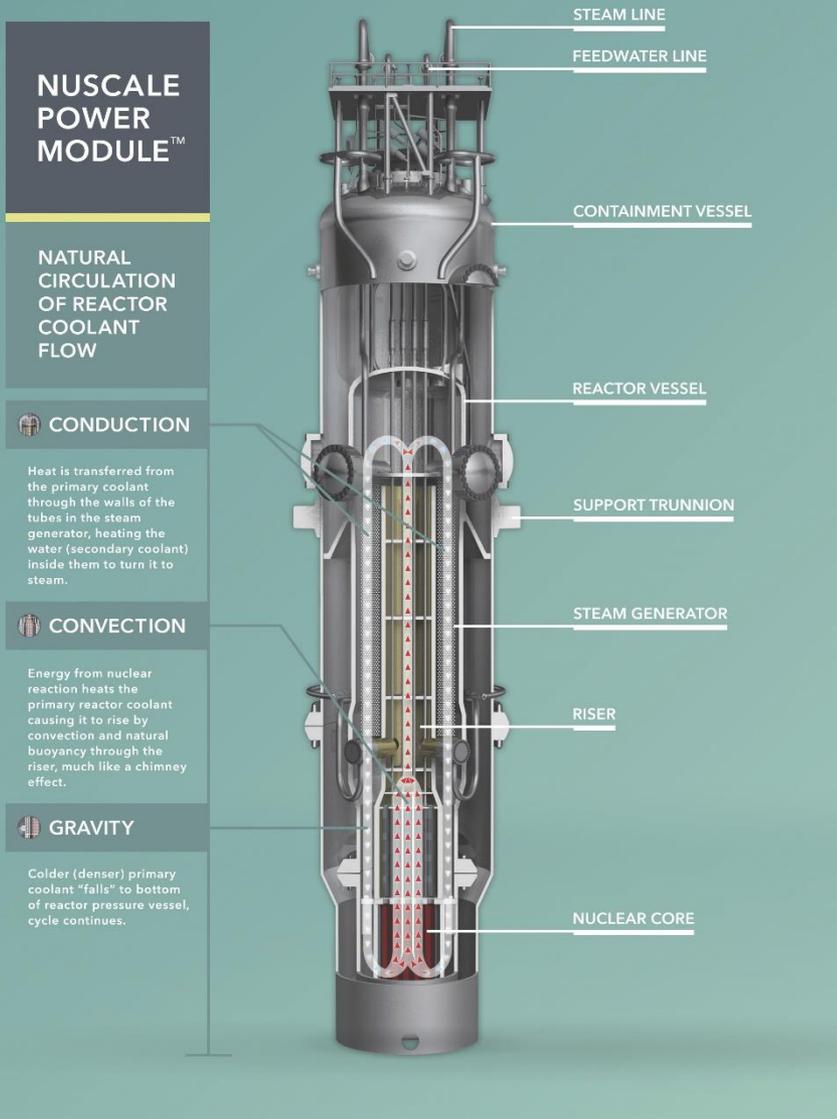
TRANSFORMATIVE CLEAN ENERGY TECHNOLOGY

To meet the increasing energy demands of global prosperity, while protecting the environment and the air in our cities that we breathe, we need a game changer.



This is a very good example of the SMR size perspective, the entire reactor & containment vessel. 76' x 15' feet.

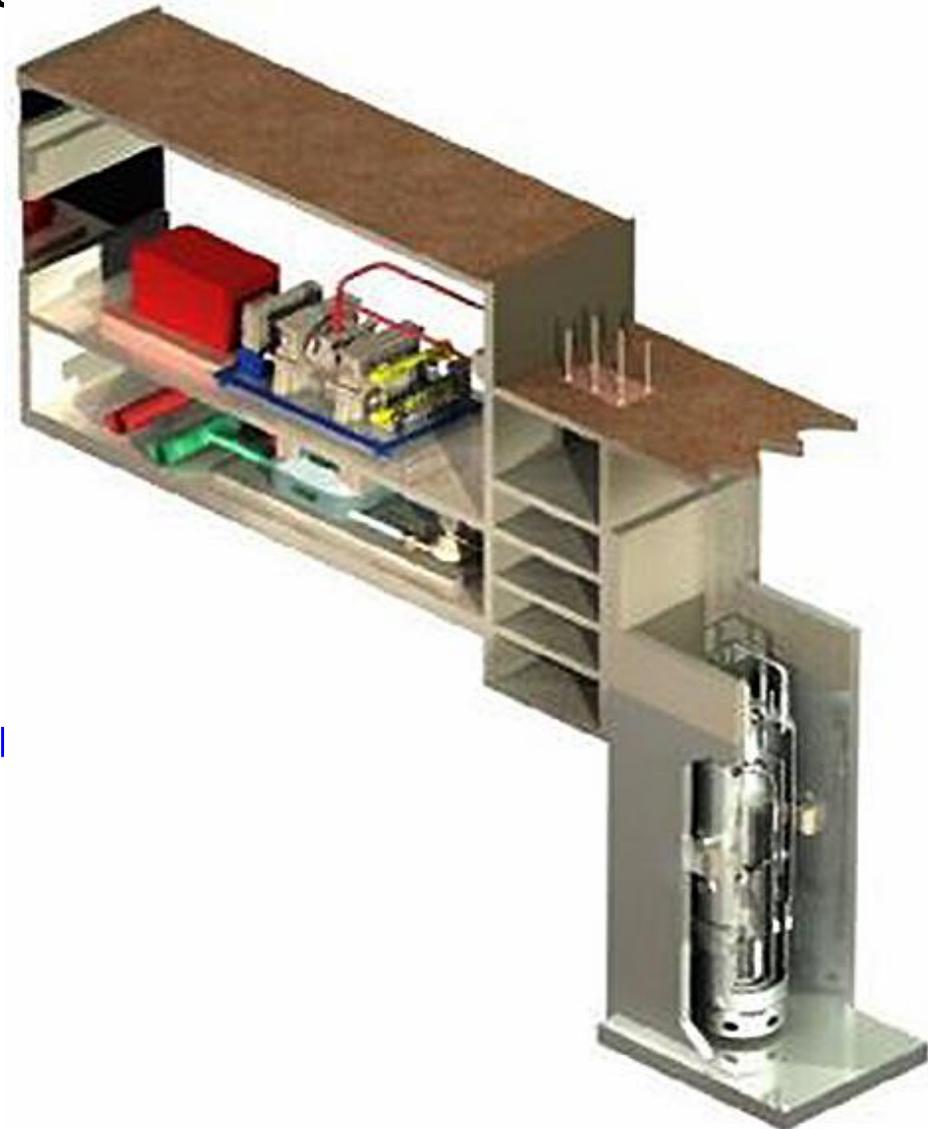
Note the man standing on the bottom right of the unit.



Can the grassroots help make the case for advanced nuclear technology development?

Why we should understand advanced reactors
Jose Reyes, CTO NuScale Power

- A new era of investing in clean nuclear energy.
- NuScale receives major NRC certification, April 2018.
- A single module is 76' tall & 15' in diameter.
- 1-module = 60 mw of power, 55,000 homes.
- A 12-module plant = 660,000 homes.
- Why safer? Sits in a one-time fill of water as a heatsink.
- It is housed in a category-1 seismic building.
- All modules can shut down without computer or human intervention.





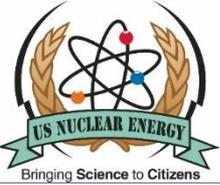
Industry must engage grassroots public policy

- The nation's primary example of science versus media & political gridlock is **NUCLEAR TECHNOLOGY** and the **FACT** is that the nuclear industry doesn't make nuclear political, media & politicians do. The DOE and NRC didn't make nuclear technology political. ANS, NEI, our universities and national laboratories didn't make nuclear political, they spend thousands of hours doing the **HARD CORE RESEARCH!**
- The **ONLY** way that our nuclear industry can counter the misrepresentation of media and political opinion is to **EDUCATE** the grassroots public on the **FACTS**. Citizens, must make the decision to adjust the perception that **MEDIA & POLITICS** have given us!
- Until America's industries, agencies and associations recognize the need for grassroots (voter education) on these **ISSUES**, nuclear advocacy will continue its 50 year failed public relations record.



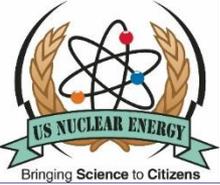
The road to a community friendly nuclear technology Is an educated grassroots citizen.

- The nation's failure to support nuclear technology has been responsible among other issues for the prevention of new nuclear research in the US.
- Grassroots public education is required for public policy reversal. E.G. NIMBY politics: Over 50% of Nevada Counties favor completion of the Yucca Mountain Application Review Process.
- USNEF has spent a decade developing & distributing educational facts about the Yucca Mountain Study for the Nevada grassroots public.



The Road to a Community Friendly Perception is GRASSROOTS EDUCATION

- The nuclear rebranding will have to demonstrate proven safety, longevity & security.
- We need to encourage the public to engage representatives to support advanced nuclear energy.
- The industry, agencies and associations will have to sign-on to supporting this grassroots public policy mission in order to bring the program to success.
- It is a vital step in proving that the public can alter political direction through an educated grassroots voter.

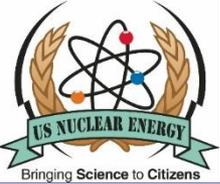


Some great \$ numbers about micro-nuclear

Micro-reactors As Cheap As Natural Gas Without Air Pollution

Brian Wang | January 16, 2019

- Westinghouse about the **eVinci reactor** which is their commercial evolution of Megapower.
- They are working on automated mass production of the heat pipes. Heat pipes are the critical technology for the reactor. They are looking to reduce the cost of heat pipes by ten times. After the first reactors are built, they will scale up to factory mass production. They will be able to build complete units in one month or less.
- The cost of the micro-reactors has a capital cost goal of \$1.98 per watt. This is the capital cost for natural gas reactors. They would be **4 times cheaper than large nuclear reactors** in the USA or Europe. They would be lower cost than large nuclear reactors in China or South Korea. There would not be the costs for containment. There would not be interest rate costs and risks for long construction times.



Some great \$ numbers about micro-nuclear

- The reactors would operate at 800 degrees celsius, which is optimal for process heat for co-generation. This would enable the reactor to fully utilize the heat and not just the electricity. This doubles the economic value of reactors.
- The newest design shows supercritical CO2 turbines. Supercritical CO2 is **many times smaller than regular steam turbines**. The small modular power enables the current supercritical CO2 turbines to be used. Large supercritical CO2 turbines have not been built.
- This reactor design does not change what is happening with nuclear waste. Nuclear waste is unburned fuel. It would be a breakthrough in construction cost, construction time, enabling higher and more valuable operating temperatures, operating safety and staffing levels.
- The \$2 per watt of electricity target price means a cost of \$20 million for a 10 MWe reactor that fits on truck. This will be a breakthrough technology for many space applications. We will be able power space bases and colonies and new propulsion. \$20 million reactors that take one month to build will be a huge breakthrough that puts nuclear power back as a major solution for global warming and for electrical and industrial transformation.