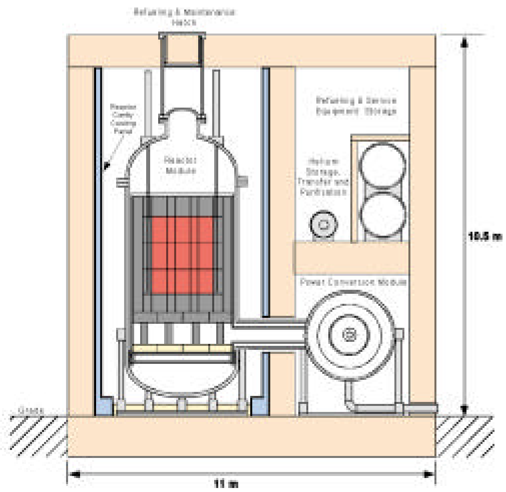
Remote Site - Modular Helium Reactor (RS-MHR)
Secure Nuclear Power for Remote Locations

The RS-MHR is a small nuclear reactor concept for providing inherently safe, secure power to remote communities and military bases. Depending on site requirements, the RS-MHR could provide steady-state power in the range of 10 to 25 MWe, i.e., sufficient power for communities of 10,000 to 25,000 people. In addition, the RS-MHR could provide heat for district heating or for desalination of seawater. The RS-MHR can be constructed in 1 year. All equipment can be truck transported over rural roads. The plant could be operated by a small technician staff and monitored by a central home office through satellite uplink.



RS-MHR Reactor System Arrangement

The Compact RS-MHR is Made Possible by Recent Technological Developments

The RS-MHR uses a gas-cooled reactor coupled to an advanced gas turbine system to achieve high efficiency and small size. Significant, recent technological developments that have made the RS-MHR possible include:

- Ultra-high quality coated particle fuel to prevent radioactive contamination of power equipment and prevent radioactivity releases even in the event of accidents.
- Compact, high-temperature plate-fine and prime surface heat exchangers to achieve very high efficiency in a small size system.
- Actively controlled electromagnetic bearing to eliminate the use of lubricants in the gas-cooled reactor system
- Major gas turbine MHR development program in the U.S. and in Russia (under the guidance of U.S. experts) through U.S. DOE, Russian and International funding.

Numerous Remote Locations Need Small Power Sources – and Fresh Water

The world still has numerous small communities, which have neither a reliable grid connection nor a steady supply of modestly priced fossil fuels. The viability of these communities in our technological age is threatened by the substandard conditions that accompany an inadequate supply of energy.

Remote Northern Community

Remote Islands need steady shipments of fuel at high transportation cost. Most islands also suffer from inadequate fresh water, which

GENERAL ATOMICS

could be alleviated by desalination using energy from an economic power supply. ***Alaska and Northern Territories*** have many small isolated communities. Some have native populations and others support mining, logging and oil supply operations. ***Isolated Communities*** in Asia, Africa and South America lack of a reliable fuel supply, and many of these communities have insufficient or polluted water supplies. ***Remote Military Bases*** rely on long-distance fuel transport, often airlifted, at very high cost.

Remote Power Plants Differ Significantly from Large Utility Power Plants

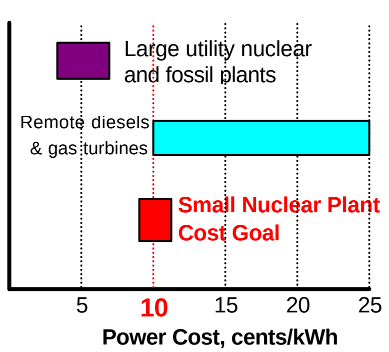
Small, remote nuclear plants must satisfy all site needs. Some unique feature include:

- ***Small Power Output*** – Peak power demand varies widely, but 10-25 MWe is a suitable range for communities of 10,000 to 25,000 people or for mining operations or military bases.
- ***Rapid Load Changes*** - Remote sites have large day-to-night load swings due to low nighttime power use. Load changes can be very rapid because of statistically fewer users. The plant itself must maintain frequency since it cannot by synchronized with a large grid.
- ***Inherent Safety*** – Remote communities, for economic and logistic reasons, cannot provide an expert staff to operate the plant or to respond to emergencies. Hence, the remote plant must be designed to reduce dependence on human beings. The plant must be inherently safe, i.e., plant safety should be assured by the laws of physics as opposed to engineered systems.
- ***Remote Transport and Construction*** – Lack of transportation access, weather and cost all restrict remote site accessibility. Refueling and special maintenance must be infrequent. Construction must be simple and not require large excavations or heavy lifting equipment. Fabricated assemblies must be transportable over rural roads with limited weight capability.
- ***Security and Non-Proliferation*** - The plant must not only be safe against neglect or error, but also malicious intent. It is very difficult to maintain effective surveillance and deterrence at remote sites. Therefore, the remote plant must have intrinsic design features to deter acts of sabotage or efforts to divert nuclear materials.
- ***Heat Rejection*** – Many remote sites have limited or no access to cooling water. The necessary civil works to make the water available may not be too expensive. Small nuclear plants that are not dependent on cooling water have a major advantage.

Competitive Power Cost is the Major Challenge

The most difficult requirement for a small nuclear plant is to have a competitive power cost with other generating options, viz., diesels and gas turbines. The competitive cost range for remote power generation is typically 10-25 cents/kWh. By comparison, the most expensive electricity in the contiguous U.S. is ~10 cents/kWh; whereas residents in the small islands off Honshu (Japan) pay ~25 cents/kWh. On balance, a 10-25MWe nuclear plant that can produce power at 10 cents/kWh would be considered attractive. Significant design simplification will be required to compensate for fixed costs, such as safety and licensing.

Small Nuclear Plant Competitive Cost Range Compared to Other Generation Types



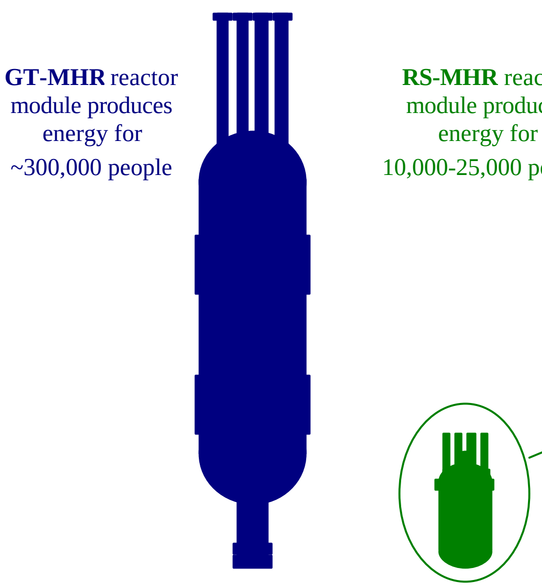
Modular Helium Reactors Offer a New Solution to an Old Problem

The use of small nuclear plants to serve remote sites without ready access to fuel is not new. In the 1960s, the U.S. Army Portable Nuclear Power Program deployed several small nuclear plants at locations such as Greenland and Antarctica. Since then several advanced concept studies, sponsored by government and industry, have addressed the problem with similar conclusions, i.e., it is extremely difficult for small nuclear plants to be cost-competitive with diesel generators and gas turbines, even with high fuel and maintenance costs. The main reason is that previous small nuclear plant concepts were burdened with the same safety requirements and sophisticated technical infrastructure as large nuclear plants. Additional concerns for security and non-proliferation generally have made small, remotely-sited nuclear reactors unattractive.

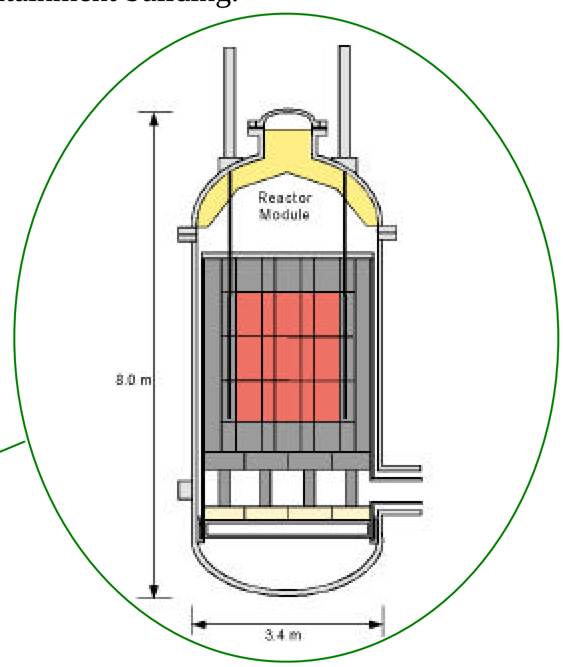
Nevertheless, it may be time to re-examine the "small reactor dream." There are two reasons: there is greater incentive for reducing the economic disparity between remote and central communities, and the available technology for solving problems unique to small remote reactors has evolved substantially in the last decade. The Modular Helium Reactor is an excellent example of such a technological advance.

The RS-MHR Uses Advanced Technology for a Compact Configuration

A small 10-25 MWe RS-MHR can be very compact for low cost and easy transport. The entire reactor and power conversion system can fit into two small pressure vessels contained within a shielded reactor building segment. The vessels are only about a one-fifth of the height of a utility version of the MHR and can be transported by standard flatbed truck. A shielded concrete structure with an ~11x10m base and ~10.5 m height above the basemat would enclose the two vessels along with all radionuclide containing, equipment, storage space and the helium purification system. The structure would be required only for shielding and not for pressure retention as in the case of a conventional reactor containment building.



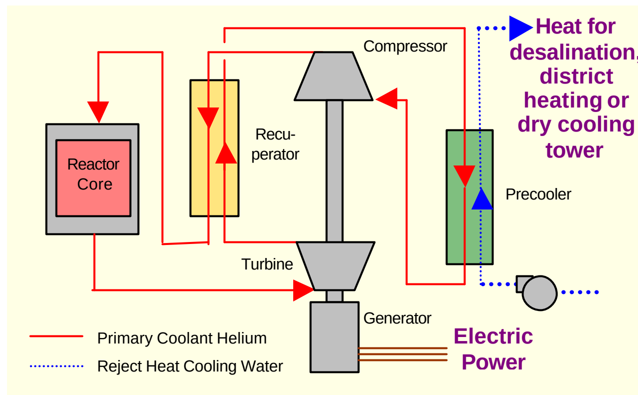
Large Utility GT-MHR vs RS-MHR



Compact RS-MHR Reactor Vessel

The RS-MHR Differs Markedly from Conventional Nuclear Plants

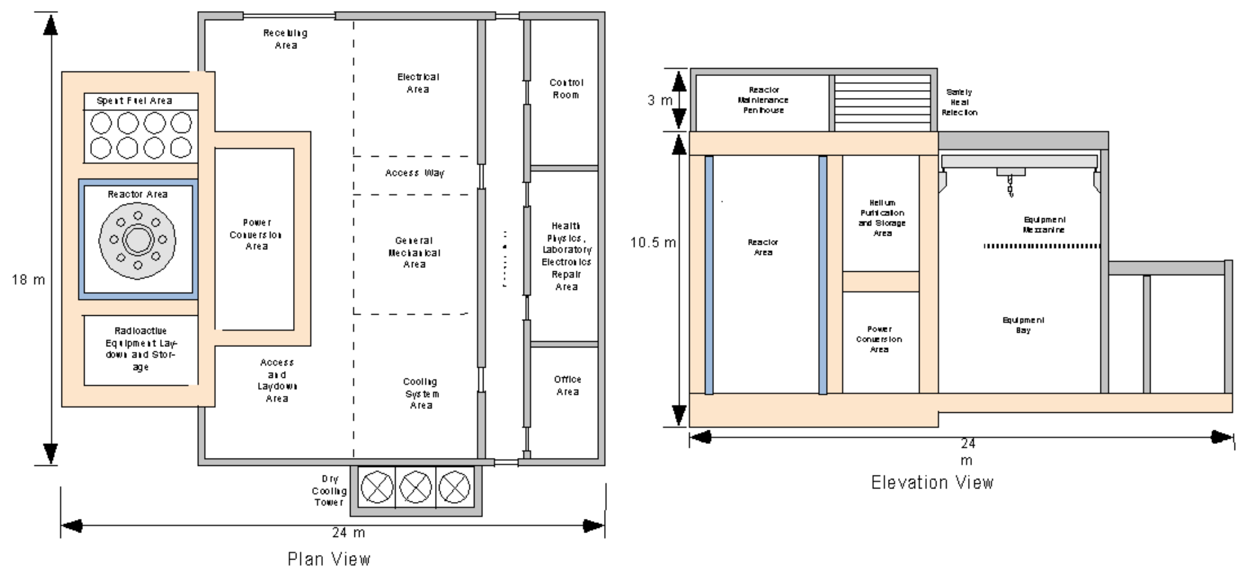
The reactor is cooled by helium gas instead of water. This enables it to be coupled directly to an advanced closed gas turbine to produces a very compact plant and eliminate many components normally associated with conventional nuclear plants such as steam generators, condensers and feedwater systems. The RS-MHR uses ceramic materials for reactor internal structures. This allows it to operate safely at high temperature, hence, high efficiency. The compact design and high efficiency help reduce the power cost. Like all gas turbines, it can reject heat at modest temperature directly to the air so that it is not dependent on cooling water. However, the reject heat can also be used for desalination or district heating at the remote site.



RS-MHR Gas Turbine Power Cycle

The RS-MHR Uses Above-Grade Construction for Rapid Deployment

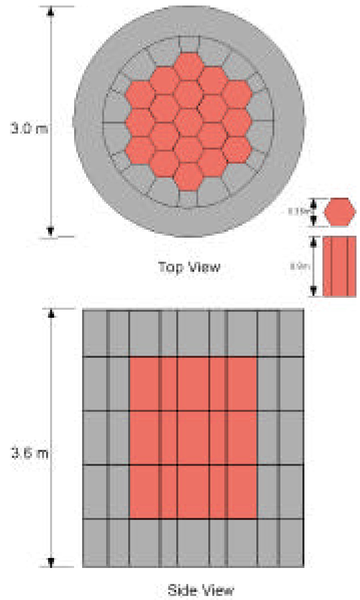
The power plant and support systems can be housed in an above-grade facility mounted on a single basemat. This eliminates the need for excavation equipment and facilitates rapid deployment. Above-grade construction also enables a high degree of siting flexibility, particularly in areas with permafrost or high ground water, e.g. islands. The reactor portion of the building is reinforced concrete ranging 0.8 to 1.2m in thickness for shielding. The support portion of the building is a standard tilt-wall or Butler-type construction and houses the service systems and control room. The total building basemat requires less than 1,300 m^3 of concrete.



RS-MHR Above-Grade Plant Layout Showing Reactor and Support Facility Arrangement

The RS-MHR Uses Proven Components From Utility Reactor Service

The reactor uses the same design principals and components that were developed and proven in large helium-cooled utility reactor operation, viz., the Fort St, Vrain Nuclear Generating Station.

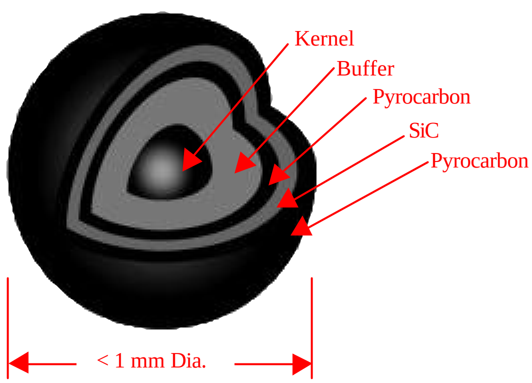


10 MWe RS-MHR Core

A 10MWe RS-MHR active core would be composed of 57 standard hexagonal graphite block blocks, while a 25 MWe core would contain 148 blocks. Each block is 0.36m across the flats by 0.8m high. The blocks have longitudinal channels for coolant flow and fuel compacts containing coated particle fuel. The core uses low enriched uranium (19.9% LEU). The active core is surrounded by a graphite reflector with an average thickness of ~0.65m. Core reactivity is regulated by control rods located in the reflector region. The core, reflectors elements and control rods would be installed in the reactor vessel at the site. The core would contain sufficient fuel for 5-10 years of operation without the need for refueling.

Coated Particle Fuel is the Key to Safety and Long Refueling Intervals

Coated particle fuel plays an important role in the safety of the RS-MHR. The ceramic coatings retain fission products during both normal operation and accident conditions. The ceramic coatings can tolerate much higher temperatures than can be achieved during even the most severe accidents. Therefore, no radioactive fission products can be released under any credible condition. These practically indestructible ceramic fuel coatings assure the safety of the residents and the protection of the environment at all times. The ceramic coated particles can burn a much higher percentage of the fissionable fuel than conventional reactors. This helps the RS-MHR to achieve long refueling intervals, an important requirement for remote sites. The core can be optimized for refueling intervals of 5 to 10 years. The high burnup also helps reduce residual plutonium and other actinides in the spent fuel. This reduces the amount of long-lived radioactive waste and makes the RS-MHR fuel cycle unusually proliferation resistant. The residual actinides in MHR spent fuel are typically ~2.5 times less than a conventional nuclear reactor.



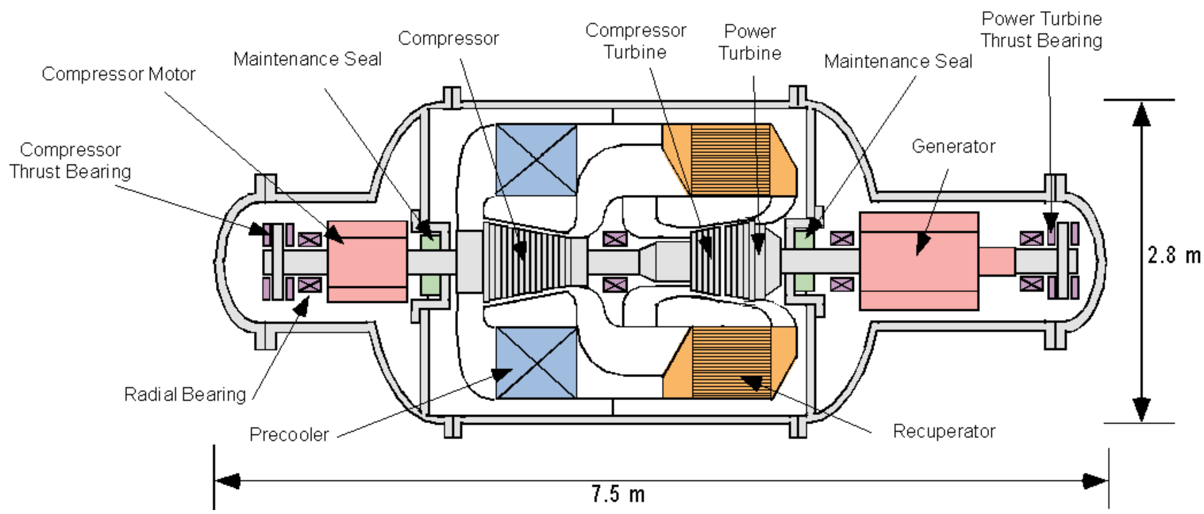
Ceramic Coated Particle Fuel

No Equipment or Operator Action is Required to Guarantee RS-MHR Safety

In addition to coated particle fuel, the RS-MHR safety is enhanced by a combination of passive and intrinsic safety features. Safety-related core decay heat is removed passively by conduction, radiation and natural convection to the environment. The inherent physics features of the core automatically terminates power excursions and shuts the reactor down in the event of operator error or control system failure. The inert helium coolant prevents the possibility of chemical reactions. There are no high-pressure water sources that could inject water into the reactor. The RS-MHR has no active safety features and requires no operator action to ensure safety.

All Power-Producing Equipment are Contained in a Single Vessel

All power conversion system equipment is contained within a horizontally orientated vessel, ~ 8m long by 2.5m in diameter. The vessel can be shipped by truck to the site with equipment installed. The system uses the most advanced gas-turbine technology available, i.e. a non-intercooled, split-shaft helium turbocompressor. The compressor is driven by the high-pressure turbine, while the generator is driven by a separate low-pressure turbine. Both shafts are suspended on magnetic bearings. The compressor and generator shafts can be conveniently pulled from opposite ends of the vessel for maintenance or replacement.



RS-MHR Power Conversion Module

The system charges power level by adjusting turbine speed. An efficient solid-state frequency converter transforms the generator output to steady 60 cycle line frequency. Plant startup is initiated by the compressor motor, which is briefly powered by the backup diesel generator. The reactor is made critical by withdrawing the control rods and the core power is increased until compressor operation is self-sustaining. Load is then applied to the generator. The reactor power and core outlet temperature are then increased until the full load demand is met.

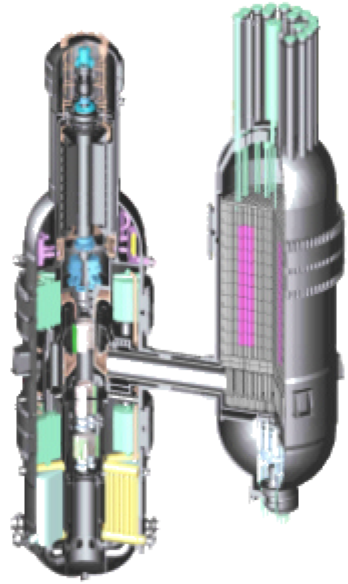
Core Decay Heat Can be Removed by Several Methods During Shutdown

Core decay heat removal is important to safety. In the RS-MHR, decay heat can be removed by either of two methods. During normal shutdown and maintenance, decay heat is removed via forced helium circulation by the compressor at reduced speed with the compressor motor. This allows the decay heat to be transferred to the precooler and rejected through the normal heat sink. A backup, passive, safety-related method of decay heat removal is accomplished by conduction through the reactor vessel wall and radiation/convection to vertical water-cooled panels inside the reactor building. The water circulates via natural convection to an air-cooled heat exchanger on the roof. If no power is available, the water is evaporated directly to the atmosphere. Several days of makeup water is provided from a small reservoir tank on the roof.

The RS-MHR has Benefits from an Extensive International Technology Base

The technology base for the RS-MHR is derived from a rich history of gas-cooled reactor development in the U.S., U.K. Germany, Japan and Russia. The technology for core design and fuel manufacture is well-developed and has been demonstrated in several operating power plants using steam cycle power conversion systems. Most notable are the Ft. St. Vrain and Peachbottom power plants in the U.S., the THTR power plant in Germany, the Dragon prototype plant in the U.K., and the recently started HTTR for process heat testing in Japan.

Likewise, several small fossil-fired, closed-cycle helium gas turbine systems have been constructed with power outputs up to 50MWe for utility service.



GT-MHR with 285 MWe Output

The coupling of the helium-cooled graphite moderated reactor to a closed-cycle gas turbine system has been studied in both the U.S. and Germany. The U.S. DOE-NE sponsored the GT-MHR program from 1992-95. This GT-MHR is a large utility-size plant with a net output of 285 MWe. Because of its ability to burn plutonium, The GT-MHR development work is being continued under a joint DOE-MINATOM program for weapons-grade plutonium disposition in Russia. At present, over 600 Russian engineers are involved in the GT-MHR design and development with oversight from U.S. experts including General Atomics.

Proposed Program for Investigating the RS-MHR

The small RS-MHR requires a much less design/development effort than a large MHR. Because of the smaller size, a wider range of potential vendors for key components are available. Many of the components, including fuel can be adapted or extrapolated from existing suppliers. The major uncertainty, hence challenge, is to determine whether the RS-MHR can be cost competitive with conventional remote power suppliers, notably diesel generators and natural gas-fired gas turbines. In order to bracket this uncertainty, it is necessary to perform a conceptual design and optimization study. This study would begin with selection of the design requirements, which would be developed from a collection of user requirements, safety standards and competitive system performance specifications. These requirements will serve as the basis for developing and optimizing the conceptual design. The conceptual design, in turn, will be used to perform a cost estimate as well as a plan for development and deployment of a first unit.

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