Status Report - FMR (United States of America)

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1. Overview

☐ **In Operation**

☐ **Under Construction**

☐ **Described in**

Link to PRIS	--

☑ **New Concept**

Number of Units	--
Year	2030

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	42
Gross Power Output (MWe)	--

1.1 Introduction

The Fast Modular Reactor (FMR) is a 100-MW thermal Gas-cooled Fast Reactor (GFR) being developed by General Atomics Electromagnetic Systems (GA-EMS) as a flexible and dispatchable power source to the US electricity market in the mid-2030s. The goal is to develop a safe, maintainable, cost-effective, and distributed nuclear energy-generating station based on simplified design features such as an inert coolant material, pellet-loaded fuel rods, installations with air-cooling as ultimate heat sink, and small and passive heat removal systems. Specific technologies selected to achieve this goal are helium coolant that is an inert gas with no chemical reaction with structural components, not activated, single phase, enabling high temperature operation and high thermal efficiency Brayton cycle; conventional uranium dioxide fuel, which is the most widely used and well-known fuel material, capable of high burnup and long fuel life; and silicon carbide (SiC) composite (SiGA®) cladding and internal structures, which are chemically inert in the helium environment and exceptionally radiation tolerant.

1.2 Development Milestones

2021	Start of design
2026	Concept design complete
2027	Start of pre-licensing vendor design review (in USA)
2029	Engineering design complete/ Secure necessary licenses (in USA)
2030	Start construction of a demonstration unit (in USA)
2036	Commercial operation

1.3 Design organization or vendor company

Christina.Back@ga.com

1.4 Links to designer/vendor website

https://www.ga.com/

1.5 Design Description

Figure 1. Reactor building and major systems and components arrangement designed with defense-in-depth.

1.6 Licensing Application Support Documents

Most Recent Licensing Application Support Document:

- Principal Design Criteria (PDC)
- Quality Assurance Program (QAP)

1.7 Reactor Unit in PRIS

2. Category Fields

Table 1: ARIS Category Fields

ARIS Category	Value	Units of Examples
Current/Intended Purpose	Commercial – Electric/Non-Electric	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Dispatchable	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Below-Ground	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)	Multiple Units	e.g. Single Unit, Dual Unit, Multiple Unit (# units)
Core Coolant	He	H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Reactor Core Size (1 core)	30 MWth <= Thermal power < 1000 MWth	e.g. Thermal Power < 30 MWth, 30 MWth ≤ Thermal power < 1000 MWth, 1000 MWth ≤ Thermal power ≤ 3000 MWth, Thermal power > 3000 MWth
Reactor Type	GFR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	None	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout	Direct-cycle	e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type

Primary Circulation	Forced (1 pumps)	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Brayton	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	Other	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly/Bundle	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Triangular	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	120	e.g. #, n/a
Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Conceptual Design	e.g. Conceptual, Detailed, Final (with secure suppliers)
Licensing Status		e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)
Neutron Spectrum	Fast	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	60	Years
Lifetime Capacity Factor	90	%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages	22	# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources	10/25	# Staff in Operation / Maintenance Crew during Normal Operation

Reference Site Design	1	n Units/Modules
Capacity to Electric Grid	42	MWe (net to grid)
Non-electric Capacity	N/A	e.g. MW(th) heat at x ºC, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption	1.9	MWe
Plant Footprint	2000	m2 (rectangular building envelope)
Site Footprint	38000	m2 (fenced area)
Emergency Planning Zone		km (radius)
Releases during Normal Operation	0/0/0	TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed	50 – 100%, 20% per minute	x – 100%, % per minute
Seismic Design (SSE)	0.3	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	7	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)		MPa(abs), i.e. MPa(g)+0.1, at secondary side outlet
Primary Coolant Inventory (incl. pressurizer)	210	kg
Nominal Coolant Flow Rate (primary)	67	kg/s
Nominal Coolant Flow Rate (secondary)		kg/s
Core Inlet Coolant Temperature	506	ºC
Core Outlet Coolant Temperature	800	ºC
Available Tempeature as Process Heat Source	N/A	ºC
NSSS Largest Component	RPV	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	11000	mm
- NSSS Largest Component Diameter	4600	mm

- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	230	tonne
Reactor Vessel Material	316H	e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design	N/A	e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory	N/A	kg
Pressurizer Design	None	e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume	N/A	m3 / m3 (total / liquid)
Containment Type	Dry (single)	Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume	4500	m3
Spent Fuel Pool Capacity and Total Volume	60/2100	Years of full-power operation / m3
Non Electric Application		-
Core Delta Temperature	294	ºC
Fuel/Core		
Single Core Thermal Power	100	MW(th)
Refuelling Cycle	180	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	17.6/19.75	%
Average Neutron Energy	100000	eV
Fuel Cladding Material	SiC	e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”	198	Specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit	140	kg
Total Fissile Loading (initial)	3100/U-235/UO2	kg fissile material (specify isotopic and chemical composition)
% of fuel outside core during normal operation	N/A	Applicable to online refuelling and molten salt reactors

Fraction of fresh-fuel fissile material used up at discharge	47	%
Core Discharge Burnup	100	MWd/kgHM (heavy metal, eg U, Pu, Th)
Pin Burnup (max.)	135	MWd/kgHM
Breeding/Conversion Ratio	<1	Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing	None	e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Rods	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber	B_4C	e.g. Gd_2O_3
Core Volume (active)	7.5	m^3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary	7E9	n/(cm²*s)
Max. Fast Neutron Flux	1.3E14	n/(cm²*s)
Core Control Rod Absorber		-
Core Soluble Neutron Absorber		-
Safety Systems		
Number of Safety Trains	Active / Passive	% capacity of each train to fulfil safety function
- reactor shutdown	Active/Passive	100 / 100 / -
- core injection	Active/Passive	100 / - / -
- decay heat removal	Active/Passive	100 /100 / -
- containment isolation and cooling	Active/Passive	100 / - / -
- emergency AC supply (e.g. diesels)	Active/Passive	- / - / -
DC Power Capacity (e.g. batteries)		Hours
Events in which Immediate Operator Action is required	None	e.g. any internal/external initiating events, none

Limiting (shortest) Subsequent Operator Action Time		Hours (that are assumed when following EOPs)
Severe Accident Core Provisions	No core melt	e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)		x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions	None	e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)	0	x/reactor-year (based on reference site and location)
Overall Build Project Costs Estimate or Range (excluding Licensing, based on the Reference Design Site and Location)		
Construction Time (nth of a kind)	24	Months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort		Person-years (PY) [DP&P]
Construction and Commissioning Effort		PY [C&C]
Material and Equipment Overnight Capital Cost		Million US$(2015) [M&E], if built in USA
Cost Breakdown	%[C&C]/%[M&E]	
- Site Development before first concrete		(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (-----------) (to add up to 100/100)
- Nuclear Island (NSSS)		
- Conventional Island (Turbine and Cooling)		
- Balance of Plant (BOP)		
- Commissioning and First Fuel Loading		
Factory / On-Site split in [C&C] effort		%/% of total [C&C] effort in PY (e.g., 60/40)
Nuclear System		
System Steam Flow Rate		kg/s
System Steam Pressure		MPa
System Steam Temperature		ºC
System Feedwater Flow Rate		kg/s

System Feedwater Temperature		ºC
Reactor Core		
Active Core Height		m
Equivalent Core Diameter		m
Average Linear Heat Rate		kW/m
Average Fuel Power Density		kW/kgU
Average Core Power Density	13.33	MW/m3
Outer Diameter Of Fuel Rods		mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

The FMR plant contains five main buildings for the reactor, auxiliary system, cooling tower, warehouse, and administration. The reactor building includes the underground containment structure, which contains the sealed containment vessel, reactor, power conversion system, and reactor cooling system, as well as the reactor vessel passive cooling system, control room, spent fuel storage, helium service system, and support equipment. The reference design allocates 9.5 acres for the FMR plant, excluding the switchyard and exclusion zones. The total space allocation including the switchyard is 16.5 acres.

Figure 2. Site-flexible FMR plant layout.

4.1 Site Requirements during Construction

4.2 Site Considerations during Operation

4.3 Grid Integration

5. Technical NSSS/Power Conversion System Designn

SUMMARY FOR BOOKLET

Primary circuit

The primary circuit consists of reactor system coupled in fluid communication to the power conversion unit. The reactor pressure vessel and power conversion unit are coupled by a cross-duct that comprises concentric inner and outer flow passageways. The power conversion unit includes a turbine, compressors, a generator, and heat exchangers. The fluid-driven turbine-generator provides a continuous output of electrical power. The reactor core cooling is conducted by the power conversion unit during normal operation and shutdown.

Reactor core and Fuel

The reactor system has a compact annular core surrounded by advanced fast neutron reflector material, i.e., zirconium silicide, graphite, and steel vessel. Low core power density and use of uranium dioxide fuel and silicon carbide composite matrix ceramic cladding secures the safety margin of the fuel. A three-batch refuelling scheme is used to enhance higher fuel utilization and reduce the requirement of excess reactivity control. The average discharge burnup is 100 GWd/tU with high assay low enriched uranium.

Fuel handling

Fuel handling activities are carried out from the floor of the maintenance hall. All access to and removal of the fuel will be by remote handling. The refuelling equipment includes a dry spent fuel storage canister and a fuel-handling machine.

Reactor protection

The reactor protection system provides automatic protective actions. These actions are accomplished by detecting abnormal plant conditions and initiating safety protective action for any condition that could threaten the integrity of a fission product barrier and, consequently, the public safety. The protection system works in functional groups that provide separation for the two types of reactor trips and all engineered safeguards.

Secondary side

The turbo-compressor is designed at 800 ºC and 7 MPa, and for a 44-MW electrical energy output. The permanent magnet generator and variable frequency converter generate electricity. The generator operates with variable turbine speeds from 6,000 rpm to 11,400 rpm and can operate as a pump motor for helium circulation during startup operations. The reference design is at 60 Hz, but it can be configured to 50 Hz. This heat sink is dry cooling with cooling towers sited outside the reactor building.

Containment

The sealed containment vessel is a free-standing cylindrical pressure vessel constructed of stainless-steel plate that is located inside the concrete containment building, independent of the concrete mat foundation, walls, or slab above. The main function of the sealed containment is to prevent the uncontrolled release of radiological material into the surrounding environment under normal operating, abnormal accident, or extreme environmental conditions including severe accident temperature and pressure changes.

Electrical, I&C and human interface

The plant electrical system includes the AC/DC power distribution, grounding and lightning protection, backup electric supply, and plant uninterruptible power supply. The I&C consists of the safety-related reactor protection system (RPS) and the non-safety-related plant protection system (PPS), plant control, data, and instrumentation system (PCDIS), and plant monitoring system (PMS). The I&C employs methods such as prioritization and plant state dependency for alarms, to avoid operator information overload caused by untimely or unnecessary audible or visual information.

Unique technical design features

The unique design features of the FMR include the helium coolant that provides super operational safety due to its single phase, non-radioactive, non-corrosive, non-toxic, and optically transparent properties; use of SiC composite material that enables high-temperature and high-burnup operation for high thermal efficiency and passive safety; dry-cooling heat sink that enables siting and quick installation at geographically diverse nodes and off-grid locations, without need for a large water source; and closed Brayton cycle that provides a high efficiency, resulting in economic benefit as well as reduced fuel consumption and high-level waste.

5.1 Primary Circuit

The primary circuit consists of reactor system coupled in fluid communication to the power conversion unit. The reactor pressure vessel and power conversion unit are coupled by a cross-duct that comprises concentric inner and outer flow passageways. The power conversion unit includes a turbine, compressors, a generator, and heat exchangers. The fluid-driven turbine-generator provides a continuous output of electrical power. The reactor core cooling is conducted by the power conversion unit during normal operation and shutdown.

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5.3 Fuel Handling

Fuel handling activities are carried out from the floor of the maintenance hall. All access to and removal of the fuel will be by remote handling. The refuelling equipment includes a dry spent fuel storage canister and a fuel-handling machine.

5.4 Reactor Protection

The reactor protection system provides automatic protective actions. These actions are accomplished by detecting abnormal plant conditions and initiating safety protective action for any condition that could threaten the integrity of a fission product barrier and, consequently, the public safety. The protection system works in functional groups that provide separation for the two types of reactor trips and all engineered safeguards.

5.5 Secondary Side

The turbo-compressor is designed at 800 °C and 7 MPa, and for a 44-MW electrical energy output. The permanent magnet generator and variable frequency converter generate electricity. The generator operates with variable turbine speeds from 6,000 rpm to 11,400 rpm and can operate as a pump motor for helium circulation during startup operations. The reference design is at 60 Hz, but it can be configured to 50 Hz. This heat sink is dry cooling with cooling towers sited outside the reactor building.

5.6 Containment/Confinement

The sealed containment vessel is a free-standing cylindrical pressure vessel constructed of stainless-steel plate that is located inside the concrete containment building, independent of the concrete mat foundation, walls, or slab above. The main function of the sealed containment is to prevent the uncontrolled release of radiological material into the surrounding environment under normal operating, abnormal accident, or extreme environmental conditions including severe accident temperature and pressure changes.

5.7 Electrical, I&C and Human Interface

The plant electrical system includes the AC/DC power distribution, grounding and lightning protection, backup electric supply, and plant uninterruptible power supply. The I&C consists of the safety-related reactor protection system (RPS) and the non-safety-related plant protection system (PPS), plant control, data, and instrumentation system (PCDIS), and plant monitoring system (PMS). The I&C employs methods such as prioritization and plant state dependency for alarms, to avoid operator information overload caused by untimely or unnecessary audible or visual information.

5.8 Unique Technical Design Features (if any)

The unique design features of the FMR include the helium coolant that provides super operational safety due to its single phase, non-radioactive, non-corrosive, non-toxic, and optically transparent properties; use of SiC composite material that enables high-temperature and high-burnup operation for high thermal efficiency and passive safety; dry-cooling heat sink that enables siting and quick installation at geographically diverse nodes and off-grid locations, without need for a large water source; and closed Brayton cycle that provides a high efficiency, resulting in economic benefit as well as reduced fuel consumption and high-level waste.

6. Technology Readiness

SUMMARY FOR BOOKLET

There are key systems and components specific to the FMR that need to be developed fully for a design to achieve its goal. Examples are the fully ceramic fuel element, reactor enclosure for the helium system, and safety system that require experimental verification of the design. The technology readiness level of the FMR is at 4 as the experimental measurements have been partially conducted for the high-burnup UO2 fuel measurements of fission gas release and swelling, a series of thermal, mechanical, and safety measurements of the SiC composite tube, low-fluence irradiation of zirconium silicide reflector, and passive reactor vessel cooling.

6.1 Deployed Reactors
6.2 Reactors under Licensing Review
6.3 Reactors in the Design Stage

7. Safety Concepts

SUMMARY FOR BOOKLET

The FMR safety is enhanced by materials and design features. The helium coolant is non-hazardous, non-explosive, non-corrosive, and not activated. The annular core configuration reduces the power peaking but promotes cooling capability during emergency. Low power density and high-temperature materials secure the safety margin in the highly unlikely event of an accident. The engineered safety features (ESFs) of the FMR mitigate the consequences of postulated accidents. The ESFs include reactivity control system, reactor protection system, maintenance cooling system, reactor vessel cooling system (RVCS), and containment. The RVCS provides a redundant, passive means of transporting core residual heat during the loss of coolant accident (LOCA) followed by station blackout. The heat is removed by radiation from the reactor vessel and by natural circulation of water through the cooling system, keeping the reactor core and vessel temperatures under the design limits.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

The reference FMR design is based on once-through fuel cycle with interim storage and direct disposal. Recycling is feasible through a proliferation-resistant dry process that uses only thermal-mechanical treatment of oxide fuel without any involvement of chemicals.

The radioactive waste management systems segregate, collect, process, store, and dispose of radioactive liquid, gaseous, and solid wastes. The liquid waste system includes filtration, demineralization, and discharging processed wastes to the solid waste system. The gaseous waste system reduces the activity of the waste gas to a level acceptable for discharge to the atmosphere.

The solid waste systems include collection, solidification, packaging, and storage facilities for radioactive materials prior to their offsite shipment for disposal.

8.1 Fuel Cycle Options
8.2 Resource Use Optimization
8.3 Unique Fuel/Fuel Cycle Design Features

9. Safeguard & Physical Security

SUMMARY FOR BOOKLET

The FMR has no new or unique proliferation risks. For example, individual fuel assemblies are uniquely identified for item counting, and there is no on-line refuelling or liquid fuel. The fuelling interval is 15-year, and the total discharge is two full cores after 60-year life.

Transparent gas cooling does not interfere with inspection. Spent fuel storage is secure, below grade with restricted access; therefore, surveillance of access floor is sufficient for domestic and IAEA requirements. Spent fuels remain in storage area throughout plant lifetime and are shipped off-site during decommissioning. The plant design incorporates measures to prevent unauthorized access and/or theft of nuclear material, complying with 10 CFR 73.55 for physical protection of licensed activities in nuclear power reactors against radiological sabotage and 10 CFR 73.67 for the physical protection of special nuclear material of moderate and low strategic significance.

9.1 Safeguards
9.2 Security
9.3 Unique Safeguards and/or Security Features

10. Project Delivery & Economics

SUMMARY FOR BOOKLET

The FMR will impact the distributed energy market by providing a safe, carbon-free source of energy that is compatible with renewables and is economically viable with modular design, factory-fabrication, truck-transportation, on-site assembly, site flexibility, and low cost of capital features. The FMR is important for the 2035-and-beyond needs of the world to serve the electric power customers such as those in unique areas with almost no grid support, independent system operators (ISOs) in need of small, distributed generation, and capacity markets suffering from the continuing retirement of conventional baseload generation. The LCOE of the Nth-of-a-kind (NOAK) FMR is targeted to be $70/MWh or less.

10.1 Project Preparation and Negotiation
10.2 Construction and Commissioning
10.3 Operation and Maintenance