Status Report - HOLOS-QUAD (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	--

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	10
Gross Power Output (MWe)	--

1.1 Introduction

The HOLOS-Quad microreactor is a high-performance gas-cooled reactor designed for transport, featuring four Sealed Power Modules (SPMs) that convert thermal energy into electricity. Each SPM uses a closed-loop full Brayton gas thermodynamic cycle, with an efficiency of 42% for air-cooling and 45% for water-cooling. The system has a load-following rate of 10% of the reactor nominal power per minute and is offered in different configurations to meet specific requirements and power rating.

The HOLOS-Quad design is a high-temperature process heat generator suitable for non-carbon fuel production (e.g., hydrogen), steelmaking and other high-temperature industrial applications. It has load-following capability, making it suitable for distribution, powering microgrids and stand-alone electric island. The scalable design can also supply emergency power generation for disaster areas, and large commercial reactors. Scaled-down versions can supply power on demand for space propulsion, deep-space, lunar surface and Mars missions. Traditional applications include providing carbon-free power to remote communities and terrestrial or offshore mining operations currently relying on fossil fuel burning.

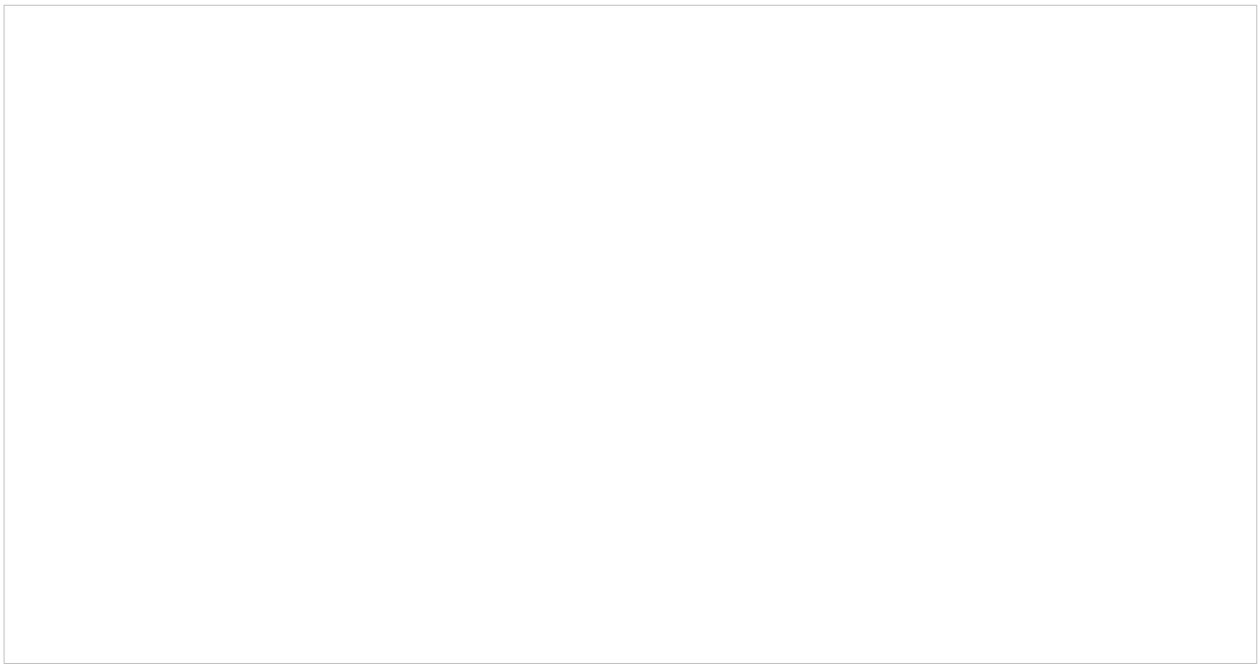


Figure 1. HOLOS-Quad Concept

1.2 Development Milestones

2017	Conceptual design developed by Filippone & Associates LLC (F&A)
2018	HolosGen LLC developed and successfully tested the Holos-Test-Assembly-1 (HTA-1) subscale prototype equipped with a surrogate core
2019	HolosGen awarded by the U.S. DOE ARPA-e MEITNER funding program to demonstrate safety and techno-economic performance
2022	Completed construction of the Sealed Power Module subscale simulator (SPM-SS) with helium as working fluid at 7 MPa pressure for the full-scale SPM. Completed design validation demonstrating: 45% net plant efficiency; fully fitted within a single 40-foot ISO shipping container; 8 EFPY, passive decay heat removal; load-following capability at a rate of 1MWe/min and safety margins with core water flooded. Key design aspects validated via testing
2023	Completed the Preliminary Safety Analysis Report (PSAR) for specific use cases involving an expandable Holos Power Station with multiple 10MWe units with undersurface installation at a U.S. federal facility
2024	Developed detailed step-by-step installation procedure for a 30MWe Holos Power Station equipped with a prefabricated removable building with reduced footprint and deactivation and decommissioning costs

2027	Planned to complete digital twin and electrical full-scale twin of the HOLOS-Quad configuration.
2028	Planned FOAK nuclear testing at U.S. DOE or alternate facility
2029	Planned conversion of the FOAK demonstrator unit into first commercial unit.

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

The underlying design philosophy for all HOLOS design configurations relies on unique design features that enhance safety by eliminating or reducing the Balance of Plant (resulting in lowered Loss Of Coolant Accident probability) and reduced power plant footprint. Through high-rate and high-efficiency load-follow capability the deign operates with higher fuel utilization, which directly reduces the volume of spent fuel and thermal pollution per unit of electrical energy generated. From an economic standpoint the HOLOS design philosophy results in substantial reductions of the costs associated with: i) capital construction; ii) operations & maintenance; iii) spent fuel transport and storage; and iv) deactivation and decommissioning activities.

1.6 Licensing Application Support Documents

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)	Mobile/Propulsion, Non-electric (The HOLOS-Quad design is a high-temperature process heat generator suitable for non-carbon fuel production (e.g., hydrogen), steelmaking and other high-temperature industrial applications.)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Inland	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)		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)	Thermal Power < 30 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	GCR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	Microreactor	e.g. PWR, SMR
Neutron Moderator	Graphite	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout		e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Brayton	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid		e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Coated Sphere	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Hexagonal	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle		e.g. #, n/a
Fuel Material Type	Carbide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Detailed 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	Thermal	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		%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages		# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources		# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design		n Units/Modules
Capacity to Electric Grid	10	MWe (net to grid)
Non-electric Capacity		e.g. MW(th) heat at x °C, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	82	m2 (rectangular building envelope)
Site Footprint		m2 (fenced area)
Emergency Planning Zone		km (radius)
Releases during Normal Operation		TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed		x – 100%, % per minute
Seismic Design (SSE)	4 (rail transport track limits)	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)		kg
Nominal Coolant Flow Rate (primary)		kg/s
Nominal Coolant Flow Rate (secondary)		kg/s
Core Inlet Coolant Temperature	590	°C
Core Outlet Coolant Temperature	855	°C

Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	Reactor vessel	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	9500	mm
- NSSS Largest Component Diameter	2300	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	40	tonne
Reactor Vessel Material		e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design		e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory		kg
Pressurizer Design		e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume		m3 / m3 (total / liquid)
Containment Type		Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume		m3
Spent Fuel Pool Capacity and Total Volume		Years of full-power operation / m3
Non Electric Application		-
Core Delta Temperature	265	ºC
Fuel/Core		
Single Core Thermal Power	22	MW(th)
Refuelling Cycle	96	months or “continuous”
Fuel Material	UCO	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	19.95	%
Average Neutron Energy		eV
Fuel Cladding Material		e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”		Specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit		kg

Total Fissile Loading (initial)		kg fissile material (specify isotopic and chemical composition)
% of fuel outside core during normal operation		Applicable to online refuelling and molten salt reactors
Fraction of fresh-fuel fissile material used up at discharge		%
Core Discharge Burnup	61	MWd/kgHM (heavy metal, eg U, Pu, Th)
Pin Burnup (max.)		MWd/kgHM
Breeding/Conversion Ratio		Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing		e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Control drum inside fuel cartridge and shutdown rods	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber		e.g. Gd2O3
Core Volume (active)		m3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary		n/(cm²*s)
Max. Fast Neutron Flux		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	- / - / -
- core injection	Active/Passive	- / - / -
- decay heat removal	Passive	- /- / -
- containment isolation and cooling	Active/Passive	- / - / -
- emergency AC supply (e.g. diesels)	Active/Passive	- / - / -
DC Power Capacity (e.g. batteries)		Hours

Events in which Immediate Operator Action is required		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		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		e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)		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)		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		MW/m3
Outer Diameter Of Fuel Rods		mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

The HOLOS-Quad is a highly integrated, transportable nuclear power plant that can be positioned horizontally within a prefabricated concrete “shield building”, or vertically within a low-cost borehole. The active magnetic bearings enable horizontal and vertical positioning of the SPMs. Each borehole is sealed at the top through a removable shielding cap. In the subsurface configuration, a first reactor unit is housed within a prefabricated building assembled with components transported within shipping containers. This design expedites installation and de-installation activities, reducing capital and decommissioning cost at the end of the licensed life of the “HOLOS Power Station”. The prefabricated building can be expanded to house multiple units with reduced upfront cost and may include an Independent Spent Fuel Storage Installation (ISFSI). The design eliminates the Balance of Plant, increases thermal-to-electric conversion efficiency with a reduced power plant footprint per unit of electric energy generated. This configuration is ideal for non-invasive installation on commercial ships and supports decarbonized “cold ironing”.

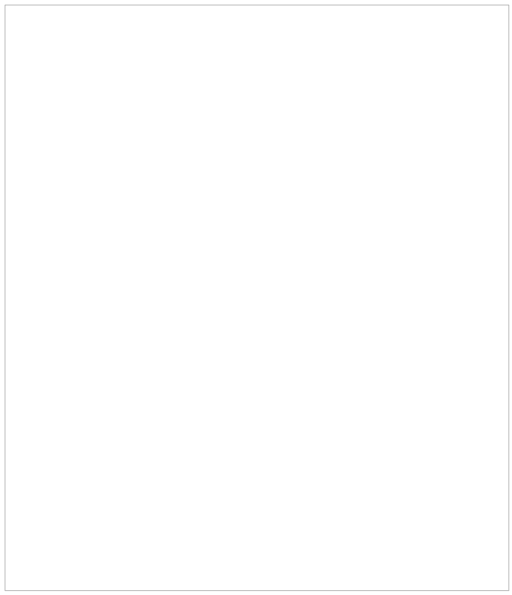


Figure 2. Layout and installation

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

Nuclear Steam Supply System

The HOLOS-Quad design configuration integrates the components forming a Brayton cycle with intercooler and recuperator heat exchangers altogether with the fuel cartridge equipping each of the four coupled SPMs. This design architecture approach eliminates the traditional Balance of Plant, reduces the working fluid inventory and the plant footprint, while enabling high-efficiency electricity supply satisfying highly variable power profiles. The design may be equipped with an intermediate heat exchanger to supply thermally coupled high-temperature process heat working fluids to support industrial applications.

Reactor Core

The HOLOS-Quad configuration of SPM contains ¼ of the core, which is mechanically coupled to form a pseudo cylindrical core geometry. The core is equipped with four fuel cartridges loaded with accident tolerant qualified TRISO fuel and burnable poison embedded within hexagonal graphite elements, ensuring optimized burnout for approximately 8 Effective Full Power Years (EFPY). The core design is safety compliant and allows safe transport during thermally active, and spent SPMs. The U.S. Argonne National Laboratory conducted and published analyses on the HOLOS-Quad SPM core performance.

Reactivity Control

The reactivity controls for the HOLOS-Quad design is achieved through independent, diversified and redundant reactivity control mechanisms based on banks of control drums and shutdown rods with assured negative reactivity insertion even under failure of a number of control drum and sbutdown rod banks.

Reactor Pressure Vessel and Internals

The HOLOS-Quad design utilizes four compact reactor pressure vessels forming independent SPMs that replace the traditional Reactor Pressure Vessel (RPV). Each SPM is designed with easy to manufacture power conversion components, integrated altogether with the reactor core. Silicon Carbide (SiC) sleeves represent the pressure boundary within the core, allowing high-pressure circulation of helium coolant at high temperature.

Reactor Coolant System and Steam Generator

Core and auxiliaries are cooled by helium thermally coupled with the Ultimate Heat Sink (UHS) through the Brayton intercooler and cooler heat exchangers. The UHS may be represented by environmental air, or environmental water assumed at 30°C. For space applications the UHS is represented by radiators for radiative heat transfer. The HOLOS-Quad design does not utilize steam generators; however, steam can be

generated as part of the process heat secondary system for selected applications.

Primary pumps

Each of the four SPMs is equipped with a High-Pressure and Low-Pressure axial compressor forming turbomachinery rotors. Each compressor is driven by a dedicated direct-drive (no gear box) variable speed motor. There is no metal-to-metal or metal-to-ceramic contact between rotary and stationary components and no need for a lubrication system as the design is equipped with redundant active magnetic bearings (AMBs).

Instrumentation and Control Systems

All HOLOS design configurations are equipped with integral power conversion components designed to follow the electrical load automatically and at high rate. The control system regulates the power flows between the thermal-to-electric conversion components, the black-start & ballast battery or flywheels (forming the ESS), the electrical loads and the core reactivity rate. The instrumentation and control systems further manage the active magnetic bearings, control drum and shutdown rod drives. During load following maneuvering the control system negotiates the compressor speed and the inventory control system which enables fast-acting power maneuvering. For a 10MWe unit, the digital instrumentation and control equipment, altogether with the ESS, occupies the volume equivalent to a 20-foot “digital I&C” ISO container, electrically coupled to the 40-ft reactor container via shielded, Electro Magnetic Interference- and Electro-Magnetic Pulse-shunted data and power cables. Note that the HOLOS-Quad does not require connection to the power grid to operate.

5.1 Primary Circuit
5.2 Reactor Core and Fuel
5.3 Fuel Handling
5.4 Reactor Protection
5.5 Secondary Side
5.6 Containment/Confinement
5.7 Electrical, I&C and Human Interface
5.8 Unique Technical Design Features (if any)

6. Technology Readiness

SUMMARY FOR BOOKLET

Testing Conducted for Design Verification and Validation

The HOLOS-Quad design has been validated by scientists and subject matter experts at the U.S. national laboratories and academic institutions through comparisons of high-fidelity computer model projections, sponsored in part by the U.S. DOE ARPA-E MEITNER funding program, with test data obtained through a non-nuclear Sealed Power Module-Subscale Simulator (SPM-SS). An electrically heated surrogate core equipping the SPM-SS was operated to mimic TRISO fuel compacts and thermal-hydraulic performance under normal operations, off-normal and accident conditions. A series of peer-reviewed technical reports, published by the Argonne National Laboratory and by the Nuclear Engineering Department at the University of Michigan, document and validate the HOLOS-Quad tecnnical and safety performance.

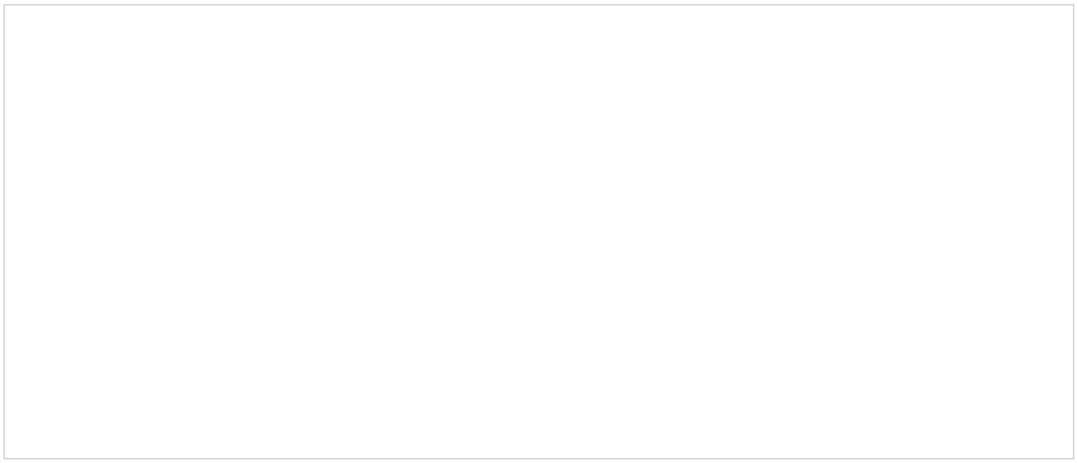


Figure 3. HOLOSGen SPM-SS Loop

Figure 4. SPM-SS HTA-2

Design and Licensing Status

A preliminary safety assessment report (PSAR) for a 30MWe HOLOS Power Station equipped with multiple units was completed in 2023. The PSAR included risk assessments during installation and removal and factored onsite and offsite maintenance, refurbishing and refueling operations, power flow and parallel connection with the bulk power grid and ESSs. A risk assessment report for multiple unit installations configured for stationary and for ship propulsion applications with tailored specific power profiles will be completed in 2024. PSARs will be submitted for review by the U.S. Nuclear Regulatory Commission (NRC) pending client's identification of final power requirements.

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

7. Safety Concepts

SUMMARY FOR BOOKLET

Engineered Safety System Approach and Configuration

The HOLOS-Quad reactor design, featuring a low power density core and passive cooling, is designed to ensure safety under normal and off-normal operating conditions. The sleeves, in each SPM, prevent radionuclide migration from potentially damaged TRISO fuel elements and eliminate the need for helium clean-up system. The Argonne National Laboratory conducted safety and technical performance analyses and the results of the inherent safety of the HOLOS-Quad thermal-hydraulic design are documented in multiple technical reports, such as the “Preliminary Thermal-Hydraulics and Selected Safety Analysis for HOLOS-QUAD Reactor Design.”

Safety Approach and Configuration to Manage DBC

The core is represented by a relatively large mass of graphite with respect to the total amount of fuel, with a relatively low power density. As a result, the fuel does not experience substantial temperature excursions under total loss of coolant circulation and total loss of coolant scenarios. As part of the design validation activities the results of thermal-hydraulic and heat transfer performance, as well as the effectiveness of passive decay heat removal have been independently peer-reviewed and published by the Argonne National Laboratory.

Safety Approach and Configuration to Manage DEC

The HOLOS-Quad design underwent Design Basis Accident and Beyond Design Basis Accident simulations validated by physical data obtained through testing of the Sealed Power Module-Subscale Simulator (SPM-SS) equipped with a graphite core and electrical heaters replacing and mimicking the behavior of TRISO fuel. The results validate the inherent safety of the design under postulated DEC as documented by technical reports published by the Argonne National Laboratory and the University of Michigan Department of Nuclear Engineering.

Containment System

The HOLOS-Quad design utilizes accident tolerant TRISO fuel with functional containment trapping radionuclides, eliminating the need for sealed structures. However, additional engineered pressure boundaries are included in all HOLOS design configurations to enhance safety. These boundaries prevent radionuclides from leaking from potentially damaged or defective microspheres and trap air surrounding the SPMs.

Spent Fuel Cooling Safety Approach / System

The HOLOS-Quad design allows for the “hot” removal of individual SPMs by mechanically separating and transferring them into shipping containers with shielded casks. If the SPMs are removed before reaching “spent” conditions, they can be repositioned and reassembled into the engineered container, allowing load-follow power generation until they become spent. The irradiated SPMs can be removed and reassembled, or permanently stored within 72 hours of their last shutdown. This is an innovative and unique feature of the HOLOS-Quad design.

Plant Safety and Operational Performances

Plant safety is ensured by the low core power density, the passive removal of decay heat, the inherent TRISO fuel tolerance to high temperature operations and excursions, and the presence of burnable poison within the graphite-TRISO matrix to ensure that core reactivity remains below safety margins even under water flooding events. As the design is configured to perform load-following power generation and can be seamlessly coupled to a “black-start & ballast” battery bank, or fly-wheel banks as Energy Storage Systems (ESSs), the operational performance is effectively real-time automatic. This approach relaxes the requirements associated with monitoring conducted by operation personnel and further reduces the Operation & Maintenance costs. Analyses conducted by the Argonne National Laboratory indicated that the net power plant efficiency remains higher than 40% for power maneuvering between 30% and 100% of nominal power. Maintaining high net plant efficiency through such a large power spectrum is another innovative and unique feature of the HOLOS designs. High efficiency operations result in a proportionally higher fuel utilization, which translate into additional sellable electricity, and a lowered volume of spent fuel per unit of electrical or process heat energy generated.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

Fuel Cycle Approach

The 10MWe HOLOS-Quad design is currently equipped with a core optimized for approximately 8 Equivalent Full Power Years (EFPY). Spent fuel elements, housed and sealed within each SPM, passively dissipate decay heat and can be placed within dual purpose transport and storage shielded dry casks with the ability to initiate transport 72 hours from the unit last shutdown. The dry casks with spent fuel, or the fuel cartridge separated from the integral power conversion system surrounded by shielding materials, comply with the dimensional constraints of ISO shipping containers. Spent fuel can also be stored at on-site Independent Spent Fuel Storage Installations (ISFSI) with transport to offsite ISFSIs at the end of the Power Station life. This approach reduces shielding requirements and costs associated with transport and storage. The currently adopted fuel cycle is “once through”.

Waste Management and Disposal Plan

The great majority of power conversion components and their ancillary components are not exposed to direct neutron irradiation, thus requiring simplified decommissioning procedures. Almost all of the SSCs forming an individual SPM can be classified as low-level radioactive and non-radioactive waste, ready for refurbishment or disposal. Costs associated with spent fuel handling, transport, and storage to onsite or offsite ISFSI are included in the HOLOS-Quad costing analysis and factor the reduced mass of spent fuel produced over 40-60 years of licensed life because of high-efficiency thermal-to-electric conversion.

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

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

10. Project Delivery & Economics

SUMMARY FOR BOOKLET

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