Status Report - HOLOS-MONO (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-Mono design is a scalable reactor that offers high-efficiency electricity and high-temperature process heat supply, ensuring compliance with customer and application-specific power profile requirements. It uses a single, scaled-up, SPM housing a traditional monolithic core, reducing capital cost and deployment time. The design optimizes the High Temperature Gas Reactor (HTGR) typology utilizing qualified TRistructural ISOtropic (TRISO) fuel, considered an Accident Tolerant Fuel (ATF). TRISO fuel has high radionuclide retention capability and does not require further containment. The HOLOS-Mono design integrates a Chemical and Volume Control System (CVCS) with the helium inventory control system, enhancing containment functions. For power rating up to 10MWe the HOLOS-Mono can be transported as a complete reactor system by standard shipping containers, while special transport is required for versions of the design with higher power rating comparable to large and Small Modular Reactor (SMR) designs (e.g., from 45MWe to 1GWe).

The HOLOS-Mono features high-efficiency load-follow electricity maximizing fuel utilization and reducing spent fuel production per unit of electric energy generated, and high-temperature process heat to support non-carbon fuel production, steelmaking and other energy intense industrial applications. The HOLOS-Mono system/sub-system model and non-nuclear prototype has been

demonstrated in an operational environment qualifying it to TRL6 (Technology Readiness Level as per NASA definition). This represents a major step forward as it retires the high technological risks associated with new and innovative technologies. The design features of scalability, customization and capability to support variable electrical loads make it ideal to support a large variety of applications including, for example, power generation for data centers, ship propulsion for commercial shipping and offshore power production, and on-demand power compensating for the intermittency of renewable energy sources. The design can also be configured to supply high-temperature process heat to decarbonize energy-intensive industrial processes.

Figure 1. HOLOS-Mono 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	Successfully tested the Sealed Power Module-Subscale Simulator (SPM-SS) operated to verify computer model projections developed by the Argonne National Laboratory. The SPM-SS was further operated through multiple shutdown and startup to simulate thermal cycling and accelerated material aging. The SPM-SS further validated safety performance under beyond design basis accident scenarios.
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-Mono 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

Safety is paramount under all operating, shutdown, transport and storage modes. By design the fuel cannot experience challenging temperatures under both design basis and beyond design basis accident scenarios. Passively cooling provides heat removal under loss of coolant and total loss of electricity. The HOLOS-Mono core operates at a relatively low power density with the graphite moderator acting as a “thermal flywheel” that prevents substantial temperature excursions under all scenarios. For example, under worst case scenarios the fuel maximum temperature briefly reaches approximately 1350°C, well below TRISO fuel

melting temperature. The ability of the design to supply variable power with high-efficiency and minimum loss in efficiency lowers the volume of spent fuel per unit of electric energy generated, thus reducing the frequency of spent fuel transport as well as risks and costs associated with these 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 (High-temperature process heat to support non-carbon fuel production, steelmaking and other energy intense industrial applications)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Inland, Below-Ground, Marine-Mobile	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		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		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 ºC, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	5000 (stationary 10 MWe underground version)	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	ºC
Core Outlet Coolant Temperature	855	ºC
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	60	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	82	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	Drums 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	Passive	- / - / -
- core injection	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

For power rating up to 10MWe per unit the HOLOS-Mono design features a highly integrated, transportable nuclear power plant fully comprised within the dimensional constraints of standard shipping containers. For above surface applications, the container is positioned via tractor trailer inside a prefabricated removable air-crash and fire-engulfment protected building. For underground operations the reactor installation is “verticalized” as the active magnetic bearings enable horizontal, angled or vertical operations. The HOLOS Power Station can also be equipped with HOLOS-Mono units with >10MWe load-follow power output without changing the design architecture.

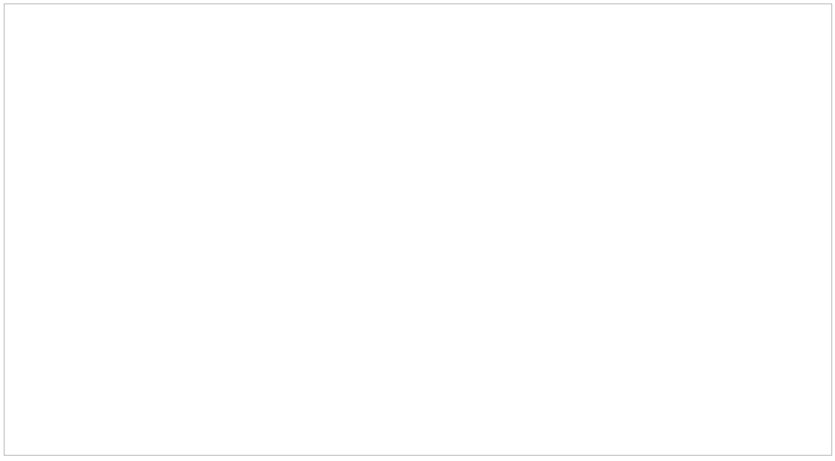


Figure 2. Plant layout

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

Nuclear Steam Supply System

HOLOS-Mono integrates the components forming a Brayton cycle with intercooler and recuperator heat exchangers altogether with the monolithic core, thus eliminating the need for the traditional Balance of Plant, reducing the working fluid inventory and plant footprint. A motor-driven compressor, mechanically decoupled from the expander, enables unique power control features and eliminates the gearbox normally coupling the compressor to the expander turbomachinery. By enabling independent rotary speed control of the compressor and the expander rotors, the design results in high conversion efficiency and high-rate load-follow power regulation. The design supports electricity and process heat supply through thermal coupling of the recuperator heat exchanger with an intermdediate heat exchanger.

Reactor Core

HOLOS-Mono core is helium cooled, graphite moderated and fueled with commercially qualified accident tolerant TRISO fuel. The core is further equipped with burnable poison optimizing the core burnout to provide for approximately 8 Effective Full Power Years (EFPY) of operation and ensuring shutdown margins under core water flooding event. Key safety and technical performance parameters have been test-validated.

Reactivity Control

Reactivity is controlled by 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 shutdown rod banks and under water flooding of the core.

Reactor Pressure Vessel and Internals

HOLOS-Mono is equipped with a non-traditional simpler to manufacture primary pressure vessel with relatively small components forming a scaled-up Sealed Power Module (SPM) comprising the power conversion system and the core. The motor-driven compressor turbomachinery and the turbine-driven generator are housed witihn portions of the primary pressure vessel designed to normally operate at a maximum pressure of 7MPa with the majority of the vessel operating at 3.5MPa. The control drums and shutdown rods are also housed within the primary pressure vessel.

Reactor Coolant System and Steam Generator

Core and auxiliaries are cooled by helium thermally coupled to the Ultimate Heat Sink (UHS) by the cooler and intercooler heat exchangers. The UHS is represented by open- or closed-loop water, or environmental air assumed at 30°C for efficiency calculations. When water-steam is selected as the process heat working fluid, steam can be generated through the intermediate heat exchanger wherein the process heat working fluid is thermally coupled to the helium circulating through the power conversion system. During operations cooling is active (as a result of the compressor operations), while decay-heat removal occurs passively.

Primary Pumps

The scaled up SPM housing the core is equipped with a helium compressor formed by High-Pressure and Low-Pressure axial turbomachinery rotors, driven by a 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 lubrication system is required as the design is equipped with redundant active magnetic bearings (AMBs).

Instrumentation and Control Systems

The design follows the electrical load automatically, with a power flow control system that maximizes the thermal-to-electric conversion efficiency while regulating the black-start/ballast battery or flywheel banks and the electrical loads. (Note that the HOLOS-Mono does not require connection to the power grid to operate). The digital instrumentation and control (I&C) system further regulates the active magnetic bearings, control drum and shutdown rod drives, and varies the compressor speed at a high-rate (supporting fast-acting power maneuvering). For a 10MWe unit, the equipment supporting I&C altogether with the power management modules regulating the Electric Storage System (ESS), occupies the volume equivalent to a 20-foot “digital I&C container” electrically coupled to the 40-ft container via shielded electro-magnetic interference and electro-magnetic pulse shunted data and power cables.

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

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Testing Conducted for Design Verification and Validation

The design has been investigated for several years by design and resource teams formed by scientists and subject matter experts at the national laboratories, industry and academic institutions, sponsored in part by the U.S. DOE ARPA-E MEITNER funding program. Validation activities included safety, technical and economic performance quantification via high-fidelity computer modeling developed by the U.S. national laboratories and testing through a subscale simulator equipped with a graphite core and electrical heater to mimic TRISO fuel behavior under normal operations, off-normal and accident conditions.

Design and Licensing Status

Preliminary safety performance analyses based on a HOLOS Power Sation formed by 3x 10MWe units with the ability to further uprate the station have been completed and verified through operations of a Sealed Power Module-Subscale Simulator (SPM-SS). Safety assessments were validated through operations of the SPM-SS at relevant full-scale operating and accident conditions. Validation testing was completed in 2022 and continued in subsequent years, qualifying the design to TRL6. A preliminary safety assessment report (PSAR) for the design installed underground at a U.S. federal facility has been completed in 2023. The PSAR 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

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Engineered Safety System Approach and Configuration

The design is equipped with the traditional HTGR safety features with enhanced safety through engineered multiple containments capable of storing the whole working fluid inventory. Decay heat is removed passively with multiple natural heat transfer mechanisms and the fuel maximum temperature remains within safety margins under Loss Of Coolant Accident and Station Black Out scenarios.

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. As a result the fuel does not experience significant temperature transients under total loss of coolant circulation and total loss of coolant scenarios with decay heat removed by natural heat transfer mechanisms with the air surrounding the SPM.

Safety Approach and Configuration to Manage DEC

The 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), a reactor simulator equipped with a graphite core and electrical heaters replacing TRISO fuel. The results validate the inherent safety of the design under postulated DEC as documented by numerous techncial publications developed by the Argonne National Laboratory and the Nuclear Engineering Depertment at the University of Michigan.

Containment System

Although qualified TRISO fuel does not require the classic large volume reinforced concrete containment mandatory for light water reactors, the equivalent primary pressure vessel within the SPM is surrounded by a secondary pressure vessel which operates at a low vacuum to capture potential helium leaks from the primary pressure vessel. As helium is collected within the volume of the second pressure vessel it is compressed back into the primary pressure vessel. A third pressure boundary formed by the volume of the shipping container is designed to capture potential helium leaking from the second pressure vessel. A final fourth containment, formed by the “reactor cavity” for subsurface configurations or “reactor compartment” for above surface, ship or off-shore configurations, ensures that potentially leaked helium and potentially activated Argon gas contained in the air surrouding the reactor remains captured until the activated Argon natrually decays a few hours later and the potentially contaminated helium is treated prior to opening the reactor cavity or compartment (e.g., for refueling, maintenace operation or for deactivation and decommissioning activities.

Spent Fuel Cooling Safety Approach / System

For HOLOS-Mono units rated at 10MWe with monolithiv cores lasting 8 years at full power, the whole unit is left within its cavity or compartment for a cooling period prior to transporting it to a specialized refueling, refurbishing or storing facility. Alternatively, the unit can be opened to conduct onsite refueling, refurbishing and maintenance activities. For these units and units with higher power rating the reactor cavity features remotely controlled equipment to robotically conduct these activities with a closed-loop passive air circulation system continuously supporting passive decay heat removal. The reactor cavity remains sealed during these periodic activities and can act as an Independent Spent Fuel Storage Installation (ISFSI) as per U.S. Department of Energy definition. Spent fuel is ultimately removed from the primary pressure vessel and inserted within transport and storage licensed spent fuel casks for onsite or offsite long term storage.

Plant Safety and Operational Performances

The underlying defense-in-depth offered by the HOLOS-Mono design is based on its qualified, accident tolerant, TRISO fuel. This type of fuel also enables high-temperature opearations leading to a high thermal-to-electric conversion efficiency. The SPM is further sealed within the container (for units’ power rating up to 10MWe) and the container is further sealed within a dedicated compartment (above

surface, ship and off-shore installation) or a reactor cavity through a low-cost borehole (below surface installations). These configurations multiple pressure boundaries engineered to trap working fluid potentially contaminated (e.g. by defective TRISO) for treatment and neutralization, thus enhancing the already high safety performance associated with HTGR technologies. The unique integral power conversion system equipping this design further enables high-rate load following maintaining >40% efficiency for electrical load >30% of its nominal power. This translates into high operational performance, higher fuel utilization, and proportionally lowered spent fuel production per unit of electric energy generated. This further enhances safety as lowered volumes of spent fuel translate into reduced risks associated with spent fuel handling, transport and storage per unit of electricity produced.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

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Fuel Cycle Approach

The design configured to supply 10MWe per unit is currently equipped with a core optimized for 8 EFPY. Spent fuel passively dissipate decay heat, and can be placed within dual purpose transport and storage licensed shielded dry cask. Overall, HOLOS-Mono spent fuel will be stored at onsite or offsite ISFSI. The fuel cycle approach currently adopted for this design is once through.

Waste Management and Disposal Plan

The great majority of the power conversion components and their ancillary components are not exposed to irradiation effects as the design is equipped with internal shields to protect turbomachinery equipment and will not require specialized decommissioning procedures. As the HOLOS-Mono power conversion system performs at high efficiency, costs and volumes associated with spent fuel transport, storage and general handling are reduced per unit of electric and process heat energy generated. Equipment subjected to irradiation and classified either as high-level or low-level radiation, as well as spent fuel in dry casks, will be processed and stored at ISFSIs.

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

9. Safeguard & Physical Security

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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