Status Report - Copenhagen Atomics Waste Burner (Denmark)

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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)	--
Gross Power Output (MWe)	--

1.1 Introduction

The Copenhagen Atomics Waste Burner is an autonomous small single module 100 MW(t) heavy water moderated, fluoride salt based, thermal spectrum, molten salt reactor the size of a 40 feet shipping container. The reactor doesn't require refuelling, human intervention, or maintenance for its 5-year design life and operates completely autonomously with passive decay heat removal. The salts and heavy moderator have, in principle, unlimited lifetime and will be reused in subsequent reactors, while the reactor vessel is the consumable and fission products are left as a by-product.

The Copenhagen Atomics Waste Burner can burn transuranics and has the potential to transition to breeding within 3 years of operation. The core and liquid moderator, fuel salt loop, blanket salt loop, coolant salt loop, fission product separation systems, dump tank, heat exchangers, and pumps, are all contained in a leak-tight steel containment, the size of a 40 feet shipping container, which in tern is placed inside a leak-tight steel 'cocoon' together with auxiliary equipment. In this way the Copenhagen Atomics Waste Burner employs three barriers to nature.

Target application

Copenhagen Atomics will design, licence, build, operate, and decommission all Copenhagen Atomics

Waste Burners. Each reactor delivers heat as a service, in the form of up to 560°C nitrate salt, to the customer. In order to facilitate early mass deployment, Copenhagen Atomics plans to initially sell to customers that need double digit GW thermal capacity to produce commodities, such as ammonia, steel, aluminium, and desalinated water.

1.2 Development Milestones

2015	Copenhagen Atomics was founded in 2015 by a group of passionate engineers and scientists meeting up since 2013 and based on an open-source model, where results and findings are shared with the thorium molten salt reactor community.
2015	First simulations of neutron economy and online fission product removal
2016	First static molten salt test
2017	First pressure driven circulation molten salt loop
2018	First pumped circulation molten salt loop
2019	Award two Danish research grants and start of collaboration with Alfa Laval
2020	First public funding round and first fertile salt test
2022	Completion of non-fission prototype of a 1MW(t) demonstration reactor
2023	Moved to 11,000 m2 production facility
2024	Started collaboration to build and license first test reactor
2026	Planned first 1 MW(t) test reactor
2028	Planned first 100 MW(t) commercial reactor

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

Design Philosophy

Copenhagen Atomics see autonomous operation without maintenance and road transportable completely factory assembled single unit reactors as essential for mass deployment and scaling of nuclear power to terawatt levels. To this end Copenhagen Atomics are developing thermal spectrum reactors with high specific fissile inventory (thermal power to total fissile inventory) and online fission product separation and targeting low enriched uranium and burning of spent nuclear fuel transuranics, as kickstarter fuel for a thermal spectrum thorium breeding cycle.

Copenhagen Atomics is focused on building and testing ‘minimal viable product’ iterations of our Copenhagen Atomics Waste Burners before going through a commercial licensing process. As part of this development process Copenhagen Atomics have developed most of the components that go into a reactor from scratch and with the ability to operate for 5 years without need of maintenance. This includes canned active electromagnetic pumps, electrochemical sensors, autonomous consensus steering electronics and software.

1.6 Licensing Application Support Documents

Design and Licensing Status

Copenhagen Atomics plans to run multiple test reactors in multiple countries before moving to commercial deployment. In 2024, Copenhagen Atomics and Paul Scherrer Institute (PSI) started a collaboration to build a facility for running moderate power criticality experiments, and are planning to license Copenhagen Atomics’s 1MW test reactor for operation at PSI.

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)	Non-electric	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location		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	Molten Salts	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	MSR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	D2O	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		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		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		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		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		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	50 000 m2 per 2.5GW(th) plant	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)	N/A	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)		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	600	ºC

Core Outlet Coolant Temperature	700	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component		e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length		mm
- NSSS Largest Component Diameter		mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight		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		ºC
Fuel/Core		
Single Core Thermal Power		MW(th)
Refuelling Cycle		months or “continuous”
Fuel Material	7LiF-UF4 or 7LiF-ThF4-(TRU)F3	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	LEU or TRU/RGPu	%
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	900 – 1000 GWd/ton	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	Heavy water level adjustment	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	Active/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

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Plant Layout Arrangement

The reactor and containment structures function as an adjacent heat source for existing or new industrial plants on site but are inaccessible from the rest of the site with a land claim of roughly 50,000 m2 per 2.5GW(t)/1GW(e) plant. Since the customer is served up to 560°C molten nitrate salt the reactor site and user can also be physically separated by up to kilometres with pipelines in between.

4.1 Site Requirements during Construction
4.2 Site Considerations during Operation
4.3 Grid Integration

5. Technical NSSS/Power Conversion System Designn

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Main Design Features

Power Conversion Unit

The Copenhagen Atomics Waste Burner delivers heat as a service and is operated by Copenhagen Atomics. The customer of the heat can choose to couple the reactor heat output with a power conversion system.

Reactor Core

The Copenhagen Atomics Waste Burner uses 7LiF-UF4 or 7LiF-ThF4-(TRU)F3 kickstarter fuel salt, 7LiF-ThF4 blanket salt, and unpressurized room temperature heavy water moderator. Bred uranium from the blanket is transferred to the fuel salt online from within the reactor container.

The heavy water moderator is circulated and cooled, and thermally isolated from the molten salts, so that the vast majority of moderator heating is through the thermalization of neutrons. The moderator cooling is achieved with an external commercial chiller, consuming a small fraction of the produced heat to maintain the moderator temperature. Employing a blanket salt allows for a compact core while maintaining a low neutron leakage. The reactor core design enables self-sustained breeding in thermal spectrum with the thorium fuel cycle, if fission products are removed online and composite core construction material is employed. Current versions of the Copenhagen Atomics Waste Burner prototype's core uses stainless steel core construction material and fission product separation limited to volatile gases.

Reactivity Control

During normal operation the liquid moderator allows core reactivity control through a simple heavy water level adjustment. Gradual lowering of fissile inventory from transuranic burning period can be compensated by gradually increasing the heavy water level. Gradual build-up of fissile inventory from breeding when predominantly running on thorium cycle can be compensated by gradually lowering the heavy water level.

The highly negative temperature reactivity feedback of the Copenhagen Atomics Waste Burner is relied upon as a second and independent reactivity control mechanism.

The fuel salt, blanket salt, and heavy water moderator are all respectively being continuously and passively drained from the core at a high rate and actively pumped and cooled before going back into the core. If power is shut off or any of the pumps tripped the reactor will shut down, due to the lack of fuel, moderator, and or reflector blanket.

Instrumentation and Control System

Copenhagen Atomics makes/writes all of our own electronics and software for the Copenhagen Atomics Waste Burner. The system uses redundant consumer grade electronics running consensus steering for autonomous operation of the reactor throughout its 5-year lifetime. All instrumentation and control systems are sealed inside the 40 feet sized reactor vessel, only serve a data uplink through data diodes, and can't be accessed or altered after production.

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

Copenhagen Atomics relies extensively on prototype testing and is envisaging testing several prototype reactors before offering a commercial reactor.

Currently, Copenhagen Atomics are operating a non-fission test reactor prototype, multi-ton scale salt production, two dozen pumped molten salt loops, four dozen static molten salt test systems, and are setting up a large scale thorium and uranium salt production, lithium enrichment facility, and production of several more non-fission test reactor prototypes at Copenhagen Atomics's 11,000 m2 facility in Copenhagen.

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 entire reactor operation and shutdown is designed to be completely autonomous with decay heat removed passively. Safety is ensured through inherent safety instead of operator action.

Decay Heat Removal System and Emergency Core Cooling System

The fuel salt is pumped through the dump tank so that in the case of a pump trip the fuel salt drains quickly to the dump tank, where the decay can conduct through the tank bottom and through the primary radiation shielding to the surroundings. This enables completely passive decay heat removal

but also means that there's always a parasitic heat loss through the same heat path during normal operation. This is an economic trade-off for enhanced passive safety.

Containment System

The reactor containment consists of three physical barriers to nature. The first barrier is the fuel salt and fission product trap wetted structure and components. The second barrier is the leak tight 40 feet size vessel that surrounds the first barrier, reactor core, reactor coolant salt, and other components. The third barrier is an exterior onsite constructed leak tight 'cocoon' containment that also serves as radiation shielding. Another path is through the reactor coolant and secondary coolant salt which is served to the customer. Here the three heat exchangers serve as three physical barriers, first the fuel salt to reactor coolant salt heat exchanger, second the reactor coolant salt to secondary coolant salt, both of these are located inside the 40 feet sized vessel, and third the heat exchanger or boiler on the customer side.

Spent Fuel Cooling Safety Approach / System

If online fission product removal is employed then the fuel salt can be transferred to a new reactor unit, at the end of life or after failure of one unit. If only online volatile fission product removal is employed then intermediate salt cleaning will be necessary before transfer to a new unit. Thus, due to the continuous use of the fuel there is no spent fuel. Fission product traps are envisioned to be left in the used reactor vessel, where their decay heat can be passively removed through the normal decay heat removal system for a cool down period before decommissioning. In the case of a failure of the salt wetted barrier where the fuel salt can't be transferred through the normal means then it would be left for a cool down period before decommissioning, where the fuel would be separated, cleaned, and reused.

Plant Safety and Operational Performances

The Copenhagen Atomics Waste Burner's safety is not dependent on the use of the heat that is delivered to the customer. The reactor doesn't require refuelling, human intervention, or maintenance for its 5-year design life and operates completely autonomously with passive decay heat removal. A plant is envisaged to have dozens of reactor units, placed together and inaccessible during operation, besides for swapping of reactor vessels under observation. Satisfactory safety statistics for commercial operation will be determined from reactor prototype operation.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

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Fuel Cycle Approach

The Copenhagen Atomics Waste Burner uses 7LiF-UF4 fuel salt with 27% mol low uranium or 7LiF-

ThF4-(TRU)F3 fuel salt with or 3% mol (TRU)F3 or RGPuF3 kickstarter fuel salt and 7LiF-ThF4 blanket salt. The reactor can transition to a breeder reactor using the heavy water level for coarse reactivity adjustment. The reactor core design enables self-sustained breeding in the thermal spectrum and thorium fuel cycle if fission products are removed online and carbon or silicon carbide composite core construction material is employed. The 100MW(t) Copenhagen Atomics Waste Burner requires an initial load of roughly 2500 kg of 4.95% enriched uranium or 300 kg of TRU/RGPu, respectively, and doesn't require any refuelling for its 5-year operation. After 5-year operation most of the fissile material in the fuel salt is 233U that was produced in the blanket. The fuel and blanket salt can be reused in subsequent reactors without adding makeup fuel.

Waste Management and Disposal Plan

The Copenhagen Atomics Waste Burner can transition to breeding within the first three years of operations with online removal of fission products and carbon or silicon carbide composite core construction material. However, the high power density of the small core limits the operation life of the reactor due to neutron irradiation, but the salts and heavy moderator have, in principle, unlimited lifetime and will be reused in subsequent reactors, while the reactor vessel is the consumable and fission products are left as a by-product.

After operation the reactor vessel and fission product trap are left to cool down before decommissioning. For decommissioning it's envisaged to separate fission products for vitrification or other uses and remelting of the vessel for non-nuclear reuse with low remaining activity and non-metals separated in the slag.

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

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10.1 Project Preparation and Negotiation

10.2 Construction and Commissioning
10.3 Operation and Maintenance