Status Report - MoveluX (Japan)

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1. Overview

- ☐ **In Operation**
- ☐ **Under Construction**
- ☐ **Described in**

Link to PRIS	--

- ☑ **New Concept**

Number of Units	--
Year	2035

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	4
Gross Power Output (MWe)	--

1.1 Introduction

MoveluX, Mobile-Very-small reactor for Local Utility in X-mark, is a 10 MW(t) class multi-purpose micro reactor. A heat-pipe is used as a primary core cooling that provides passive safety as well as system simplification. MoveluX uses low enriched uranium fuel of less than 4.99 wt% that improves nuclear security and non-proliferation. Moderator material is required to reduce the core size. In addition, high temperature operation is essential for the multi-purpose micro reactor. Therefore, calcium-hydride (CaH2) capable of operating at up to 800°C is adopted for the moderator material.

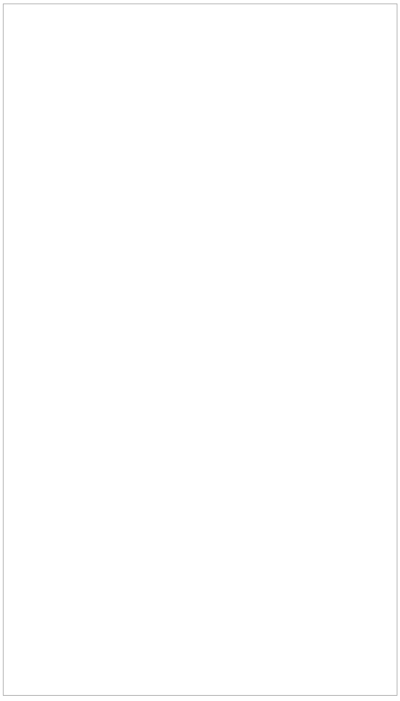


Figure 1. MoveluX design

The MoveluX reactor system is a multipurpose energy source that can be used to produce electricity, hydrogen and high temperature heat. Since the reactor system can be installed in remote sites, the heat can be provided for chemical plants and steel mills. When it is used as a power plant it can be used as a base load power source on small grids, possible in combination with renewable energy sources. Since MoveluX generates around 3 – 4 MW(e) and it can also be used for off-grid applications in remote places.

1.2 Development Milestones

2015	Start fundamental study based on the space reactor design
2017	Complete reactor type decision
2019	Start concept design
2028	Complete concept design and component demonstration
2030	Complete system demonstration without nuclear fuel
2035	FOAK demonstration

1.3 Design organization or vendor company

rei.kimura@toshiba.co.jp

1.4 Links to designer/vendor website

https://www.toshiba.co.jp/worldwide/index.html

1.5 Design Description

The MoveluX reactor system is designed as a multi-purpose energy source that includes off-grid and micro-grid electricity, high temperature heat source, hydrogen production and so forth. Designed to produce 10 MW(t), it can be used also for electricity production, possibly varying the output. Therefore, when the MoveluX reactor system is connected to a small/micro grid with load following as required and achieved by the passive reactivity control system. The figure below shows the MoveluX reactor system as a multi-purpose energy source in such a micro grid.

The major provisions of the MoveluX reactor for resource use optimization are as follows:

- Simplified plant design contributes to wastes reduction during operation and decommissioning.
- Low maintenance requirement using no-moving parts component contributes to low maintenance costs/labours and low waste amount.
- Reduced emergency planning zone contributes to accident management burden and/or cost such as for evacuation.

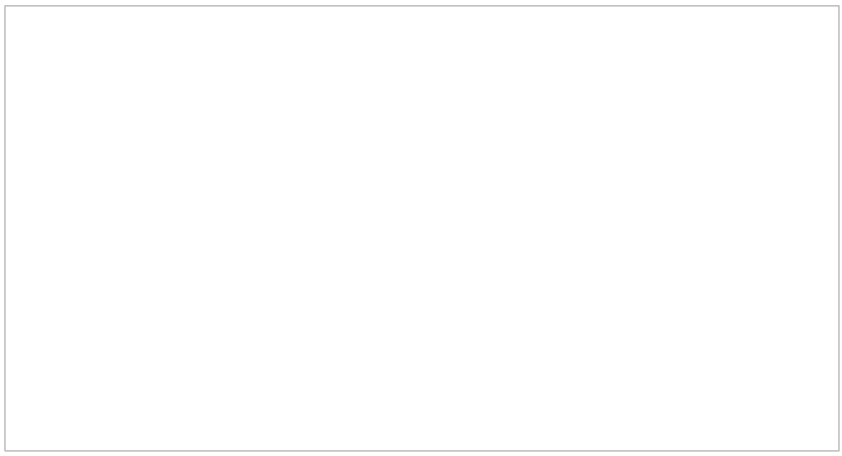


Figure 2. Utilization image of the MoveluX

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	Prototype/FOAK	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental

Main Intended Application (once commercial)	Baseload, Non-electric (District heating, industrial heating and hydrogen production)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Underground vessel and above ground turbine and generator facility	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	Sodium heat-pipe cooled	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	Others	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	Microreactor	e.g. PWR, SMR
Neutron Moderator	Other	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	Natural	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Brayton	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	He	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Prismatic	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	Other	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	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	15	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	3-4	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	100	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)	0.3	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	0.1	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	0.3	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	680	ºC
Core Outlet Coolant Temperature	685	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	6000	mm
- NSSS Largest Component Diameter	2000	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	Process heat supply, Hydrogen production	-
Core Delta Temperature		ºC
Fuel/Core		
Single Core Thermal Power	10	MW(th)
Refuelling Cycle	Continuous	months or “continuous”
Fuel Material	U3Si2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	4.8-5.0	%
Average Neutron Energy		eV
Fuel Cladding Material		e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”	66 Fuel assemblies, 72 CaH2 assemblies	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	1	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	In-Ga expansion module (IGEM)	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

SUMMARY FOR BOOKLET

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

Power Conversion

The MoveluX is considering using the gas turbine system for power conversion. The MoveluX can provide a high temperature of around 680°C, therefore, the gas turbine was selected from the viewpoint of the conversion efficiency.

Reactor Core

The MoveluX core consists of the fuel, moderator, heat-pipe and control devices. In this core, uranium silicide and calcium-hydride were used as a fuel and moderator materials. The maximum fuel enrichment is set as 4.99 wt%, from the viewpoint of economics and non-proliferation. Fuel components are installed to the core in the fabrication phase and loaded as a lifetime core, i.e. this fuel will not be extracted from the core and therefore fuel handling is not required during operation. The fuel and moderator has 10 cm wide-hexagonal shape except for the sides where provision is made (cut off is made) for the heat-pipe installation.

Fuel Characteristics

The Uranium silicide fuel has high melting point and large thermal conductivity.

Reactivity Control

A safety-rod is placed at the centre of the core for criticality safety assurance and reactor start-up. The core reactivity is controlled by the passive reactivity control device, such as In-Gd Expansion Module (IGEM).

In the case of emergency such as loss of cooling ability and/or RIA (with a postulated failure of the safety rod insertion) the core will be shut down autonomously by the material property of calcium-hydride. Specifically, calcium-hydride ability to moderate neutrons (neutron moderation power) decreases with increasing temperature since hydrogen dissociates in high temperature environments above 800°C. The proposed core design therefore has inherent safety for criticality in emergencies. If

the hydrogen pressure is increased by its dissociation, hydrogen will be processed at a hydrogen processor (details still to be examined).

Reactor Pressure Vessel and Internals

Reactor vessel with atmospheric pressure is adopted.

Reactor Coolant System

The primary circuit of the MoveluX reactor system makes use of heat-pipes which is one of the passive cooling devices, therefore, the primary circuit does not have pumps or other forced circulation devices. In the current design, sodium is selected as a working fluid of the heat-pipe from the viewpoint of usable temperature and heat transportability. The pressure in the primary system can be set close to atmospheric pressure since the proposed system does not utilize a pump for primary fluid circulation. Therefore, the risk of large-scale radioisotopes release can be reduced.

Secondary System

The secondary side of the MoveluX reactor system is currently a helium gas system. This gas system can provide high temperature around 700°C and therefore usable not only for electric power generation, but also for heat supply, hydrogen production and so on. For electricity generation a Brayton cycle can be used as the power generation system.

Steam Generator

The MoveluX not uses the steam generator in the current design, however, this option can be examined.

Instrumentation and Control System

Few I&C devices are installed to the MoveluX reactor system for the reactor start-up, monitoring and active control. Technically, the manned operation is not required during nominal operation in current design concept.

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 experiment for the verification and modelling of the thermos-syphon heat-pipe and the compact heat exchanger have been conducting. Additionally, IGEM kinetic behaviour is measured by the neutron radiography. These experiments are scale test. The actual scale test will be conducted step by step.

Design and Licensing Status

MoveluX is at the conceptual design stage.

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 reactor vessel is place below ground to enhance reactor protection and radiation shielding. The radiation shield on top of the reactor is protect the reactor from physical attacks. For the natural hazards, the MoveluX reactor protection is by the core inherent safety characteristics based on the natural principles.

Decay Heat Removal System / Reactor Cooling Philosophy

The decay heat after reactor shut down is removed passively. If heat-pipe and secondary circuit are keeping their function, decay heat removal are the same as for heat removal during nominal operation. In the case of loss of cooling ability of the heat-pipe, the decay heat is removed from the surface of reactor vessel by natural circulation of air. Furthermore, in the reactor vessel, the heat is transported from the centre to the periphery of the core by natural circulation and thermal conduction of liquid Pb-Sn, present in the gap between the fuel, heat-pipe and moderator. This decay heat removal system does not require a power source and can therefore realize a long (infinite) grace period. Consequently, the risk of core meltdown is expected to be very small.

Containment System

The fuel material is contained in the reactor vessel. The fuel material is separated from primary cooling system, because, heat-pipe is closed heat transportation device. Additionally, the heat-exchanger between heat-pipe and secondary circuit is functioning as one of the boundaries. Therefore, radionuclide will be confined in the reactor vessel unless reactor vessel breaking.

Chemical Control

The MoveluX reactor does not required chemical control.

Figure 3. Schematic view of the MoeluX reactor system

Plant Safety and Operational Performances

For the MoveluX reactor system operation, water as a coolant is not required in current design, because the final heat sink is assumed to be the atmosphere. The reactor operation will be automated as possible by passive control devices based on natural principles. Thus, manpower for the reactor operation is minimized. Because remote monitoring and operation would become an option for operation cost reducing.

- Core Damage Frequency (CDF) : Extremely low.
- Refueling : No refueling during the plant life time.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

Fuel Cycle Approach

The MoveluX reactor can be applied to either once-through fuel cycle scheme or closed fuel cycle scheme. It mainly depends on user country's fuel cycle policy.

Waste Management and Disposal Plan

The reactor vessel contains the spent fuel as it is, additionally, this spent fuel is carried out to temporary storage site with reactor vessel. After that, treatment of the spent fuel depends on the country's fuel cycle policy. On one hand, in the once-through scheme, spent fuel is extracted from the core at the facility, then, spent fuel is stored to the cask for disposal. On the other hand, in the closed fuel cycle scheme, spent fuel is re-processed and re-fabricated as a fresh fuel for recycling use in MoveluX, LWR or FR.

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