Offshore power: Floating low-carbon energy solutions for remote areas

Chair:
Tim Yeo
Chairman
New Nuclear Watch Institute

Speakers:

Kirsty Gogan
Co-Founder, TerraPraxis

Elena Pashina
Marketing Director, Rusatom Overseas

Mikal Boe
Chief Executive Officer, Core Power

Peder Norborg,
Chief Technical Officer, Seaborg Technologies

Richard Jones
Head of Nuclear R&D, EDF Energy

17 November 2021
WEBINAR

Offshore power: Floating low-carbon energy solutions for remote areas

Kirsty Gogan
Co-Founder, TerraPraxis

17 November 2021
INNOVATION FOR CLIMATE

ENERGY INNOVATION FOR A PROSPEROUS PLANET

November 2021
ABOUT TERRAPRAXIS

- TerraPraxis specializes in assembling solutions: Innovative technology configurations, delivery and deployment models designed against well-defined market requirements
- TerraPraxis provides leadership across multiple disciplines to break the deadlock on decarbonisation
- TerraPraxis has a strong track record in leading successful engagements, identifying leaders and aligning stakeholders around a broader range of solutions
- TerraPraxis designs and executes complex, high leverage strategies that inspire and mobilise leaders to initiate activity in multiple spheres of influence that generate and sustain their own momentum
De-Risking the Terawatt Transition at COP26

H.E. Mohamed Al Hammadi, Managing Director and Chief Executive Officer, Emirates Nuclear Energy Corporation

Eng. Andrew N. Kamau, Principal Secretary, State Department of Petroleum, Kenya

H. E. Aminath Shauna, Cabinet Minister of Environment and Climate Change, Maldives Government

Dr Dirk Smit, Chief Scientist, Shell (remotely)

Dr Sama Bilbao y León, Director General, World Nuclear Association

Mr. Jens ÓRÐARSON, Chief Operating Officer, Icelandair (remotely)

Photo credit: Julie Broadfoot

Moderated by Kirsty Gogan, TerraPraxis
**Cost:** Oil price ‘guardrails’ of the hydrogen economy ($0.50–$1.50/kg)

*Source: Missing Link to a Livable Climate, LucidCatalyst (2020)*
Shipyard Construction of a Power, Fuels and Desalination Plant

Modular blocks are added to an FPSO under construction in a dry dock.
Ammonia Bunker Offloading from a Production Platform

Source: 
*Missing Link to a Livable Climate*, LucidCatalyst (2020)

See also: forthcoming report: 
Electric Power Research Institute (EPRI) Report: 
*Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors*. December 2021
Multi-Product Platform Making Hydrogen, Power, Ammonia and Fresh Water

Source: *Missing Link to a Livable Climate*, LucidCatalyst (2020)

See also: forthcoming report:
Electric Power Research Institute (EPRI) Report:
*Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors*. December 2021
Market Opportunity

Commercial air miles traveled are expected to nearly triple by 2050 from 2020.

The vast amount of arable land required to produce biofuel alternatives for aviation makes such a solution challenging.

In the future, demand for greener air travel experiences could represent a major opportunity for producers of cost-competitive, carbon-neutral synfuels.
IEA: Sustainable Aviation Fuel Projected Costs Compared to Off-Shore Platform Synthetic Jet A Fuel

Source
Electric Power Research Institute (EPRI) Report: Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors. December 2021
Zero-Carbon Commercial Aviation Fuel

FPSO platform for production of synthetic Jet A with bulk carrier arriving alongside for delivery of limestone feedstock.

The bulk carrier (smaller vessel on right) drops off the limestone (CaCO$_3$) reagent and picks up lime (CaO) byproduct. Reagents and byproducts are stored in the hull of the FPSO close to the calcination equipment in the stern.

Source
Electric Power Research Institute (EPRI) Report: Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors. December 2021
Carbon Negative Jet Fuel

For a net carbon-negative fuel option, the byproduct lime can be dissolved in seawater to result in the net removal of 1.7 moles of CO$_2$ for each molecule of CO2 removed from the limestone.

Bulker carrier moored alongside a Synfuel FPSO

Source
Electric Power Research Institute (EPRI) Report: *Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors*. December 2021
Decarbonising Aviation
Large Scale Fuels Production for Global Markets
Additions and Cumulative Fuel Production Facilities

- New ship construction, annual rate
- Cumulative fleet of production ships
ENERGY INNOVATION FOR A PROSPEROUS PLANET

Kirsty Gogan  
kirsty.gogan@terrapraxis.org

Eric Ingersoll  
eric.ingersoll@terrapraxis.org
WEBINAR

Offshore power: Floating low-carbon energy solutions for remote areas

Elena Pashina
Marketing Director, Rusatom Overseas

17 November 2021
Rosatom SMR solutions for the market

Elena Pashina
Marketing Director

Rusatom Overseas
2021
FROM SUFFICIENT MARKET SIZE FOR SERIAL CONSTRUCTION AT HOME TO EXPORT OF A TRIED AND TESTED TECHNOLOGY:

- SMRs are a part of country’s Energy strategy 2035
- SMRs are a key track of Comprehensive R&D program of Russian nuclear industry
- Special purpose office within ROSATOM was established with participants from Rosatom major subsidiaries
- Government support for FOAK projects implemented in Russia
Why is ROSATOM investing into small modular reactors?

**EXISTING EXPERIENCE**

- **The leader** on nuclear power plant construction market
- Vast experience in small reactors development for marine applications – more than 400 reactor-years

**NEW MARKET OPPORTUNITIES**

- Smart grids are developing
- Energy systems decentralization is required where small capacity energy units prevail
- Global trend for decarbonization
ROSATOM and development of small reactors

- **1945** – “birth” of Russian nuclear industry
- **Since 1954**, OKBM Afrikantov (ROSATOM) has been designing marine reactors (<60 MWe)
- **Over twenty small reactors** for civil marine applications have been manufactured and operated so far
- **Total experience** of operation of small reactors for icebreaker fleet – about **400 reactor-years**
World’s only floating nuclear power plant “Akademik Lomonosov” commissioned in May 2020

TODAY THE FNPP PROVIDES RELIABLE AND CLEAN HEAT AND POWER SUPPLY TO LIVING AREAS AND ENSURES POTENTIAL FOR INDUSTRIAL DEVELOPMENT IN CHUKOTKA REGION
World’s first floating nuclear power plant Akademik Lomonosov commissioned

Displacement 21 000 t
Length 140 m
Beam 30 m
Draught 5.6 m
Fuel cycle 3 years
Design life 40 years
Time to maintenance 12 years

2 x KLT-40S

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal capacity</td>
<td>300 MW</td>
</tr>
<tr>
<td>Electrical capacity</td>
<td>Up to 77 MW</td>
</tr>
<tr>
<td>Thermal power</td>
<td>146 Gcal/h</td>
</tr>
</tbody>
</table>

*including operational and support staff
FNPP construction
Floating nuclear power plant: layout

Rendering based on the real layout at port Pevek
ROSATOM SMR evolution: from KLT-40S to RITM-200

- **Time proven PWR technology**
- **Integral configuration**
- **3+ generation**
- **45% less** in the dimensions, **35% less** in mass*

more **400**

Reactor-years of successful operation of small reactors on icebreakers

* Compared to KLT-40S

The content of this presentation is for discussion purposes only, shall not be considered as an offer and doesn’t lead to any obligations to Rosatom and its affiliated companies. Rosatom disclaims all responsibility for any and all mistakes, quality and completeness of the information.
RITM series reactors incorporate all the best features from its predecessors

- Based on 400 reactor-years experience of ROSATOM in operation of small reactors for marine applications
- Time proven PWR technology
- Integral configuration
- 3+ generation
- 190 MWth
- Proven efficiency and ultimate safety at all stages of the life cycle
- 45% less in the dimensions, 35% less in mass compared to KLT-40S
- Floating or land-based NPP design is available
New Arktika icebreaker

21 OCTOBER 2020 ARKTIKA ICEBREAKER OFFICIALLY ENTERED SERVICE WITH THE RUSSIAN NUCLEAR ICEBREAKER FLEET

- Equipped with two RITM-200 reactors
- Able to break through ice up to 3 meters
- Sibir, Ural, Yakutia icebreakers to enter operation in 2021, 2022, 2025

Source of the picture: United shipbuilding corporation
RITM series SMR: key components

RITM SERIES SMR ENVISAGES SIMPLIFIED INTEGRAL DESIGN WITH THE STEAM GENERATORS INCORPORATED INTO THE REACTOR PRESSURE VESSEL

CONTROL AND SAFETY RODS
- Based on the drives used in KLT-40S reactor
- 12 control rods
- 6 safety rods

4 STEAM GENERATORS
- Steam of 295°C at 3.82 MPa
- 305 t/h – capacity

CORE
- 199 fuel assemblies
- Low-enriched cermet fuel
- 1650 mm – height of the core
- 8 TWh – assigned service life
- Power changes with a design rate of 0.1%/s

REACTOR PRESSURE VESSEL
- Integral reactor configuration almost eliminates the classic large LOCA

4 MAIN CIRCULATION PUMPS
- Provide stable forced circulation of coolant
- Similar to those used on KLT-40S
# Versatile applications of RITM series SMRs

<table>
<thead>
<tr>
<th>RITM-200</th>
<th>RITM-200N</th>
<th>RITM-200M</th>
<th>RITM-400</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Thermal capacity, MW</strong></td>
<td>175</td>
<td>190</td>
<td>315</td>
</tr>
<tr>
<td><strong>Steam generating capacity, t/h</strong></td>
<td>248</td>
<td>305</td>
<td>450</td>
</tr>
<tr>
<td><strong>Design lifetime, years</strong></td>
<td>40</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td><strong>Fuel cycle, years</strong></td>
<td>4-7</td>
<td>5-6</td>
<td>5</td>
</tr>
<tr>
<td><strong>Reactor containment dimensions, m</strong></td>
<td>6 x 6 x 15.5</td>
<td>Ø8.8 x 22</td>
<td>9 x 8.2 x 17.5</td>
</tr>
<tr>
<td><strong>Status of the development</strong></td>
<td>In operation</td>
<td>Land-based NPP under development</td>
<td>Technical design in progress</td>
</tr>
<tr>
<td><strong>Year of commissioning</strong></td>
<td>2020</td>
<td>2028</td>
<td>2027/2028</td>
</tr>
</tbody>
</table>

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Two options of ROSATOM small NPPs based on RITM series SMRs

FLOATING NPP (FNPP) EQUIPPED WITH RITM SERIES SMR

LAND-BASED NPP EQUIPPED WITH RITM
Two options of ROSATOM small NPPs based on RITM series SMRs
FNPP is capable of supplying energy to both onshore and offshore consumers

- Offshore Territories
- Offshore Agglomerations
- Ports
- Islands
- Archipelagos
- Off-Shore Facilities
- Mining Facilities
- Large Facilities Under Construction
- Mineral Processing Facilities
FNPP: optimized solution for coastal areas power supply

TECHNICAL PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor</td>
<td>2 x RITM-200M</td>
</tr>
<tr>
<td>Electrical capacity</td>
<td>100 MW</td>
</tr>
<tr>
<td>Fuel cycle</td>
<td>up to 10 years</td>
</tr>
<tr>
<td>Design life</td>
<td>60 years</td>
</tr>
<tr>
<td>Displacement</td>
<td>18 670 tons</td>
</tr>
<tr>
<td>Length</td>
<td>112 m</td>
</tr>
<tr>
<td>Beam</td>
<td>30 m</td>
</tr>
<tr>
<td>Draught</td>
<td>5.84 m</td>
</tr>
</tbody>
</table>

CURRENT STATUS OF OPTIMIZED FNPP

- August 2020 – conceptual design completed
- IV quarter 2020 – start of technical design stage

OPTIMIZATION RESULTS COMPARED WITH FNPP AKADEMIK LOMONOSOV

- by 28 m – length reduction
- by 4 320 t – displacement reduction
- 30% – electrical capacity increase
Optimized FNPP benefits

ALL BENEFITS OF NUCLEAR POWER:

- A continuous base-load power supply within a 60-year life
- Effective cost management due to fixed total electricity cost throughout a 60-year life
- Synergy with the renewable energy sources
- Multipurpose application including water desalination, district heating

ADDITIONAL SPECIFIC ADVANTAGES OF FNPP

- Short period of construction works at the site
- No decommissioning at the site
- Long fuel campaign (up to 10 years)
- Flexible life-time period
Key principles of the FNPP safety

ENSURED nuclear and radiation safety

GUARANTEED resistance against external events

- NO RADIATION EXPOSURE
- RESISTANT TO EXTERNAL IMPACTS
- NATURAL
- MAN-CAUSED
- PITCHING & ROLLING

Radiation exposure on population during normal operation and design accident has no impact on natural radiation background level.

Application of the nuclear safety technical and organizational measures excludes nuclear and radiation accidents.

No necessity for compulsory evacuation measures planning zone.
FNPP lifecycle

1. **PORT OF ORIGIN**
   - FNPP construction and first fueling
   - Radioactive waste management
   - Maintenance and refueling

2. **TRANSIT COUNTRIES**
   - (intergovernmental agreements, if required)

3. **HOST COUNTRY**
   - Power production at operation site (up to 10 years before refueling)
   - Possibility of FNPP relocation to another site when required

4. **OPERATION SITE**
   - Transportation for maintenance and refueling

FNPP LIFE CYCLE 60 YEARS

**CONSUMER IN HOST COUNTRY**
Optimized floating power unit legal regulation

An optimized floating power unit has features of
- a vessel
- a nuclear power plant

Existing international regulatory framework **does not prohibit** OFPU operation, however, specialized requirements for non-self-propelled floating units with nuclear reactor do not exist.

It is necessary to establish safety criteria for non-self-propelled floating units with nuclear reactors that would meet international approval. These criteria would give an opportunity:
- **to developers and operators:** to develop a required scope of documentation in advance in order to prove safe operation
- **to stakeholders:** to objectively assess safety of operation

*Safety assessment* is assumed to be a possible solution. It is obligatory for self-propelled nuclear vessels and it can be adjusted to non-self-propelled floating units with nuclear power facility.

* Safety assessment is required by SOLAS-74 and by Code of safety for nuclear merchant ships Res. A.491 (XIII) passed by International Maritime Organization
International cooperation in the field of SMR development

**IAEA**
- Technical Working Group on Small or Modular Reactors (3 participants, 2 observers)
- INPRO TNPP-2 (8 participants, 40 side experts)
- Regional TC Project RER2014 Facilitating Capacity Building for Small Modular Reactors: Technology Developments, Safety Assessment, Licensing and Utilization (3 participants)
- Small Modular Reactor (SMR) Regulators’ Forum (5 participants)
- Working Group on Licensing Issues

**WNA**
Cooperation in Reactor Design Evaluation and Licensing (CORDEL)
- Licensing and Permitting Task Force
- Small Modular Reactors Task Force

**NEA OECD**
- Nuclear Law Committee
  - Working Party on the Legal Aspects of Nuclear Safety (Licensing of SMRs)
- Committee on Nuclear Regulatory Activities
  - Working Group on the Regulation of New Reactors (WGRNR)
  - Codes and Standards Working Group
- Multinational Design Evaluation Programme (MDEP)
Nuclear can become a stable and reliable element for the all-out support of the system.

SUSTAINABLE ENERGY ECOSYSTEM

NUCLEAR POWER IS A WIN-WIN LOW-CARBON SOLUTION FOR COUNTRIES TO STRIKE THE RIGHT BALANCE BETWEEN ALL THE ELEMENTS
Thank you for your attention
Offshore power: Floating low-carbon energy solutions for remote areas

Mikal Boo
Chief Executive Officer, Core Power
Molten salt future.

Molten salt → electric ships.
Electric ships → clean power in ports.
Clean power in ports → offshore processing.
Offshore processing → improved value chains.
Improved value chains → competitive industry.

Clean energy you can rely on. Always there, always from CORE POWER – www.corepower.energy / mikal.boe@corepower.energy
Offshore power: Floating low-carbon energy solutions for remote areas

Peder Norborg
Chief Technical Officer, Seaborg Technologies

17 November 2021
Rethinking nuclear

Enabling world wide deployment by design and regulatory approach

Peder Norborg
Chief Technical Officer
THE CMSR POWER BARGE

Developing

The Compact Molten Salt Reactor

- Small modular nuclear reactor
- Mass produced
- Deployed on barges
- 200-800 MWe power barges
SEABORG IN A NUTSHELL

Privately held and privately funded company

75+ employees
Scaling to 90 employees in 2021

Partnerships with shipyards, nuclear and heavy industry

HQ in Copenhagen, Denmark
Business offices in South Korea & Singapore
We will only reach our goals for **decarbonisation** if the alternative is **cheap** enough and scales **fast**.

**VISION**

Transform energy markets and **out-compete fossil fuels** to create a bright future with abundant clean energy for everyone.

**UNPRECEDENTED OPPORTUNITY**

Executing a rapid **world-wide deployment** of the Compact Molten Salt Reactor via **shipyard serial production** of power barges.
THE MAGIC IS IN THE SALT
Molten fluoride salt makes nuclear inherently safe

The fluoride salt contains the radioactive elements

- No release of gases
- Very low solubility in water
- Below 490°C, it is a rock
- Boils at 1500 °C

Safety is ensured by the laws of nature

FUNaK Fuel Salt
The Seaborg CMSR is inherently safe. It:

- **Cannot** melt down or explode
- **Cannot** release radioactive isotopes to air or water
- **Cannot** be used for nuclear weapons
- Operates for **12 years without refuelling**
MODULAR CMSR POWER BARGE
24 years operational life time

2 empty CMSR compartments for the second 12-year fuel cycle

Steam turbine with generator and condenser

2 CMSRs for the first 12-year fuel cycle

Compartments below turbine with auxiliaries for steam generation, power transmission and the CMSR

24 years operational life time
## TURNKEY FLOATING POWER PLANT

The CMSR Power Barge

### Flexible, convenient and fast:
- **Standard designs** with 200/400/600/800 MWe
- **3 years** from order to grid
- Fully commissioned **at shipyard**
- **First power barge delivered in 2026**

<table>
<thead>
<tr>
<th></th>
<th>Length [m]</th>
<th>Thermal output [MWt]</th>
<th>Electrical output [MWe]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x CMSR</td>
<td>98.4</td>
<td>500</td>
<td>200</td>
</tr>
<tr>
<td>4x CMSR</td>
<td>160.8</td>
<td>1000</td>
<td>400</td>
</tr>
<tr>
<td>6x CMSR</td>
<td>223.2</td>
<td>1500</td>
<td>600</td>
</tr>
<tr>
<td>8x CMSR</td>
<td>285.6</td>
<td>2000</td>
<td>800</td>
</tr>
</tbody>
</table>
The International Atomic Energy Agency - is the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field.

The International Maritime Organization – is the United Nations global standard-setting authority for the safety, security and environmental performance of international shipping.
BUILDING THE SAFETY CASE

1. Introduction and General Description of the Plant and Supporting Facilities
2. Site Requirements
3. General Design Safety
4. Ship and its general safety
5. Description and conformance to the design of plant systems
6. Safety Analyses
7. Commissioning
8. Operational Aspects
9. Transport Arrangements
10. Radiological Protection
11. Emergency Preparedness & Response
12. Radioactive waste management
13. Safeguards and Security
14. Decommissioning
15. Control of Non-Radiological Hazards
16. Environmental Protection

IAEA Safety Standards
for protecting people and the environment

Leadership and Management for Safety
General Safety Requirements
No. GSR Part 2

Safety Assessment for Facilities and Activities
General Safety Requirements
No. GSR Part 4 (Rev. 1)

Safety of Nuclear Power Plants: Design
Specific Safety Requirements
No. SSR-2/1 (Rev. 1)

IAEA Safety Standards
for protecting people and the environment

149 Sub-Chapters
American Bureau of Shipping (ABS) is a member of the International Association of Classification Societies (IACS)

- Founded in 1862 with HQ in Texas. Operates 200 offices with 5,500 employees.

- Rules established by IACS also adopt and include the rules from the International Maritime Organization on behalf of the flag states.


- American Bureau of Shipping (ABS) Group has performed advanced compliance assessments for several nuclear facilities.
REGULATORY ROLES

UN authorities

IMO  The International Maritime Organization
IAEA  The International Atomic Energy Agency

ABS  Independent verification

Rules & regulations
Guidelines

Flag state
(e.g. Singapore, UK etc. etc.)
Approval of the Power Barge

Owner
Operation, Maintenance & Decommissioning

Port state control

Local authorities

Potential additional local requirements
Safeguards inspections

Approval

Potential additional flag state requirements
ABUNDANT, CHEAP AND CLEAN ENERGY

200 Power Barges per year by 2035

Develop in Denmark

Build in South Korea

Power the World

Electricity
- Replacing coal and gas power
- Solving grid stability
- Powering hydrogen production

Heat
- Process heat for industry
- Production of ammonia
- Production of fresh water
Thank you!

www.seaborg.com
Offshore power: Floating low-carbon energy solutions for remote areas

Richard Jones
Head of Nuclear R&D, EDF Energy

17 November 2021
EDF R&D in Figures

1,900 employees in France
225 employees outside France
13 laboratories set up with our partners
29 nationalities represented
117 Ph. D. students

In contact with
8,000 start-up

9 centres in France and abroad

510 Million budget
EDF R&D (EDF SA)

4 petaflops computing capacity
1906 patents

1/3 of which is used for forecasting and paving the way for the Group's future
2/3 of which is used to support the performance of the Group's various business lines
UK R&D Nuclear - Who are we?

UK Nuclear

Circa.
£10m per annum

University of Glasgow
University of Lancaster
University of Liverpool
Barnwood (Head of & Programmes)
University of Bristol
University of Reading
Manchester (Modelling and Simulation)
University of Manchester
University of Sheffield
University of Cranfield
Croydon (Natural Hazards)
Imperial College London

University of Glasgow
University of Lancaster
University of Liverpool
Barnwood (Head of & Programmes)
University of Bristol
University of Reading
Manchester (Modelling and Simulation)
University of Manchester
University of Sheffield
University of Cranfield
Croydon (Natural Hazards)
Imperial College London
UK R&D Nuclear – Where are we and where are we going?

NOW

14 AGR Reactors + PWR (SZB)

0 – 5 YEARS

Challenges: High Temperatures +600C; Boiler and Graphite Lifetime

SHORT FUTURE TERM

PWR SZB + HPC/SZC

5 – 10 YEARS

Challenges: Transition; D&D, Operating, Building

LONG TERM FUTURE

SMALL + LARGE PWR + AMR?

10 +

Opportunities: Energy mix; small vs large; HT expertise from AGR onto SMR?
UK R&D Nuclear – Floating Off-Shore Nuclear?

- UK an Island – lots of water! Reactors next to coast…
- Large projects (HPC) are complicated and costly… but provide large efficiencies
- Land is at a premium for new nuclear – “not in my back yard”
- Opportunity to combine small/with HT UK expertise… why not offshore?

- No special site for construction
- Low impact on local communities and environment
- Ease of transport – no roads?
- Earthquake safety?
- Movable

- How do staff “get to work”? 
- How do emergency services get to site?
- Security – submarine attack for example
- Major sea pollution risk?