Opening remarks

Prof. Kamal Araj
Vice Chairman of the Jordan Atomic Energy Commission
IFNEC Steering and Executive Committee Representative
Introductory remarks

Suzanne Jaworowski
Senior Advisor. U.S. Department of Energy (DOE)
IFNEC Steering Group Chair
Office of Nuclear Energy
Prof. Kamal Araj

Vice Chairman of the Jordan Atomic Energy Commission
IFNEC Steering and Executive Committee Representative
Mr. Jon Ball
Executive Vice-President
GE-Hitachi

BWRX-300: Innovative, Cost-Competitive, and Ready for Deployment
Decades of Innovation

Rich history of nuclear innovation ready to support advanced reactor market

OVER 80 YEARS OF NUCLEAR EXPERIENCE AND INNOVATION

1939 - First GE involvement in nuclear physics
1941 - Aircraft nuclear propulsion
1945 - GE Atomic Division established
1957 - Vallecitos BWR AEC License #1
1971 - PRISM development commences
1986 - 50th GE BWR operational
1996 - 1st ABWR built: on time on budget
2014 - ESBWR NRC License
2017 - BWRX-300 launched
2018 - VTR Contract PRISM

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New Nuclear is Essential to Achieving a Decarbonized World

Cost is a Key Driver to New Nuclear

**Decarbonization**

"... more than 60 countries have said they will try to reduce their net carbon emissions to zero by 2050."

**Cost**

"Nuclear is potentially an important part of the future Net Zero energy system in the UK but nuclear cost reduction is a necessary pre-requisite."

International Energy Agency

Nuclear Power in a Clean Energy System

A range of technologies, including nuclear power, will be needed for clean energy transitions around the world.

Prime Minister Boris Johnson

July 25, 2019

"It is time for a nuclear renaissance and I believe passionately that nuclear must be part of our energy mix," adding that nuclear energy will help the country meet its carbon emission reduction targets.


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- Design-to-cost approach
- Targeting LCOE competitive with gas
- Significant capital cost reduction per MW
- 10th generation Boiling Water Reactor
- Scaled from U.S. NRC licensed ESBWR
- World class safety
- Capable of load following
- Ideal for industrial applications and electricity generation
- Constructability integrated into design
- Initiated licensing in the U.S. and Canada

Operational by 2027
BWRX-300 Design Simplification

LOCA mitigation enables dramatic simplification

✓ LTR submitted to NRC and accepted for review

✓ Engineering design work confirmed 90% reduction in concrete vs. ESBWR

>50% building volume reduction/MW
>50% less concrete/MW
Utilizing Proven Technology

**Dryer:**
Same features as ABWR* and ESBWR...
Same as upgrades for existing fleet...
Size nearly identical to KKM**

**Steam separators:**
Same as ABWR* and ESBWR...
Similar to others in the BWR fleet

**Reactor pressure vessel:**
Same material and fabrication processes as ABWR*, ESBWR and many of the BWR fleet...
Diameter almost identical to KKM**

**GNF2 fuel:**
>19,000 bundles delivered...
Utilized by ~70% of BWR fleet

**Chimney:**
Uses ESBWR and Dodewaard*** technology... Simplified

**Control rod blades:**
Same as ABWR*...
Longer than ESBWR...
Almost identical to latest design for BWR fleet

**Fine motion control rod drives:**
Same as ABWR* and ESBWR

---

* ABWR fleet has combined 22+ years of operating experience
** Kernkraftwerk Mülheim (KKM): 355 MW(e) BWR/4 in operation since 1972
Cost-Competitive Position – NOAK (Nth-of-a-kind)
BWRX-300: Licensing

Canadian pre-licensing review starts for BWRX-300

- Vendor Design Review
- Combined Phase 1&2

GEH Launches NRC Licensing Process for BWRX-300

- Part 50 Approach
- Leverage ESBWR design certification
- Supplement with License Topical Reports (LTRs)

Targeting Commercial Operation in US by 2027 and Canada by 2028

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BWRX-300: Recent headlines on Partnerships

GE Hitachi Nuclear Energy and ČEZ Announce Small Modular Reactor Technology Collaboration in the Czech Republic

GE Hitachi to partner with Synthos on small modular reactor in Poland

GE Hitachi Collaborates to Bring SMR Design To Estonia

US DOE Awards Grants to Digital Research Using BWRX-300 SMR Design

Source: NucNet

US DOE ARPA-E Grant Partners

MIT
GE Research
Exelon Generation
The University of Tennessee, Knoxville
Oak Ridge National Lab
BWRX-300

Ready for near-term deployment

✓ Strong industry partners
✓ Affordable and simple design
✓ Licensable technology
✓ Certified and proven fuel design
✓ Track record of deploying reactor technology
✓ Ability to establish supply chains
✓ Strong after-market services capability

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SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits
Chinese HTR Program

Prof. Li Fu
Deputy Chief Engineer of INET
Tsinghua University
Outline

- 1 Mission of HTR in China
- 2 Overview of Chinese HTR program
- 3 HTR-PM progress
- 4 HTR-PM600
1 Mission of HTR in China

- **Supplement to PWRs**
  - for power generation, especially to replace coal-fired power plant in popular region

- **Co-generation**
  - of steam and electricity,
  - & Hydrogen production

- **Technology Innovation**
2 Overview of Chinese HTR program

- China chose pebble bed HTR
- Research was started in 1970s
- Benifited from international cooperation

Fundamental R&D: 1970s

Test reactor: 1986, HTR-10

Demonstration plant: 2001, HTR-PM

Commercial plant: 2014, HTR-PM600
3 HTR-PM progress

- **HTR-PM**: High temperature gas cooled reactor--pebble bed module

- **HTR-PM demonstration plant**
  - Supported by the Chinese National Key Science and Technology Project (1 of 16 projects)
    - Government support the R&D
    - Commercial operation
  - Located in Shidao Bay, Shangdong Province
HTR-PM demonstration plant in Shida Bay, Shandong
The overview of the HTR-PM site
3 HTR-PM progress

- Technology based on HTR-10
  - Single zone core
  - Side by side arrangement of reactor & SG
  - Super heat steam
  - Modular design
3 HTR-PM progress

- 2 NSSS modules connected with 1 turbine in HTR-PM
- 6 modules will be connected with 1 turbine in HTR-PM600

SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits
## HTR-PM Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant electrical power, MWe</td>
<td>211</td>
</tr>
<tr>
<td>Core thermal power, MW</td>
<td>250</td>
</tr>
<tr>
<td>Number of NSSS Modules</td>
<td>2</td>
</tr>
<tr>
<td>Core diameter, m</td>
<td>3</td>
</tr>
<tr>
<td>Core height, m</td>
<td>11</td>
</tr>
<tr>
<td>Primary helium pressure, MPa</td>
<td>7</td>
</tr>
<tr>
<td>Core outlet temperature, °C</td>
<td>750</td>
</tr>
<tr>
<td>Core inlet temperature, °C</td>
<td>250</td>
</tr>
<tr>
<td>Fuel enrichment, %</td>
<td>8.5</td>
</tr>
<tr>
<td>Steam pressure, MPa</td>
<td>13.25</td>
</tr>
<tr>
<td>Steam temperature, °C</td>
<td>567</td>
</tr>
</tbody>
</table>
3 HTR-PM progress

Milestones for construction:

- 2012/12/09: FCD
- 2015/06/30: Reactor building
- 2015/12: Full scope simulator
- 2016/03/20: 1st RPV installed
- 2016/08: Start of fuel fabrication
- 2016/09: 2nd RPV installed
- 2019/04: 1st SG installed
- 2019/07: 2nd SG installed
- 2020/04: fixed RPV, HDPV, SGPV
3 HTR-PM progress

- Ongoing work
  - Commissioning test
    - Test of auxiliary/supporting system started in 2016
  - Criticality and power operation is scheduled in 2021
3 HTR-PM progress

Main achievements

- Standard NSSS module with full scale test and operation demonstration
- Experience & team covering design, manufacturing, licensing, construction & installation, commissioning test, operation, ...
- Licensing framework
- Test facilities for future development
- Whole supply chain
- Fuel fabrication capability
- Operation experience feedback for future plants
# Test Facilities for HTR-PM Project

| ETF-HT | Engineering Test Facility- Helium Technology | 10MW test power, 7.0MPa, 250-750°C, helium | Test source to verify steam generator | Finished |
| ETF-SG | Engineering Test Facility- Steam generator | 10MW test power, 13.25MPa, 205-570°C, water | Secondary loop and third loop to verify steam generator | Finished |
| ETF-HC | Engineering Test Facility- Helium Circulator | 4.5MW, 7.0MPa, 250°C, helium | Full scale verification of helium circulator | Finished |
| ETH-FHS | Engineering Test Facility- Fuel Handling System | 7.0MPa, 100-250°C, helium, two chain | Full scale verification of fuel handling system | Finished |
| TH-FHS | Test Facility- Fuel Handling System | Full geometry size, air, 0.1MPa | Verification of the fuel movement in the PHS system | Finished |
| ETF-CRDM | Engineering Test Facility- Control Rods Driving Mechanism | 1MPa, 100-250°C, helium | Full scale verification of Control Rods Driving Mechanism | Finished |
| ETF-SAS | Engineering Test Facility- Small Absorber Sphere System | 7.0MPa, 100-250°C, helium | Full scale verification of small absorber sphere system | Finished |
| ETF-SFS | Engineering Test Facility- Spent Fuel System | Full geometry size, air, 0.1 MPa | Full scale verification of major components of spent fuel storage system | Finished |
| TF-SFGD | Test Facility- Spent Fuel Canister Drop | Full geometry size, Full height (30m), Full weight (17t) | Full scale drop verification of spent fuel canister | Finished |
| ETF-HPS | Engineering Test Facility- Helium Purification System | 7.0MPa, 25-250°C, helium | Purification flow rate: 40kg/h, Verification of purification efficiency (greater than 95% and system resistance less than 200Pa), | Finished |
| TF-PBEC | Test Facility- Pebble Bed Equivalent Conductivity | 1600°C, helium/vacuum | Measurement of pebble bed equivalent conductivity | Finished |
| TF-PBFD | Test Facility- Pebble Bed Flow 3D | 0.1 MPa, room temperature, air | Three-dimensional simulation test for pebble bed flow (1:5 scale) | Constructing |
| TF-HGM | Test Facility- Hot Gas Mixing | atm,20-150°C, air | Reduced scale (1:2.5) verification of hot gas mixing at reactor core outlet | Finished |
| ETF-DCS | Engineering Test Facility- Distributed Control System | Reactor power control system, fuel cycle control system, VDU-based Man-Machine Interface | Verification of DCS architecture and major control Systems | Finished |
| ETF-RPS | Engineering Test Facility- Reactor Protection System | Prototype of Reactor Protect System with 4 channels | Full scale verification of Reactor Protect System | Finished |
| ETF-MCR | Engineering Test Facility- Main Control Room | 1:1MCR control consoles, mimic panels, layouts and inner | Full scale verification of Man-Machine interface | Finished |
3 HTR-PM progress

HTR-PM Supply chain:

- Main Components Suppliers:
  - Shanghai Electric: RPV, Metallic Reactor Internals, CRDMs, SASs, Steam Turbine, Helium Circulators
  - Harbin Electric: Steam Generator, Generator
  - Toyo Tanso: Graphite
  - CGNPC: RPS, DCS, Simulator
- Fuel supplier: CNNC with INET
- Nuclear island EPC Contractor: CHINERGY
- R&D, NSSS and main NI system Engineering: INET
- Other components: companies inside and outside China
4 HTR-PM600

- Batch construction of HTR-PM is possible
- Improved version of HTR-PM600 is designed
  - 6 NSSS modules connect to 1 steam turbine, comparing with 2 modules in HTR-PM, with
    - the same safety features,
    - the same major components,
    - the same primary circuit parameters,
  - With the same site footnote and building volume comparing with the same size PWRs.
  - With the interface of steam extraction capability for co-generation
  - With lower construction cost
4 HTR-PM600

Evolution of HTR-PM600 layout:
The volume of seismic qualified building was reduced 50%, the same as PWR
4 HTR-PM600

- Optimized layout, economy with proven technology
## 4 HTR-PM600

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power of one Reactor Module</td>
<td>MW</td>
<td>250</td>
</tr>
<tr>
<td>Reactor Module number</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Plant thermal power</td>
<td>MW</td>
<td>1500</td>
</tr>
<tr>
<td>Plant electric power</td>
<td>MW</td>
<td>655</td>
</tr>
<tr>
<td>Pressure of the primary circuit</td>
<td>MPa</td>
<td>7</td>
</tr>
<tr>
<td>Reactor inlet temperature</td>
<td>ºC</td>
<td>250</td>
</tr>
<tr>
<td>Reactor inlet temperature</td>
<td>ºC</td>
<td>750</td>
</tr>
<tr>
<td>Feed water temperature</td>
<td>ºC</td>
<td>205</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>ºC</td>
<td>566</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>MPa</td>
<td>13.24</td>
</tr>
<tr>
<td>Power generation efficiency</td>
<td>%</td>
<td>44</td>
</tr>
</tbody>
</table>
Conclusion remarks

HTR-PM will provide:

- **Proven Technology and Budget:** the world first 200 MWe pebble-bed modular high temperature gas-cooled reactor demonstration plant (HTR-PM) will soon be operated in China.

- **Generation IV Safety:** eliminate off-site emergency response through a Meltdown-Proof Reactor.

- **Huge Market Potential:** provide 200, 600 MWe high efficiency power plant and co-generate steam up to 560 °C, with flexible size, with standardized NSSS modules.

- **Whole supply chain.**
Conclusion remarks

- More capability from HTR for process heat application including hydrogen production will be explored and demonstrated, via domestic project and international cooperation.
  - Gen IV International Forum is one of platform
  - All type of international cooperation is welcomed
Thanks for listening
&
Thanks for comments!
The IMSR® power plant – a resilient and cost-competitive clean energy alternative

Mr. Simon Irish
Chief Executive Officer
Terrestrial Energy
Terrestrial Energy

- Terrestrial Energy is developing a Generation IV (molten salt) nuclear power plant

Why?

- Solves nuclear power’s market cost problem
  - Lack of affordability and cost-competitiveness of Generation III systems
- Achieved with demonstrated molten salt technology in a pragmatic market-focused design
  - Integral Molten Salt Reactor (IMSR®)
  - Under 5% LEU fueled

- Terrestrial Energy is on a clear path to market
  - First commercial IMSR® plant within 10 years

- Terrestrial Energy commenced the Canadian nuclear regulatory process at the start of 2016
  - CNSC Vendor Design Review Phase 1 completed successfully in late 2017
  - CNSC Vendor Design Review Phase 2 started in 2018

**IMSR® technology is deployable in the near-term and will transform global energy markets where price matters**
Mr. Simon Irish, Chief Executive Officer, Terrestrial Energy

Innovation - problem statement

- Prosperity (OECD and non-OECD) requires increasing amounts of cost-competitive heat and power
- Fossil fuels with current technologies cannot be increased due to escalating environmental concerns
- Nuclear energy is clean and scale. It is capable of replacing fossil fuel use
- However, Conventional Nuclear power has the “problem of 10’s”
- New nuclear plant is commercially uncompetitive against alternatives, principally natural gas
  - >$10 billion per 1 GWe unit
  - >10+ years to construct
  - >10 US cents per kWh LCOE
  - High complexity
- Conventional nuclear too big, complex and costly for new build
- These are direct and unavoidable consequences of technology choices

We need to rethink
Costs drivers - Generation III SMR innovation
LCOE USD per MWh

Modularity and reduced size alone are not sufficient innovations
IMSR® is the synthesis of 60 years of lab effort and market-focused private sector innovation

- United States sovereign effort from 1950s to 1980s at Oak Ridge National Laboratory, TN.
- Two MSRs were built. One was operated for ~18,000 hours and was an R&D success

The result is the Integral Molten Salt Reactor, “IMSR®”

**Deployment advantages**
- High inherent and passive safety
- Clear regulatory pathway
- No fundamental technology barriers
- Replaceable core addresses material lifetime requirements

**Commercial advantages**
- Cost reduction
- Small reactor
- Simple modular design for factory-based component production
- 600°C heat supply

Private sector led innovation focused on practicable commercial solutions for timely product deployment in response to market needs
Costs drivers - Generation IV IMSR innovation
LCOE USD per MWh

Innovation set is unique to
Generation IV - IMSR

Affordable and cost-competitive
IMSR® – dispatchable low-cost clean energy

- Non-dispatchable clean energy technology at specific locations are good solutions but are limited by transmission and the requirements for a resilient and stable grid.
- Dispatchable IMSR® power plants do not have such constraints. They are affordable and cost competitive.

U.S. Levelized Cost of Electric Power – New Plant

Reference spot natural gas price for power plant delivery is $2.74 per MMBtu. A $1 increase in the price of natural gas increases the LCOE of Gas Advanced CC electric power by ~$10 per MWh to $48 per MWh. A $50 per tonne carbon dioxide avoidance fee will increase the price of natural gas by $2.9 per MMBtu and Gas Advanced CC electric power by $30 per MWh to $68 per MWh.

Source: US EIA Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020 - Table 1b
### Power Market Opportunity by 2040

<table>
<thead>
<tr>
<th>Scenario / GWe</th>
<th>NPPs in operation</th>
<th>NPPs under construction</th>
<th>Retirement of NPPs</th>
<th>Additional NPPs</th>
<th>Total NPPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative</td>
<td>392</td>
<td>60</td>
<td>77</td>
<td>303</td>
<td>678</td>
</tr>
<tr>
<td>Base-case</td>
<td>392</td>
<td>60</td>
<td>150</td>
<td>630</td>
<td>932</td>
</tr>
<tr>
<td>Upside</td>
<td>392</td>
<td>60</td>
<td>200</td>
<td>4,248</td>
<td>4,500</td>
</tr>
</tbody>
</table>

- Defined by two factors:
  - Immediate deployment opportunity: Replacement of aging western fleet of nuclear power plants
    - Between 77 GWe and 200 GWe will retire by 2040
    - IEA, May 2019: Advanced economies could lose a quarter of their nuclear capacity by 2025 and two-thirds by 2040
  - Further deployment opportunity: replace coal and natural gas in OECD and non-OECD
    - Coal replacement, growth in electricity and zero-emission environment policies create a further 303 GWe to 4,248 GWe of new nuclear demand

- The bigger picture:
  - Wind, Solar and Biofuels have attracted ~$300 billion per year in infrastructure capital
  - Total installed generating capacity is $2,500 GWe, half of which was installed in the last 10 years

*Price drives deployment*
Deployment timeline and milestones for first IMSR® power plant

Where we are now

- Phase I completed
- Phase II completed
- Completion of Phase III-1
- Completion of Phase III-2
- Completion of Phase III-3

MILESTONES

- VDR Phase 1
- VDR Phase 2
- Construction with first utility
- Site preparation and licensing with first utility
- First IMSR® power plant operational

IMSR® is on a clear path to market
IMSR® provides cost-competitive industrial heat and electric power

IMSR® 600°C heat can be coupled with many industrial activities in a clean industrial park – it is not just for producing electricity for the grid.
THANK YOU!

W: www.TerrestrialEnergy.com
T: twitter.com/TerrestrialMSR
Moltex: An Overview and Update

Mr. Rory O'Sullivan
Chief Executive Officer
Moltex Energy (North America)

www.moltexenergy.com
Moltex Energy: Overview and update

Agenda
• Our solution
• Current activities
• Technical overview
• Conclusion
Mr. Rory O'Sullivan, Chief Executive Officer, Moltex Energy (North America)

Our solution

- Moltex technology has three unique benefits:

1. Costs less – by eliminating meltdown risk
2. Reduces waste – by recycling and reducing existing spent nuclear fuel (“waste”)
3. Enables renewables – by storing peak power and supplying it when needed

- Patent in all major nations + Canadian IP
- Independent validation

<table>
<thead>
<tr>
<th>Conventional</th>
<th>Moltex</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Solid uranium pellets</td>
<td></td>
</tr>
<tr>
<td>- High pressures</td>
<td></td>
</tr>
<tr>
<td>- Liquid salt fuel</td>
<td></td>
</tr>
<tr>
<td>- Atmospheric pressures</td>
<td></td>
</tr>
</tbody>
</table>
GridReserve: Hybrid clean nuclear and thermal storage

- Moltex technology operates as a 33% capacity peaking plant – at the same cost as gas ($1000/kWe)
- Storage cost of U$50/kWh – eight times the cost of Tesla batteries (U$400/kWh)

300 MW stable salt reactor producing heat 24/7

GridReserve thermal energy storage from renewables

900 MW capacity for eight hours a day – ONLY when needed
A closed fuel cycle

- 300 MW low-carbon electricity
  - Reduced waste disposal
  - Social license
  - Less mining
Mr. Rory O'Sullivan, Chief Executive Officer, Moltex Energy (North America)

All that matters

Making nuclear so inexpensive that coal and gas are left in the ground

Actual US costs from Koomey & Hultman (2007)
The market for low cost clean energy is ENDLESS

• At $2,000/kW, an estimated 500 GW of nuclear is required in the US by 2050

Energy mix in US in 2050 at different price points

Mr. Rory O’Sullivan, Chief Executive Officer, Moltex Energy (North America)

Current activities

- Partnered with NB Power and Gov of NB to build first reactor in NB
- Finalizing CNSC Phase 1 VDR and preparing for Phase 2
- Fuel R&D with University of NB and CNL
- Office of 15+ in NB with recruitment ongoing
- Opened new office in Manchester, UK and partnered with University of Manchester
- Various work with US labs through DOE funding
- Seeking funding from the federal government for next phase with private financing already secured
SSR-W design

- Power 300 MWe
- Fuel assemblies like a sodium fast reactor
- Fuel 45% KCl / 55% actinide trichloride
- Coolant 42% ZrF4 / 58% KF
- Burnup 100-150 GWd/t
Plant operations

- Facility will require conventional staffing but reduced numbers due to reduced number of SSCs
- Fuel conversion facility will require high security and regular IAEA inspections
- Staffing will be optimized with adjacent light water reactor
Conclusion

• Moltex’s reactor technology costs less, reduces waste and partners well with renewables
• Current activities in NB and UK demonstrate strong support and momentum
• New nuclear in NB can play a major role in clean economic recovery post COVID-19
• Moltex intends to put the NB supply chain first!

Rory O’Sullivan

roryosullivan@moltexenergy.com
NuScale Power SMR Overview and Update

Mr. Thomas Mundy
Chief Commercial Officer
NuScale Power
Acknowledgement and Disclaimer

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NuScale’s Mission

NuScale Power provides scalable advanced nuclear technology for the production of electricity, heat, and clean water to improve the quality of life for people around the world.
Who is NuScale Power?

- NuScale Power was formed in 2007 for the sole purpose of completing the design and commercializing a small modular reactor (SMR) – the NuScale Power Module™.
- Initial concept had been in development and testing since the 2000 U.S. Department of Energy (DOE) MASLWR program.
- Fluor, global engineering and construction company, became lead investor in 2011.
- In 2013, NuScale won a competitive U.S. DOE Financial Assistance Award for matching funds, and has been awarded over $300M in DOE funding since then.
- >530 patents granted or pending in nearly 20 countries.
- >400 employees in 6 offices in the U.S. and 1 office in the U.K.
- Rigorous design review by the U.S. Nuclear Regulatory Commission (NRC) to be completed in 2020.
- Total investment in NuScale to date is greater than US$950M.
- On track for first plant operation in 2027 in the U.S.
Comparison to a Large Pressurized Water Reactor (PWR)

- **Robust**, the Nuclear Stream Supply System is all contained in the NuScale Power Module™ (NPM).
- **Affordable**, the NPM is fully factory fabricated. No field construction, erection, or manufacture.
- **Reliable**, each NPM feeds steam to its own power conversion equipment.
- **Resilient**, the NuScale Plant can operate off-grid, available to support mission critical facilities and to restart the grid after a major event. Black start, first responder power, and island mode operation capable.
- **Safe**, site boundary Emergency Planning Zone (EPZ) possible and Triple Crown of Safety
- Truly small modular nuclear power generation.
NuScale Advanced Small Reactor Overview

- Each module produces up to 60 MWe
- up to 12 modules for 720 MWe gross (683 MWe net) total plant output

**Triple Crown of Safety** - NuScale Plant safely shuts down with:
- No operator or control system actions
- No AC/DC power
- No additional water

Emergency planning zone (EPZ) ends at site boundary
Blazing the Trail to Commercialization

- **First Plant Delivery (2027)**
- **Standard Plant Design Complete - Ready for Construction (2022)**
- **Core Fabrication (2023)**
- **Core Forging Order (2021)**
- **NRC Design Approval (2020)**
- **Design for Manufacturing Contract Awarded to Fabricator (2018)**
- **DCA Completed (2016), Docked (2017)**
- **Site Selection (2016)**
- **U.S. DOE SMR Award Recipient (2015)**
- **Secured First Customer (2013)**
- **Simulator (2012)**
- **Formation of Advisory Board (2011)**
- **Fluor Acquisition (2011)**
- **Begin NRC Pre-Application (2008)**
- **Formation of NuScale Power, LLC. (2007)**
- **1/5 Scale Integrated Test Facility (2005)**
- **DOE MASWR Program (2000)**

---

SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits
First SMR to Undergo Licensing in the U.S.

- Design Certification Application (DCA) completed in December 2016
- Docketed and review commenced by U.S. Nuclear Regulatory Commission (NRC) in March 2017
- Phase 4 of the NRC review completed December 2019; technical review is complete
- NRC is completing review of Phase 5 and 6

NuScale will make its mark this year (Sept ’20) as the first SMR technology to receive U.S. NRC design approval

DCA Statistics
- 12,000+ pages
- 14 Topical Reports
- >2 million labor hours
- >800 people
- >50 supplier/partners
- Over $500M
Mr. Thomas Mundy, Chief Commercial Officer, NuScale Power

NuScale 720 MWe U.S. Plant Cost Summary

Nth-of-a-Kind Cost (NOAK)

$2,508,569,000

$3,672/KW

Excludes:
- Warranty
- Contingency
- Fee

- 2017 USD
- Generic Southeast U.S. Site
- 12 module plant
- 683 MWe net

NuScale Power Module™ cost estimate – conforms to AACE International Class 3 cost estimate

- Performed by experienced large nuclear component manufacturer includes:
  - Manufacturing bill of material.
  - Welding, machining, and non-destructive examination processes developed.
- Transportation costs developed by expert heavy load transport engineering team.
- Fluor estimated EPC scope.

- NOAK based on assumed learning from FOAK cost estimate

NOAK based on the following First-of-a-Kind (FOAK) cost:

- Design maturity
  - Equipment lists, P&IDs, 3D plant models, etc.

- Rigorous and systematic “bottoms up” approach
  - Conforms to AACE International 18R-97 – Class 4 cost estimate.
  - Over 14,000 line items (equipment, material, etc.) priced using Fluor’s current proprietary cost data or actual vendor quotes.
  - Labor costs and productivity data from recent U.S. new build projects or applicable Fluor EPC experience and industry data.
First Deployment: UAMPS Carbon Free Power Project

• Utah Associated Municipal Power Systems (UAMPS) provides energy services to community-owned power systems throughout the Intermountain West.

• First deployment will be a 12-module plant (720 MWe) within the Idaho National Laboratory (INL) site, slated for commercial operation in 2027.

• DOE awarded $63.3 million in matching funds to perform site selection, secure site and water, and prepare combined operating license application to NRC and advance the site specific design.
International Opportunities

- NuScale made its first submittal to the Canadian Nuclear Safety Commission (CNSC) for pre-licensing vendor design review (VDR) and signed MOUs with Ontario Power Generation (OPG) and Bruce Power.

- NuScale has been actively involved in the United Kingdom’s SMR market activity for several years and is now exploring deployment opportunities.

- NuScale and Nuclearelectrica SA signed MOU to evaluate SMRs for Romania’s energy needs.

- NuScale signed an MOU with ČEZ Group to explore SMR opportunities in the Czech Republic and broader region.

- NuScale signed MOU with Jordan Atomic Energy Commission (JAEC) to evaluate NuScale’s SMR for use in Jordan.

- Many international opportunities for NuScale SMR deployment in Europe, the Middle East, Southeast Asia, and Africa.
The Future of Energy is Here
SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits
Rosatom RITM series SMRs

Ms. Elena Pashina
Marketing Director
Rusatom Overseas
ROSATOM is the world’s only company of a complete nuclear power cycle

>50 COUNTRIES of business around the globe

255,000 EMPLOYEES

>300 SUBSIDIARIES
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**

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First floating nuclear power plant in the world

AKADEMIK LOMONOSOV FNPP COMMISSIONED

2 X KLT-40S REACTORS (PWR) 77 MWe

Small reactors for marine applications since 1954

June 2019
Operation license is issued

December 2019
FNPP was connected to the grid

May 2020
FNPP was fully commissioned
RITM series reactors – the latest development that incorporates all the best features from its predecessors

ROSATOM small reactors evolution

- Based on 400 reactor-years experience of ROSATOM in operation of small reactors for marine applications
- Time proven PWR technology
- Integral configuration
- 3+ generation
- 165 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
Transportation of equipment

- **RITM-200 reactor pressure vessel** is the heaviest component of the plant.
- RPV dimensions are 4.5 x 3.4 x 7.5 m.
- RPV weight is **146 tons**.
- The RPV can be transported:
  - by rail, using a special carriage;
  - by means of heavy-duty vehicles;
  - by means of water transport.
- Other equipment will have **modular design** fit for transportation by regular means of transport.
### Key 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>
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<tbody>
<tr>
<td><strong>Thermal capacity, MW</strong></td>
<td>175</td>
<td>165</td>
<td>175</td>
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<tr>
<td><strong>Electrical capacity, MW</strong></td>
<td>40</td>
<td>53</td>
<td>50</td>
</tr>
<tr>
<td><strong>Steam generating capacity, t/h</strong></td>
<td>261</td>
<td>261</td>
<td>280</td>
</tr>
<tr>
<td><strong>Design lifetime, years</strong></td>
<td>40</td>
<td>60</td>
<td>60</td>
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<tr>
<td><strong>Fuel cycle, years</strong></td>
<td>4-7</td>
<td>6-7</td>
<td>10</td>
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<tr>
<td><strong>Reactor containment dimensions</strong></td>
<td>$6 \times 6 \times 15,5$</td>
<td>$6 \times 6 \times 15,5$</td>
<td>$6,8 \times 6,8 \times 16$</td>
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<tr>
<td><strong>Status of the development</strong></td>
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<td></td>
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</tr>
<tr>
<td><strong>Six reactors manufactured</strong></td>
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<td></td>
<td></td>
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<tr>
<td><strong>Year of commissioning</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Land-based NPP under development</strong></td>
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<td></td>
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<tr>
<td><strong>Year of commissioning</strong></td>
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<td>2027</td>
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<tr>
<td><strong>Concept design in progress</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Year of commissioning</strong></td>
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<tr>
<td><strong>Basic design in progress</strong></td>
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</tr>
<tr>
<td><strong>Year of commissioning</strong></td>
<td></td>
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</table>

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Land-based NPP equipped with RITM series SMR

2×53 MWe – 106 MWe

2 RITM-200N reactors

TECHNICAL PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Electrical capacity</td>
<td>106 MW (2 x 53 MW)</td>
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<tr>
<td>Thermal capacity</td>
<td>330 MW (2 x 165 MW)</td>
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<tr>
<td>Refueling cycle</td>
<td>up to 7 years</td>
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<tr>
<td>Design life</td>
<td>60 years</td>
</tr>
<tr>
<td>Availability factor</td>
<td>90%</td>
</tr>
<tr>
<td>Construction period</td>
<td>3 - 4 years</td>
</tr>
</tbody>
</table>

FLEXIBLE, TAILOR-MADE SMALL NPP SOLUTION BASED ON 3+ GENERATION RITM SMR IS DESIGNED TO ADDRESS A WIDE RANGE OF CUSTOMER DEMANDS
Land-based NPP conceptual design based on RITM series SMR

Modularity

MODULAR APPROACH ENABLES PLANT ELECTRICAL CAPACITY EXTENSION BY CONSTRUCTING ADDITIONAL MAIN BUILDING AND COOLING TOWERS WITH SHARED USE OF AUXILIARY BUILDINGS

Auxiliary buildings area
(shared infrastructure)

106 MWe
15 acres

+ 2 additional reactors
212 MWe
22 acres

+ 2 additional reactors
318 MWe
30 acres
Key components of NSSS of RITM series SMR

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
- 261 t/h – capacity

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

**CORE**
- 199 fuel assemblies
- Low-enriched cermet fuel
- 1,650 – height of the core
- 8 TWh – assigned service life
- Power changes with a design rate of 0.1%/s

**4 MAIN CIRCULATION PUMPS**
- Provide stable forced circulation of coolant
- Similar to those used on KLT-40S
RITM series SMR safety concept

INHERENT SAFETY FEATURES

• Negative temperature coefficient of reactivity
• High thermal conductivity and heat capacity materials
• Integral reactor configuration

PHYSICAL BARRIERS

• Fuel matrix
• Fuel cladding
• Primary circuit
• Biological shielding
• Hermetically sealed envelope
• Double containment

SAFETY SYSTEMS

• Emergency shutdown system
• 2 active trains of decay heat removal system (DHRS)
• 2 active trains of Emergence Core Cooling System (ECCS)
• Passive containment cooling system

BEYOND DBA MANAGEMENT

• Hydrogen passive recombiners
• In-vessel retention system
• Reactor envelope overpressure protection
• 2 passive trains of DHRS
• 2 passive trains of ECCS
• Soluble poison injection system
Ms. Elena Pashina, Marketing Director, Rusatom Overseas

Enhanced protection against external hazards

PARAMETERS FOR FOAK PROJECT IN RUSSIA

- peak acceleration of the station up to 0.3g
- peak acceleration of RITM SMR up to 3g
- up to 9 points on the MSK-64 scale

Earthquakes

Aircraft crash

- 20-ton aircraft (200 m/s) is a DBA
- 200-ton commercial aircraft (100 m/s) is a BDBA

Air pressure waves

up to 30 kPa

Tornadoes and sand storms

Extreme temperatures

Wind loads

up to 330 m/sec
Rosatom approach to licensing of SMR NPPs

- Design license (Central Design Bureau “iceberg”) – ISSUED
- Construction license (Baltic shipyard) – ISSUED
- Operation license (JSC «ROSENERGOATOM») – ISSUED, JUNE 2019

License for design process NI + equipment (Designer/Manufacturer)
Site license (Operator)
Construction license (Operator)
Operation license (Operator)

License for design process NI + equipment (Designer/Manufacturer)
Construction license (Shipyard)
Operation license (Operator)

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Development team and development status of ROSATOM SMR project

Project development time frame:
- Concept design developed
- FOAK site selection process started
- FOAK site in Russia selected
- Site license obtained
- License for construction obtained, start of construction
- LAND-BASED SMR NPP COMMISSIONING IN RUSSIA

ROSATOM LAND-BASED SMR NPP CAN BE POTENTIALLY COMMISSIONED ABROAD STARTING FROM 2028 AND BEYOND AS NTH OF A KIND
SMRs are an essential tool to ensure global sustainable development

There must be an element in every country’s energy mix that will be 100% predictable in terms of:

- Costs
- Reliability of supply
- Low carbon footprint

Nuclear power is a solution that provides for achieving sustainable development goals:

- Combat climate change
- Clean and affordable energy
- Industry and economic growth

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THANK YOU FOR YOUR ATTENTION!

Rusatom Overseas

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Dr. Martin J. Goodfellow, Strategy & Business Development Manager, SMR – Rolls-Royce

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Rolls-Royce consortium SMR

June 2020
Context – changing energy systems

- Nuclear provides only ~2% total **global energy** demand today (across power, heat, transport)
- 1 SMR is ~1/1000 of the existing global installed nuclear capacity
- Most existing capacity will be retired / replaced over the next 30 years
- Nuclear can play a large role and be relevant in the context of decarbonisation...
  ...BUT NOT AT ANY COST
Dr. Martin J. Goodfellow, Strategy & Business Development Manager, SMR – Rolls-Royce

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Power station design:

The principle of lowest LCOE is the primary requirement

Cost of Electricity = (capital + total O&M + decom + fuel costs + financing cost) / Power Generating potential x Capacity factor

Reduce O&M

Manage Investment

Reduce capital

Maximise power

Maximise reliability

Reduce Fuel cost

Compatibility with support infrastructure and Sites

Public Perception

Utility Familiarisation / Selection of Technology

Delivery Partnership Potential

Global Market
Electricity Market pricing

Electricity price is volatile and heavily linked to Oil Price

SMR electricity generation economics is detached from oil price and brings long term certainty

Financing cost is key – function of:
- Capital
- Time to build
- Risk or perceived risk

Electricity prices fluctuate considerably – Example:

UK Wholesale electricity market 2000-2018

- SMRs provide clean, dispatchable electricity at scale
- Price of electricity from an SMR provides long term price certainty
- Operating costs of an SMR are fixed, with little variation or external influence
Innovation to reduce

- **Capital**
- **Construction period**
- **Risk**

- **Power station** design NOT just nuclear reactor
- Smaller in physical size and power output (440MWe)
- Designed for all aspects of **lifecycle**
- **Whole plant modularisation**
- **Seismic raft** to standardise all plant modules
- **Short construction** period from modular approach
- **Site canopy** to improve efficiency / remove environmental risk from construction schedule
Summary

- Most methods of decarbonisation require more **clean** electricity
- SMRs can play a key role but not at any cost
- Our design is a power station NOT just a nuclear reactor
- Innovation for benefit not for technology sake
- Driven by economics and market requirements
Dr. Martin J. Goodfellow, Strategy & Business Development Manager, SMR – Rolls-Royce

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Rolls-Royce consortium SMR

June 2020
SMART development with validated technologies

Dr. Han-Ok Kang
SMART Project Management Division
KAERI

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SMART Introduction

System-integrated Modular Advanced Reactor

Advanced Integral PWR for Electricity Generation and District Heating or Desalination

- Thermal: 365 MWt
- Electricity: 100 MWe
- Fresh Water: 40,000 t/day

Sea Water

Desalination Plant

Fresh Water
SMART Development Chronicle

1997 - '99.3
Conceptual Design

1999 - '02.3
Basic Design

2002 - '06.2
SMART Prototype

2006 - '07.6
Pre Project Service

2007 - '08.12
Technology Optimization

2009 - '09.1 - '12.6
Standard Design Approval

2012 - '12 - '15
Safety Enhancement
International Coopera.

2016 - '15.12 - '18.11
SMART PPE

2019 - '19.1
SMART SDOA & Construction

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ROK-KSA SMART Partnership

High-Level Commitments

- A Robust Project Supported by KSA-ROK Governmental Agencies

2013 2014 2015 2016 2017 2018

Joint Implementation

- Joint Design of FOAK SMART by PPE (Pre-Project Engineering)

- Joint Export of advanced SMRs based on IP Ownership Sharing
Pre-Project Engineering

- The 1st Phase project for SMART Partnership between ROK and KSA

- FOAK Engineering Design for SMART
  - Project Period: 2015.12 ~ 2018.11
  - Work Scopes
    - Reactor System Design
    - Fuel Design
    - Balance of Power Design
    - Main Component Design and Validation
    - PSAR Preparation

- Human Capacity Buildup Program
  - CRT-Basic, CRT-Technical, OJT and OJP
  - 48 KSA Engineers at KAERI
Reactor Vessel Assembly

- No large RPV penetrations
  - Less than 2 inch penetrations
  - Penetrations above the top of SG
- In-Vessel Steam Pressurizer
- 4 Reactor Coolant Pumps
  - Canned motor type
  - Horizontally mounting
- 8 Helical Steam Generators
  - Once through SG
  - Produce superheated steam
  - Inlet orifices (DWO)
- 57 Fuel Assemblies
  - Standard 17x17 UO2 (< 5 w/o U235) w/ reduced height (2 m)
  - Performance proved at operating PWRs
- Flow Mixing Head Assembly
Passive Safety Systems

- To maintain a reactor in the safe condition for 72 hours without any operator action at the postulated design basis accidents.
- All safety systems can operate not depending on electrical power form emergency diesel generator for 72 hours.
- Safety-grade batteries provide necessary DC power for valve initiation and post accident monitoring.
Site Plot for 2 SMART Units
Comprehensive Performance and Safety Validation (I)

Standard Design Approval (SDA)  Safety Enhancement Research (SER)  Pre-Project Engineering (PPE)

VISTA-ITL (Small-Scale IET)
- SBLOCA, CLOF
- PRHRS performance 17

1st Phase Tests
- VISTA-ITL counterpart
- Characterization

PSS (1-Train)
- PSS Concept Verification
- CMT, BIT, ADS

PSS (2-Train)
- PSS Train Effects

DBA (w/ 4-Train PSS)
- Full Train PSS Tests
- SBLOCA, CLOF, FLB
- SGTR, RIA, NC, TLOSHR

OM, SG
- Operation & Maintenance
- SG Concept Verification

09 10 11 12 13 14 15 16 17 18

52 tests finished
Comprehensive Performance and Safety Validation (II)

SMART-ITL

SMART-MCR

SMART-FUEL
Standard Design Approval (SMART100)

- KAERI, K.A.CARE and KHNP applied Standard Design Approval for SMART100 which is current SMART model with uprated power and passive safety systems last December.

- The SMART100 SDA enters the regular technical review phase after the compliance review phase completed.

<table>
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<tr>
<th>Subjects</th>
<th>Year/Month</th>
<th>2020 – 2021</th>
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<tr>
<td>Compliance Review</td>
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<tr>
<td>- Confirmation of Compliance Review Response</td>
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<tr>
<td>- Compliance Review Report</td>
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<td></td>
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<tr>
<td>Technical Review Plan</td>
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<td></td>
</tr>
</tbody>
</table>

- Technical Review
  - Request of Additional Info (RAI)
  - Working Meeting
- Safety evaluation report
- 1st RAI
- 2nd RAI
- No open issues
- Committee and advisory committee (NSC)
Dr. Han-Ok Kang, SMART Project Management Division, KAERI

SMART Business Model

- **KAERI and K.A.CARE are Joint SMART Technology Owners.**
  - Recently KHNP began to play a role as an EPC for global SMART commercialization. SMART team (KAERI, K.A.CARE, and KHNP) is the best combination for SMART development, deployment, and global commercialization.

- **SMART team is ready to develop optimal business model with each country for better financing, project structure, and long term operation.**
  - Multi-lateral SMART collaboration model for newcomer countries (country-wise solutions for operation, maintenance, licensing, and HRD)

The Milestones Approach of IAEA is holistic and considers 19 specific infrastructure issues.
Summary

- SMART can be utilized for various application including electricity generation, seawater desalination, and process heat supply.

- SMART design is mixture of innovative concepts and proven technologies for licensing and market acceptability. New technologies were proven through comprehensive technology validation program.

- Korea and Saudi Arabia jointly have ownership of SMART technology and cooperate for global commercialization. Two countries are ready to cooperate with newcomer countries to deploy SMART technology.
THANK YOU
감사합니다
Technology Overview of the Xe-100 GEN IV Reactor

Eben J. Mulder, Senior VP and Chief Nuclear Officer (CNO)

June 23, 2020

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Part I: X-energy Overview
Our Approach

Reactors →
- Design & License
- Integrate & Assemble
- Bring to Site
- Operate & Maintain

Fuel →
- Uranium Mining
- Enrichment
- Fuel Fabrication
- Fuel Delivery
- Reactor Consuming Fuel
Dr. Eben Mulder, Chief Nuclear Officer, X-Energy

Our Solutions, Part 1 — Reactors

Proven Design
- 50+ years of research and test reactors
- Base load, load-following energy
- Grid-scale down to mobile form factors
- Simplicity in design makes construction & regulation more predictable

Safe
- True walk-away safe: physics ensures safety, not mechanical systems
- Safest fuel available. No melt down, no safety requirement for active cooling. Ever.
- 400 meter safety perimeter

Nearest to Market Gen IV
- No research or material hurdles remain
- Commercial reactor products are in the design phases
- Accelerating US & Canada approval tracks

Modular Design & Manufactured Components
- Leading to scalability, timeline & cost control never before seen in nuclear energy
- 2 1/2 years construction time for a single unit; 4 years for a 4-pack (NOAK)
Our Solution, Part 1 – Reactors

TRISO-fueled High Temperature Gas-Cooled Reactors

Grid-Scale w/ Load-Following Capabilities

Xe-100: 75MW increments, expected 300MW sweet spot

Timeline & Cost Controllable
Modular, manufacturable design minimizes on-site construction

On approval track with both US & Canada
Our Solution, Part 2 — Fuel

TRISO-X

Most Robust Nuclear Fuel on Earth

- Encapsulated fuel that is safe (self-contained, melt-proof) & offers efficient burn-up
- Leverages long-term investment and testing by the U.S. DOE

TRISO / HALEU UCO

- HALEU UCO kernel coated with layers of carbon, pyrolytic carbon & silicon carbide to form a TRISO particle

Our Product: TRISO-X

- Higher quality and production efficiency stemming from re-invented manufacturing process
The Xe-100 Leverages Proven Technology with Novel Integration

Continuous innovation to improve safety and economics (capital cost and operating cost) with a focus on simplicity, reliability, & flexibility

The HTGR is the advanced reactor technology nearest deployment and the Xe-100 is the most optimized, meltdown proof design – deployable within 5 years

>$700 million U.S. DOE investment, including development and testing of the safest fuel – UCO TRISO coated particles
Part II: Xe-100 Technology Overview
Xe-100 Technology

- X-energy did not start from scratch
- X-energy benefits from a rich history of design development, testing and operation of Pebble Bed Reactors across the globe
- R&D requirements were identified in 2015 and were fully funded through to July 2021 by DOE ARC program (currently 80% complete)
- HTGR is the most mature GEN IV advanced reactor technology
- The Xe-100 design is a cutting-edge design evolution that can be deployed in the next 5-6 years while providing a cost competitive, low risk, carbon free, versatile energy source
Safety Design Philosophy

- Any system that performs or contributes to support a safety function would be classified as a safety system or important to safety.

- X-energy has ensured that all safety functions can be performed using passive design features.

- No power or operator action is required to ensure that fuel is not damaged.

Preliminary classification of Safety Systems:
- TRISO-based fuel
- RPV
- Reactor building supporting the reactor
- Shut-down rods
- Reactor Protection System

- Systems Classified as Non-Safety Related with Special Treatment:
  - Burnup measurement
  - Control Rods (normal operation)
  - Helium Purification System
  - Fuel Handling System

By incorporating... We meet...

Design Selection/Feature

Safety Function

Control Critically
Control – Inherently/Passively
- Low power density
- Low exo-xa reactivity (due to online refueling)
- Strong negative temperature coefficient
- Fixed moderator (matrix graphite)
- Large thermal inertia

Contain Radionuclides
Contain – Passively
- High retention capability of fission products in coated particles (99.999%)
- High temperature tolerance during loss of forced heat removal
- Multiple independent physical barriers

Cool Passively
- Low power density
- Strong negative temperature coefficient
- Single phase heat transport fluid
- Large thermal inertia
- Large pressure vessel surface area to remove heat passively

Maintain Core Geometry

Multi-physics analysis
Thermal and flow analysis

Multi-physics analysis
Thermal and flow analysis

Neutronics analysis
Thermal and flow analysis
Fuel Performance analysis

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The Xe-100 Design Solution

- Proven High Temperature Pebble Bed Reactor

- Derived from over 50 years of design and development to significantly reducing costs to enable competitive deployment

- Proven fuel technology (US DOE Advance Gas Reactor irradiation program)

- Versatile Nuclear Steam Supply System (NSSS) that can be deployed for electricity generation and/or process heat applications

- Conservative design that does not require new material development and or code cases

- Steam pressure and temperature designed to provide steam to multiple Commercially Off The Shelf (COTS) Steam Turbine / Generator sets (typically those used in Combined Cycle Power Plants)
Independent Nuclear Island

Dr. Eben Mulder, Chief Nuclear Officer, X-Energy

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Standard Technology Offering (4-Reactor Plant)

- Standard power plant consists of four independent Reactor Modules (Reactor and Steam Generator)
- Each reactor module is connected to its own Steam Turbine/Generator
- Single shared control room with only three operators

RB – Reactor Building
TB – Turbine Building
CT – Cooling Tower
EB – Electrical Building
WT – Water Treatment Facility
WS – FW/PW Storage Tank
PH – FW/PW Pump House
MS – Maintenance Workshop
SB – Security Building
WH – Warehouse
SY – Switch Yard
AB – Admin/Engineering/Training Building
HS – Helium Services Facility
TB – Turbine Building
I-SFSF – Intermediate Spent Fuel Storage Facility
HE-SFSF – High Energy Spent Fuel Storage Facility
Reactivity Control and Shutdown System (RCSS)

- The primary shutdown mechanism is the strong negative temperature coefficient over the entire operational range.
- The secondary diverse shutdown system comprises of 9 shutdown rods that are inserted into channels in the side reflector for shutting the reactor down.
- The Control Rods provide a third independent means to shut the reactor down.
- As a Defense in Depth option defueling approximately 1.0 m³ of pebbles will shut the reactor down without the use of control rods.

![Graph: Temperature Coefficient of Reactivity](image)
Steam Generator

- **SG Pressure Vessel**
  - Pressure: 7.0 MPa
  - Design Temperature: 285°C
- **Internal Structures Design Conditions:**
  - 760°C (High Temperature Regions)
  - 285°C (Lower Temperature Regions)
- **Tube Design Conditions:**
  - Helium temperature at bundle inlet: 760°C
  - Helium temperature at bundle outlet: 285°C
  - Feed-water inlet temperature: 220°C
  - Steam temperature: 580°C
  - Helium Pressure: 7.0 MPa
  - Steam pressure: 17.5 MPa
- **Design Life**
  - Designed for a 60 year operating life
- **Inspection Requirements**
  - The SG design shall permit inspection of the full length of all tubes (tube bend radius > 9D)
  - 158 tubes arranged in 25 cylinders
Spent Fuel Storage

- Spent fuel is placed in a high energy interim storage building for about 6 months where it is cooled using natural convection before it is placed in a long-term storage cask and moved out to a spent fuel storage pad.
Dr. Eben Mulder, Chief Nuclear Officer, X-Energy

Plant Control Systems

- The Xe-100 deploys four different I&C systems:
  - Distributed Control System (DCS)
  - Investment Protection System (IPS)
  - Reactor Protection System (RPS)
  - Post Event Monitoring System (PEMS)

- To ensure multiple mission capability (i.e. electricity or process heat) the DCS is designed to only need control input from the Nuclear Island Systems

- This approach ensures that downstream systems/processes do not affect the operation of the Reactor Module

- The intent is to have the Reactor Protection System as the only safety related I&C system
Training Simulator for Human Factors Engineering

- X-energy has already started to develop a training simulator
- The training simulator is developed in conjunction with our first principles engineering simulator (Flownex)
- Currently we have completed Phase 1 and 2 of the simulator and will now start with Phase 3 with a planned completion date of December 2022.
Conventional Island – Power Conversion

- 100% Commercial-Off-The-Shelf (COTS) steam turbine generator set – including condenser and all auxiliary systems
- Hi turbine thermal efficiency of up to 42.3%
- Skid mounted turbine allows for fast swap out/replacement instead of in-situ refurbishment
- Condenser cooling can be done using wet or dry cooling modules
- Rankine cycle cooling also uses COTS modular dry/wet or hybrid cooling towers
Summary

- Xe-100 is a HTGR design based on proven technology

- Safety characteristics and size of Xe-100 reactor enable deployment in densely populated and remote Jordanian areas

- Inherent radionuclide retention capability of the UCO TRISO fuel is at the center of the Xe-100’s intrinsically safe design

- Key Personnel have been a part of the U.S. and international HGTR community for 30+ years – working together on the Xe-100 for the past 10 years, ensuring our ability to meet all milestones
SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits
Panel Discussion and Q&A Session

To ask a question, please use the Q&A section.