Micro-Reactors Rural Use Considerations

Alaska House Resources Committee

Marc Nichol
Senior Director of New Reactors
Marc 14, 2022

NUCLEAR ENERGY INSTITUTE

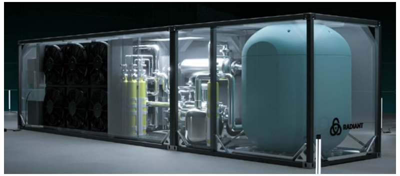
Micro Reactor Technology

Designed to replace Diesel Generators

Oklo Aurora
1.5 MWe

Ultra Safe Nuclear Corporation
5 MWe

Westinghouse eVinci
5 MWe



Radiant Kaleidos
1.2 MWe

- Very small size
  - Site as small as 0.1 acres, building ~size of a house
  - Reactor is road shippable, minimal site work
- Resilience – withstand, mitigate or quickly recover from
  - Extreme natural events
  - Man-made physical and cyber threats
- Operations
  - Automatic operations, island mode and black-start
  - Flexible – hybrid energy and renewables integration

<u>Other Designs (not all inclusive)</u>

- BWXT
- General Atomics
- HolosGen
- Hydromine
- NuGen
- NuScale
- X-energy

Market Opportunities

Topics

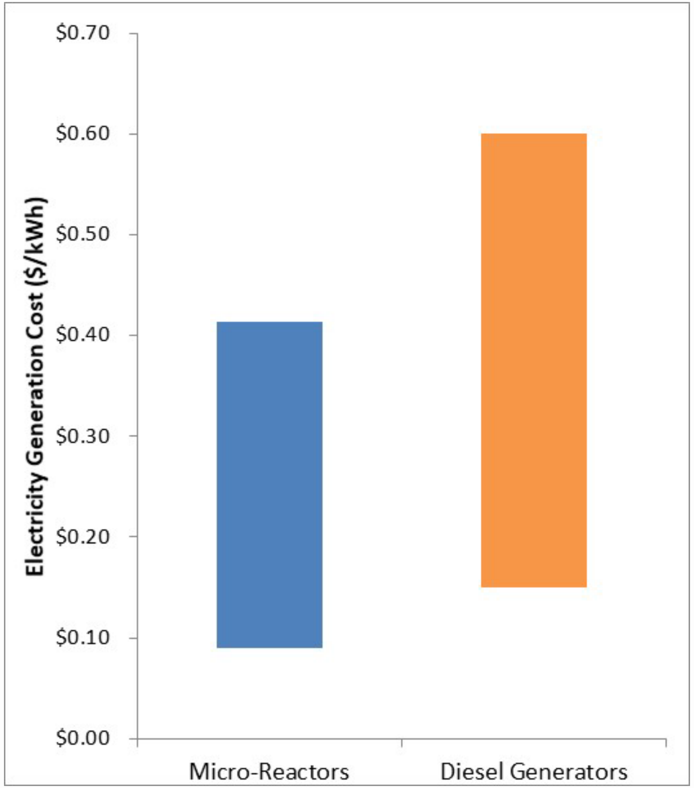
- Costs and Workforce
- Safety and Security
- Used Fuel and Decommissioning
- Deployment Plans and Policies

Costs and Workforce

Cost Comparison

Full cost of micro-reactor vs only diesel fuel cost

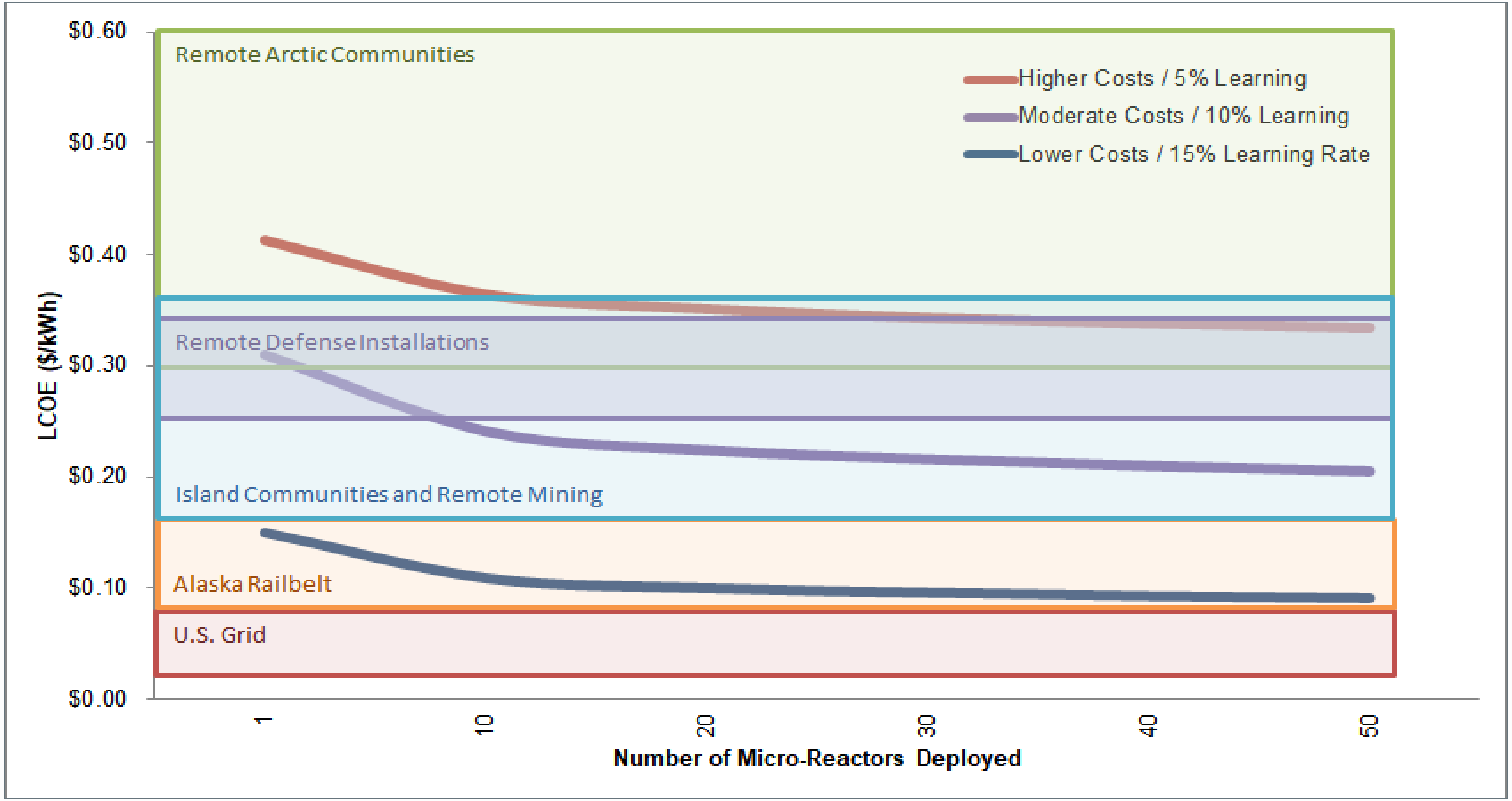
- Diesel generator costs
  - Primarily fuel costs
  - Fuel from $2.86/gallon to $4.89/gallon
- Micro-reactor costs
  - Include used fuel disposal and decommissioning
  - 10 year fuel life
  - 40 year plant life
  - 95% capacity factor



NEI: *Cost Competitiveness of Micro-Reactors for Remote Markets*, April 2019

Micro-Reactor Cost Competitiveness

Cost of generation is lower than cost to customer



Source: NEI *Cost Competitiveness of Micro-Reactors for Remote Markets*, April 2019
https://nei.org/resources/reports-briefs/cost-competitiveness-micro-reactors-remote-markets

Financing Micro-Reactors

Capital Costs of 5 MWe plant = $50M to $100M*

- Conventional business model
  - Local utility finances capital costs
  - Financing typically by debt at low rates, amortized

- New business models
  - Developer owns and operates plant, uses a Power Purchase Agreement
  - Local utility does not finance capital costs, only pays for power

- Similarities and differences
  - In both: customers only pay as levelized cost of capital
  - New business model: developer bears bulk of financial risk of project

*Derived from NEI *Cost Competitiveness of Micro-Reactors for Remote Markets*, April 2019
https://nei.org/resources/reports-briefs/cost-competitiveness-micro-reactors-remote-markets

Micro-Reactor Workforce

Target <10 employees to power rural areas

Technology enablers	NRC considering for micro-reactors
Safety and simplicity in design	Minimal worker training and qualifications
Automatic operations	Operators allowed additional duties (e.g., maintenance, administrative)
Remote operations	No operator needed on site
Security by design	No armed security guards needed

- Hub areas: population sizes that can supply workers
  - Direct use of electricity and heat with existing grid and district heating
- Spoke areas: population sizes that cannot supply workers
  - Electric transmission from hub region (if close by); OR
  - Use hydrogen or ammonia from hub region (low-cost due to economics of micro-reactors and short transport distances)

Safety and Security

Micro-Reactor Safety

Building upon a strong safety record

- Operating fleet: one of the safest industrial working environments
  - Strong-Independent Regulator, Built tough, Operational Performance
- Enhancing safety for advanced reactors*
  - Safety profile fundamentally differ from other power reactors

Inherent Safety Features

- Robust hardened structures
- Rely on physics
  - Natural circulation
  - Gravity
- Fail-safe, shuts itself off
- Operational simplicity: very few instruments and controls

Reduce Risks

- Much smaller radionuclide inventory
- Minimize potential for accidents
- Mitigate consequences
- Proliferation resistant fuel and enrichments below 20% U-235

Emergency Response

- No credible event that could result in unacceptable off-site doses
- Maintain safety without the need for
  - Power
  - Additional coolant
  - Human actions
- Emergency planning

*Features vary by design

U.S. Nuclear Regulatory Commission

Regulatory Reviews are Rigorous

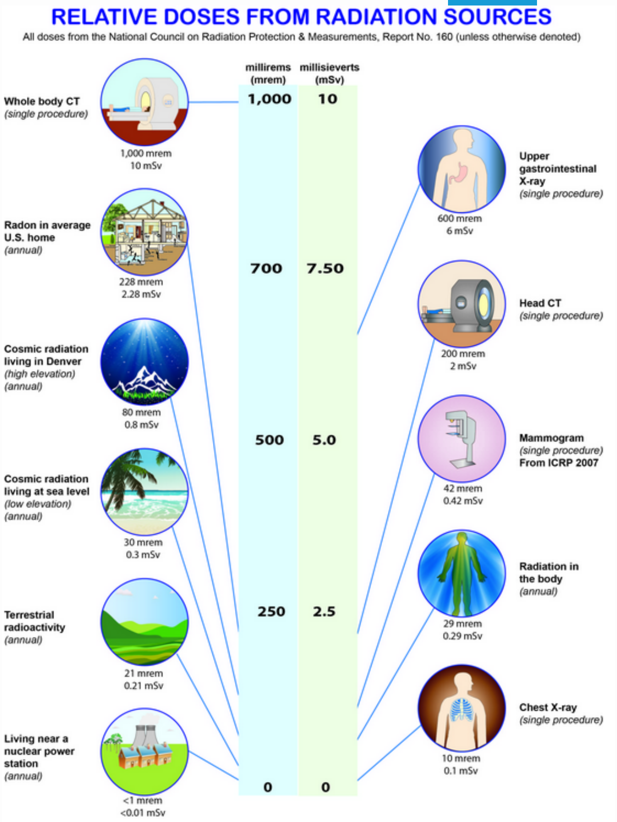
- Information Reviewed[1]
  - Applications are thousands of pages (NuScale was 12,000 pages)
  - NRC reviews and audits supporting information (NuScale was 2 million pages)
- NRC Resources Expended [1]
  - Schedule for typical design review is 3 to 4 years
  - Fees for typical design review are $45M to $68M (~ 200,000 person-hours)
- Coordination with Other Agencies
  - DHS and other agencies involved in defining the design basis threat
  - FEMA involved in Emergency Planning[2]
- Public Involvement
  - Public can file contentions on the application
  - Hearing opportunities before licenses are granted

1) These are historical for grid-scale reactors, micro-reactors are expected to be less due to enhanced safety and simplicity
2) NRC rulemaking is considering whether FEMA would be involved in review when the EPZ does not extend beyond the site boundary

U.S. Nuclear Regulatory Commission

What NRC Approval Means

- Safety
  - Risks from nuclear plant to public are much lower than other societal risks (less than 0.1%)
  - Dose to public is less than 100 mrem/yr[1]
- Security
  - Protected against radiological sabotage
  - Protected against theft and diversion
- Emergency Planning
  - Worst case dose at Emergency Planning Zone expected to be less than 1 rem
  - Micro-reactors expected to have EPZ at site boundary
- Environmental
  - Plant and site meet all NEPA and other Environmental Laws (e.g., Water, Air)



*Source: EPA

1) Average dose from food and water (e.g., banana, beans, meat, carrots) is 30 mrem per year; from living near a nuclear plant is less than 1 mrem

Used Fuel and Decommissioning

Addressing Waste

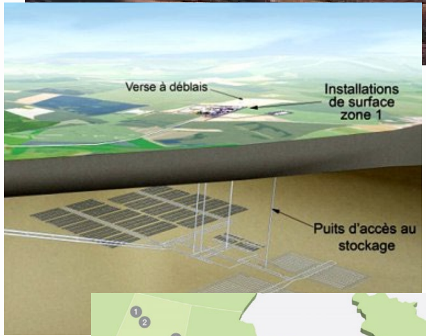
All Energy Sources Have Waste, and All Must Do Three Things to Address it

- Must be able to manage it safely
  - Used fuel is solid, compact and there is proven technology to store it safely
  - Over 1,300 used fuel shipments safely completed in U.S.
- Must be able to pay for it
  - U.S. law requires nuclear plants to fund used fuel management and decommissioning activities
  - Over $40 billion in Nuclear Waste Fund
- Must have a place to put it
  - Department of Energy required dispose of used fuel
  - Most micro-reactor companies will take back used fuel soon after refueling

Nuclear Fuel

Final Disposal

- Nations making progress on spent nuclear fuel disposal
  - Finland – repository licensed and under construction
  - Sweden – repository approved for constructing
  - France – site identified, in public consultation toward pilot phase
  - Canada – List of 22 candidate sites narrowed down to 2, geologic investigations under way
  - Switzerland – geologic investigations supporting siting process underway
  - U.S. – Yucca Mountain designated by law, alternatives being considered
- Consolidated Interim Storage
  - France, Sweden, and Switzerland all have deployed CIS
  - U.S. companies pursuing CIS solutions



Optimizing the value of nuclear feedstock

- Future reactors may economically recycle used nuclear fuel to extract even more energy from uranium already mined

- Initial new reactor startups will be on new fuel
- Between 6 and 9 advanced reactor suppliers may be able to power their machines with used fuel
- Most envisioned recycling strategies would not separate out pure plutonium

Deployment Plans and Policies

Government Deployment Support

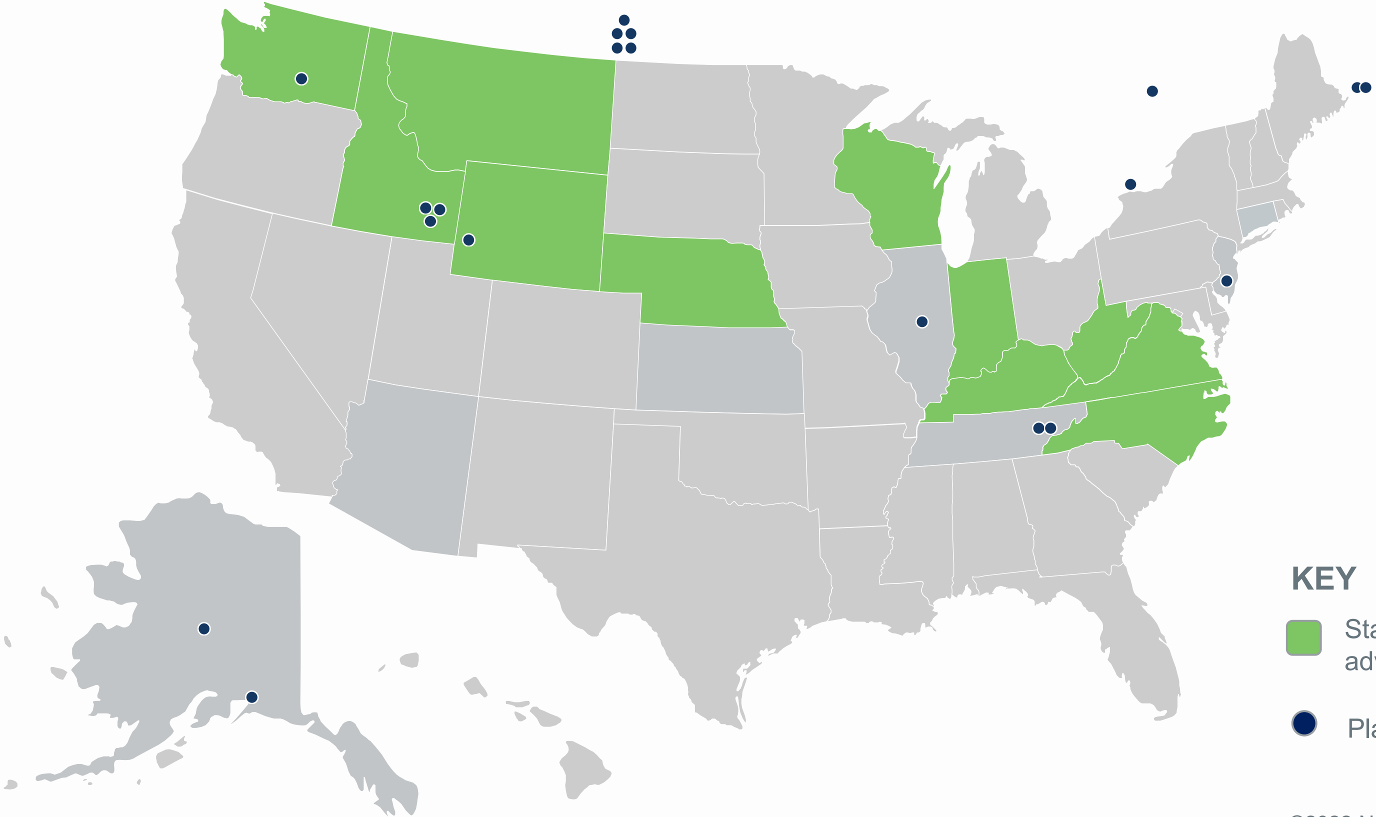
- Valuing all carbon-free sources of energy
- Federal Programs
  - Demonstrations
  - Tax Credits (e.g., Production)
  - Loan Guarantees
  - Federal Power Purchase Agreements
- State Programs
  - Tax incentives (e.g., property)
  - Advanced cost recovery
  - Infrastructure

http://smrstart.org/wp-content/uploads/2017/07/SMR-Start-State-Options-for-New-Nuclear-Approved-2017-06-26.pdf

http://smrstart.org/policy-statement/

Advanced Nuclear Deployment Plans

More than 20 projects in planning or under consideration in U.S. and Canada; >30 globally



KEY

State policies to support advanced nuclear in place

Planned project

Micro-Reactor Deployment Projects

Planned to be on-line by 2025 to 2027

NEI

Developer	Utility / User	Location	Size	Target Online
Oklo	Oklo	Idaho, USA	1.5 MW	2025
	Compass Mining	TBD	TBD (150 MW total)	TBD
Ultra Safe Nuclear	Global First / OPG	CRL, Canada	5 MW	2025
	University of Illinois	Illinois, USA	5 MW	2027
	Copper Valley (CVEA)	Alaska, USA	5 MW	TBD
Westinghouse	TBA	West Canada	5 MW	2027
	Bruce Power	ON, Canada	5 MW	2027
	Univ. (TBA)	USA	5 MW	2027
Radiant	TBA	Idaho, USA	1.2 MW	2026
TBD	Eielson AFB	Alaska, USA	1 – 10 MW	2027
X-energy or BWXT	DoD SCO	Idaho, USA	1.5 MW	2025

QUESTIONS?

Marc Nichol, NEI, Senior Director, New Reactors

mrn@nei.org 202-739-8131

By Third Way, GENSLER