Work Plan for the Selection of the μReactor Design at UIUC

Draft

Kathryn D. Huff,
Mehmet Turkmen,
Zoe Richter

October 2, 2019

1 Introduction

Micro-reactors are the reactors which produce power typically less than 20 MWe and site less than 500 m2 (0.1 acre) in the size of shipping container or a big house. They are considered to be automated operation with minimum operating staff. Due to the small size and low consequences of micro-reactors, the regulations applied to the existing (non)commercial reactors may not fully applicable to micro-reactors. Apart from other advanced reactor designs like SMRs, micro-reactors have specific following licencing issues: security, aircraft strike, emergency preparedness, source term analysis, staffing, remote operation, decommissioning, transportation, manufacturing licenses, quality assurance, probabilistic risk assessment and NRC oversight.

2 Reactors

Nine designs of micro-reactors are under investigation: Westinghouse (eVinci), Holosgen (Holos), LANL (MegaPower), MicroNuclear, NuScale (NuScale), Oklo (Oklo), Starcore (Starcore), Urenco (U-battery) and X-energy (Xe-100) (in alphabetical order). Kairos does not have any reactor designs which produce power less than 200 MWe. A brief comparison of the selected reactors is listed in Table 1. In addition, recent progresses in the design reviews of different reactors around the world are provided in Table 2.

The information on reactor designs was mainly gathered from the following sources.

1. International and domestic government organization databases: design information was collected from the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (OECD-NEA), the U.S Department of Energy (U.S. DOE), and the U.S. Nuclear Regulatory Commission (U.S.NRC) online databases.

2. Vendor database: the latest design brochures, catalogues and reports were directly obtained from the vendors.

Notes:

1. GA is developing a mobile nuclear power supply that is truck/air shippable and would fit in a standard military shipping container. This modular, autonomous system has a load-following generating capacity of up to 10 MWe and a refueling period greater than 10 years. (source: press releases)

2. The NuGen Engine developed by NuGen is a direct-cycle gas-cooled microreactor. The concept design, by Professor Tsvetkov at the Department of Nuclear Engineering at Texas A&M University, produces 1-50 MWe scalable output. It is in the stage of patent aproaval. (source: https://www.nucdev.com/about-us.html)

3. In the case of MSR design at micro-level, only Terrapower has started to adopt its MCFR design to 1-10 MWe with more than 10 years refueling.(source: press releases of the president)

Table 1: A brief comparison of micro-reactor designs

Design	eVinci	Holos	MegaPower	NuScale	Oklo	Starcore	U-battery	Xe-100
Institution	Westinghouse	Hologen	LANL	NuScale	Oklo Inc.	Starcore	Urenco	X-energy
Source	[9];[3];[4]	[16]	[15];[14]	[6]	[19]	[12]	[11]	[10];[13]
Type	Heat Pipe	HTGR (Pebble)	Heat Pipe	PWR/Heat Pipe	Heat Pipe	HTGR (Pebble)	HTGR (Pebble)	HTGR (Pebble)
Spectrum	Epithermal	Thermal	Fast	Thermal/Thermal	Fast	Thermal	Thermal	Thermal
Power (MWe)	0.2-5	10/13	2	10-50 /1-10	∽2	2x10	4-8	75
Refueling (years)	5 to 10	12 or 20	5	2/-	12 (estimated)	5	5-10	Online refueling
Enrichment (%)	19.75	8 for 12 or 15 for 20	19.75	<4.95/-	5 to 20	<20	20-17	15.5
Core Diameter (m)	1.5	1.8	1.5	1.5/-		1.5	3.5-1.8	5
Fuel	UN/U-Mo	UCO TRISO	UO2	UO2/-	U-Zr	UCO TRISO	UCO TRISO	UCO TRISO
Clad	-	Silicon carbide	-	M5/-	-	Silicon carbide	Silicon carbide	Silicon carbide
Heat Pipe fluid	Na/K	-	K	-	Na/K	-	-	-

Table 2: Worldwide design reviews

	Country of Origin	Company	Reactor type	Output(MWe)	Status
1	Canada/US	Terrestrial Energy	Molten Salt Integral	200	PHASE 1 COMPLETED PHASE 2 PENDING
2	US/Korea/China	UltraSafe Nuclear /Global First Power	High-temperature gas prismatic block	5	PHASE 1 IN PROGRESS completion date 2018 PHASE 2 Service Agreement under development
3	Sweden/Canada	LeadCold	Molten lead pool fast spectrum	3-10	PHASE 1 ON HOLD AT VENDOR REQUEST
4	US	Advanced Reactor Concepts	Sodium pool fast spectrum	100	PHASE 1 IN PROGRESS
5	UK	U-Battery	High temperature gas prismatic block	4	PHASE 1 Service Agreement under development
6	UK	Moltex Energy	Molten salt fast spectrum	300	PHASE 1 IN PROGRESS
7	Canada/US	StarCore Nuclear	High-temperature gas prismatic block	10	PHASE 1 and 2 Service Agreement under development
8	US	SMR, LLC. (A Holtec International Company)	Pressurized Water	160	PHASE 1 Service Agreement under development
9	US	NuScale Power	Integral Pressurized Water	50	PHASE 2* Service Agreement under development
10	US	Westinghouse Electric Co.	eVinci Micro Reactor	<25	PHASE 2* Service Agreement under development
11	Japan	4S	Na cooled fast reactor	10	Licensing pre-application
12	Russia	ABV	PWR	2x7.9	Part of design licensed
13	Argentina	CAREM-25	PWR	27	Licensing in progress
14	Russia	KLT-40S	PWR	2x35	Licensed and under construction

2.1 Westinghouse

Full design details have not been revealed yet for public; only general information is given by the company. However, several academic studies, most of them eVinci-like, can be found in the literature. Recently, two papers, [1] and [2], have been published in 18th NURETH conference. Those are not available for now but reaching them somehow would be valuable. Westinghouse is planning to finalize the current design of eVinci by 2022, testing by 2023 and commercializing by 2025. Hernandez et al. [5] performed a series of calculations in eVinci-like (not eVinci) for natural resource utilization, burnup analyses, waste management and environmental impacts. The details of eVinci design obtained from the documents published by Westinghouse are presented in Table 3. Reactor core configuration and 3D design representation are given in Figs. 1 and 2.

Table 3: eVinci design parameters

Design	Value (from Westinghouse reports) [10];[9];[3];[4]	Value (other) [5]
Core Diameter (in)	59.06	
Monolith materials		Type-316 SS
Refueling (years)	Up to 10	
Fuel	UN/U-Mo	
Fuel Pellet Density, % TD	96	
Enrichment (%)	19.75	
Fuel channel radius (in)		0.281
Number of fuel channels	378 (1 MWth), 4219 (14 MWth)	2112 (5 MWth)
Reflector material		BeO
HP channel radius (in)		0.298
Number of HP channels		1224
HP to HP web thickness (in)		0.039
Fuel to fuel web thickness (in)		0.059
HP total length (ft)		13.12
HP fluid	Na/K	
HP fluid temperature (K)	920	

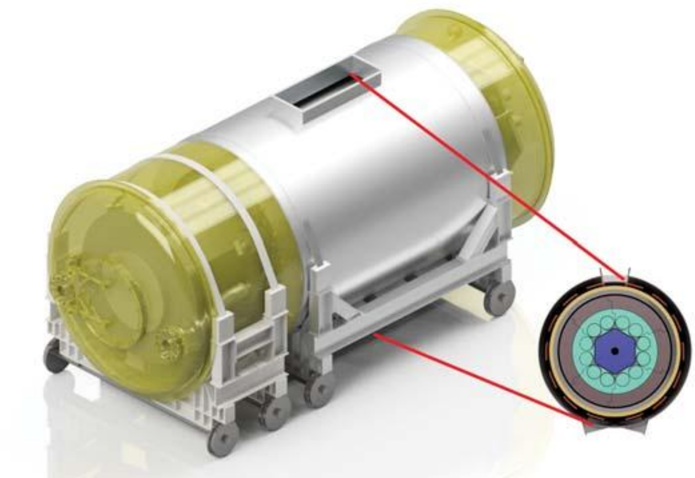

Figure 1: eVinci Core Configuration

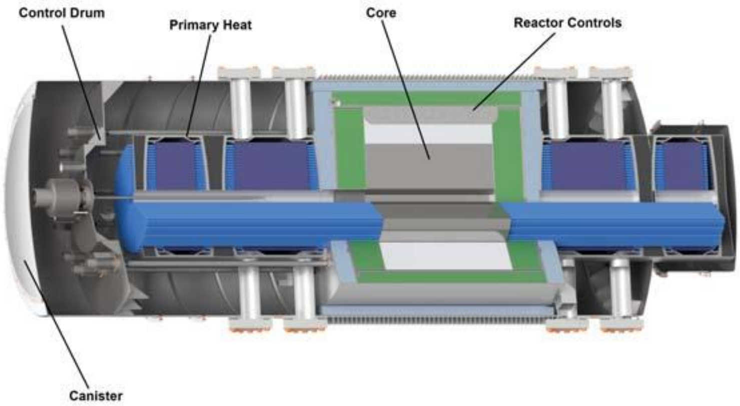

Figure 2: eVinci Micro Reactor Overview

2.2 Holosgen

Holos design uses four subcritical fuel cartridges as given in Fig. 3. TRISO fuels fill the fuel channels, as illustrated in Fig. 4. Complete design details including radiation protection and shielding, and safety are available in [16].

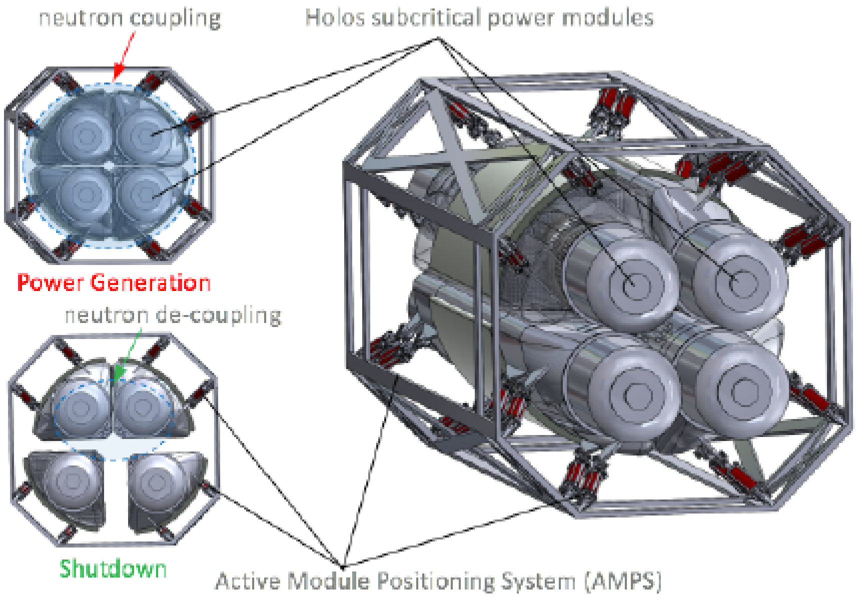

Figure 3: Holos Quad generator

Table 4: Holos core geometry and composition

Design	Value
Reactor thermal power (MWt)	22
U-235 enrichment (wt%)	8-15
Whole core volume (m3)	6.9
Fuel Channels	19x4
Fuel Channel Diameter (cm)	1.4
Coolant Channels	54x4
Coolant Channel Diameter (cm)	0.7
Brick Graphite Density (g/cm3)	2.23
Brick Edge Length (cm)	6
Brick Height (cm)	10
UO2 Density (g/cm3)	10.8
Kernel Diameter (cm)	0.05
Buffer Layer Thickness (cm)	0.01
SiC, IPyC, OPyC Thickness (cm)	0.012
TRISO Sphere Diameter (cm)	0.094
Total core bricks	1,925
Packing Fraction (%)	70
TRISO spheres in one fuel channel	24,778
TRISO spheres in one brick	470,777
TRISO spheres in core	$3.62\text{x}10^9$
Temperature Coefficient of Reactivity -ρ_T- (pcm)	-8
Delayed Neutron Fraction -β_{eff}- (pcm)	733
Generation Time -Λ- (μs)	233

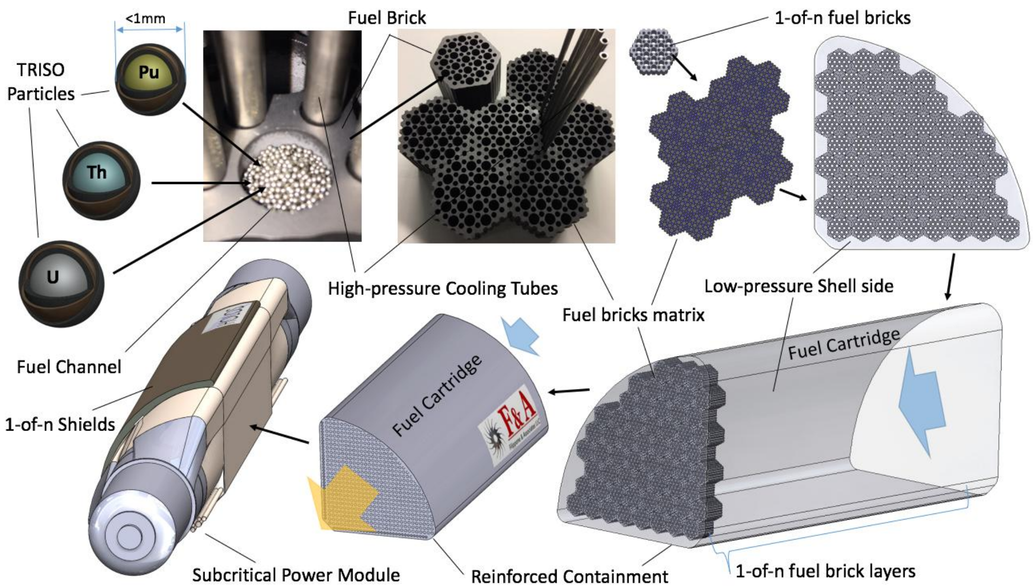

Figure 4: Holos subcritical assembly design

2.3 LANL

MegaPower is a Los Alamos National Laboratory (LANL) reactor design concept. Table 5 provides important features of MegaPower reactor parameters. More specific design details can be found in the reports [14] and [15]. Results of the neutronics and thermal-hydraulics analyses have been published by INL and LANL in various reports. Apart from 5 MWt design, there is an advanced 15 MWt design which uses UN fuel and Na as HP fluid. However, publications are mostly on the first design shown in Figs. 5 and 6.

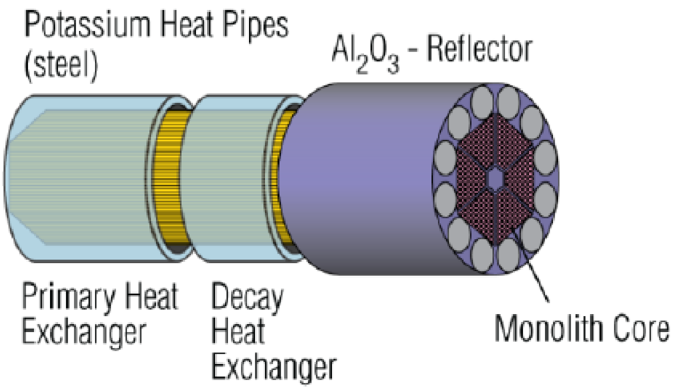

Figure 5: Megapower concept design

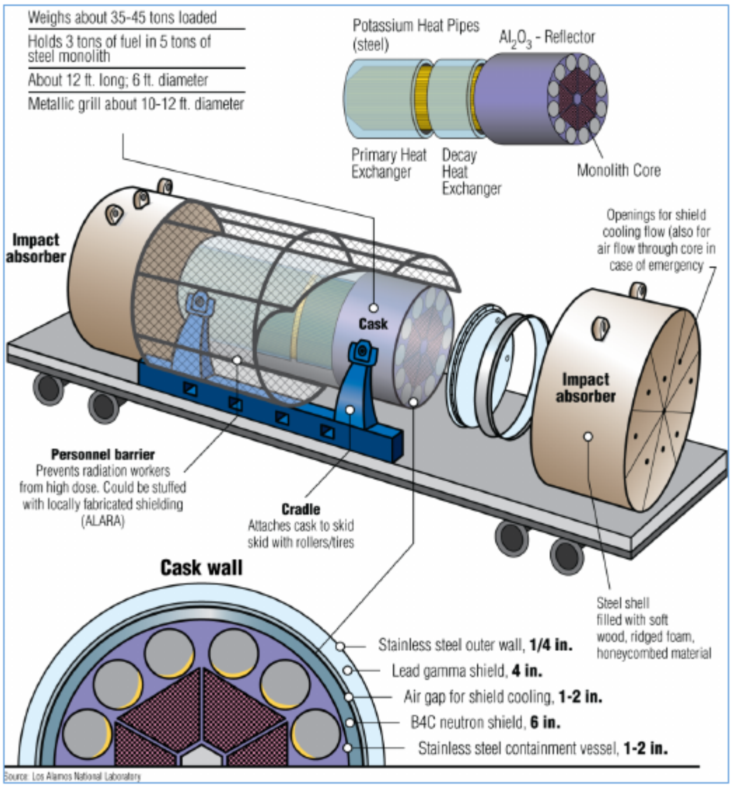

Figure 6: Megapower reactor overview

Table 5: MegaPower Reactor Core Description

Design	Value
Reactor thermal power	5 MW
Reactor electrical power output	2 MW(e)
Reactor core orientation	Horizontal
Cycle length	5 years
Coolant system	Heat pipes
Reactor structure	Type 316 Stainless steel monolith
Fuel Form	UO2
Theoretical density	10.96 g/cm3
Percent of theoretical density	96.0%
U-235 enrichment	19.75 wt%
Fuel channel hole outer diameter	1.425 cm
Fuel pellet geometry	Cylindrical
Fuel pellet outer diameter	1.412 cm
Gas gap thickness	0.0065 cm
Fuel rod length	150.0 cm
Fuel-to-fuel pitch	1.60 cm
Fuel-to-HP pitch	1.60 cm
Gas	Helium
Gas pressure	20 atmospheres
Number of fuel rods in-core	2,112
Number of HPs in-core	1,224
HP hole diameter (in-core)	1.575 cm
HP-to-HP pitch	2.7713 cm
HP working fluid	Potassium
HP total length	4.0 m
HP isothermal temperature	675C
Monolith material	Stainless steel (SS316)
Monolith steel density	8.03 g/cm3
Monolith edge thickness (HP-to-edge)	2 mm
Web thickness between HP-to-fuel holes	0.100 cm
Web thickness between fuel-to-fuel holes	0.175 cm
Web thickness between HP-to-edge of block	0.150 cm
Side reflector material	Alumina (Al2O3)
Alumina density	3.9 g/cm3
Side reflector outer radius	77.85 cm
Side reflector radial thickness	2129 cm
Top/bottom reflector material	SS316 + BeO
Number of control drums	12
Number of emergency control rods	2
Control material	B4C

2.4 MicroNuclear

There is absolutely nothing on MsNB design of MicroNuclear LLC company. I think this company has a weak desire to go into the micro-nuclear world.

2.5 NuScale

Detailed technical specifications (as seen in Table 6) related to reactor core design, source term, licensing requirements and safety assessments are given in the NRC web-page [8]. This is the FSAR for the SMR design of NuScale. NuScale considers two different micro-reactor concepts [18]: one (10-50 MWe) is based on current small modular reactor tecnhnology and the other (1-10 MWe) is based on heat pipe reactor technology. The first one is very similar to the SMR. FSAR report seems quite sufficient by supplying all the details about the plant. 2D and 3D views of the reactor are illustrated in Figs. 7 and 8, respectively. This design can be altered for the μR concept of NuScale for a nominal electric power of less than 20 MW. There is no detail on the heat pipe design.
In 2018, BWX Technologies was selected to provide manufacturing input. In 2019, Doosan Heavy Industries and Construction and NuScale signed an MOU.

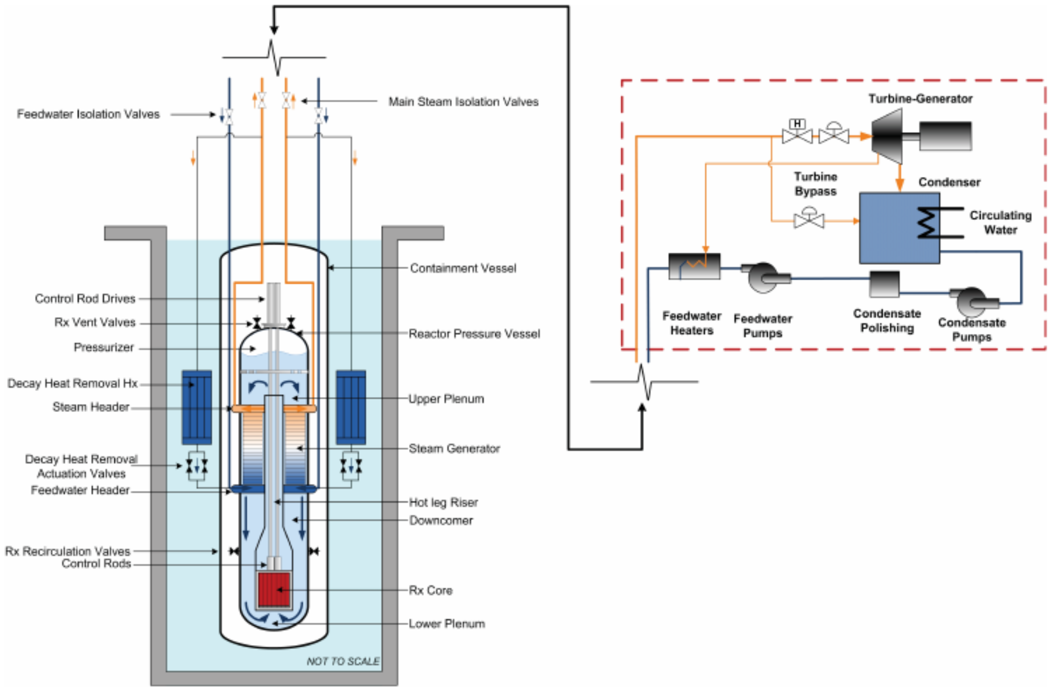

Figure 7: Two-dimensional schematic of a single NuScale unit

Design	Value
Core diameter (in)	59.25
Active fuel height (in)	78.74
Number of FA	37
Rod array	17x17
Fuel assembly length (in)	94
Fuel assembly pitch (in)	8.466
Fuel rod pitch (in)	0.496
Number of spacer grids	5
Grid height (in)	1.75
Number of Fuel rods	264
Number of Guide tubes	24
Number of Instrumentation tubes	1
Number of FR	264
Diametral gap (in)	0.0065
Cladding material	M5
Cladding outside diameter (in)	0.374
Cladding inside diameter (in)	0.326
Cladding thickness (in)	0.024
Fill gas	helium
Fuel Pellet Density, % TD	96
Material	UO2 (sintered)
Diameter (in)	0.3195
Length (in)	0.40
Number of CR Assemblies	16
Upper absorber material	boron carbide
Lower absorber material	silver-indium-cadmium
Cladding	304 stainless steel
Fill gas	helium
BA Material Type	integral with fuel
Material	gadolinia (Gd2O3)
Number	Up to 32 per assembly
Nuclear Design Parameters (for Equilibrium Cycle)	
Core Average Linear Power (kw/ft)	2.5
Total Heat Flux Hot Channel Factor	1.860
Nuclear Enthalpy Hot Channel Factor	1.386
Reactivity Coefficients	
Doppler temperature coefficient (pcm/F)	-1.4 to -2.25
Moderator temperature coefficient (HZP-HFP) (pcm/F)	+6 to -43
Boron coefficient (pcm/ppm)	-10
Effective Delayed Neutron Fraction and Prompt Neutron Lifetime	
β_{eff} BOC	0.0059
β_{eff} EOC	0.0052
Prompt lifetime BOC (10-6 seconds)	18.35
Prompt lifetime EOC (10-6 seconds)	-6
Boron Concentration (BOC) (ppm)	2000

Table 6: NuScale Reactor Core Description [6]

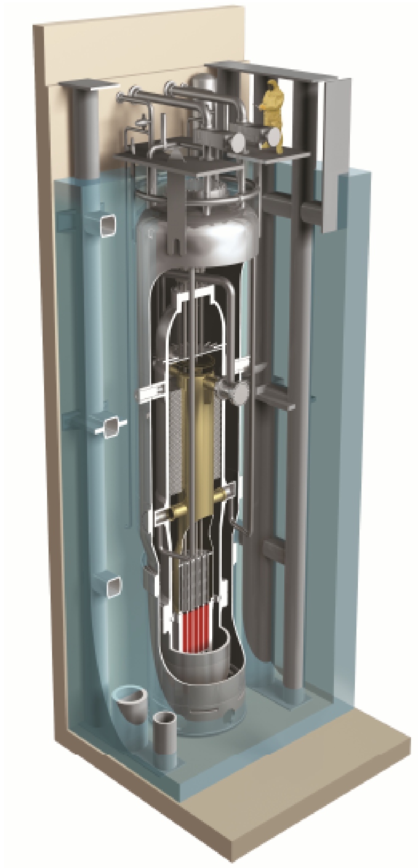

Figure 8: NuScale 3D SMR view

2.6 Oklo

Oklo is working on a Compact Fast Reactor design since 2013. Since November 2016, NRC has been engaged in pre-application activities (the docket number - 99902046) with Oklo. Public version of the final safety analysis report of Oklo [19] is not enough for the understanding of the reactor design. Full version has the details such as probabilistic risk assessment, release pathway and enviromental impact but was closed to public access. Even company web site is unreachable. The company is now making collaboration with ANL and INL.

2.7 Starcore

The StarCore technical data is acquired directly from the vendor website and summarized in Table 7 below. In terms of size and basic technical characteristics, the reactor, illustrated in Fig 9, is similar to HTR-10, a prototype pebble bed modular reactor built and operated in China, and HTTR, a 30 MWth experimental gas cooled reactor in Japan.

HTGR reactor with 2 reactor units per standard plant is embedded 15m underground in Ultra High Strength Concrete (UHSC) silos. The reactors are installed in silos 57 metres deep (as seen in Fig. 10) and 13 metres in diameter, made from double-walled high performance concrete with a steel canister silo at the base. TRISO fuel compacts supplied by BWX Technologies. StarCore is fully automated and has only two operating states: Load Following and Shutdown.

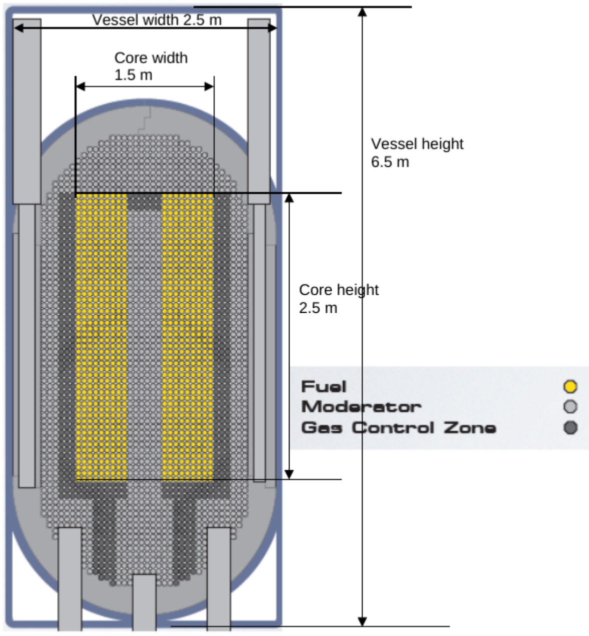

Figure 9: StarCore reactor core

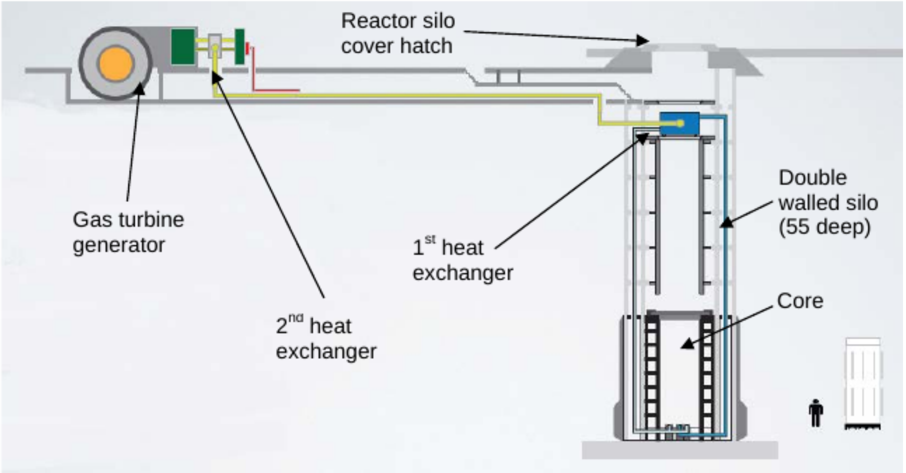

Figure 10: Side view of Starcore

Table 7: StarCore reactor design

Design	Value
Core Diameter (m)	1.5
Core Height (m)	2.5
Refueling (y)	5 (off-site)
Fuel	UCO TRISO Pebbles
Enrichment (%)	<20
Number of fuel pebbles	26,800
Number of TRISO particles per pebble	2,000
Pebble fuel core diameter (mm)	60
Fuel element geometry	Truncated cuboctahedron
Cladding material	Silicon carbide
Primary side coolant	Helium
Core outlet temp (C)	850
Core operating pressure (MPa)	7.5
Secondary side coolant	Nitrogen
Secondary side operating pressure (MPa)	6.8

2.8 Urenco

The concept design, namely U-battery, has been made by the Universities of Manchester, Dalton Institute (UK) and Technology University of Delft (Netherlands). There is strong desire to operate the reactor by 2026. Main design parameters [11] are tabulated in Table 8. A 3D view and core layout of the reactor are displayed in Figs. 11 and 12.

Table 8: U-battery design

Design	10 MWe	20 MWe
Reflector composition	BeO	Graphite
Control rods (#)	4	6
Fuel Blocks (#)	6*4	30*4
Enrichment (%)	20	17
Fuel life time (a)	5	10
Fuel block dimension (cm)	36*80	36*80
Fuel mass (kg)	208	1.040
Burn-up (MWd/kg HM)	88	70
Outer diameter (cm)	180	370
Vessel thickness (mm)	<100	100
Reactor core diameter (cm)	108	252
Reflector thickness (cm)	20 (BeO)	29
Insulation thickness (cm)	5 (SiC fiber)	10 (SiC fiber)
Barrel thickness (cm)	2	2
Gap thickness (cm)	5	5
Core Height (cm)	320	320
Top reflector (cm)	20 (BeO)	50
Bottom reflector (cm)	20 (BeO)	50
Top plenum (cm)	20	20
Bottom plenum (cm)	50	50
Top insulation (cm)	30	30
Bottom insulation (cm)	60	60
Core support plate (cm)	10	15
Support structure (cm)	60	60
Vessel height (cm)	590	655
BeO mass (kg)	7.900	0
Graphite mass (kg)	8.100	70.000
Flask inner diam (cm)	180	-
Flask inner height (cm)	>500	-

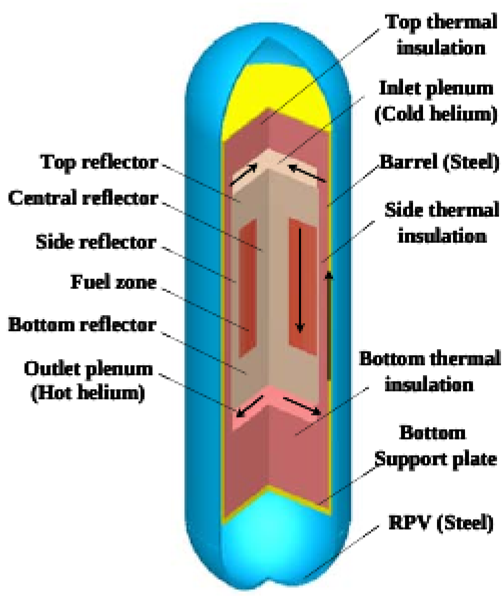

Figure 11: 3D reactor configuration of U-battery

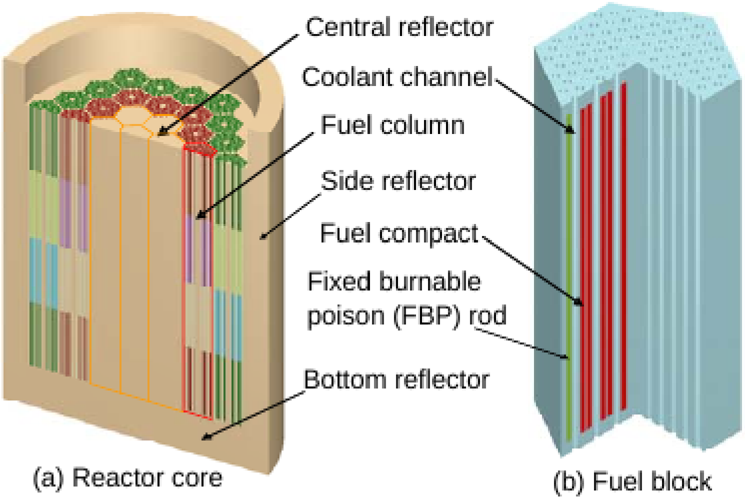

Figure 12: Core and fuel block of U-battery

2.9 X-energy

X-energy company provides various reactor designs ranging from 600 MWt to 30 MWt, called as Pebble Bed Fuel Reactor. The main micro-rector design is ST-OTTO (refering to Fig. 13) which produces 30-48 MWt power. But the design details are not open for public. I think the design is very identical to the design of 200 MWt, as presented in Table 9 except for the reactor size and fuel type. Th-based fuel is under consideration for the use in TRISOs.

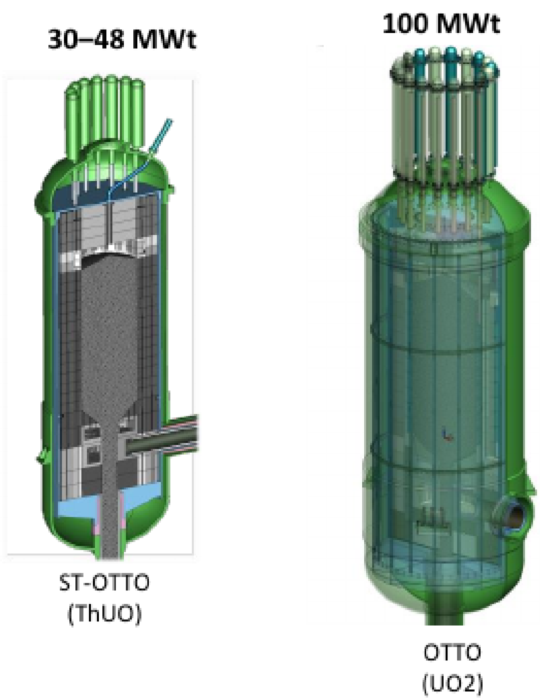

Figure 13: X-energy micro-reactor overview

Table 9: X-energy design

Design	Value
Core Diameter (m)	4.88
Core Height (m)	20
Refueling	Online fuel loading 175 fresh pebbles/day
Fuel	UCO TRISO Pebbles
Enrichment (%)	15.5
Number of fuel pebbles	220,000
Number of TRISO particles per pebble	18,000
Pebble fuel core diameter (mm)	55
Pebble diameter (mm)	55
Pebble fuel core diameter (mm)	60
Number of passes	60
Final burnup (GWd/tHM)	160
Burnable poison	no
Power density (MW/m3)	4.8
UCO TRISO kernel radius (mm)	0.2125
Porous Carbon Buffer thickness (mm)	0.095
Inner Pyrolytic Carbon Layer thickness (mm)	0.04
Silicon Carbide Layer thickness (mm)	0.035
Outer Pyrolytic Carbon Layer thickness (mm)	0.04
Core Inlet temp (C)	259
Core Outlet temp (C)	750
Core Inlet Pressure (MPa)	6
Core Outlet Pressure (MPa)	5.84

3 Site Requirements

For site requirement, main documents are:

1. Idaho National Laboratory, Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors, Probabilistic Risk Assessment Approach, Rev 0, August 2019.
2. Idaho National Laboratory, Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors, Selection and Evaluation of Licensing Basis Events, Rev 0, August 2019.
3. Idaho National Laboratory, Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors, Safety Classification and Performance Criteria for Structures, Systems and Components, Rev 0, August 2019.
4. Idaho National Laboratory, Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors, Risk-Informed and Performance-Based Evaluation of Defense-inDepth Adequacy, Rev 0, August 2019.

4 Source Term

A general source term analysis comprises transient scenario modeling, fuel pin radionuclide distribution, failed pin radionuclide release, radionuclide bubble transport, offsite dispersion analysis and containment region analysis. Some of them can, however, be eliminated or new ones can be added depending on which micro-reactor is to be chosen. As an example, the micro-reactor design does not include any spent fuel storage, thus the source term would not. For the source term analysis of a selected micro-reactor design, phenomena and release paths of accident scenarios first need to be identified. Pathways for some advanced reactors (i.e., HTGR, SFR, MSR) are illustrated in Fig. 14. There are on-going discussions in the NRC on the evaluation of the source term of micro-reactors; it is expected to come to a conclusion on the licencing issues including the source term by the end of this year (estimated).

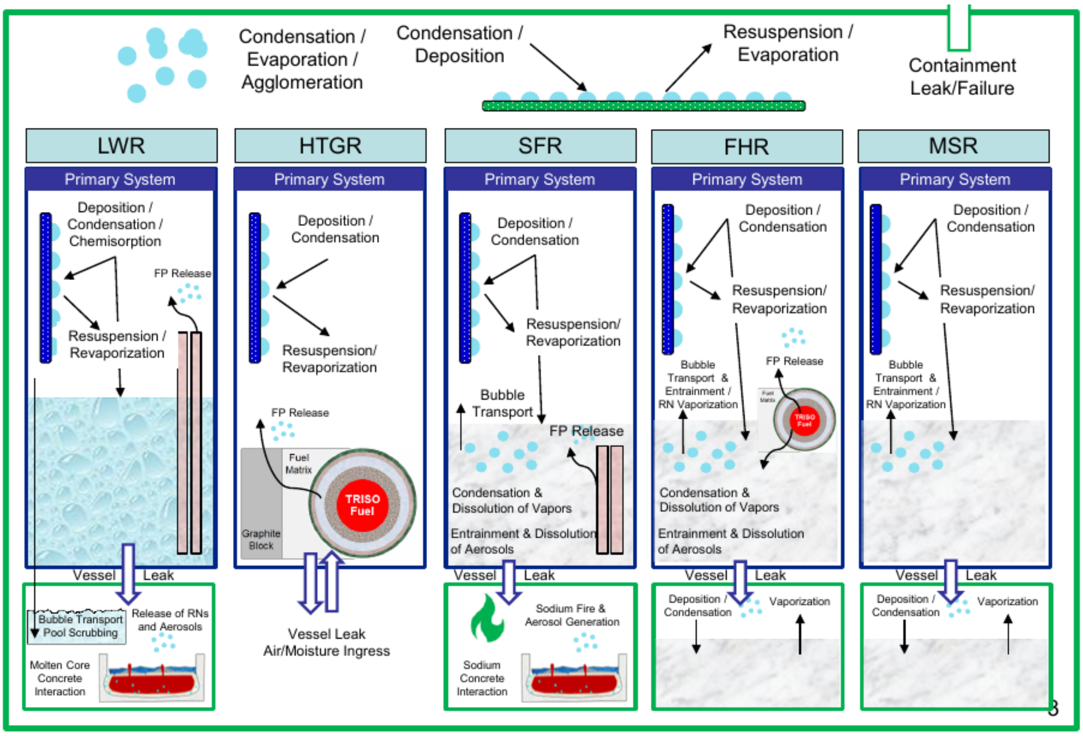

Figure 14: Pathway for radioactive release for several reactor types

There is a possibility to make an assumption for the pathway identification of the micro-reactors. We can use the same or modified pathways of the existing reactors, accepted by the NRC, for the analogy to the selected micro-reactor design. Yet, heat pipe reactors may still require as the release ways have not completely known. The method for the source term calculation recommended by the NRC is given in Fig. 15. The method to be applied changes with the type of the reactor. In any cases, MELCOR, system accident analysis code, produce the source term for the defined design-basis accidents. For probabilistic offsite consequence analysis bounded by the calculated source term, MACCS code needs to be utilized. The code is capable of evaluating the Level 3 PRA including the radionuclide release, atmospheric transport, meteorology, protective actions, site data, dosimetry, health effects, economic factors, and so forth. Design-specific and site-related issues must be input to the code. Meteorological statistics (i.e., day and night temperatures, magnitude and direction of the wind, tornados, flooding level), topographical data and population density and distribution, habitat of the animals and the location of the endemic plants are to be recorded. The methodology and the results on the source term calculations are presented in detail in the relevant documents of NuScale [8] and eVinci [7].

According to the NuScale, the potential radionuclide source term associated with a severe accident is much smaller (5%) than that associated with a 1000 MWe design. This value is 1% for eVinci.

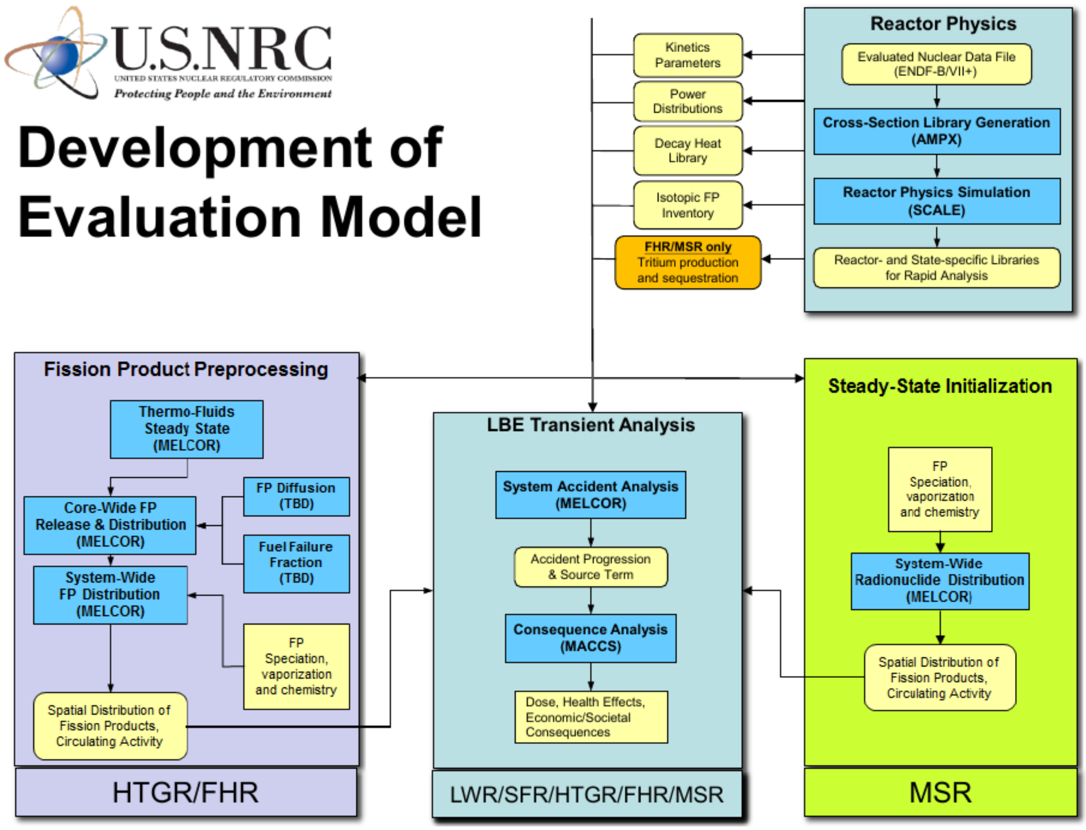

Figure 15: Source term evaluation model

5 Licencing Procedure

For the licensing of the research reactors, below documents are critical:

1. Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Standard Review Plan and Acceptance Criteria (NUREG 1537, Part 2).

2. Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Format and Content (NUREG 1537, Part 1).

https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1537

A reference document [17] has discussed the micro-reactor from the various acpects inculding waste management, fuel supply and action plans.

6 Safety Assessment

This part is going to be discussed later but will include accident scenarios including design-basis that a nuclear facility must be designed and built to withstand, and beyond design accidents that are possible but were not fully considered in the design process.

7 Discussion on the Report

Considering available data of the interested reactors given in Section 2, full core modeling capabilities are presented in Table 10. it should be taken into account that desing details of the reactor to be selected can be gathered from the corresponding vendor. What should be the criteria for the selection of the micro-reactor?

Table 10: Full core modeling

Design	eVinci	Holos	MegaPower	NuScale	Oklo	Starcore	U-battery	Xe-100
$\times$ or $\surd$	$\times$	$\surd$	$\surd$	$\surd$	$\times$	$\surd$	$\surd$	$\surd$

8 Conclusion

References

[1] Hong, X., Jurie J., van W., Richard F., W., 2019. Thermal Analysis for eVinci Micro Reactor. Presented at the 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH18), Portland, OR.

[2] Wright, R.F., Dokmanovich, A.M., 2019. Phenomena Identification and Ranking Table for the eVinciTM Micro Reactor. Presented at the 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH18), Portland, OR.

[3] Yan, B.H., Wang, C., Li, L.G., 2020. The technology of micro heat pipe cooled reactor: A review. Annals of Nuclear Energy 135, 106948. https://doi.org/10.1016/j.anucene.2019.106948

[4] Yasir Arafat, Jurie Van Wyk, Nuclear Plant Journal: eVinci Micro Reactor Our Next Disruptive Technology, http://www.westinghousenuclear.com/Portals/0/new

[5] Hernandez, R., Todosow, M., Brown, N.R., 2019. Micro heat pipe nuclear reactor concepts: Analysis of fuel cycle performance and environmental impacts. Annals of Nuclear Energy 126, 419426. https://doi.org/10.1016/j.anucene.2018.11.050

[6] NuScale, NuScale Standard Plant Design Certification Application - Chapter 4: Reactor, Part 2-Tier 2, Revision 2, ML18310A325, October 2018. https://www.nrc.gov/reactors/new-reactors/design-cert/nuscale.html.

[7] Southern Company, Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors: Westinghouse eVinciTM Micro-Reactor Licensing Modernization Project Demonstration, DOE, SC-29980-202, 2019.

[8] NuScale, NuScale Standard Plant Design Certification Application: Chapter Nineteen Probabilistic Risk Assessment and Severe Accident Evaluation, Rev. 2, 2018.

[9] Levinsky, A., Wyk, J.J., Arafat, Y., et al., 2018. Westinghouse eVinci Reactor for Off-Grid Markets. Transactions of the American Nuclear Society, Orlando, Florida, November 11-15.

[10] IAEA, Advances in Small Modular Reactor Technology Developments A Supplement to: IAEA Advanced Reactors Information System (ARIS), 2018.

[11] Ding, M., Kloosterman, J.L., Kooijman, T., Linssen, R., 2011. Design of a U-Battery (No. PNR-131-2011-014). Urenco, and Koopman and Witteveen.

[12] http://starcorenuclear.ca

[13] Harlan, B., 2018. X-energy Xe-100 Reactor initial NRC meeting, AccessionNumber=ML18253A109. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?.

[14] Sterbentz, J.W., Werner, J.E., Hummel, A.J., Kennedy, J.C., Wright, R.N., Biersdorf, J.M., 2017. Special Purpose Nuclear Reactor (5 MW) for Reliable Power at Remote Sites Assessment Report: Using Phenomena Identification and Ranking Tables (PIRTs) (No. INL/EXT-16-40741). Idaho National Laboratory Nuclear Science and Technology Division.

[15] McClure, P., Poston, D., Rao, D.V., Reid, R., 2015. Design og MegaWatt Power Level Heat Pipe Reactors (No. LA-UR-15-28840). Los Alamos National Laboratory.

[16] Filippone, C., Jordan, K.A., 2017. The Holos Reactor: A Distributable Power Generator with Transportable Subcritical Power Modules.

[17] Nichol, M., 2018. Roadmap for the Deployment of Micro-Reactors for U.S. Department of Defense Domestic Installations (Technical Report). Nuclear Energy Institute.

[18] Nichol, M., 2019. Cost Competitiveness of Micro-Reactors for Remote Markets (Technical Report). Nuclear Energy Institute.

[19] Oklo, Inc., 2018. Pilot Application for DG-1353, Enclosure 1 (Submittal to Support NRC Development and Implementation of DG-1353, A Guidance to Risk-Inform Application Development and Contents Including Event Selection and SSC Classification No. Oklo-2018-R10-NP, Rev 0), Pilot Application. Oklo, Inc.