Fuel Design Innovations for Heat Pipe Micro-Reactors

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Nuclear Fuels – Tendencies and Feasible Advances Facing the Near Future

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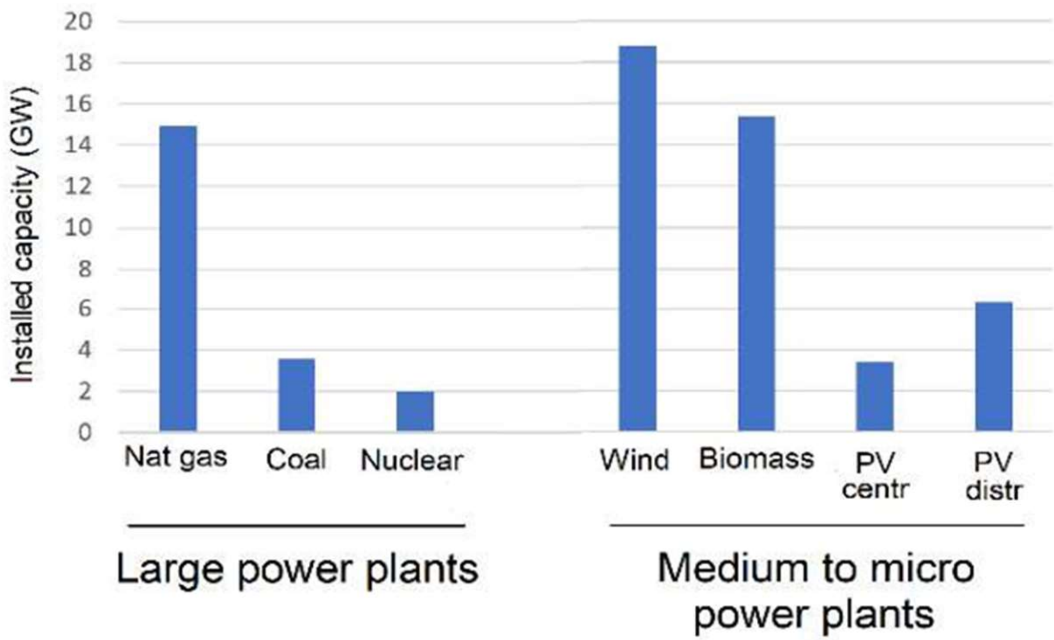
Summary

- Importance of the microgeneration market for nuclear power
- R&D activities needed for micro-reactors
- Different fuel and core designs
  - Monolith for fast and thermal micro-reactor
  - Monolith with fuel elements
  - Fuel element cores
- Final remarks

Large, small and micro generation in Brazil (except Hydropower) - 2021

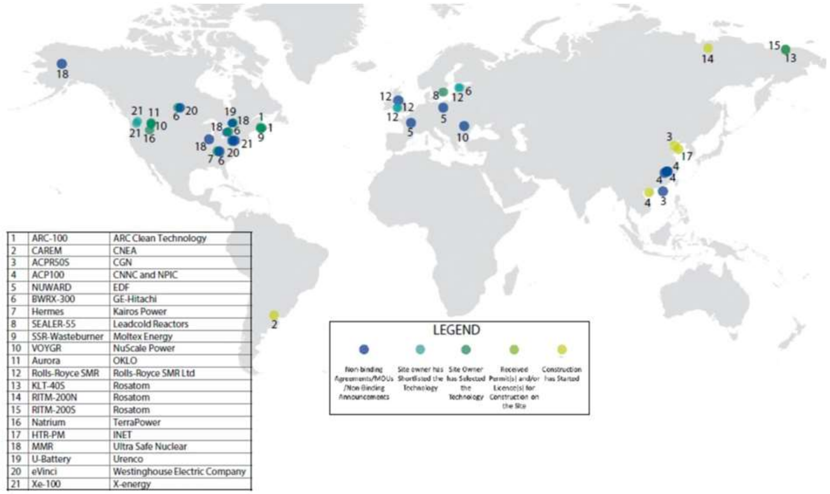
- Growing share of medium size and micro generation markets
- Microgeneration market presents the greatest growth rate in recent years
- Micro-reactors may participate in the micro generation market
- It allows developing the supply chains for materials and services for a sustained nuclear power in the country

Installed capacity in Brazi (GW)l, 2021



Some SMR and micro-reator projects in the world

Name	Design organisation	Headquarter (city/region)	Country	Thermal power (MWth)	Outlet temperature (ºC)	Spectrum (thermal/fast)	Fuel type
ARC-100	ARC Clean Technology	Saint John, New Brunswick	Canada	286	510	Fast	Metallic UO_2
CAREM	CNEA[1]	Buenos Aires	Argentina	100	326	Thermal	UO_2 pellets
ACPR50S	CGN[2]	Shenzhen	China	200	321.8	Thermal	UO_2 pellets
ACP100	CNNC[3] and NPIC[4]	Hainan Province	China	385	319.5	Thermal	UO_2 pellets
Nuward	EDF[5]	Paris	France	540	307	Thermal	UO_2 pellets
BWRX-300	GE-Hitachi/ Hitachi-GE	Wilmington, North Carolina	United States	870	287	Thermal	UO_2 pellets
Hermes	Kairos Power	Alameda, California	United States	35	585	Thermal	TRISO pebble
SEALER-55	Leadcold Reactors	Stockholm	Sweden	140	432	Fast	Metallic UO_2
Stable Salt Reactor - Wasteburner	Moltex Energy	Saint John, New Brunswick	Canada	750	590	Fast	Molten salt fuel
VOYGR	NuScale Power	Portland, Oregon	United States	250	321	Thermal	UO_2 pellets
Aurora	OKLO	Sunnyvale, California	United States	4	500	Fast	Metallic UO_2
Rolls-Royce SMR	Rolls-Royce SMR Ltd	Manchester	United Kingdom	1 358	325	Thermal	UO_2 pellets
KLT-40S	Rosatom	Moscow	Russia	150	316	Thermal	UO_2 pellets
RITM-200N	Rosatom	Moscow	Russia	190	321	Thermal	UO_2 pellets
RITM-200S	Rosatom	Moscow	Russia	198	318	Thermal	UO_2 pellets
Natrium	TerraPower	Bellevue, Washington	United States	840	500	Fast	Metallic UO_2
HTR-PM	INET[6]	Beijing	China	500	750	Thermal	TRISO pebble
MMR	Ultra Safe Nuclear	Seattle, Washington	United States	15	630	Thermal	TRISO prismatic
U-Battery	Urenco	Stoke Poges	United Kingdom	10	710	Thermal	TRISO prismatic
eVinci	Westinghouse Electric Company	Cranberry Township, Pennsylvania	United States	13	750	Thermal	TRISO
XE-100	X-energy	Rockville, Maryland	United States	200	750	Thermal	TRISO-X pebble



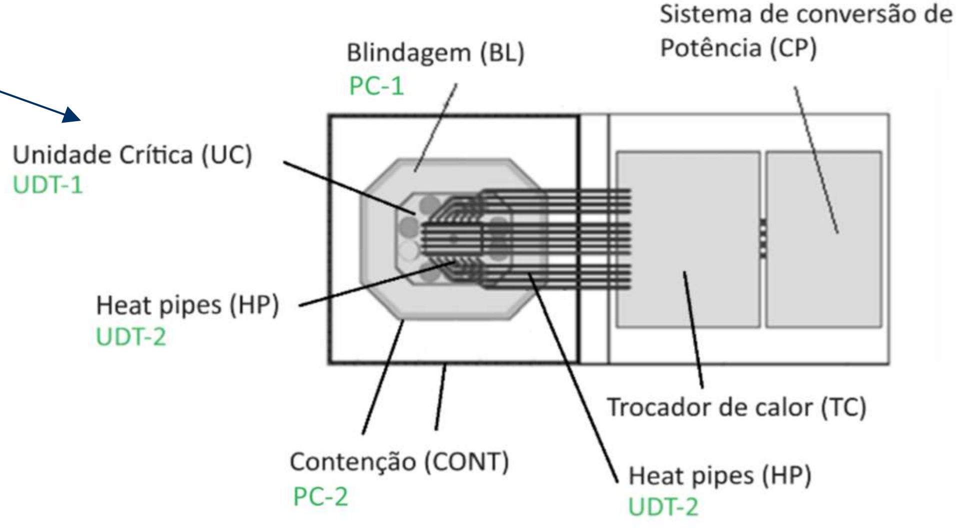
Micro reatores a heat pipes

https://www.oecd-nea.org/jcms/pl_90816/the-nea-small-modular-reactor-dashboard-second-edition

Main R&D activities for micro-reactors

Fuel and
core design

Desenvolvimento e Teste de Tecnologia
aplicável a micro reatores



Sistema de instrumentação, controle e proteção UDT-4
Transferência de calor integrada entre UC-HP-TC
com varetas aquecidas eletricamente UDT-3

Alinhamento com a Autoridade Regulatória quanto às normas de
segurança aplicáveis à tecnologia de micro reatores

Comparison of fuel requirements for micro-reactors and large power reactors

Typical values

Parameter	Large LWR	Micro-reactor
Power density in the fuel region (W/cm3)	400	10 – 50
Cycle length (year)	1 - 2	5 – 10
Fuel burnup (MWd/kg U)	65	< 15
Coolant average temperature (°C)	~ 320	~ 700
Fuel average temperature (°C)	~ 1300	~ 1300
Thermal power to mass ratio (kWt/kg U)	60	1 – 2

- Micro-reactor high temperatures are due to the saturation temperature of the heat pipe working fluid (usually a liquid/vapor metal)
- Typical fuels for micro-reactors: UO_2, UN, UC, Triso, U-metal alloys and recycled fuel with Am, Cm, Pu

Main components of the micro-reactor (INL/EXT-16-40741 Rev 1, 2017)

Core
(fue and heat
pipe region)

Neutron
Reflector

Rotation drums
for reactivity
control

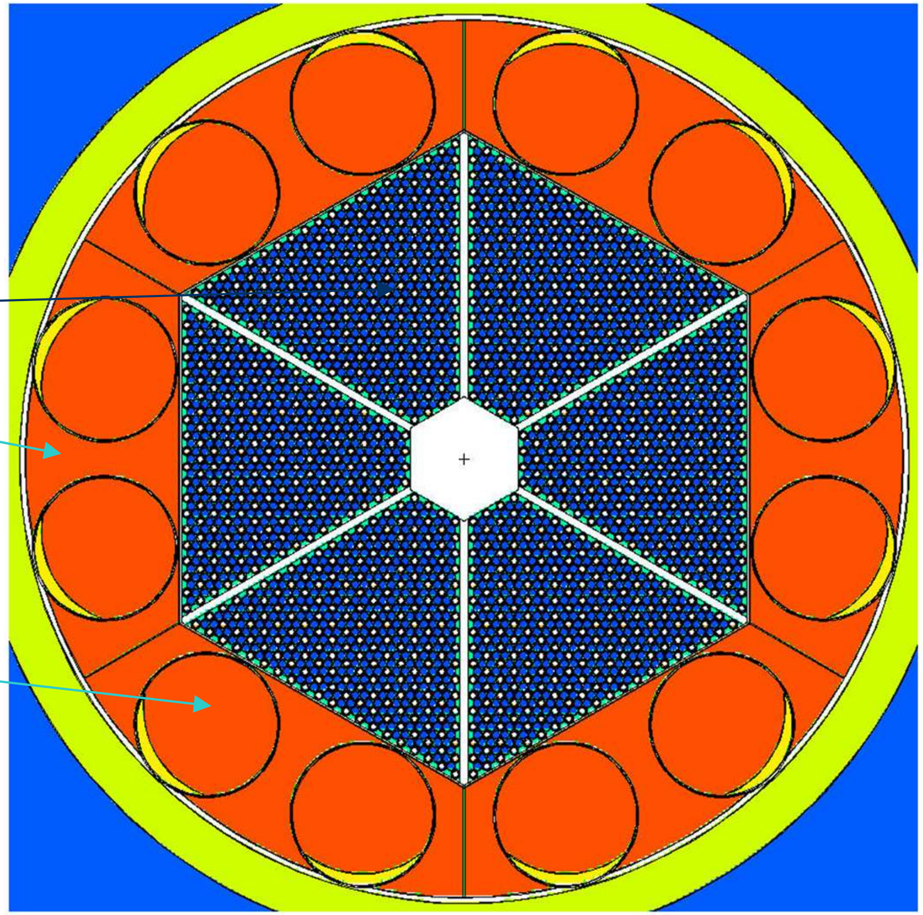


Figure E-1. Cross-sectional view of the LANL Special Purpose Reactor core.

Monolith core (INL/EXT-16-40741 Rev 1, 2017)

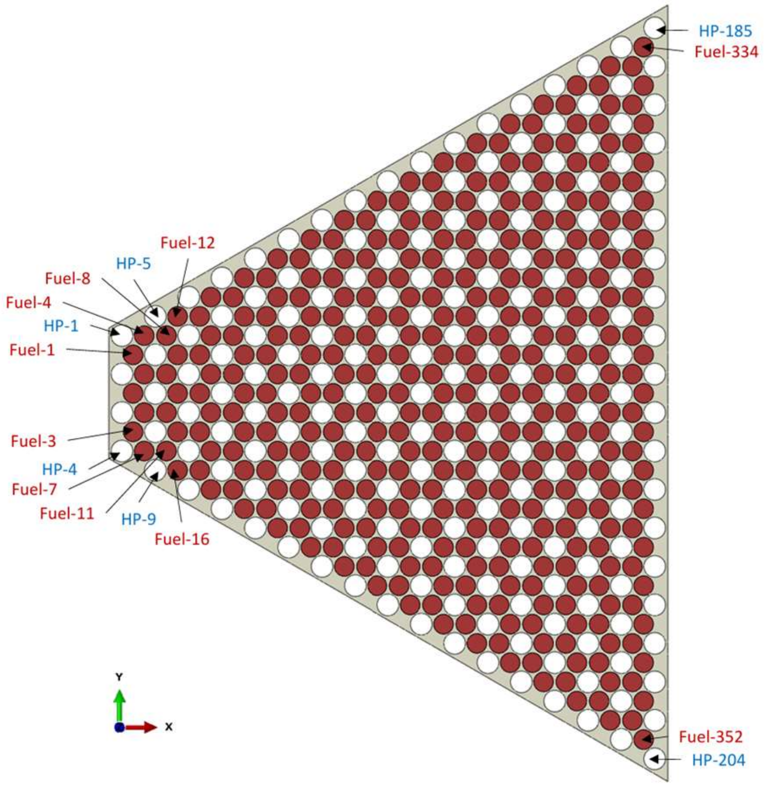


Figure E-4. Heat pipe and fuel pin numbering scheme.

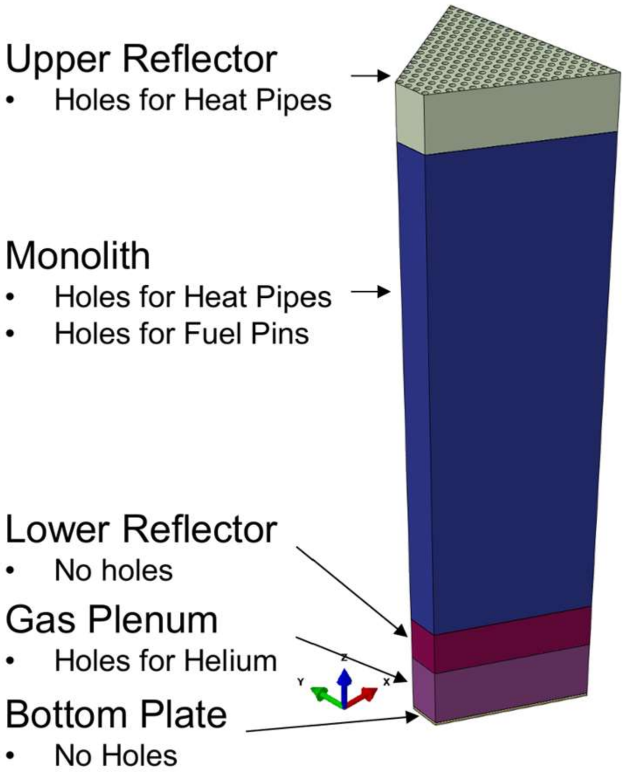
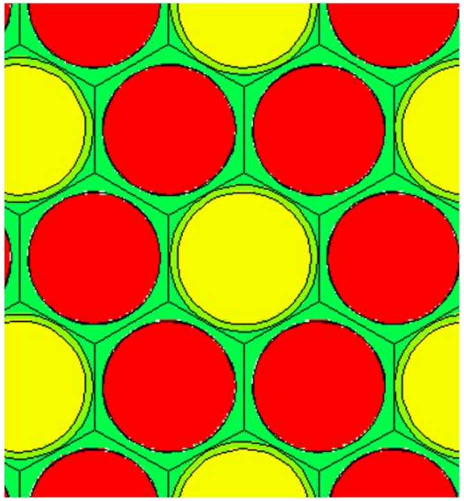


Figure E-2. Abaqus model geometry of a single 60° reactor core sector.

No singular fuel element

Fast or thermal reactor core

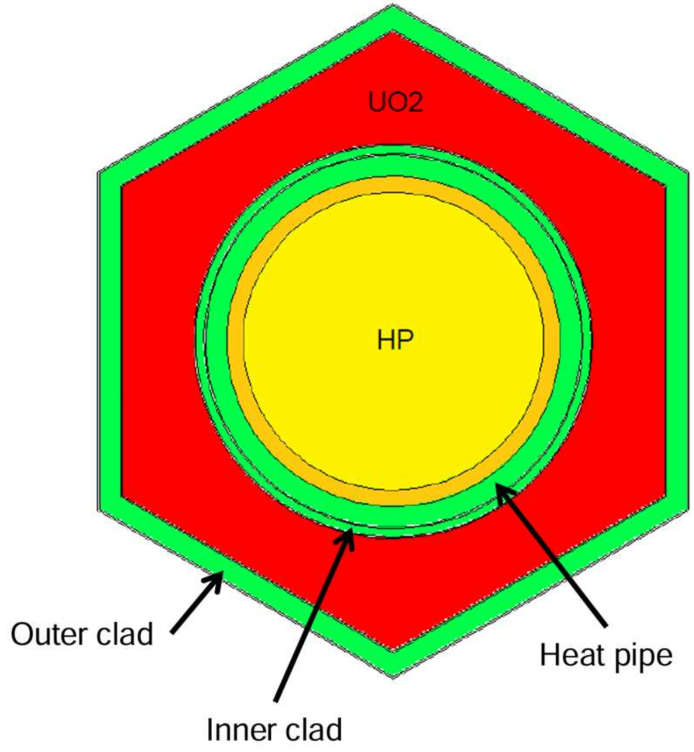
- The monolith defines the neutron spectrum of the core
  - SS (fast), graphite (termal)
- Heat transfer through conduction



- Green region: monolith
- Red: fuel pins
- Yellow: heat pipe

Fuel element design with an internal heat pipe

INL/EXT-17-43212 Ver 1, 2018



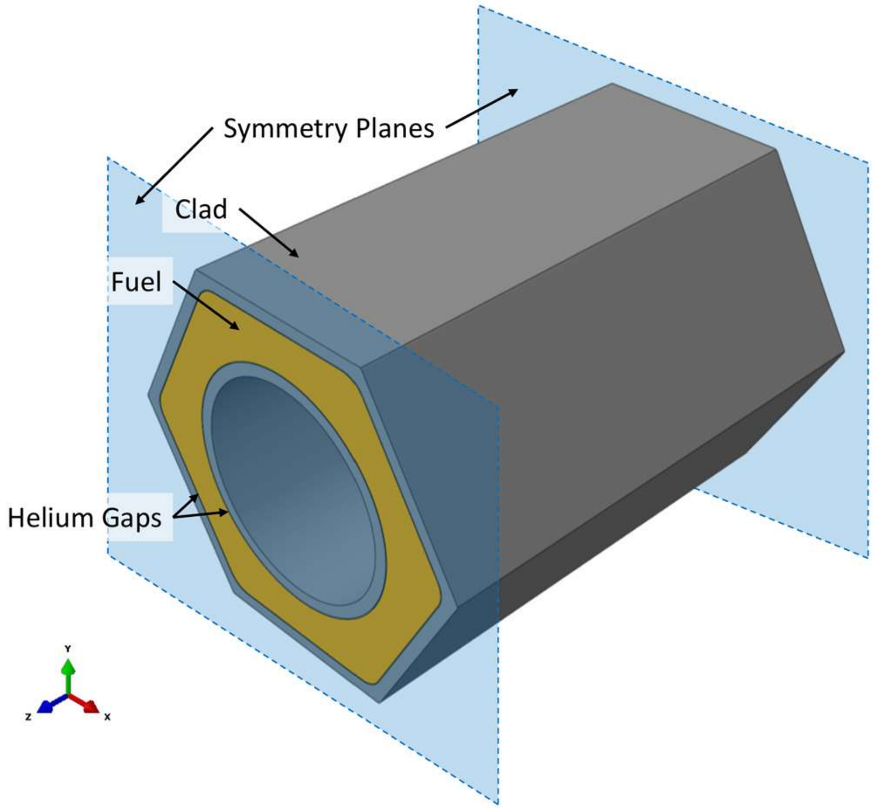
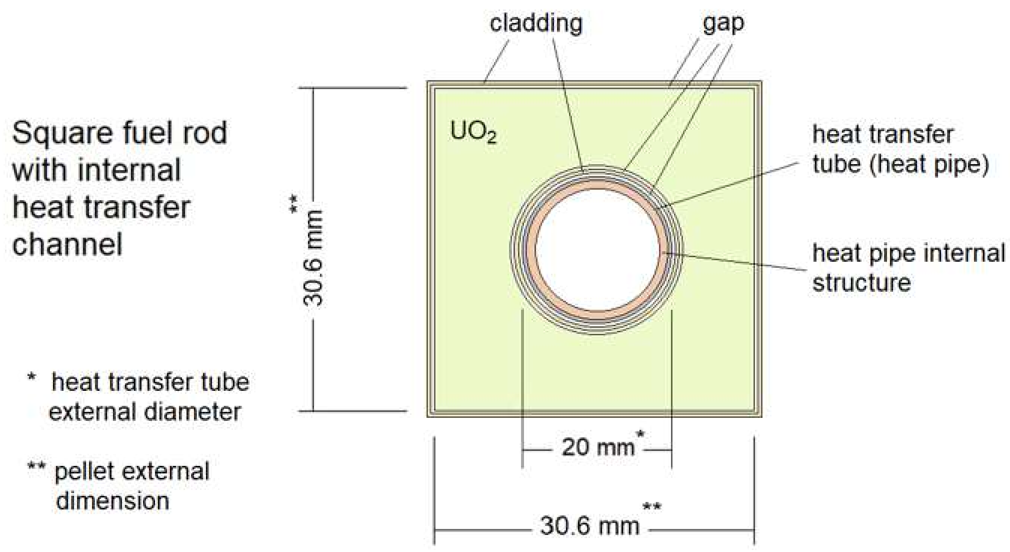
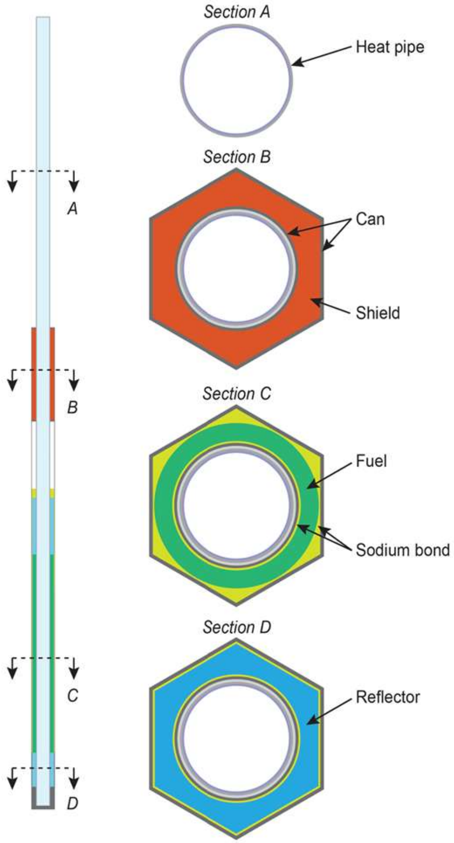


Figure 1.1. Short-parametric model geometry

Alternative fuel element designs with internal heat pipe



Nucl Eng Des, 423 (2024) 113205

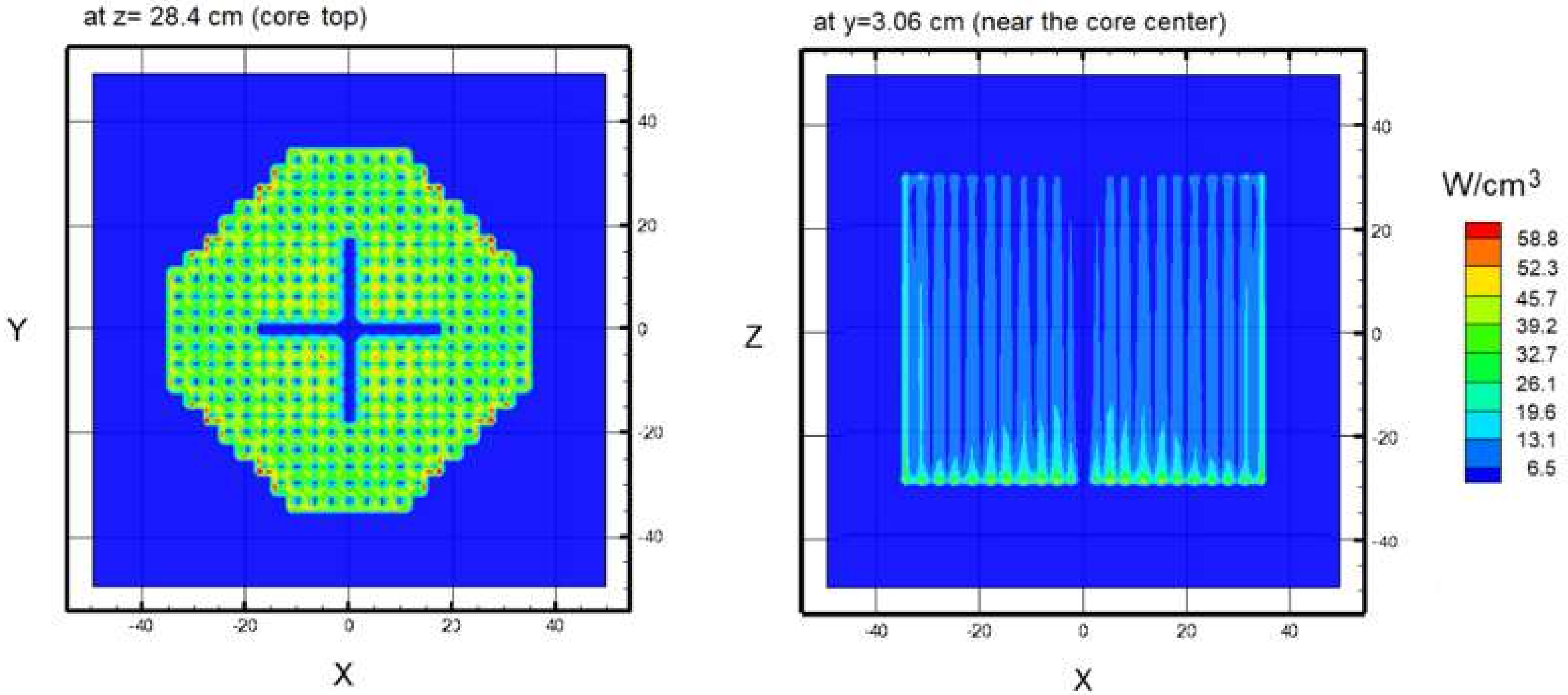


favors core reactivity

favors core heat transfer

OkloPower-2020-PartII-NP, Rev. 0

What is the impact of heat pipes on core reactor physics?



The power density distribution becomes unbalanced due to nêutron streaming out of the core through the heat pipes

Nucl Eng Des, 423 (2024) 113205

Final remarks about fuel design of micro-reactors

- The core can have a fast or thermal neutron spectrum
- Different fuel design requirements
- Low burnup and low power density in the fuel region
- High temperatures due to the use of heat pipes
  - Thermal stresses due to high temperatures
  - Use of fluids to facilitate heat transfer between components of the core (He and liquid Na)
- Complex integration of fuel and heat pipe in the core
- Heat transfer through conduction and heat pipes – new safety parameters

- Thank you