Design Status of a New Research Reactor in Japan

nEDM2023 - The 5th Workshop on Searches for a Neutron Electric Dipole Moment

2023-11-07

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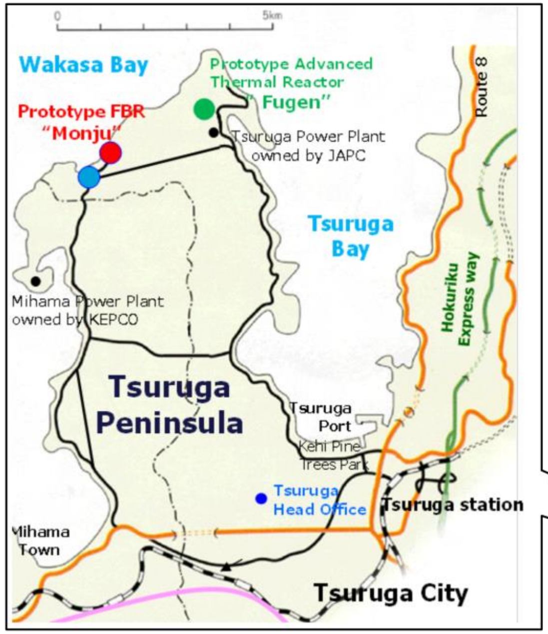
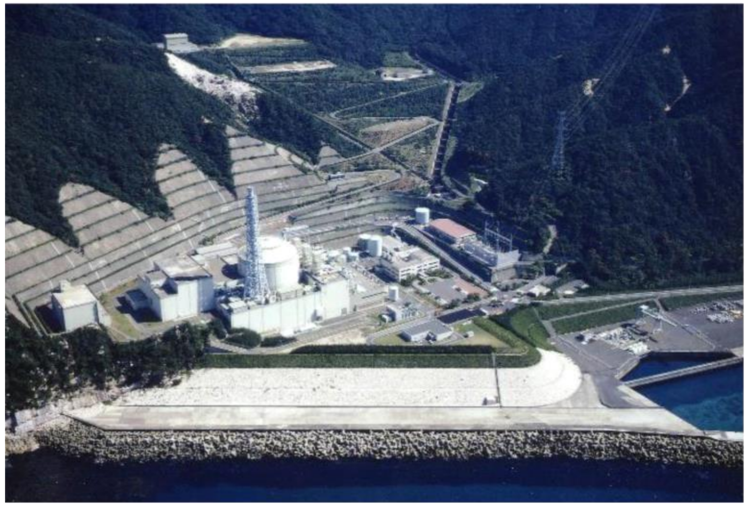
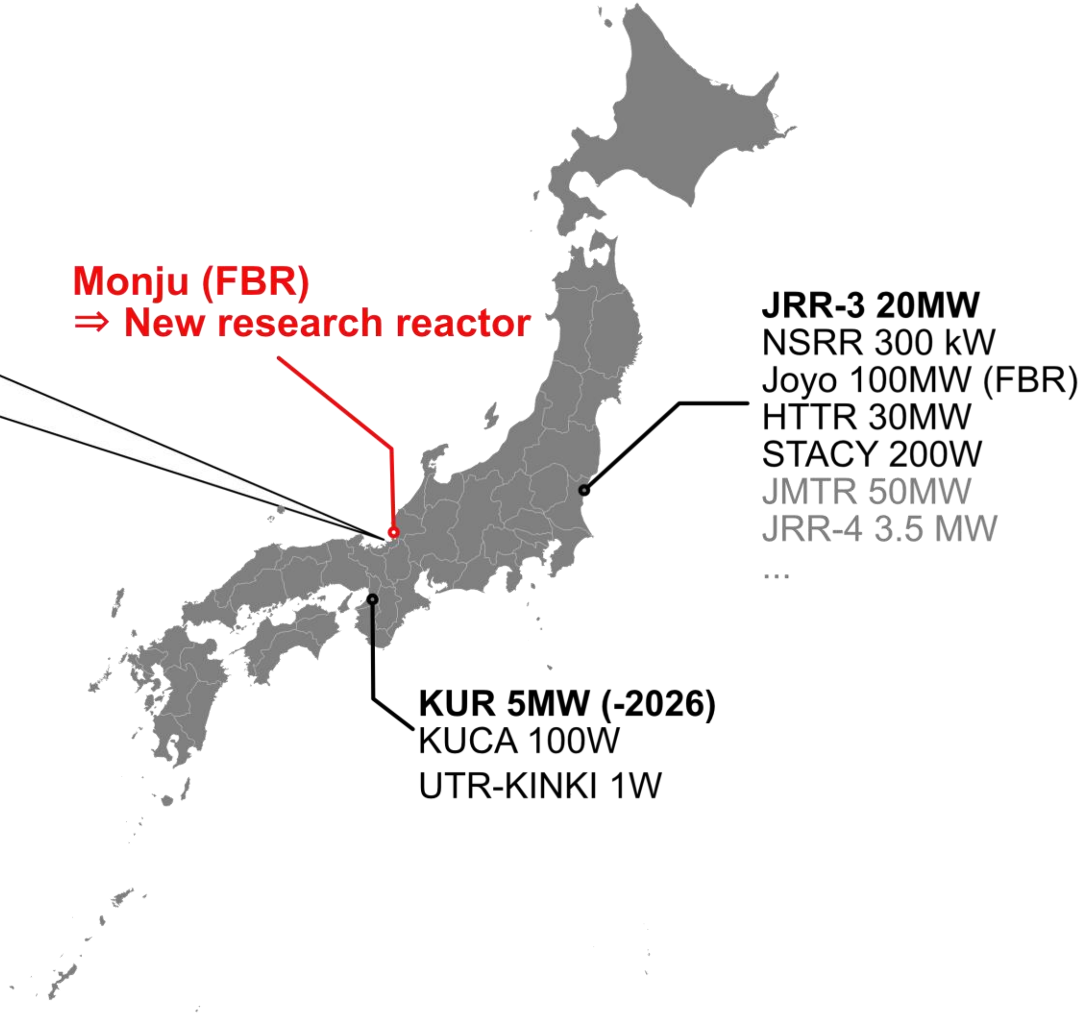
Research reactors in Japan







Background

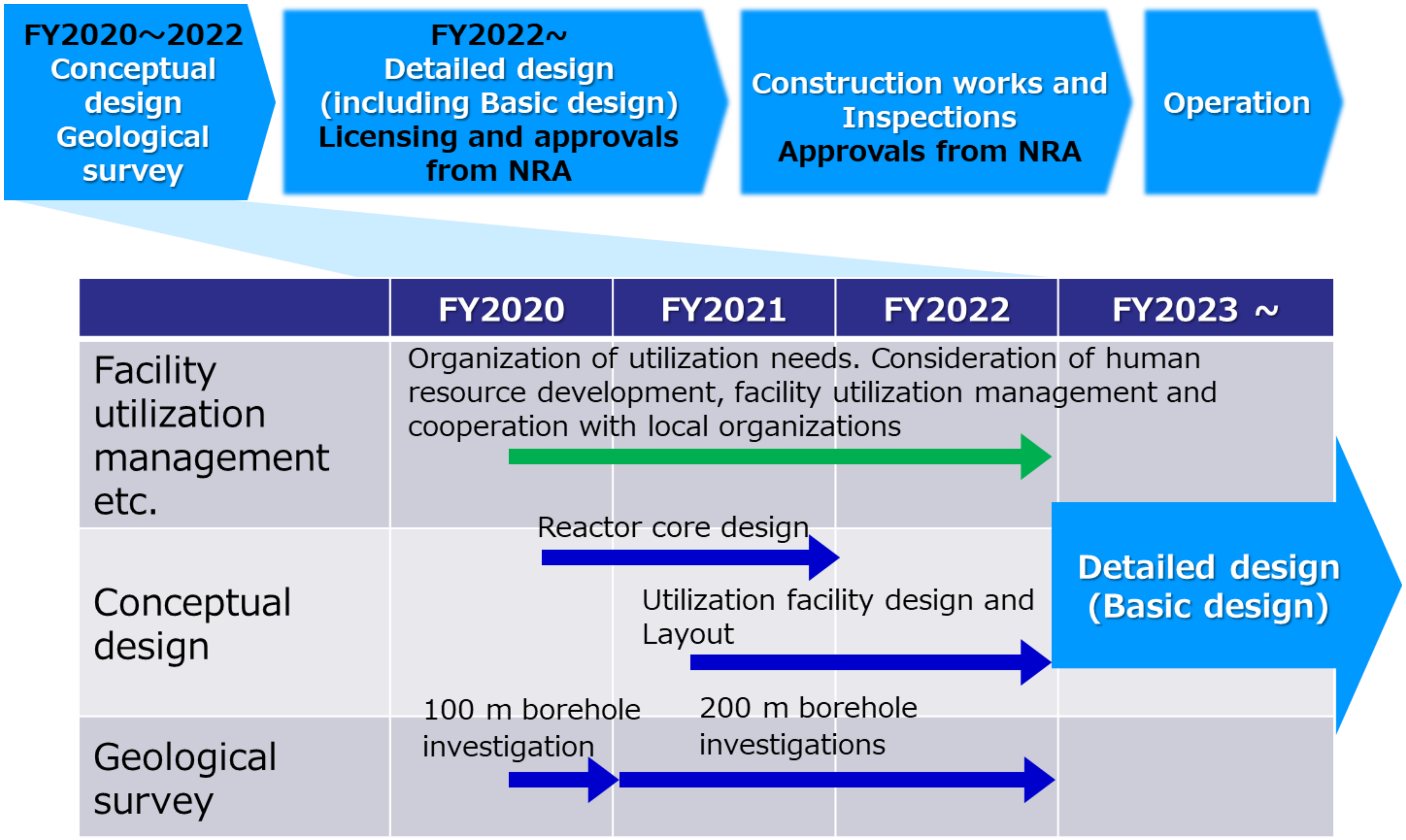
- 2016.12: **Decision by the government to build the new research reactor**
  - Decided decommission of Monju and construction of the new research reactor on the same site
- 2017-2019: **Government-led opinion survey**
  - Survey conducted by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in an expert committee consisting of various stakeholders
- 2020.09: **Baseline of the reactor defined, call for conceptual design**
  - Medium-power (10 MW) for wide applications from basic science to industrial uses
  - Expected to contribute to the local community, be a core base in the western Japan for nuclear research and human resource development
  - Public call by MEXT for conceptual design studies and related researches
- 2020.11 : **Conceptual design project started (JAEA, Kyoto U., U. Fukui)**
- 2020.12 : **JAEA selected to be a lead implementer of the project**
- 2023.03 : **Shifted to detailed design phase for application of installation license**

Medium thermal power selected

Reactor Type	Zero power	Low power	Medium power	High power
Thermal Output	< 10kW	< 500kW	< 10MW	> 20MW
Reactor Physics Study	O	X	X	X
Neutron Science	X	O	O	O
Industrial Application	X	X	O	O
Education	Scientist	Operator	Operator	Operator
Location Applicability	O	O	O	X
Typical # of users (persons x days)	KUCA 1,000	UTR-KINKI 1,200	KUR 5,400	JRR-3 22,500

- **Medium-power reactor (10MWth)** was selected, which can be applied widely from academic to industrial application with a substantial number of users.
- Regulatory definition by the Nuclear Regulation Authority of Japan (based on IAEA): Medium power: 500 kW to 10,000 kW

Timeline



FY2020～2022
Conceptual design
Geological survey
FY2022～
Detailed design
(including Basic design)
Licensing and approvals from NRA
Construction works and Inspections
Approvals from NRA
Operation
FY2020
FY2021
FY2022
FY2023 ～
Facility utilization management etc.
Organization of utilization needs. Consideration of human resource development, facility utilization management and cooperation with local organizations
Conceptual design
Reactor core design
Utilization facility design and Layout
Geological survey
100 m borehole investigation
200 m borehole investigations
Detailed design
(Basic design)

Design policies

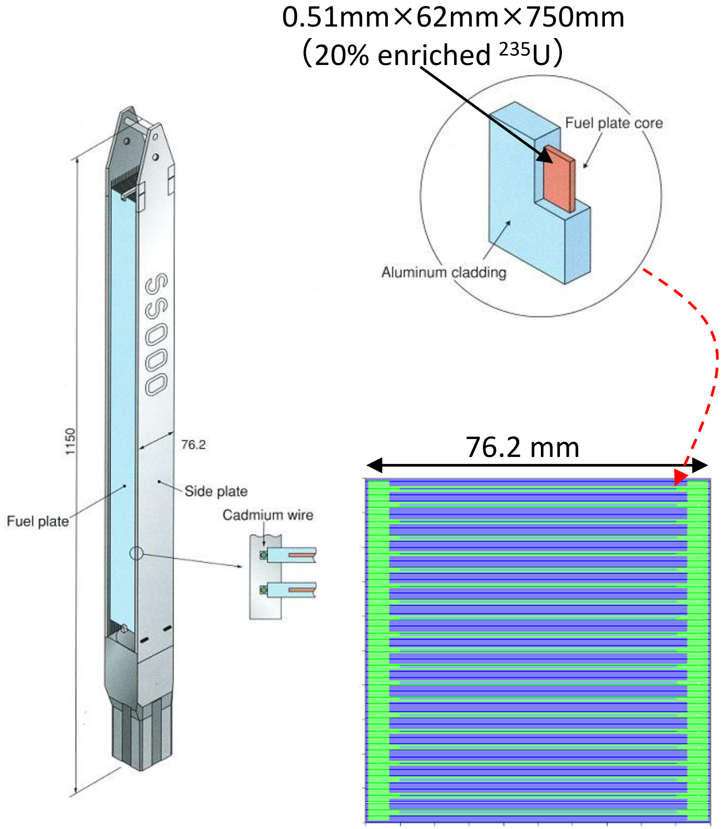
- **Enhanced safety performance**
  - ✓ Minimize the potential hazard
  - ✓ Multiplexing and diversification of safety functions
- **Economical design**
  - ✓ Apply existing and proven technologies
  - ✓ Reduction of construction, operation, and maintenance costs
- **Ensured operation stability (high operation uptime)**
  - ✓ Minimize scrams, prevent troubles by design
  - ✓ Simplify the maintenance to shorten inspection period
- **Improved user convenience**
  - ✓ Reasonable arrangement of user accessibility, easy handling of user equipment, and enhancement of available space

➤ **Conventional and proven fuel assembly design**
  - ✓ Conventional MTR-type fuel assembly to achieve economical design and short time of approval process

➤ **Advanced and improved experimental facilities including the Cold Neutron Source (CNS) and peripheral facilities**

Fuel element

- **Standard MTR-type**
  - ✓ Standard fuel material with enrichment no higher than 20%
  - ✓ Based on MTR-type fuel assembly of the existing research reactors (e.g. JRR-3, JMTR)

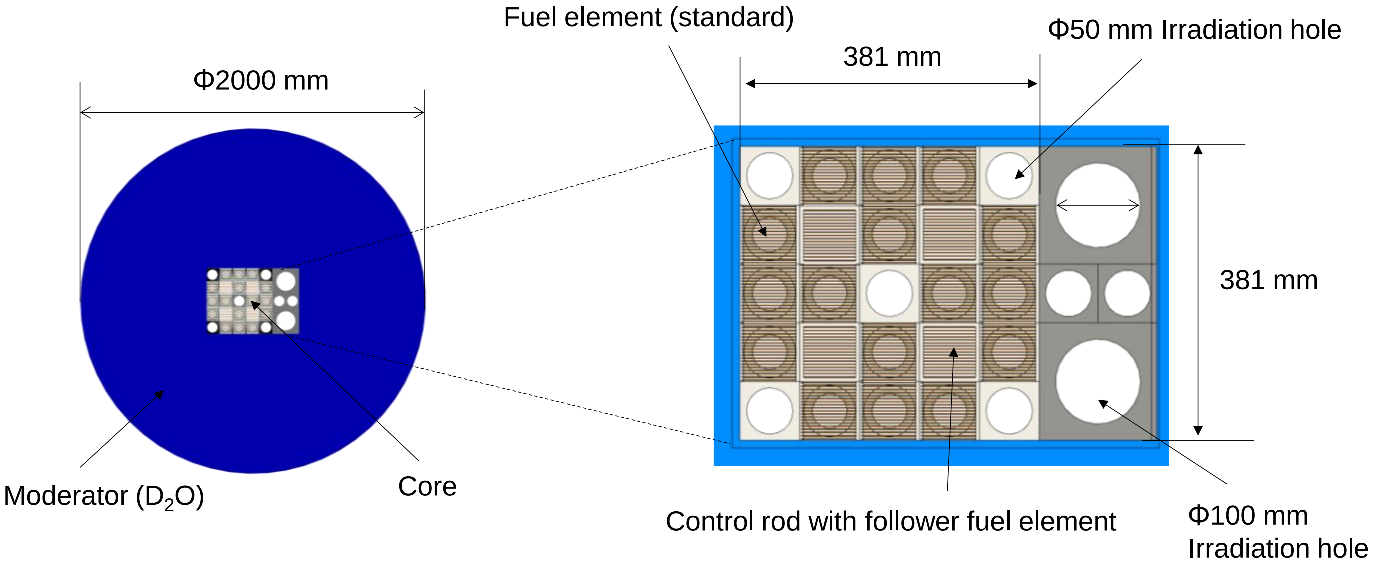


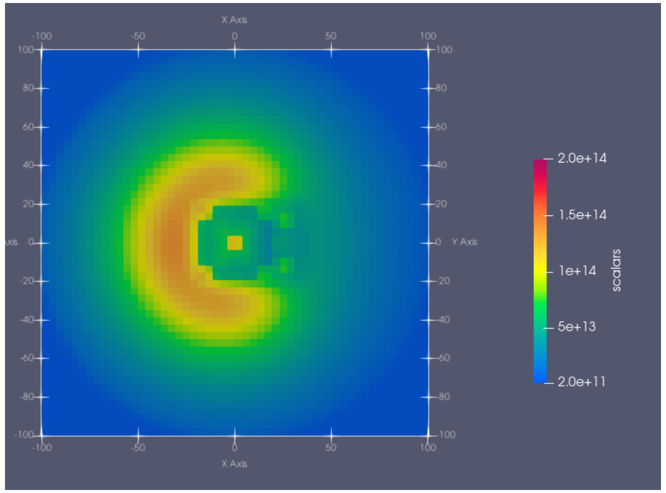
Size		76.2 × 76.2 × 1150 mm
Nuclear Fuel		U_3Si_2
^{235}U enrichment		Approx. 20 wt%
^{235}U content		Approx. 472 g
Uranium density		4.8 g/cm^3
Fuel meat	Thickness	0.51 mm
	Width	62 mm
	Length	750 mm
Cladding		Aluminum alloy
Cladding thickness		0.38 mm
Fuel plate	Thickness	1.27 mm
	Width	71 mm
	Length	770 mm
Number of coolant channel		20
Coolant channel thickness		2.35 mm (×20)

Specification of JRR-3 fuel assembly

Arrangement of irradiation holes (tentative)

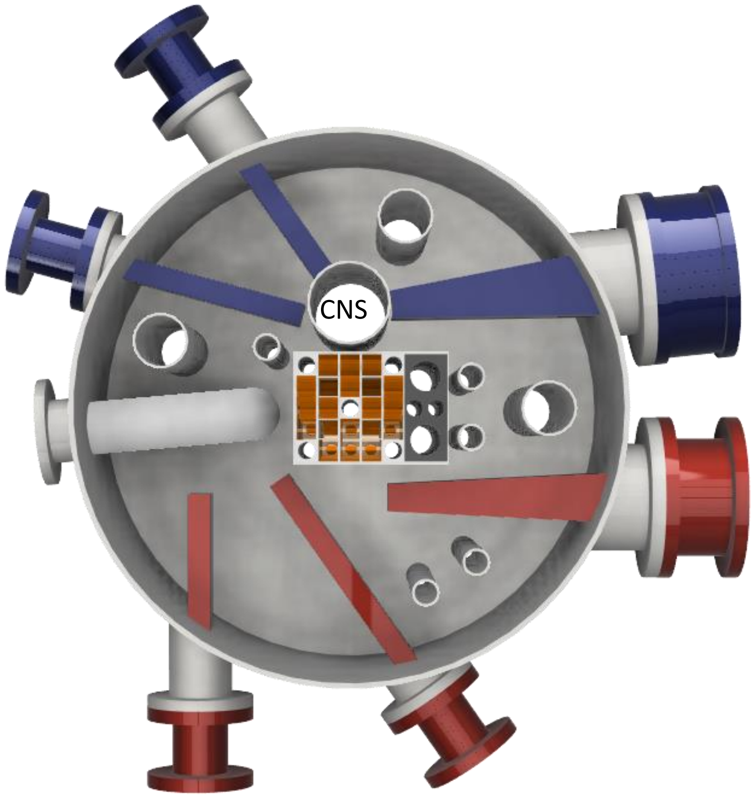
- **Core configuration of irradiation holes**
  - ✓ Open pool-type reactor with a central core and heavy water reflector
  - ✓ The core has 16 standard fuels, 4 control rods with follower fuels, and 5 irradiation holes in 5x5 grids.
  - ✓ Large diameter (ϕ100mm) irradiation holes next to the fuel core.

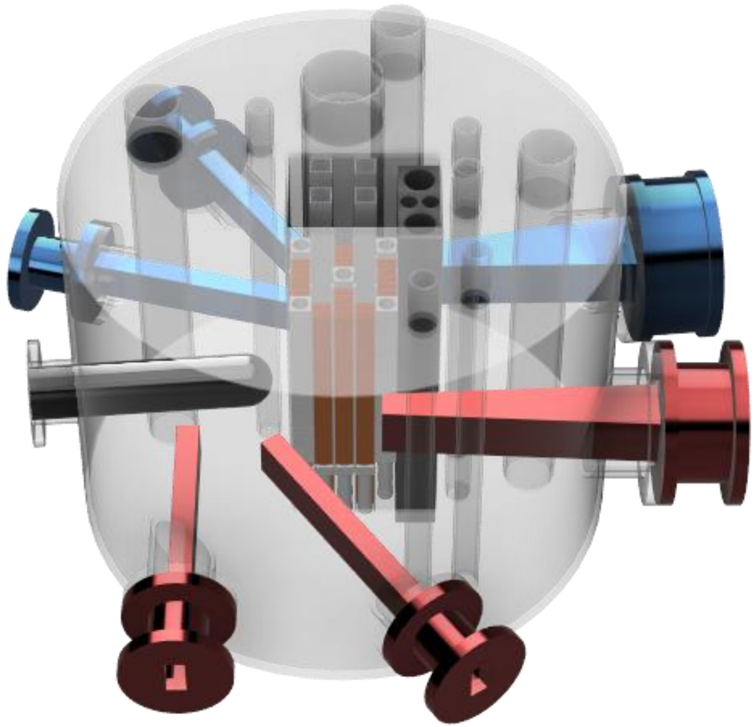




Arrangement of neutron beam lines (tentative)

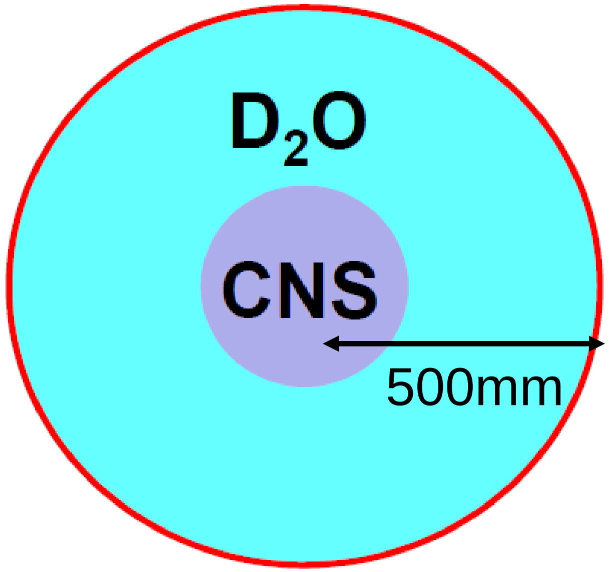
- **Arrangement plan of the Cold Neutron Source (CNS) and neutron beam**
  - ✓ Main objective : Utilization of neutron beams
  - ✓ Advanced design for CNS
  - ✓ Sufficient space to locate facilities and experimental devices in the reflector



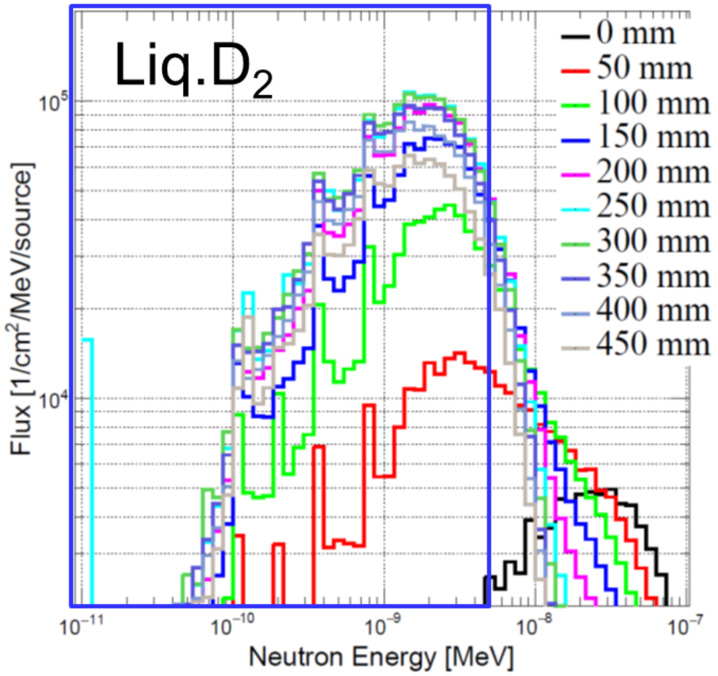


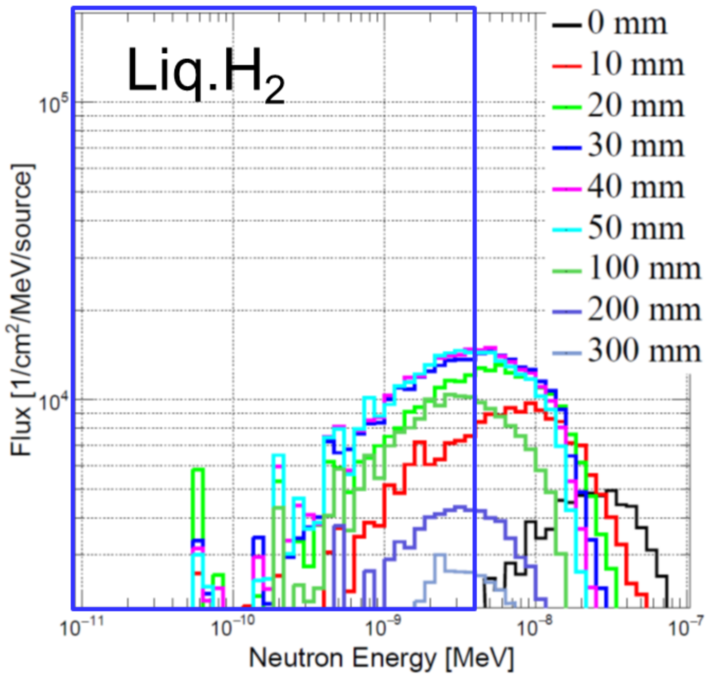
Simple simulations of the CNS moderator

- The first step of simulations with a simple geometry
  - 2 MeV fast neutrons from outside to the inside of the sphere
  - Moderator material Liq. D_2 (100% ortho) or Liq. H_2 (100% para)
  - Size of the sphere of D_2O + cold moderator fixed to 500 mm radius, swept moderator thickness



PHITS (Ver3.23)





Prioritized neutron instruments

Small-Angle Neutron Scattering Instrument

Analysis of forms and sizes of collective structure of atoms or molecules

JRR-3 SANS-U

Neutron Imaging Instrument

Visualization of internal structure and phenomena of machines, piping, plants etc.

JRR-3 TNRF

Neutron activity analysis instrument

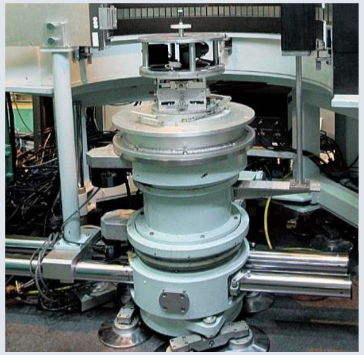
Analysis for microelement by non-radioactive assay

KUR Pneumatic tube

Ge detector

Neutron Diffraction Instrument

Crystal structure analysis



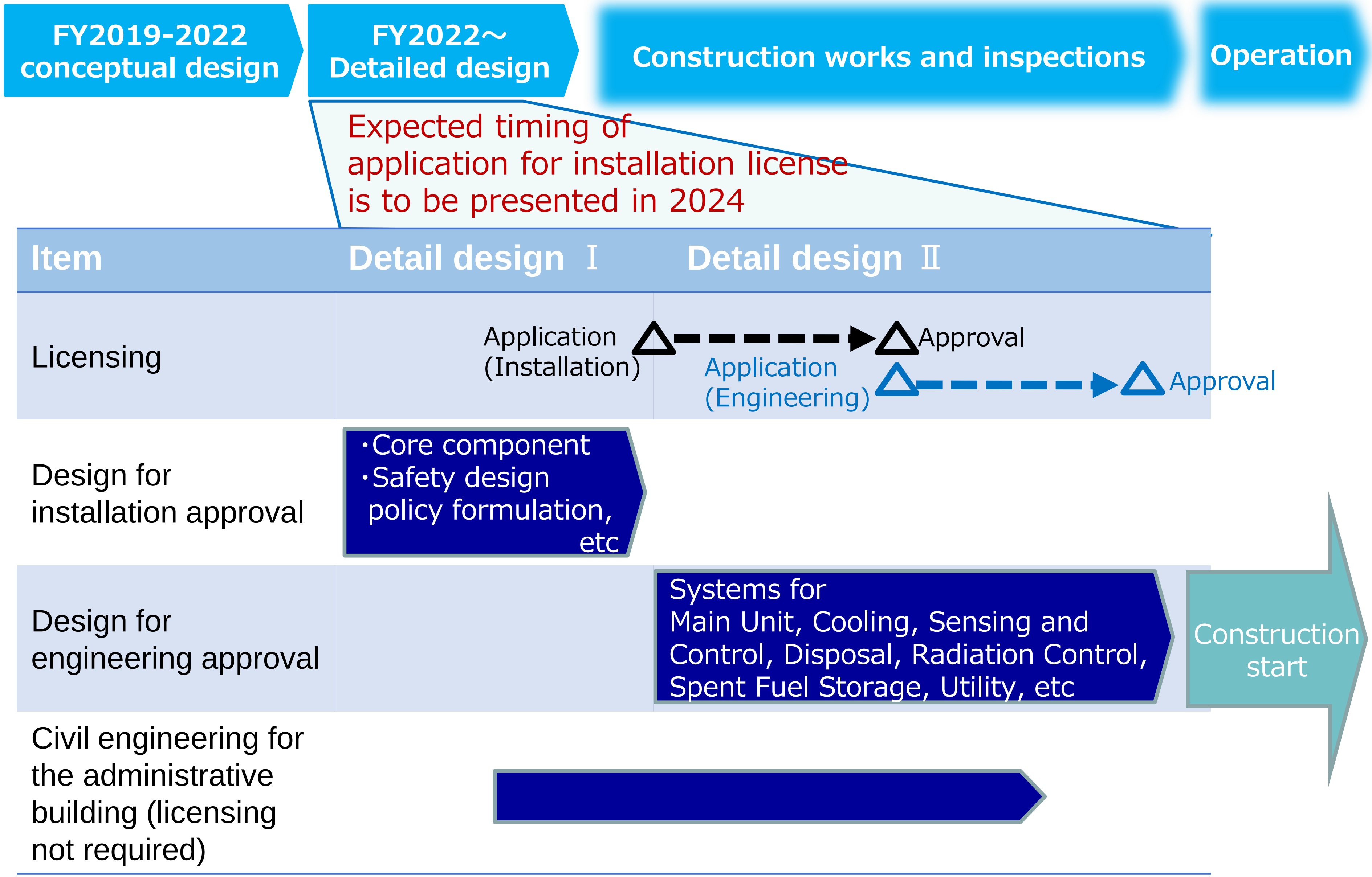
JRR-3 HRPD

Neutron Reflectometer

Structural analysis of materials interfaces and surfaces

JRR-3 MINE

Future timeline



Consortium of stakeholders


Signing ceremony on May 8, 2023

Role of Core Institutions

JAEA
- Design, installation and test operation

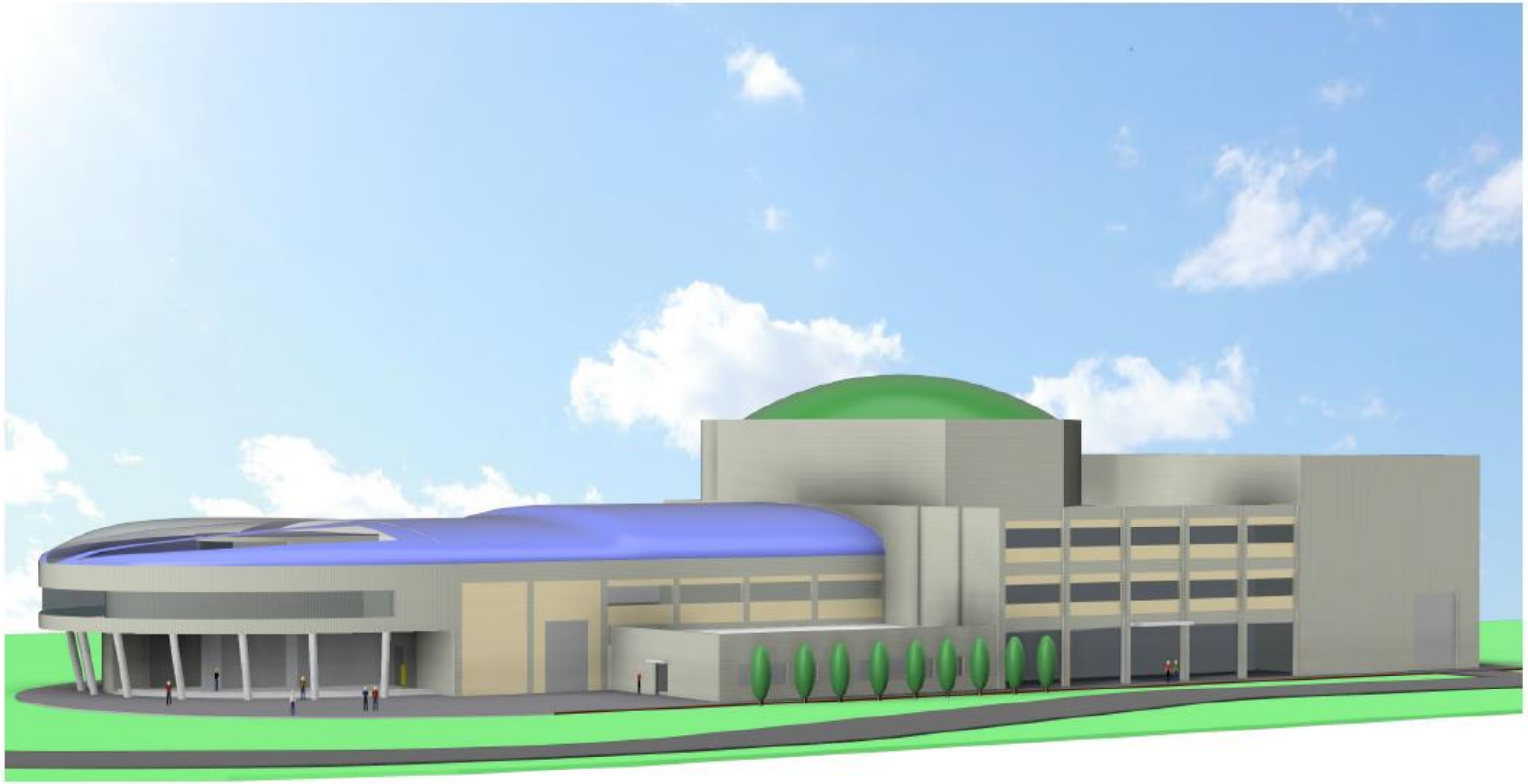
Kyoto University
- Aggregation of wide-range applications and provision of services based on the experience of KUR operation

University of Fukui
- Cooperation with local universities, research institutes, companies, etc. in Fukui

Steadily advance the project by the core institutions with consideration of wide range opinions from academia, industry, local organizations, etc.

Acknowledgements

- MEXT-commissioned project: “Investigation on conceptual design and project management schemes for the new research reactor at the Monju site”



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MEXT

MINISTRY OF EDUCATION,
CULTURE, SPORTS,
SCIENCE AND TECHNOLOGY-JAPAN

How about UCN?

Consideration for a UCN Source at the New Research Reactor

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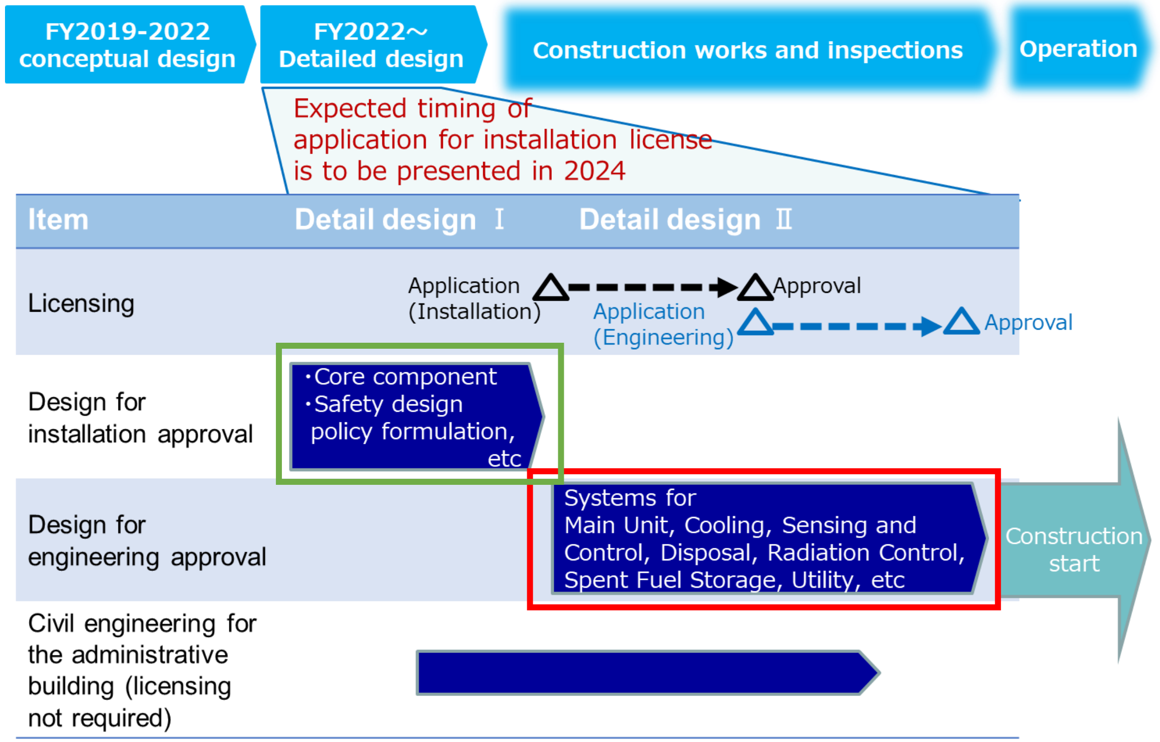
2023-11-07

T. Higuchi, S. Kawasaki, K. Mishima

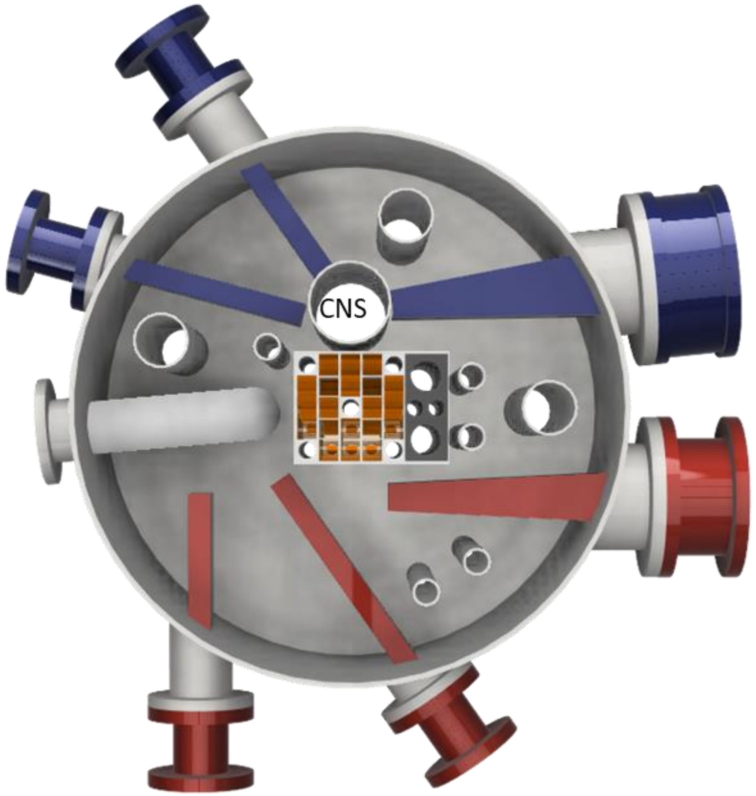
The new research reactor status

- The current design efforts focused on the core and the core building ("detail design I")
  - Fuel arrangements, irradiation holes, # of extraction ports…
    → these need to be fixed to apply for legal permission of the construction
- Everything downstream is still flexible!
  - Possibility of proposing new ideas during the long "detail design II"
- Reactor-based UCN source is under consideration



Boundary conditions

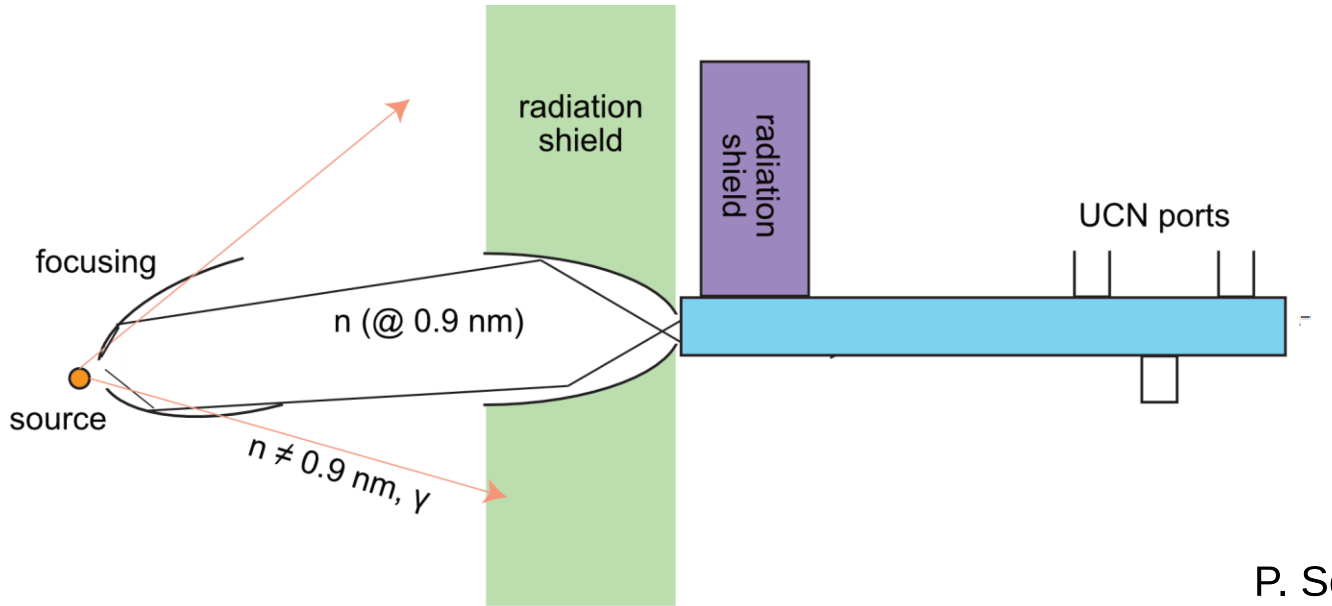
- sD_2 or He-II ? ⇒ He-II
  → sD_2 near the core is difficult (we don't want to make ambitious challenge around the core)
  We want not to delay the entire reactor due to the UCN source
- Arrangement of extraction ports:
  - Still flexible. The only thing we need to decide imminently is the size of the beam port

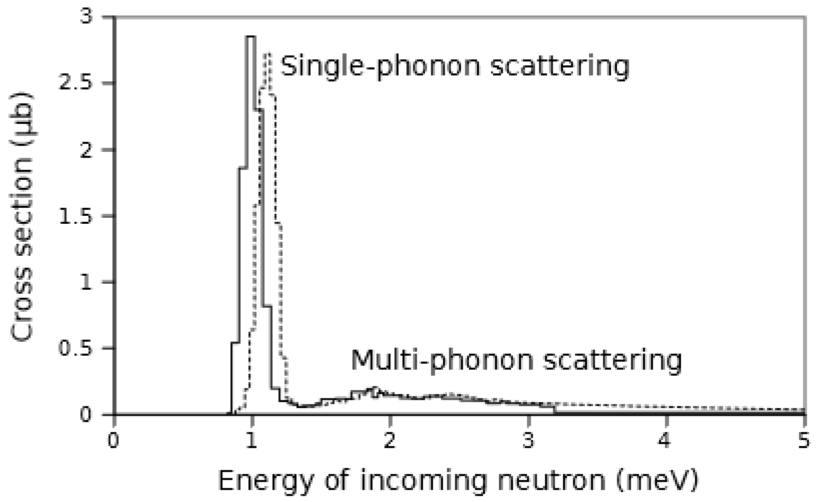


- Our proposal:
  He-II UCN source with an advanced cold neutron optics

Concepts

- Design neutron optics that has large solid-angle coverage by a high-m super mirror
  - Critical cold-neutron wavelength for UCN production: ~1 meV (0.9 nm)
  - Maximize the solid angle from the source for 0.9 nm neutrons by the use of high θc supermirrors

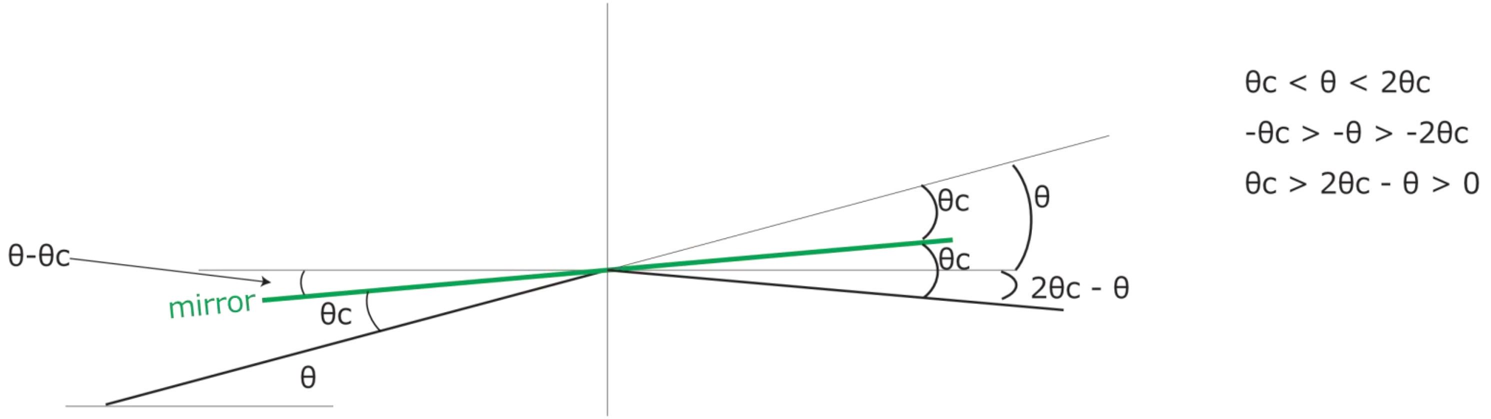




P. Schmidt-Wellenburg, et al., Phys. Rev. C **92** (2015) 024004
E. Korobkina et al., Phys. Lett. A **301** (2002) 462 – 469.

Idea of the focusing optics

- By combination of mirrors that form θc to each other, angle up to 2θc from the source can be covered



⇒ Focus beams within θc < θ < 2θc

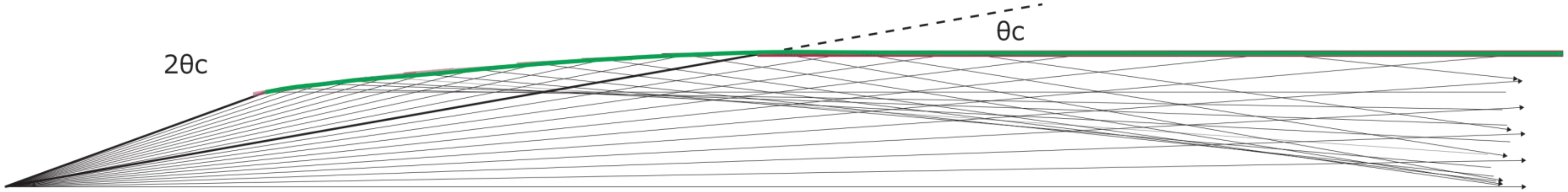


figure made for θc = 10 deg

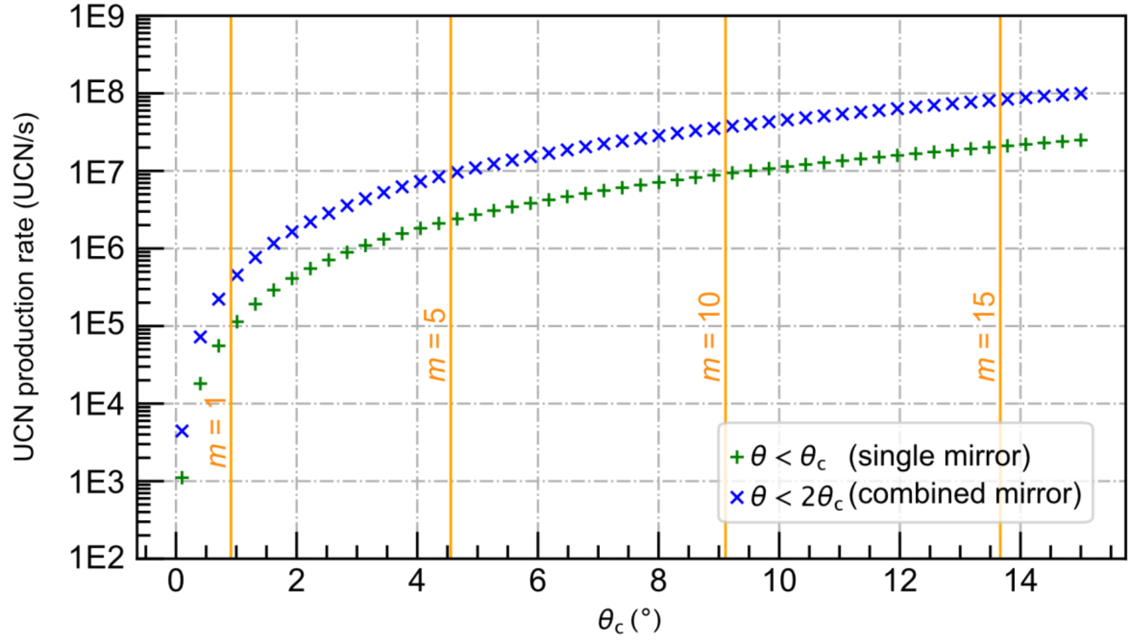
Simplistic estimates

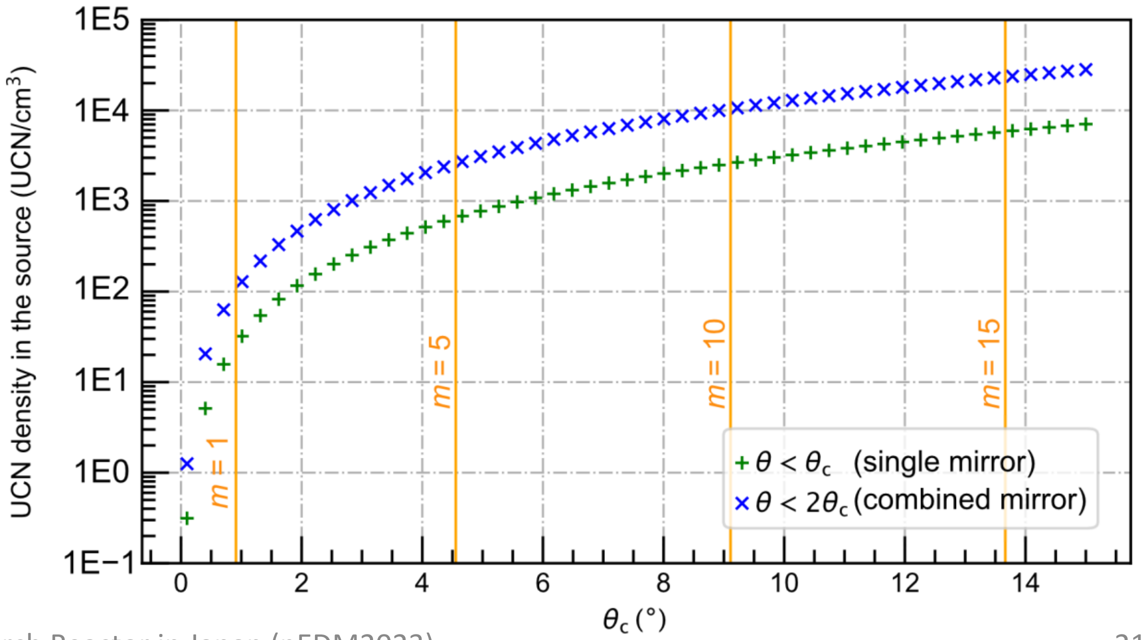
- Assumptions:
  - UCN production cross section at 1 meV: 1. 5 μb
  - Cold neutron flux: 1.0×10^{10} n/cm²/s/sr
  - Supermirror reflectivity:1
  - He-II volume: 350 L (Φ=30 cm,, L = 500 cm)
  - He-II density: 0.145 g/cm³
  - UCN lifetime: 100 s

Expectation with m=5 supermirrors,

- production rate: **~10^7 UCN/s**

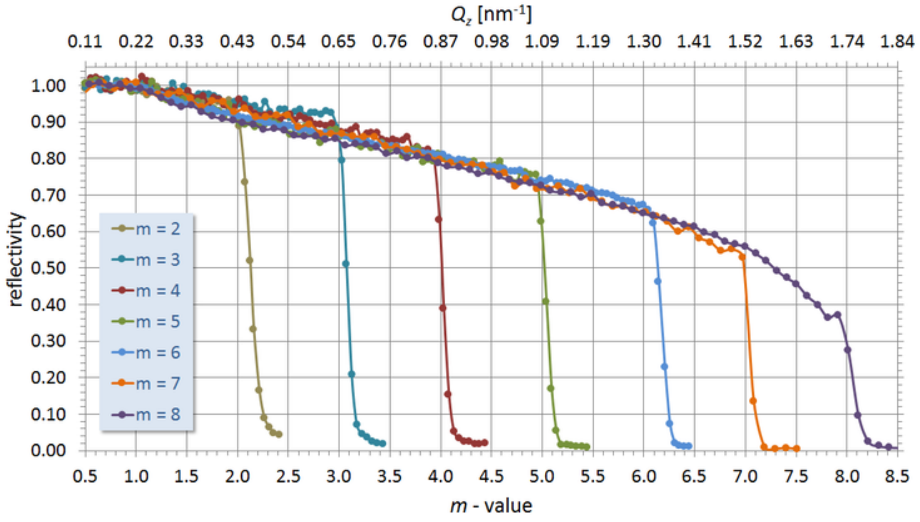
- source UCN density: **~ 1×10^3 UCN/cm³**



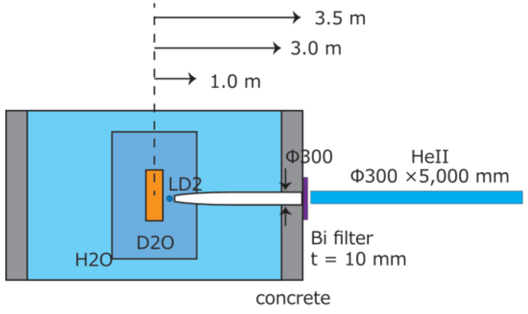


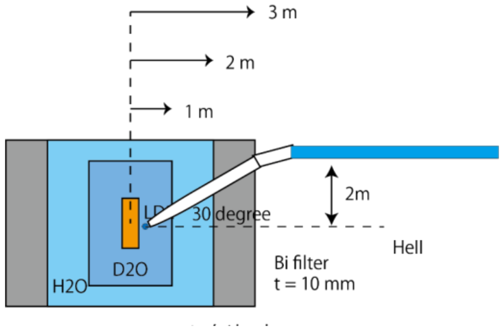
Further considerations

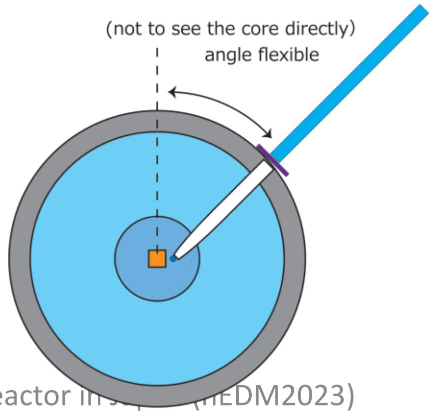
- In reality, the supermirror reflectivity decreases at a larger angle
- Radiation tolerance of supermirrors: test data acquired at PSI
- Temperature dependence of UCN production in He-II
  → The core to He-II distance, heat load from the neutron flux, cryostat cooling power
- 3D arrangement of the UCN source and ports (higher position: preferrable for UCN experiments and reducing higher-energy neutrons)



Swiss Neutronics (https://www.swissneutronics.ch)







Summary

- Opportunities at the new research reactor: most of the elements are still yet to be designed
- Possibility of a He-II UCN source with an advanced neutron optics:
  - Use supermirrors to maximize the solid angle coverage of 0.9-nm cold neutrons
  - Estimates with m=5 supermirrors → 10^7 UCN/s, 10^3 UCN/cm^3
  - Technological improvement of multilayer mirror production may boost the production rate
- Interested? → talk to me!

Thank you for your attention!

Backup

Expected neutron flux

- Thermal neutron flux target value: 10^{14} n/cm^2/s
- Cold neutron source at JRR-3 (LH2): not optimized (cold neutron flux lower by a factor of 2 than what should be expected from a thermal neutron flux)

→ By improved CNS, we expect to have a comparable cold-neutron flux to JRR-3