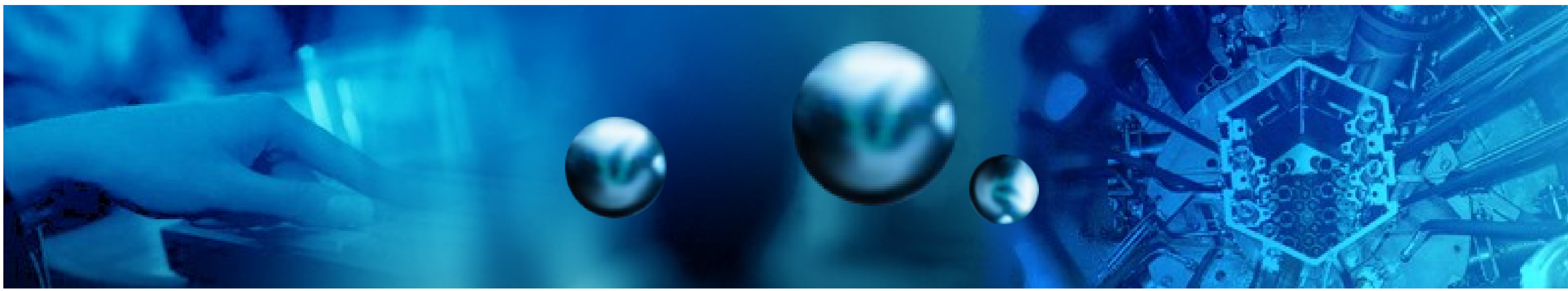
KAERI HANARO
High-flux Advanced Neutron Application Reactor

Current Status of the HANARO CNS Moderator Cell Design



IGORR at Gaithersburg
Sept. 12~16, 2005

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Contents

Cold Neutron Research Facility Project

Project Period : July 2003 – April 2008

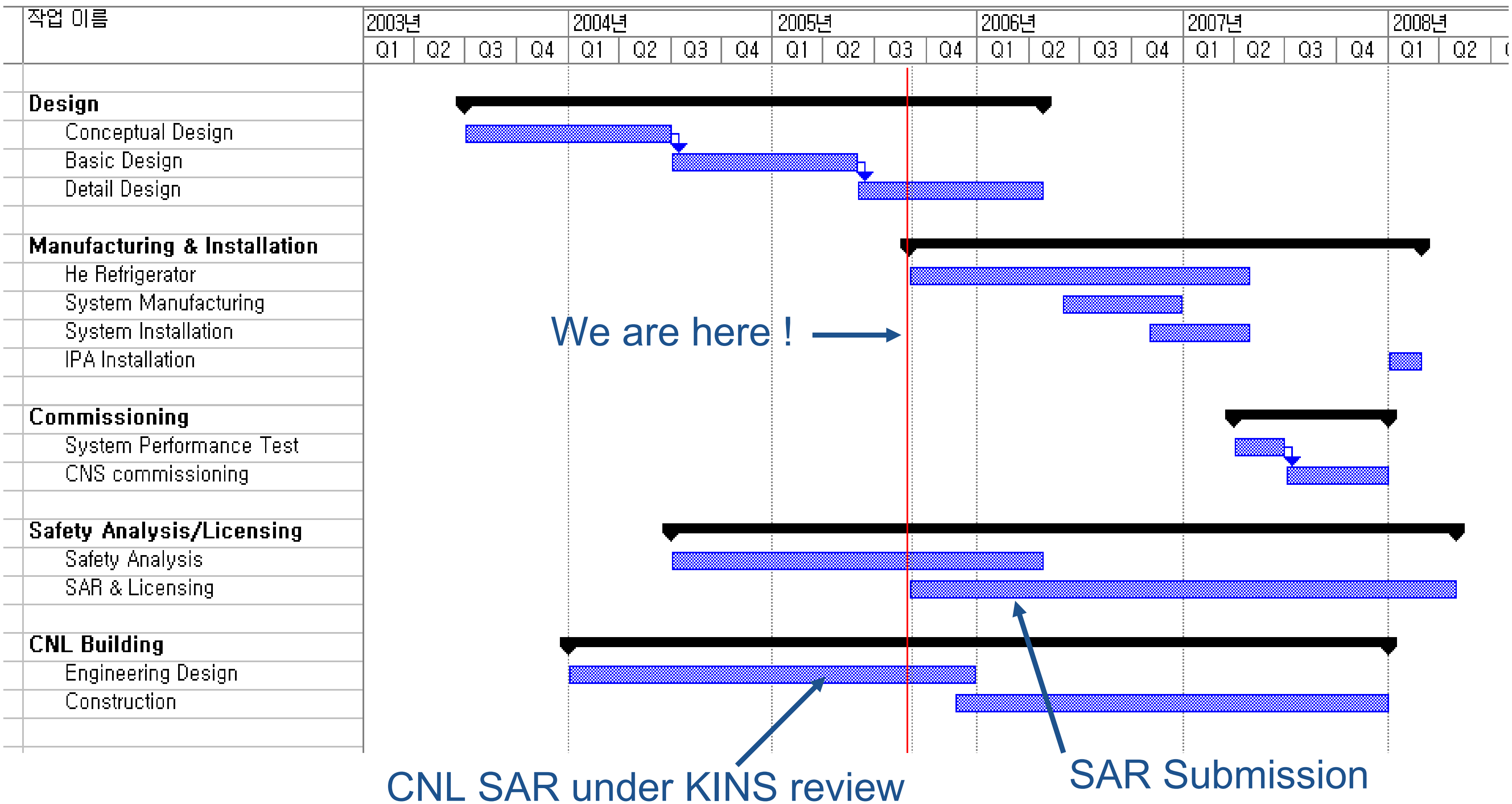
Project Scope

- **Cold Neutron Source and related system (CNS)**
- **Neutron Guides (NG)**

  5 neutron guides
- **Neutron Scattering Instruments (NS)**
  1. 8 m SANS, REF-V, REF-H: improvement & relocation
  2. 40 m SANS, Cold-TAS, DC-TOF: new installation

- **Cold neutron laboratory**

Project Milestone



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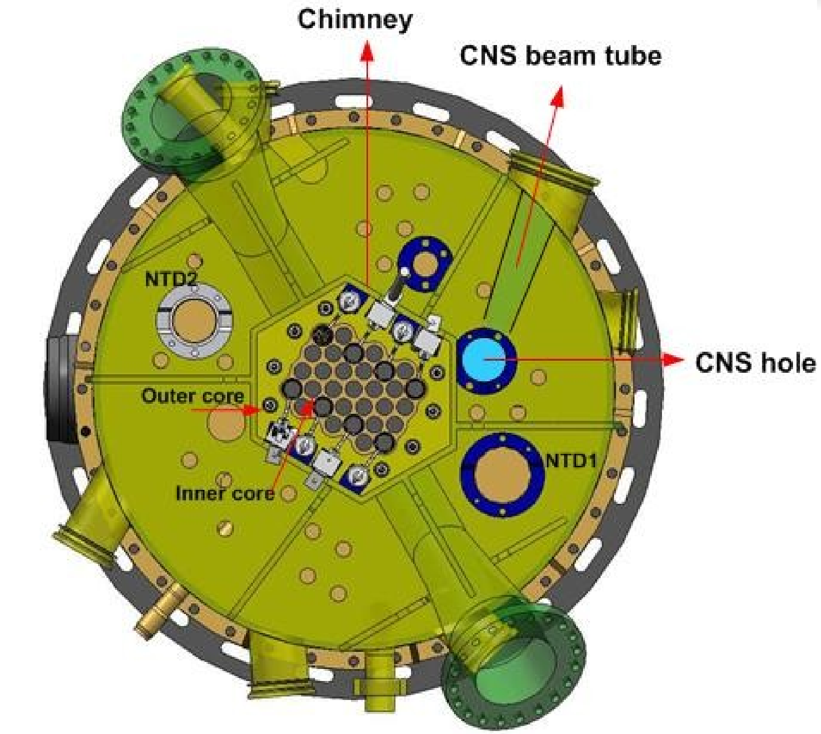
IGORR10

HANARO CNRF Project

HANARO reactor

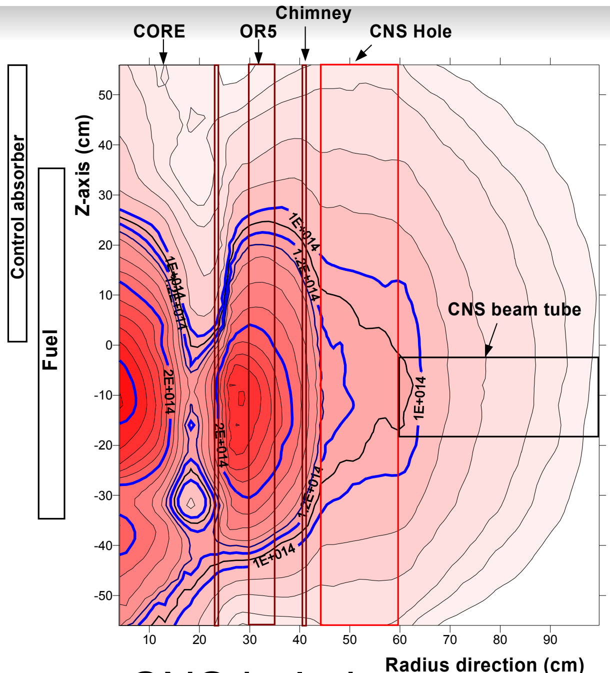


Reactor Specifications

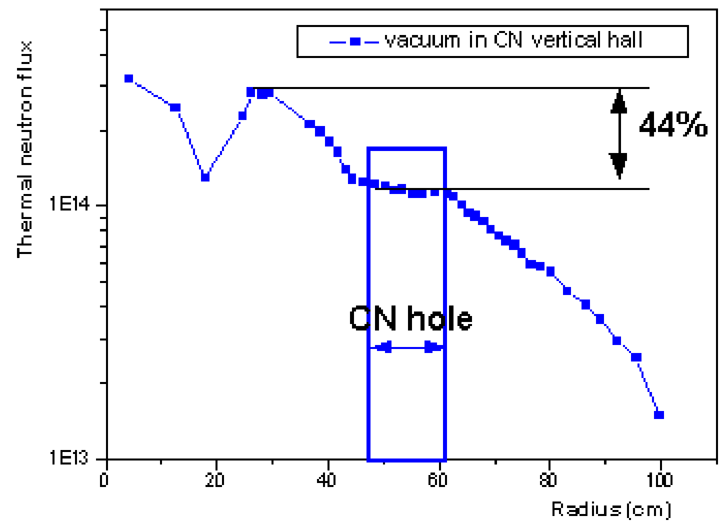
Type	Open-tank-in-Pool
Max. Th. Power	30MWth
Coolant	Light Water
Reflector	Heavy water
Fuel Materials	U_3Si, 19.75% enriched manufactured at KAERI
Absorber	Hafnium

- 7 beam tube
- NAA, HTS, 2 NTD, CN, FTL, 17 IP
- CNS hole : positioned in 51.93cm apart from the core center

Thermal Neutron Distribution

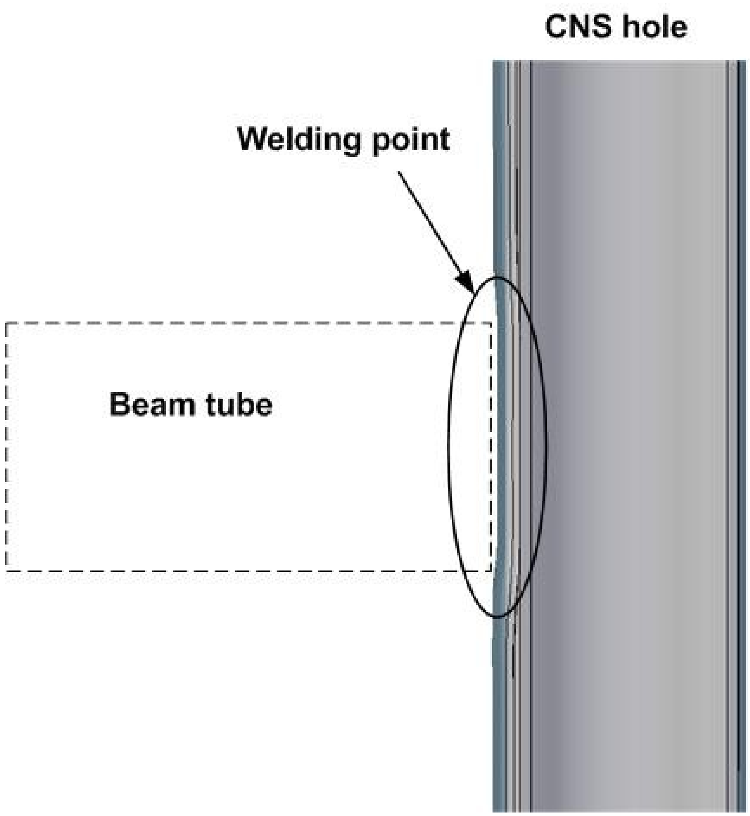


CNS hole in vacuum



- When the CN hole is in vacuum, the flux in the CN hole is 44% of the outer core thermal peak
- The CN hole was placed very close to chimney wall
- During the full power operation, the elevations of control absorbers are middle
- The peak of neutron flux appears around 10cm below the middle, CN beam tube is installed at that point

CNS hole



- Light water gap is between the vacuum chamber and the wall of the CN hole
- Diameter : Designed 16 cm, measured as 15.67cm
- CN beam tube is made by Zircaloy 4 , 5mm
- CNS hole is made by Zircaloy 4, 5mm

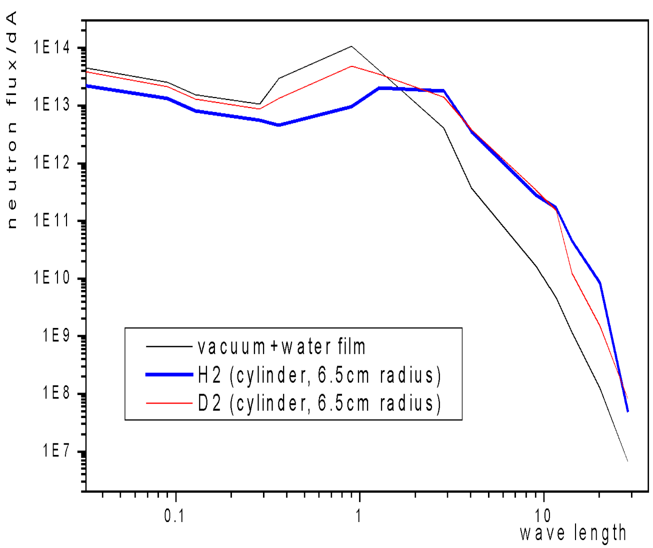
Moderator selection

LD_2 for longer wavelength neutron

HFR at ILL, FRM-2, OPAL

LH_2 for small volume **JRR-3M, Orphee**

Element	Molecular weight	Scattering σ	Σ_{total}	Mean free path
LH_2	2.0159	20.47 barn	0.434 cm^{-1}	2.3 cm
LD_2	4.0282	3.389 barn	0.086 cm^{-1}	11.614 cm



In case of HANARO,
CNS hole diameter is just 16 cm
Considering the mean free path,
Liquid hydrogen is more suitable for HANARO

Material for M/C & V/C

Material	Density [g/ ㎤]	Thermal Conductivity at 300K (20K) [W/m-K]	CTE 273-373K [$10^{-6}K^{-1}$]	Cross Section [barns]		Activity [μCi/g]*
				σ_{abs}	σ_s	
Mg	1.74	155-170	26	0.063	3.7	No
Al Al-Mg(5000) Al-Mg-Si(6000)	2.7	200-238(225) 130(22) 160(21)	23	0.23	1.5	6.4e-09
Zr Zircaloy	6.5	23-24 17	5.9	0.18	6.5	No
Stainless Steel 304	7.9	16(1.9)	16	2.8	9.5	0.005

- The low density materials are more advantageous in the point of the manufacturing
- Small absorption XS and low activity are better in the neutron economic
- High thermal conductivity is more advantageous against the nuclear heating
- Hydrogen embrittlement

Al alloy is the best material for the CNS

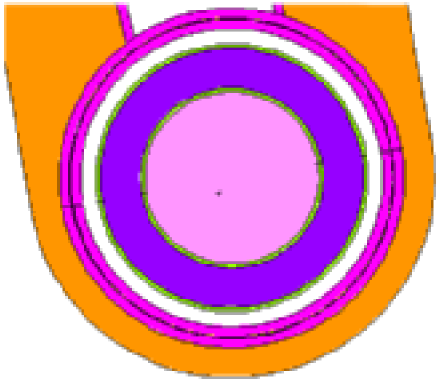
Material for M/C & V/C

Comparison of Al alloy

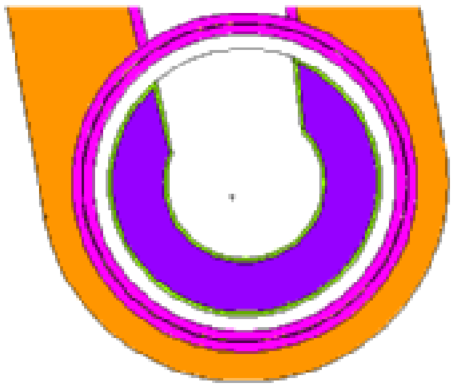
Property	Comparison
Mechanical properties	5xxx ≒ 6061
Tear resistance	5xxx < 6061
Weld ability	5xxx > 6061
Irradiation tolerance	5xxx < 6061

- Al 5xxx alloy and Al 6061-T6 alloy are the most widely used alloys in the CNS
- Al 6061-T6 alloy is superior to tear resistance, tolerance
- Welding is not a difficult matter regarding to the recent welding technology
- adopt the Al 6061-T6 alloy for M/C & V/C

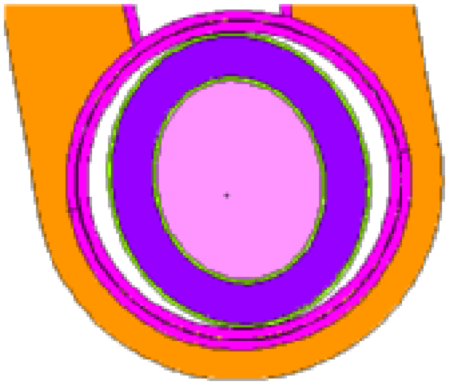
Moderator Shape Selection



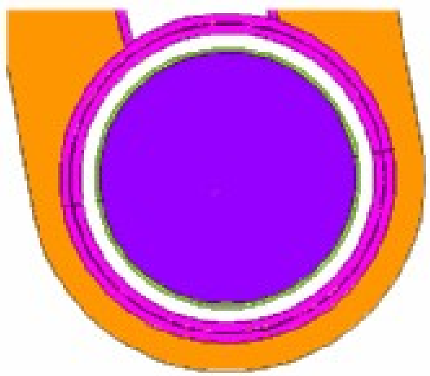
Double cylinder



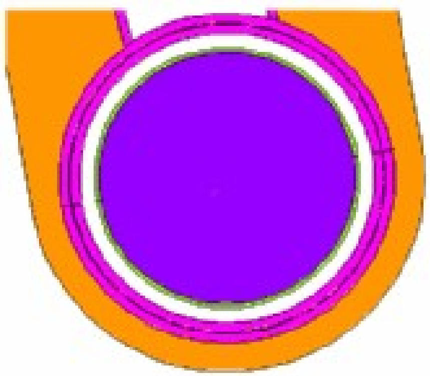
Double cylinder with open cavity



Elliptical

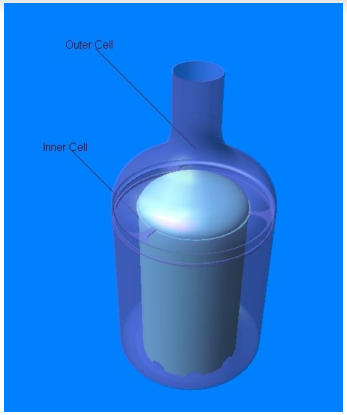


cylinder

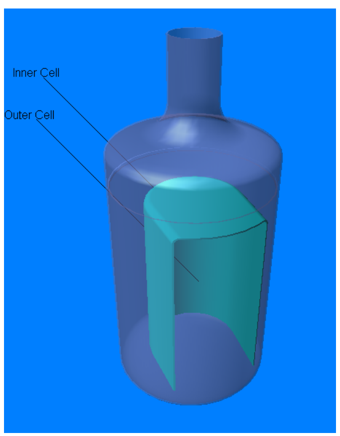


Sphere

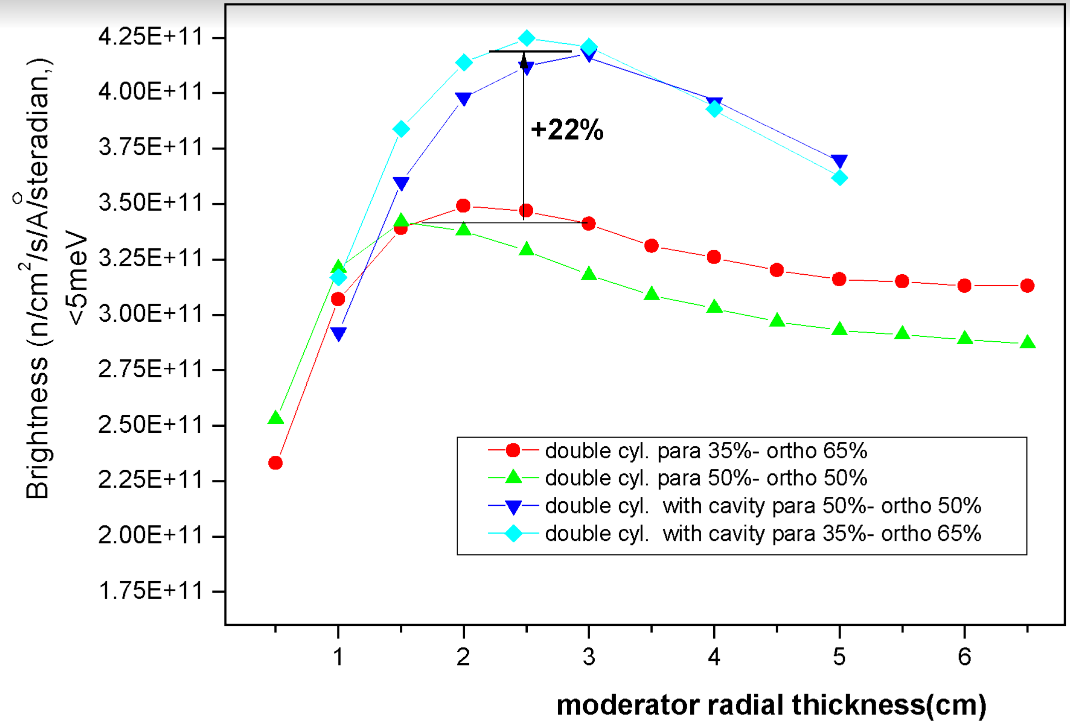
M/C Shape Selection



Double cylinder



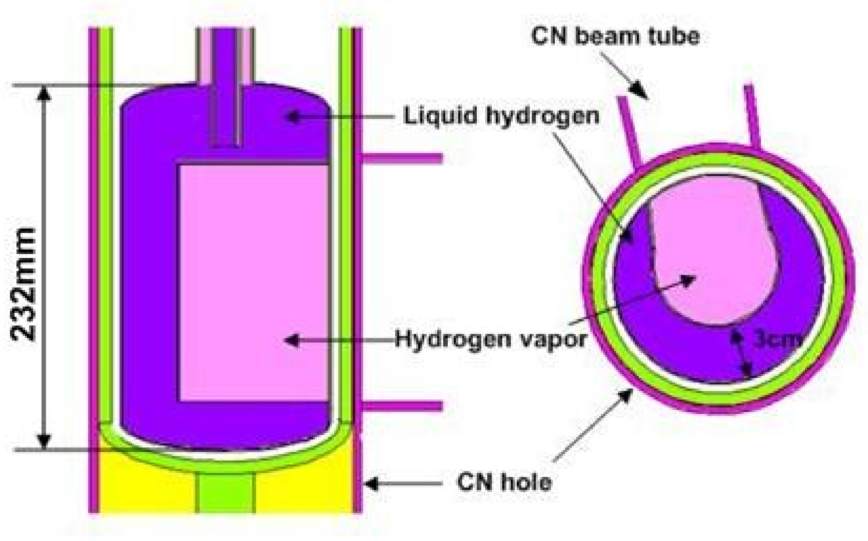
Double cylinder with open cavity

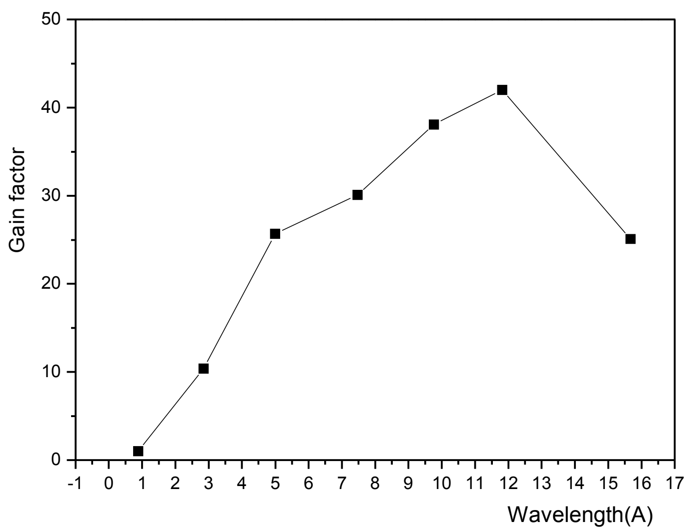


- The inner cylinder shape is changed into an open cavity shape towards the CN beam tube, brightness increase up to 22 %
- It seems that the cavity reduces the possibility of the up-scattering and the absorption of the cold neutron

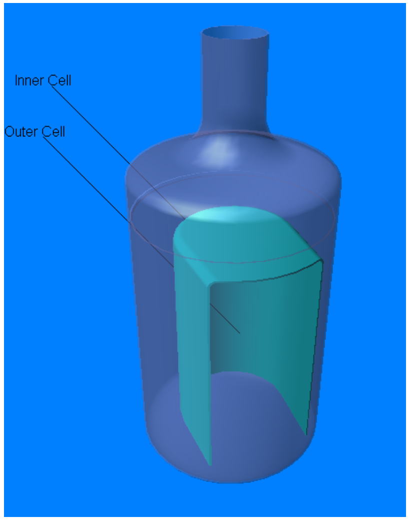
M/C Shape Optimization

- Moderator Cell shape : Double cylinder with open cavity
- Maximum radial thickness : 3 cm
- Liquid H_2 ortho/para ratio : 50% versus 50%
- Moderator cell height : 232 mm
- Moderator cell wall thickness : 1 mm
- Inner cylinder height : 15 cm, aligned with CN beam tube
- Calculated gain factor of the cold neutron (less than 5meV) : 31.7
- Maximum gain factor : 42 at about 11.8 Å





Nuclear Heating

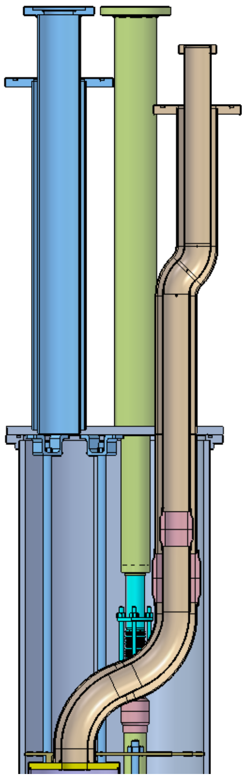


	Specific heating rate (W/g)				Mass	Heating rate (W)
	Neutron	Gamma	Beta	Sum		
Outer cyl. Al	0.0034	0.4238	0.1503	0.58	360.6	208.2
Cavity Al	0.0039	0.4786	0.2389	0.72	127.1	91.7
Tube Al	0.0019	0.2264	0.0857	0.31	422.2	132.6
Outer cyl. H_2	0.9828	0.9482		1.93	87.5	168.9
Cavity H_2	0.8607	0.7782		1.64	2.4	4.0
Tube H_2	0.5243	0.4580		0.98	9.8	9.6
others					661.4	13.9
Total (W)	95.7	398.6	120.7	629	1670.9	629

Others are hydrogen and tube above 60 cm, which is the height of the reflector from the core center.

- Heat load is calculated by MCNP code
- Total nuclear heating to be removed is 629 W
- Heat load generated at Al 6061 is 68.8%
- Gamma ray is dominant in the nuclear heating : 63%

In-pool Assembly Design

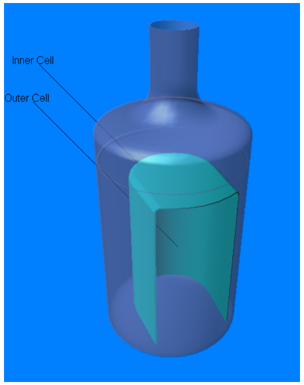


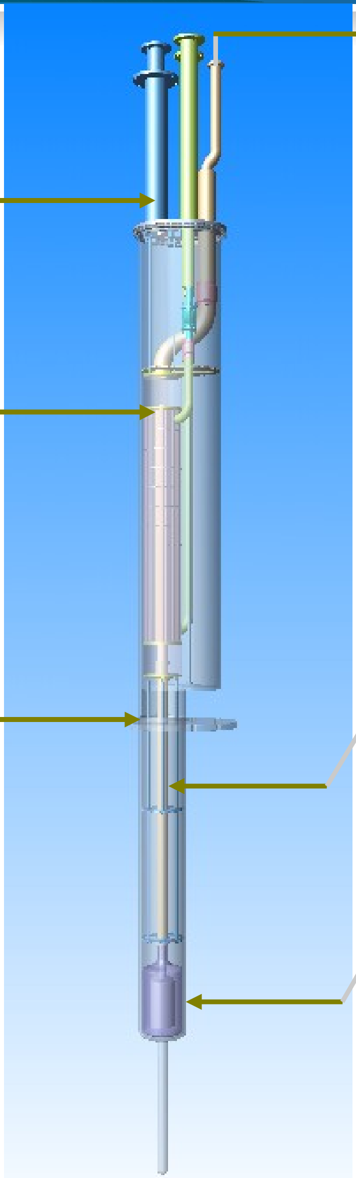
Material: Al6061-T6

Vacuum pipe (ID50)

Heat Exchanger
- **Tube side :**
  hydrogen at 1.5 atm, 21.6 K
- **Shell side :**
  helium gas at T_{in} of 14 K, 2 atm
  He flow rate of 50~60 g/sec

Vacuum chamber (5t)





To Buffer tank
- **Operation press: 1.5 atm**
- **Initial press : ~ 3 atm at RT**
- **Volume : ~ 1.3 m³**

Two-phase
Thermo-siphon

Transfer tube
Double tube (ID18.5/35)

Moderator Cell
130IDx232Hx(1)t
Liquid hydrogen

Small scale Mock-up Test

Small-scale mock-up test performed at KAIST

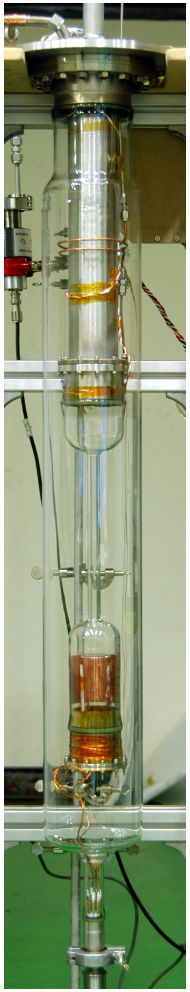
- Using liquid argon as a working fluid in a mock-up made of Pyrex glass
- Argon exists in a liquid phase within a narrow temperature range like LH_2

	density (kg/m)		Boiling point (K)	Melting point (K)
	liquid	vapor		
Hydrogen	69	1.9	21.6	14
Argon	1369	8.4	91.3	83.8

- Visualization of the thermo-siphon in a small-scale mock-up

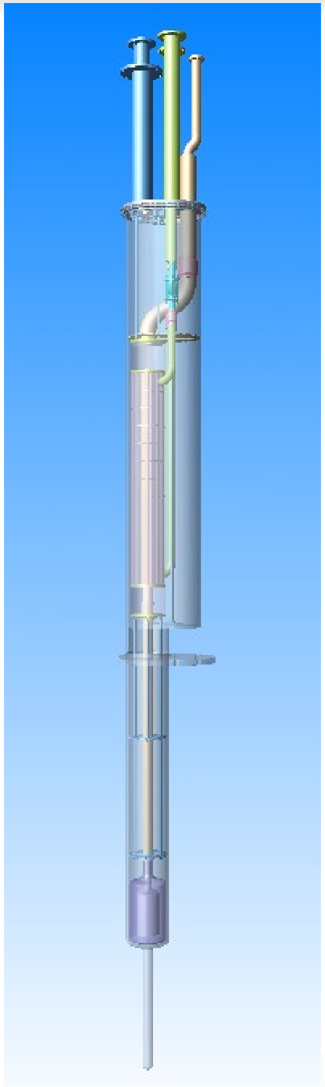
- No flooding under the maximum considered heat load

- Measurement of the void fraction by fluid capacitance



Full scale Mock-up Test

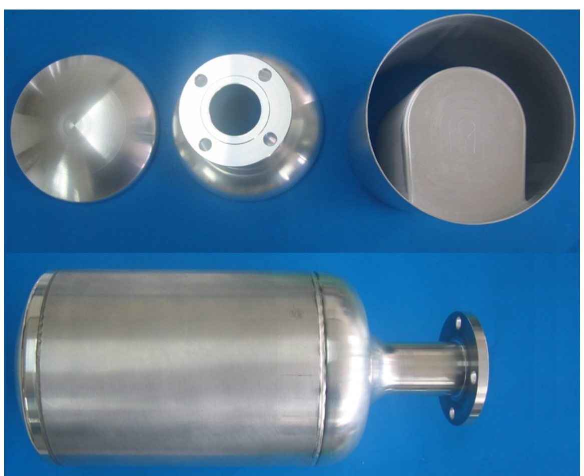
- One of major activities of this fiscal year
- Liquid hydrogen as a working fluid
- Real scale fabrication of the IPA (in-pool assembly)
- Confirmation of IPA design and stable operation in the full-scale thermo-siphon
- Vacuum test and cryogenic test
- Measurement of void fraction using the gamma ray densitometer which is on the developing stage



Manufacturing Test of M/C

1st test

- Manufacturing of moderator cell, double cylinder at 1.2 mm thick
- Evaluation of the manufacturing capability
- Welding test of the moderator cell
- Good results at the visual and dimension inspection,
  non-destructive test, leak test, tensile test



2nd test

- Double cylinder with open cavity at 1mm thick
- The visual and dimension inspection is passed
- leak, tensile, fatigue and cryogenic test are in progress

Project Schedule

- Full-scale mock-up test will start in the beginning of Nov.
- Current target is to submit the SAR by the end of April 2006
- Purchase the He refrigerator
- Complete the detail design until the end of May 2006
- Manufacture the system equipments and neutron guide
- Start the construction of the CNL in this year