1.1. Introduction to Nuclear Reactor Physics Experiments

Nuclear Engineering Department

Shim, Hyung Jin

AGN-201

- AGN-201 were manufactured and installed by "Aerojet General Nucleonics" at 22 sites in the world during period of 1957-1977 for education and training.

Myung Hyun Kim, Reactor Experiment, Reactor Research & Education Center, Kyung Hee University (2018).

경희대 교육용 원자로 (AGN-201K) 연혁

- 1967. 1. – 미국 Colorado State University (CSU) 운전 시작
- 1976. 3. – 미국 DOE의 조정으로 CSU가 경희대학교에 기증
- 1978. 1. – 과학기술처 건설허가 취득
- 1981. 10. – 원자로건물 준공 및 부대시설 완공
- 1982. 10. – 원자로 설치 및 정비 완료
- 1982. 12. – 원자로 가동 개시 (0.1W 허용출력)

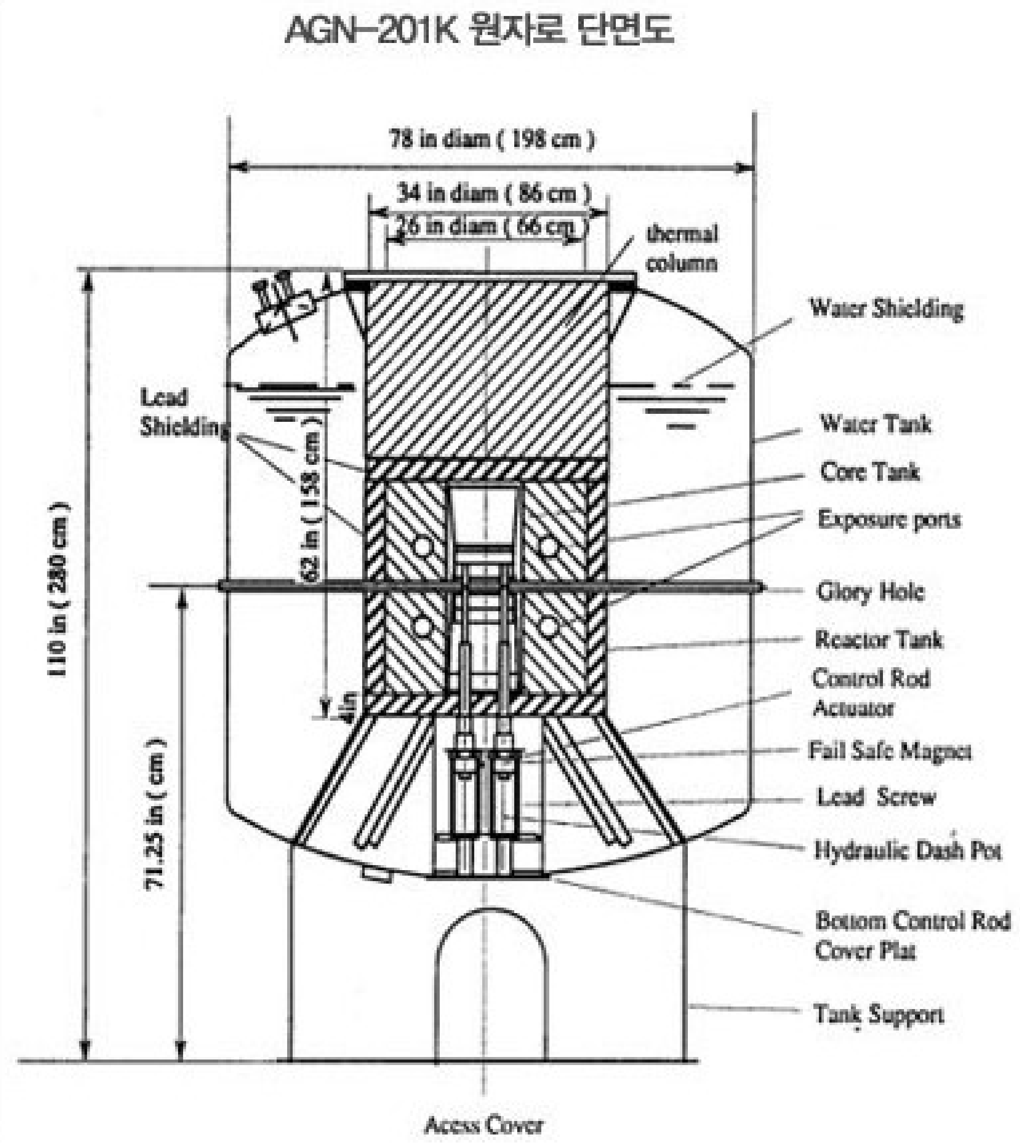
…

- 2005. 10. – 원자로 출력증강에 따른 시설변경허가 신청 (과학기술부)
- 2007. 5. – 과학기술부 건설(보수공사) 허가 취득
- 2007. 10. – 과학기술부 운영허가 취득 (10W 허용출력)
- 2008. 8. – 원자로센터 설립

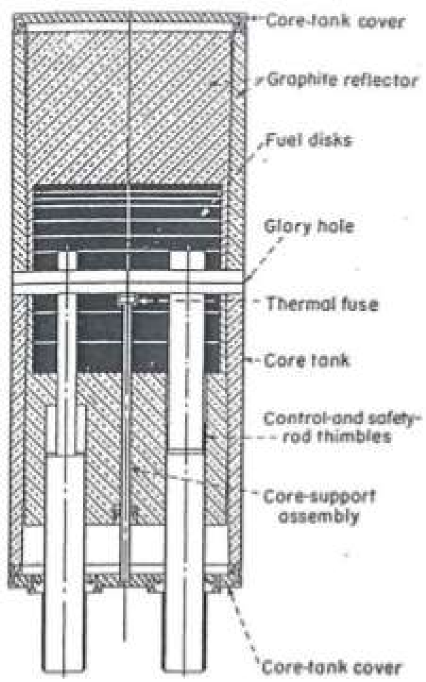
경희대 교육용 원자로(AGN-201K) 특징

1. Zero Power Reactor
   - ✓ Licensed power = **10 Watt**
   - ✓ Design power level = 20 Watt
2. Homogeneous Cylindrical Core with **Graphite Reflector**
   - ✓ LEU fuel: 690g of ^{235}U in **19.5% enriched UO_2 powder**
   - ✓ Mixed with **polyethylene moderator** (11 kg)
   - ✓ High density (1.75 g/cc) **graphite reflector**
3. Intensive Biological Shielding
   - ✓ **10 cm thick lead tank** for gamma shielding
   - ✓ 1,000 gallon (3,785 liter) **water tank** for neutron shield
   - ✓ 60 cm thick **concrete wall**
4. Reactor Protection & Safety
   - ✓ **Very small excess reactivity** (0.18 %$\Delta k/k$ at 20ºC)
   - ✓ High temperature feedback coefficient (-0.0275 %/ºC)
   - ✓ **2 safety rods & 2 control rods**

AGN-201 Core Configuration

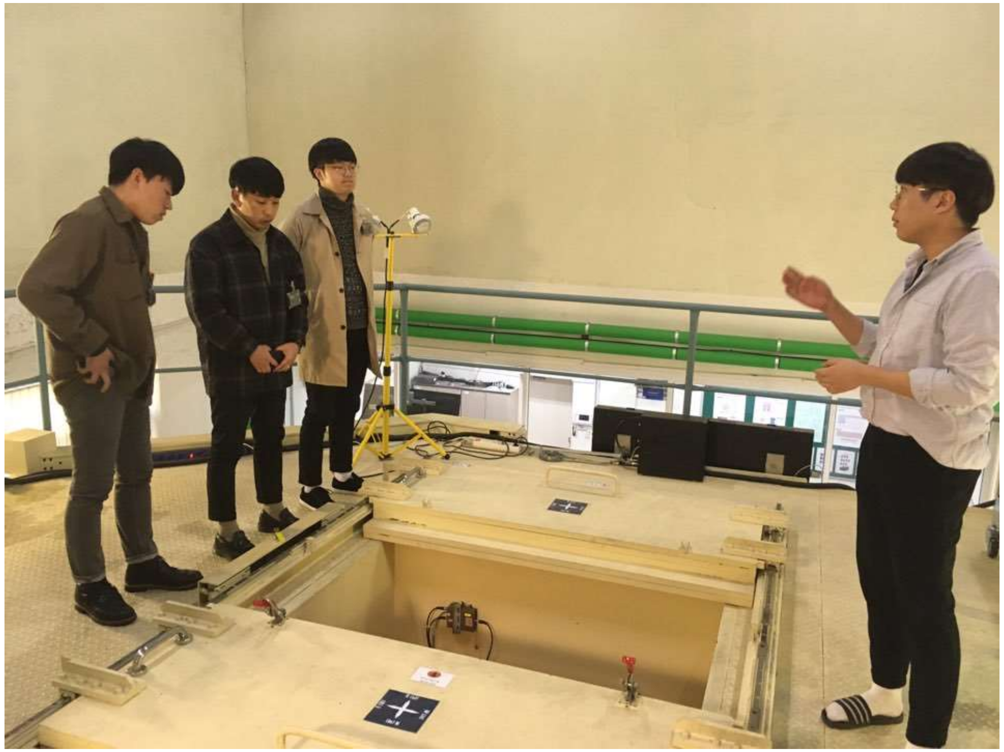


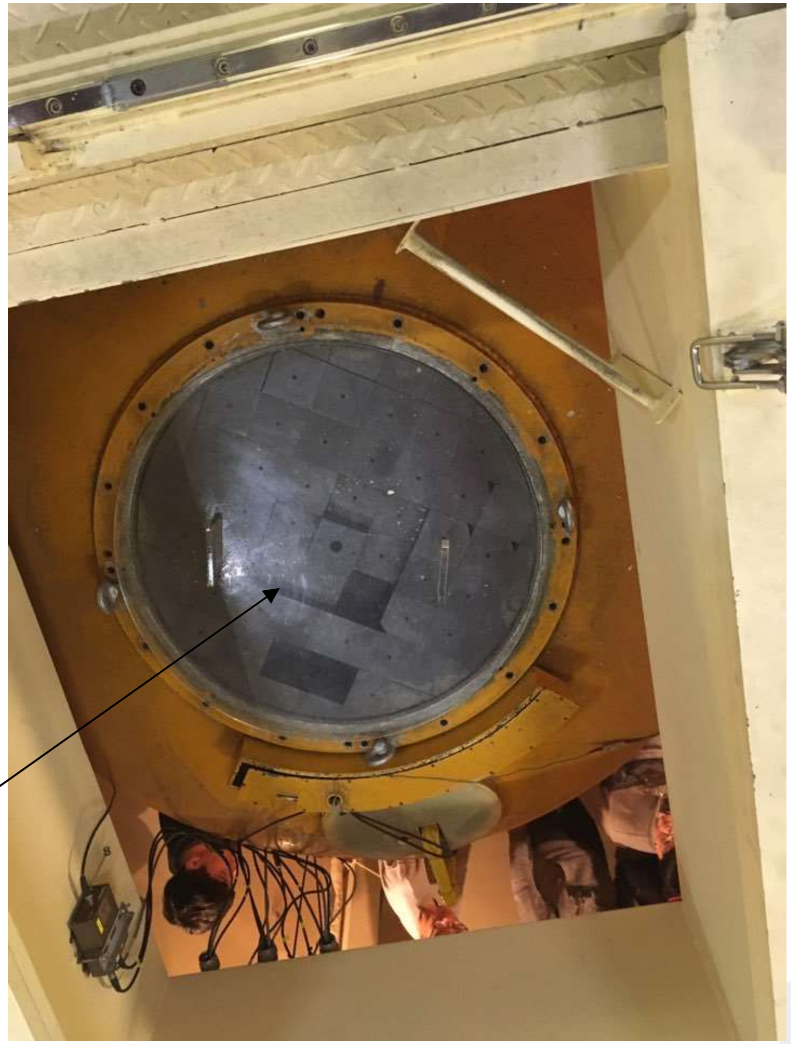
- ✓ Core (26D ×24H cm)
- ✓ Core Tank (Al, 2mm)
- ✓ Graphite Reflector (20cm thickness)
- ✓ Lead Shielding (10cm thickness)
- ✓ Water Neutron Shield (55cm thickness)



Myung Hyun Kim, Reactor Experiment, Reactor Research & Education Center, Kyung Hee University (2018).

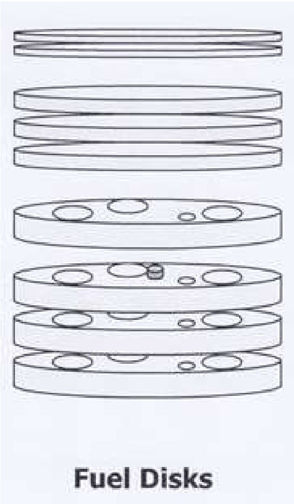
Thermal Column

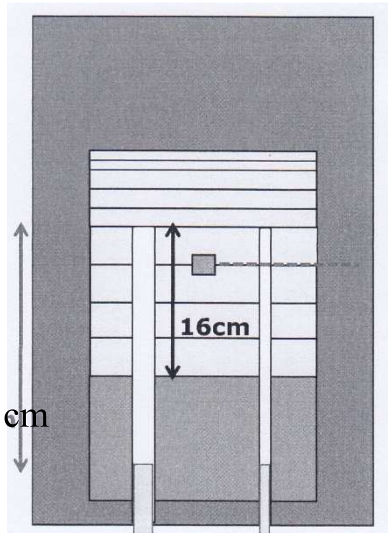




Graphite

Fuel Disks Making Core





Part	Height	Weight of ^{235}U	Function
Fuel disk 1, 2, 3, 4	4×4[cm/disk]	4×102[g/disk]	Core
Fuel disk 5, 6, 7	3×2[cm/disk]	3×58[g/disk]	
Fuel disk 8, 9	2×1[cm/disk]	2×29[g/disk]	
Thermal fuse*	2.2D×0.9H [cm]	4 g (double density fuel)	Safe shutdown
Safety rod 1 & 2	4 fuel pieces (16 cm)	2×14.5[g/rod]	Shutdown
Coarse control rod	4 fuel pieces (16 cm)	14.5 g	Control
Fine control rod	3 fuel pieces (12 cm)	2.5 g	Control
Totol ^{235}U mass		690 g	

* Melting point of U+polystyrene = 100ºC
cf. Melting point of U+polyethylene = 200ºC

Myung Hyun Kim, Reactor Experiment, Reactor Research & Education Center, Kyung Hee University (2018).

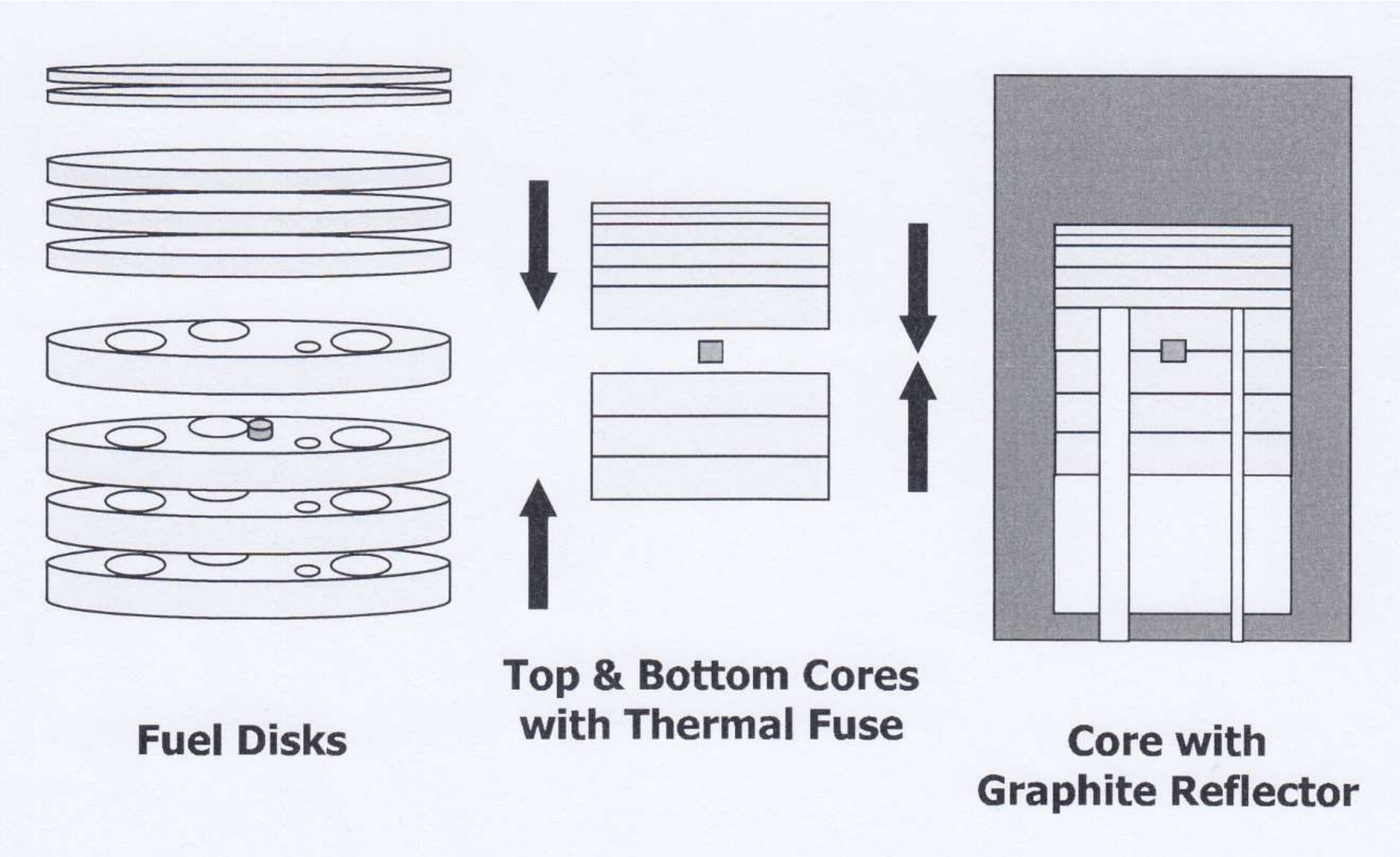
Fuel Disks

Bottom Core
(Height=12cm)

Top Core
(Height=12cm)

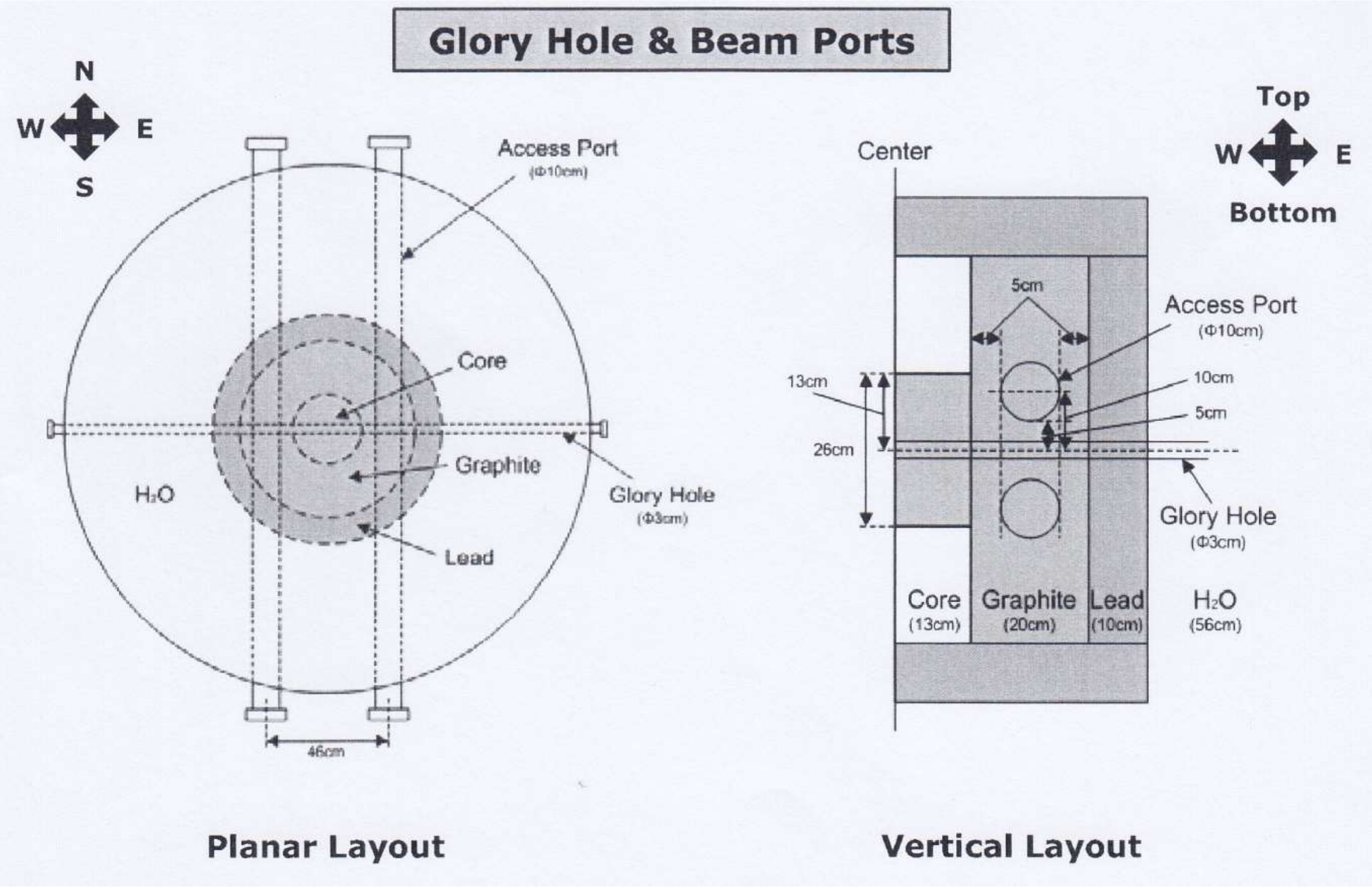
Core
(Height=24cm)

Fuel Disks Making Core



Myung Hyun Kim, Reactor Experiment, Reactor Research & Education Center, Kyung Hee University (2018).

Glory Hole & Beam Ports



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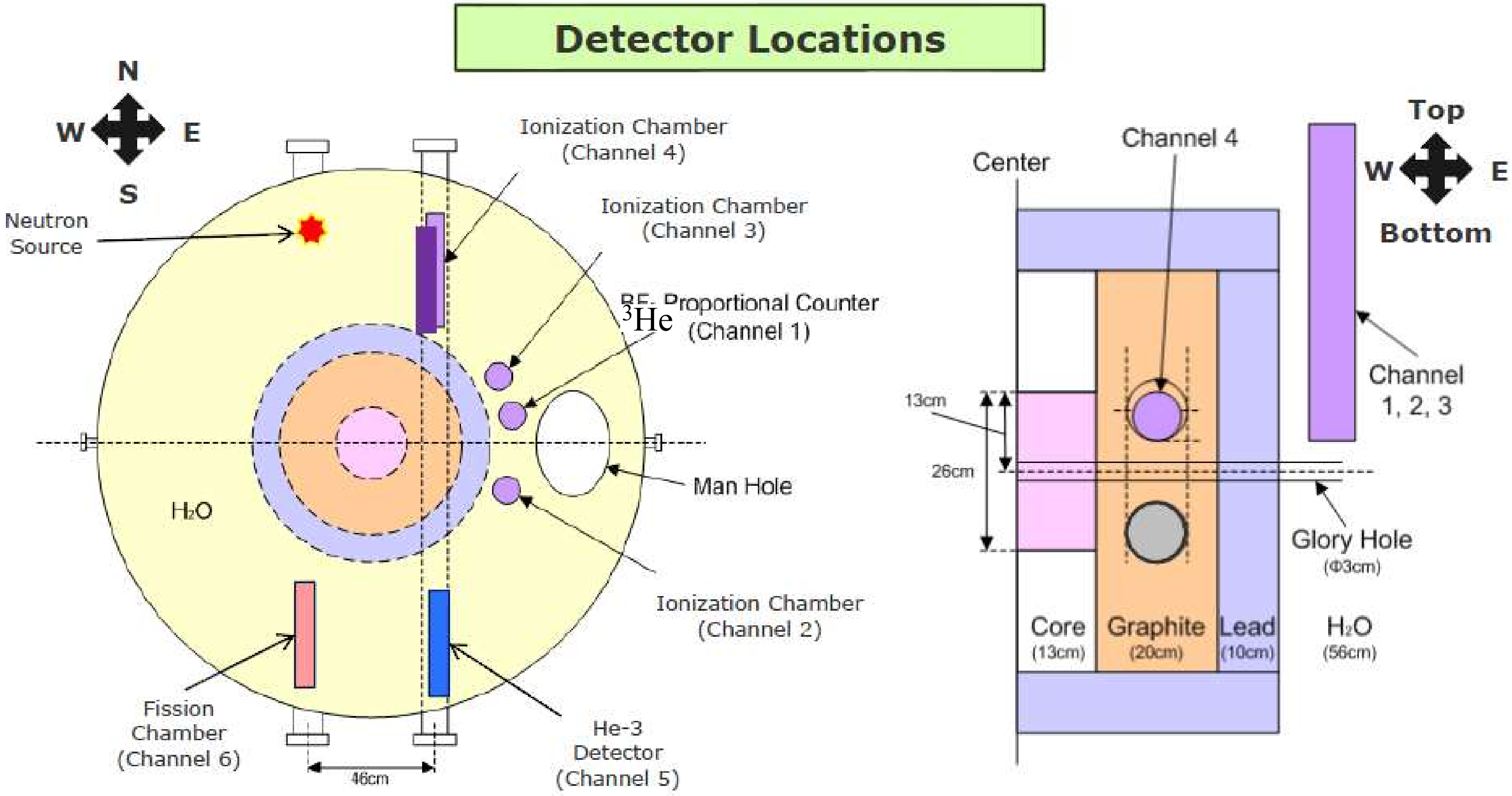
Glory Hole

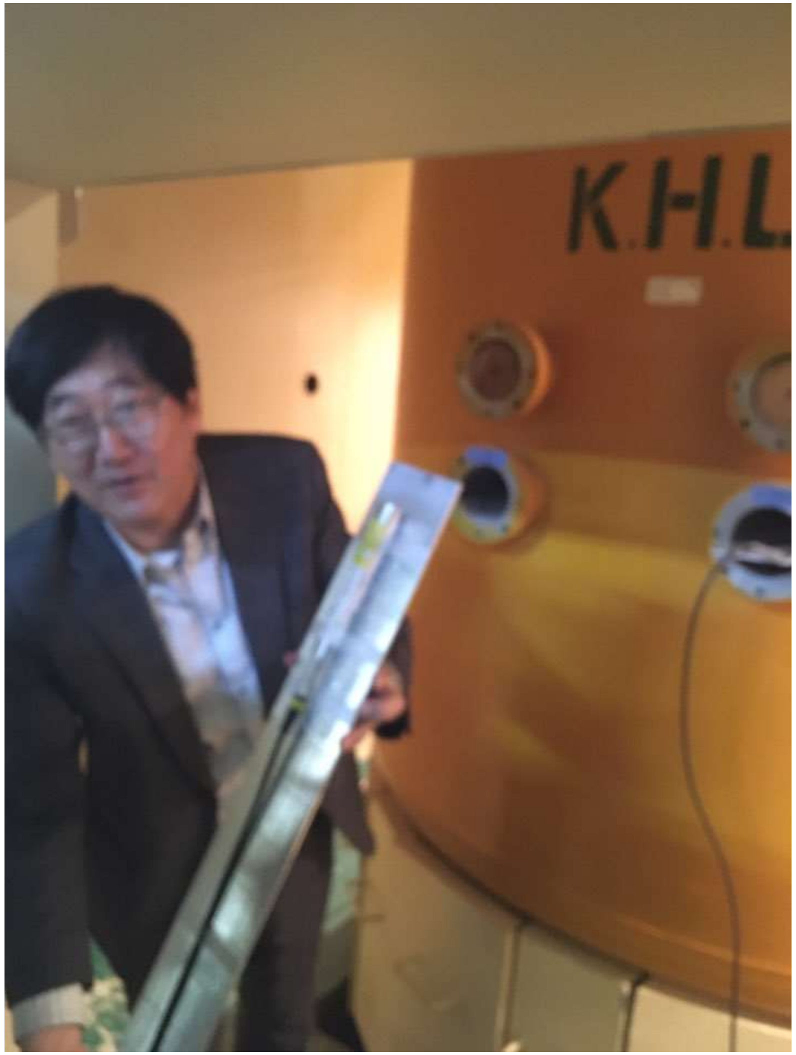
Detector Locations

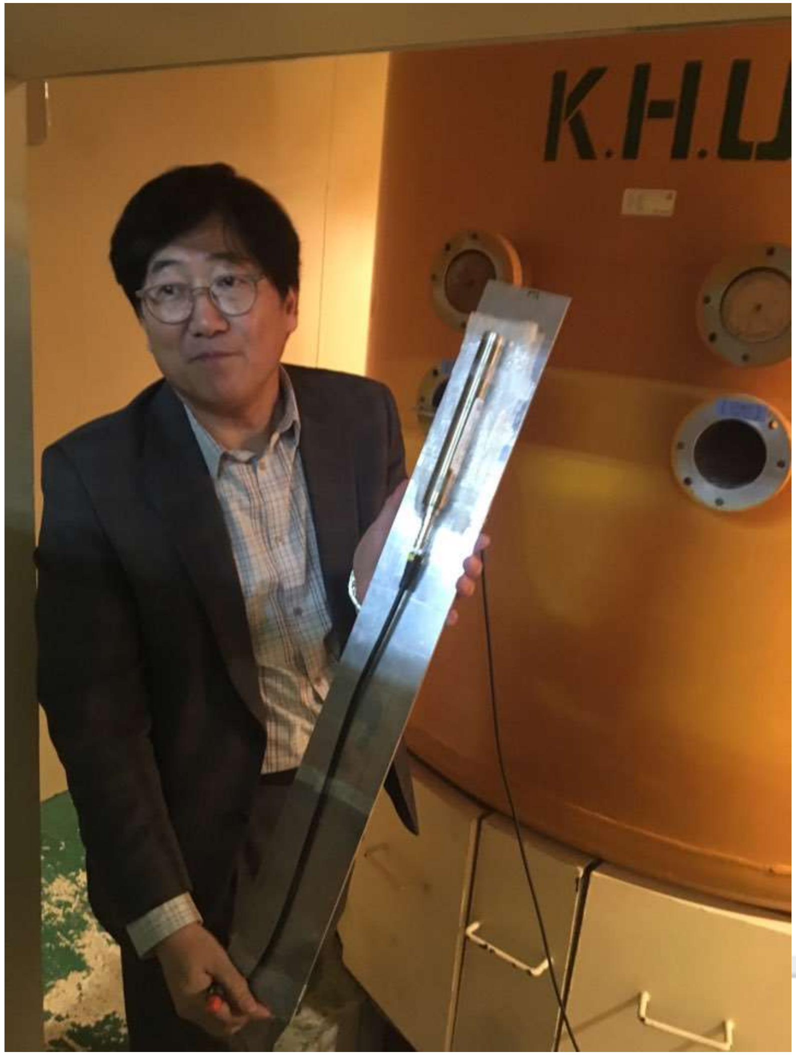


Planar Layout **Vertical Layout**

Myung Hyun Kim, Reactor Experiment, Reactor Research & Education Center, Kyung Hee University (2018).

Channel 5 (^{3}He) & 6(Fission Chamber)





Channel 4 (BF_3 Ionization Chamber)

Neutron Source

RaBe Source(10mCi)

$${}^{9}_{4}\mathrm{Be} + \alpha$$
$$\rightarrow {}^{12}_{6}\mathrm{C} + n$$
$$+ \gamma(4.44\mathrm{MeV})$$

15×10^{6}
neutrons/sec per Ci

Cf. PuBe, AmBe

Kinetics Parameters from KHU

Group	λ_i [sec-1]	β_i	$a_i(=\beta_i/\beta)$
1	0.0124	0.000211	0.03285
2	0.0305	0.001400	0.21797
3	0.1110	0.001250	0.19461
4	0.3010	0.002530	0.39390
5	1.1300	0.000736	0.11459
6	3.0000	0.000296	0.04608
sum		0.006423	1.00000

Prompt neutron lifetime, $l_p = 1.0 \times 10^{-4}$ sec.

Kinetics Parameters from AGN-201K McCARD Analysis

Group	λ_i [sec-1]	$\beta_{i,eff}$	$a_i(=\beta_i/\beta)$
1	0.0133	0.000261	0.03454
2	0.0327	0.001365	0.18063
3	0.1208	0.001313	0.17375
4	0.3028	0.002910	0.38507
5	0.8496	0.001211	0.16025
6	2.8535	0.000497	0.06577
sum		0.007556	1.00000

Prompt neutron lifetime, $l_p = 6.22131 \times 10^{-5}$ sec.

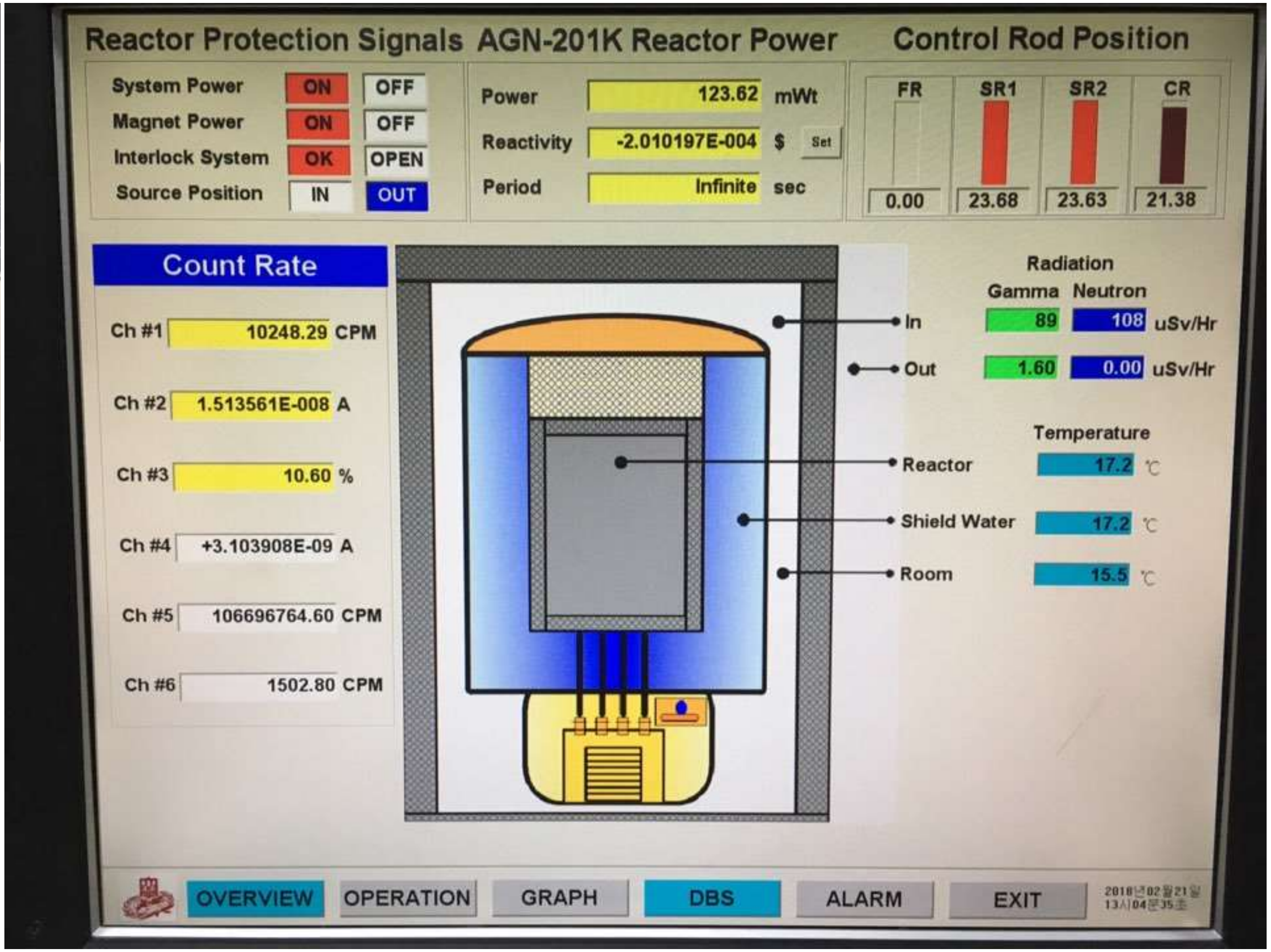
Nuclear Design Data

(1) Fuel Loading (a) Critical Mass (b) Excess Reactivity at 20ºC	*Experiment #3* 687 g of ^{235}U 0.18 %$\Delta k/k$
(2) Neutron Flux Level (a) Average Thermal Flux (b) Maximum Thermal Flux	*Experiment #5* 3.0×10^8 n/cm^2·sec at 10 W 4.5×10^8 n/cm^2·sec at 10 W
(3) Reactivity Worth (a) Safety Rod & Coarse Control Rods (b) Fine Control Rod (c) Temperature Feedback Coefficient	*Experiment #4* 1.25 % 0.31 % *Experiment #6* -0.0275 %/ºC

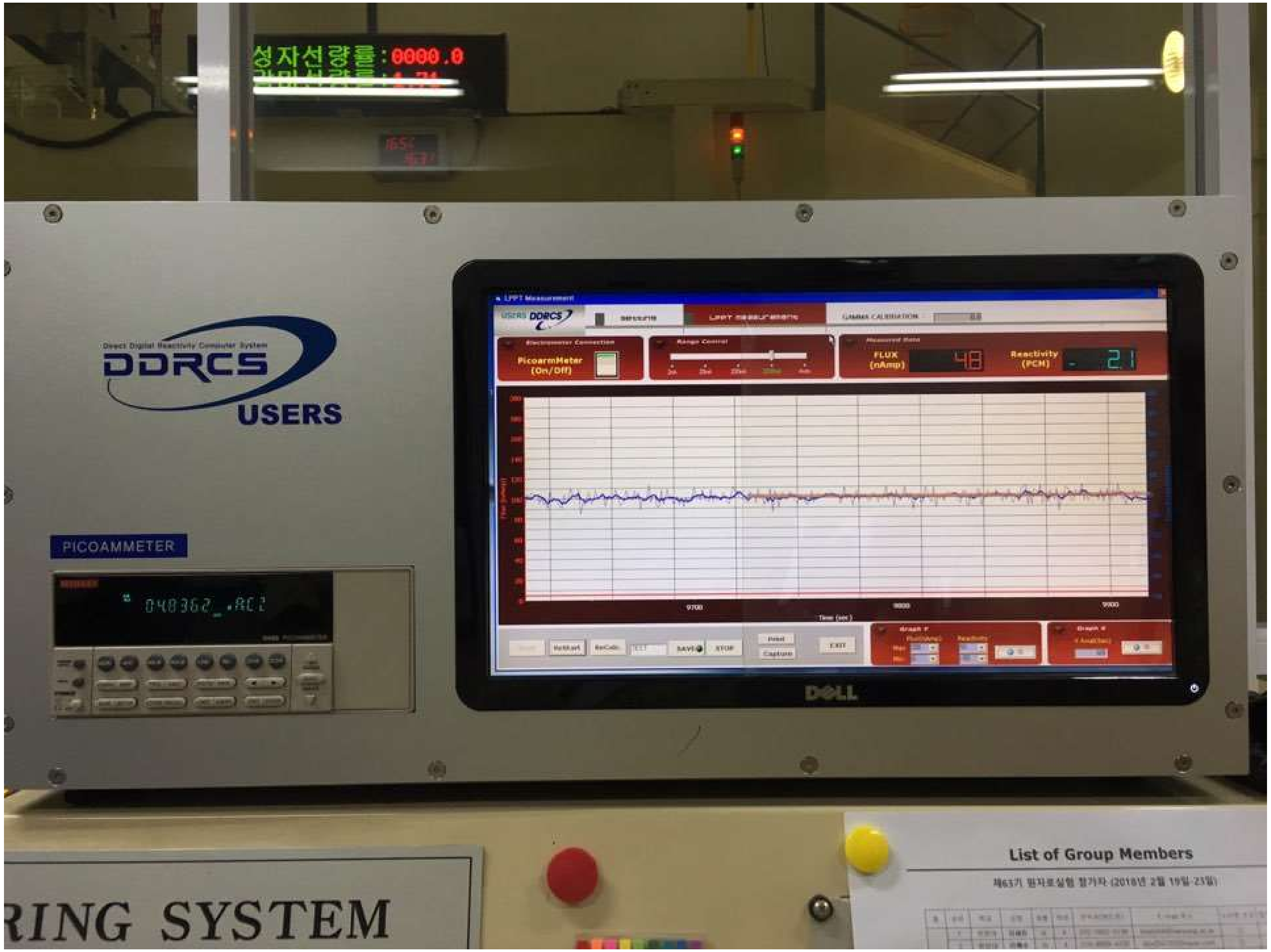
Refurbishment of Facility Equipment

Control Panel

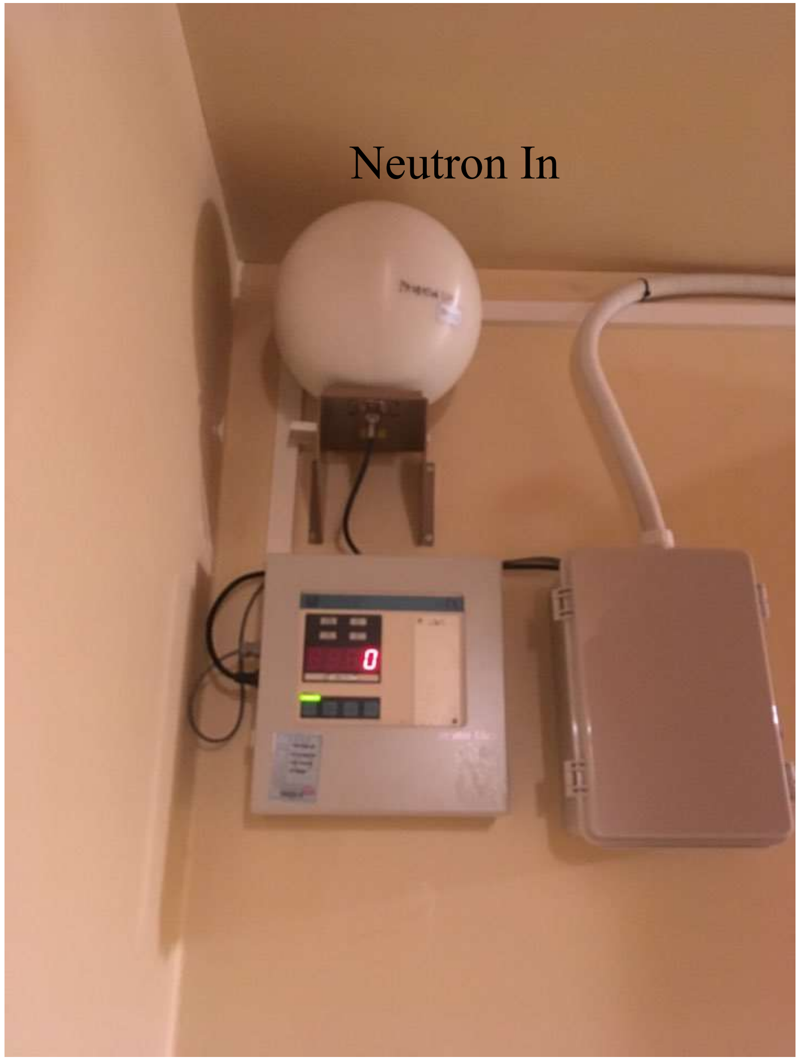
New Control Panel

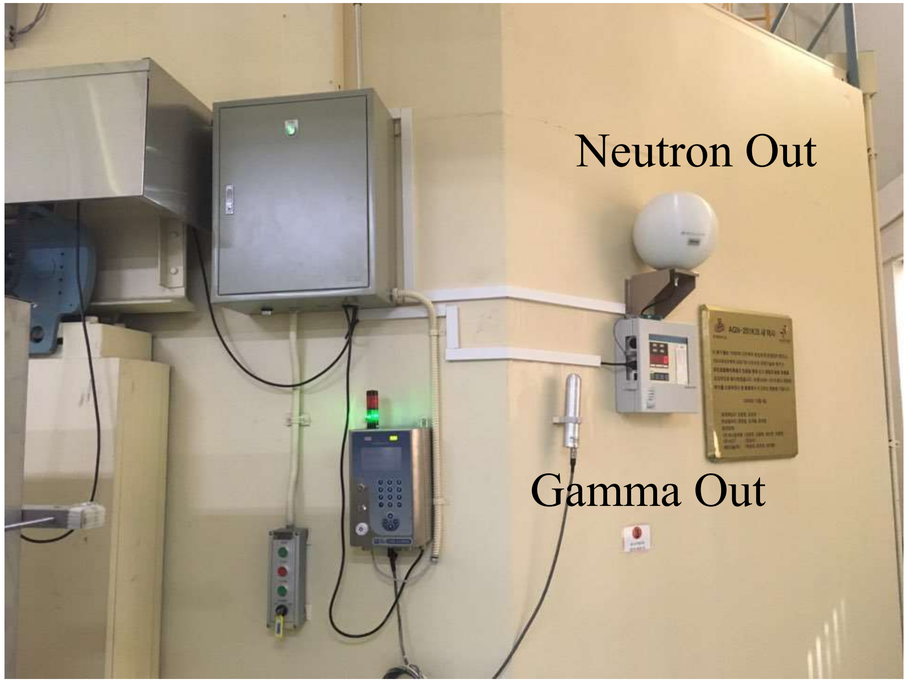


Reactivity Meter



Radiation Detectors





Exp #1. Criticality Experiment
Exp. #1-A. Signal – Power Linearity Experiment

Exp. #1 Procedure

- In this experiment, all students operate the reactor for power level change one after another. Each students receive his/her mission from supervisor to raise or drop power level from steady state condition to the new target power level. At the very first stage, reactor should be ready at critical condition by the reactor operator (RO).
- At the initial standby condition, RO makes a reactor critical at 0.01 watt. Thereafter, RO should stay at the analog operating console under supervision of supervisory reactor operator (SRO). SRO ordered two students sit at the digital monitoring console. One student has a duty of operation first and the other student is waiting for the next operator. Once the first mission is completed, next turn is repeated with a new student from waiting line. Detail procedure of repetition action is as the following.
  ① Student operator should read all reactor conditions and write down at the worksheet first. They are temperatures at various locations, source position, neutron and gamma radiation dose in the reactor hall. Once steady state condition is confirmed, he should write down control rod positions, power level and all kinds of detector signal values; such as current in nA, % power, cpm, etc. This values are said to be values at "Before".

Experimental Procedure (Contd.)

② SRO (as experiment instructor) asked student operator change the power level from "Before" power level to "After" power level. This order is given based on the signal from Channel #3.

③ Once right of operation is given to digtal monitoring console by RO after turning the switch at the operating console, student operator can move two CR and FR. Once he reach near to the target power level, he should make CR position to be the same level at "Before". After moving FR rod only and making reactor critical, SRO announce the time of criticality.

④ Then two students read and write all detector signals as "After" for student operator and as "Before" for the next standby operator.

⑤ All this procedure is done with two students; standby student now as student operator and a new student now as standby operator.

Data Sheet for Exp. #1

Experiment Condition		수치	단위			수치	단위
Reactor power		146	mwatt	Temp	Console	19	C
Source Posit.		out			Reactor	19.4	C
Gamma Dose	in	89	uSv/h		Sheild Water	19.4	C
	out	1.48	uSv/h		Room	18.4	C

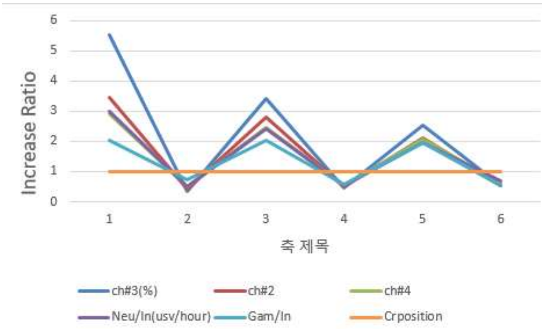
Trial		1	2	3	4	5	6	단위
목표치		10	50	20	60	30	70	%
Time		15:52	16:01	16:06	16:15	16:20	16:28	time
reactivity	DDRCS	0	0	0	0	0	0	pcm
	DC	0	0	0	-2.20E-03	-1.70E-03	0	$
period	DC	infinite	infinite	infinite	infinite	infinite	infinite	sec
Ch#3(BF3)		10.2	48.5	20.8	57.5	30.15	68	%
Ch#2(BF3)		1.38E-08	6.40E-08	2.70E-08	7.70E-08	3.98E-08	9.33E-08	A
Ch#4(BF3)		3.60E-09	1.45E-08	6.62E-09	1.70E-08	9.35E-09	2.00E-08	A
Neutron in		116	450	214	508	280	644	uSv/h
Gamma in		79	319	155	395	200	450	uSv/h
Neutron out		0	1	0	1	1	1	uSv/h
Gamma out		1.64	5.54	2.84	6.55	3.77	7.78	uSv/h
Temp. anal.		19	19	19	19	19	19	C
CR posit.		20.36	20.36	20.36	20.38	20.36	20.38	cm
FR posit.		14.38	14.38	14.38	14.38	14.38	14.38	cm

Comparison Among Detector Signals

	원래	1	2	3	4	5	6	unit
Time	16:38	16:45	16:51	16:57	17:02	17:08	17:12	
ddrcs		0	0	0	0	0	0	pcm
digital	0	0	0	0	0	0	0	$
period	Inf	Inf	Inf	Inf	Inf	Inf	Inf	s
ch#3	10.3	56.8	20.45	69.5	31.55	79.5	41.7	%
ch#2	2.25E-09	7.8E-09	3.2E-09	9E-09	4.57E-09	9.7E-09	5.4E-09	(A)
ch#4	6.78E-10	1.97E-09	9.6E-10	2.34E-09	1.26E-09	2.59E-09	1.55E-09	(A)
Neu/In	20	65	29	70	37	72	49	usv/hour
Gam/In	19	39	29	59	35	68	36	
Neu/Out	0	0	0	0	0	0	0	
Gam/Out	0.506	1.17	0.833	1.12	0.548	1.33	0.721	
Anal/temp	19	19	19	19	19	19	19	(섭씨)
Crposition	20	20.01	19.98	20.06	20	20.03	20.02	
Frposition	16.35	16.35	16.35	16.35	16.35	16.35	16.35	

(After실험값/Before실험값)

	1	2	3	4	5	6
ch#3(%)	5.514563107	0.360035211	3.398533007	0.453956835	2.519809826	0.524528302
ch#2	3.466666667	0.41025641	2.8125	0.507777778	2.122538293	0.556701031
ch#4	2.935103245	0.48241206	2.4375	0.538461538	2.055555556	0.598069498
Neu/In(usv/hour)	3	0.483333333	2.413793103	0.528571429	1.945945946	0.680555556
Gam/In	2.052631579	0.743589744	2.034482759	0.593220339	1.942857143	0.529411765
Crposition	1.0015	0.997503744	1.004004004	0.997008973	1.0015	0.999500749



Exp. #1-A. Experimental Worksheet

Experimental Worksheet

Experiment #1-A: Detector Linearity Check

Group #:

Name:

Date:

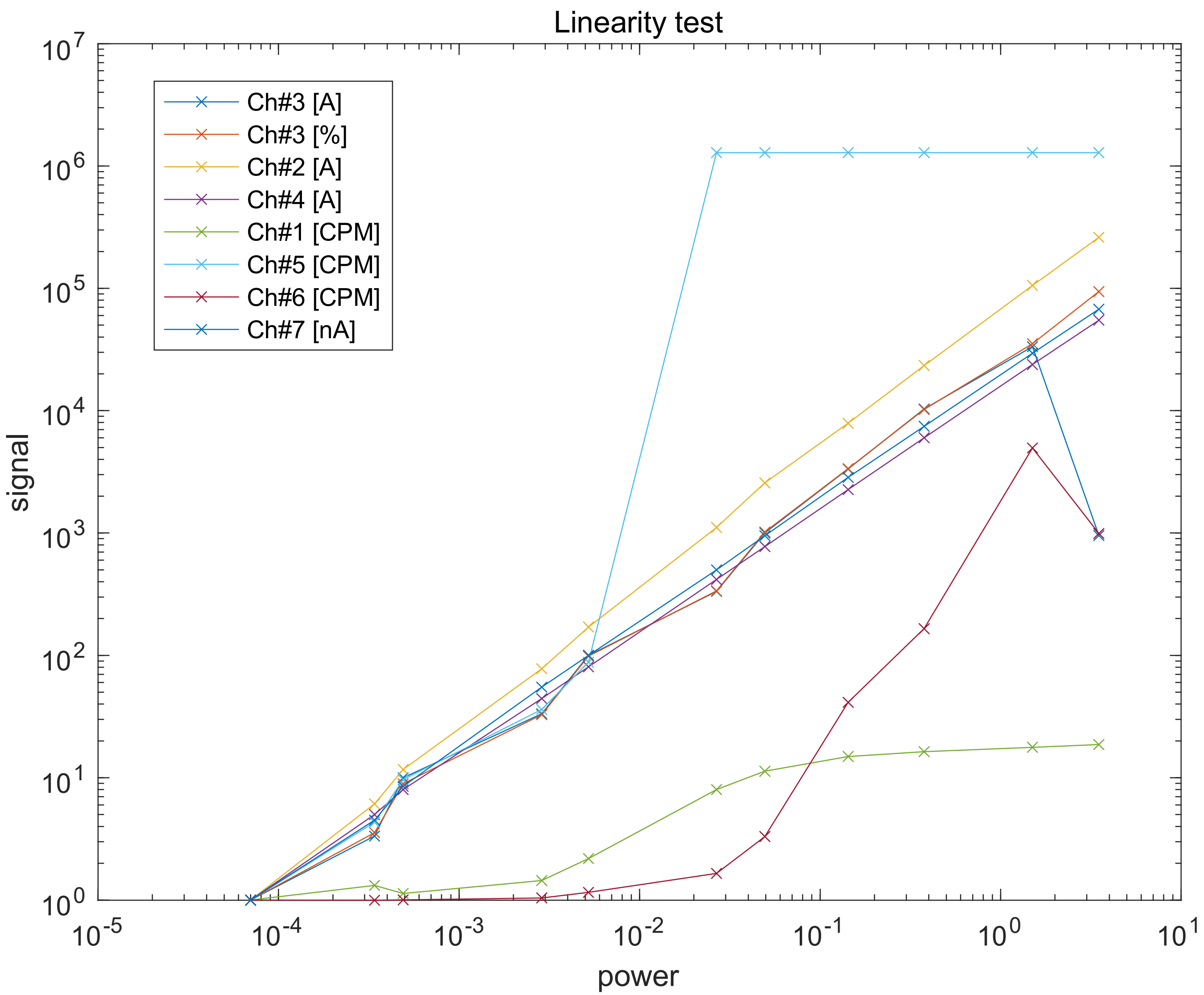
Time:

	Power	Ch #3 I.C.	Ch #2 I.C.	Ch #4 I.C.	Ch #1 He-3	Ch #5 He-3	Ch #6 F.C.	Ch #7 I.C.
1	3 Watt							
2	1 Wt							
3	0.3 Wt							
4	0.1 Wt							
5	0.03 Wt							
6	0.01 Wt							
7	0.003 Wt							
8	1 mwatt							
9	0.3 mW							
10	0.1 mW							
11	0.03 mW							
12	0.01 mW							
13	0.003 mW							
14	0.001 mW							

Results Example of Exp. #1-A

Power (W)	Ch #3 I.C. (10^(-9)A)	Ch #2 I.C. (10^(-9)A)	Ch #4 I.C. (10^(-9)A)	Ch #1 He-3 (cpm)	Ch #5 He-3 (cpm)	Ch #6 F.C. (cpm)	Ch #7 I.C. (nA)
3	28.7	470	88	11900		500000	135
1	10.85	189	38.1	11200		3000000	59
0.3	3.16	42	9.61	10300		130000	14.9
0.1	1	14.7	3.67	9400		19527	5.5
0.03	0.311	4.62	1.24	7234		1833	1.9
0.01	0.102	2.05	0.666	5151		1200	1
0.003	0.03	0.3	0.129	1380	7200	800	0.2
0.001	0.01	0.14	0.07	911	3104	3100	0.11
0.0003	0.003	0.021	0.0115	730	800	810	0.017
0.0001	0.001	0.011	0.007	830	350	605	0.009
0.00003	0.0003	0.002	0.0012	840	83	610	0.002

Results Example of Exp. #1-A (Contd.)



Discussion Points

1. Is it possible for a reactor to have its critical states with different power level?
2. What would be reasons of different signal-power linearity depending on the detector type and position?