The 10th CPS/HEP conference

Cryogenics and distillation tower of PandaX-4T Experiment at CJPL -II

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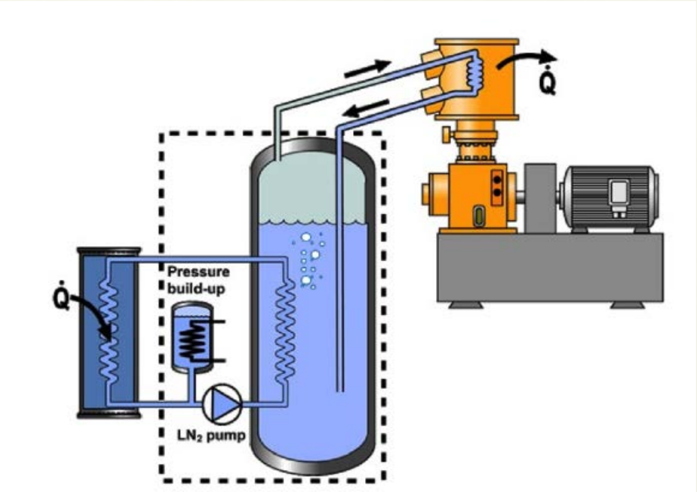
(on the behalf of PandaX collaboration)

Outline

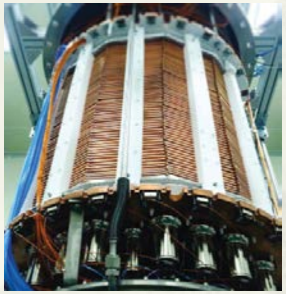
- Motivation;
- Design of Cryogenics;
- Tests of cooling bus;
- Distillation tower;
- Summary.

1.1 Motivation

LZ Cryogenics（LN2） （Xenon: 7T(10T)
Cooling power: ~1000W

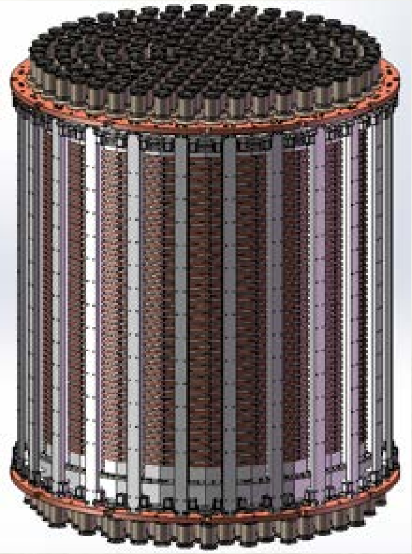


Total Xe:~1.2T



PandaX-II: 580KG(FV)
Running now

Total Xe:~6T



PandaX-4T: 4T(FV)
The next step.

XENON1T(3T） Cryogenics（2*PC150）
Cooling power: ~400W

1.2 Design Parameters of Cryogenics and circulation

PandaX-II, total Xenon： ~1.2ton.   Outer vacuum can not be separated.

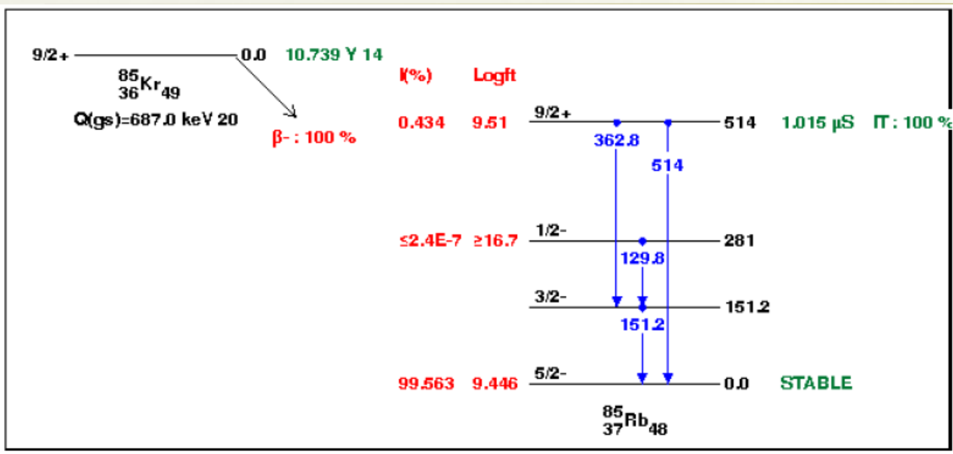
Parameter	Cooling Power(W) at -95	Heat Load(W)	Filling Speed	Circulation Flow Rate	Recuperation Speed
Value	180	~75W	~30slpm (240Kg/day)	~65SLPM	~30slpm (240Kg/day)
Module	PC150	IV Surface:~5.5m2	1*PC150+LN2 coil	1*K070(HE), PS4-MT50-R-2	By LN2

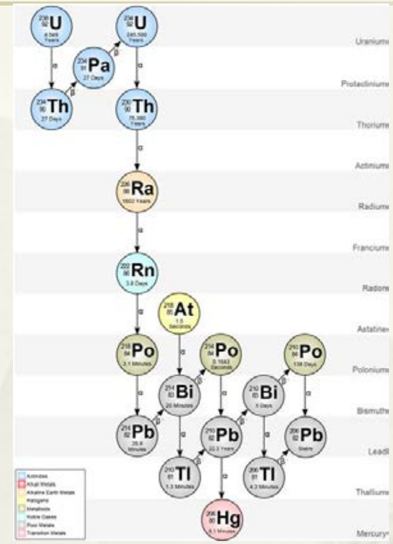
PandaX-4T, total Xenon： ~6ton. Each coldhead can be maintained separately.

Parameter	Cooling Power(W) at -95	Heat load(W)	Filling Speed	Circulation Flow Rate		Recuperation Speed
value	~590	~177	~70slpm (560Kg/day)	~200SLPM		42kg/h (1ton/day)
Module	PC150(180W） + PT90(170W)+ 500B(240W)	IV Surface:~13m 2	PC150+PT90 +500B+LN2 coil	2*K205 (HE)	PS5-MGT50-R-909 SimPure 9NG300-R	HP Diaphragm Pump

So, a new powerful cryogenics is needed

1.3 ^{85}Kr and ^{222}Rn contamination



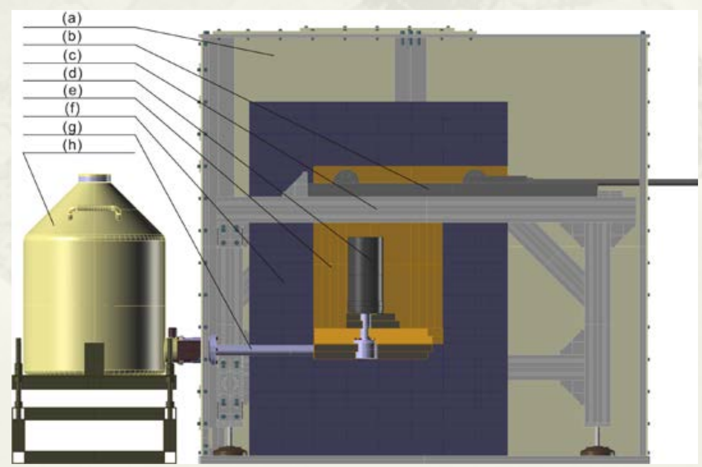


^{85}Kr background:

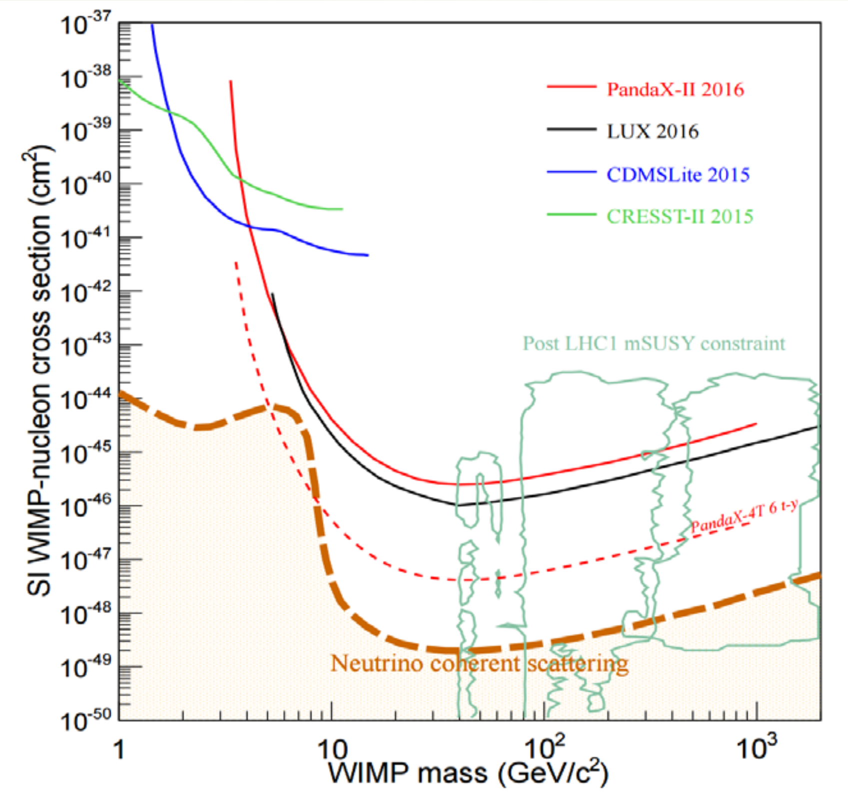
- ^{85}Kr dominat β-decay with $T_{1/2}$=10.756y
- ^{85}Kr/Kr ~ 10^{-11} in air
- Uniform distribution in liquid xenon

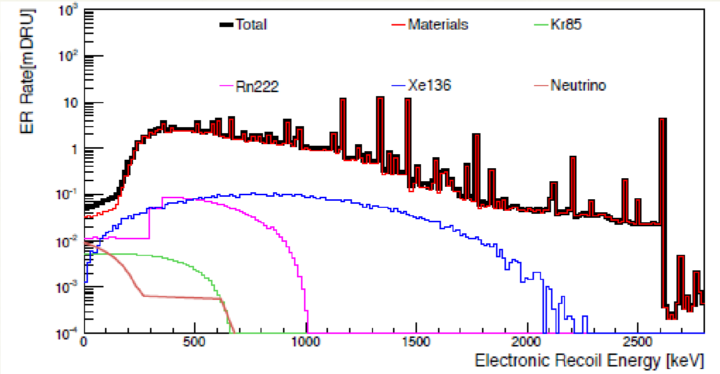
^{222}Rn background:

- 3.8 days decay half-life;
- Material selection with HPGe;



1.4 PandaX-4T Background(MC)



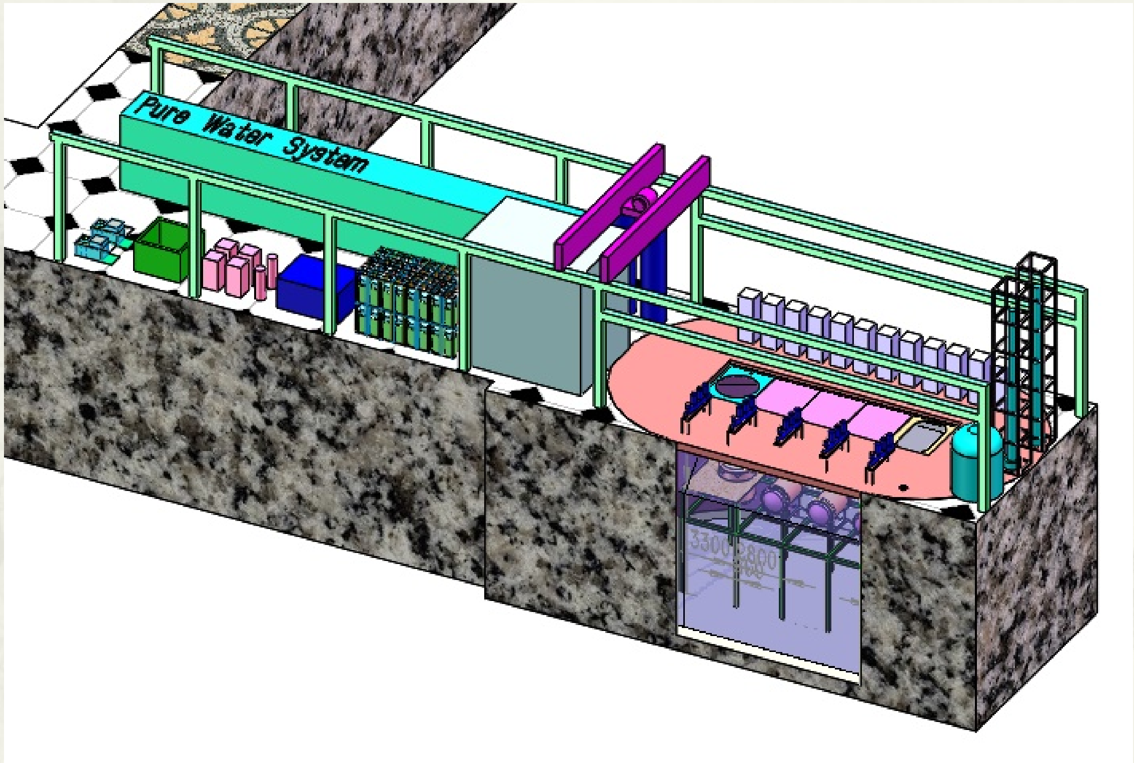


Background for DM search [0,10keV$_{ee}$]	mDRU
ER: Materials	0.020
ER: 222Rn	0.011 **(1μBq/kg)**
ER: 85Kr	0.005 **(0.1ppt)**
ER: 136Xe	0.002
ER: Solar Neutrino	0.009
Total ER	0.047
Total NR	3×10^{-4}

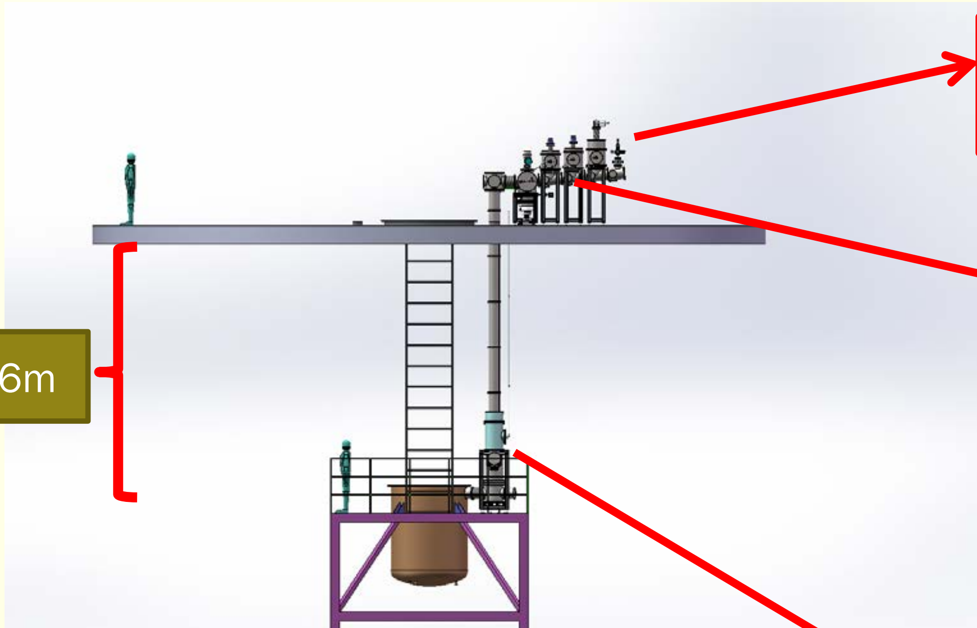
3.1 New home(PandaX-4T), CJPL-II

1)Lab size:
L:65m, H:14m,W:14m

2)Water pool(water shielding):
D:14m, W:14m, L: 25m

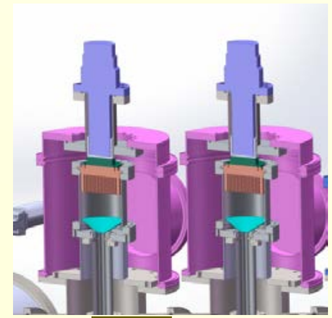


3.2Layout of Cryogenics and circulation system in CJPL-II



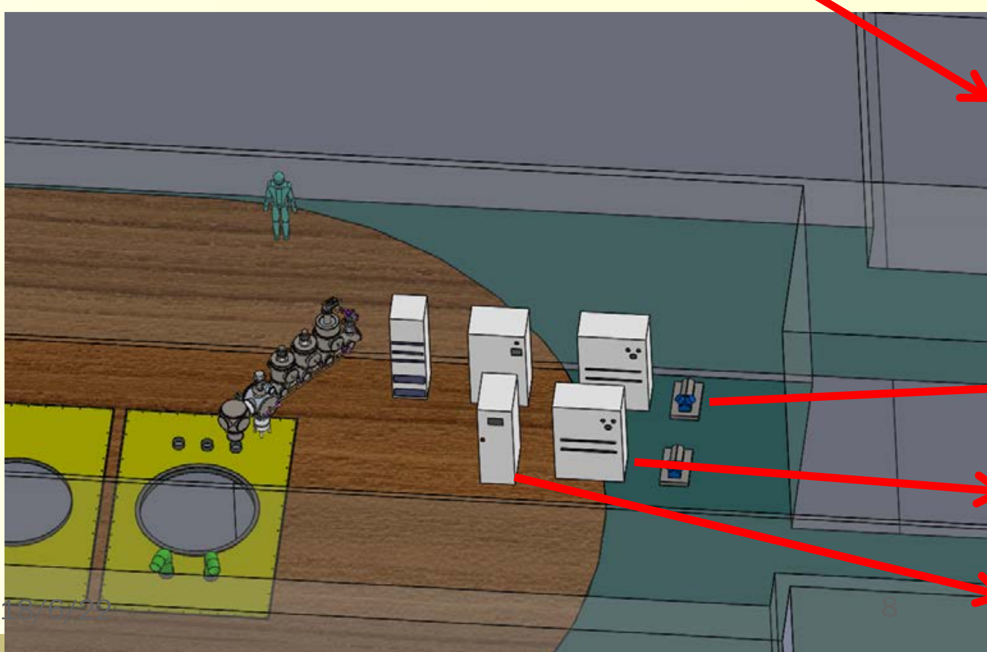
~6m

Cooling bus with 3 coldheads and 1 LN2



Outer vacuum of each cooling tower is separated

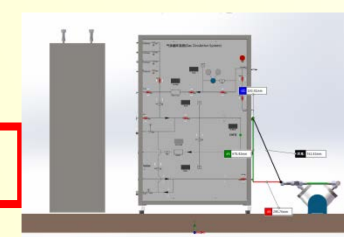
Heat exchanger module



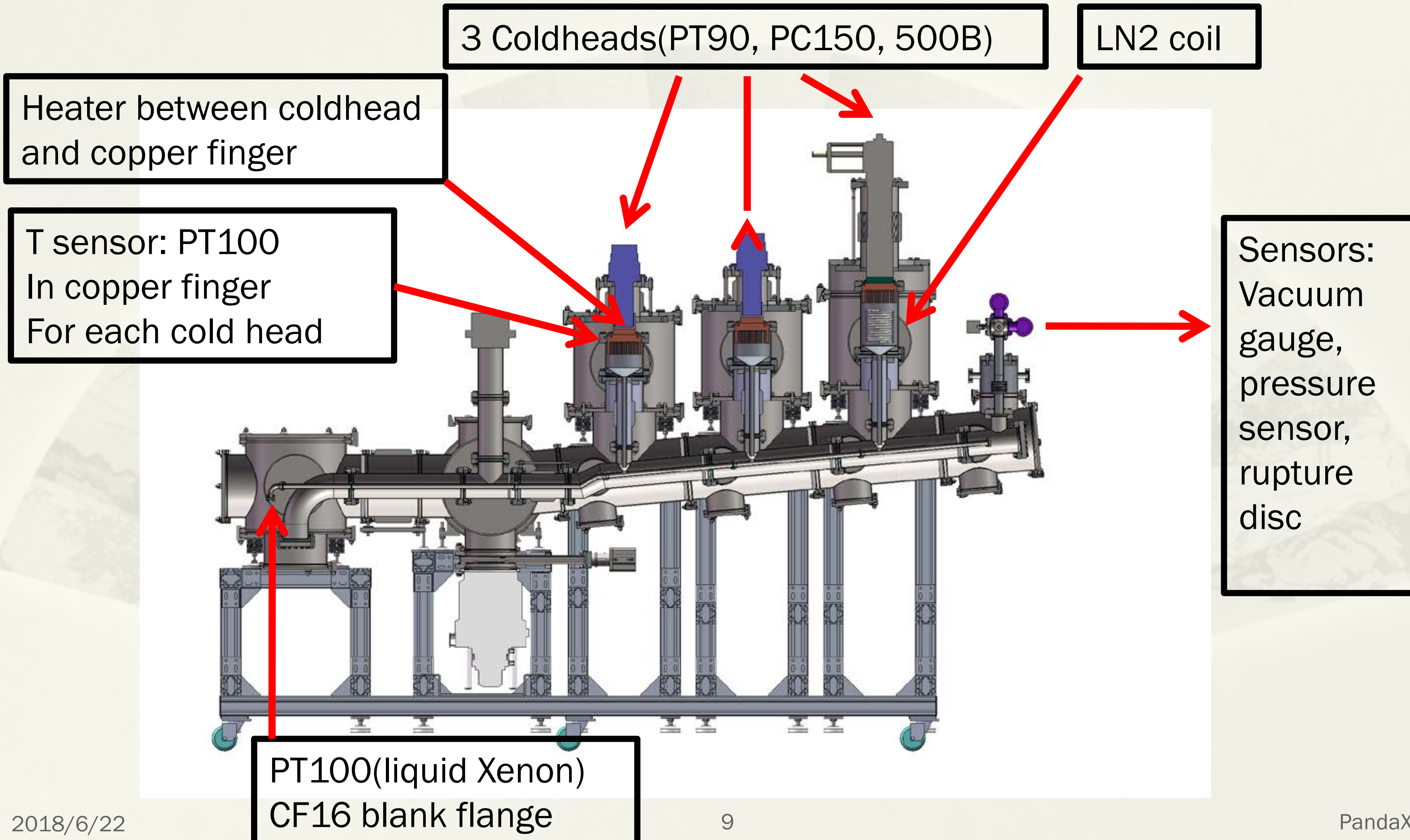
Circulation pump

Gas controller panel

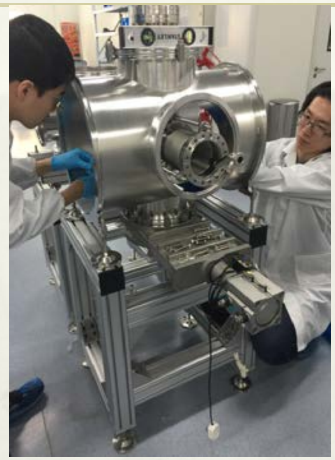
Purifier



3.3 Design of cooling bus



3.4 installing of Cooling bus



Parts

Cooling bus

3.5 Cooling power of coldheads

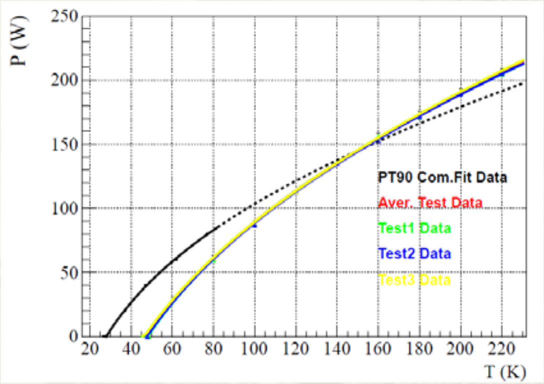
Conditions:

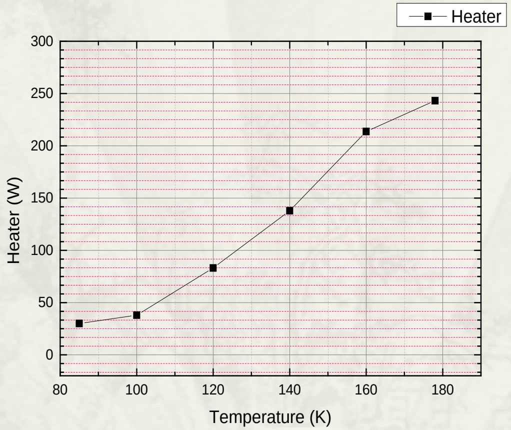
Outer vacuum: 9.0E -4Pa, inner vacuum: 6.7E-4Pa, multilayer heat insulation is used

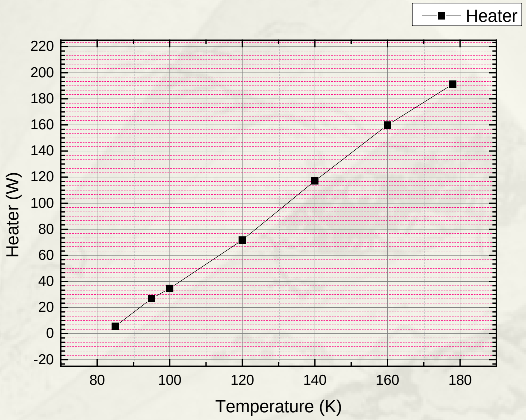
PT90 (PTR)
~170W at 178K

500B(GM)
~240W at 178K

PC150(PTR)
~190W at 178K







Efficiency Cooling power = power of heater as the temperature of copper finger is stable at certain point. Heat load is small.

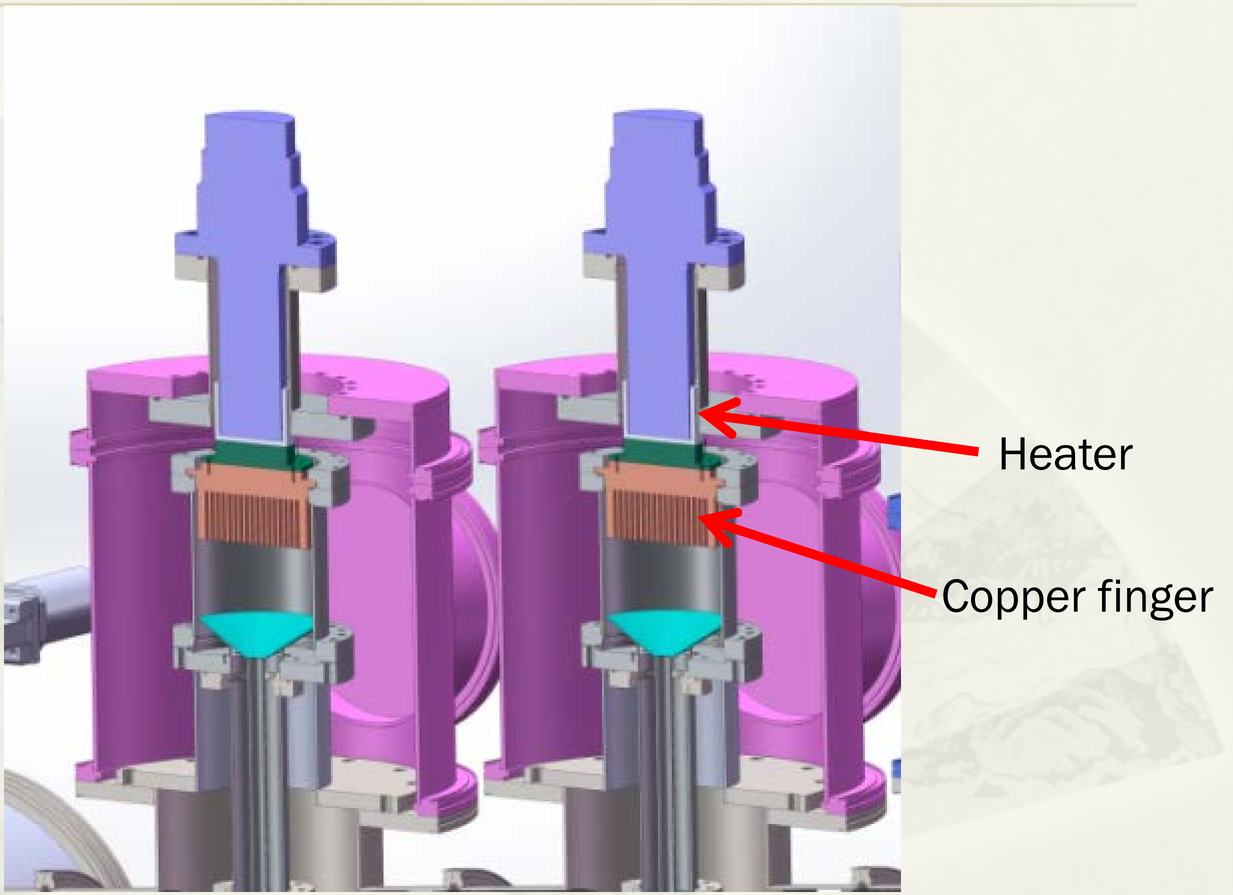
3.6 double coldheads working

2 coldhead;
RDK500B, PC150

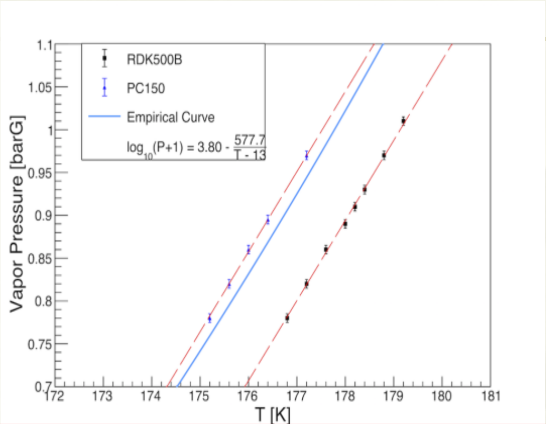
Each coldhead has independent heater, temperature sensor and copper finger.

Only way to talk is to liquefy Xenon gas.

What is their heat Load Distribution?

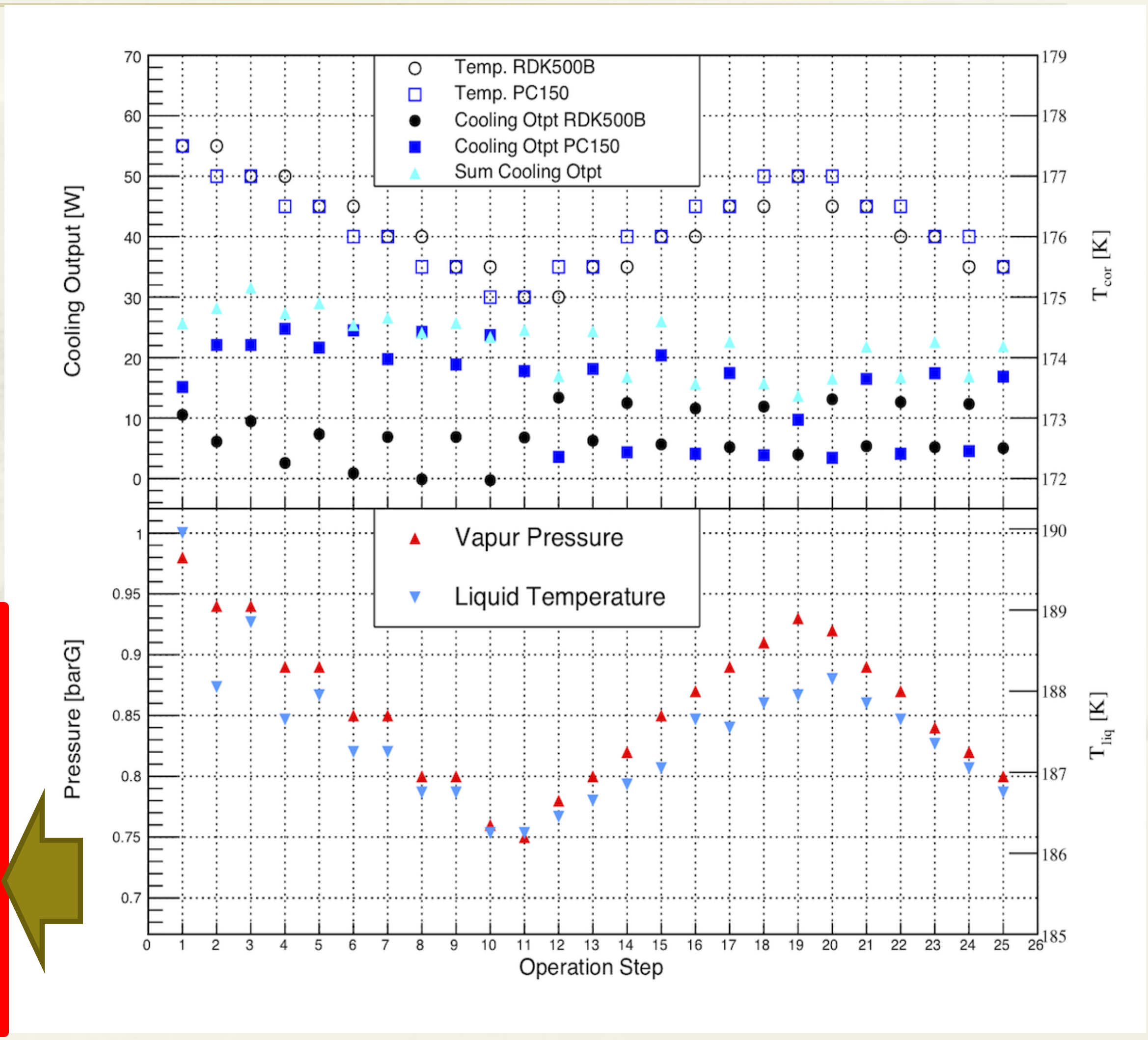


3.7 double coldheads working



Calibration of T sensor according to empirical P vs T curve for Xenon

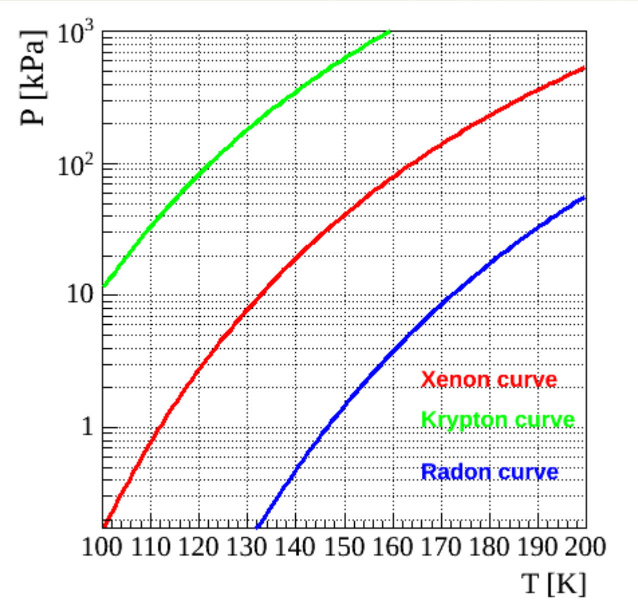
A)The load distribution is roughly stable regardless of history.
B)The load distribution can be adjusted by tuning the temperature of two heads at slightly different Ts.
C)Pressure was determined by the lowest cold temp of all heads.



4.1 Phase-I Distillation column

- 5kg/h flow rate with ~10^3 designed reduction factor
- Purify about 2ton original xenon
- **Krypton level in detector is 4.4ppt**

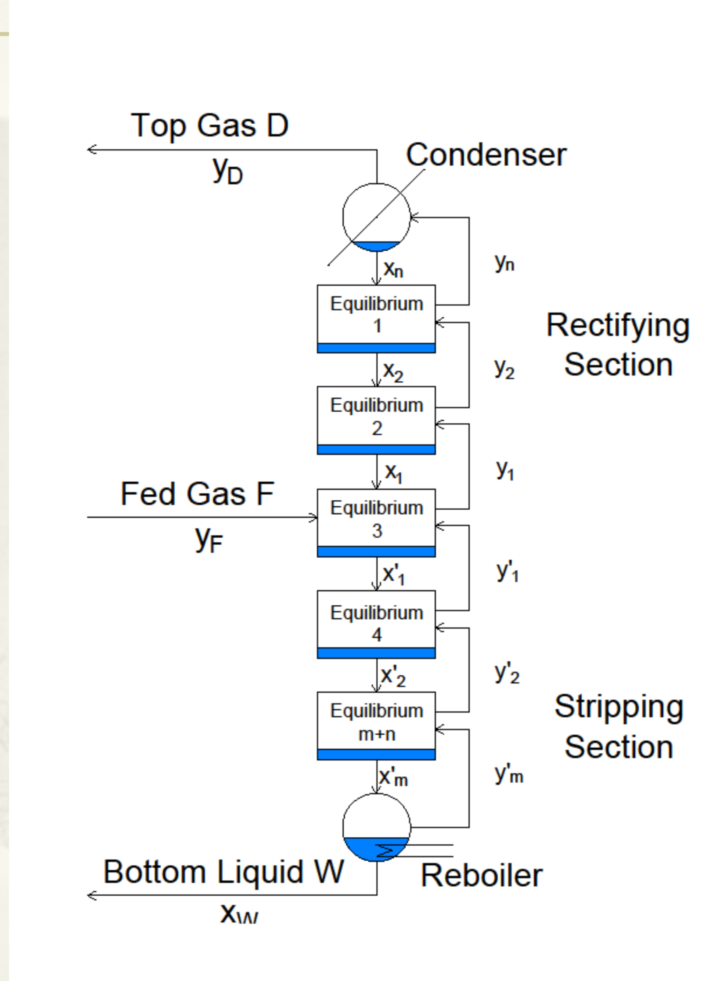
4.2 Kr/Rn removal by distillation



$$T = 178K:$$

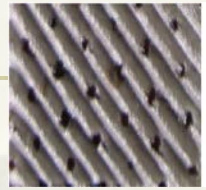
$$\alpha_{Kr} = \frac{P_{Kr}}{P_{Xe}} = 10.4$$

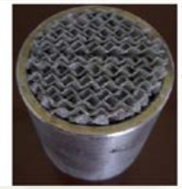
$$\alpha_{Rn} = \frac{P_{Xe}}{P_{Rn}} = 13.8$$



- Krypton more volatile than xenon
- Xenon more volatile than radon
- Kr and Rn have very low concentration
- T=178K as the operation temperature

4.3 M-T diagram for Kr removal

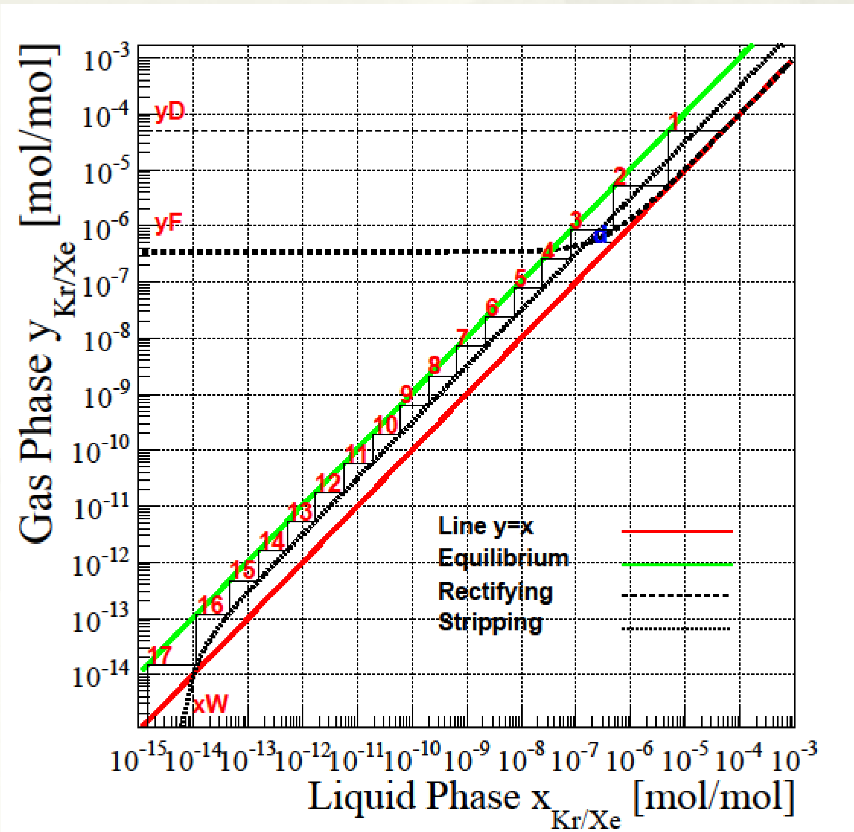




$$y_{vol.} = \frac{\alpha \cdot x_{vol.}}{1+(\alpha-1)\cdot x_{vol.}}$$

$$\xrightarrow{x<<1} y_{vol.} = \alpha \cdot x_{vol.}$$

Reduction factor has no related to the inlet concentration

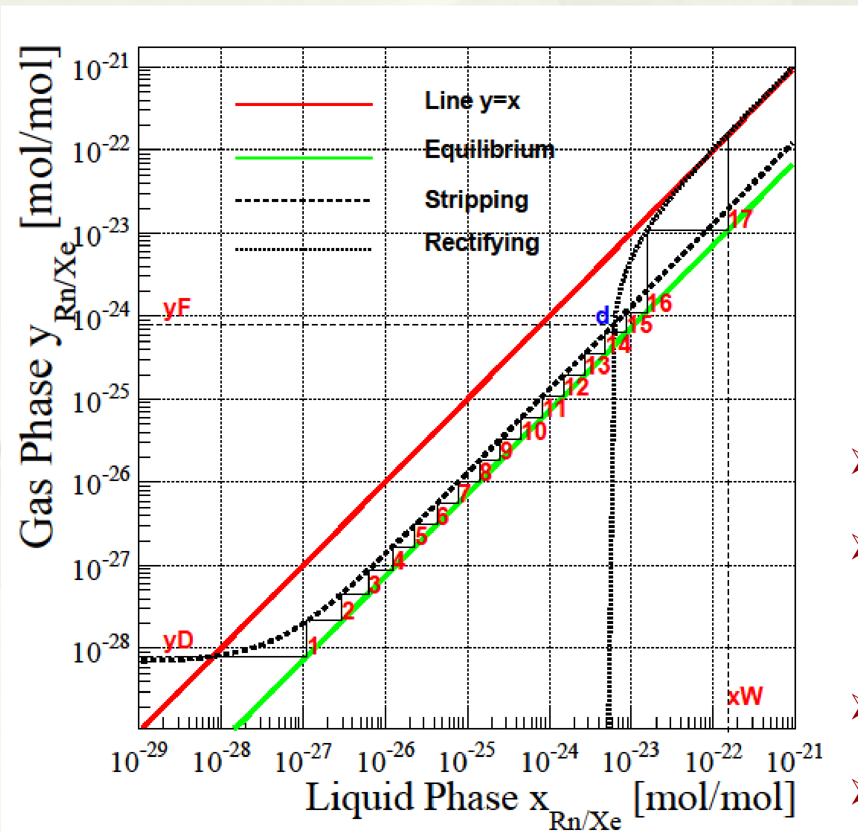


- HETP=35cm as the same packing used in the Phase-I column.
- **Theoretical plates number is 17 based on the height limitation of the CJPL-II .**
- 10kg/h processing mass flow.
- **0.01ppt production concentration with 0.5ppm inlet xenon.**
- 99% collection efficiency.
- Reflux ratio is 145 which the R_{min}=109.

4.4 Radon removal efficiency

Using PandaX-II radon concentration (7.73uBq/kg) as the inlet condition:

$$X_{Rn} = \frac{7.73\mu Bq/kg}{\left(1-e^{-\lambda}\right)\cdot N_A}\cdot\frac{1kg}{M_{Xe}} = 8.03\times10^{-25}\,mol/mol$$



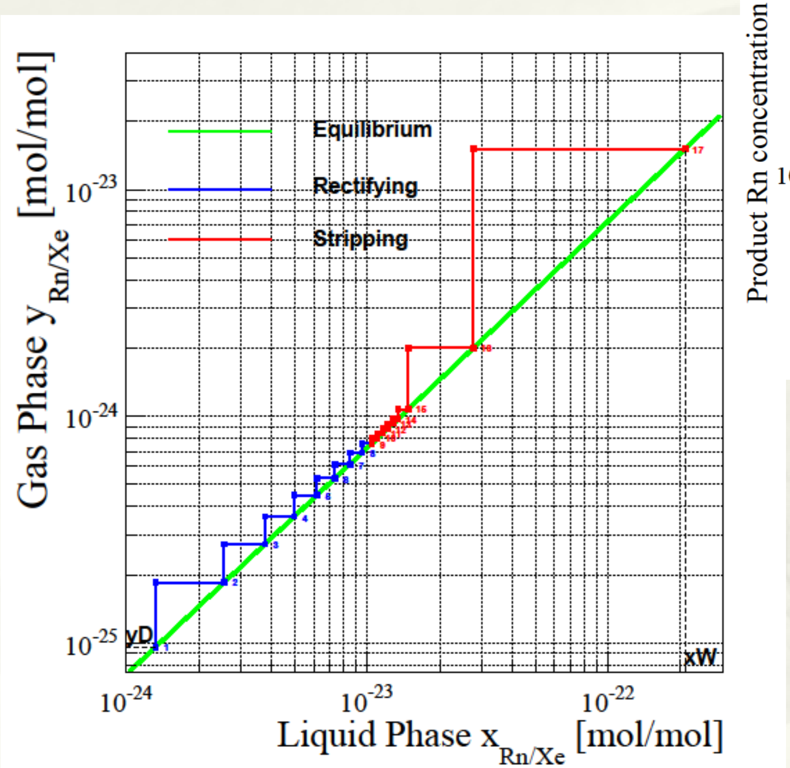
$$Equibrilium: y_{Rn} = \frac{x_{Rn}}{\alpha}$$

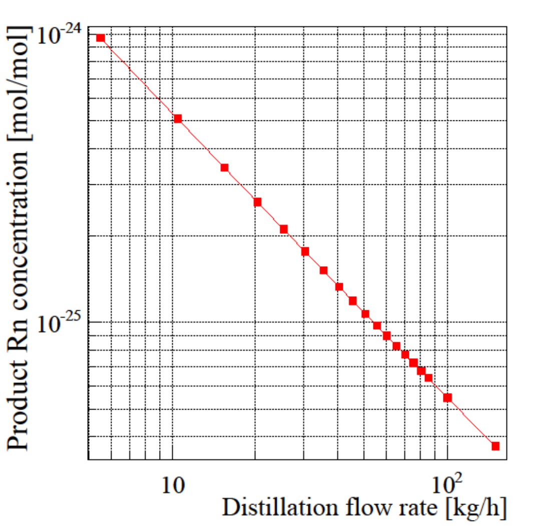
$$Rectifying: y_{n+1}^{Rn} = \frac{R}{R+1}x_n^{Rn} + \frac{x_D^{Rn}}{R+1}$$

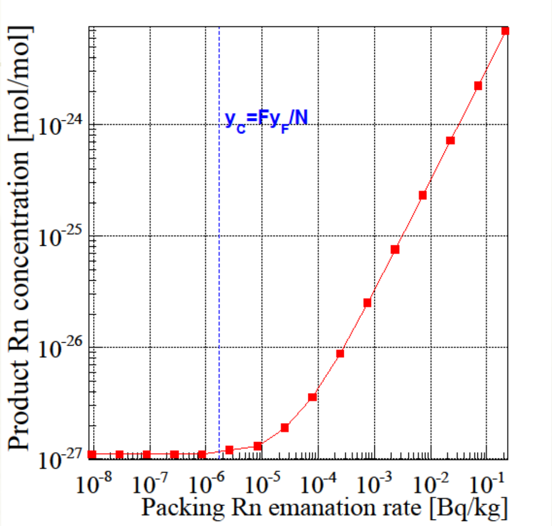
$$Stripping: y_{m+1}^{Rn} = \frac{R'}{R'-1}x_m^{Rn} - \frac{x_W^{Rn}}{R'-1}$$

- Same HETP as krypton removal.
- Reflux ratio R=0.15 which the R_{min}=0.077.
- **The reduction factor ~10^4.**
- Mass flow rate is 56.5kg/h as consider of the D=125mm.

4.5 Reduction factor with packing

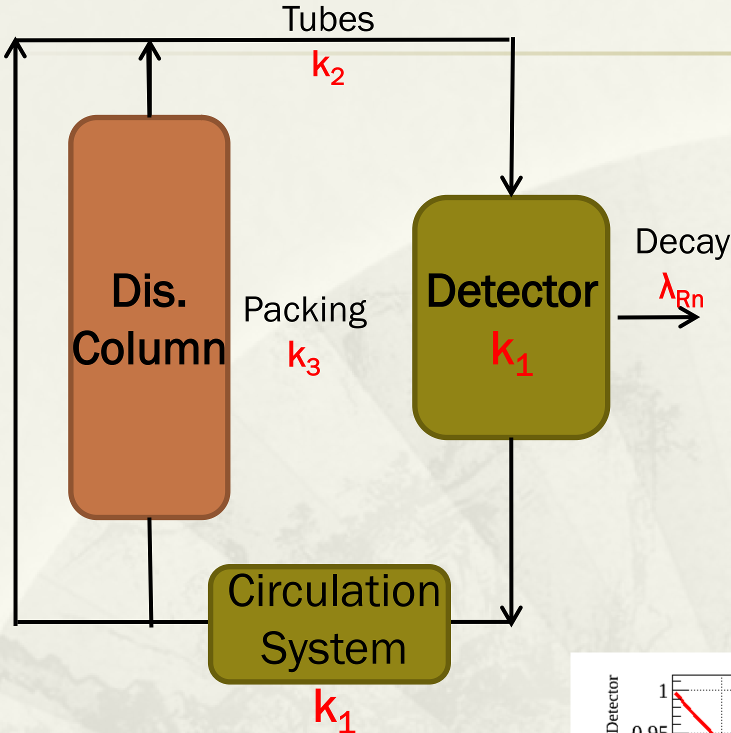






- Reflux ratio R=0.15 just the same.
- The reduction factor Re~8.37 when the inlet plate is 8.
- **Reduction factor is related to the processing flow rate and the radon emanation rate from the packing.**

4.6 Detector radon concentration



Without the distillation circle: $N_{without} = \frac{k_1 + k_2}{\lambda_{Rn}}$;

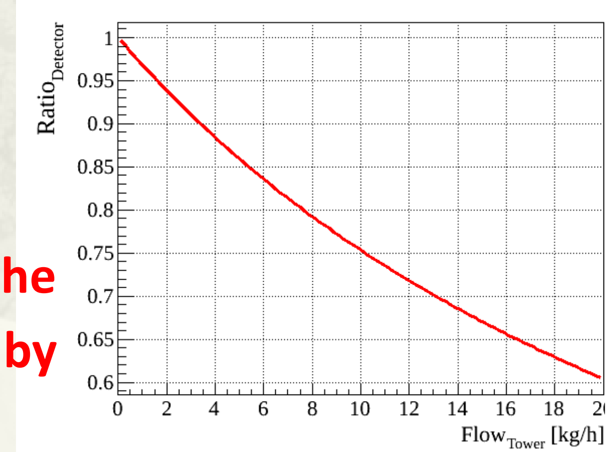
With the distillation circle: $N_{with} \xrightarrow{t\to\infty} \frac{k_1 + \frac{k_2}{\mathrm{Re}_{Rn}}}{\lambda_{Rn} + f \cdot \left(1 - \frac{1}{\mathrm{Re}_{Rn}}\right)}$.

Radon reduction factor in the detector :

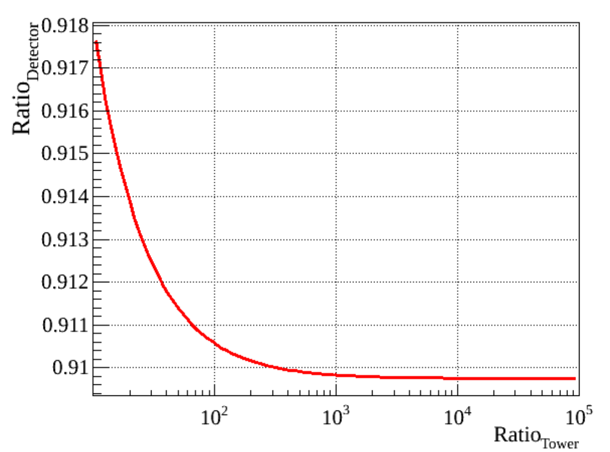
$$\mathrm{Re}_{detector} \xrightarrow{k_2 \ll k_1} \frac{\lambda_{Rn}}{\lambda_{Rn} + f \cdot \left(1 - \frac{1}{\mathrm{Re}_{Rn}}\right)}$$

- k_2 source are much less than k_1;
- **The reduction factor in the detector are dominated by the distillation flow *f*.**

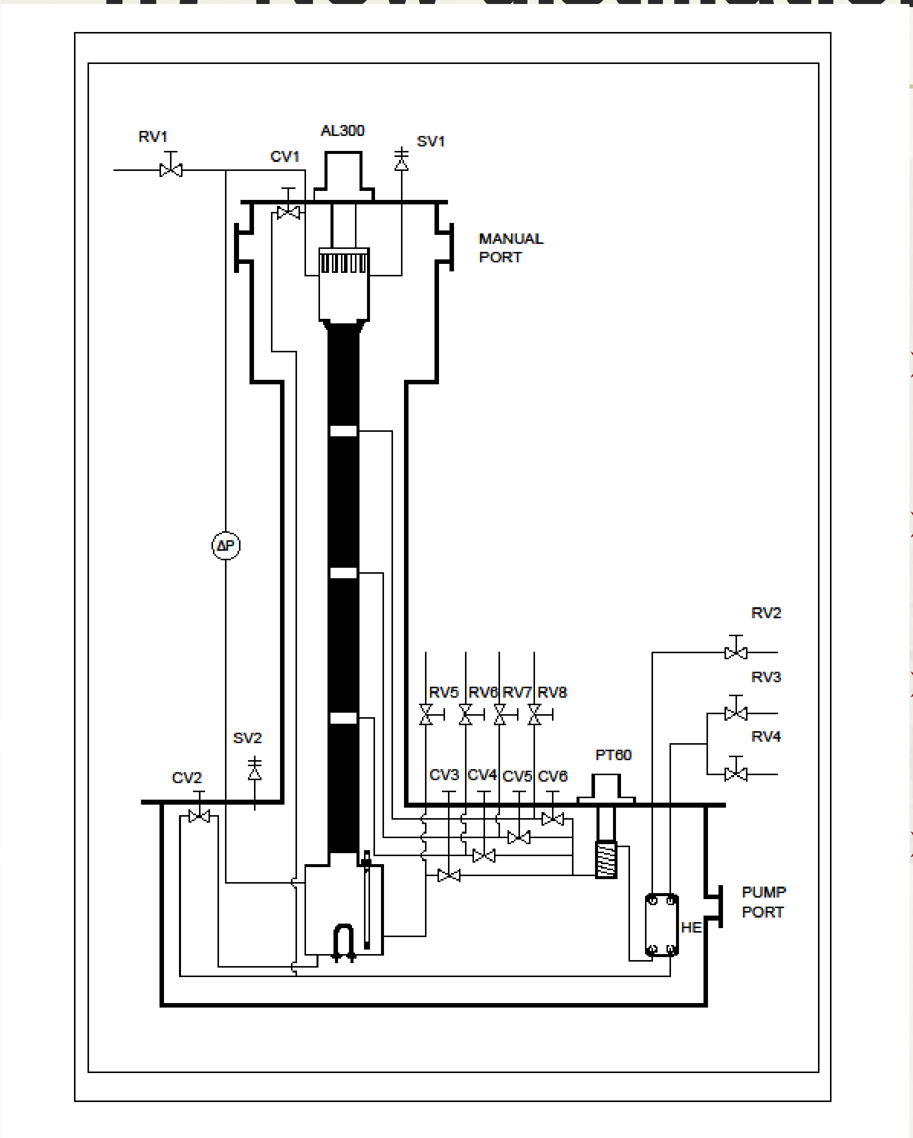
Flow rate



Reduction factor



4.7 New distillation column



$$Reboiler: Q_{Kr} = 118W; Q_{Rn} = 201W;$$
$$Condenser: Q_{Kr} = 373W; Q_{Rn} = 216W;$$
$$\Delta P \sim 4kPa;$$

- Cryomech AL300 as the condenser cryocooler;
- Cryomech PT60 and one PHE for the inlet pre-cooling;
- Same PHE as the heater exchanger for the Krypton and Radon removal;
- Three different inlet port for Kr/Rn removal and some study;

Summary

1)Cooling bus with Multi-coldhead, it can work well. Total cooling power: ~600W

A)The load distribution is roughly stable regardless of history.

B)The load distribution can be adjusted by tuning the temperature of two heads at slightly different Ts.

C)Pressure was determined by the lowest cold temp of all heads.

2) Calculation, design and drawing of distillation tower finished. It is on processing.

Thanks a lot