20th Workshop on Recoil Separator for Superheavy Element Chemistry & Physics
(TASCA 23)

Preparation of the Nihonium Chemistry at IMP

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April 27, 2023

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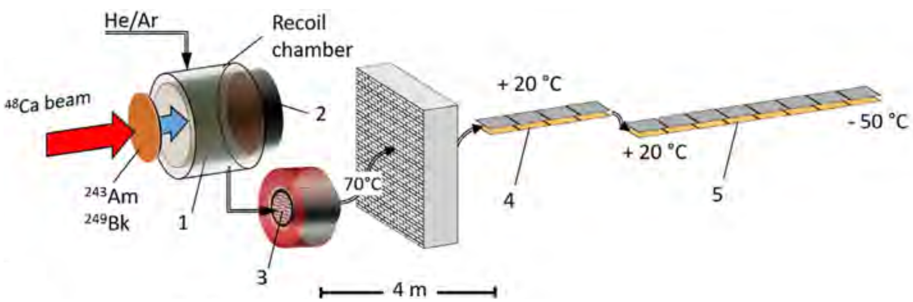
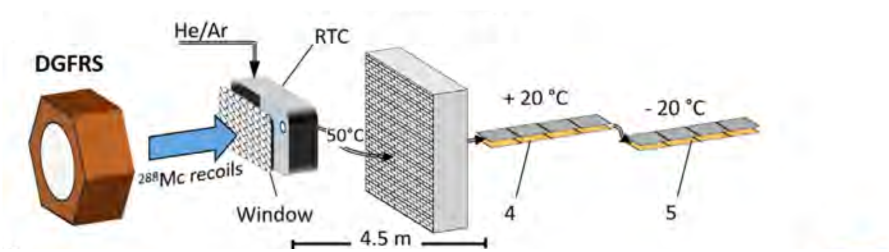
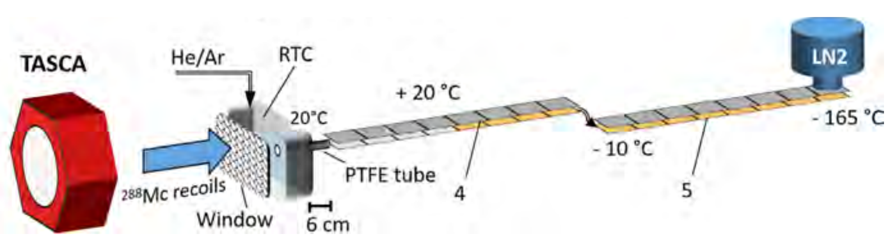
Institute of Modern Physics, Chinese Academy of sciences

Background

History of Nh adsorption studies (I)：Dubna & GSI, 2014~2017







① **Dubna (*Mendeleev Commun. 24, 2014*)**

- **^{48}Ca+^{243}Am, U-400+RTC, 13.5 days**
- **5 events**
- **Confirmed the synthesis of E115 and E113 by ^{48}Ca+^{243}Am reaction**
- **No physical pre-separation; Formation of NhOH could not be excluded**
- **-ΔH > 60 kJ/mol**

② **Dubna (*Eur. Phys. J. A. 53, 2017*)**

- **^{48}Ca+^{243}Am, U-400 + DGFRS + RTC，4.5m capillary**
- **0 events**
- ***too long transfer PTFE capillary (4.5m) for Nh; the retention of elemental Nh on a Teflon surface is larger than expected***
- **-ΔH > 45 kJ/mol**

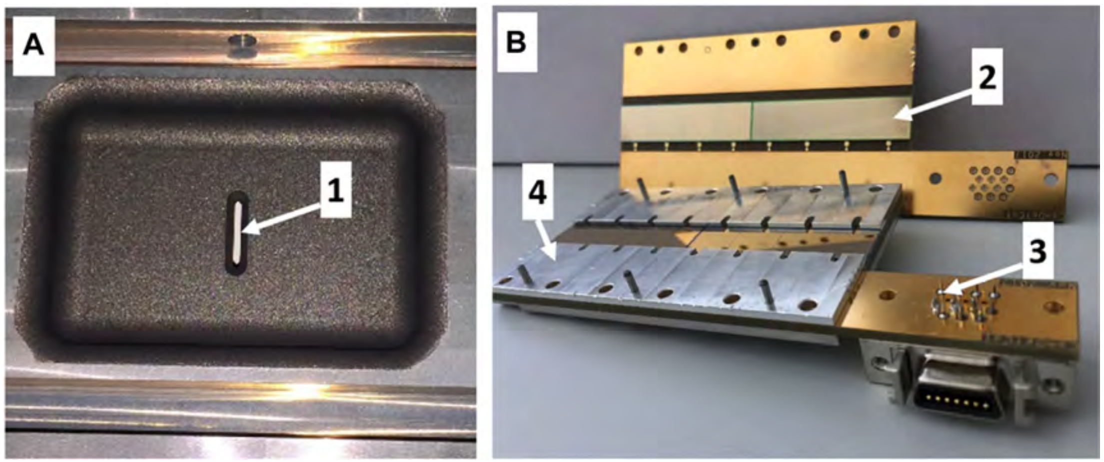
③ **GSI (*Frontiers in Chemistry, 9, 2016*)**

- **^{48}Ca+^{243}Am, TASCA + RTC, 20 days，6cm capillary**
- **0 events**
- **-ΔH > 50 kJ/mol**

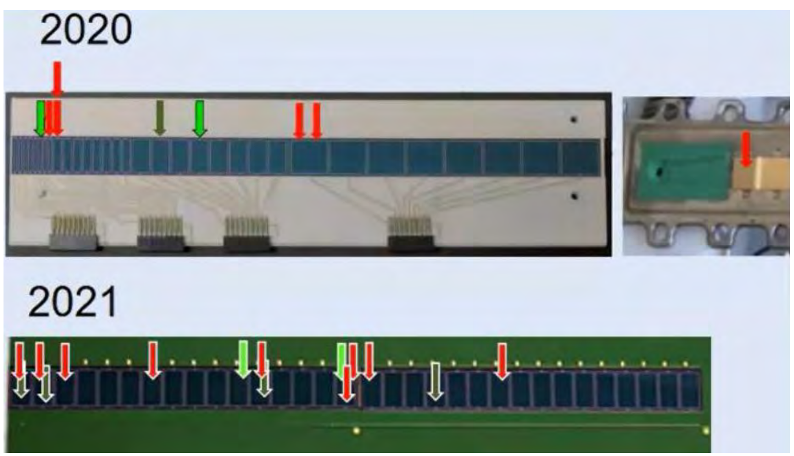
Yakushev, A. et al; First Study on Nihonium (Nh, Element 113) Chemistry at TASCA. Front. Chem. ***2021****, 9, 753738*

Background

History of Nh adsorption studies (II)： RTC-miniCOMPACT, GSI, 2020~2021



RTC-miniCOMPACT @ GSI

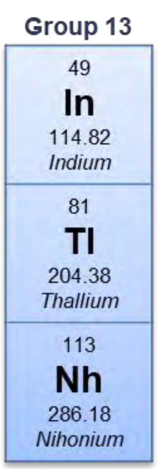


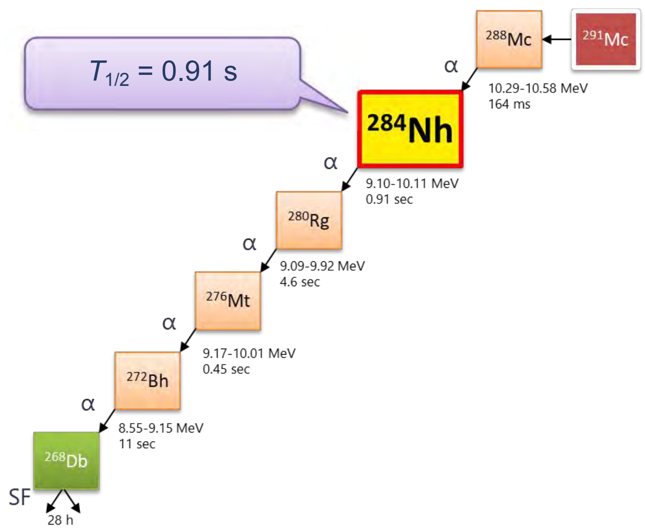
^{284}Nh ^{288}Mc SF(^{284}Nh	<u>2012</u>: Decay spectroscopy at ***TASCA*** **22** long decay chains in **3** weeks <u>2020/2021</u>: Chemistry at ***TASCA*** **18** long decay chains in **6** weeks ***40%***

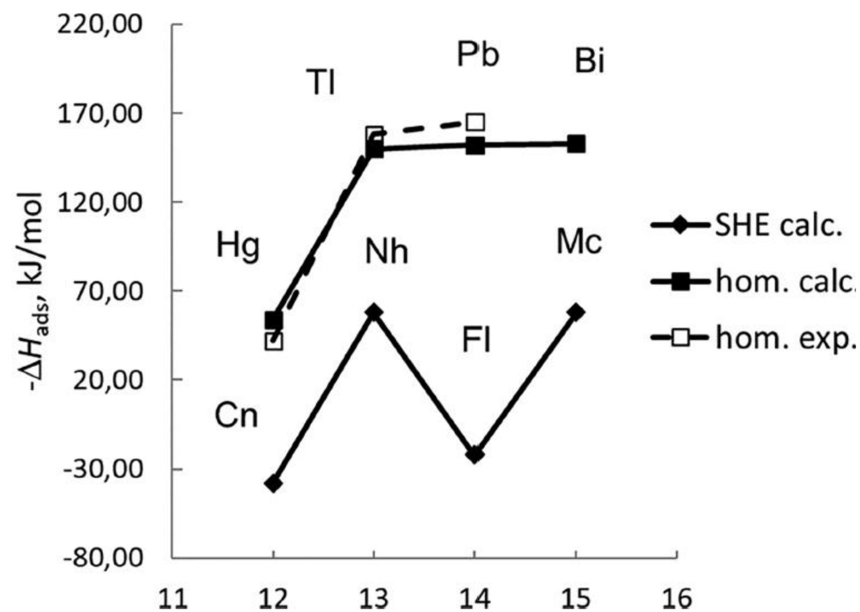
Yakushev, A. et al; First Study on Nihonium (Nh, Element 113) Chemistry at TASCA. Front. Chem. ***2021****, 9, 753738.*

Motivation: Preparation for Nh adsorption experiments

1. Development of the on-Line Experiment in Gas-phasE for Nihonium Detector array (LEGEND) system
2. Evaluation of the transport efficiency for RTC+LEGEND system
3. Preparations for online experiment on short-lived Tl and Fr







Theoretical predictions of $-\Delta H_{ads}$(kJ/mol) on a hydroxylated quartz surface

(V. Pershina, M. Iliaš, and A. Yakushev, *Inorg.Chem.*)

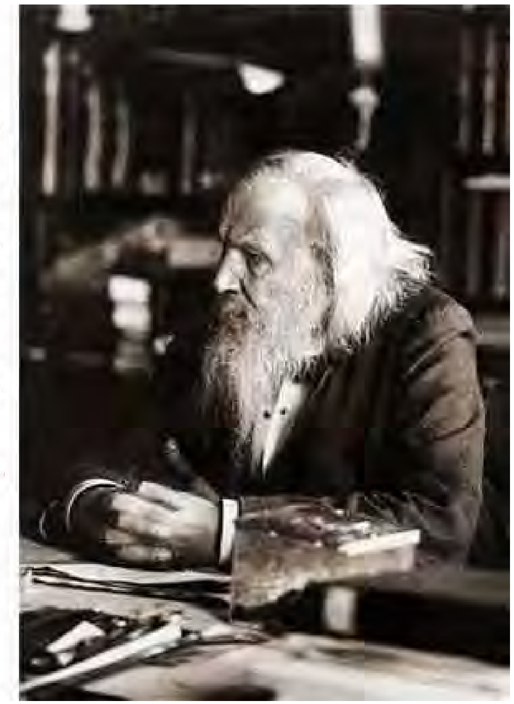
Preparations for Nh adsorption chemistry

Nh compared with Tl and Fr:

- Physical and atomic properties
- Valence shell electron configuration
- Chemical reactivity

Why we choose Fr?

- High chemical reactivity
- Low transport efficiency
- Non-volatile; lower limit for Nh
- Suitable for on-line experiment:
  - ü Produced by $^{40}Ar+^{169}Tm$ reaction
  - ü Short-lived, $T_{1/2}$ around 1 s
  - ü α-α correlation



Atomic properties of Tl, Fr and Nh

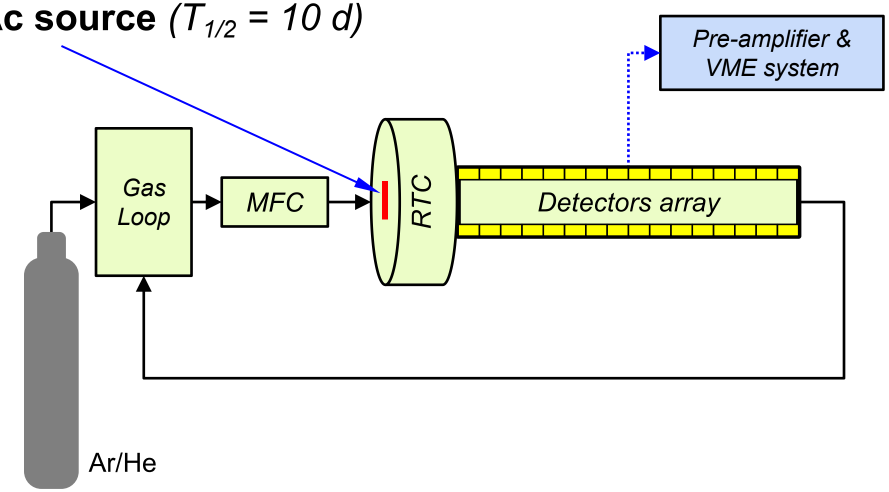
	m.p.(K)	b.p.(K)	R_{vdw}(Å)	AR(Å)	IP(eV)	EA(eV)	α(au)	Valence Electron Configuration	$-\Delta H_{ads}$(kJ/mol)		
									Quartz	Teflon	Au
Tl	577	1746	1.96	1.90	6.11	0.38	51	$6p^1$	153~172	20	~250
Fr	300	950	3.09	n/a	4.07	0.49	311.5	$7s^1$	unknown	21; 72(?)	136
Nh	700	1430	1.84	1.22	7.31	0.68	29.9	$7p^1$	~60	14	120~180

Offline experiments on francium isotopes

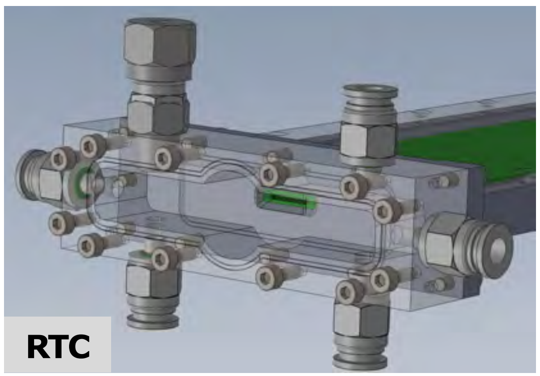
Experimental setup

Calibration: ^{227}Ac source *($T_{1/2}$ = 21.772 y)*

^{221}Fr generator: ^{225}Ac source *($T_{1/2}$ = 10 d)*

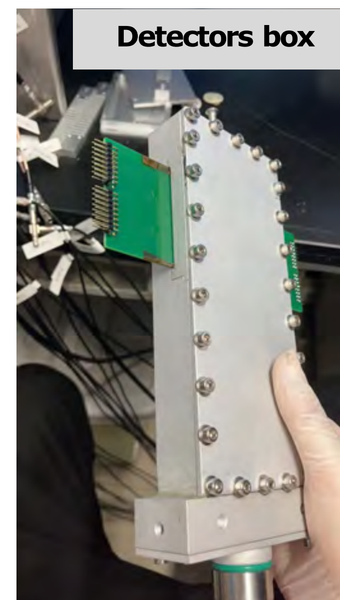


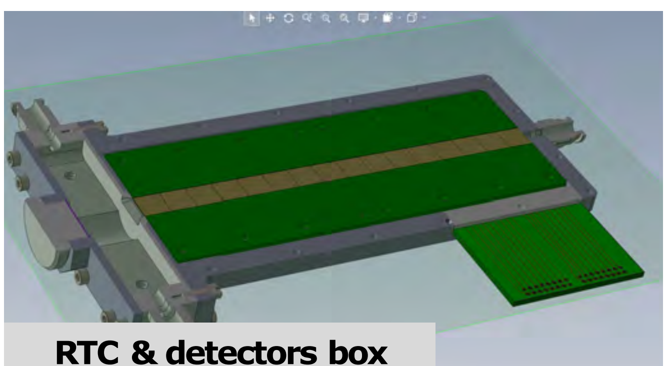
VME digitizer system



RTC

Detectors box





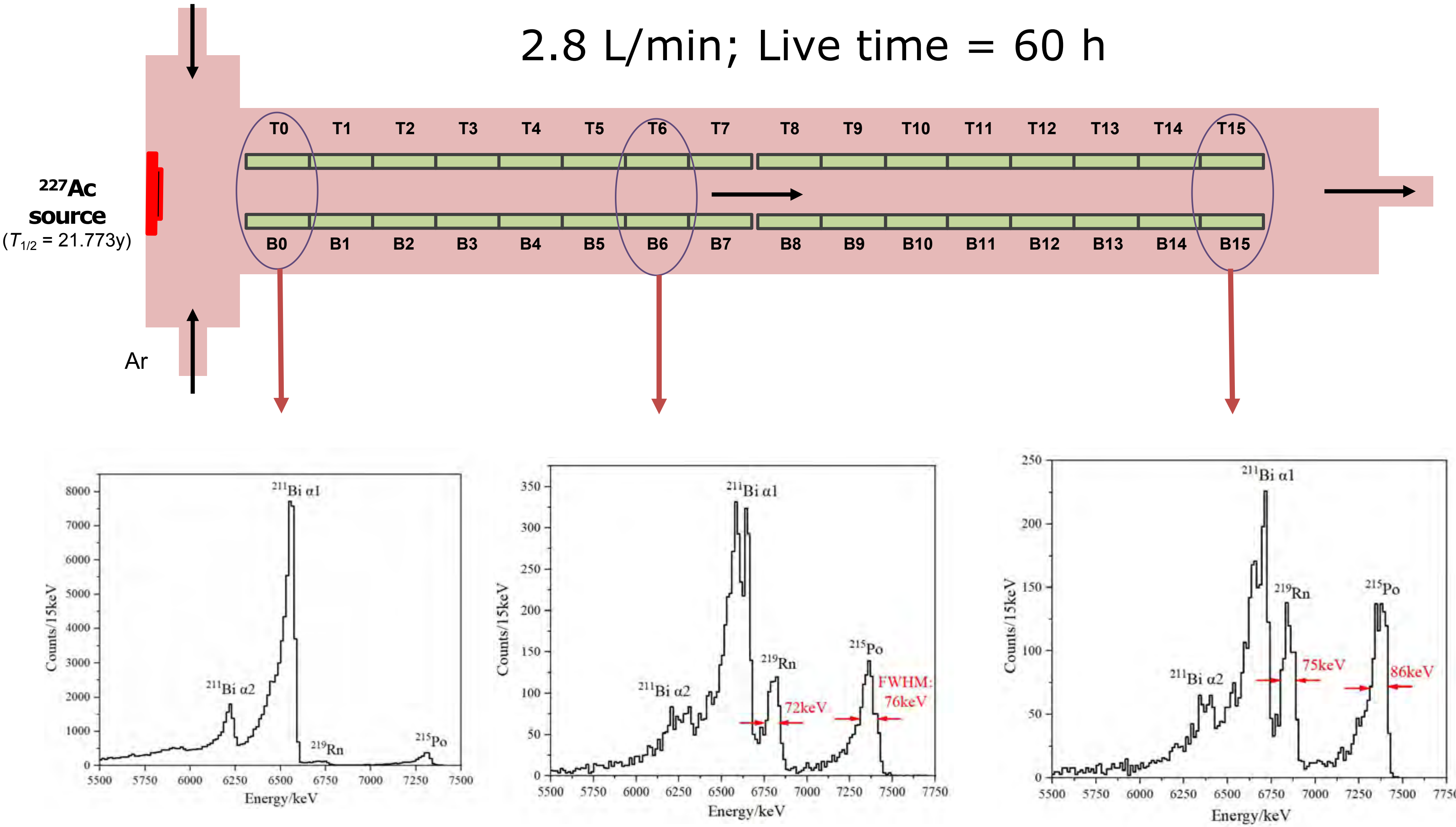
RTC & detectors box

16-pair detectors array

Offline experiments on francium isotopes

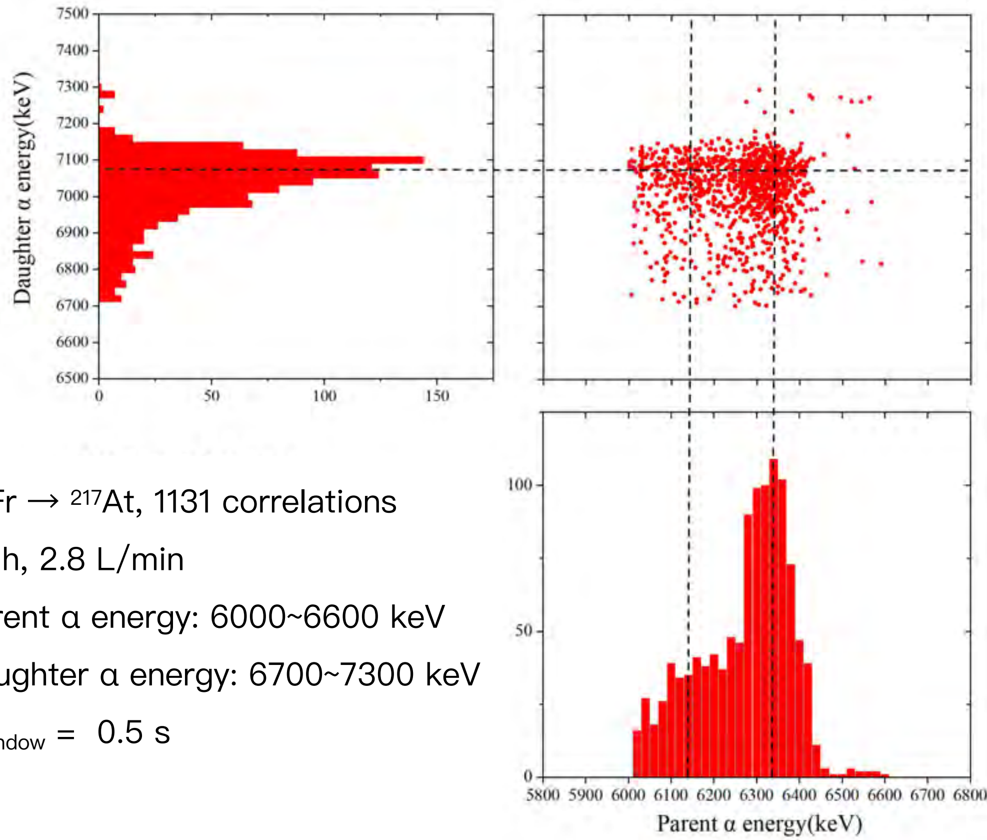
α spectra for calibration by ^{227}Ac

2.8 L/min; Live time = 60 h



Offline experiments on francium isotopes

α–α correlations of $^{221}Fr \longrightarrow {}^{217}At$



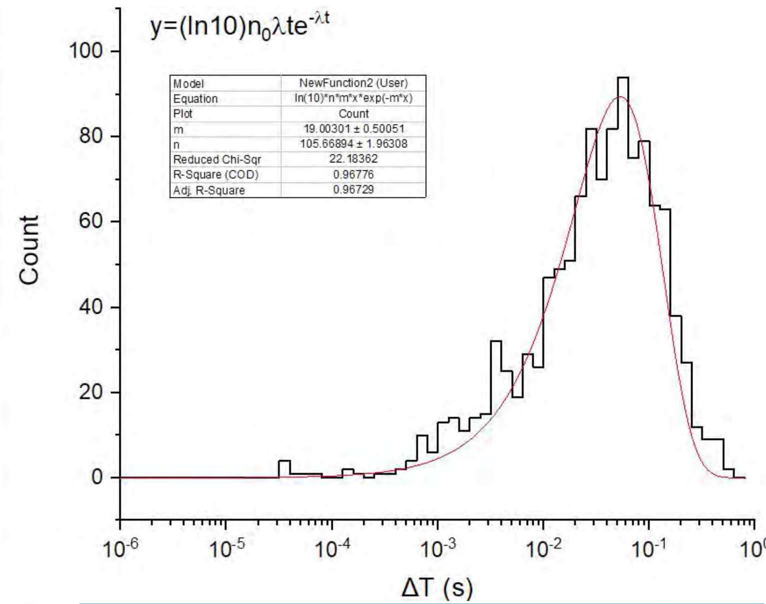
$^{221}Fr \longrightarrow {}^{217}At$, 1131 correlations

45 h, 2.8 L/min

Parent α energy: 6000~6600 keV

Daughter α energy: 6700~7300 keV

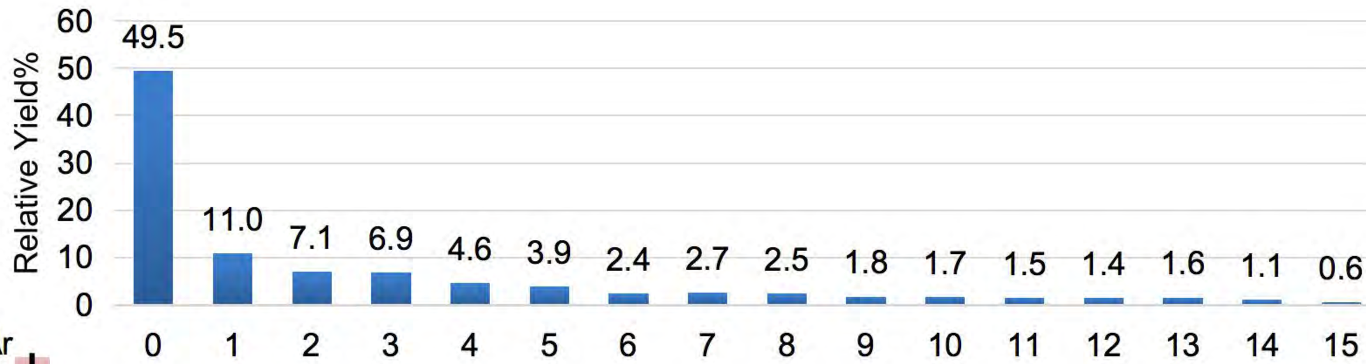
T_{window} = 0.5 s



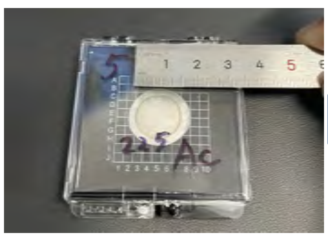
	^{217}At $T_{1/2}$ (ms)
Non–linear curve fitting	36.5 ± 1.4
maximum likelihood	34.0 ± 1.0
Ref. data	32.3 (4)

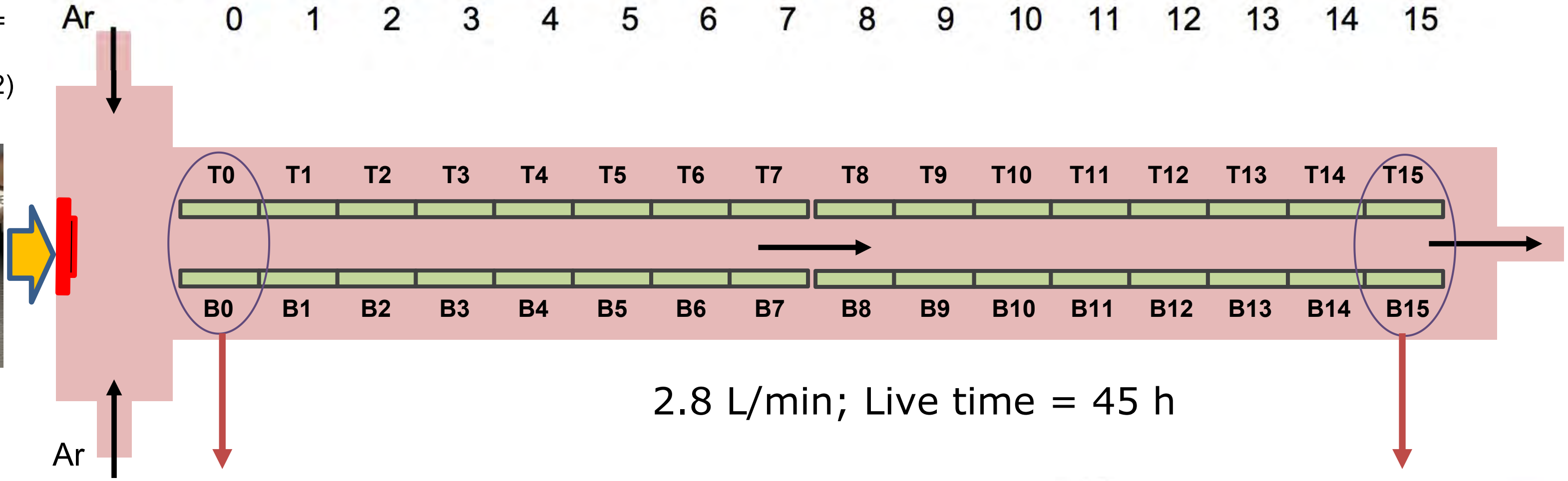
Offline experiments on francium isotopes

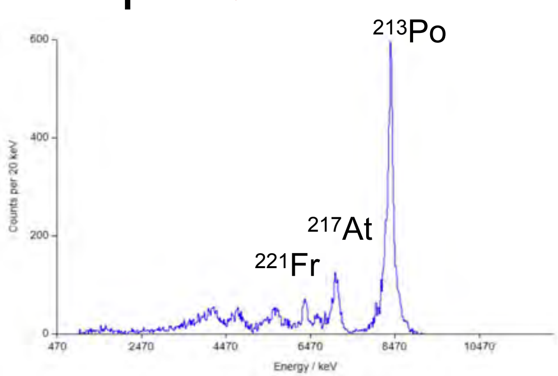
Distribution of ^{221}Fr on Aluminum surface

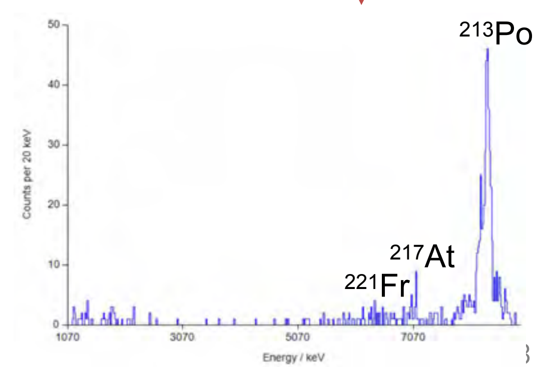


^{225}Ac source ($T_{1/2}$ = 10d)
A_0=21 Bq (Sept. 8, 2022)



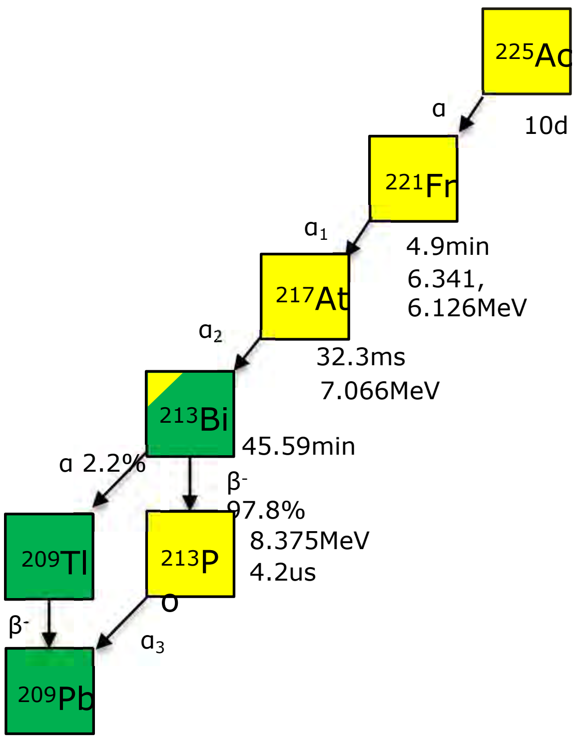


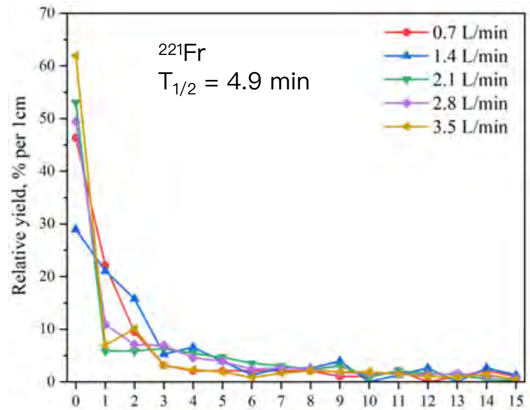


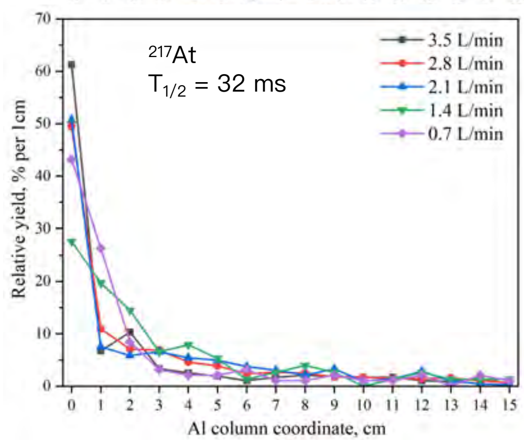


Offline experiments on francium isotopes

^{221}Fr efficiency on Aluminum: distribution

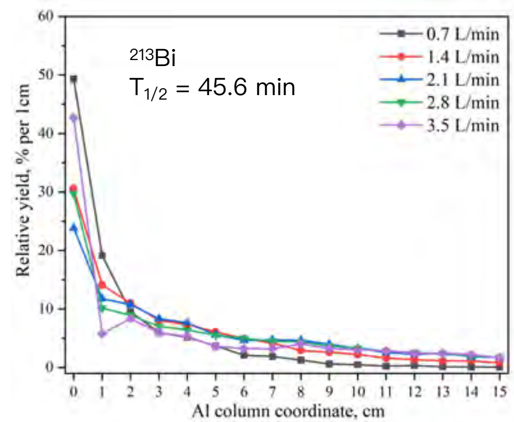






Species	$-\Delta H_{ads}$ (kJ/mol) on SiO_2	ΔH_{subl} (kJ/mol)
^{221}Fr (4.9min)	unknown	unknown
^{217}At (32ms)	130	170
^{213}Bi (46min)	150	210
^{213}Po (4.2us)	100	150

Serov, A., et al. *Radiochimica Acta* 99, no. 9 (2011): 593-600.



For Fr isotopes:

- Exponentially decreasing deposition: high reactive, strong interaction and non-volatile for ^{221}Fr species
- Higher gas flow rate: leads to large migration and wider distribution
- ^{217}At represent the chemical behavior of ^{221}Fr

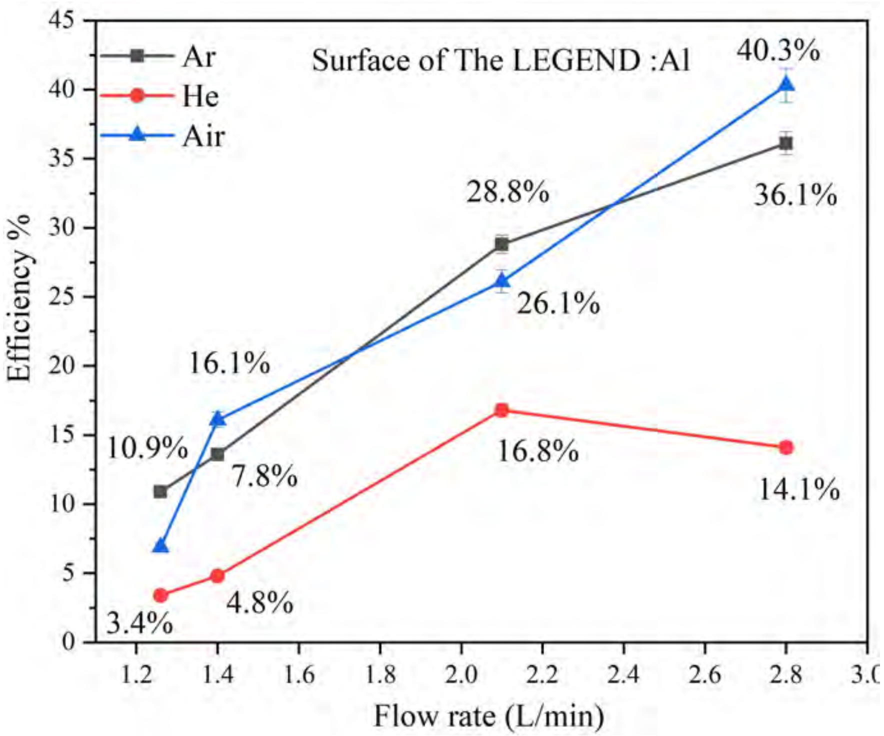
For Bi isotopes:

- ^{213}Bi/^{213}Po mainly adsorbed on T0+B0 and T1+B1
- ^{213}Po represents the chemical behavior of ^{213}Bi
- **Al detector array directly connected to RTC is available for non-volatile Fr and Bi**

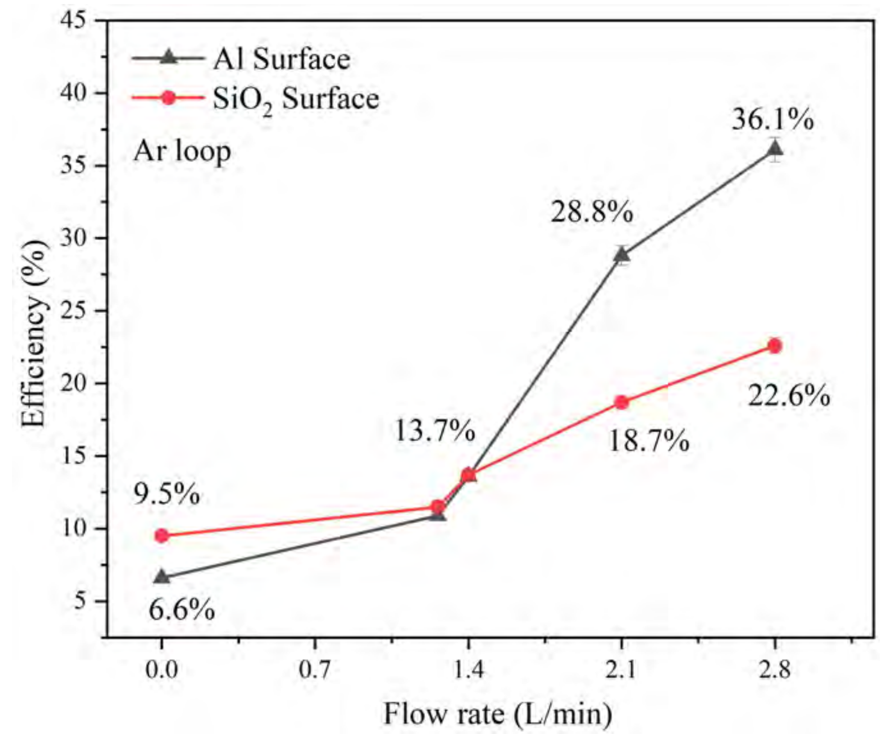
Offline experiments on francium isotopes

^{221}Fr efficiency at different gas flow rate

With different carrier gas on Aluminum surface



With Argon on different surface

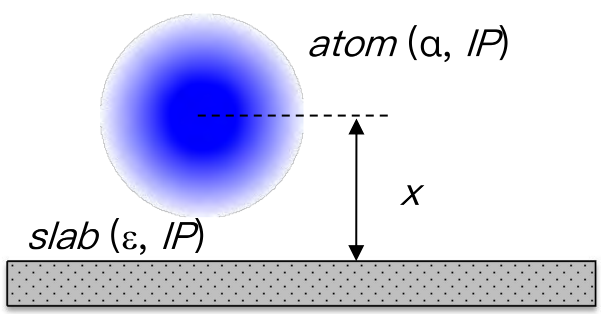


Estimation of ΔH_{ads}

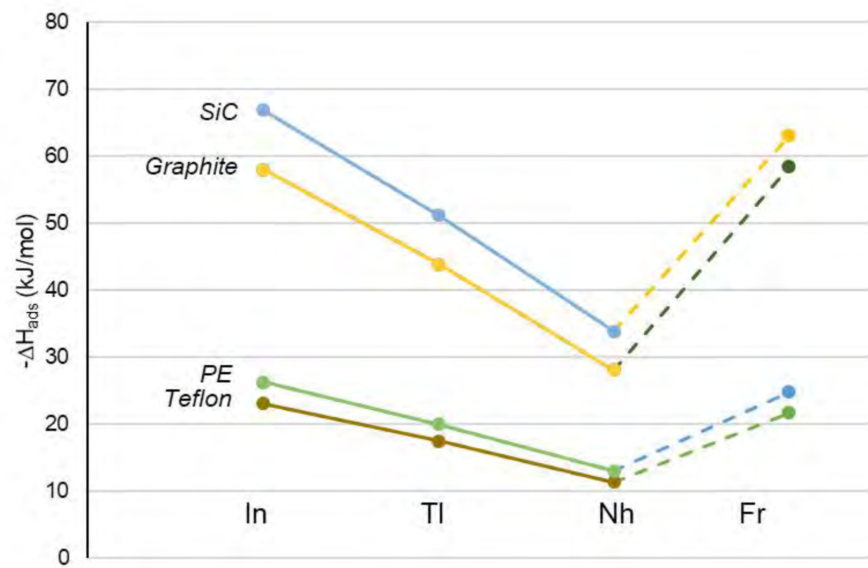
Estimated ΔH_{ads} for In, Tl, Nh, Fr on Teflon, PE, graphite and SiC

The dispersion interaction energy derived from a model of an atom–slab interaction:

$$E(x) = -\frac{3}{16}\left(\frac{\varepsilon-1}{\varepsilon+2}\right)\frac{\alpha_{atom}}{\left(\frac{1}{IP_{slab}}+\frac{1}{IP_{atom}}\right)x^3}$$



V. Pershina et al., J. Phys. Chem. A 2008, 112, 13712



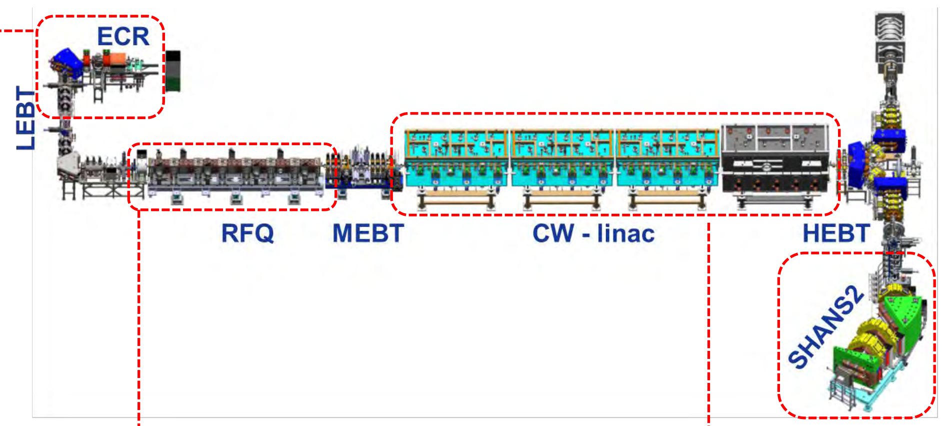
- Order of $-\Delta H_{ads}$ value: In ≈ Fr > Tl > Nh
- $-\Delta H_{ads}$ values on materials: SiC > Graphite > PE ≈ Teflon

Preparations for Nh chemistry

China Accelerator Facility for Superheavy Elements (CAFE2)

(started in May 2019 – commissioned in Feb. 2022)

Electron cyclotron resonance ion source (ECR)



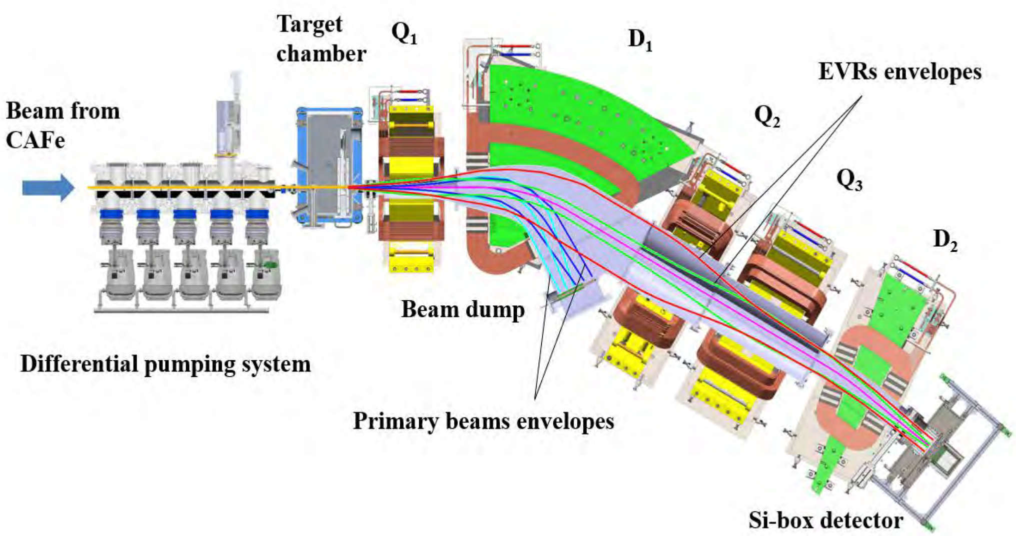
Designed parameters	Goal
Ions	Ca ~ Zn
A/Q	3
Beam energy	4.5-7 MeV/u
Beam current	5-10 pμA
Running mode	CW

Radio frequency quadrupole (RFQ)

Super-conducting linear accelerator (CW - linac)

Preparations for Nh chemistry

New gas–filled separator: **SHANS2**



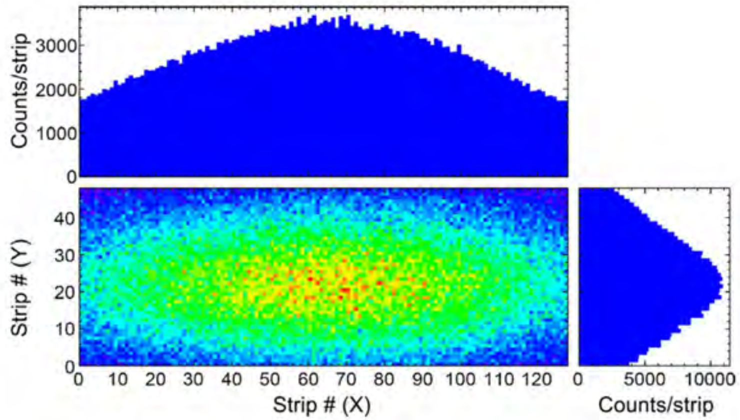
Gas-filled recoil separator (SHANS2):

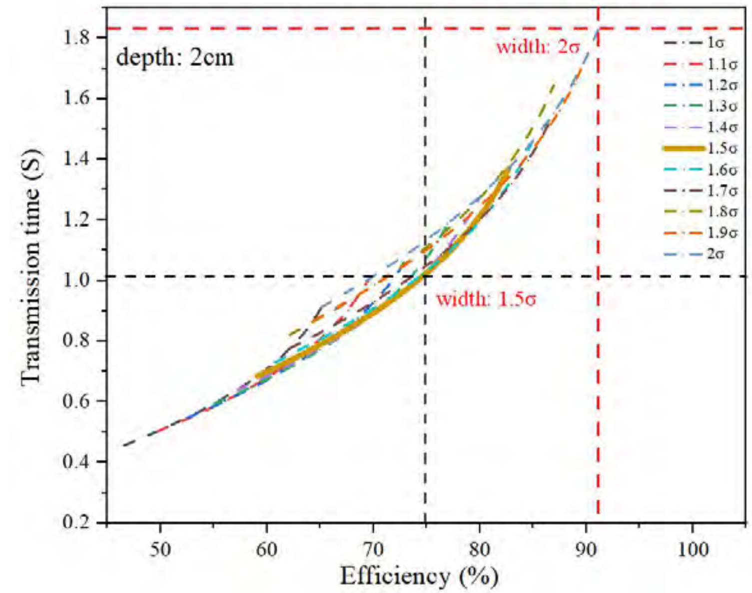
Location	IMP Lanzhou China
Configuration	$Q_vDQ_hQ_vD$
Deflection angle	$(30+10)^{\circ}$
Max. B×ρ (Tm)	2.56
Length (m)	5.97
Dispersion (mm/%B×ρ)	20.9
Solid angle (msr)	25

L. N. Sheng, *et al.*, NIM A1004, 165348 (2021).

Preparations for Nh chemistry

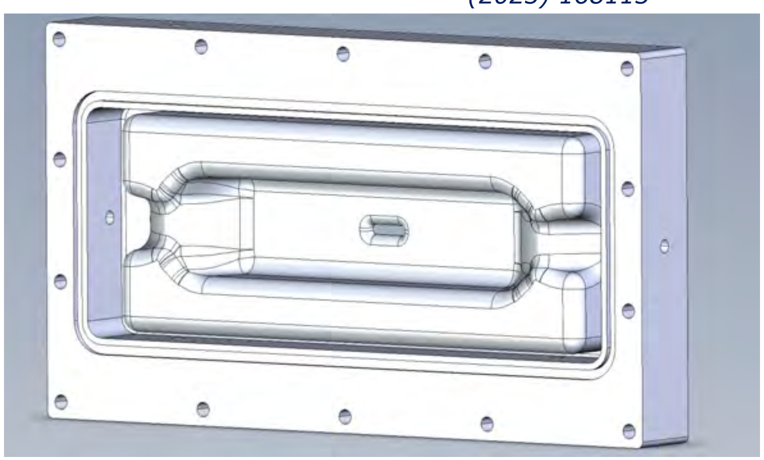
The design of RTC





The standard deviations in the horizontal (σ_x) and vertical (σ_y) directions are 50.7 mm and 15.0 mm respectively.

Nuclear Inst. and Methods in Physics Research, A 1050 (2023) 168113



The structure of IMP RTC

- RTC 1 ($2\sigma \times 2\sigma$ = 95.4% × 95.4% = 91.0%)
  X = 101.4 mm   Y = 30 mm   D = 20 mm
  V = 60.84 mL
  Time = 1.8 s Flow rate = 2 L/min (Ar)

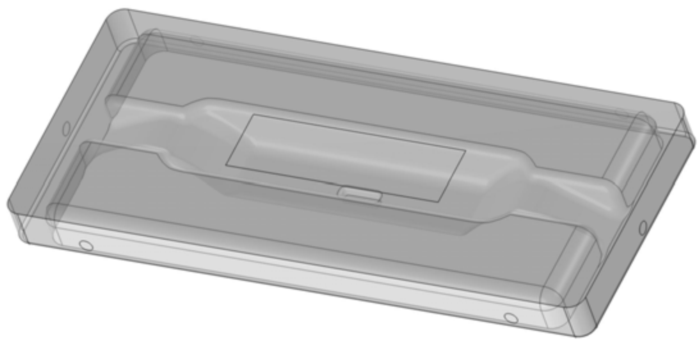
- RTC 2 ($1.5\sigma \times 1.5\sigma$ = 86.6% × 86.6% = 75.0%)
  X = 76 mm   Y = 22.5 mm   D = 20 mm
  V = 34.2 mL
  Time = 1.0 s Flow rate = 2 L/min (Ar)

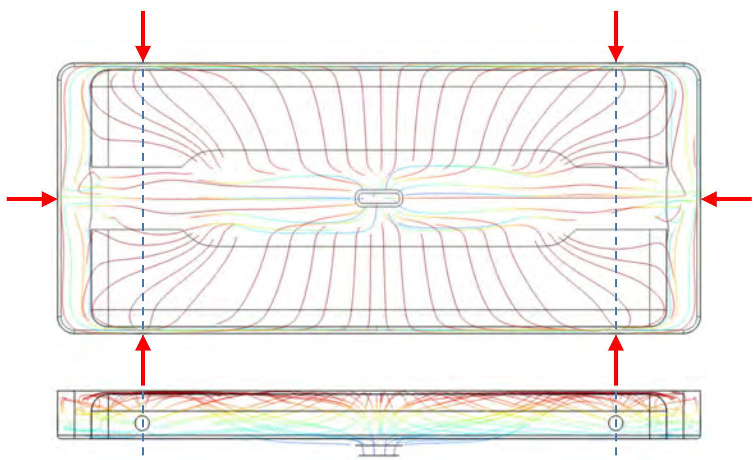
Preparations for Nh chemistry

PAUL SCHERRER INSTITUT PSI

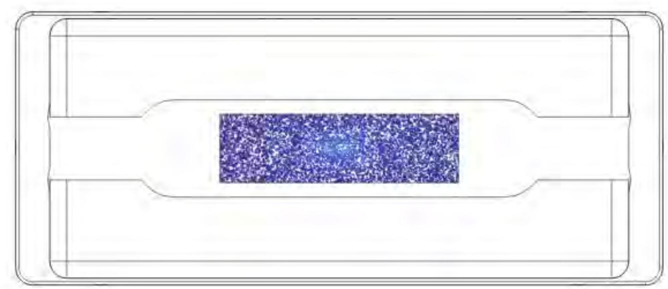
COMSOL simulations by Patrick Steinegger, PSI

Flushing-out behavior of RTC





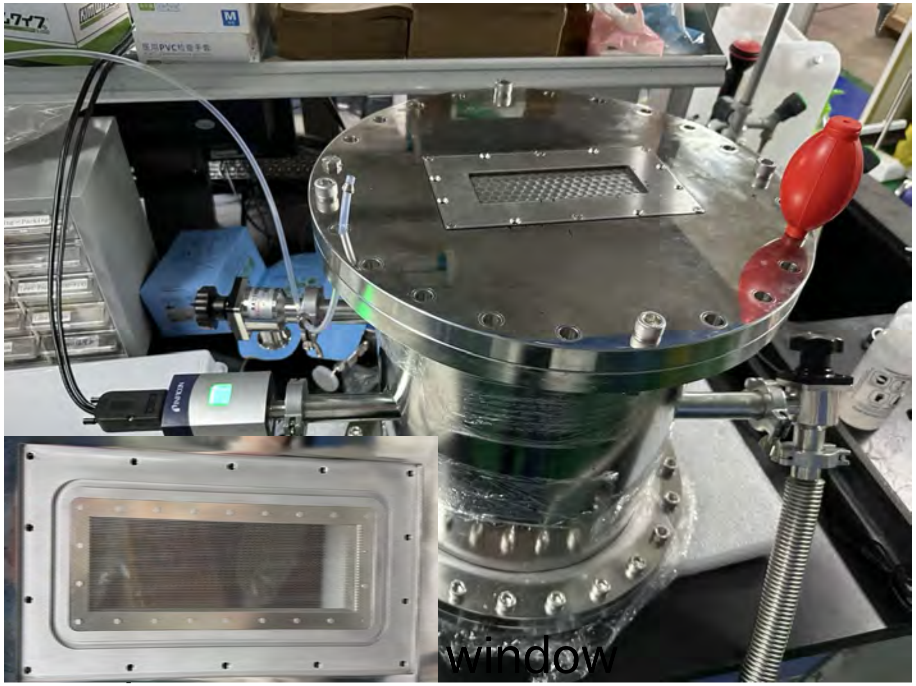
13 mm from window



1 mm from window

- Good flushing-out behavior
- Gas flow through all six inlets should be the same! → Individual mass flow controllers will be used

Preparations for Nh chemistry



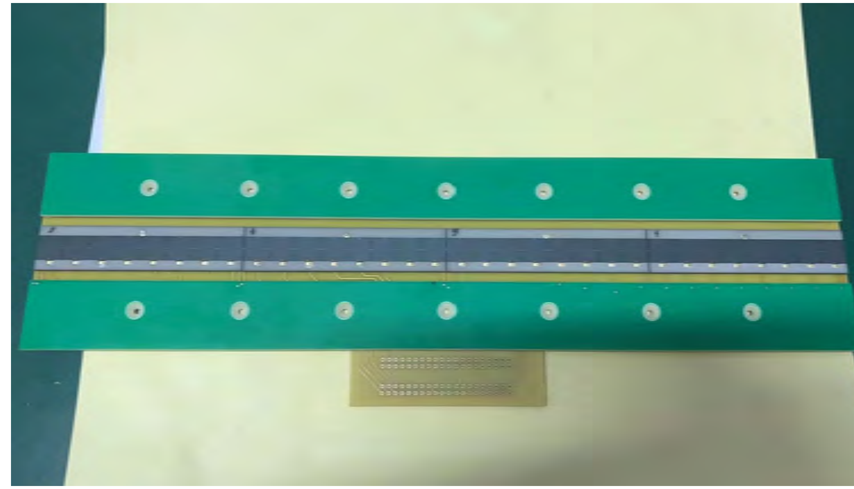
Adapter with vacuum window (15 × 5 mm²)

Honeycomb mesh: 2 mm + 0.1 mm thick SUS

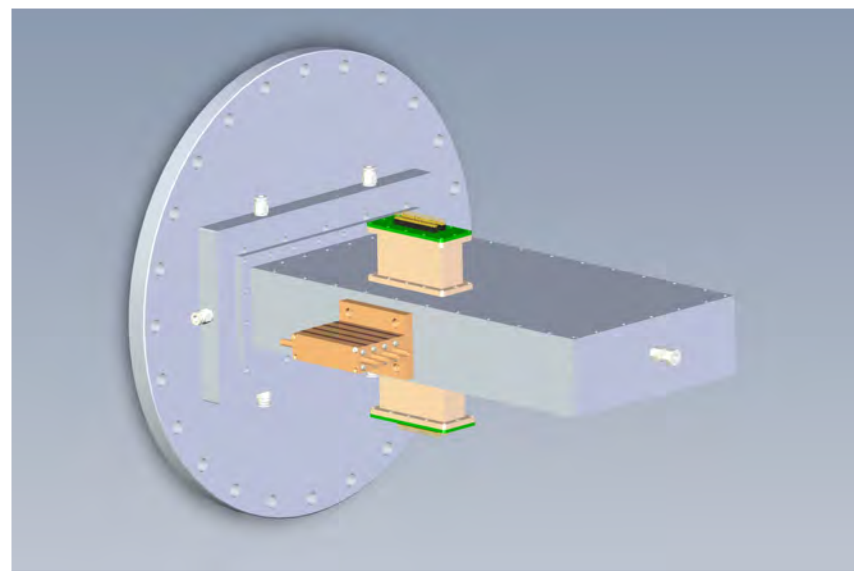
10 mm

88.7% (>2.5 μm)

74.1% (<2.5 μm)



Si detectors for LEGEND

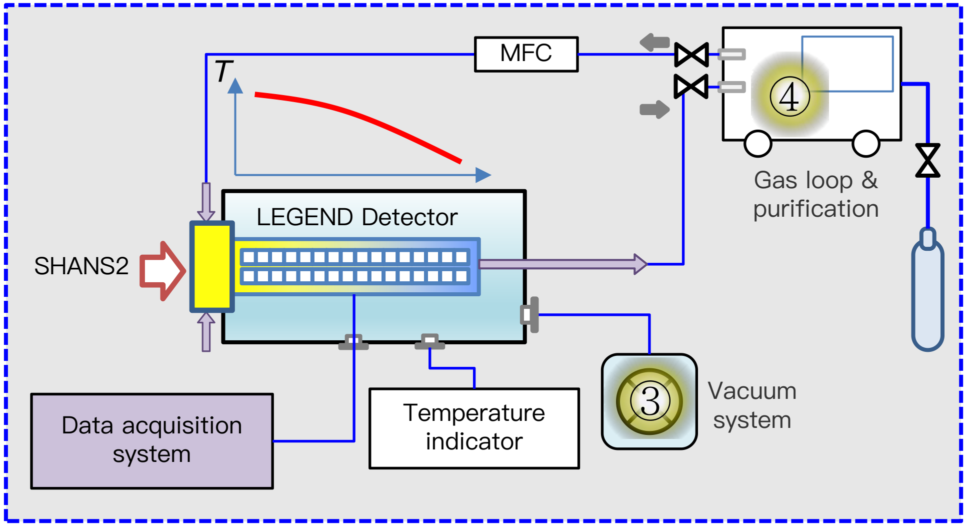


RTC+LEGEND box

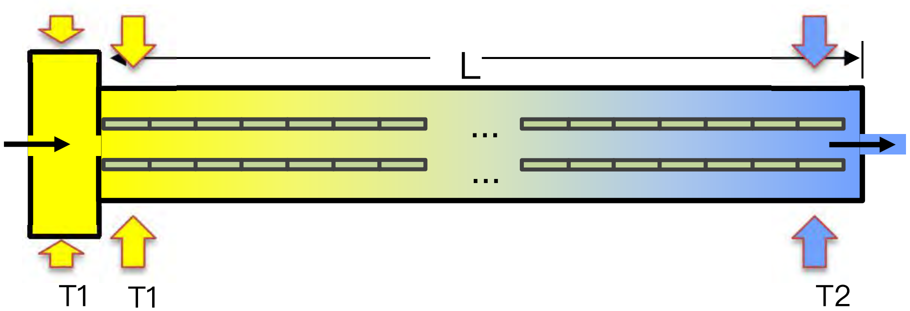
Preparations for Nh chemistry

Design of the on-Line Experiment in Gas-phasE for Nihonium Detector array (LEGEND) system

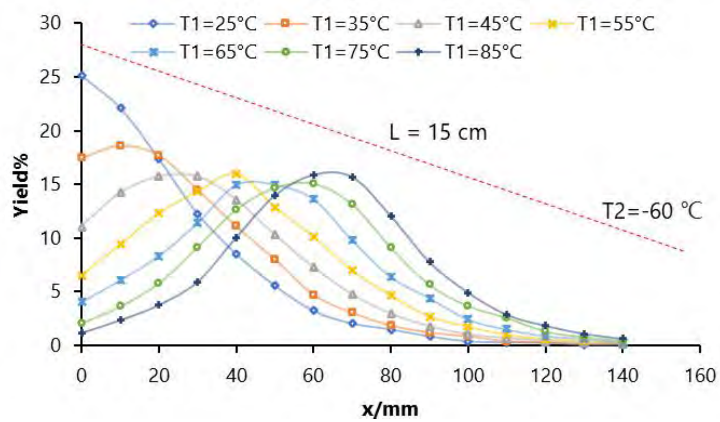
LEGEND system



Legend with temperature gradient

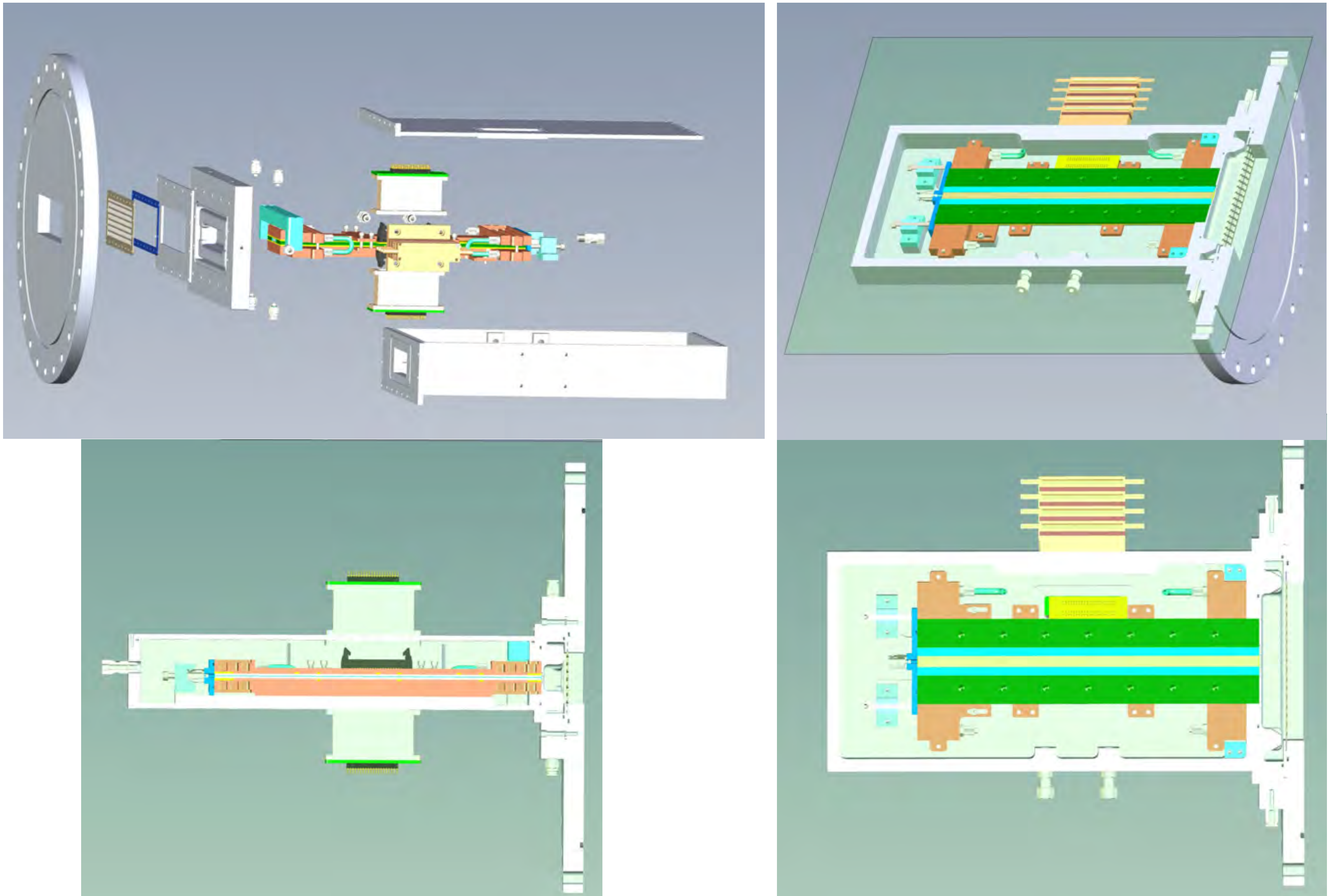


Monte Carlo simulation [$-\Delta H_{ads}$(Nh)=58kJ/mol]



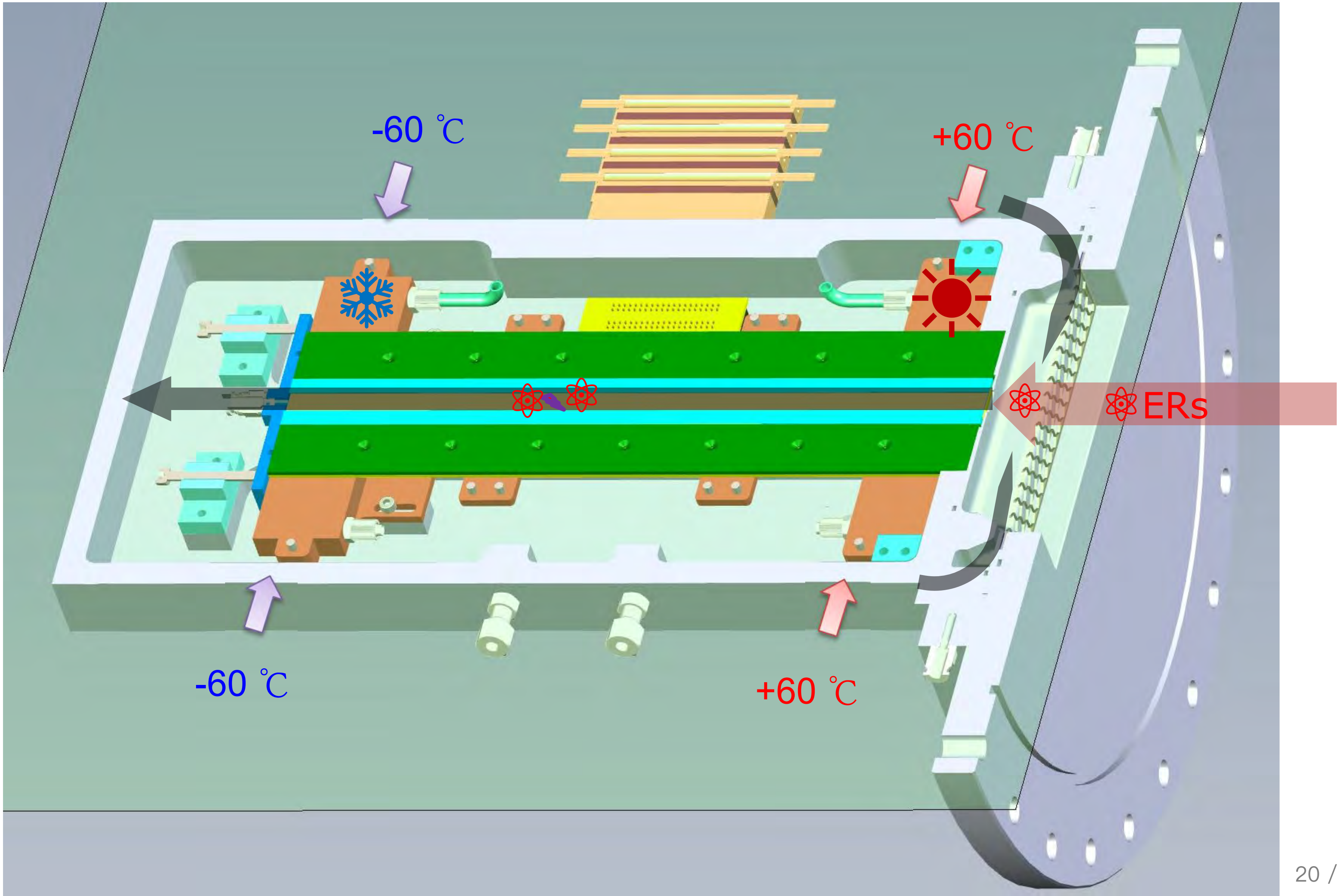
Preparations for Nh chemistry

The structure of LEGEND with temperature gradient



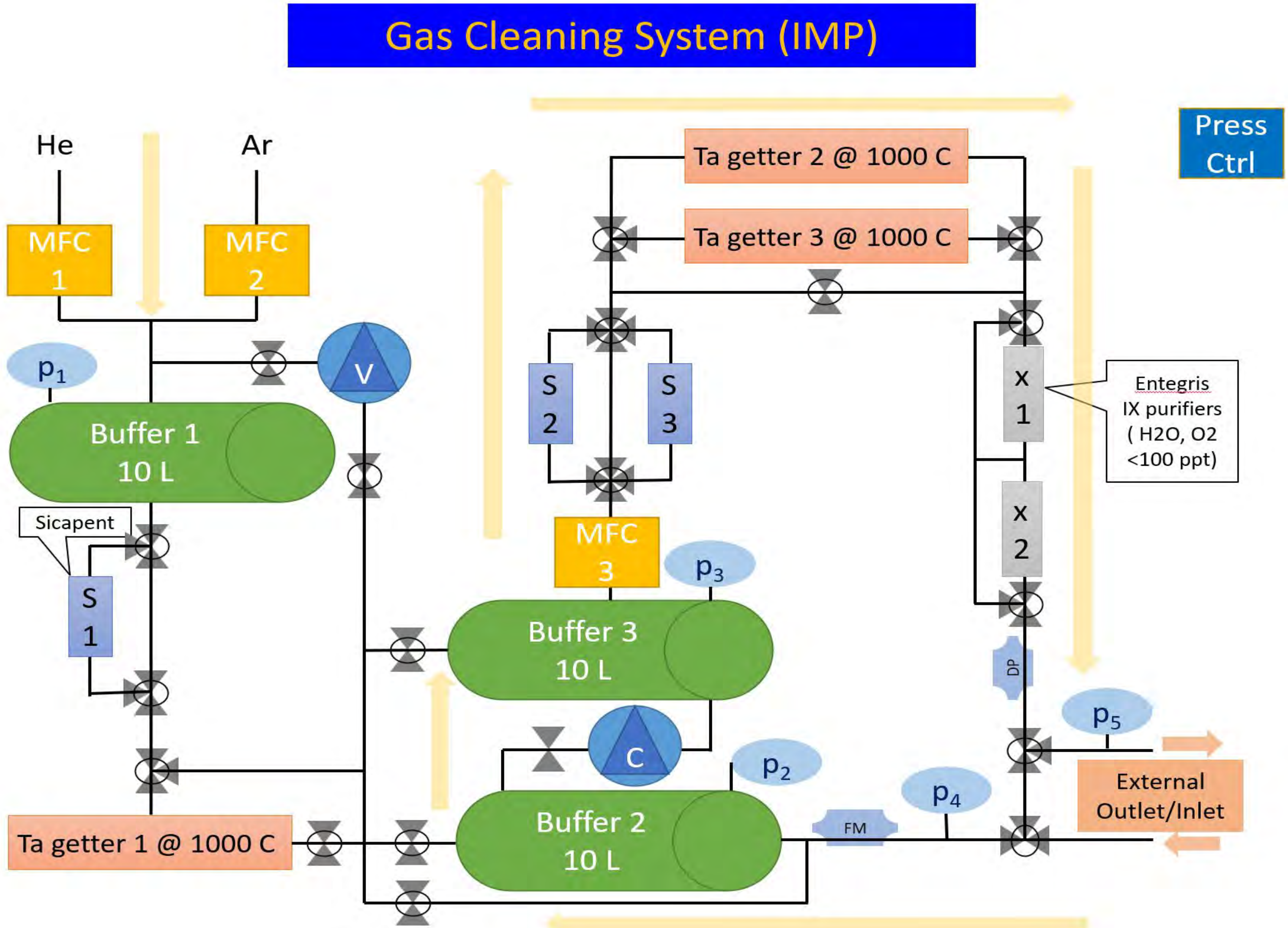
Preparations for Nh chemistry

The structure of LEGEND with temperature gradient



Preparations for Nh chemistry

Gas Cleaning System



International collaboration is warmly welcomed

The legend of Dunhuang, Mogao Grottoes Cave 390, Gansu Province, China. Jin dynasty (366–535 A.D.)

Gansu Dance Troupe's *The Legend of Dunhuang*

The city of Dunhuang in north-western Gansu province of China was a major stop on the ancient Silk Road. An oasis city, it was an important hub for trade and cultural exchange, a meeting point between the civilizations of Asia, India, Europe and the Islamic world. It is perhaps most famous for the Mogao Caves, a complex system of Buddhist temples outside the city, a wondrous cache of art and literature. The so-called Library Cave – walled off in the 11th century and rediscovered in the 20th – was found to contain everything from folks songs and government records to Buddhist, Confucian, Taoist and even Nestorian Christian texts, with manuscripts in languages from Chinese to Hebrew. Most famous of all, however, are the beautiful and elaborate murals that cover the walls of the Mogao caves, dating across a period of over a thousand years.

7th International Conference on the Chemistry and Physics of the Transactinide Elements (TAN23)

November 12~17, 2023, Huizhou, China

Institute of Modern Physics, CAS

- IMP was founded in 1957.
- Affiliation: Chinese Academy of Sciences (CAS)
- Annual Budget:~65 M$??

- ~1000 Employees.
- 348 Postgraduate.

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of sciences

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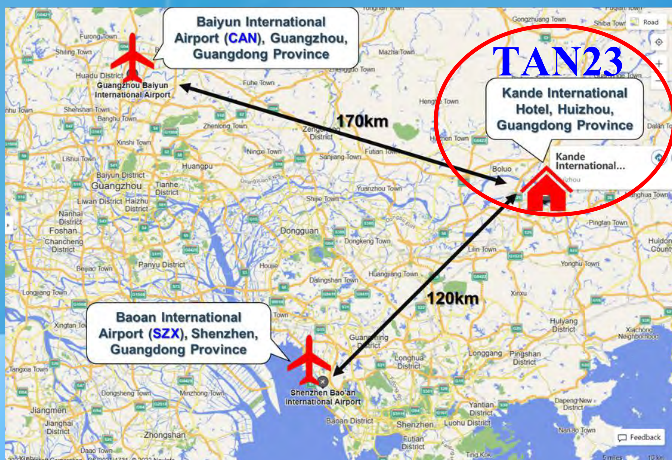

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Hiromitsu Haba (Japan)
Robert Eichler (Switzerland)
Jacklyn M. Gates (USA)
Katsuhisa Nishio (Japan)
Michael Block (Germany)
Christoph E. Düllmann (Germany)
Heinz W. Gäggeler (Switzerland)
Hushan Xu (China)
Zhiyu Sun (China)

Scope

- **Theories and experiments of heaviest-element synthesis**
- **Nuclear reaction studies**
- **Nuclear structure and spectroscopy**
- **Atomic physics studies**
- **Chemical properties of transactinide elements**
- **Technical developments**
- **Large-scale facilities in the field of superheavy element research**

Conference Website: https://indico.impcas.ac.cn/e/tan23

Online registration & **abstract submission** has already been opened.

2023年11月12日至17日
Kande International Hotel, Huizhou, China
Asia/Shanghai 时区

- Welcome
- 2nd Circular
- 注册
- 征集摘要
- Important Dates
- Venue
- Accommodation
- Invited Speakers

Contact
tan23@impcas.ac.cn

Welcome

7th International Conference on the Chemistry and Physics of the Transactinide Elements (TAN23)

Conference Poster

- Poster A2 (4.1 MB)
- Poster A3 (2.5 MB)
- Poster A4 (1.6 MB)

Important Dates

2nd Circular	March 2023
Registration	April 2023
Deadline for abstract submission	August 30, 2023
3rd Circular/Final program	August 2023
Deadline for registration	September 30, 2023
Conference	November 12-17, 2023

Some invited speakers

- Ephraim Eliav (Tel-Aviv University, Israel)
- Mikhail Itkis (FLNR Dubna, Russia)
- Yuri Oganessian (FLNR Dubna, Russia)
- Katsuhisa Nishio (JAEA Tokai, Japan)
- Valeria Pershina (GSI, Germany)
- Witold Nazarewicz (FRIB, Michigan State Univ., USA)
- Patrick Steinegger (PSI, Switzerland)
- Robert Eichler (PSI, Switzerland)
- Sergey Dmitriev (FLNR Dubna, Russia)
- Anastasia Borschevsky (Univ. Groningen, Netherlands)
- Zhong-zhou Ren (Tongji University)
- Shan-gui Zhou (ITP CAS, China)
- Jun Li (Tsinghua University)
- Meng Wang (IMP CAS, China)
- Zhi-Yuan Zhang (IMP CAS, China)

To be added…

Welcome to TAN23

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

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東江實驗室
先进能源科学与技术广东省实验室
ADVANCED ENERGY SCIENCE AND TECHNOLOGY GUANGDONG LABORATORY

HIAF + CiADS

HIAF项目总体布局图

TAN23 Conference in Huizhou, China; Nov.12-17, 2023

Online registration is open now!

Conference website: https://indico.impcas.ac.cn/e/tan23