February 27, 2019 @ Milano

Search for a New Element at RIKEN Nishina Center

The nSHE collaboration

Hideyuki Sakai
RIKEN Nishina Center
Professor Emeritus, University of Tokyo

Contents

1 Periodic table (Chemical elements)
2 IUPAP vs. IUPAC and JWG
3 New SHE search, cold vs. hot
4 nSHE experiment at RIKEN Nishina Center

Elements and periodic table (PT)

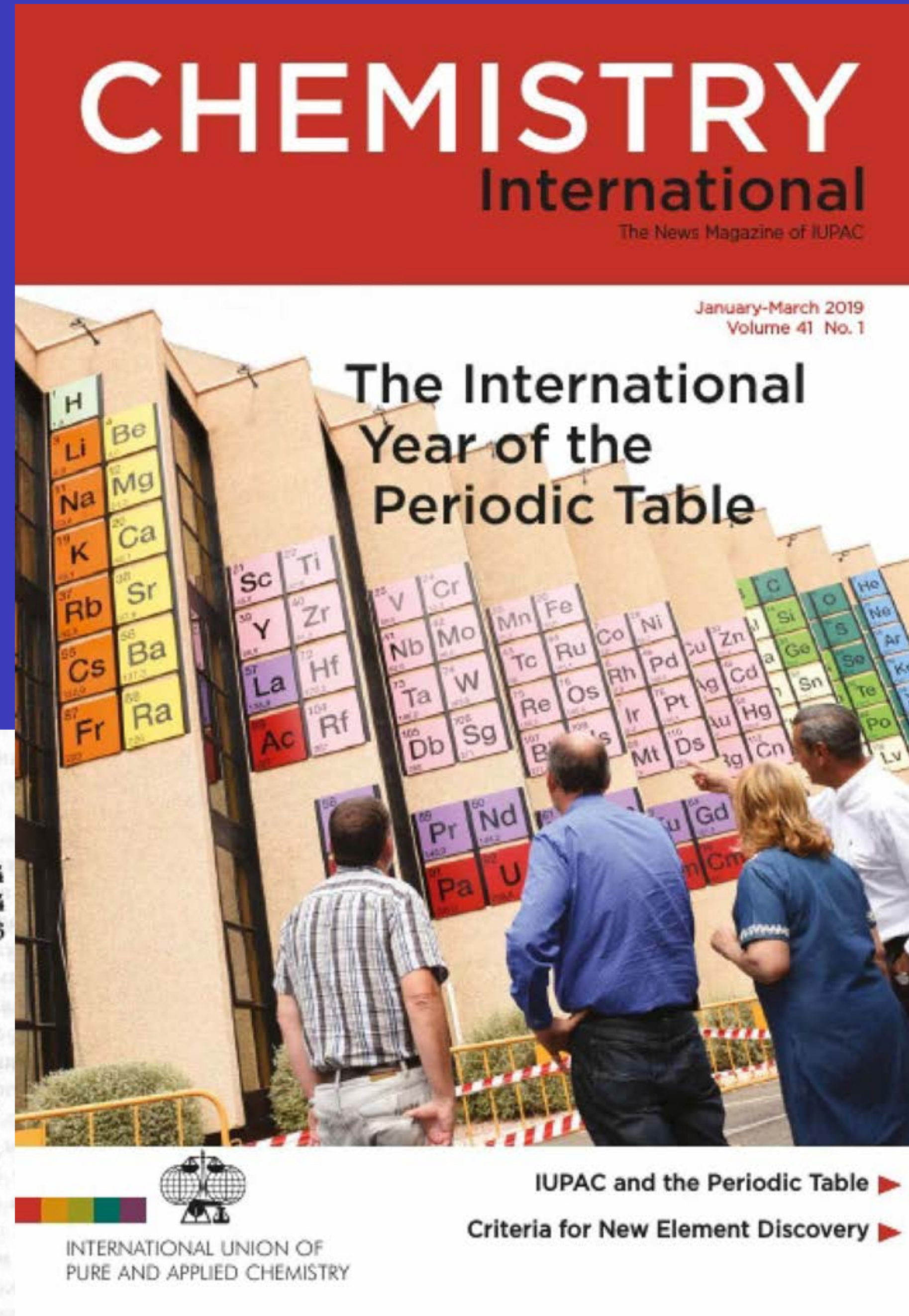
- **118** elements known
- IYPT
- 150 y since PT proposed by Mendelejew

United Nations Educational, Scientific and Cultural Organization

2019 IYPT
International Year of the Periodic Table of Chemical Elements

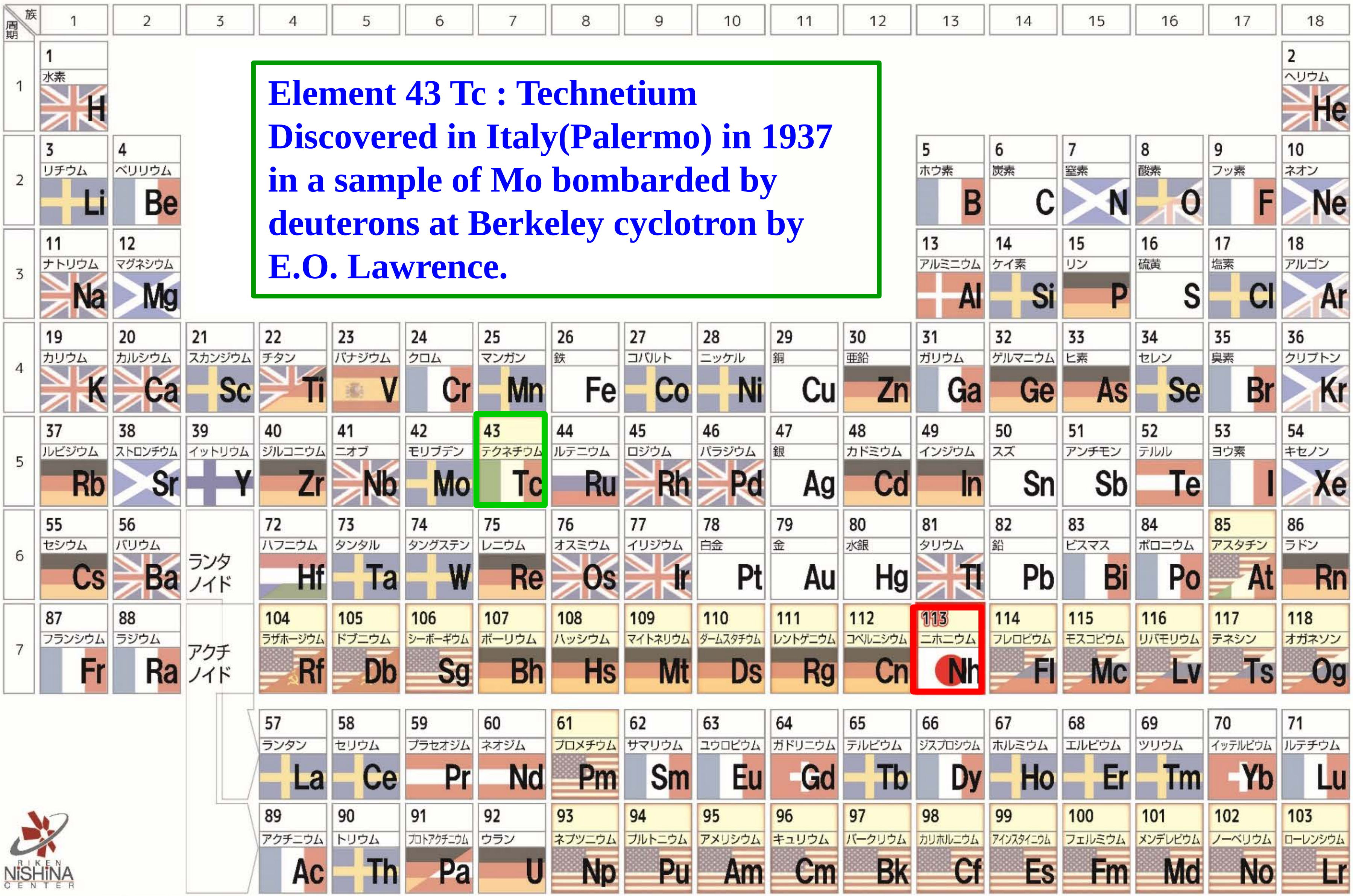
D. I. Mendelejew, Zhurnal Russkogo khimicheskogo obshchestva 1(2–3), 60–77 (1869).

			Ti=50	Zr=90
			V=51	Nb=94
			Cr=52	Mo=96
			Mn=55	Rh=104,4
			Fe=56	Ru=104,4
			Ni=Co=59	Pl=106,6
H=1			Cu=63,4	Ag=108
	Be=9,4	Mg=24	Zn=65,2	Cd=112
	B=11	Al=27,4	?=68	Ur=116
	C=12	Si=28	?=70	Sn=118
	N=14	P=31	As=75	Sb=122
	O=16	S=32	Se=79,4	Te=128?
	F=19	Cl=35,5	Br=80	J=127
Li=7	Na=23	K=39	Rb=85,4	Cs=133
		Ca=40	Sr=87,6	Ba=137
		?=45	Ce=92	
		?Er=56	La=94	
		?Yt=60	Di=95	
		?In=75,6	Th=118?	



Periodic table of today

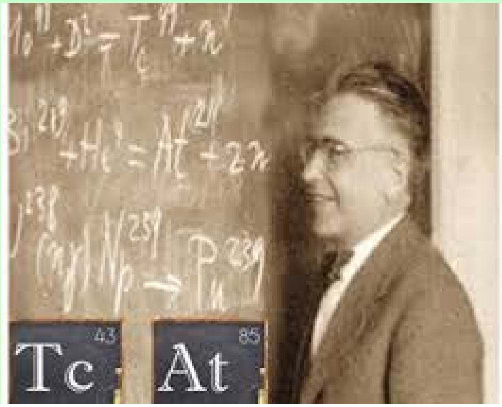
Element 43 Tc : Technetium
Discovered in Italy(Palermo) in 1937 in a sample of Mo bombarded by deuterons at Berkeley cyclotron by E.O. Lawrence.



※113番、115番、117番、118番元素については、2016年11月現在パブリックレビュー中

出典：「羽場宏光 "イラスト図解 元素" 日東書院本社（2010.5.1）」
「IUPAC ウェブサイト（http://www.iupac.org/）」

Anecdote



Emillo Segre
1905 - 1989
1959 Nobel prize
Discovery of antiproton

1947 named as "τεχνητός"(technitos)

Why not It (Itarium) instead of Tc ?

SEPTEMBER, 1937 JOURNAL OF CHEMICAL PHYSICS VOLUME 5

Some Chemical Properties of Element 43

C. PERRIER AND E. SEGRÈ,
Royal University, Palermo, Italy
(Received June 30, 1937)

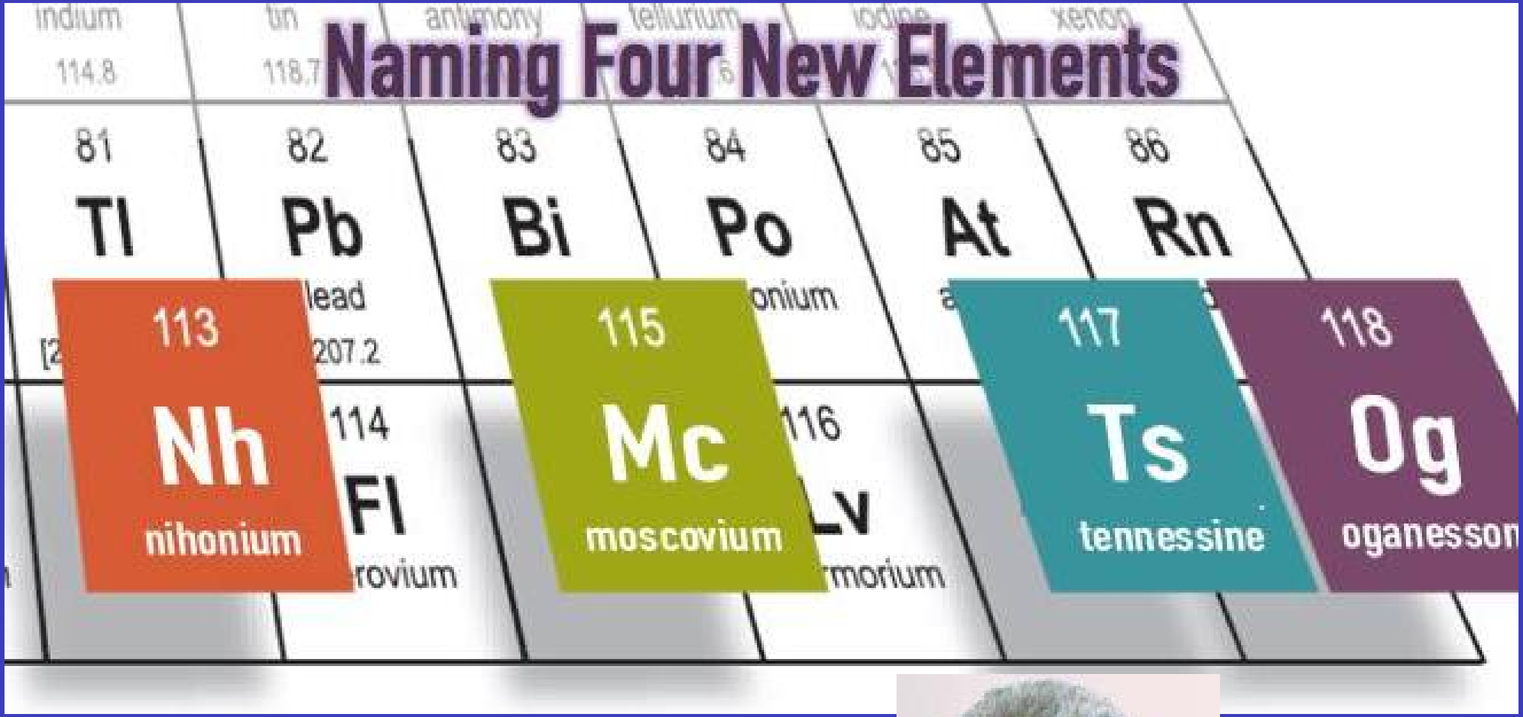
1. INTRODUCTION

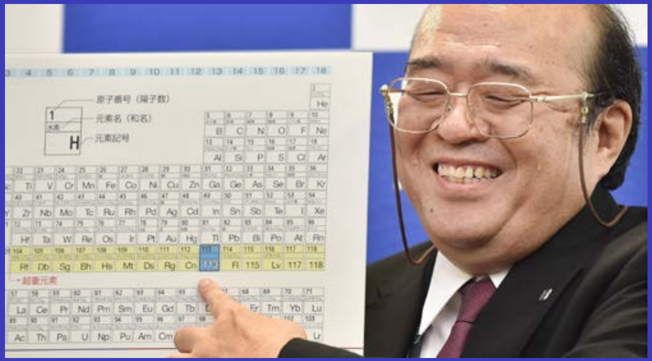
PROFESSOR E. O. LAWRENCE gave us a piece of molybdenum plate which had been bombarded for some months by a strong deuteron beam in the Berkeley cyclotron. The molybdenum has been also irradiated with secondary neutrons which are always generated by the cyclotron. The molybdenum plate shows a strong activity, chiefly due to very slow electrons. The radioactivity is due to more than one substance of a half-value period of some months and to the radioactive phosphorus isotope P^{32}.[1] The substance was sent from Berkeley on December 17, 1936 and we started our chemical investigation on January 30, 1937; all short period substances have decayed in these 6 weeks and we could

[1] We will give more details on the radioactive side of this investigation in a later paper to appear in the *Physical Review*.

Recent discovery of new elements

IUPAC announced discoveries of 4 new elements (Dec. 2015) and approved the names (Nov. 2016)





Dr. Kosuke Morita

Dr. Yuri Oganessian

Who approves new element ?

IUPAC (International Union of Pure and Applied Chemistry)
IUPAP (International Union of Pure and Applied Physics)

JWP
(Joint Working Party)

- considers claims for discovery and announces the priority

Announce, naming etc. (IUPAC)

- Announce and naming of new chemical elements (IUPAC takes this as their privilege)

There was a strong complaints from IUPAP to IUPAC for the way of handling.

President: Cecilia Jarlskog EPJ Web Conf 131, 06004 (2016)

All SHE were created and found by nuclear physicists working day and night. Nevertheless chemist takes all the credit and . . .

What are the next ?

7th period completed !
Next target :119 or 120 on the 8th period!

周期 \ 族	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 水素 H																	2 ヘリウム He
2	3 リチウム Li	4 ベリリウム Be											5 ホウ素 B	6 炭素 C	7 窒素 N	8 酸素 O	9 フッ素 F	10 ネオン Ne
3	11 ナトリウム Na	12 マグネシウム Mg											13 アルミニウム Al	14 ケイ素 Si	15 リン P	16 硫黄 S	17 塩素 Cl	18 アルゴン Ar
4	19 カリウム K	20 カルシウム Ca	21 スカンジウム Sc	22 チタン Ti	23 バナジウム V	24 クロム Cr	25 マンガン Mn	26 鉄 Fe	27 コバルト Co	28 ニッケル Ni	29 銅 Cu	30 亜鉛 Zn	31 ガリウム Ga	32 ゲルマニウム Ge	33 ヒ素 As	34 セレン Se	35 臭素 Br	36 クリプトン Kr
5	37 ルビジウム Rb	38 ストロンチウム Sr	39 イットリウム Y	40 ジルコニウム Zr	41 ニオブ Nb	42 モリブデン Mo	43 テクネチウム Tc	44 ルテニウム Ru	45 ロジウム Rh	46 パラジウム Pd	47 銀 Ag	48 カドミウム Cd	49 インジウム In	50 スズ Sn	51 アンチモン Sb	52 テルル Te	53 ヨウ素 I	54 キセノン Xe
6	55 セシウム Cs	56 バリウム Ba	ランタノイド	72 ハフニウム Hf	73 タンタル Ta	74 タングステン W	75 レニウム Re	76 オスミウム Os	77 イリジウム Ir	78 白金 Pt	79 金 Au	80 水銀 Hg	81 タリウム Tl	82 鉛 Pb	83 ビスマス Bi	84 ポロニウム Po	85 アスタチン At	86 ラドン Rn
7	87 フランシウム Fr	88 ラジウム Ra	アクチノイド	104 ラザホージウム Rf	105 ドブニウム Db	106 シーボーギウム Sg	107 ボーリウム Bh	108 ハッシウム Hs	109 マイトネリウム Mt	110 ダームスタチウム Ds	111 レントゲニウム Rg	112 コペルニシウム Cn	113 ニホニウム Nh	114 フレロビウム Fl	115 モスコビウム Mc	116 リバモリウム Lv	117 テネシン Ts	118 オガネソン Og
8th	119	120																

57 ランタン La	58 セリウム Ce	59 プラセオジム Pr	60 ネオジム Nd	61 プロメチウム Pm	62 サマリウム Sm	63 ユウロピウム Eu	64 ガドリニウム Gd	65 テルビウム Tb	66 ジスプロシウム Dy	67 ホルミウム Ho	68 エルビウム Er	69 ツリウム Tm	70 イッテルビウム Yb	71 ルテチウム Lu
89 アクチニウム Ac	90 トリウム Th	91 プロトアクチニウム Pa	92 ウラン U	93 ネプツニウム Np	94 プルトニウム Pu	95 アメリシウム Am	96 キュリウム Cm	97 バークリウム Bk	98 カリホルニウム Cf	99 アインスタイニウム Es	100 フェルミウム Fm	101 メンデレビウム Md	102 ノーベリウム No	103 ローレンシウム Lr

※113 番、115 番、117 番、118 番元素については、2016 年 11 月現在パブリックレビュー中

出典：「羽場宏光 "イラスト図解 元素" 日東書院本社（2010.5.1）」
「IUPAC ウェブサイト（http://www.iupac.org/）」

Criteria to verify the discovery of new element

Transfermium Working Group visit the Berkeley laboratory, 19-23 June 1989. The photo shows the nine members of TWG and Glenn Seaborg as the host of the group. Front row: Ivan Ulehla (Czechoslovakia, co-secretary), Denys Wilkinson (UK, chairman), Glenn Seaborg (USA, leader of LBNL), Yves Jeannin (France). Back row: Marc Lefort (France), Norman Greenwood (UK), Andrzej Hrynkiewicz, (Poland), Mitsuo Sakai (Japan), Robert Barber (Canada), Aaldert Wapstra (co-secretary, Netherlands). Jeannin and Greenwood were named by IUPAC, the others by IUPAP. The TWG has held the following meetings, of which the first and last were "private", with the remainder in the laboratories of chief concern: 3-5 February 1988, Nonant (France); 12-17 December 1988, Darmstadt (Germany); 19-23 June 1989, Berkeley (USA); 12-16 February 1990, Dubna (Russia); and 16-20 April 1990, Prague (Czechoslovakia).

- **TWG report**
  Wapstra et al., PAC 63, 879(1991)
- **Applied for elements 110 - 118**

Since exp. technology improved much but criteria remained, it took long time to reach final conclusions for 113-118 in JWP.

Foundation meeting of the JWG in Egelsbach near Darmstadt, Germany, 20-22 May 2017. Left to right: Sigurd Hofmann (Chair), Sergey Dmitriev, Jacklyn Gates, Natalia Tarasova (2017 President of IUPAC) proudly keeping the Chart of Nuclei in her hands, Bruce McKellar (2017 President of IUPAP), James Roberto, Hideyuki Sakai (Vice Chair), and Claes Fahlander, respectfully holding the Periodic Table of the Elements.

- **JWG was set up in 2017 to revise criteria**
  Hoffmann et al., PAC 90, 1773(2018)
- **Will be Applied for >118**

Report of JWG

DE GRUYTER

Pure Appl. Chem. 2018; 90(11): 1773–1832

Provisional Report

Sigurd Hofmann[a,*], Sergey N. Dmitriev[a], Claes Fahlander[b], Jacklyn M. Gates[b], James B. Roberto[a] and Hideyuki Sakai[b]

On the discovery of new elements (IUPAC/IUPAP Provisional Report)

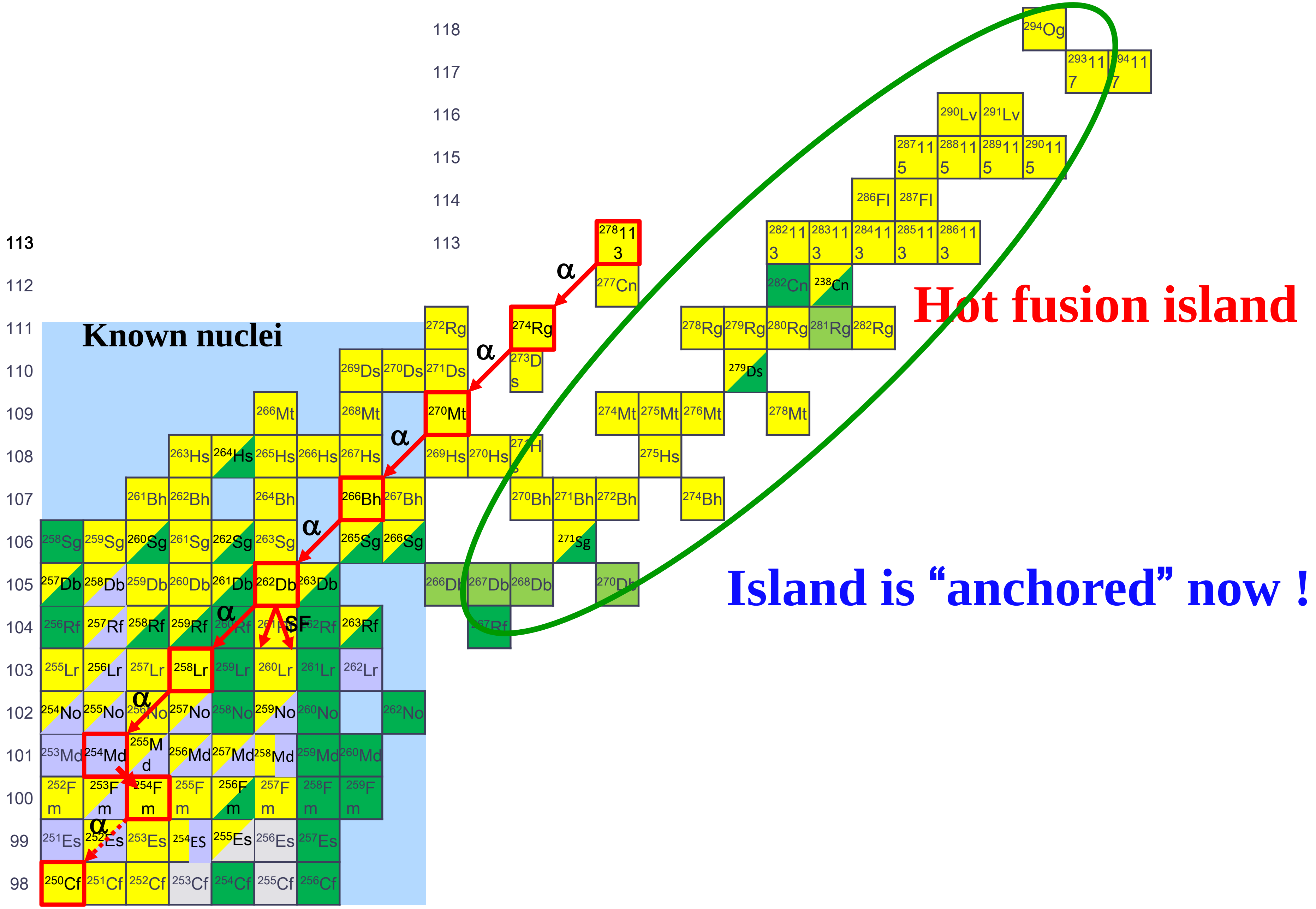
Provisional Report of the 2017 Joint Working Group of IUPAC and IUPAP

https://doi.org/10.1515/pac-2018-0918
Received August 24, 2018; accepted September 24, 2018

Abstract: Almost thirty years ago the criteria that are currently used to verify claims for the discovery of a new element were set down by the comprehensive work of a Transfermium Working Group, TWG, jointly established by IUPAC and IUPAP. The recent completion of the naming of the 118 elements in the first seven periods of the Periodic Table of the Elements was considered as an opportunity for a review of these criteria in the light of the experimental and theoretical advances in the field. In late 2016 the Unions decided to establish a new Joint Working Group, JWG, consisting of six members determined by the Unions. A first meeting of the JWG was in May 2017. One year later this report was finished. In a first part the works and conclusions of the TWG and the Joint Working Parties, JWP, deciding on the discovery of the now named elements are summarized. Possible experimental developments for production and identification of new elements beyond the presently known ones are estimated. Criteria and guidelines for establishing priority of discovery of these potential new elements are presented. Special emphasis is given to a description for the application of the criteria and the limits for their applicability.

Hot-fusion island isolated from main land

RIKEN NISHINA CENTER



Hot-fusion island anchored

PHYSICAL REVIEW LETTERS **121**, 222501 (2018)

Editors' Suggestion | Featured in Physics

First Direct Measurements of Superheavy-Element Mass Numbers

J. M. Gates,[1,*] G. K. Pang,[1] J. L. Pore,[1] K. E. Gregorich,[1] J. T. Kwarsick,[1,2] G. Savard,[3,4] N. E. Esker,[5] M. Kireeff Covo,[1] M. J. Mogannam,[1] J. C. Batchelder,[2] D. L. Bleuel,[6] R. M. Clark,[1] H. L. Crawford,[1] P. Fallon,[1] K. K. Hubbard,[1,2] A. M. Hurst,[2] I. T. Kolaja,[2] A. O. Macchiavelli,[1] C. Morse,[1] R. Orford,[3,7] L. Phair,[1] and M. A. Stoyer[6]

[1]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

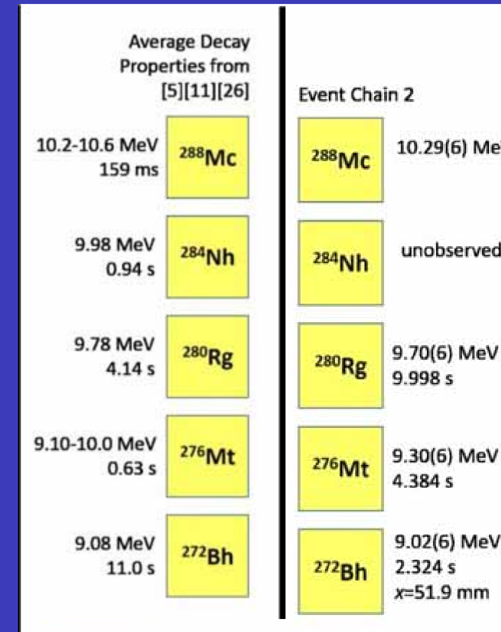
(A determined but not Z)

Lawrence Livermore National Laboratory, Livermore, California 94550, USA

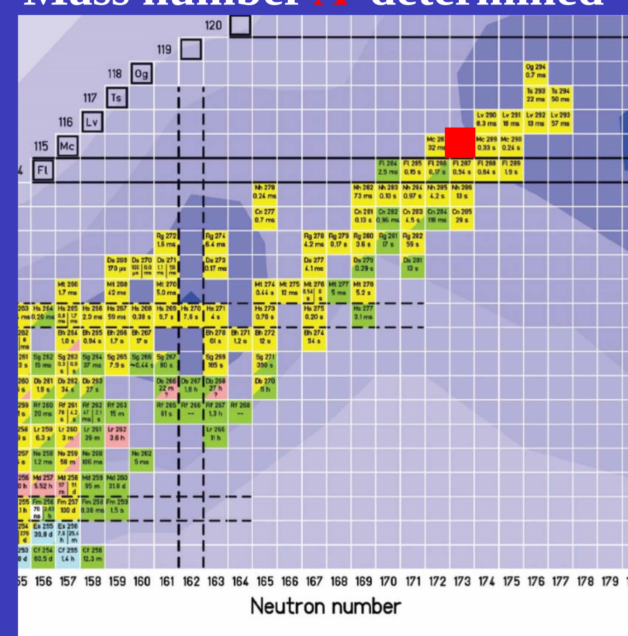
[7]*McGill University, Montreal, Québec H3A 0G4, Canada*

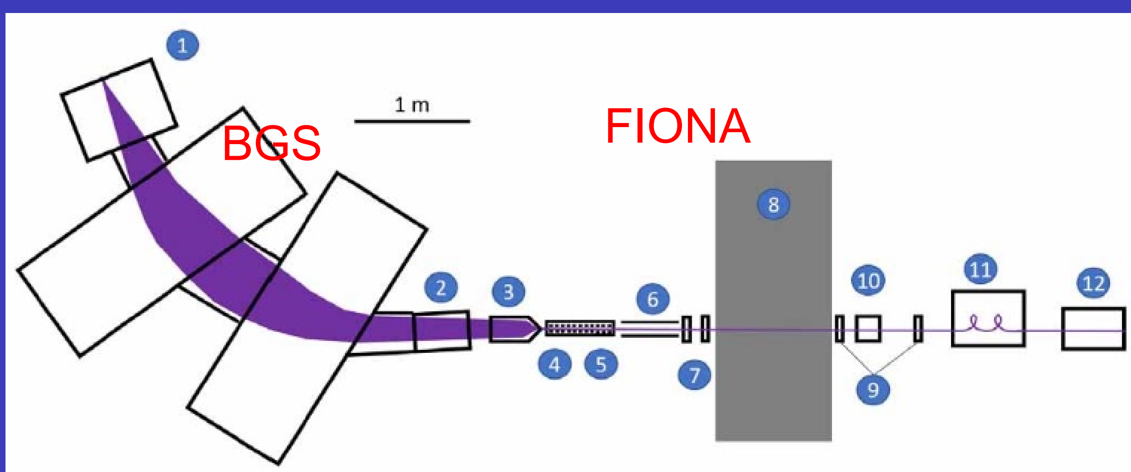
(Received 20 June 2018; revised manuscript received 7 September 2018; published 28 November 2018)

An experiment was performed at Lawrence Berkeley National Laboratory's 88-in. Cyclotron to determine the mass number of a superheavy element. The measurement resulted in the observation of two α-decay chains, produced via the ^{243}Am(^{48}Ca, xn)$^{291-x}$Mc reaction, that were separated by mass-to-charge ratio (A/q) and identified by the combined BGS + FIONA apparatus. One event occurred at $A/q = 284$ and was assigned to ^{284}Nh ($Z = 113$), the α-decay daughter of ^{288}Mc ($Z = 115$), while the second occurred at $A/q = 288$ and was assigned to ^{288}Mc. This experiment represents the first direct measurements of the mass numbers of superheavy elements, confirming previous (indirect) mass-number assignments.



Mass number A determined

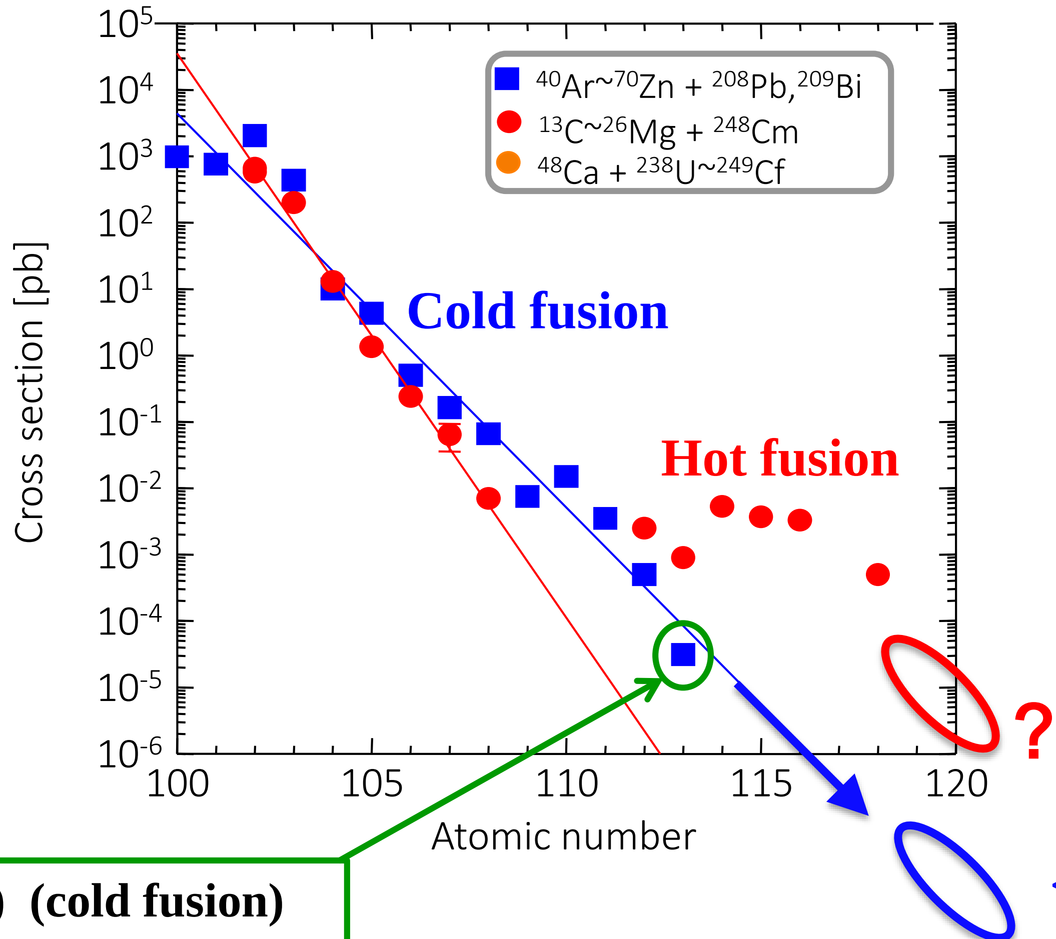




Next challenge : discover Z=119, 120

- **Cold or hot ?**
- **Beam and target combination ?**

Cold or hot ?

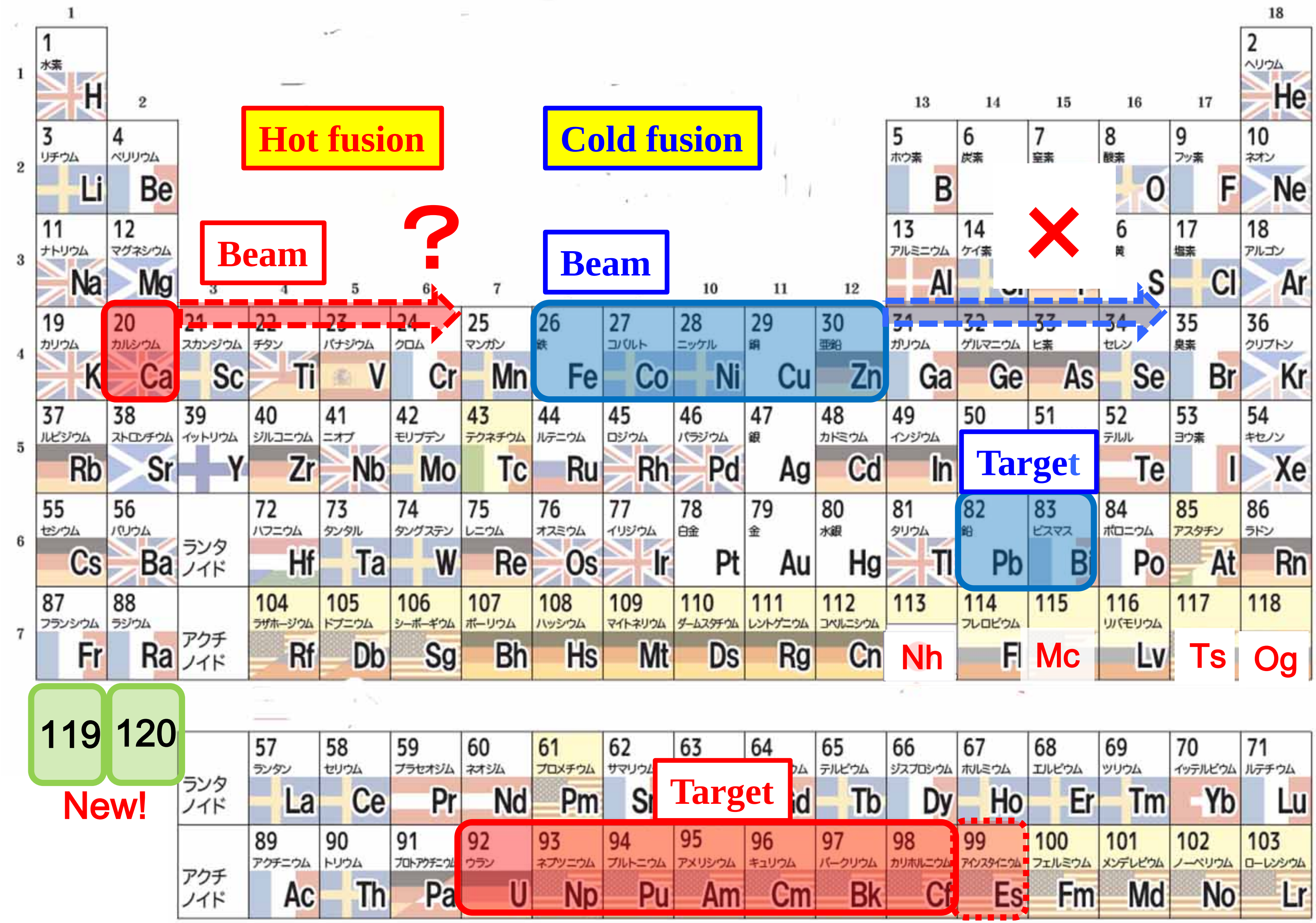


Nh(113) (cold fusion)
22 fb, 1 event / 200 day

<0.01 fb unrealistic
Hopeless !

Cold fusion → Hot fusion

Beam & target combination ?



~ 10 mg

~ µg (rotating target ?)

Our realistic decision

- **Hot fusion by $^{248}Cm(Z=96)$**
  - **$^{249}Bk(Z=97)$/ $^{mix}Cf(Z=98)$: not easy to prepare**

- **Z=119 $^{248}Cm + ^{51}V \rightarrow 119$**

- **Z=120 $^{248}Cm + ^{54}Cr \rightarrow 120$**

Start with ^{51}V-beam : Z=119

Element 119 search

$^{248}Cm(^{51}V,xn)^{299\text{-}x}119$

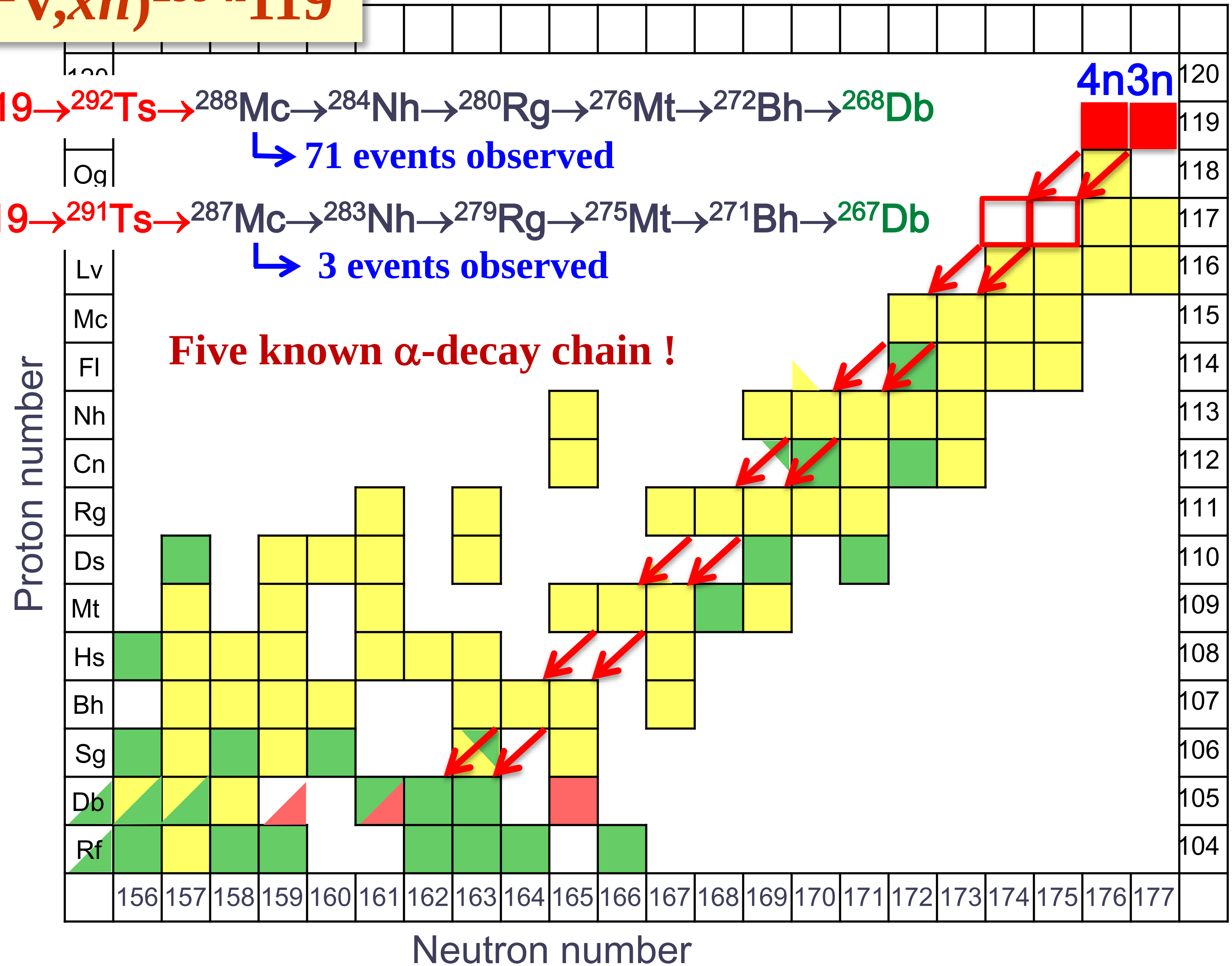
3n: $^{296}119 \rightarrow ^{292}Ts \rightarrow ^{288}Mc \rightarrow ^{284}Nh \rightarrow ^{280}Rg \rightarrow ^{276}Mt \rightarrow ^{272}Bh \rightarrow ^{268}Db$

↳ 71 events observed

4n: $^{295}119 \rightarrow ^{291}Ts \rightarrow ^{287}Mc \rightarrow ^{283}Nh \rightarrow ^{279}Rg \rightarrow ^{275}Mt \rightarrow ^{271}Bh \rightarrow ^{267}Db$

↳ 3 events observed

Five known α-decay chain !



Key elements for Z=119, 120

- **Predicted cross sections are extremely small. (< 10 fb ?)**

- **High efficiency** setup for **hot fusion reaction is needed!**
  → **Developed** new separators **GARIS-II** and **GARIS-III**

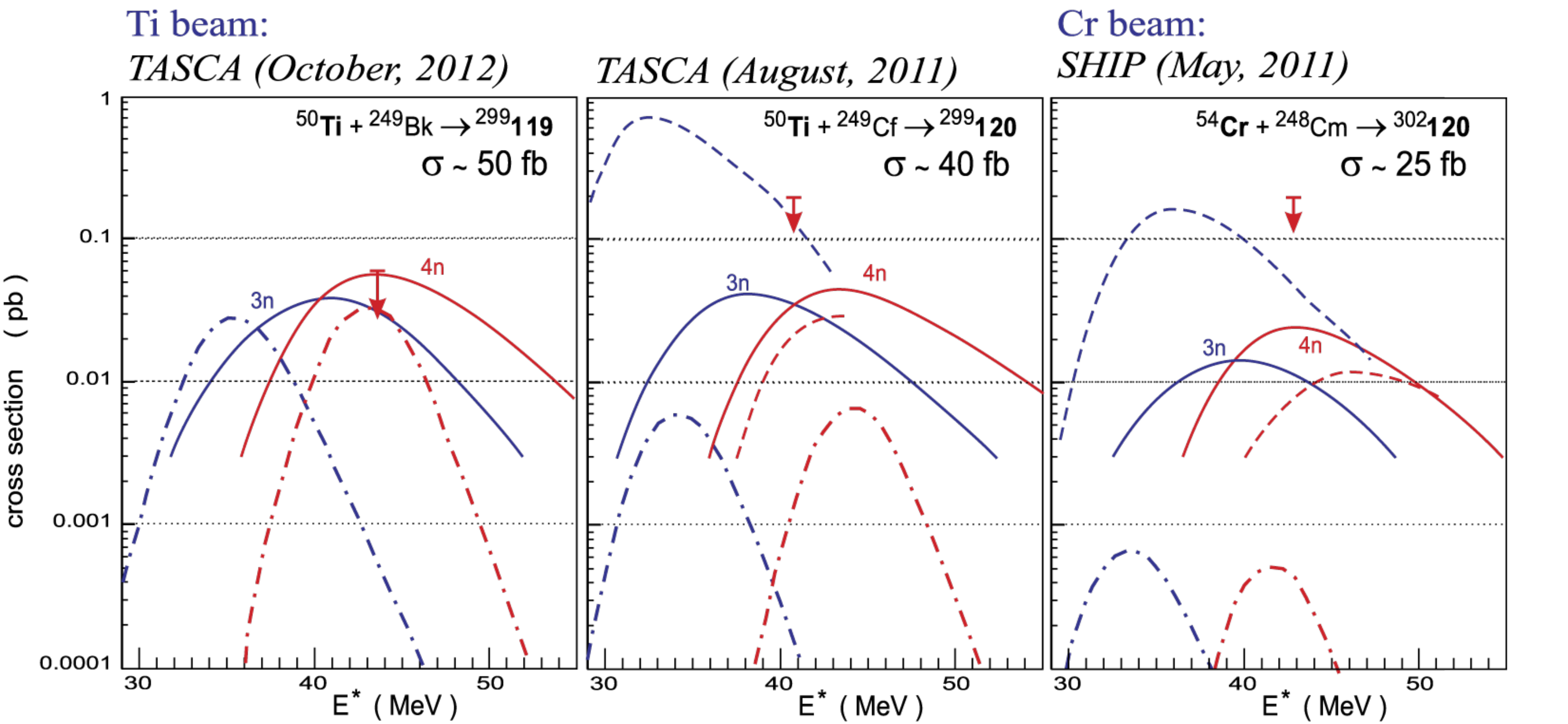
- Strong **beam intensity is needed!**
  → **Upgrading of RILAC and Ion source**

- **Actinide material** for target is needed!
  → **Collaboration with ORNL (DOE)**

- **Enormous amount of beam dose is needed!**
  → **Long BT when sRILAC+GARIS-III becomes available**
  → **Parallel run** (RRC+GARIS-II and new sRILAC+GARIS-III)

Hot fusion with ^{50}Ti or ^{54}Cr beam

Zagrebaev and Greiner, Nucl. Phys. A944 (2015) 257.



No prediction on $^{51}V+^{248}Cm$

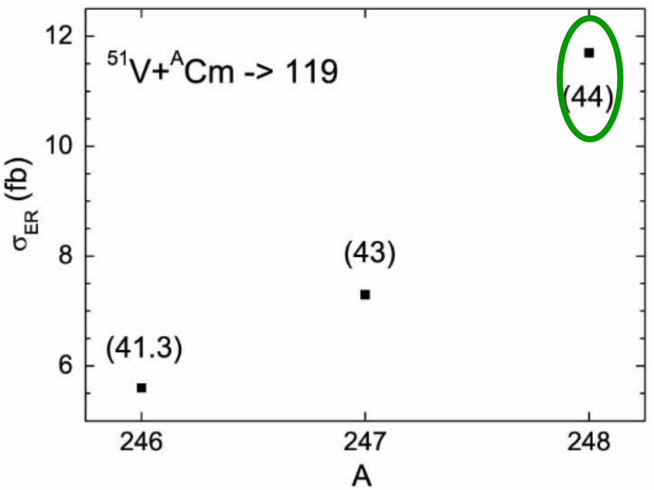
~10 fb (heuristic guess!)

→ Need reliable predictions !

Prediction with ^{51}V beam

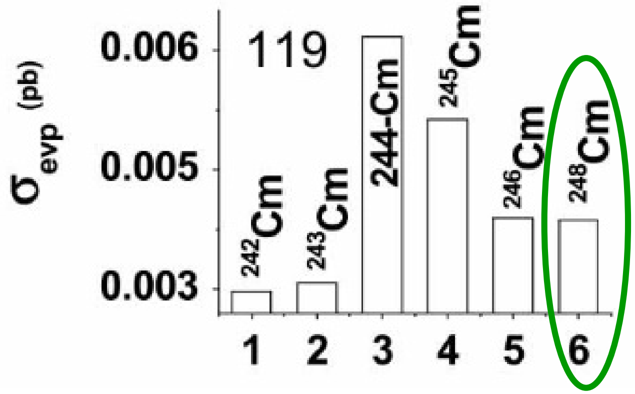
Adamain, Antonenko and Lenske
Nucl. Phys. A 970 (2018) 22

$^{51}V+^{248}Cm \rightarrow ^{255}119+4n$: 12 fb



Manjunatha, Sridhar and Ramalingam
Nucl. Phys. A 981 (2019) 17

$^{51}V+^{248}Cm \rightarrow ^{256}119+3n$: 4 fb



Private comm. : K. Siwek-Wilczynska, 8 fb

~ 10 fb ?

Key elements for Z=119, 120

- **Predicted cross sections are extremely small.** **(< 10 fb ?)**

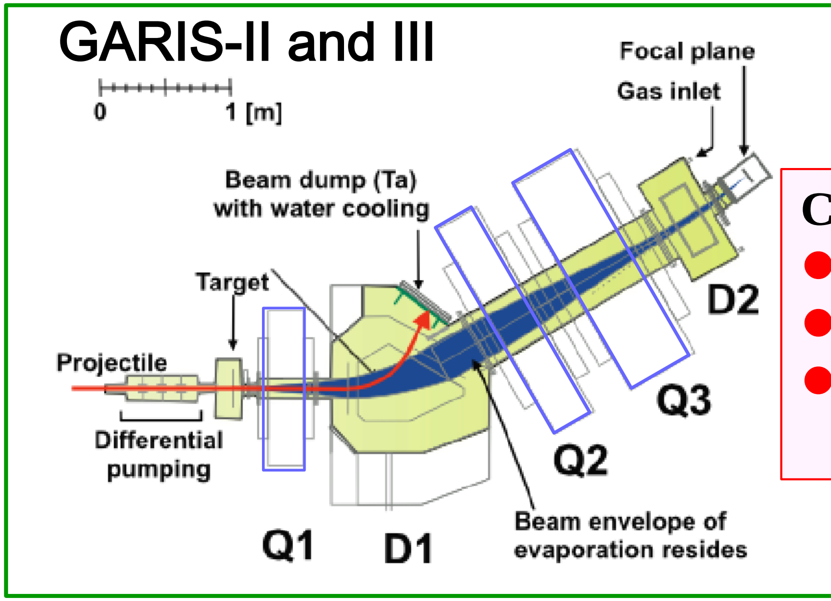
- **High efficiency** setup for **hot fusion reaction is needed!**
  → **Developed** new separators **GARIS-II** and **GARIS-III**

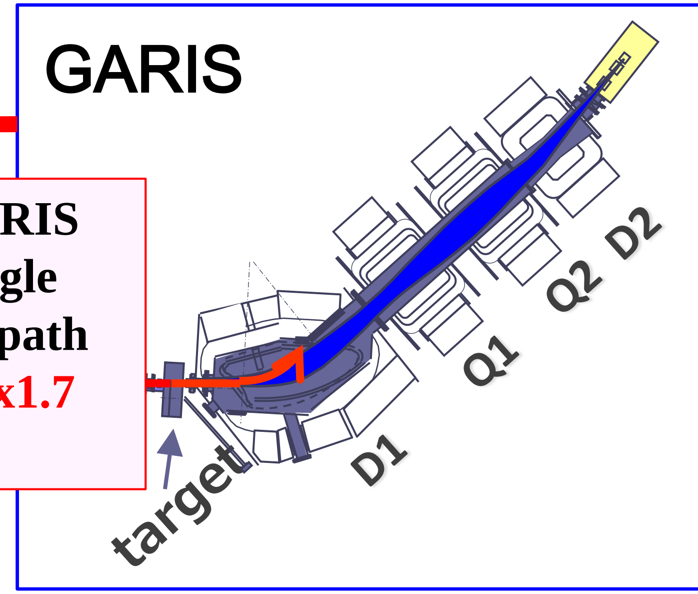
- Strong **beam intensity is needed!**
  → **Upgrading of RILAC and Ion source**

- **Actinide material** for target is needed!
  → **Collaboration with ORNL (DOE)**

- **Enormous amount of beam dose is needed!**
  → **Long BT when sRILAC+GARIS-III becomes available**
  → **Parallel run** (RRC+GARIS-II and new sRILAC+GARIS-III)

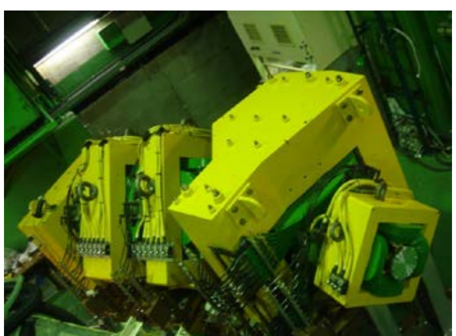
New Separator GARIS-II and GARIS-III



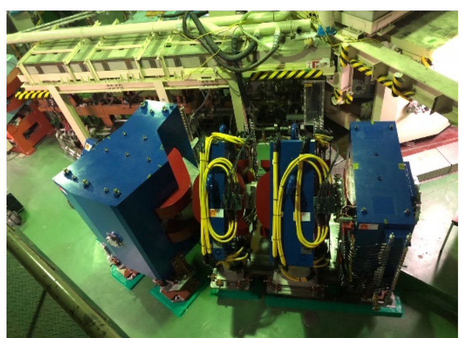


Compared to GARIS

- Large solid angle
- Shorter flight path
- Transmission x1.7 for hot fusion



GARIS-II
@E6



GARIS-III
@RILAC

	GARIS	GARIS-II
Configuration	DQ_hQ_vD	$Q_vDQ_hQ_vD$
Total length [m]	5.8	5.1
Bend. Angle [deg]	45+10	30+7
Solid angle [msr]	12.2	18.5
Bρ(max) [Tm]	2.16	2.48
Dispersion [mm/%]	9.7	19.3
Transmission [%]	40	70

Key elements for Z=119, 120

- **Predicted cross sections are extremely small.** **(< 10 fb ?)**

- **High efficiency** setup for **hot fusion reaction is needed!**
  → **Developed** new separators **GARIS-II** and **GARIS-III**

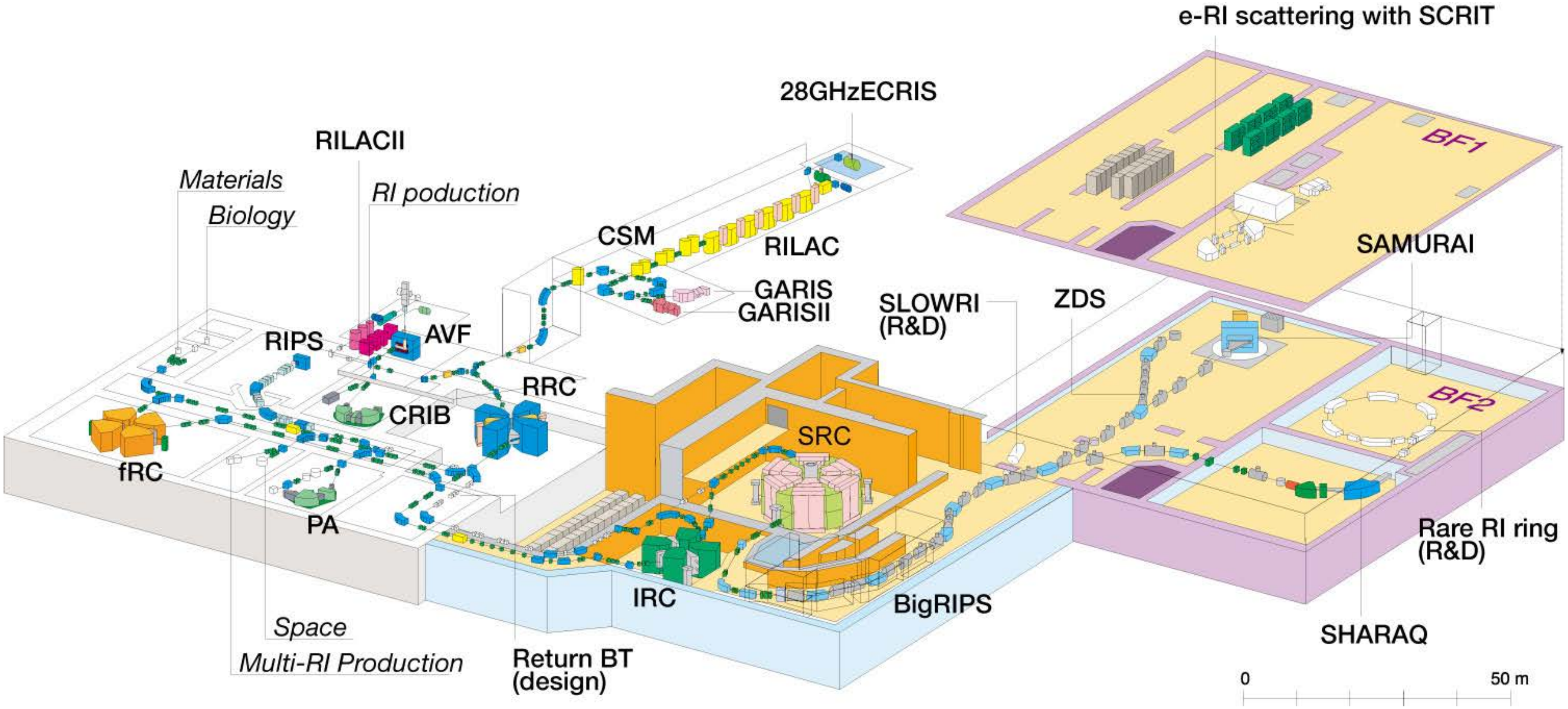
- Strong **beam intensity is needed!**
  → **Upgrading of RILAC and Ion source**

- **Actinide material** for target is needed!
  → **Collaboration with ORNL (DOE)**

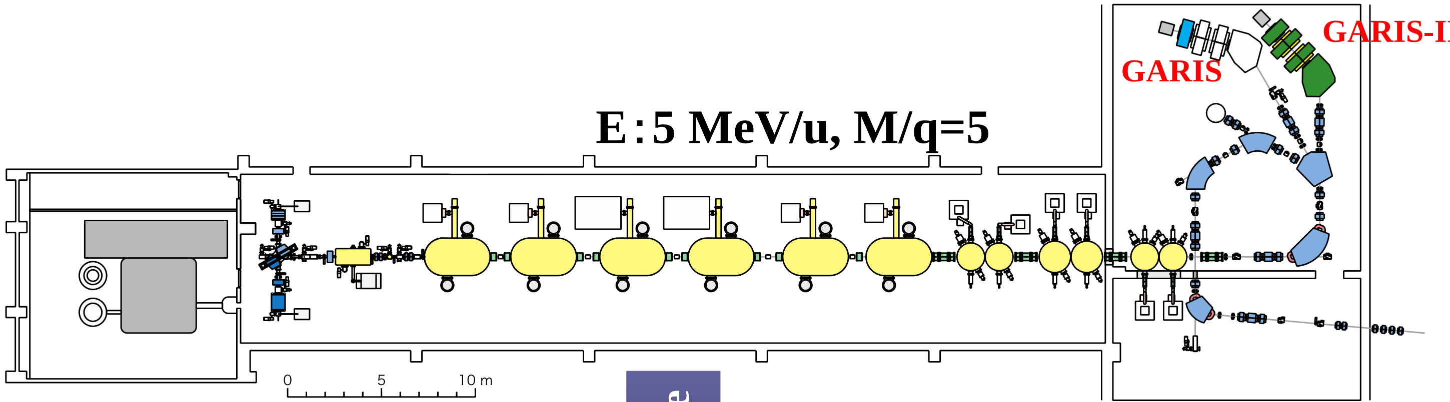
- **Enormous amount of beam dose is needed!**
  → **Long BT when sRILAC+GARIS-III becomes available**
  → **Parallel run** (RRC+GARIS-II and new sRILAC+GARIS-III)

Strategy of new element search (Facility)

- RILAC facility upgrade
- GARIS-II in RILAC facility transferred to RRC facility
- GARIS-III will be installed in upgraded RILAC facility

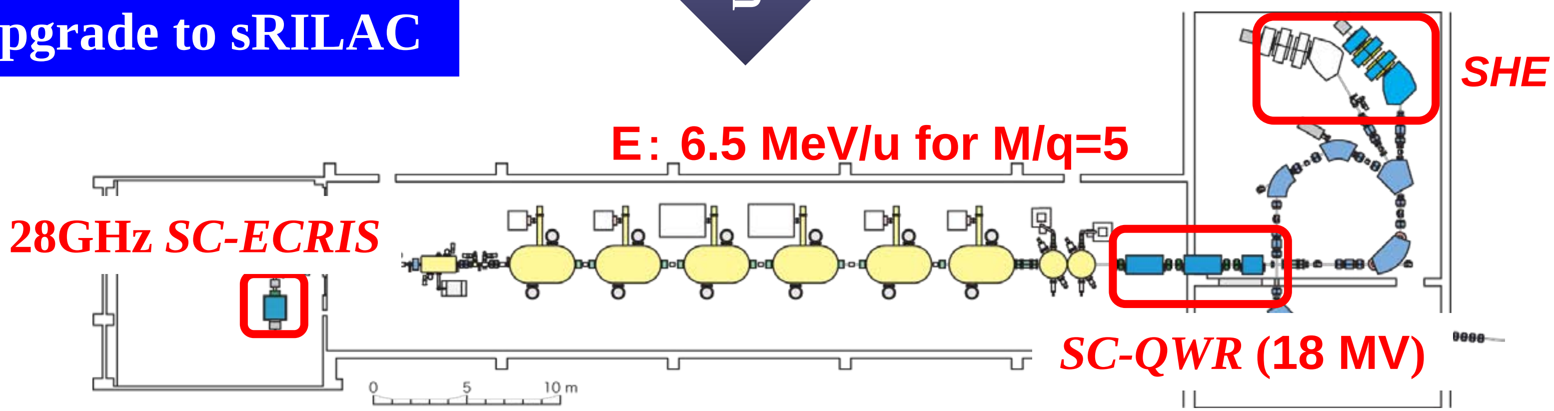


RILAC upgrade (2017 -2019)



Upgrade

Upgrade to sRILAC



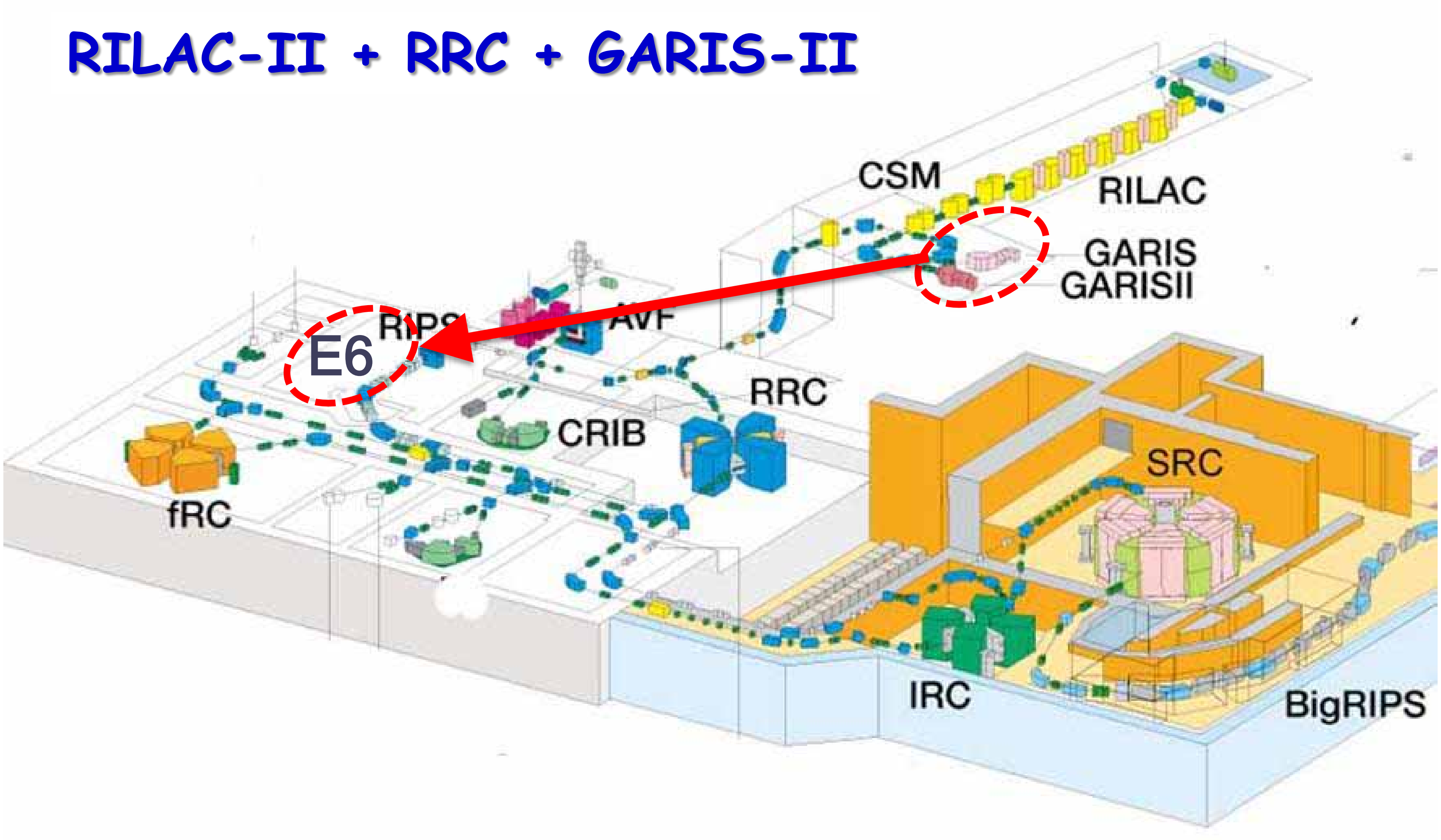
- **Stop operation: end of June, 2017**
- **Construction: 2017 – 2019**
- **Resume operation: 2020**

Avoid complete shut down during the construction

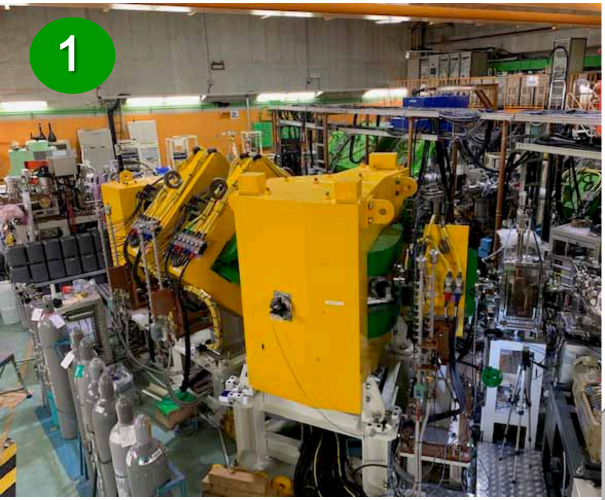
Beam intensity → > 5 times

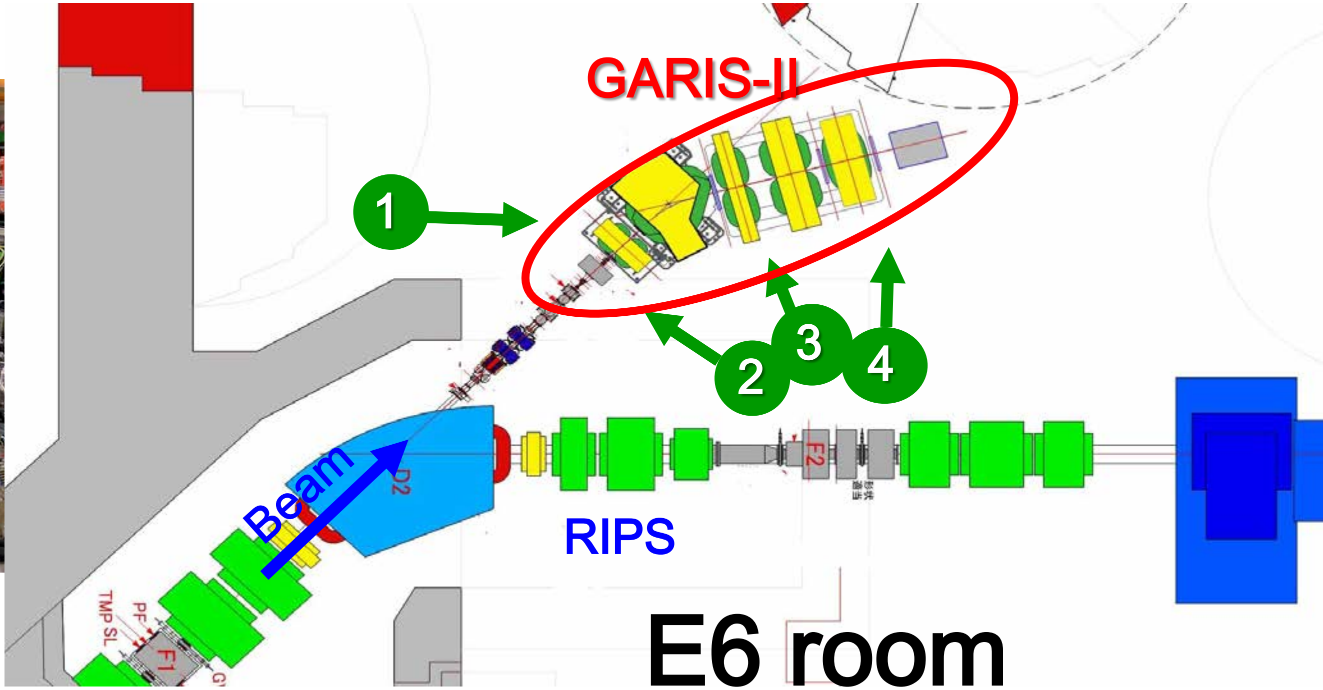
Transfer GARIS-II to E6 exp. room

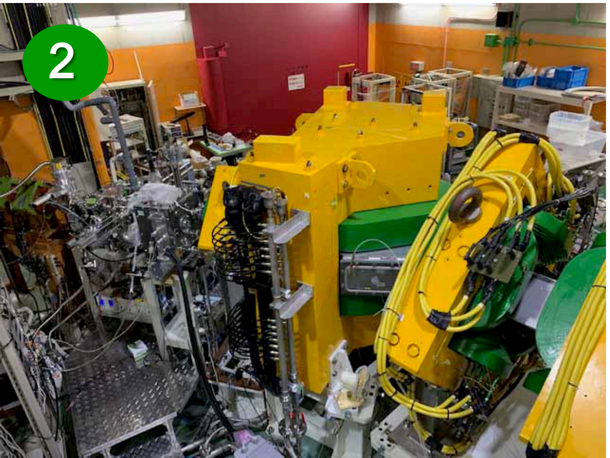
(continue the research during the upgrade shutdown)

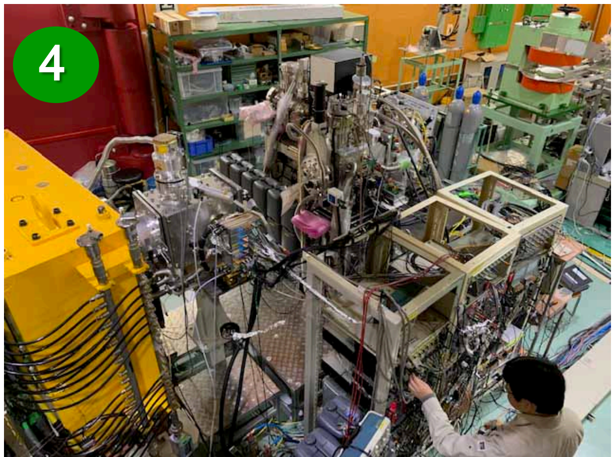


GARIS-II in E6 exp. room



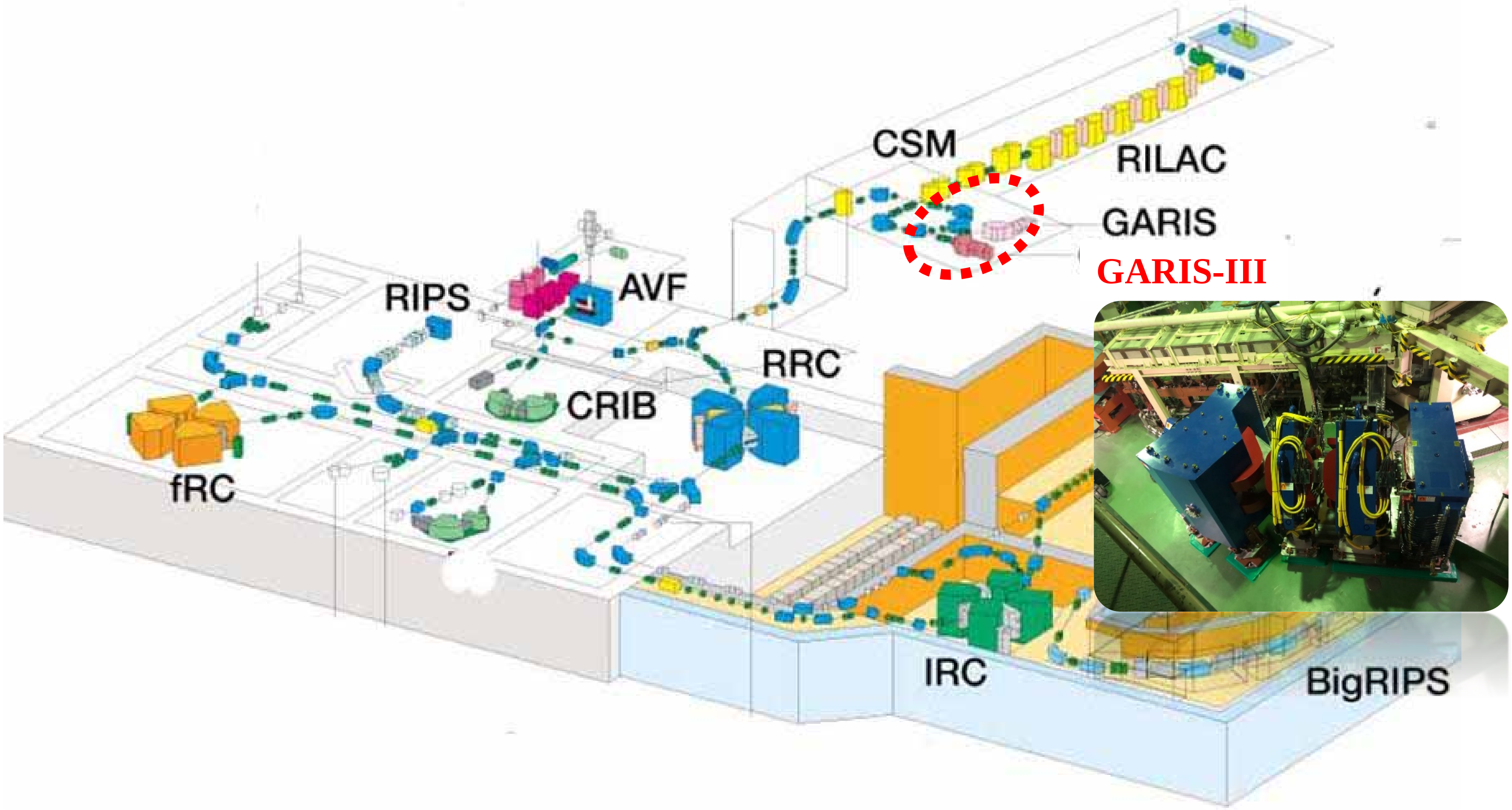






New separator (GARIS-III)

GARIS-III (≅ GARIS-II) already manufactured and was installed.
Same place as of GARIS-II. It will be operational in 2020.



Key elements for Z=119, 120

- **Predicted cross sections are extremely small.** **(< 10 fb ?)**

- **High efficiency** setup for **hot fusion reaction is needed!**
  → **Developed** new separators **GARIS-II** and **GARIS-III**

- Strong **beam intensity is needed!**
  → **Upgrading of RILAC and Ion source**

- **Actinide material** for target is needed!
  → **Collaboration with ORNL (DOE)**

- **Enormous amount of beam dose is needed!**
  → **Long BT when sRILAC+GARIS-III becomes available**
  → **Parallel run** (RRC+GARIS-II and new sRILAC+GARIS-III)

Rotating ^{248}Cm target is "ready"

- **Collaboration started with Oak Ridge National Laboratory**
- **^{248}Cm material transferred**

Rotating system

Target sector

Key elements for Z=119, 120

- **Predicted cross sections are extremely small. (< 10 fb ?)**

- **High efficiency** setup for **hot fusion reaction is needed!**
  → **Developed** new separators **GARIS-II** and **GARIS-III**

- Strong **beam intensity is needed!**
  → **Upgrading of RILAC and Ion source**

- **Actinide material** for target is needed!
  → **Collaboration with ORNL (DOE)**

- **Enormous amount of beam dose is needed!**
  → **Long BT when sRILAC+GARIS-III becomes available**
  → **Parallel run** (RRC+GARIS-II and new sRILAC+GARIS-III)

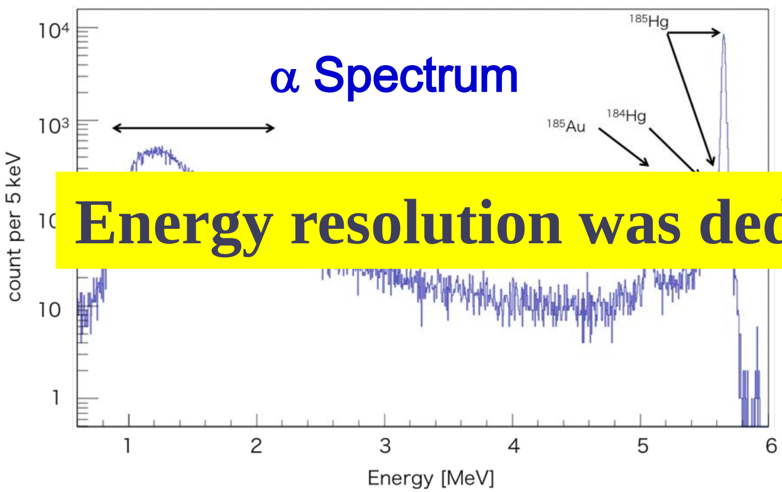
Experimental status

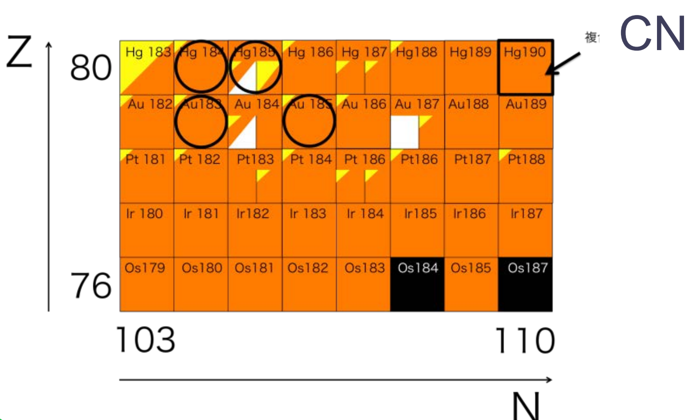
System check and detector calibration

RRC+GARIS-II

$^{51}V+^{139}La$ reaction

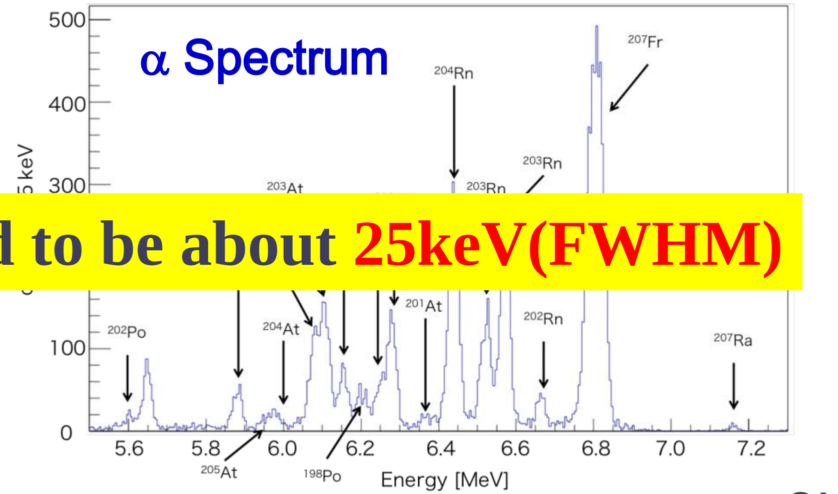
242.6 MeV (center of target)

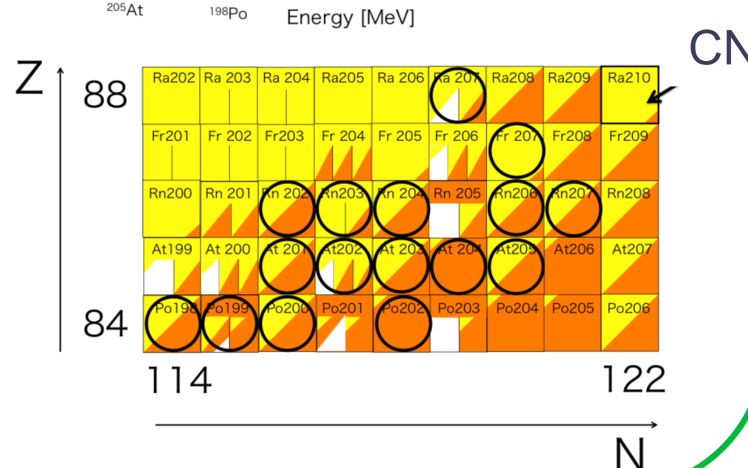




$^{51}V+^{159}Tb$ reaction

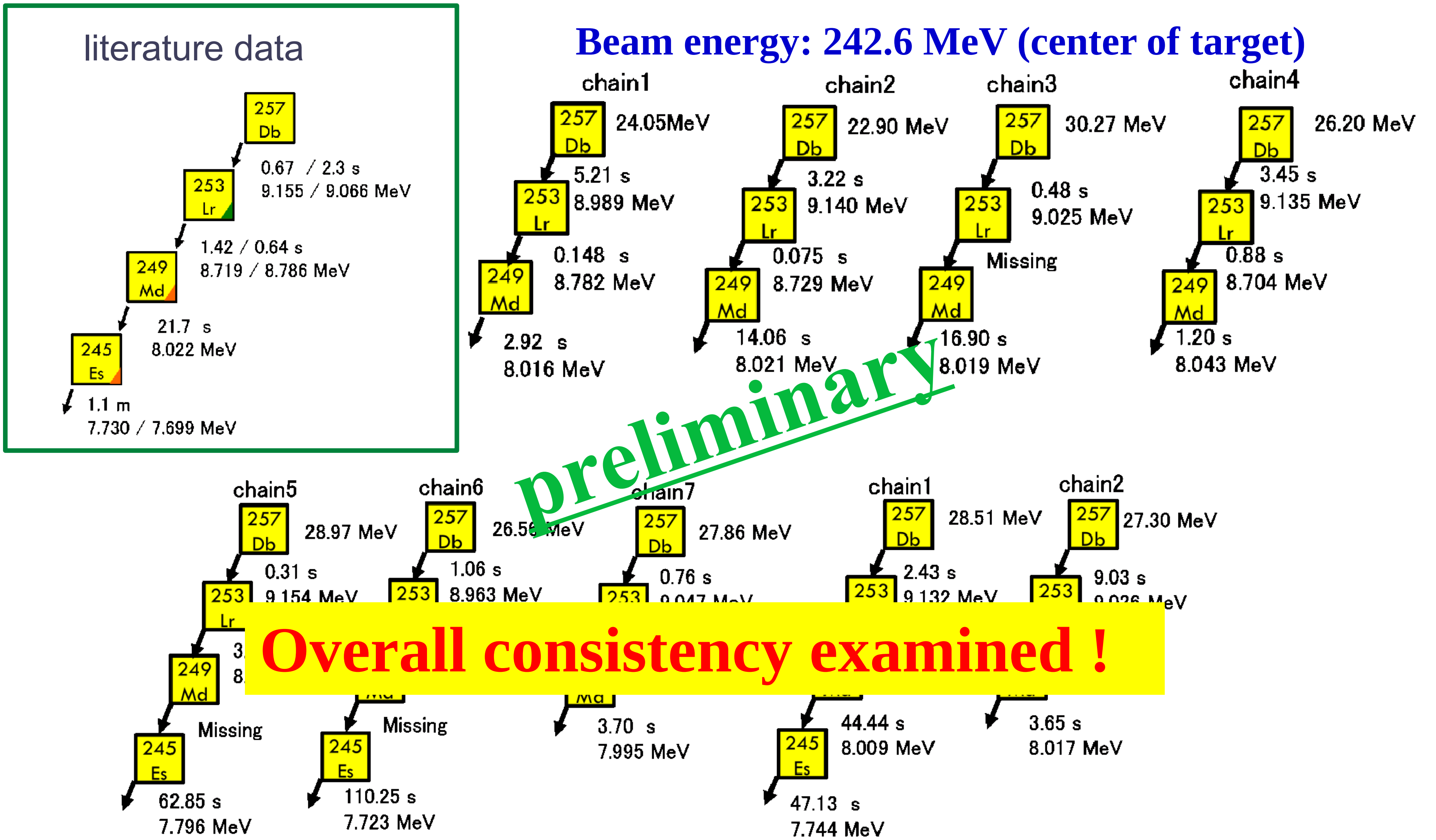
224.8 MeV (center of target)





Energy resolution was deduced to be about 25keV(FWHM)

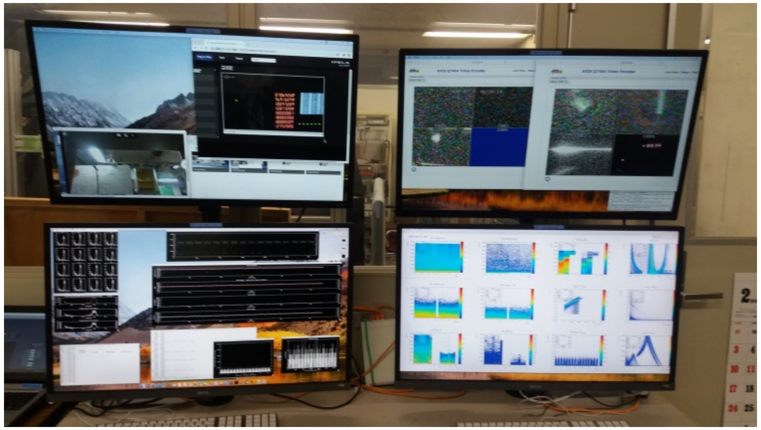
^{208}Pb (^{51}V,2n)^{257}Db reaction



Phys. Rev. C 78, 034604(2008) J. Gates *et al.*,

$^{248}Cm(^{51}V,xn)^{299-xn}119$ measurement

- **Search was started since Jan. 2018.**
- **Experiment is running intermittently.**
- **Still a lot of development is needed.**
  target, background suppression,
  'on-line' analysis, . . .

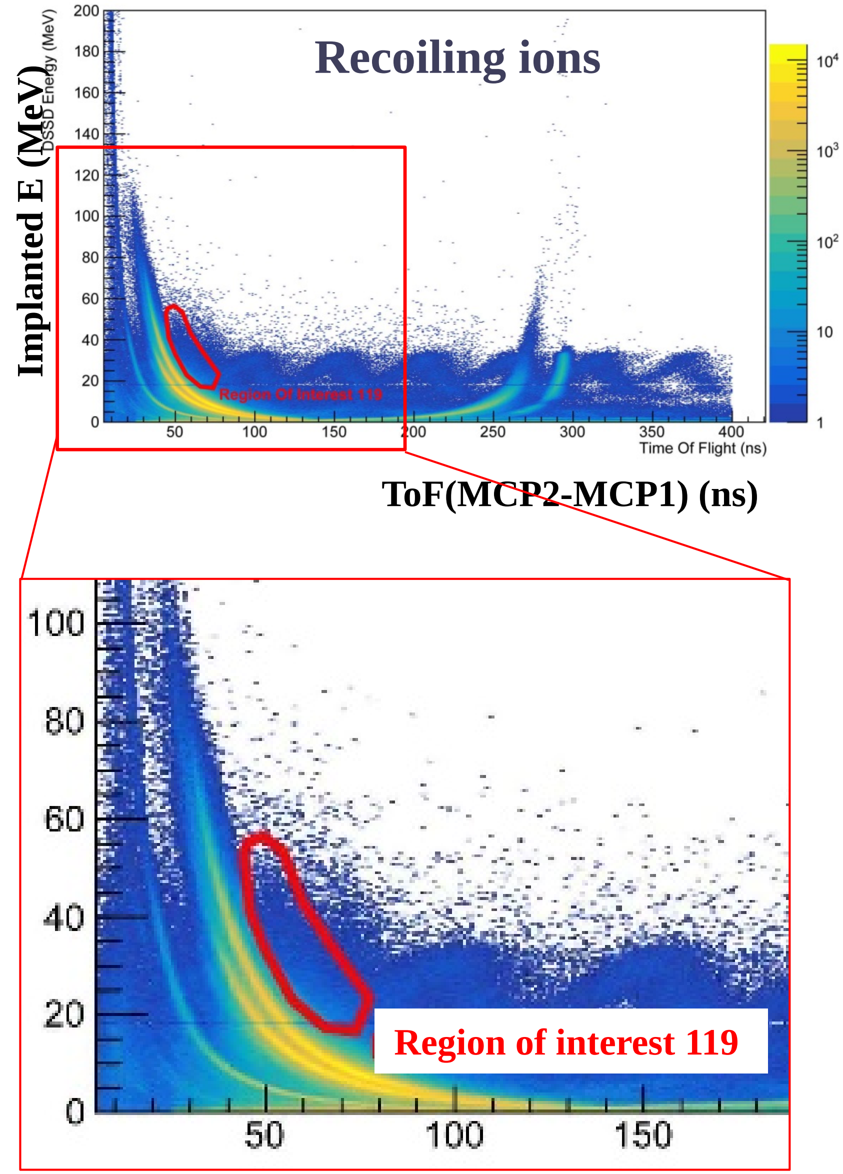


- **Irradiation energy**, **intensity**, **accumulated dose** and **details of target** are treated as **confidential** under nSHE corroboration group.
  Sorry for this inconvenience !

On-line spectra

- **Video shot**

^{51}V-beam with rotating target



Summary

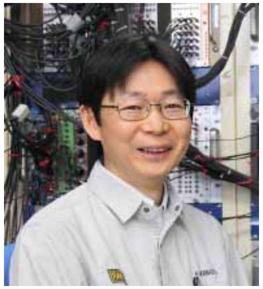
- Element 119 search started but not yet in final form.
- A lot of study/work needed.
- Some headache: beam time, target material, budget, . . .

Long term perspective

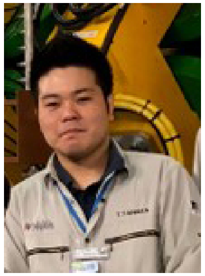
- RRC + GARIS-II is intermittently running!
- Upgraded SRILAC + GARIS-III will be ready by beginning? of 2020

Parallel operation becomes possible in principle, if other difficulties solved

This talk is partly helped in preparing materials by

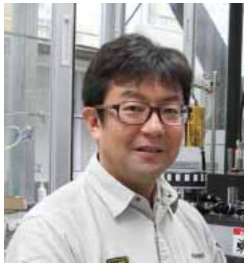


Kouji Morimoto



Taiki Tanaka

Pierre Brionnet



Hiromitsu Haba

The nSHE Collaboration

ORNL, Oak Ridge (USA)
IPHC, Strasburg (France)
RIKEN, Wako (Japan)
Kyushu U, Fukuoka (Japan)
U Tennessee, Knoxville (USA)
JAEA, Tokai (Japan)
IMP, Lanzhou (China)
Tohoku U, Sendai (Japan)
Osaka U, Suita (Japan)
Yamagata U, Yamagata (Japan)