

# **Superheavy element research at RIKEN Nishina Center**

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

**Naming Four New Elements**

|                              |                                                |                               |                                 |                                |                               |
|------------------------------|------------------------------------------------|-------------------------------|---------------------------------|--------------------------------|-------------------------------|
| indium<br>114.8              | tin<br>118.7                                   | antimony                      | tellurium<br>6                  | iodine<br>1                    | xenon                         |
| 81<br><b>Tl</b>              | 82<br><b>Pb</b>                                | 83<br><b>Bi</b>               | 84<br><b>Po</b>                 | 85<br><b>At</b>                | 86<br><b>Rn</b>               |
| 113<br><b>Nh</b><br>nihonium | lead<br>207.2<br>114<br><b>Fl</b><br>flerovium | 115<br><b>Mc</b><br>moscovium | 116<br><b>Lv</b><br>livermorium | 117<br><b>Ts</b><br>tennessine | 118<br><b>Og</b><br>oganesson |



Prof. Kosuke Morita



Prof. Yuri Oganessian

# Present Periodic Table

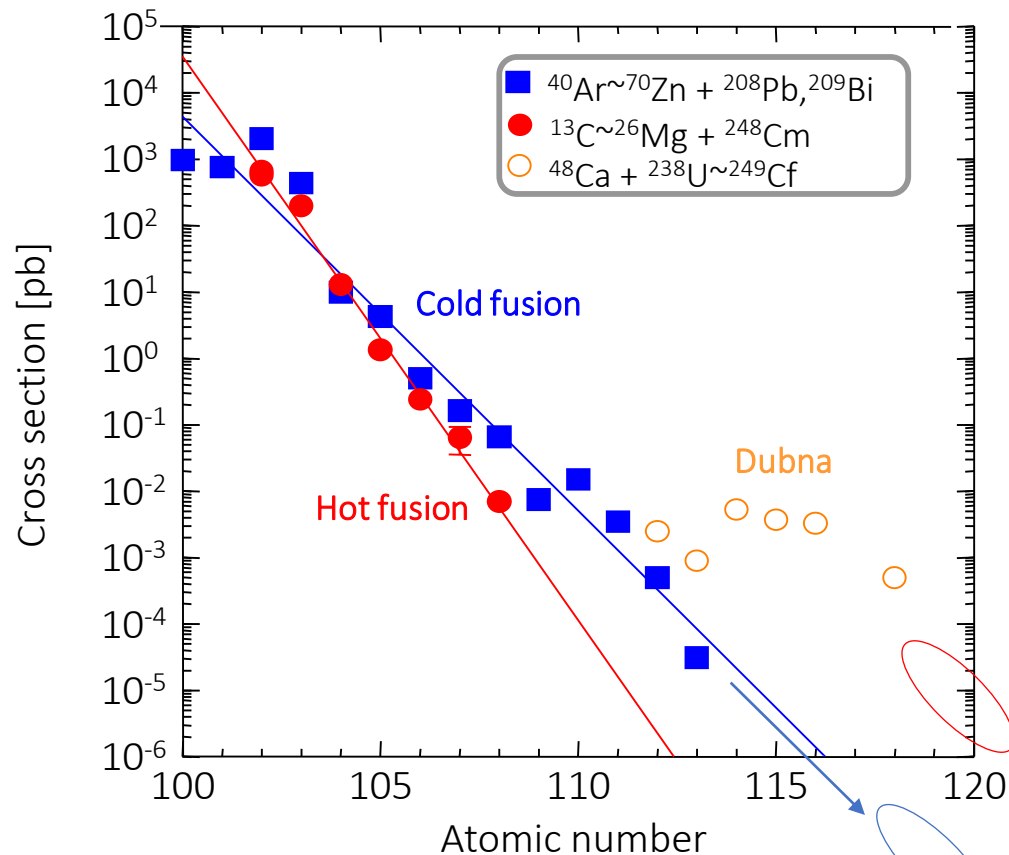
| 族<br>周期 | 1                  | 2                   | 3                  | 4                        | 5                  | 6                    | 7                  | 8                  | 9                    | 10                    | 11                   | 12                   | 13                  | 14                   | 15                  | 16                   | 17                  | 18                 |
|---------|--------------------|---------------------|--------------------|--------------------------|--------------------|----------------------|--------------------|--------------------|----------------------|-----------------------|----------------------|----------------------|---------------------|----------------------|---------------------|----------------------|---------------------|--------------------|
| 1       | 1<br>水素<br>H       |                     |                    |                          |                    |                      |                    |                    |                      |                       |                      |                      |                     |                      |                     |                      |                     | 2<br>ヘリウム<br>He    |
| 2       | 3<br>リチウム<br>Li    | 4<br>ベリリウム<br>Be    |                    |                          |                    |                      |                    |                    |                      |                       |                      |                      | 5<br>ホウ素<br>B       | 6<br>炭素<br>C         | 7<br>窒素<br>N        | 8<br>酸素<br>O         | 9<br>フッ素<br>F       | 10<br>ネオン<br>Ne    |
| 3       | 11<br>ナトリウム<br>Na  | 12<br>マグネシウム<br>Mg  |                    |                          |                    |                      |                    |                    |                      |                       |                      |                      | 13<br>アルミニウム<br>Al  | 14<br>ケイ素<br>Si      | 15<br>リン<br>P       | 16<br>硫黄<br>S        | 17<br>塩素<br>Cl      | 18<br>アルゴン<br>Ar   |
| 4       | 19<br>カリウム<br>K    | 20<br>カルシウム<br>Ca   | 21<br>スカンジウム<br>Sc | 22<br>チタン<br>Ti          | 23<br>バナジウム<br>V   | 24<br>クロム<br>Cr      | 25<br>マンガン<br>Mn   | 26<br>鉄<br>Fe      | 27<br>コバルト<br>Co     | 28<br>ニッケル<br>Ni      | 29<br>銅<br>Cu        | 30<br>亜鉛<br>Zn       | 31<br>ガリウム<br>Ga    | 32<br>ゲルマニウム<br>Ge   | 33<br>ヒ素<br>As      | 34<br>セレン<br>Se      | 35<br>臭素<br>Br      | 36<br>クリプトン<br>Kr  |
| 5       | 37<br>ルビジウム<br>Rb  | 38<br>ストロンチウム<br>Sr | 39<br>イットリウム<br>Y  | 40<br>ジルコニウム<br>Zr       | 41<br>ニオブ<br>Nb    | 42<br>モリブデン<br>Mo    | 43<br>テクネチウム<br>Tc | 44<br>ルテニウム<br>Ru  | 45<br>ロジウム<br>Rh     | 46<br>パラジウム<br>Pd     | 47<br>銀<br>Ag        | 48<br>カドミウム<br>Cd    | 49<br>インジウム<br>In   | 50<br>スズ<br>Sn       | 51<br>アンチモン<br>Sb   | 52<br>テルル<br>Te      | 53<br>ヨウ素<br>I      | 54<br>キセノン<br>Xe   |
| 6       | 55<br>セシウム<br>Cs   | 56<br>バリウム<br>Ba    | ランタノイド<br>f        | 72<br>ハフニウム<br>Hf        | 73<br>タンタル<br>Ta   | 74<br>タングステン<br>W    | 75<br>レニウム<br>Re   | 76<br>オスミウム<br>Os  | 77<br>イリジウム<br>Ir    | 78<br>白金<br>Pt        | 79<br>金<br>Au        | 80<br>水銀<br>Hg       | 81<br>タリウム<br>Tl    | 82<br>鉛<br>Pb        | 83<br>ビスマス<br>Bi    | 84<br>ポロニウム<br>Po    | 85<br>アスタチン<br>At   | 86<br>ラドン<br>Rn    |
| 7th     | 87<br>フランシウム<br>Fr | 88<br>ラジウム<br>Ra    | アクチノイド<br>f        | 104<br>ラザホージウム<br>Rf     | 105<br>ドブニウム<br>Db | 106<br>シーボーギウム<br>Sg | 107<br>ボーリウム<br>Bh | 108<br>ハッシウム<br>Hs | 109<br>マイトネリウム<br>Mt | 110<br>ダームスタチウム<br>Ds | 111<br>レントゲニウム<br>Rg | 112<br>コペルニシウム<br>Cn | 113<br>ニホニウム<br>Nh  | 114<br>フレロビウム<br>Fl  | 115<br>モスコビウム<br>Mc | 116<br>リバモリウム<br>Lv  | 117<br>テネシン<br>Ts   | 118<br>オガネソン<br>Og |
| 8th     | 119                | 120                 |                    | 57<br>ランタン<br>La         | 58<br>セリウム<br>Ce   | 59<br>プラセオジム<br>Pr   | 60<br>ネオジム<br>Nd   | 61<br>プロメチウム<br>Pm | 62<br>サマリウム<br>Sm    | 63<br>ユウロビウム<br>Eu    | 64<br>ガドリニウム<br>Gd   | 65<br>テルビウム<br>Tb    | 66<br>ジスプロシウム<br>Dy | 67<br>ホルミウム<br>Ho    | 68<br>エルビウム<br>Er   | 69<br>ツリウム<br>Tm     | 70<br>イッテルビウム<br>Yb | 71<br>ルテチウム<br>Lu  |
|         | 89<br>アクチニウム<br>Ac | 90<br>トリウム<br>Th    |                    | 91<br>protactinium<br>Pa | 92<br>ウラン<br>U     | 93<br>ネプツニウム<br>Np   | 94<br>プルトニウム<br>Pu | 95<br>アメリシウム<br>Am | 96<br>キュリウム<br>Cm    | 97<br>バークリウム<br>Bk    | 98<br>カリホルニウム<br>Cf  | 99<br>アインシュタイン<br>Es | 100<br>フェルミウム<br>Fm | 101<br>メンデレビウム<br>Md | 102<br>ノーベリウム<br>No | 103<br>ローレンシウム<br>Lr |                     |                    |

Periodic table was fully filed to end of 7<sup>th</sup> period.  
Next new element may be 119 or 120  
On the 8<sup>th</sup> period!

Next New!

# Cold fusion → Hot fusion

Further new element search using cold fusion is hopeless because of its **small production cross-section**.



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

# $^{48}\text{Ca}$ beam to $^{50}\text{Ti}$ , $^{51}\text{V}$ , $^{54}\text{Cr}$ beam

(Not easy!)

All products  $Z > 112$  produced by hot fusion reactions, were produced **by using  $^{48}\text{Ca}$  beam**.

**Cf** ( $Z=98$ ) is the **heaviest target realistically available**.

( $^{244}\text{Es}$  ( $Z=99$ )) is not enough material available  
for high intensity beam experiment)

Then  $\text{Cf} + \text{Ca} \rightarrow$  **118(Og)** is **heaviest element**  
**produced by  $^{48}\text{Ca}$  beam**.

**We must change  $^{48}\text{Ca}$  induce reaction to Ti, V or Cr**  
induce reaction.

But the prediction of the **production cross sections are**  
**smaller than  $^{48}\text{Ca}$  induced reactions**.

# Combination of Beam and Target

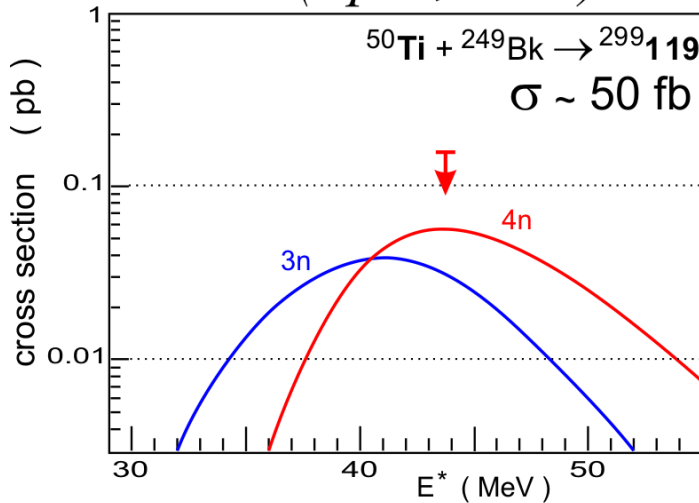
|                    |                     |                    |                      |                    |                       |                    |                    |                      |                       |                      |                      |                     |                       |                     |                      |                     |                      |
|--------------------|---------------------|--------------------|----------------------|--------------------|-----------------------|--------------------|--------------------|----------------------|-----------------------|----------------------|----------------------|---------------------|-----------------------|---------------------|----------------------|---------------------|----------------------|
| 1                  | 2                   | 3                  | 4                    | 5                  | 6                     | 7                  | 8                  | 9                    | 10                    | 11                   | 12                   | 13                  | 14                    | 15                  | 16                   | 17                  | 18                   |
| 1<br>水素<br>H       | 2<br>ヘリウム<br>He     |                    |                      |                    |                       |                    |                    |                      |                       |                      |                      |                     |                       |                     |                      |                     |                      |
| 3<br>リチウム<br>Li    | 4<br>ベリリウム<br>Be    |                    |                      |                    |                       |                    |                    |                      |                       |                      |                      | 5<br>ホウ素<br>B       | 6<br>炭素<br>C          | 7<br>窒素<br>N        | 8<br>酸素<br>O         | 9<br>フッ素<br>F       | 10<br>ネオン<br>Ne      |
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| 37<br>ルビウム<br>Rb   | 38<br>ストロンチウム<br>Sr | 39<br>イットリウム<br>Y  | 40<br>ジルコニウム<br>Zr   | 41<br>ニオブ<br>Nb    | 42<br>モリブデン<br>Mo     | 43<br>テクネチウム<br>Tc | 44<br>ルテチウム<br>Ru  | 45<br>ロジウム<br>Rh     | 46<br>パラジウム<br>Pd     | 47<br>銀<br>Ag        | 48<br>カドミウム<br>Cd    | 49<br>インジウム<br>In   | 50<br>スズ<br>Sn        | 51<br>アンチモン<br>Sb   | 52<br>テルル<br>Te      | 53<br>ヨウ素<br>I      | 54<br>キセノン<br>Xe     |
| 55<br>セシウム<br>Cs   | 56<br>バリウム<br>Ba    | ランタノイド             | 72<br>ハフニウム<br>Hf    | 73<br>タンタル<br>Ta   | 74<br>タングステン<br>W     | 75<br>レニウム<br>Re   | 76<br>オスミウム<br>Os  | 77<br>イリジウム<br>Ir    | 78<br>白金<br>Pt        | 79<br>金<br>Au        | 80<br>水銀<br>Hg       | 81<br>タリウム<br>Tl    | 82<br>鉛<br>Pb         | 83<br>ビスマス<br>Bi    | 84<br>ポロニウム<br>Po    | 85<br>アスタチン<br>At   | 86<br>ラドン<br>Rn      |
| 87<br>フランシウム<br>Fr | 88<br>ラジウム<br>Ra    | アクチノイド             | 104<br>ラザホージウム<br>Rf | 105<br>ドブニウム<br>Db | 106<br>シーボーギウム<br>Sg  | 107<br>ボーリウム<br>Bh | 108<br>ハッシウム<br>Hs | 109<br>マイトネリウム<br>Mt | 110<br>ダームスタチウム<br>Ds | 111<br>レントゲニウム<br>Rg | 112<br>コペルニシウム<br>Cn | 113<br>Nh           | 114<br>フレロビウム<br>Fl   | 115<br>Mc           | 116<br>リバモリウム<br>Lv  | 117<br>Ts           | 118<br>Og            |
| 119                | 120                 | ランタノイド             | 57<br>ランタン<br>La     | 58<br>セリウム<br>Ce   | 59<br>プラセオジム<br>Pr    | 60<br>ネオジム<br>Nd   | 61<br>プロメチウム<br>Pm | 62<br>サマリウム<br>Sm    | 63<br>ユウロピウム<br>Eu    | 64<br>ガドリニウム<br>Gd   | 65<br>テルビウム<br>Tb    | 66<br>ジスプロシウム<br>Dy | 67<br>ホルミウム<br>Ho     | 68<br>エルビウム<br>Er   | 69<br>ツリウム<br>Tm     | 70<br>イットリウム<br>Yb  | 71<br>ルテチウム<br>Lu    |
|                    |                     | アクチノイド             | 89<br>アクチニウム<br>Ac   | 90<br>トロンリウム<br>Th | 91<br>プロトアクチニウム<br>Pa | 92<br>ウラン<br>U     | 93<br>ネプツニウム<br>Np | 94<br>プルトニウム<br>Pu   | 95<br>アメリシウム<br>Am    | 96<br>キュリウム<br>Cm    | 97<br>バークリウム<br>Bk   | 98<br>カリホルニウム<br>Cf | 99<br>アインスタイニウム<br>Es | 100<br>フェルミウム<br>Fm | 101<br>メンデルビウム<br>Md | 102<br>ノーベリウム<br>No | 103<br>ローレンシウム<br>Lr |

~10 mg ~μg (rotating target X)

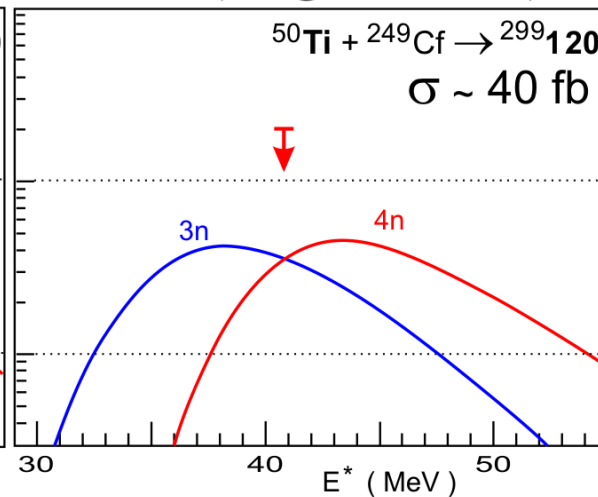
# Example of the cross section predictions of $^{48}\text{Ca}$ to $^{50}\text{Ti}$ , $^{51}\text{V}$ , $^{54}\text{Cr}$

Ti beam:

*TASCA (April, 2012)*

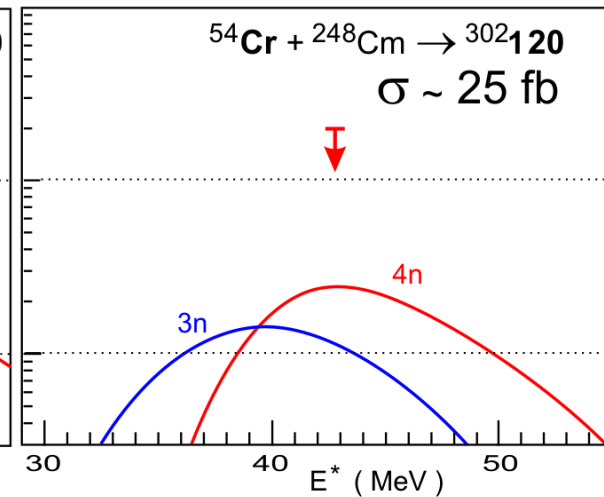


*TASCA (August, 2011)*



Cr beam:

*SHIP (May, 2011)*



predictions: Zagrebaev & Greiner. PRC 2008

**Predicted cross sections are less than 50 fb.  
But, no one knows real value.**

**→ We need the reliable predictions !**

# Strategy of new element search at RIKEN

Past **RILAC + GARIS-I or GARIS-II** (until end of June 2017)

•  $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow \text{Lv}(116) \rightarrow$  **See J. Phys. Soc. Jpn. 86, 034201 (2017)**

• Study for barrier distributions of  $^{248}\text{Cm} + ^{48}\text{Ca}$  **Taiki Tanaka's Talk**

$^{249}\text{Cf} + ^{48}\text{Ca} \rightarrow ^{297}\text{Og} + xn$

$^{248}\text{Cm} + ^{50}\text{Ti} \rightarrow ^{298}\text{Og} + xn$

**See also J. Phys. Soc. Jpn. 87, 014201 (2018)**

**interrupted by upgrading**

**RILAC-II + RRC + GARIS-II** (started in Dec. 2017)

- $^{248}\text{Cm} + ^{51}\text{V} \rightarrow$  **119**  $\rightarrow$  **Running!**
- $^{248}\text{Cm} + ^{54}\text{Cr} \rightarrow$  **120** (after the 119)

**New RILAC + GARIS-III** (will be started early in 2020)

- $^{248}\text{Cm} + ^{51}\text{V} \rightarrow$  **119**
- $^{248}\text{Cm} + ^{54}\text{Cr} \rightarrow$  **120** (after the 119)

# Key points 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**

Higher **beam intensity is needed!**

→ **Upgrading of RILAC and Ion source**

**Actinide material** for target is needed!

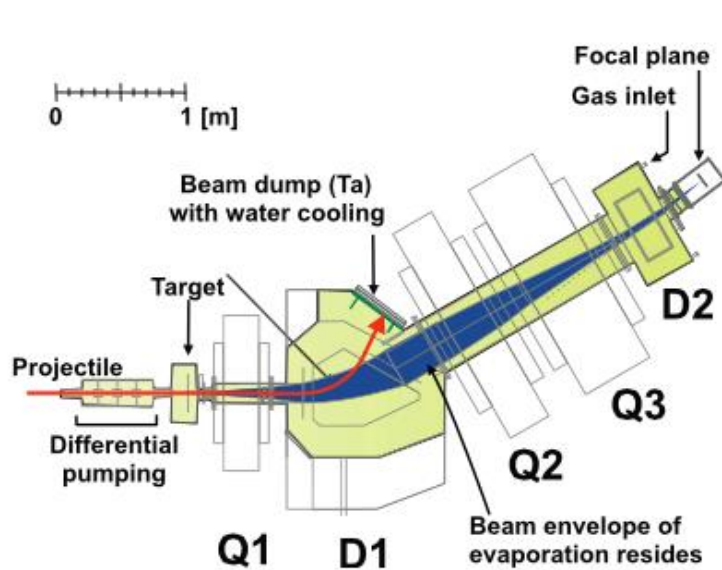
→ Started to **Collaborate with ORNL (DOE)**

**An enormous beam dose is needed!**

→ **Long Beam Time**

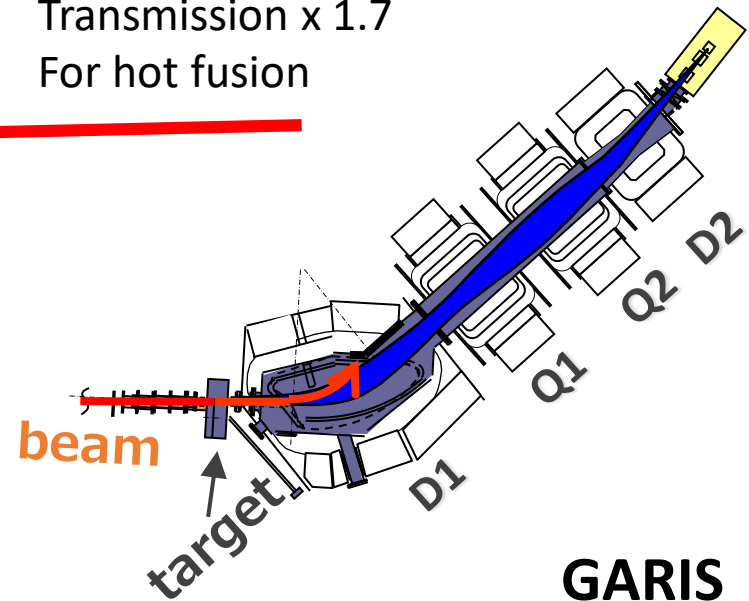
→ **Parallel run** (RRC+GARIS-II and new RILAC+GARIS-III)

# New Separator GARIS-II and GARIS-III

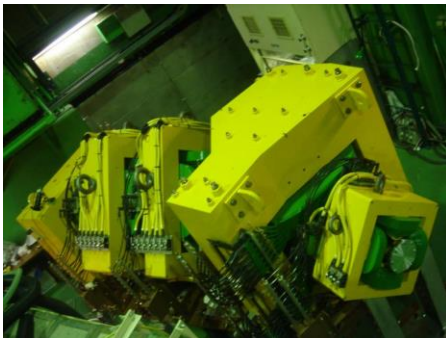


**GARIS-II and III**

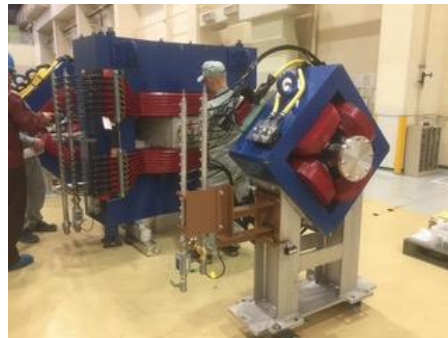
Transmission x 1.7  
For hot fusion



**GARIS**



**GARIS-II**



**GARIS-III**

**Asymmetric (hot fusion) reaction:**

- Small momentum of ERs
- recoil effect of neutron emissions
- multiple scattering with He gas

→ **Large angular acceptance**  
**Short pass length is needed!**

# Key points for Z=119, 120

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

**High efficiency** setup for **hot fusion reaction needed!**

→ **Developed** new separators **GARIS-II** and **GARIS-III**

Higher **beam intensity needed!**

→ **Upgrading of RILAC and Ion source**

**Actinide material** for target needed!

→ Started to **Collaborate with ORNL (DOE)**

**An enormous beam dose needed!**

→ **Long Beam Time**

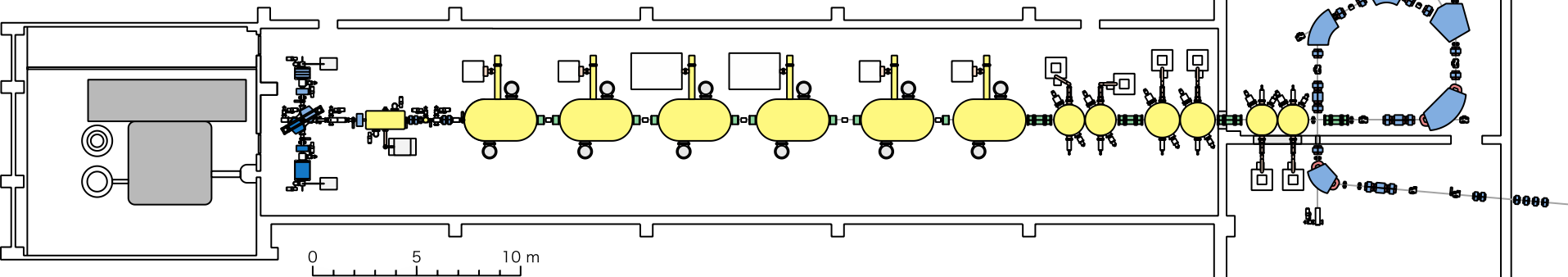
→ **Parallel run** (RRC+GARIS-II and new RILAC+GARIS-III)

# **Upgrade plan of RILAC Facility**

# RILAC Upgrade plan

RILAC June, 2017

$E: 5 \text{ MeV/u}, M/q=5$



## Upgrade plan



**28GHz SC-ECRIS**

**$E: 6.5 \text{ MeV/u}$  for  $M/q=5$**

**$7.5 \text{ MeV/u}$  for  $M/q=4$**

**$12 \text{ MeV/u}$  for  $M/q=2$**

**SHE**

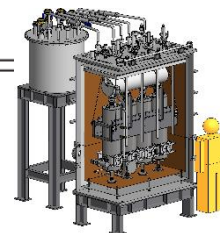
**RI**

**SC-QWR**

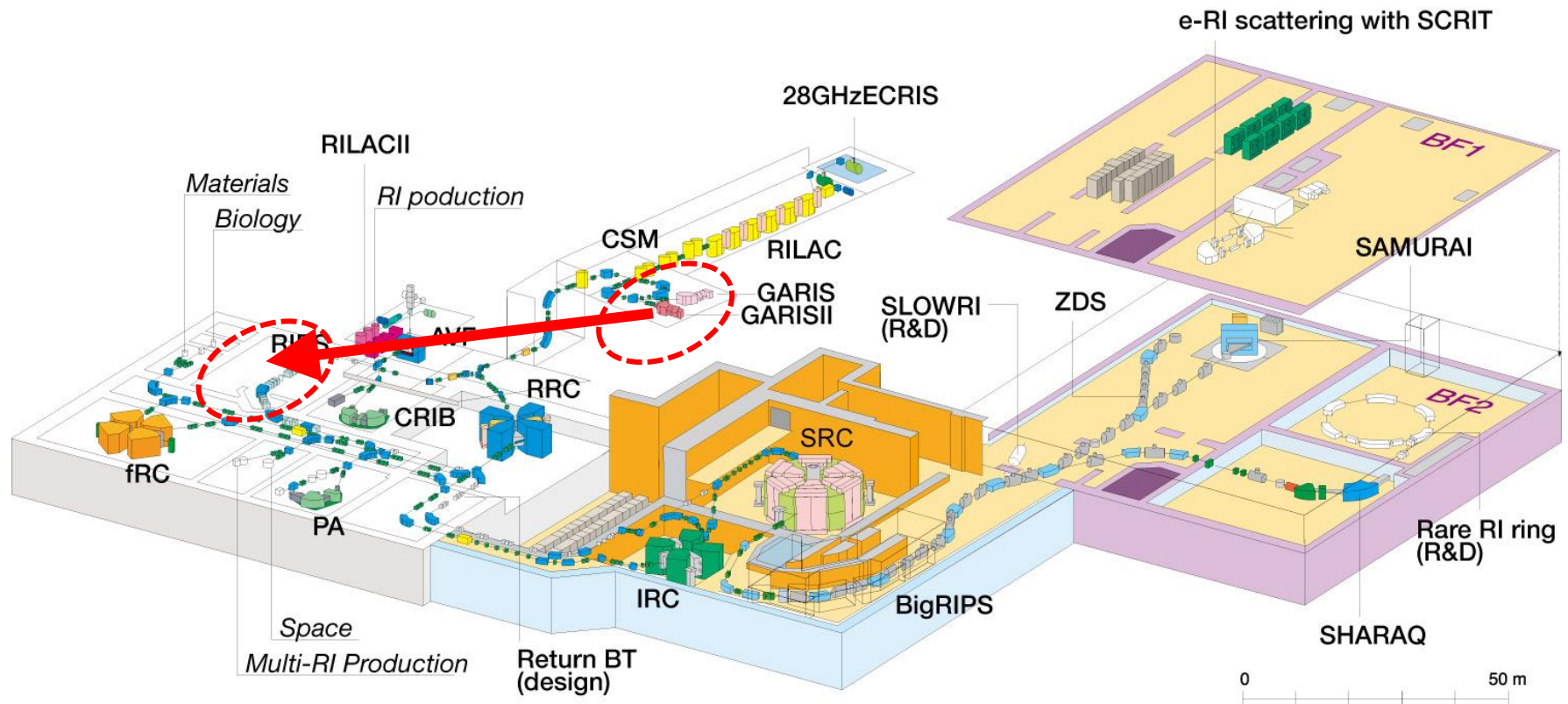
**18 MV**

**$\sim 16 \text{ MV}$**

**Beam increase  $\sim$  factor of 10 !**



# GARIS-II was moved from RILAC to RRC facility. ( in order to continue the research during the upgrade)





# Key points for Z=119, 120

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

**High efficiency** setup for **hot fusion reaction needed!**

→ **Developed** new separators **GARIS-II** and **GARIS-III**

Higher **beam intensity needed!**

→ **Upgrading of RILAC and Ion source**

**Actinide material** for target needed!

→ Started to **Collaborate with ORNL (DOE)**

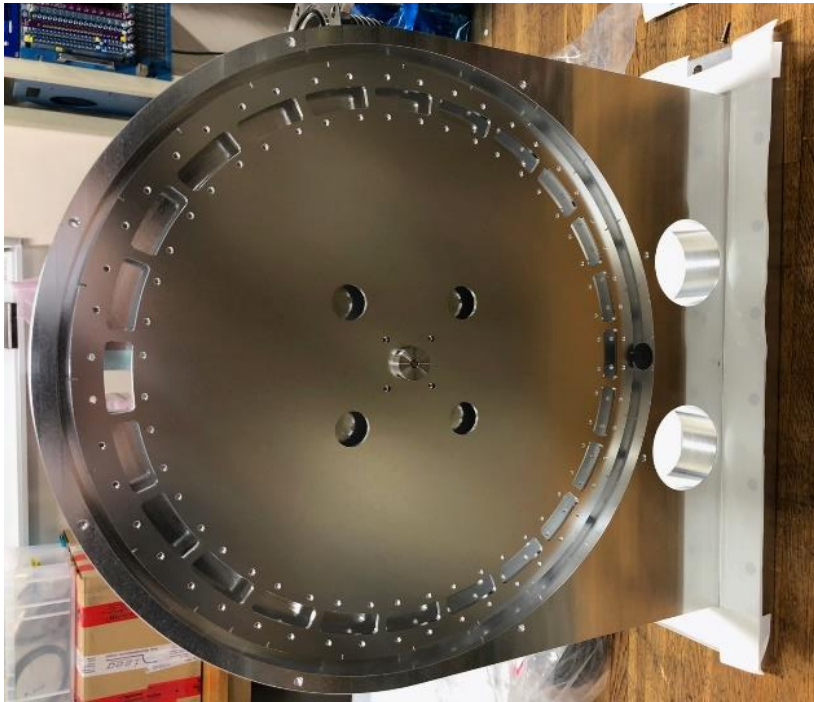
**An enormous beam dose needed!**

→ **Long Beam Time**

→ **Parallel run** (RRC+GARIS-II and new RILAC+GARIS-III)

# Rotating $^{248}\text{Cm}$ target is ready

We started to collaborate with Oak Ridge National Laboratory, and  $^{248}\text{Cm}$  material was already supplied.



Rotating system



Target sector

# Key points for Z=119, 120

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

**High efficiency** setup for **hot fusion reaction needed!**

→ **Developed** new separators **GARIS-II** and **GARIS-III**

Higher **beam intensity needed!**

→ **Upgrading of RILAC and Ion source**

**Actinide material** for target needed!

→ Started to **Collaborate with ORNL (DOE)**

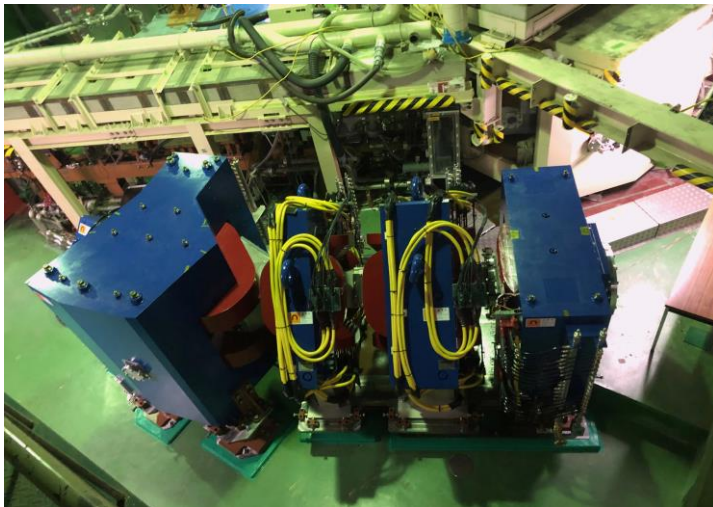
**An enormous beam dose needed!**

→ **Long Beam Time** → **New element search has first priority.**

→ **Parallel run** (RRC+GARIS-II and new RILAC+GARIS-III)

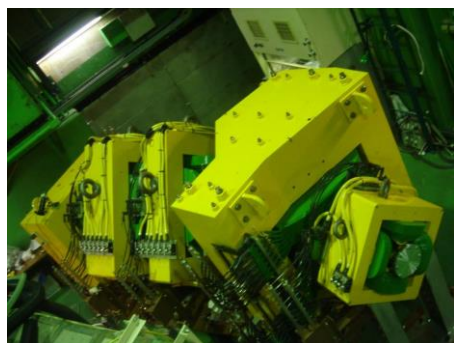
# **Status of new RILAC Facility**

# GARIS-III just installed to RILAC experimental hall

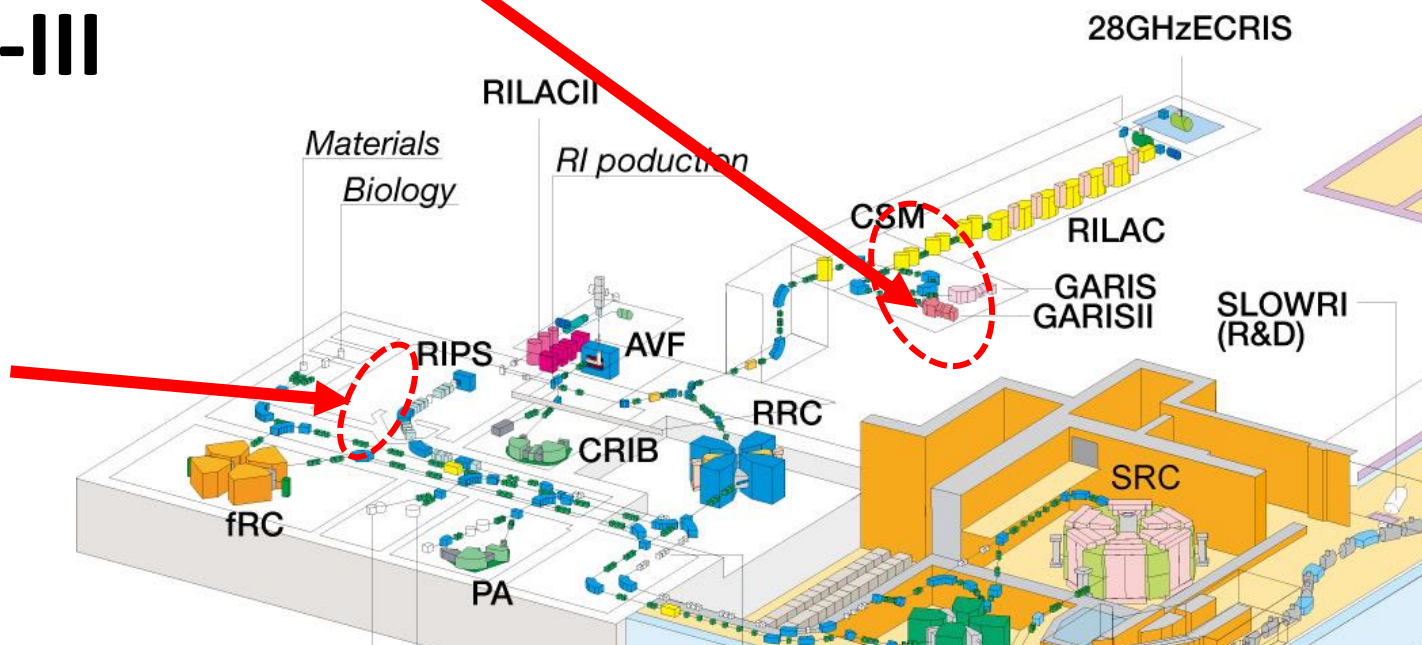


**GARIS-III**

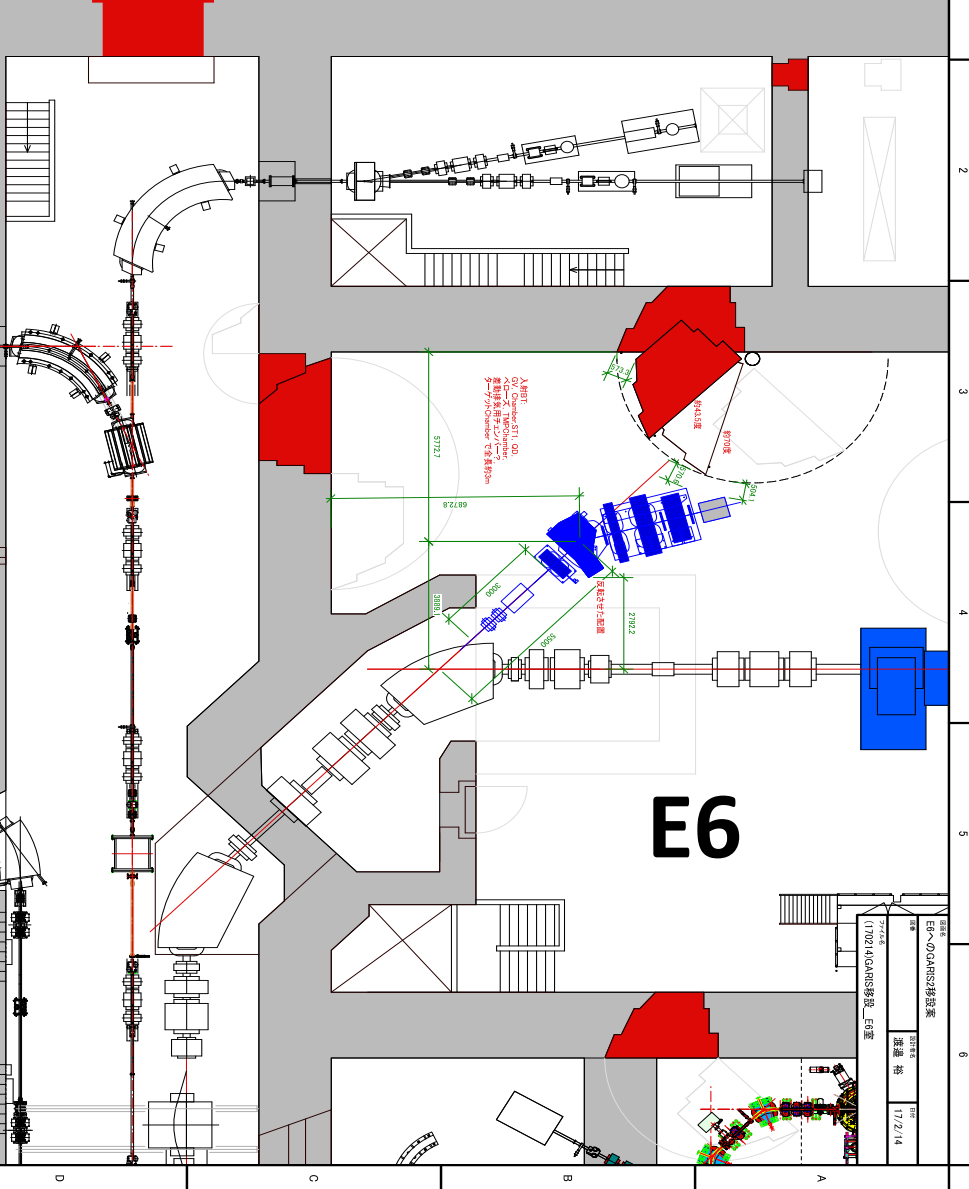
**New RILAC and GARIS-III  
will be ready in beginning of 2020.**



**GARIS-II**

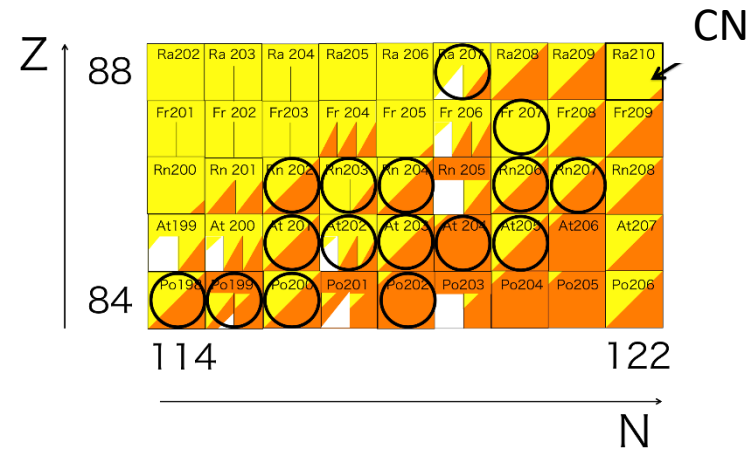
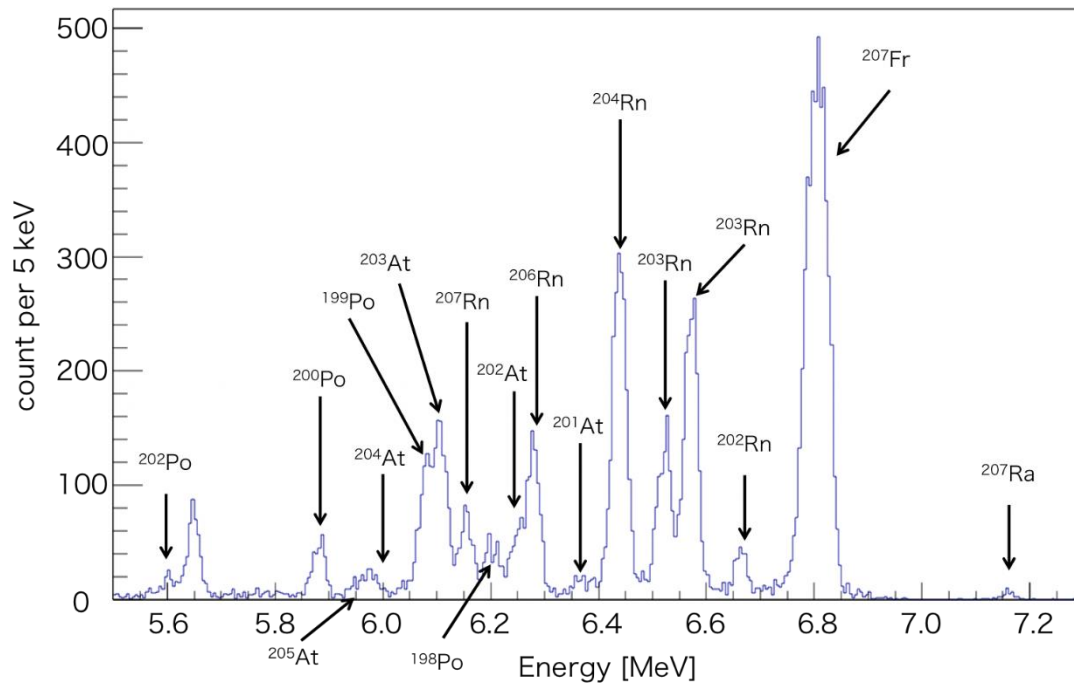


**Status of experiment for new element**



**GARIS-II was moved at E6 room next to the RIPS.  
LINAC2 + RRC + GARIS-II became ready in Dec. 2017.**

# System check and detector calibration for new configuration RRC + GARIS-II.

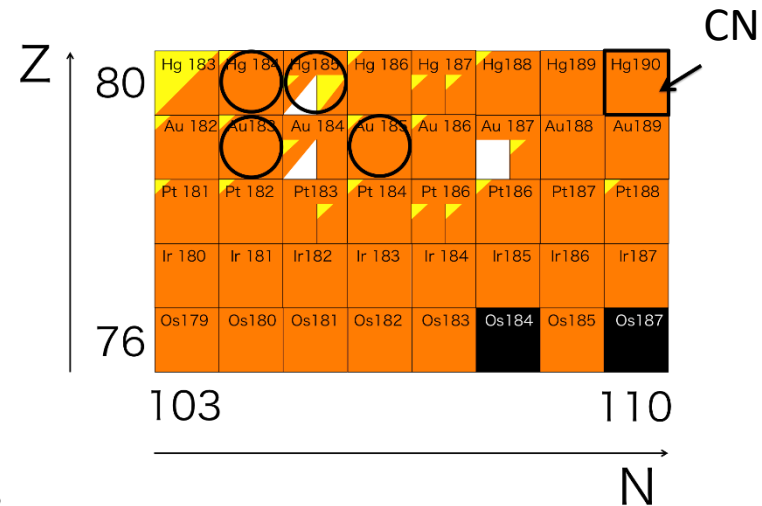
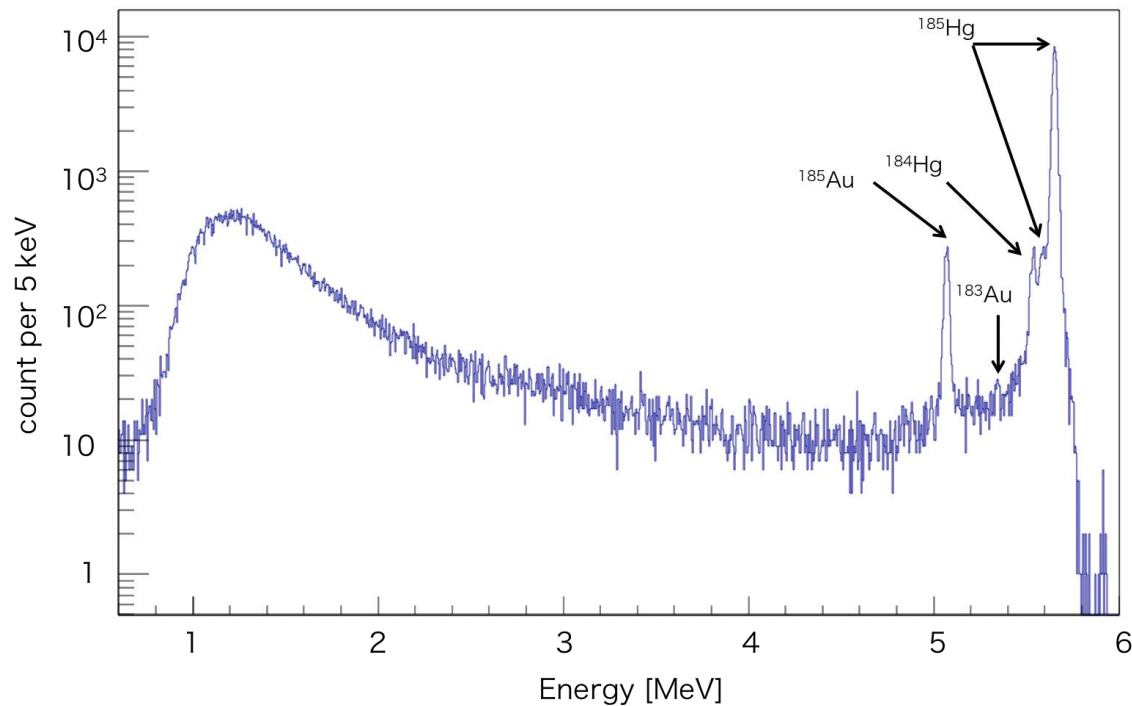


Data obtained by  $^{51}\text{V} + ^{159}\text{Tb}$  reaction

Beam energy: 224.8 MeV (center of target)

DSSD was calibrated and energy resolution was deduced about **25keV(FWHM)**

# System check and detector calibration for new configuration RRC + GARIS-II.



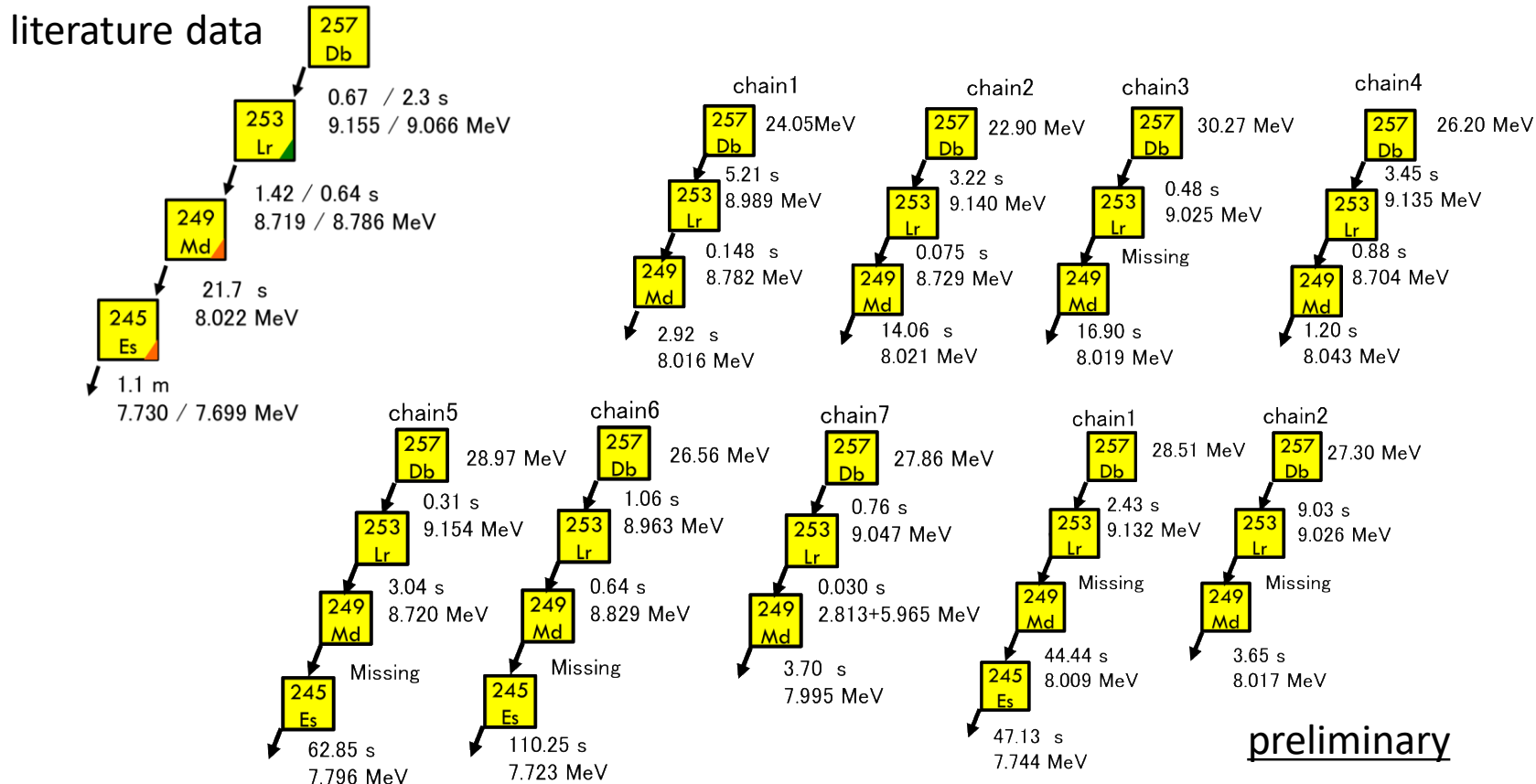
Data obtained by  $^{51}\text{V} + ^{139}\text{La}$  reaction

Beam energy: 242.6 MeV (center of target)

# $^{51}\text{V}(^{208}\text{Pb}, xn)^{259-xn}\text{Db}$

RRC+GARIS-II

Beam energy: 242.6 MeV (center of target)



Observed cross section was confirmed in the order of magnitude with Ref.1.  
The position distribution in the focal plane detector was proper. (Bp setting OK!)

**Overall system performance was confirmed!**

Ref.1: Phys. Rev. C **78**, 034604(2008) J. Gates *et al.*,

# Strategy of new element search at RIKEN

Past **RILAC + GARIS-I or GARIS-II** (until end of June 2017)

- $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow \text{Lv}(116) \rightarrow \text{Succeeded!}$
- Study for barrier distributions of  $^{248}\text{Cm} + ^{22}\text{Ne}, ^{23}\text{Na}, ^{30}\text{Si}, ^{34}\text{S}, ^{40}\text{Ar}, ^{50}\text{Ti}, ^{51}\text{V}$
- $^{248}\text{Cm} + ^{50}\text{Ti} \rightarrow \text{Og}(118)$  pilot reaction (study for post  $^{48}\text{Ca}$ )  
 $\rightarrow$  interrupted by upgrading

**RILAC-II + RRC + GARIS-II** (started in Dec. 2017)

- $^{248}\text{Cm} + ^{51}\text{V} \rightarrow 119 \rightarrow \text{Running!}$
- $^{248}\text{Cm} + ^{54}\text{Cr} \rightarrow 120$  (after the 119)

**New RILAC + GARIS-III** (will be started early in 2020)

- $^{248}\text{Cm} + ^{51}\text{V} \rightarrow 119$
- $^{248}\text{Cm} + ^{54}\text{Cr} \rightarrow 120$  (after the 119)



**119<sup>th</sup> element search was started from Jan. 2018.**

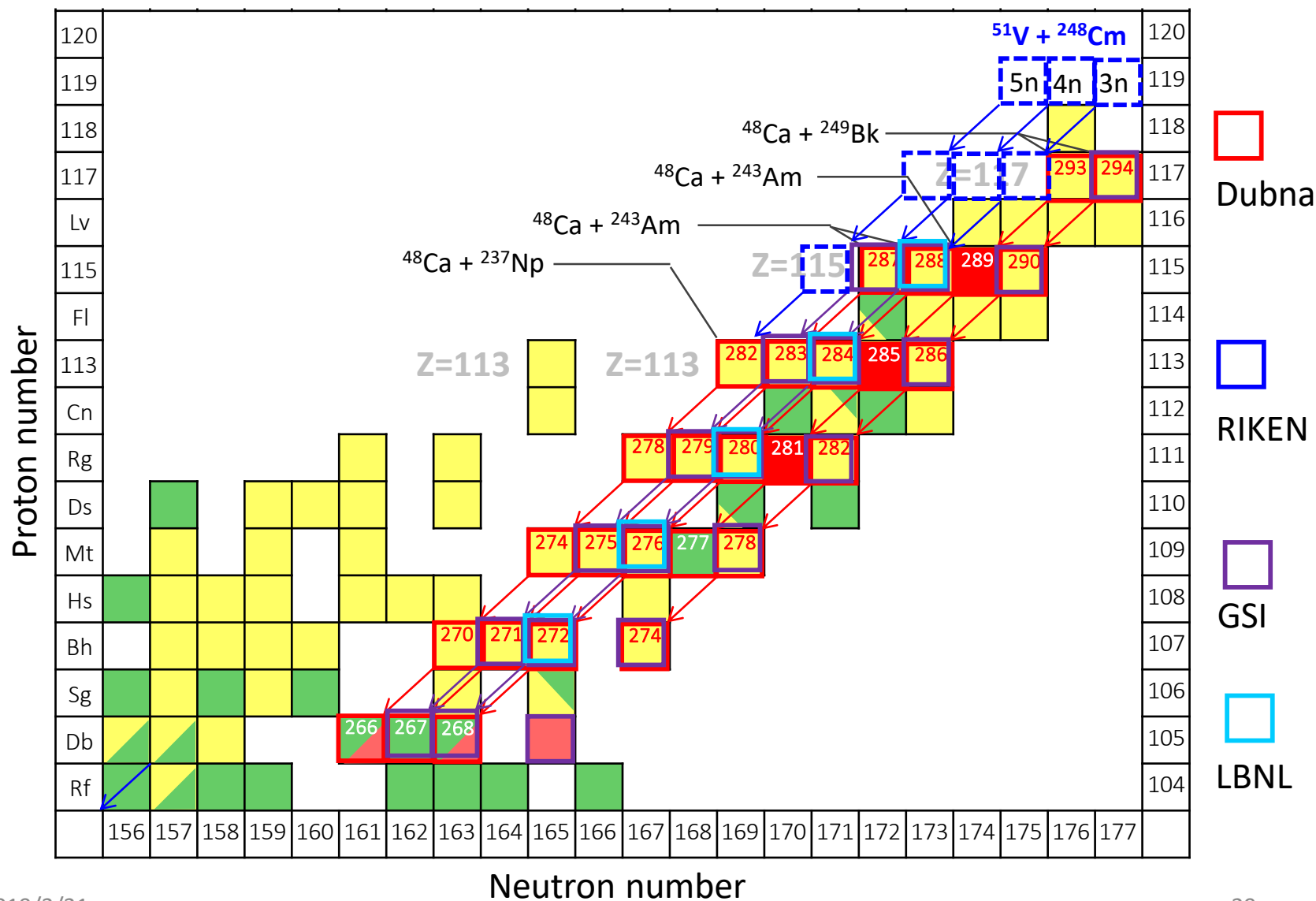
**Irradiation energy , beam intensity, accumulated dose and details of target are confidential matter of new SHE corroboration group.**

I could not present the detail of this time. Sorry.

**Experiment is continued intermittently.**

This year, we already run Jan. 7<sup>th</sup> to Mar. 7<sup>th</sup>.  
Next beam time is scheduled from Apr. 21<sup>st</sup>.

# Prospected decay chains of V + Cm



# Summary of status at RIKEN

- RILAC-II + RRC + GARIS-II started new element search  
from **Jan. 2018**
- New RILAC + GARIS-III now preparing  
it will be ready **early in 2020**

When both setup will be ready,

**we can perform new element search in parallel.**

**Thank you for your attention!**