Perspectives of the superheavy element chemistry at RIKEN GARIS

Nishina Center, RIKEN
Hiromitsu Haba

CONTENTS

1. Present status of SHE chemistry at RIKEN GARIS
2. Future plans
   2.1. Production of SHE nuclides for chemical experiments
   2.2. New chemistry apparatus
3. Summary
1. Present status of SHE chemistry at RIKEN GARIS

Development of the gas-jet transport system coupled to GARIS

Startup of the SHE chemistry in RIKEN

RIKEN GARIS

Gas-jet transport system

Model experiments

\[ ^{169}\text{Tm} ( ^{40}\text{Ar}, 3n)^{206}\text{Fr} \ (15.9 \text{ s}) \]
\[ ^{208}\text{Pb} ( ^{40}\text{Ar}, 3n)^{245}\text{Fm} \ (4.2 \text{ s}) \]
\[ ^{238}\text{U} ( ^{22}\text{Ne}, 5n)^{255}\text{No} \ (3.1 \text{ min}) \]
Model experiments of the GARIS/gas-jet system

<table>
<thead>
<tr>
<th>Reaction</th>
<th>206Fr</th>
<th>245Fm</th>
<th>255No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross section</td>
<td>$^{169}$Tm($^{40}$Ar,3$n$)</td>
<td>$^{208}$Pb($^{40}$Ar,3$n$)</td>
<td>$^{238}$U($^{22}$Ne,5$n$)</td>
</tr>
<tr>
<td></td>
<td>$376 , \mu$b$^1$</td>
<td>$15 , \text{nb}^2$</td>
<td>$90 , \text{nb}^3$</td>
</tr>
<tr>
<td>Beam energy (MeV)</td>
<td>170</td>
<td>199</td>
<td>114</td>
</tr>
<tr>
<td>Recoil energy (MeV)</td>
<td>32</td>
<td>32</td>
<td>9.6</td>
</tr>
<tr>
<td>Beam intensity (p$\mu$A)</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Target ($\mu$g/cm$^2$)</td>
<td>120 (Tm)</td>
<td>420 (Pb)</td>
<td>310 (U$_3$O$_8$)</td>
</tr>
<tr>
<td>Target backing ($\mu$g/cm$^2$)</td>
<td>30 (C)</td>
<td>30 (C)</td>
<td>1270 (Ti)</td>
</tr>
<tr>
<td>Magnetic rigidity (Tm)</td>
<td>1.64</td>
<td>2.01</td>
<td>1.93</td>
</tr>
<tr>
<td>He pressure (Pa)</td>
<td>88</td>
<td>88</td>
<td>38</td>
</tr>
<tr>
<td>Mylar window ($\mu$m)</td>
<td>3.5</td>
<td>3.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Support grid (%)</td>
<td>89</td>
<td>89</td>
<td>72</td>
</tr>
<tr>
<td>Gas-jet eff. (%)</td>
<td>$88 \pm 4$</td>
<td>$83 \pm 9$</td>
<td>$84 \pm 9$</td>
</tr>
<tr>
<td>GARIS eff. (%)</td>
<td>-</td>
<td>$43 \pm 4$</td>
<td>$5 \pm 1$</td>
</tr>
</tbody>
</table>

3) This work
2. Future plans

2.1. Production of SHE nuclides for chemical experiments

(a) $^{238}$U target

$$Z = 104 \quad ^{238}\text{U} + ^{26}\text{Mg} \rightarrow ^{259}\text{Rf} + 5n: \text{Oct. 8–10, 2007}$$

- Acceleration of the $^{26}$Mg beam at RILAC ($\sim 2 \, \text{p} \mu \text{A}$)
- Production and gas-jet transport of $^{259}$Rf ($T_{1/2} = 3.0 \, \text{s}$)
  Optimization of the setting parameters of GARIS and the gas-jet system

$$^{238}\text{U} + ^{26}\text{Mg} \rightarrow ^{261}\text{Rf} (T_{1/2} = 78 \, \text{s}) + 3n$$

Background in $\alpha$-spectrometry at the new chemistry laboratory

---

Rotating $^{238}$U target

MgO rod for 18 GHz ECR ion source
Chemistry laboratory for the SHE chemistry

Background level: ~1/100 of that in the target room
(b) $^{248}Cm$ target and GARIS II

Great advantage for future SHE chemistry!!

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{248}Cm$ material (~7 mg)</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Target system R&amp;D</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Chem. Exp. @ GARIS</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>GARIS II R&amp;D</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Chem. Exp. @ GARIS II</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

GARIS/gas-jet setting parameters, decay properties, and excitation functions

$$Z = 104 \quad ^{248}Cm + ^{18}O \rightarrow ^{261}Rf + 5n$$
$$Z = 105 \quad ^{248}Cm + ^{19}F \rightarrow ^{262,263}Db + 5;4n$$
$$Z = 106 \quad ^{248}Cm + ^{22}Ne \rightarrow ^{265,266}Sg + 5;4n$$
$$Z = 107 \quad ^{248}Cm + ^{23}Na \rightarrow ^{266,267}Bh + 5;4n \ ?$$
$$Z = 108 \quad ^{248}Cm + ^{26}Mg \rightarrow ^{269,270}Hs + 5;4n$$
$$Z = 109 \quad ^{248}Cm + ^{27}Al \rightarrow ^{270,271}Mt + 5;4n \ ?$$
### Yields of SHE nuclides for chemistry experiments (rough estimation)

<table>
<thead>
<tr>
<th>Z</th>
<th>Reaction</th>
<th>$\sigma$ (pb)</th>
<th>GARIS I</th>
<th>GARIS II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Eff. (%)</td>
<td>Yield (1/d)</td>
</tr>
<tr>
<td>104</td>
<td>$^{248}$Cm($^{18}$O,$5n$)$^{261}$Rf</td>
<td>13000</td>
<td>3.4</td>
<td>700</td>
</tr>
<tr>
<td>105</td>
<td>$^{248}$Cm($^{19}$F,$5n$)$^{262}$Db</td>
<td>1500</td>
<td>4.2</td>
<td>98</td>
</tr>
<tr>
<td>106</td>
<td>$^{248}$Cm($^{22}$Ne,$5n$)$^{265}$Sg</td>
<td>240</td>
<td>6.9</td>
<td>26</td>
</tr>
<tr>
<td>107</td>
<td>$^{248}$Cm($^{23}$Na,$5n$)$^{266}$Bh</td>
<td>37*</td>
<td>8.2</td>
<td>4.8</td>
</tr>
<tr>
<td>108</td>
<td>$^{248}$Cm($^{26}$Mg,$5n$)$^{269}$Hs</td>
<td>6</td>
<td>12.5</td>
<td>1.2</td>
</tr>
<tr>
<td>109</td>
<td>$^{248}$Cm($^{27}$Al,$5n$)$^{270}$Mt</td>
<td>0.71*</td>
<td>14.4</td>
<td>0.16</td>
</tr>
</tbody>
</table>

### Assumptions
- Target thickness: 300 $\mu$g/cm$^2$
- Beam intensity: 5 $p\mu$A
- Gas-jet transport efficiency: 80%
- * from the $\sigma$ vs. $Z$ systematics
- Transport efficiency of GARIS
  - Focal plane size: $\Phi 60$mm
  - He pressure: 0.28 torr
  - Length of GARIS II: 3.9 m

---

*Simulated by N. Sato*
2.2. Chemistry apparatus

(a) Micro-chemical chip for ion exchange and solvent extraction

Micro flow path on glass or plastic surface

Laminar flow of aq. solution and org. solvent
Large relative interaction area
Short diffusion length

Rapid ion exchange and solvent extraction
Determination of distribution coefficient

Organic solvent (hydrophobic path)

Aqueous solution (hydrophilic path)

α-spectrometry

LS?
Experimental setup

- Micro-chemical chip
- Halogen lamp
- Si PIN photodiode 18×18 mm² × 32 (up/down each 2 rows)
- Ti tapes (~10 μm)
- GARIS/gas-jet system
- Dissolving unit
- He gas
- Aq. solution
- Org. solvent

α/SF measurement system
(b) Gas chromatograph column coupled to GARIS

- Primary beam
- Focal plane
- GARIS
- D1, Q1, Q2, D2
- Complexation
- Oven
- Quartz
- Water cooling
- SHE atoms
- Mylar window
- Chemical reagents without aerosols
- OLGA-type column
- Thermostat
- LN$_2$
- MANON
- COLD-type column
3. Summary

Present status of SHE chemistry at RIKEN GARIS

- Development of a gas-jet transport system coupled to GARIS
- Model experiments

\[ ^{169}\text{Tm}(^{40}\text{Ar},3n)^{206}\text{Fr}, \; ^{208}\text{Pb}(^{40}\text{Ar},3n)^{245}\text{Fm}, \; \text{and} \; ^{238}\text{U}(^{22}\text{Ne},5n)^{255}\text{No} \]

Future plans

(a) Production of SHE nuclides for chemical experiments

- \( ^{238}\text{U}(^{26}\text{Mg},5n)^{259}\text{Rf} \) on Oct. 8–10, 2007
- \( ^{248}\text{Cm} \) target (end of 2008) and GARIS II (end of 2009)

(b) New chemistry apparatus

- Micro-chemical chip for ion exchange and solvent extraction
- Gas chromatograph column coupled to GARIS

The 2nd Workshop on SHE chemistry @ RIKEN in the end of 2007

What chemistries should be studied at RIKEN GARIS?
Collaborators

**RIKEN**

**JAEA**
M. Asai, Y. Ishii, Y. Kasamatsu, H. Koura, Y. Nagame, T. Sato, H. Tome, and A. Toyoshima

**Osaka Univ.**
Y. Komori, R. Nakagaki, K. Ninomiya, K. Ooe, A. Shinohara, N. Takahashi, W. Yahagi, and T. Yoshimura

**Niigata Univ.**
S. Goto, T. Hasegawa, T. Kawasaki, and H. Kudo

**Kanazawa Univ.**
M. Araki, T. Nanri, and A. Yokoyama

**Tohoku Univ.**
T. Otsuki, K. Ozeki, and T. Shinozuka

**Tokyo Metropolitan Univ.**
K. Akiyama and Y. Oura

**Univ. Tokushima**
M. Sakama

**Univ. Tsukuba**
K. Sueki

**Tokyo Univ.**
E. Ideguchi

**Konan Univ.**
T. Wada

Participants in the 1st Workshop on SHE chemistry @ RIKEN (27 Aug. 2007)