Flerov laboratory of nuclear reactions

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Calculation of energy losses of ions ^{50}Ti and nuclei ^{290}Lv in DGFRS

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Abstract

Synthesis and study of decay properties of superheavy nuclei meet significant experimental difficulties owing to extremely low cross sections of their formation in heavy-ion fusion reactions. Energy losses calculations of colliding nuclei are necessary for planning and performing experiments of such kind.

Introduction

In the past years series of experiments with use of complete-fusion reactions (^{48}Ca + ^{233,238}U, ^{237}Np, ^{239,240,242,244}Pu, ^{243}Am, ^{245,248}Cm, ^{249}Bk, and ^{249}Cf) have been performed at the Flerov Laboratory of Nuclear Reactions employing the Dubna Gas-Filled Recoil Separator (DGFRS). These experiments were aimed at reaching the island of stability of superheavy elements [1,2] with the center at the proton number Z = 114 and neutron number N = 184 that has been predicted within various macroscopic–microscopic models. The observed trend of nuclear properties of the superheavy elements provides evidence of the existence of the island of stability on the approach to the spherical closed neutron shell N = 184.

The heaviest elements up to Z = 118 (Og) which could be synthesized in the reactions with ^{48}Ca have been already produced by now. It is expected that superheavy elements 119, 120 could be synthesized in fusion reactions of actinide isotope nuclei with ions heavier than ^{48}Ca, e.g., with ^{50}Ti, ^{54}Cr, ^{58}Fe, and ^{64}Ni. It is well known that the compound-nucleus formation cross section strongly decreases with increasing $Z_1 \times Z_2$ ($Z_{1,2}$ are the atomic numbers of the colliding nuclei). For estimating the scale of this decrease, the experiment was proposed to synthesize the already known superheavy nuclei in the reaction ^{244}Pu(^{50}Ti,4*n*)^{290}Lv.

Calculation of energy losses of ^{50}Ti allows to optimize the energy of accelerated ions in order to reach the highest cross section of the complete-fusion reaction. Also it allows to calibrate the high energy signals arising in the detectors. From calculation of energy losses of the heavy recoil nuclei in the DGFRS media we can estimate efficiency of the detector for registering α particles.

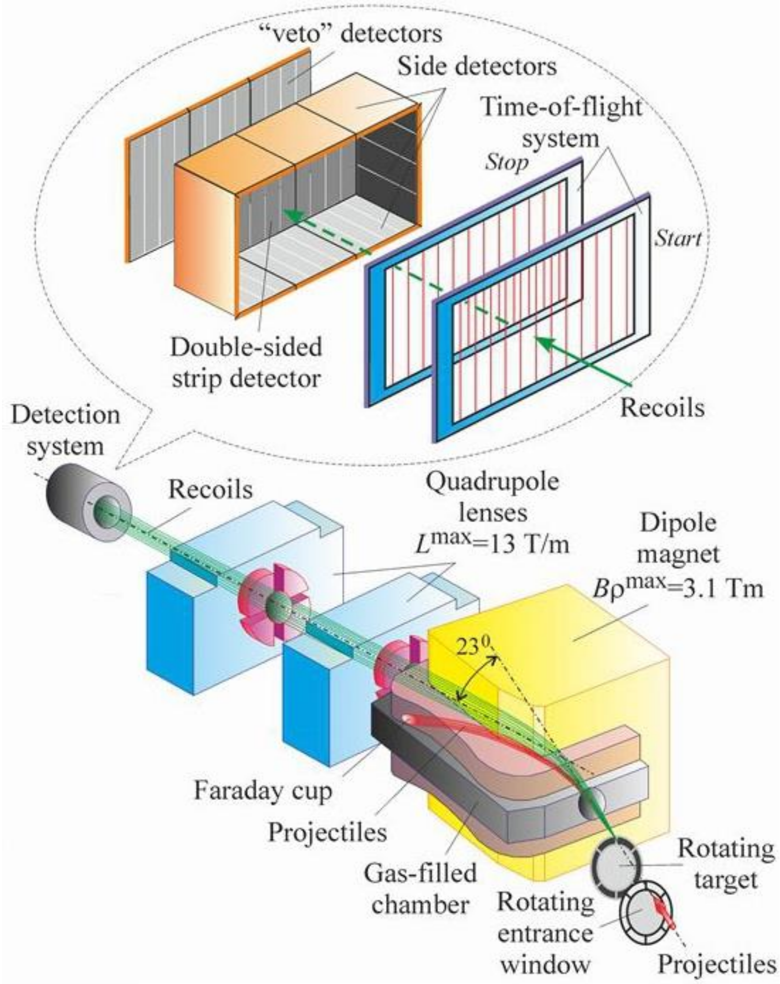

Fig. 1. Principle scheme of DGFRS.

Calculation algorithm

For calculations we used tables [3,4] that give particle range (R) depending on the respective energy (E) of the particles. We used linear interpolation between the closest points of R(E).

Algorithm of calculation:

1. Determine the interval corresponding to the input energy
2. Calculate the coefficient of proportionality between E and R for this interval and calculate R
3. Deduct thickness of material from R and find new value of energy.

This algorithm was realized in form of Python program.

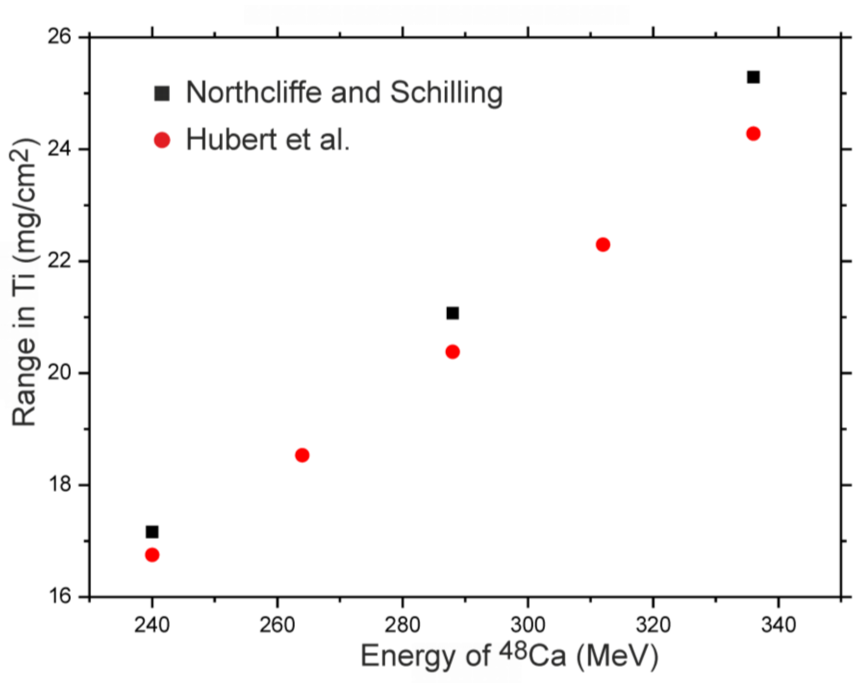

Fig.2. Example of R(E) dependence, R in mg/cm^2, E in MeV.

Input data

Calculations were performed for three different input energies of ^{50}Ti beam: 334 MeV, 334.5 MeV, and 335 MeV. Thicknesses of all materials are given in Table 1.

Table 1. Thickness of materials.

For ^{50}Ti			For $^{290}Lv_{116}$	
Material	Thickness, mg/cm^2		Material	Thickness, mg/cm^2
Ti	0.705		Pu	0.2
H	0.0053		O	0.0262
Al	2.37		H	0.0082
Ti	0.7180		H	0.0328
Pu	0.2		My	0.2040
O	0.0262		CH	0.2861
Pu	0.2			
O	0.0262			
H	0.0082			
H	0.0328			
My	0.2040			
CH	0.2861			

Results

Reaction^{244}Pu(^{50}Ti,4*n*)^{290}Lv, P[H] = 1.0, P[P]=1.6 Torr

Ranges and energies for ^{50}Ti:

```
   R_in        dR       R_out       E_in       dE            E_out
21.1990 - 0.7075 = 20.4915    334.0000 - 10.0024 = 323.9976 Ti
4.94970 - 0.0053 = 4.94440    323.9976 - 0.23970 = 323.7579 H
16.7514 - 2.3700 = 14.3814    323.7579 - 41.2053 = 282.5526 Al
17.6832 - 0.7180 = 16.9652    282.5526 - 10.9177 = 271.6349 Ti
40.7593 - 0.2000 = 40.5593    271.6349 - 1.53500 = 270.0999 Pu
12.1400 - 0.0262 = 12.1138    270.0999 - 0.48090 = 269.6190 O
40.4966 - 0.2000 = 40.2966    269.6190 - 1.53500 = 268.0840 Pu
12.0301 - 0.0262 = 12.0039    268.0840 - 0.48090 = 267.6031 O
10.0657 - 0.0000 = 10.0657    267.6031 - 0.00000 = 267.6031 C
3.76680 - 0.0082 = 3.75850    267.6031 - 0.40850 = 267.1946 H
3.75850 - 0.0328 = 3.72570    267.1946 - 1.63230 = 265.5623 H
10.3135 - 0.2040 = 10.1095    265.5623 - 4.15800 = 261.4043 My
8.32770 - 0.2861 = 8.04160    261.4043 - 6.81580 = 254.5886 CH
```

Ranges and energies for ^{290}Lv:

```
    R_in        dR      R_out      E_in        dE          E_out
5.64560 - 0.2000 = 5.44560    45.2297 - 1.84530 = 43.3844 Pu
1.58830 - 0.0262 = 1.56210    43.3844 - 1.00100 = 42.3834 O
1.22530 - 0.0000 = 1.22530    42.3834 - 0.00000 = 42.3834 C
0.47390 - 0.0082 = 0.46570    42.3834 - 1.15250 = 41.2309 H
0.46570 - 0.0328 = 0.43280    41.2309 - 4.60530 = 36.6256 H
1.11080 - 0.2040 = 0.90680    36.6256 - 8.65650 = 27.9691 My
0.74190 - 0.2861 = 0.45570    27.9691 - 12.5108 = 15.4583 CH
0.6770  Si
==============================================
```

Ranges and energies for ^{50}Ti:

```
   R_in        dR       R_out       E_in       dE            E_out
21.2345 - 0.7075 = 20.5270    334.5000 - 9.98610 = 324.5139 Ti
4.96110 - 0.0053 = 4.95580    324.5139 - 0.23970 = 324.2742 H
16.7816 - 2.3700 = 14.4116    324.2742 - 41.1858 = 283.0884 Al
17.7188 - 0.7180 = 17.0008    283.0884 - 10.8989 = 272.1895 Ti
40.8315 - 0.2000 = 40.6315    272.1895 - 1.53500 = 270.6545 Pu
12.1703 - 0.0262 = 12.1441    270.6545 - 0.48090 = 270.1736 O
40.5689 - 0.2000 = 40.3689    270.1736 - 1.53500 = 268.6386 Pu
12.0603 - 0.0262 = 12.0341    268.6386 - 0.48090 = 268.1577 O
10.0896 - 0.0000 = 10.0896    268.1577 - 0.00000 = 268.1577 C
3.77790 - 0.0082 = 3.76970    268.1577 - 0.40850 = 267.7492 H
3.76970 - 0.0328 = 3.73690    267.7492 - 1.63230 = 266.1169 H
10.3407 - 0.2040 = 10.1367    266.1169 - 4.15800 = 261.9590 My
8.35100 - 0.2861 = 8.06490    261.9590 - 6.81580 = 255.1432 CH
```

Ranges and energies for ^{290}Lv:

```
    R_in        dR      R_out      E_in        dE          E_out
5.65570 - 0.2000 = 5.45570    45.3228 - 1.84530 = 43.4775 Pu
1.59080 - 0.0262 = 1.56450    43.4775 - 1.00100 = 42.4764 O
1.22720 - 0.0000 = 1.22720    42.4764 - 0.00000 = 42.4764 C
0.47450 - 0.0082 = 0.46630    42.4764 - 1.15250 = 41.3240 H
0.46630 - 0.0328 = 0.43350    41.3240 - 4.60530 = 36.7186 H
1.11260 - 0.2040 = 0.90860    36.7186 - 8.67570 = 28.0430 My
0.74340 - 0.2861 = 0.45720    28.0430 - 12.5249 = 15.5181 CH
0.6794  Si
==============================================
```

Ranges and energies for ^{50}Ti:

```
   R_in        dR       R_out       E_in       dE            E_out
```

```
21.2700 - 0.7075 = 20.5625    335.0000 - 9.97060 = 325.0294 Ti
4.97250 - 0.0053 = 4.96720    325.0294 - 0.23970 = 324.7896 H
16.8117 - 2.3700 = 14.4417    324.7896 - 41.1663 = 283.6233 Al
17.7543 - 0.7180 = 17.0363    283.6233 - 10.8802 = 272.7431 Ti
40.9037 - 0.2000 = 40.7037    272.7431 - 1.53500 = 271.2081 Pu
12.2005 - 0.0262 = 12.1742    271.2081 - 0.48090 = 270.7272 O
40.6410 - 0.2000 = 40.4410    270.7272 - 1.53500 = 269.1922 Pu
12.0905 - 0.0262 = 12.0643    269.1922 - 0.48090 = 268.7113 O
10.1134 - 0.0000 = 10.1134    268.7113 - 0.00000 = 268.7113 C
3.78910 - 0.0082 = 3.78080    268.7113 - 0.40850 = 268.3028 H
3.78080 - 0.0328 = 3.74800    268.3028 - 1.63230 = 266.6705 H
10.3679 - 0.2040 = 10.1639    266.6705 - 4.15800 = 262.5126 My
8.37420 - 0.2861 = 8.08810    262.5126 - 6.81580 = 255.6968 CH
```

Ranges and energies for ^{290}Lv:

```
   R_in      dR     R_out      E_in       dE          E_out
5.66570 - 0.2000 = 5.46570    45.4156 - 1.84530 = 43.5704 Pu
1.59320 - 0.0262 = 1.56700    43.5704 - 1.00100 = 42.5693 O
1.22900 - 0.0000 = 1.22900    42.5693 - 0.00000 = 42.5693 C
0.47520 - 0.0082 = 0.46700    42.5693 - 1.15250 = 41.4168 H
0.46700 - 0.0328 = 0.43410    41.4168 - 4.60530 = 36.8115 H
1.11450 - 0.2040 = 0.91050    36.8115 - 8.69470 = 28.1168 My
0.74490 - 0.2861 = 0.45880    28.1168 - 12.5390 = 15.5777 CH
0.6818  Si
==============================================
```

Discussion

Energy losses of ^{50}Ti and recoil nuclei ^{290}Lv in DGFRS are calculated with use of tables [3,4]. This type of calculation is necessary for performing experiments on the synthesis of new superheavy nuclei. Next steps of calculations are aimed at estimating the charge of the produce heavy recoil nuclei in the separator media, simulation of particle trajectory through separator, and calibration of detectors.

REFERENCES

1.Super-heavyelement research. Yu.Ts. Oganessian and V.K. Utyonkov, Rep. Prog. Phys. **78**, 036301 (2015).

2. Superheavy nuclei from ^{48}Ca-induced reactions. Yu.Ts. Oganessian and V.K. Utyonkov, Nucl. Phys. A **944**, 62 (2015).

3. Range and stopping-power tables for heavy ions. L.C. Northcliffe and R.F. Schilling, Nuclear Data Tables A**7**, 233(1970).

4. Range and stopping-power tables for 2.5-500 MeV/nucleon heavy ions in solids. F. Hubert, R. Bimbot and H. Gauvin, Atomic Data and Nuclear Data Tables **46**,No. 1, 1-213(1990).