The predicted evaporation residue cross sections for the synthesis of unknown isotope of element Rf

H. M. Devaraja[1,*], M. Gupta[1], Y. K. Gambhir[1, 2], and G. Münzenberg[1, 3]
[1]Manipal Centre for Natural Sciences, Manipal University, Manipal 576104, Karnataka, India
[2]Department of Physics, IIT-Bombay, Powai, Mumbai-400076, India
[3]GSI Helmholtzzentrum für Schwerionenforschun gmbH,
Planckstr. 1, D64291 Darmstadt, Germany
**email: devaraja.h1@learner.manipal.edu*

Introduction

The production and study of Super Heavy Elements (SHE) is an important area of research in present experimental nuclear physics. The element ^{294}118 (Z = 118, A = N+Z = 294) is the heaviest one reported at present in the ^{249}Cf (^{48}Ca, 3n) [1, 2] hot fusion reaction with a production cross-section of 0.5 picobarns. However, a gap remains in the upper end of the nuclear chart between the Super Heavy Nuclei (SHN) produced in cold fusion using Pb and Bi targets and hot fusion reactions with ^{48}Ca + Actinides. It is a challenging task to fill the gap. The scarcity of suitable projectile target combinations made the experimental synthesis of these missing isotopes challenging. Since the production cross section strongly depends on beam energy and the combination of projectile and target, therefore theoretically calculated production cross-sections for such reactions may guide to choose the appropriate target-projectile combinations and the corresponding optimal beam energy in assisting experimentalists to plan future experiments.

In order to achieve this, a systematic analysis of the excitation functions of the hot fusion reactions and their comparison to experimental cross-sections leading to the synthesis of heavy and superheavy elements was performed using the HIVAP code [3]. The HIVAP code requires several input parameters which need to be adjusted to suit the requirements of different mass regions. We show that it is possible to find a single set of parameters which can be used to describe the existing experimental production cross-sections for a range of hot fusion reactions reasonably well [4]. We extended the same procedure to propose new reactions required to reach still heavier, unstudied mass region.

Here we propose the reaction of ^{18}O projectile incident on ^{250}Cm target for the synthesis of a new isotope ^{264}Rf of the element Rutherfordium (Rf). The half-life of ^{250}Cm is large (8300 yr) enough to be used as a target.

Details of the calculations

The HIVAP code adopts the conventional two-step process: (a) complete fusion after passing the barrier and (b) the statistical de-excitation of a fully equilibrated compound nucleus producing the evaporation residue (EVR) of interest. Fusion is expected to occur when the Bass interaction barrier (B_{int}) [5] is passed. Below the barrier, a WKB (Wentzel - Kramer - Brillouin) approximation method have been used to estimate the barrier penetration. Barrier distribution is assumed to be of Gaussian shape with cut-off at both sides after five standard deviations for the calculation of fusion probabilities. The main parameters involved in the calculation of de-excitation of the excited compound nuclei, are level density, fission barriers and masses. HIVAP adopt level density calculations from [6] and level density ratios from [7] and fission barriers from [8]. For known nuclei with Z≤103 the masses listed in Audi 2012 are used [9]. For nuclei with Z >103 the direct measurement of masses are not available, hence masses taken from Myers and Swiatecki [10] are used. The details of the calculation are given in reference [3].

Results and discussion

The calculated evaporation residue cross sections with excitation energy E* of the compound nucleus for the reaction $^{18}O+^{250}Cm$ leading to the synthesis of various isotopes of Rutherfordium are displayed in Fig. 1. Here $E^* = E_{CM} + Q$, with $Q = (M_P+M_T-M_{CN})c^2$ where M_P (M_T) is the ground state mass of the projectile (target) and M_{CN} is the mass of the compound nucleus. Here, B_{int} is marked in the Fig. 1 is (Bass barrier [5] + Q) the Bass interaction barrier.

The figure indicates that the maximum predicted evaporation residue cross sections is 61 nanobarns for the 5n channel at an excitation energy of 48 MeV, while for the 4n channel it is of the order of 4.2 nanobarns at an excitation energy of 45 MeV. For the 6n channel, it is around 11 nanobarns at an excitation energy of 54 MeV. Here 4n channel leads to the yet unknown isotope ^{264}Rf. In addition, there are no direct production of ^{263}Rf from the earlier experiments. The predicted high cross-sections of 61 nanobarns for ^{263}Rf indicates that one can obtain the conclusive evidence after producing directly by performing the experiment.

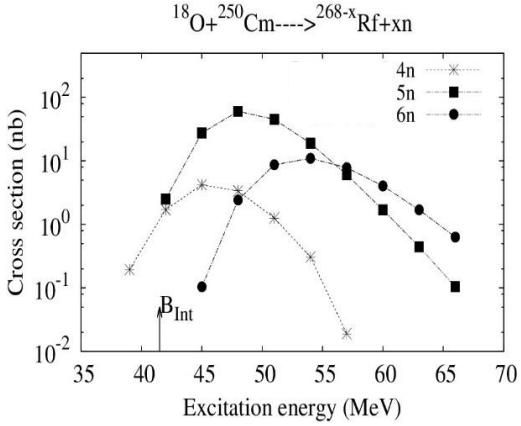

FIG. 1: Excitation energy (E*) dependence of the evaporation residue cross sections for the $^{250}Cm(^{18}O,xn)$ reaction for n=4, 5, and 6, leading to the synthesis of various isotopes of the element Rutherfordium.

In conclusion, these experiments can be performed at the available facilities and can be considered as viable experiments for the direct synthesis of ^{263,265}Rf and new isotope ^{264}Rf of the element Rutherfordium.

Acknowledgements:
This work is performed in partial fulfilment of the PhD degree at MCNS, Manipal University by H. M. Devaraja.

References

[1] Yu. Ts. Oganessian *et al.*, Phys. Rev. C. **74**, 044602 (2006).
[2] Y. T. Oganessian *et al.*, Phys. Rev. Lett. **109**, 162501 (2012).
[3] W. Reisdorf and M. Schädel, Zeitschrift für Physik A Hadrons and Nuclei **343**, 47 (1992).
[4] H. M. Devaraja *et al.*, Phys. Rev. C. **93,** 034621 (2016).
[5] R. Bass, Phys. Rev. Lett. **39**, 265 (1977).
[6] W. Reisdorf, Zeitschrift für Physik A Atoms and Nuclei **300**, 227-238 (1981).
[7] J. Töke and W.J. Swiatecki, Nuclear Physics A **372**, 141-150 (1981).
[8] S. Cohen, F. Plasil, and W. J. Swiatecki, Ann. Phys. (N.Y.) **82**, 557 (1974).
[9] M. Wang *et al.*, Chin. Phys. C **36**, 1603 (2012).
[10] W. D. Myers and W. J. Swiatecki, Table of Nuclear Masses According to the 1994 Thomas-Fermi Model, Report No. LBL-36803, Berkeley, (1994).