Pramana – J. Phys. (2021) 95:194
https://doi.org/10.1007/s12043-021-02228-4
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Decay of dinuclear systems formed from dubnium

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MS received 25 April 2021; revised 7 July 2021; accepted 9 July 2021

Abstract. The radioactivity of the superheavy nuclei $^{250-275}$Db is studied and presented using the Coulomb and proximity potentials. The half-lives corresponding to different decay modes such as α, cluster decay (^{12}C, ^{14}N, ^{18,20}O, ^{23}F, ^{20}Ne, ^{34}S, ^{28}Mg and ^{40}Ca) and spontaneous fission in the superheavy nuclei $^{250-275}$Db are studied. The studied half-lives are compared with the available experiments. The decay modes and the branching ratios of isotopes of dubnium are presented. The isotopes of dubnium, $^{254-263}$Db, are identified as α emitters, whereas isotopes such as $^{250-253}$Db and $^{264-275}$Db are identified as having spontaneous fission. The identified alpha emitting isotopes of dubnium have decay energies from 6 MeV to 10 MeV and half-lives 1 ms to 100 s. The possible projectile–target combinations to synthesise the superheavy nuclei $^{253-263}$Db were predicted. The fusion of spherical projectile and target yields larger evaporation residue cross-sections.

Keywords. Superheavy; half-lives; alpha-decay; penetration probability; decay mode.

PACS Nos 25.85.Ca; 24.10.–I; 23.60.+e; 21.60.–n

1. Introduction

The analysis of radioactivity in the transactinide elements with $Z \geq 104$ provides an opportunity to understand the structure and properties of matter. The cold fusion reactions with lead and bismuth as the targets and hot fusion reactions with the ^{48}Ca projectile on an actinide target are used to synthesise superheavy elements [1–11]. By the cold and hot fusion reactions, the formed compound nuclei achieve a stable state by many decay methods such as α-decay, cluster decay, β-decay and spontaneous fission. However, in the superheavy region, the formed nuclei decay mainly through an α-decay followed by the spontaneous fission and in a few cases mainly by the spontaneous fission. The possibility of the heavy particle radioactivity (HPR) was also predicted in the superheavy nuclei [12,13].

Many theoretical models such as cluster model [14], multichannel cluster model [15], density-dependent M3Y (DDM3Y) effective interaction [16,17], generalised liquid drop model (GLDM) [18], Coulomb and proximity potential model (CPPM) [19], generalised density-dependent cluster model [20] and unified model for α-decay and α-capture (UMADAC) [21] were involved to evaluate the α-decay half-lives. The method of quasiparticle random phase approximation (QRPA) was used to evaluate the β-decay half-lives [22]. The β-decay half-lives are evaluated using the widely accepted models [23–25].

The spontaneous fission half-lives were first predicted by Wheeler and Bohr [26] and later on experimentally confirmed by Flerov and Petrzak [27]. During the year 1955, Swiatecki [28] evaluated spontaneous fission half-lives using the fissility parameter Z^2/A in a liquid drop model. Previous researchers [29–31] studied spontaneous fission half-lives using shell correction in a modified liquid drop model. Furthermore, cluster decay is an intermediate between an α decay and spontaneous fission [32] which was experimentally confirmed during the year 1984 [33]. Cluster decays such as ^{14}C, ^{16,18}O, ^{22,24,26}Ne, ^{23}F, ^{28,30}Mg, ^{34}Si and so on were experimentally observed from the parent nuclei ^{221}Fr to ^{242}Cm [34]. The cluster decay half-lives are evaluated using various models such as super-asymmetric fission model (SAFM) [35,36], unified fission model

Published online: 16 November 2021

[37,38] and preformation cluster model (PCM) [39,40]. The cluster decay half-lives are also evaluated using semi-microscopic methods [41–43]. Earlier researchers studied different decay modes using different models and semi-empirical relations to evaluate the half-lives [44–57].

In the present work, we have investigated decay properties such as α, cluster decay and spontaneous fission half-lives and identified decay mode of the superheavy nuclei dubnium with $Z = 105$. The α and cluster decay half-lives are evaluated using the Coulomb and proximity potential model and spontaneous fission is studied using the semi-empirical relation. The theory used to evaluate the decay half-lives and decay modes are given in §2. The corresponding results are discussed in §3 and conclusions of the present work are presented in §4.

2. Theory

2.1 *Alpha and cluster decay*

By quantum tunnelling process, the cluster and α decay are feasible. In the theoretical context, overall potential at this stage is a significant consideration. The ultimate potential is well established with regard to Coulomb, nuclear and centrifugal potentials.

$$V(R) = V_N(R) + V_c(R) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2}. \tag{1}$$

Here ℓ is the angular momentum and μ is the reduced mass of the emitted α/cluster nuclei and daughter nuclei. r is the distance between fragment centres. In the present work, we have considered Coulomb and proximity potential to evaluate total scattering potential by neglecting the centrifugal potential. The value corresponding to the centrifugal potential is almost zero for ground state to ground state transitions. The short-range Coulomb potential is evaluated as follows:

$$V_c(R) = Z_1 Z_2 e^2 \begin{cases} \dfrac{1}{R} & \text{for} \quad R > R_c, \\ \dfrac{1}{2R_c}\left[3 - \left(\dfrac{R}{R_c}\right)\right] & \text{for} \quad R < R_c, \end{cases} \tag{2}$$

where Z_1 and Z_2 are the atomic numbers of the daughter and emitted α/cluster respectively. The radial distance is obtained using the equation $R_c = 1.24(R_e + R_d)$.

The long-range proximity potential function ($V_N(R)$) is the product of two functions and it depends on the shape and geometry of the colliding system. The second is the universal function and it is expressed as follows:

$$V_p(Z) = 4\pi\gamma\Phi\bar{R}\left(\frac{r - C_1 - C_2}{b}\right) \text{MeV}. \tag{3}$$

The proximity potential is evaluated using the set of equations described in [45]. Using the total interacting potential and proximity potential, the penetration probability P is evaluated using the WKB approximation as follows:

$$P = \exp\left[-\frac{2}{\hbar}\int_{R_{\text{in}}}^{R_{\text{out}}} \sqrt{2\mu[V(r) - Q]}\,\mathrm{d}r\right], \tag{4}$$

where R_{in} and R_{out} are the classical turning points and are evaluated using the following boundary conditions: $V(r - R_{\text{in}}) = V(r = R_{\text{out}}) = Q$. Here Q is the decay energy of the emitted cluster/α and it is defined as

$$Q = M_p - M_d - M_c, \tag{5}$$

where M_p, M_d and M_c are mass excess of the parent, the daughter and the cluster/α nuclei, respectively and these are adopted from ref. [58]. Both α and cluster decay half-lives are evaluated as follows:

$$T_{1/2} = \frac{h \ln 2}{2E_v P}, \tag{6}$$

where the empirical vibrational energy E_v is calculated using the following equation:

$$E_v = Q\left[0.056 + 0.039\exp\left(\frac{4 - A_e}{2.5}\right)\right] \text{MeV}. \tag{7}$$

Here, A_e is the mass number of the emitted α/cluster particle.

2.2 *Spontaneous fission*

Spontaneous fission is the most complicated process. Bao *et al* [59] proposed semi-empirical relation for spontaneous fission by including the shell correction and isospin effect for the Swiatecki's formula [28]. Ren and Xu [60] proposed semi-empirical relation for the spontaneous fission based on the blocking effect of unpaired nucleon in the case of even–even nuclei and odd-A nuclei. Furthermore, Santhosh *et al* [61] proposed a relation for spontaneous fission half-lives based on fissility parameter and isospin effect. Karpov *et al* [62] proposed the semi-empirical relation for the spontaneous fission based on barrier height (B_f) on the potential energy surface. By including the systematics of fission isomer half-lives, Metag *et al* [63,64] proposed semi-empirical relation for the fission half-lives. Among the different semi-empirical relations available in the literature, we have considered Karpov's semi-empirical relation [62] which is based on the fission barrier height, and it is expressed as follows:

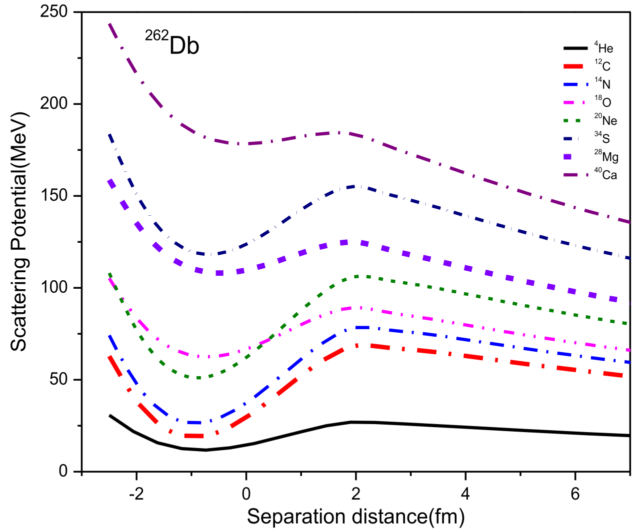

Figure 1. Variation of scattering potential as a function of separation distance during the cluster emission (^{4}He–^{40}Ca) from the superheavy nucleus ^{262}Db.

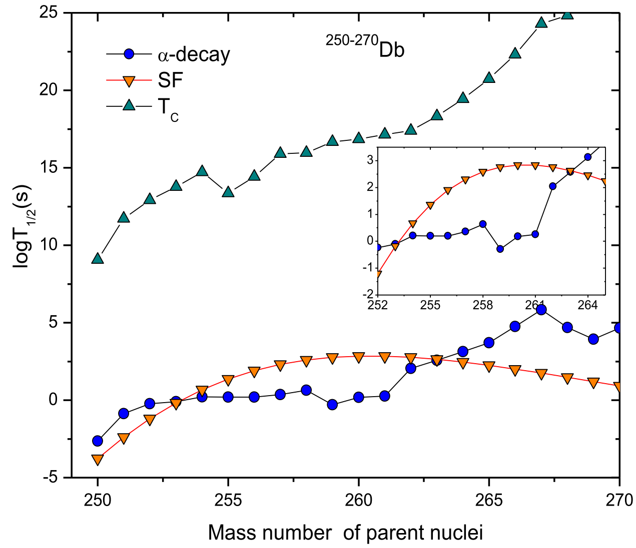

Figure 2. Variation of $\log T_{1/2}$ for different decay modes (SF, α-decay and ^{12}C emission) with mass number of the parent nuclei A_p for the superheavy element $Z = 105$.

$$\log T_{\mathrm{SF}}(s) = 1146.44 - 75.3153\left(\frac{Z^2}{A}\right) + 1.63792\left(\frac{Z^2}{A}\right)^2 - 0.0119827\left(\frac{Z^2}{A}\right)^3 + B_f(7.23613 - 0.0947022Z^2/A) + \begin{cases} 0, & Z \text{ and } N \text{ are even,} \\ 1.53897, & A \text{ is odd,} \\ 0.80822, & Z \text{ and } N \text{ are odd.} \end{cases} \quad (8)$$

Here B_f is the fission barrier and it is evaluated as the sum of the liquid drop barrier B_f(LDM) and shell correction term (δU). In the present study, we have evaluated the fission barriers using the semi-relation available in [65] for the heavy and superheavy regions.

3. Results and discussions

The half-lives of the cluster and α decay of $Z = 105$ are studied using the Coulomb and proximity potential model as explained in §2.1. During the cluster emissions, we have studied all the cluster emissions from ^{12}C to ^{40}Ca. All possible isotopes of cluster emissions were considered during the cluster decay.

Figure 1 presents the variation of scattering potential with the separation distance between the daughter and the emitted cluster nuclei (^{4}He–^{40}Ca) for the superheavy nucleus ^{262}Db. From the figure it is inferred that the short-range attractive nuclear force is dominant up to the separation distance of 0 fm. However, the value of the nuclear force varies depending on the type of cluster emitted during the decay mode. Again, the Coulomb repulsive force will be dominant and maximum value of force is observed at 2 fm. The scattering potential almost becomes constant as the separation distance increases.

Similarly, we have studied cluster and α decay half-lives in isotopes of superheavy nuclei ^{250}Db to ^{270}Db. Then the studied half-lives are compared with the spontaneous fission as explained in §2.2. Different decay modes for the isotopes of dubnium from ^{250}Db to ^{270}Db are presented in figure 2. The half-lives corresponding to ^{254}Db to ^{263}Db are shorter than the other decay modes which have been studied. The magnified portion of the region from $^{252-264}$Db is clearly shown in the inset of the same figure. But, the nuclei below ^{254}Db and above ^{263}Db have shorter half-lives for the spontaneous fission. Hence, the superheavy nuclei ^{254}Db to ^{263}Db shows maximum probability of an α-decay only. After identifying the dominant decay mode in dubnium, the corresponding half-lives are compared with the available experimental values.

Table 2 shows the comparison between the present work and the experimental values. A good agreement between the studied half-lives and available experimental values can be observed. However, there is a deviation of calculated half-lives around 10 times with the experiment in the case of ^{262}Db and ^{263}Db. Once the values obtained are comparable with the experimental values, the study is extended to other isotopes of dubnium.

Table 1. Tabulation of Q-values, $\log T_{1/2}$ and the corresponding decay mode in the isotopes of Db.

Parent nuclei	Daughter nuclei	Q (MeV)	$\log T_{1/2}$(s)	Decay mode
^{250}Db	^{246}Lr	10.41	−3.775	SF
^{251}Db	^{247}Lr	10.07	−2.39	SF
^{252}Db	^{248}Lr	9.83	−1.19	SF
^{253}Db	^{249}Lr	9.78	−0.17	SF
^{254}Db	^{250}Lr	9.66	−1.29	α
^{255}Db	^{251}Lr	9.44	0.204	α
^{256}Db	^{252}Lr	9.34	0.21	α
^{257}Db	^{253}Lr	9.207	0.36	α
^{258}Db	^{254}Lr	9.5	0.63	α
^{259}Db	^{255}Lr	9.62	−0.29	α
^{260}Db	^{256}Lr	9.5	0.18	α
^{261}Db	^{257}Lr	9.22	0.255	α
^{262}Db	^{258}Lr	8.19	2.04	α
^{263}Db	^{259}Lr	7.9	2.57	α
^{264}Db	^{260}Lr	8.2	2.45	SF
^{265}Db	^{261}Lr	8.4	2.25	SF
^{266}Db	^{262}Lr	8.2	2.01	SF
^{267}Db	^{263}Lr	7.78	1.75	SF
^{268}Db	^{264}Lr	7.635	1.475	SF
^{269}Db	^{265}Lr	7.75	1.19	SF
^{270}Db	^{266}Lr	7.12	0.92	SF

Table 2. Comparison of α decay half-lives of the present work (PW) with that of the available experiments.

Parent nuclei	$T_{1/2}^{\mathrm{Exp}}$	$\log T_{1/2}^{\mathrm{Exp}}$	$\log T_{1/2}^{\mathrm{PW}}$	Ref.
^{255}Db	20 ms	−1.6	0.204	[66]
^{256}Db	$1.6^{+0.5}_{-0.3}$ s	0.20s	0.21	[1]
^{257}Db	$1.50^{+0.19}_{-0.15}$	0.17	0.36	[1]
^{258}Db	3.6 s	0.55	0.63	[67]
^{258}Db	$4.4^{+0.9}_{-0.6}$ s	0.64	0.63	[68]
^{259}Db	0.51 ± 0.16 s	−0.29	−0.29	[69]
^{260}Db	1.52 ± 0.13 s	0.181	0.18	[70]
^{261}Db	1.8 s	0.26	0.255	[71]
^{262}Db	40.9 s	1.61	2.04	[72]
^{263}Db	27 s	1.43	2.57	[73]

The emitted cluster particle energy (Q-value) is studied by the difference of initial and final (daughter+ emitted nuclei) mass excess values and these mass excess values are taken from [58]. Based on the above studies, we have predicted the half-lives and Q-values of isotopes of dubnium from ^{250}Db to ^{275}Db. The values corresponding to the decay, Q-values and $\log T_{1/2}$ are tabulated in table 1.

After the identification of possible decay mode in the isotopes of dubnium, we have studied the corresponding decay products and the decay modes. Table 3 presents the daughter nuclei, amount of energy released during the process and $\log T_{1/2}$ of α and spontaneous fission half-lives and decay mode. The superheavy nucleus ^{254}Db has shorter half-life with α decay than with spontaneous fission and hence it is terminated to ^{253}Lr with α_1 decay and again the nucleus ^{253}Lr is not stable against α decay and hence it is ended with the spontaneous fission. Similarly, we have shown decay chains corresponding to nuclei from ^{255}Db to ^{263}Db. ^{255}Db is terminated with the single α decay followed by the spontaneous fission, whereas the nuclei ^{256}Db to

Table 3. A comparison of logarithmic α decay and spontaneous fission and its decay mode for the superheavy nuclei ^{254}Db to ^{263}Db.

Parent nuclei	Daughter nuclei	Q-values	$\log T_{1/2}$ (α)	$\log T_{1/2}$ (SF)	Decay mode
^{254}Db	^{250}Lr	9.66	0.21	0.68	α_1
^{250}Lr	^{246}Md	9.43	−2.81	−3.78	SF
^{255}Db	^{251}Lr	9.44	0.20	1.37	α_1
^{251}Lr	^{247}Md	9.43	−2.81	−2.40	SF
^{256}Db	^{252}Lr	9.34	0.20	1.91	α_1
^{252}Lr	^{248}Md	9.26	−2.34	−1.20	α_2
^{248}Md	^{244}Es	8.70	−1.28	−7	SF
^{257}Db	^{253}Lr	9.21	0.36	2.31	α_1
^{253}Lr	^{249}Md	8.94	−1.36	−0.17	α_2
^{249}Md	^{245}Es	8.46	−0.53	−5.32	SF
^{258}Db	^{254}Lr	9.50	0.63	2.59	α_1
^{254}Lr	^{250}Md	8.79	−0.9	0.68	α_2
^{250}Md	^{245}Es	9.62	−1.28	2.88	SF
^{259}Db	^{255}Lr	9.62	−0.29	2.76	α_1
^{255}Lr	^{251}Md	8.61	−0.31	1.37	α_2
^{251}Md	^{247}Es	7.99	1.08	−2.40	SF
^{260}Db	^{256}Lr	9.50	0.18	2.84	α_1
^{256}Lr	^{252}Md	8.82	−1.02	1.91	α_2
^{252}Md	^{248}Es	7.90	1.40	−1.2	α_3
^{261}Db	^{257}Lr	9.22	0.26	2.84	α_1
^{257}Lr	^{253}Md	9.01	−1.65	2.31	α_2
^{253}Md	^{249}Es	7.70	2.05	2.76	α_3
^{262}Db	^{258}Lr	8.19	2.05	2.76	α_1
^{258}Lr	^{254}Md	8.90	−1.34	2.59	α_2
^{254}Md	^{250}Es	7.86	1.53	0.68	SF
^{263}Db	^{259}Lr	7.90	2.58	2.63	α_1
^{259}Lr	^{255}Md	8.58	−0.31	2.76	α_2
^{255}Md	^{251}Es	7.91	1.34	1.37	α_3
^{251}Es	^{247}Bk	6.60	6.07	−2.4	SF

^{262}Db are determined by the 2 α decay chain and hence terminated with the spontaneous fission and ^{263}Db follows the 3α decay chain with the ^{259}Lr, ^{255}Md, ^{251}Es daughter nuclei and finally ended with the spontaneous fission. However, if the Q-values are reliable, then the obtained $\log T_{1/2}$ values show consistent decay chains followed by the spontaneous fission in the case of ^{254}Db to ^{263}Db and it is shown in table 3. The branching ratios [45] of an α with respect to cluster decay are evaluated and are presented in table 4. From the table it is inferred that the ratio of α with respect to the cluster decay shows higher value of magnitude of an order of 10^{24} to 10^{83}. From the table it is clearly observed that the branching ratios corresponding to ^{12}C, ^{14}N, ^{20}Ne, ^{34}S and ^{40}Ca show an increasing trend with mass number of the parent nuclei. However, branching ratio remains almost constant in the case of ^{18}O. These values may be due to the amount of energy released during the ^{18}O cluster emission from the isotopes of dubnium.

As smaller half-lives and higher magnitude of branching ratios are observed in the isotopes of dubnium, we

Table 4. Logarithmic values of branching ratio of α-decay with respect to cluster decay (^{12}C, ^{14}N, ^{18}O, ^{20}Ne, ^{34}S and ^{40}Ca) for the isotopes of superheavy nuclei ^{251}Db to ^{275}Db.

Isotopes	$\frac{\lambda_\alpha}{\lambda_{^{12}C}}$	$\frac{\lambda_\alpha}{\lambda_{^{14}N}}$	$\frac{\lambda_\alpha}{\lambda_{^{18}O}}$	$\frac{\lambda_\alpha}{\lambda_{^{20}Ne}}$	$\frac{\lambda_\alpha}{\lambda_{^{34}S}}$	$\frac{\lambda_\alpha}{\lambda_{^{40}Ca}}$
^{251}Db	25.95	32.89	34.32	33.68	25.63	29.79
^{252}Db	25.59	30.46	34.43	34.11	27.11	32.18
^{253}Db	25.81	33.99	35.29	34.97	28.80	35.31
^{254}Db	25.66	32.02	34.99	35.70	30.18	37.84
^{255}Db	26.91	34.05	33.74	35.38	30.77	40.06
^{256}Db	27.09	31.61	33.73	35.78	31.50	42.55
^{257}Db	27.80	35.23	33.82	36.41	32.82	45.08
^{258}Db	30.08	33.95	34.39	37.79	34.70	48.69
^{259}Db	32.51	37.83	34.97	39.26	36.44	51.68
^{260}Db	32.35	35.12	34.32	39.45	37.10	54.19
^{261}Db	32.75	37.73	34.36	40.27	37.73	56.18
^{262}Db	32.64	35.12	33.83	40.64	38.46	58.40
^{263}Db	36.87	38.39	33.75	41.64	39.24	60.48
^{264}Db	35.95	35.94	33.01	41.94	39.78	63.55
^{265}Db	34.62	39.75	33.12	42.96	40.45	65.47
^{266}Db	35.22	37.79	32.73	43.54	40.75	67.26
^{267}Db	35.97	41.85	32.57	44.13	41.09	68.93
^{268}Db	38.99	40.84	34.26	46.43	43.34	72.46
^{269}Db	41.80	45.84	35.74	48.44	45.05	75.11
^{270}Db	45.10	42.92	35.63	50.68	45.46	76.75
^{271}Db	45.23	51.42	37.57	53.85	47.16	79.72
^{272}Db	46.89	46.64	36.77	54.16	47.12	80.77
^{273}Db	50.23	50.71	38.68	55.27	48.29	83.05
^{274}Db	47.89	45.25	36.78	54.26	46.79	82.98
^{275}Db	47.36	48.57	34.80	53.25	45.84	83.26

have also made an effort to predict possible projectile–target combinations to synthesise the isotopes of dubnium. We have selected around 218 possible projectile–target combinations to synthesise superheavy nuclei ^{254}Db to ^{263}Db as predicted in table 3. We have selected the projectile–target combination in such a way that the evaporation residue cross-section is maximum. The evaporation residue cross-section is evaluated as explained in refs [74–76]. Later, we have selected 24 possible projectile–target combinations with maximum evaporation residue cross-sections to synthesise the superheavy nuclei ^{254}Db to ^{263}Db and tabulated in table 5. Among all these predicted projectile–target combinations, the fusion reaction ^{51}V+^{208}Pb, both projectile and target being spherical ($\beta_2 = 0$), shows a larger evaporation residue cross-section of 896.2nb. The second larger production cross-section is observed for the projectile with magic nuclei (^{48}Ca) and target almost spherical fusion reaction shows a larger evaporation residue cross-section of 812.7 nb.

4. Conclusions

The half-lives and branching ratios of isotopes in the superheavy nuclei $^{254-275}$Db have been studied using recent proximity otential. The study of smaller half-lives of ^{4}He and larger branching ratio reveals that α decay is dominant compared to other clusters such as ^{12}C, ^{14}N, ^{18,20}O, ^{23}F, ^{20}Ne, ^{34}S, ^{28}Mg and ^{40}Ca. The evaluated half-lives are compared with the available experimental values and a close agreement of values of the present work with the available experimental value is observed. α and spontaneous fis-

Table 5. Tabulation of the predicted projectile–target combination to synthesise the isotopes of superheavy nuclei ^{253}Db to ^{263}Db along with the centre of mass energy (E_{cm}), fusion barrier (B_{fu}), deformation parameter (β_2) of the projectile and the target and evaporation residue cross-sections.

Reaction	E_{cm} (MeV)	B_{fu} (MeV)	β_2		σ_{ER} (nb)
			Proj.	Targ.	
$^{49}V+^{206}Pb\rightarrow^{254}Db+1n$	184	202.3	0	– 0.008	13.1
$^{45}Ca+^{211}At\rightarrow^{254}Db+2n$	178	181.3	0	0.008	4.4
$^{46}Sc+^{210}Po\rightarrow^{254}Db+2n$	183	188.9	– 0.008	0	3.1
$^{47}Ca+^{210}At\rightarrow^{255}Db+2n$	178	180.4	0	– 0.018	43.9
$^{47}Sc+^{210}Po\rightarrow^{255}Db+2n$	184	188.3	– 0.008	0	30.4
$^{48}Sc+^{210}Po\rightarrow^{256}Db+2n$	185	187.7	– 0.044	0	184.5
$^{30}Si+^{230}Pa\rightarrow^{256}Db+4n$	138	144.4	0	0.190	2.8
$^{48}Ti+^{210}Bi\rightarrow^{257}Db+1n$	176	195.2	0	– 0.018	242.8
$^{48}Ca+^{211}At\rightarrow^{257}Db+2n$	179	179.6	0	0.008	812.7
$^{51}V+^{208}Pb\rightarrow^{257}Db+2n$	197	200.8	0	0	896.2
$^{40}Ar+^{221}Fr\rightarrow^{257}Db+4n$	166	166.8	0	0.120	5.7
$^{39}K+^{222}Rn\rightarrow^{257}Db+4n$	170	174.7	0	0.137	0.14
$^{40}K+^{222}Rn\rightarrow^{257}Db+5n$	174	174.1	– 0.035	0.137	1.4
$^{50}Ti+^{210}Bi\rightarrow^{258}Db+2n$	191	194.1	0	– 0.018	533.9
$^{41}Ar+^{221}Fr\rightarrow^{259}Db+3n$	159	166.3	0	0.120	5.1
$^{42}Ar+^{221}Fr\rightarrow^{259}Db+4n$	166	165.8	0	0.120	9.4
$^{41}K+^{222}Rn\rightarrow^{259}Db+4n$	169	173.5	0	0.137	0.9
$^{42}Ar+^{222}Fr\rightarrow^{260}Db+4n$	166	165.7	0	0.138	7.4
$^{41}Ar+^{223}Fr\rightarrow^{260}Db+4n$	164	165.9	0	0.146	2.5
$^{42}Ar+^{223}Fr\rightarrow^{261}Db+4n$	165	165.5	0	0.146	7.7
$^{32}P+^{234}Th\rightarrow^{261}Db+5n$	144	150.5	0	0.215	2.4
$^{32}Si+^{234}Pa\rightarrow^{262}Db+4n$	135	142.5	0	0.215	9.1
$^{14}N+^{253}Cf\rightarrow^{262}Db+5n$	79	75.1	0	0.226	4.5
$^{33}P+^{234}Th\rightarrow^{263}Db+4n$	141	150.1	0	0.215	2.6

sion emitters are identified in the superheavy region $^{250-270}$Db. The possible projectile–target combinations to synthesise the superheavy nuclei ^{254}Db to ^{263}Db are predicted.

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