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Exotic decay: Transition from cluster mode to fission mode

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Abstract. Exotic decay of some heavy nuclei with $Z \geq 100$ formed in heavy ion 'cold fusion' reaction were studied taking interacting barrier consisting of Coulomb and proximity potential. Calculated half-life time shows that some modes of decay are well within the present upper limit for measurements $(T_{1/2} < 10^{30}$ s$)$. Cluster formation probabilities are calculated for different clusters within fission model. It is found that transition from cluster mode to fission mode take place at mass of the cluster, $A_2 = 20$ in exotic decay which is comparable with the value $A_2 = 16$ of Shanmugam *et al* based on cubic plus Yukawa plus exponential model (CYEM).

Keywords. Exotic decay; cluster decay; cluster model; fission model.

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1. Introduction

The discovery of Rose and Jones [1] of the spontaneous emission of ^{14}C from ^{223}Ra has confirmed the prediction by Sandulescu *et al* [2] of rare mode of decay, the exotic decay. This phenomenon can be treated as an intermediate process between alpha decay and spontaneous fission. There are mainly two approaches in explaining the exotic decay process: (1) cluster model and (2) fission model. In cluster model [3–5] the cluster is assumed to be preformed in the parent nuclei before it penetrate the nuclear interacting barrier. In fission model [6–8] the nucleus deforms continuously as it penetrates the nuclear barrier and reaches the scission configuration after running down the Coulomb barrier.

Taking Coulomb and proximity potential as interacting barrier we studied the exotic decay of various proton-rich parents in the trans-tin region [9–11] emitting clusters ranging from ^{4}He to ^{28}Si. It is observed that most of them are well within the present upper limit for measurements. In the exotic decay studies cluster-like shapes are preferred for very high asymmetric mass splitting and fissioning shapes are most suitable for less asymmetric and symmetric mass splitting. The present paper is to study the exotic decay of some heavy nuclei with $Z \geq 100$ emitting various clusters and also to find the transition point from cluster mode to fission mode. Section 2 gives the details of the model and §3 gives the results, discussion and conclusions.

2. The model

The interacting barrier for a parent exhibiting exotic decay is given by

$$V = \frac{Z_1 Z_2 e^2}{r} + V_{\rm p}(z), \quad \text{for } z > 0. \tag{1}$$

Here Z_1 and Z_2 are atomic numbers of daughter and emitted cluster, r is the distance between the fragment centers, z is the distance between the near surface of the fragments and $V_{\rm p}$ is the proximity potential given by [12]

$$V_{\rm p}(z) = 4\pi\gamma b\, \frac{C_1 C_2}{C_1 + C_2}\, \phi\left(\frac{z}{b}\right) \tag{2}$$

with nuclear surface tension coefficient

$$\gamma = 0.9517[1 - 1.7826(N-Z)^2/A^2] \;\; \text{MeV/fm}^2. \tag{3}$$

Here N, Z and A represent neutron, proton and mass number of the parent respectively. ϕ, the universal proximity potential is given as [13]

$$\phi(\varepsilon) = -4.41 \mathrm{e}^{-\varepsilon/0.7176} \quad \text{for } \varepsilon \geq 1.9475 \tag{4}$$

$$\phi(\varepsilon) = -1.7817 + 0.9270\varepsilon + 0.01696\varepsilon^2 - 0.05148\varepsilon^3 \quad \text{for } 0 \leq \varepsilon \leq 1.9475 \tag{5}$$

with $\varepsilon = z/b$, where the width (diffuseness) of nuclear surface $b \approx 1$ and Siissmann central radii C_i related to sharp radii R_i is $C_i = R_i - (b^2/R_i)$. For R_i we use semi-empirical formula in terms of mass number A_i as [12]

$$R_i = 1.28 A_i^{1/3} - 0.76 + 0.8 A_i^{-1/3}. \tag{6}$$

The barrier penetrability P is given as

$$P = \exp\left\{ -\frac{2}{\hbar} \int_{\varepsilon_i}^{\varepsilon_f} \sqrt{2\mu(V-Q)}\mathrm{d}z \right\}. \tag{7}$$

The mass parameter is replaced by reduced mass $\mu = mA_1A_2/A$, where m is the nucleon mass and A_1, A_2 represent mass numbers of daughter and emitted cluster respectively. The inner and outer turning points ε_i and ε_f are defined as $V(\varepsilon_i) = V(\varepsilon_f) = Q$, where Q is the energy released.

The half-life time is given by

$$T_{1/2} = \ln 2/\lambda = \ln 2/\nu P. \tag{8}$$

Here λ is the decay constant and assault frequency, $\nu = 2E_{\rm v}/h$. The empirical zero point vibration energy $E_{\rm v}$ is given as [7]

$$E_{\rm v} = Q\{0.056 + 0.039 \exp[(4 - A_2)/2.5]\}, \quad \text{for } A_2 \geq 4. \tag{9}$$

3. Results, discussion and conclusions

We have done our calculation taking the potential barrier as the sum of Coulomb and proximity potential for the touching and for the separated configuration. For the overlap region we use the simple power law as done by Shi and Swiatecki [6]. The proximity potential was first used by Shi and Swiatecki in an empirical manner and has been quite extensively used by Gupta and collaborators [4] in the preformed cluster model (PCM), which is based on the 'pocket formula' of Blocki *et al* [12]. In the present model we use another formulation of the proximity potential [13].

In the present paper we studied the exotic decay of ^{246}Fm, ^{254,256}No, ^{274}Rf, ^{262}Sg, ^{270,272}110, ^{278}112 emitting clusters ranging from ^{4}He to ^{24}Ne with a view to look for some measurable modes of decay which in turn may lead to the production of some other heavy nuclei as the daughter. The main and the most observed decay from these heaviest systems is the alpha decay. These heavy nuclei can be produced in heavy ion 'cold fusion' reaction with Pb as the target. The target projectile combinations for cold synthesis of these heavy nuclei are given in table 1.

Tables 2–5 gives the half-life time and other characteristics for ground state-to-ground state decay of these heaviest systems. It is found that many of them are well within the present upper limit for measurements $(T_{1/2} < 10^{30}\ \mathrm{s})$. When these heavy systems decay from excited state i.e. when excitation energies are included, $T_{1/2}$ values decrease considerably. So in the form of daughter nuclei these heavy systems offer good possibility for the synthesis of other heavy nuclei. For calculating Q values masses are taken from Moller and Nix [14], Moller *et al* [15] and Wapstra *et al* [16].

According to Poenaru *et al* [22] the cluster formation probability, S can be calculated within the fission model as the penetrability of the internal part (overlap region) of the barrier given as

$$S = \exp(-K_{\mathrm{ov}}), \tag{10}$$

where

$$K_{\mathrm{ov}} = \frac{2}{\hbar}\int_{\varepsilon_i}^{0} \sqrt{2\mu(V-Q)}\,\mathrm{d}z. \tag{11}$$

Table 1. Target projectile combination for cold fusion reaction.

Compound nuclei	Projectile nuclei	Target nuclei	Ref.
^{246}Fm	^{40}Ar	^{206}Pb	[17]
^{254}No	^{48}Ca	^{206}Pb	[18]
^{256}No	^{48}Ca	^{208}Pb	[19]
^{274}Rf	^{58}Ti	^{216}Pb	[20]
^{262}Sg	^{54}Cr	^{208}Pb	[21]
^{270}110	^{62}Ni	^{208}Pb	[21]
^{272}110	^{64}Ni	^{208}Pb	[21]
^{278}112	^{70}Zn	^{208}Pb	[21]

Table 2. Logarithm of predicted half-life time, cluster formation probability and other characteristics of ^{246}Fm decaying by emitting various clusters.

Parent nuclei	Emitted cluster	Daughter nuclei	Q value (MeV)	Penetrability P	Decay constant	$\log_{10}(T_{1/2})$	Preformation probability, S
^{246}Fm	^{4}He	^{242}Cf	8.506	2.38622E-22	9.32514E-02	0.871	2.301E-01
			8.206	2.16394E-23	8.15824E-03	1.929	2.049E-01
			8.376	8.56569E-23	3.29623E-03	1.323	2.190E-01
	^{8}Be	^{238}Cm	16.14	5.61198E-47	2.79777E-26	25.39	4.511E-05
			15.59	5.43267E-49	2.61608E-28	27.42	3.411E-05
			15.78	3.28240E-48	1.60192E-27	26.64	3.794E-05
	^{10}Be	^{236}Cm	10.09	4.29841E-84	1.24916E-63	62.74	5.151E-06
			9.693	2.15606E-87	6.01740E-67	66.06	4.094E-06
			9.643	8.07103E-88	2.24094E-67	66.49	3.978E-06
	^{12}C	^{234}Pu	30.51	1.45870E-50	1.23950E-29	28.75	1.198E-08
			29.76	1.81063E-52	1.50073E-31	30.66	7.394E-09
			27.96	2.46391E-57	1.91868E-36	35.56	2.376E-09
	^{14}C	^{232}Pu	29.30	1.14326E-55	9.18758E-35	33.88	1.775E-08
			28.66	1.56686E-57	1.23167E-36	35.75	1.108E-08
			27.08	2.14662E-62	1.59438E-41	40.64	3.518E-09
	^{16}C	^{230}Pu	19.92	5.58463E-95	3.02943E-74	73.36	4.989E-11
			19.43	1.19569E-97	6.32658E-77	76.04	3.469E-11
			18.04	8.5942E-106	4.22191E-85	84.22	1.252E-11
	^{16}O	^{230}U	44.74	1.39432E-56	1.69912E-35	34.61	7.556E-13
			42.23	3.54003E-62	4.07186E-41	40.23	1.159E-13
			43.26	7.78990E-60	9.17811E-39	37.88	2.478E-13
	^{18}O	^{228}U	44.42	1.97124E-58	2.37748E-37	36.47	1.879E-12
			42.62	1.06111E-62	1.22793E-41	40.75	4.123E-13
			41.69	5.38606E-65	6.09725E-44	43.06	1.913E-13
	^{20}O	^{226}U	39.28	6.65567E-73	7.08841E-52	50.99	7.261E-14
			38.00	1.13089E-76	1.16517E-55	54.77	2.363E-14
			39.15	2.88196E-73	3.05950E-52	51.36	6.497E-14
	^{20}Ne	^{226}Th	54.91	6.71230E-71	9.99329E-50	48.84	7.433E-19
			53.08	6.34779E-75	9.13564E-54	52.88	1.691E-19
			53.98	6.50497E-73	9.52128E-52	50.86	3.500E-19
	^{22}Ne	^{224}Th	59.05	4.06423E-63	6.50291E-42	41.03	7.593E-17
			57.58	3.36204E-66	5.24546E-45	44.12	1.901E-17
			58.17	5.87737E-65	9.26336E-44	42.87	3.295E-17
	^{24}Ne	^{222}Th	59.16	2.26802E-63	3.63462E-42	41.28	3.404E-16
			57.84	2.92970E-66	4.59025E-45	44.18	8.786E-17
			58.89	5.84731E-64	9.32755E-43	41.87	2.570E-16

Table 3. Logarithm of predicted half-life time, cluster formation probability and other characteristics of ^{254}No, ^{256}No and ^{274}Rf decaying by emitting various clusters.

Parent nuclei	Emitted cluster	Daughter nuclei	Q value (MeV)	Penetrability P	Decay constant	$\log_{10}(T_{1/2})$	Preformation probability, S
^{254}No	^{4}He	^{250}Fm	8.336	1.15087E-23	4.40760E-03	2.197	1.799E-01
			8.230	4.79358E-24	1.81250E-03	2.58	1.718E-01
			8.240	5.21018E-24	1.97242E-03	2.545	1.725E-01
	^{8}Be	^{246}Cf	15.98	4.54312E-49	2.24245E-28	27.49	2.615E-05
	^{10}Be	^{244}Cf	10.91	3.62005E-80	1.13749E-59	58.78	4.856E-06
	^{12}C	^{242}Cm	30.47	1.45119E-52	1.23150E-31	30.75	4.943E-09
	^{14}C	^{240}Cm	30.30	6.00861E-55	4.99349E-34	33.14	1.409E-08
	^{16}O	^{238}Pu	45.15	4.55808E-58	5.60538E-37	36.09	2.697E-13
	^{18}O	^{236}Pu	45.70	4.98739E-58	6.18856E-37	36.05	1.277E-12
	^{20}O	^{234}Pu	41.34	5.07678E-70	5.69042E-49	48.09	9.711E-14
	^{20}Ne	^{234}U	55.39	6.90037E-73	1.03631E-51	50.83	1.747E-19
	^{22}Ne	^{232}U	59.96	2.93070E-64	4.76148E-43	42.16	2.292E-17
	^{24}Ne	^{230}U	59.97	8.86437E-65	1.44001E-43	42.68	8.744E-17
^{256}No	^{4}He	^{252}Fm	8.286	8.23279E-24	3.13408E-03	2.345	1.745E-01
			8.580	8.76845E-23	3.45644E-02	1.302	1.959E-01
			8.550	6.92612E-23	2.72066E-02	1.406	1.936E-01
	^{8}Be	^{248}Cf	15.64	2.81099E-50	1.35796E-29	28.71	2.200E-05
	^{10}Be	^{246}Cf	11.06	5.09652E-79	1.62344E-58	57.63	5.225E-06
	^{12}C	^{244}Cm	29.79	3.17325E-54	2.63278E-33	32.42	3.262E-09
	^{14}C	^{242}Cm	30.20	4.01867E-55	3.32872E-34	33.32	1.325E-08
	^{16}O	^{240}Pu	44.07	2.67284E-60	3.20834E-39	38.33	1.256E-13
	^{18}O	^{238}Pu	45.31	8.93097E-59	1.09876E-37	36.80	9.553E-13
	^{20}O	^{236}Pu	41.58	3.17316E-69	3.57735E-48	47.29	1.244E-13
	^{20}Ne	^{236}U	53.99	8.40330E-76	1.23012E-54	53.75	6.069E-20
	^{22}Ne	^{234}U	59.35	2.39250E-65	3.84752E-44	43.26	1.395E-17
	^{24}Ne	^{232}U	60.09	2.44522E-64	3.98019E-43	42.24	1.073E-16
^{274}Rf	^{4}He	^{270}No	10.82	7.98296E-17	3.96835E+04	-4.76	3.789E-01
	^{10}Be	^{264}Fm	26.98	2.25343E-22	1.75056E-01	0.597	7.704E-01
	^{12}Be	^{262}Fm	21.95	5.80757E-35	3.55033E-14	13.29	1.935E-02
	^{14}C	^{260}Cf	42.91	2.30833E-28	2.71672E-07	6.407	1.399E-04
	^{16}C	^{258}Cf	40.26	2.59504E-33	2.84566E-12	11.39	1.269E-04
	^{18}C	^{256}Cf	35.78	8.94123E-44	8.68636E-23	21.90	1.538E-05
	^{20}O	^{254}Cm	58.16	9.19765E-35	1.45040E-13	12.68	3.566E-07
	^{22}O	^{252}Cm	57.83	7.34256E-35	1.15056E-13	12.77	2.540E-06

Here $z = 0$ represent the touching configuration. In tables 2–5, the last column gives cluster formation probability S for each cluster. Figures 1–8 represent the plot for $-\log_{10}(S)$ vs. A_2, mass of the emitted cluster for ^{246}Fm, ^{254}No, ^{256}No, ^{274}Rf, ^{262}Sg, ^{270}110, ^{272}110,

Table 4. Logarithm of predicted half-life time, cluster formation probability and other characteristics of ^{262}Sg and ^{270}110 decaying by emitting various clusters.

Parent nuclei	Emitted cluster	Daughter nuclei	Q value (MeV)	Penetrability P	Decay constant	$\log_{10}(T_{1/2})$	Preformation probability, S
^{262}Sg	^{4}He	^{258}Rf	9.646	6.19070E-21	2.74351	−0.59	2.118E-01
			9.610	4.83443E-21	2.13446	−0.49	2.087E-01
			9.700	8.94806E-21	3.98767	−0.76	2.163E-01
	^{8}Be	^{254}No	18.70	4.27477E-43	2.46917E-22	21.45	4.110E-05
			18.81	9.28489E-43	5.39491E-22	21.11	4.352E-05
	^{10}Be	^{252}No	12.84	4.56408E-72	1.68775E-51	50.61	5.357E-06
	^{12}C	^{250}Fm	34.40	2.91193E-47	2.78984E-26	25.40	1.028E-08
	^{14}C	^{248}Fm	33.55	8.30115E-51	7.63869E-30	28.96	2.128E-08
	^{16}O	^{246}Cf	50.27	1.00325E-52	1.37367E-31	30.70	7.416E-13
	^{18}O	^{244}Cf	50.28	1.50894E-53	2.06000E-32	31.53	2.783E-12
	^{20}O	^{242}Cf	45.40	1.64841E-65	2.02911E-44	43.53	1.447E-13
	^{20}Ne	^{242}Cm	61.88	4.11068E-66	6.89683E-45	44.00	6.604E-19
	^{22}Ne	^{240}Cm	65.94	5.09794E-59	9.10861E-38	36.88	7.839E-17
	^{24}Ne	^{238}Cm	65.66	7.81358E-60	1.38975E-38	37.70	2.756E-16
^{270}110	^{4}He	^{266}Hs	10.75	2.95008E-19	1.45646E+02	−2.32	2.309E-01
			11.17	3.58154E-18	1.83799E+03	−3.42	2.734E-01
			10.92	8.36077E-19	4.19457E+02	−2.78	2.474E-01
			13.21	1.07863E-13	6.54628E+07	−7.98	6.074E-01
			10.29	1.70368E-20	8.05418	−1.07	1.926E-01
			10.75	3.02241E-19	1.49273E+02	−2.33	2.312E-01
	^{8}Be	^{262}Sg	24.46	3.93038E-31	2.96968E-10	9.368	3.411E-04
			20.64	2.22550E-40	1.41885E-19	18.69	4.374E-05
			21.42	2.67996E-38	1.77323E-17	16.59	6.571E-05
			21.75	1.88223E-37	1.26460E-16	15.74	7.819E-05
	^{10}Be	^{260}Sg	14.42	1.79150E-67	7.43981E-47	45.97	4.839E-06
	^{12}C	^{258}Rf	41.52	9.53419E-37	1.10251E-15	14.79	1.983E-07
			37.65	3.96931E-44	4.16217E-23	22.22	1.407E-08
			38.48	1.83951E-42	1.97142E-21	20.55	2.446E-08
			38.81	8.19697E-42	8.86007E-21	19.89	3.054E-08
	^{14}C	^{256}Rf	36.44	4.90734E-48	4.90469E-27	26.15	2.491E-08
	^{16}O	^{254}No	54.93	6.92995E-49	1.03682E-27	26.83	1.502E-12
	^{18}O	^{252}No	54.15	6.01504E-51	8.84376E-30	28.89	3.381E-12
	^{20}O	^{250}No	48.54	1.10115E-63	1.44921E-42	41.68	9.584E-14
	^{20}Ne	^{250}Fm	67.75	2.49065E-61	4.57517E-40	39.18	1.602E-18
	^{22}Ne	^{248}Fm	71.13	9.63327E-56	1.85667E-34	33.57	1.328E-16
	^{24}Ne	^{246}Fm	70.16	1.23681E-57	2.35059E-36	35.47	2.619E-16

Table 5. Logarithm of predicted half-life time, cluster formation probability and other characteristics of ^{272}110 and ^{278}112 decaying by emitting various clusters.

Parent nuclei	Emitted cluster	Daughter nuclei	Q value (MeV)	Penetrability P	Decay constant	$\log_{10}(T_{1/2})$	Preformation probability, S
^{272}110	^{4}He	^{268}Hs	10.55	9.34470E-20	4.52764E+01	−1.82	2.128E-01
			10.77	3.68990E-19	1.82578E+02	−2.42	2.326E-01
			10.57	1.08482E-19	5.26806E+01	−1.88	2.148E-01
			10.09	4.97522E-21	2.30634	−0.52	1.776E-01
	^{8}Be	^{264}Sg	19.93	2.66205E-42	1.63878E-21	20.63	3.062E-05
			20.61	2.18169E-40	1.38896E-19	18.70	4.345E-05
	^{10}Be	^{262}Sg	14.02	1.60403E-69	6.47654E-49	48.03	3.827E-06
	^{12}C	^{260}Rf	36.29	7.32606E-47	7.40453E-26	24.97	5.967E-09
	^{14}C	^{258}Rf	35.68	1.03952E-49	1.01729E-28	27.83	1.447E-08
	^{16}O	^{256}No	53.23	7.88275E-52	1.14288E-30	29.78	4.276E-13
	^{18}O	^{254}No	53.39	2.77390E-52	4.02116E-31	30.24	1.862E-12
	^{20}O	^{252}No	48.33	4.97591E-64	6.52040E-43	42.03	8.408E-14
	^{20}Ne	^{252}Fm	66.00	2.55552E-64	4.57307E-43	42.18	4.058E-19
	^{22}Ne	^{250}Fm	70.01	1.45454E-57	2.75927E-36	35.40	4.974E-17
	^{24}Ne	^{248}Fm	69.56	1.39098E-58	2.62098E-37	36.42	1.563E-16
^{278}112	^{4}He	^{274}110	11.87	4.47093E-17	2.43737E+04	−4.55	3.022E-01
			12.49	1.09980E-15	6.31094E+05	−5.96	3.879E-01
			10.20	2.21633E-21	1.03861	−0.18	1.557E-01
			11.46	4.85965E-18	2.55811E+03	−3.57	2.568E-01
			11.87	4.56724E-17	2.49071E+04	−4.56	3.027E-01
	^{8}Be	^{270}Hs	22.52	1.01339E-36	7.04929E-16	14.99	7.427E-05
			20.31	1.46382E-42	9.18369E-22	20.88	2.363E-05
			21.70	8.73040E-39	5.85211E-18	17.07	4.829E-05
	^{10}Be	^{268}Hs	16.76	2.87062E-58	1.38553E-37	36.70	1.148E-05
	^{12}C	^{266}Sg	39.15	9.88109E-43	1.07740E-21	20.81	1.638E-08
	^{14}C	^{264}Sg	38.25	9.85597E-46	1.03399E-24	23.83	3.828E-08
	^{16}O	^{262}Rf	55.74	1.74332E-49	2.64673E-28	27.42	7.552E-13
	^{18}O	^{260}Rf	55.81	5.89616E-50	8.93473E-29	27.89	3.415E-12
	^{20}O	^{258}Rf	51.35	1.01306E-59	1.41045E-38	37.69	2.778E-13
	^{20}Ne	^{258}No	68.40	8.91515E-63	1.65337E-41	40.62	4.513E-19
	^{22}Ne	^{256}No	72.90	2.87795E-55	5.68486E-34	33.09	9.899E-17
	^{24}Ne	^{254}No	73.03	4.66252E-55	9.22372E-34	32.88	6.468E-16

^{278}112 respectively. The solid line represents the average behavior. From these plots it is clear that the cluster formation probability decreases with the mass of the emitted cluster up to $A_2 = 20$ and then increases and remains almost a constant. We would like to point out that this type of variation was also reported by Gupta and collaborators [23,24]. From the observed variation of the cluster formation probability with the mass of the cluster,

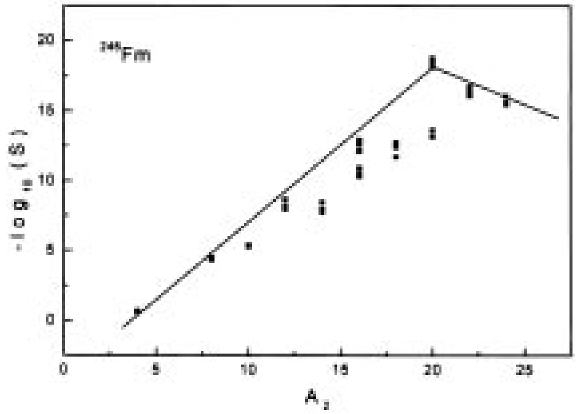

Figure 1. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{246}Fm.

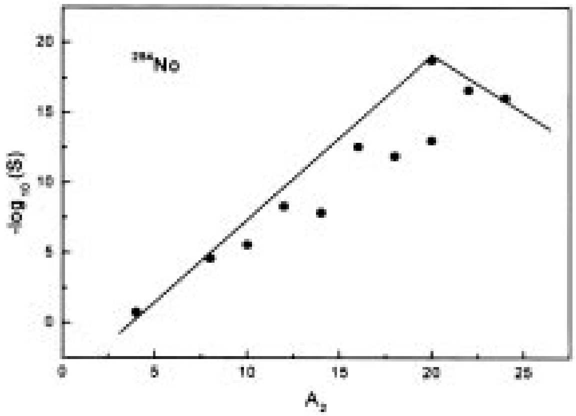

Figure 2. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{254}No.

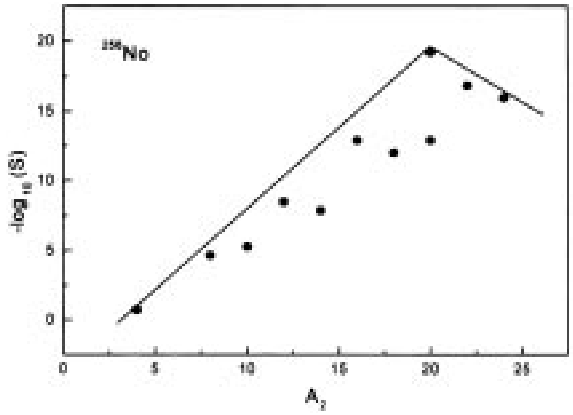

Figure 3. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{256}No.

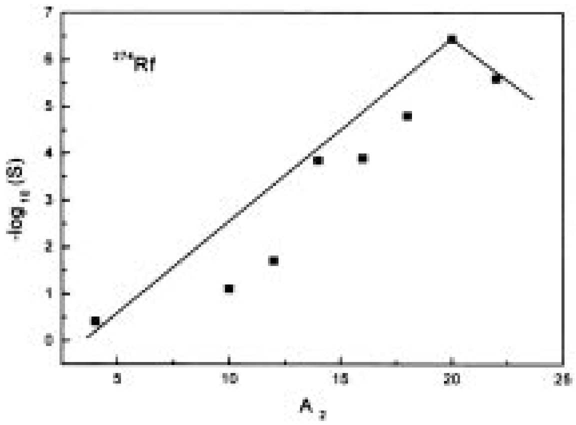

Figure 4. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{274}Rf.

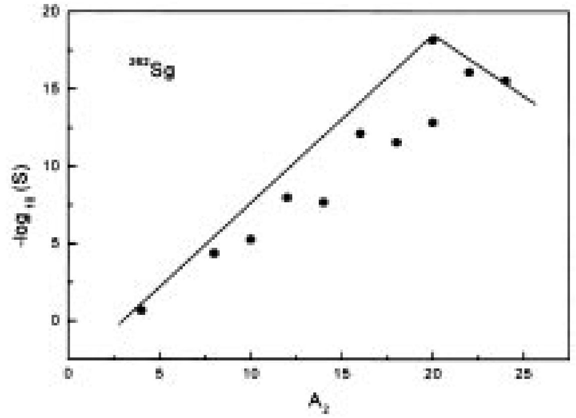

Figure 5. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{262}Sg.

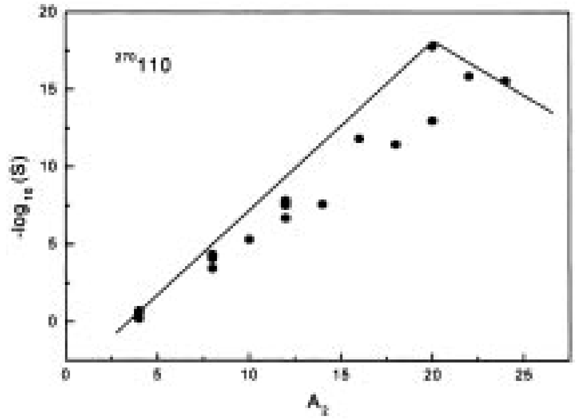

Figure 6. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{270}110.

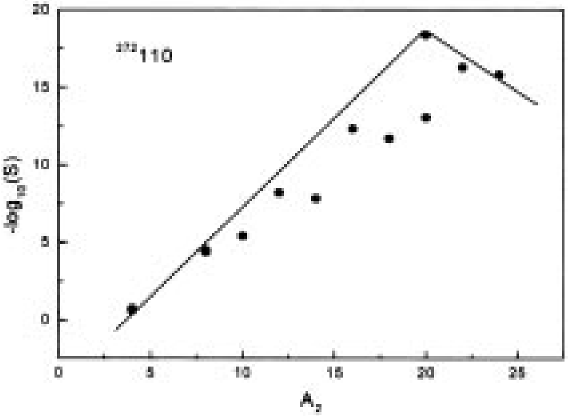

Figure 7. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{272}110.

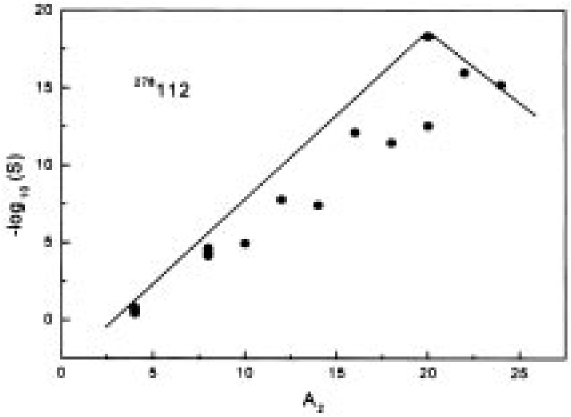

Figure 8. Plot for $-\log_{10}(S)$ vs. A_2 for the emission of various clusters from ^{278}112.

we conclude that in the exotic decays transition from the cluster mode to fission mode takes place at $A_2 = 20$. This value is comparable with the result of Shanmugam *et al* [25] based on cubic plus Yukawa plus exponential model (CYEM), according to which the transition point is at $A_2 = 16$. These authors arrived at this value by comparing half-life time values obtained for various clusters from their fission model (CYEM) with those values obtained from cluster model for the parent nuclei in the trans-tin region and found that deviation of the results become larger after $A_2 = 16$.

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