*)CENTRAL INSTITUTE OF PHYSICS
Bucharest, P.O.Box MG-6, ROMANIA
**)Institut fur Theoretische Physik der
J.W.Goethe-Universitat, Postfach 111932,
D-6000 Frankfurt am Main, F.R.GERMANY

[illegible]

IFIN - NP-70-1989 October

Cluster radioactivities of nuclei far off the beta - stability

D.N.POENARU*,**), M.IVASCU*), I.CATA-DANIL*)
W.GREINER**)

Abstract : New regions of cluster radioactivities (CR) far from the line of β-stability are predicted within analytical superasymmetric fission model. The released energy for α-decay and CR is calculated by using the mass tables published in 1988. CR of α-emitters with atomic numbers below 104, show measurable branching ratios for neutron deficient parent nuclei (e.g. ^{12}C, ^{16}O, and ^{28}Si-emissions from $^{114-116}Ba$, $^{118-125}Ce$, and $^{127,128}Sm$). CR are not the most probable decay modes of α-emitting superheavy nuclei. Another island of CR is expected for Z = 58-78, neutron rich, α-stable parents.

1 Introduction

Spontaneous fission had been discovered[1] shortly after induced fission[2,3]. Nevertheless, some properties including fragment mass asymmetry, have been explained only by taking into account both collective and single-particle nucleon motion[4]. Fragmentation theory and the asymmetric two center shell model[5] have been particularly succesful in this respect.

From the mass asymmetry parameter point of view, cluster radioactivities (CR) are intermediate phenomena between fission and α-decay. Consequently one natural way to develop the theory was to extend what was known for almost symmetric fission toward extremely large mass asymmetry. Three of the four models used in 1980 to predict CR (when it was shown that ^{14}C should be the most probable nucleus emitted from $^{222,224}Ra$), are based on this philosophy[6-8].

Four years latter, Rose and Jones discovered ^{14}C emission of the adjacent parent, ^{223}Ra . It was followed by the experimental identification of $^{24-26}Ne$, $^{28,30}Mg$, and ^{32}Si radioactivities[9-15]. There are many historical accounts on the development of CR and of the other kinds of nuclear disintegrations (for example Refs. 6, 16-18). Other fission models of CR are presented elsewhere[19-24]. Both fission theories and those developed starting from traditional α-decay treatment, can lead to halflife predictions in agreement with experimental data[12,25].

During fifty years of research, nuclear scientists learned very much about the richness of fission phenomena. According to different criteria, one has many kinds of fission : induced and spontaneous; from the ground state or from the shape isomeric state; binary or ternary; first chance or second chance; hot or cold; symmetric, low-asymmetric or superasymmetric (cluster radioactivities and α-decay), etc. The close connection of CR with cold fission phenomena[7] and its inverse process - the cold fusion[26] allowing to produce the heaviest elements[26-28], was realized very soon[29-32]. A unified description of α-decay, CR and cold fission[33,34] is best illustrated on ^{234}U nucleus for which all of these decay modes have been measured.

Some authors claimed that the observed events could be produced by ternary fission. By examining a typical energy spectrum measured in such a process[35,36] it is evident that any misinterpretation of CR as a particle accompanied fission should be ruled out due to experimental evidence of cluster monoenergeticity, demonstrating the two-body character of the output channel.

Dynamical investigations in a wide range of mass asymmetry[37-39] have shown that some confusions and mistakes have been made in the literature, and that cluster-like shapes are preferred to more compact ones for mass numbers of emitted particles lower than about 34 units.

The analytical superasymmetric fission model (ASAFM) developed since 1980, was particularly useful in predicting halflives and branching ratios relative to α-decay, which have been used to guide the experiments on : ^{14}C emission from $^{222,224,226}Ra$; $^{24-26}Ne$ emission from ^{230}Th, ^{231}Pa and $^{232-234}U$; $^{28,30}Mg$ emissions from ^{234}U, ^{238}Pu; and ^{32}Si radioactivity of ^{238}Pu. Recently a fine structure[20] had been observed[40] in the decay of ^{223}Ra by ^{14}C emission.

The availability of the new mass tables[41-50] and the smooth extrapolation of the correction energy[51] within ASAFM, allows us to update[52] the estimations of emission rates for CR[53] and to extend the regions of parents far off the beta-stability line, also including superheavy nuclei. In the following we shall present some of the results obtained in this study.

2 The Model and the Regions of Parent Nuclei

In any fission theory, the disintegration constant $\lambda = ln2/T$ of a parent nucleus AZ relative to the split into a light (emitted) A_eZ_e and a heavy (daughter) fragment A_dZ_d, may be calculated as a product νP of the number $\nu = 2E_{\nu}/h$ of assaults on a barrier in a time unit (the characteristic frequency of the collective mode leading to fission) and the probability of penetration , P, through the barrier.

The spontaneous process is energetically allowed if the released energy $Q = c^2(M - M_1 - M_2)$, given by the mass difference, is a positive quantity. Classically it is forbidden due to the potential barrier. It is essentially a quantum-mechanical phenomenon taking place by tunelling of the barrier. Within one-dimensional semiclassical WKB theory, P is well approximated by $exp(-K)$, where K is the action integral along the fission path. One has

$$\lambda = (2E_{\nu}/h)exp\{-\frac{2}{\hbar}\int_{r_a}^{r_b}[2B(r)E(r)]^{1/2}dr\} \tag{1}$$

where $B(r)$ is the nuclear inertia, $E(r)$ is the deformation energy from which Q-value and a correction E_{cr} have been subtracted out, and r_a, r_b are the turning points defined by $E(r_a) = E(r_b) = 0$. The analytical relationships derived from the above equation are presented in Ref. 6. The correction energy, motivated by static and dynamical considerations, was taken to be equal to E_{ν} in order to reduce the number of the fitting parameters. The energy conservation is expressed by

$$E_k = QA_d/A \tag{2}$$

where E_k is the kinetic energy of the light fragment.

Both shell and pairing effects have been included in E_{cr} in order to obtain the best agreement with experimental results :

$$E_{cr} = a_i(A_e)Q \qquad (i = 1, 2, 3, 4) \tag{3}$$

From a fit with about 385 α-emitters selected in four groups according to the even-odd character of the proton and neutron numbers, we have obtained four values of the coefficient a_i - the largest for even-even nuclei and the smallest for odd-odd ones. The coefficients decrease smoothly[33,51] for heavier emitted ions up to $A_e = 50$ and then increase slightly[52] toward $A_e = 100$.

By prepairing the new preprint, we have adopted the following strategy. Whenever available, the masses tabulated by Wapstra et al. are preferred. Hence the mass tables obtained from the measurement (mass code $C = 0$) and systematics $(C = 1)$[41], have been bordered with estimated masses[42-49]. In this way, the calculated Q-values in Table 1 Ref. 52, is based on the atomic masses of Refs. 41 and 42 $(C = 3)$. in all other Tables (2 to 8), only the parent nuclei which are not given by Wapstra *et al.* have been considered. Other selection requirements like : $Q_\alpha > 0$; $T < 10^{35}$ s and $B > 10^{-18.5}$, have been also employed.

Finally, Table 1 in Ref. 52 (where Q-values are calculated by using Wapstra et al.[41] or Jänecke and Masson[42] masses) contain 342 parent nuclides with Z = 54 - 108; Table 2 (masses $(C = 2)$ from Masson and Jänecke[43]) : 114 nuclides with Z = 56 - 103; Table 3 (masses $(C = 4)$ from Spanier and Johansson[44]) : 387 nuclides with Z = 56 - 114; Table 4 (masses $(C = 5)$ from Tachibana et al.[45]) : 192 nuclides with Z = 56 - 112; Table 5 (masses $(C = 6)$ from Satpathy and Nayak[46]) : 267 nuclides with Z = 52 - 112; Table 6 (masses $(C = 7)$ from Comay et al.[47]) : 200 nuclides with Z = 56 - 108; Table 7 (masses $(C = 8)$ from Möller et al.[48]) : 461 nuclides with Z = 56 - 122; Table 8 (masses $(C = 9)$ from Möller and Nix[49] : 478 nuclides with Z = 56 - 122.

Similarly, for nonα emitters $(Q_\alpha < 0)$ we got 153 nuclides with $logT(s) \leq 35$ having Z = 58 - 78 (masses from Refs. 41 or 42); 72 nuclides with Z = 56 - 78 (masses from Ref. 43); 2 nuclides with Z = 64, 65 (masses from Ref. 44); 8 nuclides with Z = 39 - 76 (masses from Ref. 46) and 102 nuclides with Z = 72 - 86 (masses from Ref. 47). No parent with mass codes 5, 8 and 9 satisfy the above mentioned conditions.

3 Results

A small difference in the mass value of one, two or three partners (parent and two fragments) obtained with different mass formulas, produces corresponding shifts in the Q_α and Q-values and induces a large variation of the lifetimes T_α and T. The dispersion of the branching ratios, B, is of course much higher. In some cases even the most probable emitted cluster may differ from table to table.

When Fig. 1 was plotted, only the parents for which at least in one table $B \geq 10^{-10}$, have been selected. As can be seen, except for some isolated cases, there are mainly five important islands of CR with high branching ratios relative to α-decay : three of α-emitters (one on the neutron deficient side, and two on the neutron rich side) and two of nuclides stable against α-decay on the neutron rich side.

3.1 Cluster radioactivities of α-emitters

3.1.1 Parent nuclides with $Z < 104$

The main results from table 1, Ref. 52 are illustrated in Fig. 2a, b. The most probable cluster emitted from nuclei are grouped in a way which assures a number of protons and/or neutrons of the daughter equal or very close to a magic number. For example such a shell effect is clearly seen in Fig. 2a at N = 88 and 90, where for ^{12}C and ^{16}O emissions respectively, one has $N_d = 82$ and at Z = 56 and 58, where $Z_d = 50$ for the same clusters.

In a similar way, in Fig. 2b one can see the effect of $N_d = 126$ at N = 130 for ^{8}Be, at N = 134 for ^{14}C, at N = 140 for ^{24}Ne, at N = 142 for ^{28}Mg, at N = 146 for ^{34}Si, etc. The proton magic number $Z_d = 82$ appear somewhat less pronounced at Z = 88 for C, at Z = 90 for O, at Z = 92 for Ne, at Z = 94 for Mg and at Z = 96 for Si emission.

A pairing effect is also present - the number of even Z and even N parent nuclei is larger than that of the corresponding ones with odd N and Z.

The decimal logarithm of the halflife expressed in seconds and of the branching ratio of some CR from Tables 1, 3 - 8, Ref. 52, are given in Table 1. From the parent nuclei of Fig. 1, we have selected those for which there is no discrepancy from table to table concerning the most probable emitted cluster. For example in all tables of Ref. 52, from $^{120}_{58}Ce$ the most probable emitted cluster is ^{16}O. Nevertheless, Q and Q_α are different, hence $logT(s)$ takes a whole range of about 8 units from 13.1 (Table 5, Ref. 52) to 20.8 (Table 3, Ref. 52). The corresponding $logB$ lies in a much larger interval (of about 24 units) from -5.5 to 18.3.

A positive value for $logB$ means CR more probable than α-decay. Very likely Q_α-values obtained for Ce isotopes in Table 3, Ref. 52 (masses from Spanier and Johansson) are too low, leading to extremely large T_α.

When the neutron number of the daughter increases over the closed shell value (50 or 126), the halflives became longer and longer.

Following emitted clusters have been noticed as the most probable: ^{5}He ; $^{8,10}Be$; $^{12,16}C$; $^{15,16,20-22}O$, ^{23}F ; $^{24-26}Ne$; $^{24,28-30}Mg$; $^{31,32}Al$; $^{28,33,34,36}Si$; ^{37}P ; $^{40,43-46}S$; ^{45}Cl ; $^{46-48}Ar$; $^{49,50}K$; $^{50-53}Ca$; ^{53}Sc ; $^{55,70}Fe$; ^{56}Co and $^{58,74,76-79}Ni$. Almost all are neutron rich nuclei.

In spite of the large discrepancies from table to table, it seems that ^{12}C and ^{16}O radioactivities have a good chance to be detected in some very neutron deficient Ba, Ce or Pr isotopes. Other possible candidates can be found in Table 1 and in Ref. 52.

3.1.2 Superheavy nuclei

Two mass tables[48,49] are extended in the region of superheavy nuclei up to $Z = 122$ and $N = 196$. They have been used to calculate Q-values of the tables 7 and 8, Ref. 52. A map of the most probable clusters in competition with α-decay, satisfying the selection criteria mentioned above is plotted in Fig. 3.

For nuclides with $Z \geq 104$ and $Q_\alpha > 0$, there are two groups of emitted clusters : 1)^{8}Be and $^{12,14}C$, 2)^{52}Ca ; ^{54}Ti ; ^{55}V ; $^{56-58,60}Cr$; ^{59}Mn ; $^{58,60,62,64,68,76}Fe$; ^{77}Co and $^{66-80}Ni$. The first group of lighter clusters is frequently met in the neutron deficient region of nuclides and the second group is located mostly around the β-stability line and on the neutron rich side. ^{8}Be and the neutron rich Ni isotopes are the main representatives of these two groups.

Some of the CR of superheavy nuclei are given in Table 2. The differences between kinetic energies and halflives of the same nucleus in Table 2, are not as large as in the preceding case.

Maximum emission rates are expected in this region from α-decay and spontaneous fission. If the masses used to compute Q-values are reliable enough, one can conclude that CR are not responsible for the fact that superheavies are still not found.

3.2 Cluster radioactivities of nonα-emitters

The neutron rich nuclides which are stable relative to α-decay are not as good cluster emitters as the neutron deficient α-emitting nuclei. This conclusion can be drawn both from the numbers of the parent nuclides mentioned at the end of the section 3.1.1 and from the Table 3, where the lifetimes are longer and the number of the mass tables leading to the same most probable cluster is much smaller compared to Table 1.

The most probable emitted clusters : $^{16,22}O$; ^{26}Ne ; ^{28}Si ; $^{44,46,48}S$; $^{50,52}Ar$; ^{53}K ; ^{56}Ca ; ^{62}Ti ; ^{74}Cr ; ^{75}Mn ; $^{74,76}Fe$; $^{75-78}Co$ and $^{57,58,74,76-82,84,86}Ni$ are further away from the line of β-stability, compared to the previously discussed two cases.

The examples plotted in Fig. 4 show a very steep decrease of the lifetime when the neutron number increases (a trend which is reversed in comparison with that from the Table 1), if the emitted cluster is lighter than Fe, and a much smaller variation for heavier clusters. Also the even - odd effect is evident.

4 Conclusions

The masses published in 1988, allows us to extend the predictions for new decay modes by cluster emission beyond the region of parent nuclides with measured masses. Comprehensive tables have been published[52]. The partial halflives of a given parent nucleus for α-decay and CR are very different from table to table due to the corresponding mass dispersion.

In spite of the high uncertainties originating from the lack of a very precise mass formula, one can draw some reliable conclusions from the study of CR emissions in the regions of parent nuclides far off the line of β-stability. In this paper we discussed results, obtained within ASAFM, concerning spontaneous cluster emission from: 1) α-emitters with $Z < 104$; 2) superheavy nuclei and 3) nuclides stable against α-decay.

Cluster emitters with measurable branching ratios relative to α-decay could be found not only around the line of β-stability, but also far removed from this line, on the neutron deficient side, e.g. ^{12}C, ^{16}O and ^{28}Si radioactivities of some Ba (A = 114 - 116), Ce (A = 118 - 125) and Sm(A =

127, 128) isotopes, respectively. In this region lifetimes decrease when the neutron number of the parent decreases.

Very likely CR are not responsible for the negative results in the search for superheavy nuclei. Nevertheless some ${}^{8}Be$ and ${}^{12,14}C$ radioactivities are expected for neutron deficient nuclei with $Z > 106$. Also around $Z = 110$, $N = 176$ there should be an island of ${}^{78}_{28}Ni_{50}$ emission because the corresponding daughter is the doubly magic ${}^{208}Pb$ and one can believe that the neutron rich fragment ${}^{78}Ni$ is doubly magic too.

Neutron rich parents far removed from the line of β-stability, with $Z = 58$ - 78 are estimated to be stable with respect to α-decay, but they could exhibit CR with emitted particles having very high neutron excess. Unlike in the neutron deficient region, the lifetimes are decreasing functions of the parent neutron number.

5 References

[1] Petrjak, K.A. and G.N. Flerov, 1940, JETP **10**, 1013.

[2] Hahn, O. and F. Strassmann, 1939, Naturwiss. **27**, 11, 89.

[3] Meitner, L. and O.R. Frisch, 1939, Nature **143**, 239.

[4] Strutinsky, V.M., 1967, Nucl. Phys. **A 95**, 420.

[5] Maruhn, J.A., W. Greiner and W. Scheid, 1980, *in Heavy Ion Collisions* edited by R. Bock (North Holland, Amsterdam), Vol. 2, p. 399.

[6] Poenaru, D.N. and M.Ivaşcu, 1988, Eds., *Particle Emission from Nuclei* (CRC, Boca Raton, Florida).

[7] Poenaru, D.N., M.Ivaşcu, and W.Greiner, 1988, chapter 7, vol. III, Ref. 6, p. 203.

[8] Greiner, W., M.Ivaşcu, D.N.Poenaru, and A.Săndulescu, 1989, in *Treatise on Heavy Ion Science*, edited by D.A.Bromley (Plenum, New York), vol. 8, p. 641.

[9] Hourani, E. and M.Hussonnois, 1988, chapter 6, vol. II, Ref. 6, p. 172.

[10] Hourani, E. , 1986,in *Lecture Notes in Physics* (Springer, Heidelberg) **279**, 383.
Hourani, E. *et al.*, 1989, Ann. Phys. (Paris) 14, 311.

[11] Price, P.B. and S.W.Barwick, 1988, chapter 8, vol. II, Ref. 6, p. 206.

[12] Price, P.B., 1989, Annu. Rev. Nucl. Part. Sci. (*in press*).

[13] Wang, S., D. Snowden-Ifft, P.B. Price, K.J. Moody and E.K. Hulet, 1989, Phys. Rev.C **39**, 1647.

[14] Haşegan, D. and S.P.Tretyakova, 1988, chapter 9, vol. II, Ref. 6, p. 234.

[15] Tretyakova, S.P., Yu.S. Zamyatnin, V.N. Kovantsev, Yu.S. Korotkin, V.L. Mikheev and G.A. Timofeev, 1989, Z. Phys. **A 333**, 349.

[16] Poenaru, D.N. and M.Ivaşcu, 1984, in *Atomic and Nuclear Heavy Ion Interactions, 2nd Part*, edited by G. Semenescu *et al.* (Central Inst. of Phys., Bucharest), p. 277.

[17] Berlovich, E.Ye. and Yu.N. Novikov, 1988, in *Modern Methods of Nuclear Spectroscopy* (in Russian) (Nauka, Leningrad), p. 107.

[18] Herrmann, G., 1989, International Conf. "Fifty Years Research in Nuclear Fission", West Berlin, April 3-7, Nucl. Phys., *in press*.

[19] Shi, Y.-J. and W.J.Swiatecki, 1987, Nucl. Phys. **A 464**, 205.

[20] Greiner, M., W.Scheid, and V.Oberacker, 1988, J. Phys. G. 14, 589.

[21] Pik-Pichak, G.A., 1986, Yad. Fiz.44, 1421 [Sov. J. Nucl. Phys. 44, 923,(1987)].

[22] Barranco, F., R.A.Broglia, and G.F.Bertsch, 1988, Phys. Rev. Lett. **60**, 507.

[23] Shanmugam, G. and B.Kamalaharan, 1988, Phys. Rev. C **38**, 1377.

[24] Malik, S.S. and R.K.Gupta, 1989, Phys. Rev. C **39**, 1992.

[25] Poenaru, D.N., W. Greiner and M. Ivaşu,1989, International Conf. "Fifty Years Research in Nuclear Fission", West Berlin, April 3-7, Nucl. Phys., *in press*.

[26] Oganessyan, Yu.Ts., 1974, in *Lecture Notes in Physics* **33**, 221.

[27] Münzenberg, G., 1986, Rep. Prog. Phys. **51**, 57.

[28] Armbruster, P., 1985, Annu. Rev. Nucl. Part. Sci. **35**, 135.

[29] Greiner, W. 1988, invited talk International Symp. on Physics and Chemistry of Fission, Gaussig near Dresden, *Proc. in press*.

[30] Poenaru, D.N., M. Ivascu and W. Greiner, 1985, Proc. Int. Conf. on SSNTD, in Nucl. Tracks, **12**, 313.

[31] Armbruster, P., 1988, invited talk International Conf. "Cluster 88", Kyoto, Japan, J. Phys. Soc. Jpn. **58**, Suppl. 232.

[32] Gönnenwein, F., B. Börsig and H. Löffler, 1986, in Proc. Internat. Symp. on Collective Dynamics, Bad Honnef, edited by P. David (World Sci., Singapore), p. 29.

[33] Poenaru, D.N., W. Greiner, M. Ivaşcu, D. Mazilu and I.H. Plonski, 1986, Z. Phys. **A 325**, 435.

[34] Barranco, F., E. Vigezzi and R.A. Broglia, 1989, Phys. Rev. C **39**, 2101.

[35] Theobald, J.P.,1989, International Conf. "Fifty Years Research in Nuclear Fission", West Berlin, April 3-7, Nucl. Phys., *in press*.

[36] Wagemans, C., 1988, chapter 3, vol. III, Ref. 6, p. 63.

[37] Ivaşcu, I. , 1988, St. Cerc. Fiz. **40**, 811.

[38] Poenaru, D.N. and M. Ivaşcu, 1988, invited talk International Conf. "Cluster 88", Kyoto, Japan, J. Phys. Soc. Jpn. **58**, Suppl. 249.

[39] Poenaru, D.N., J.A. Maruhn, W. Greiner, M. Ivaşcu, D. Mazilu and I. Ivaşcu, 1989, Z. Phys. **A 333**, 291.

[40] Brillard, L., A.G. Elayi, E. Hourani, M. Hussonnois, J.F. Le Du, L.H. Rosier and L. Stab, 1989, C.R. Acad. Sci. (in press).

[41] Wapstra, A.H., G. Audi, and R. Hoekstra, 1988, At. Data Nucl. Data Tables **39**, 281.

[42] Jänecke, J., and P.J. Masson, 1988, *ibid.*, 265.

[43] Masson, P.J., and J. Jänecke, 1988, *ibid.*, 273.

[44] Spanier, L., and S.A.E. Johansson, 1988, *ibid.*, 259.

[45] Tachibana ,T., M.Uno, M.Yamada, and S.Yamada, 1988, *ibid.*, 251.

[46] Satpathy, L., and R.K.Nayak, 1988, *ibid.*, 241.

[47] Comay, E., I.Kelson, and A.Zidon, 1988, *ibid.*, 235.

[48] Möller, P., W.D.Myers, W.J.Swiatecki, and J.Treiner, 1988, *ibid.*, 225.

[49] Möller, P., and J.R.Nix, 1988, *ibid.*, 213.

[50] Haustein, P.E.(special editor), 1988, *ibid.*, 185, and chapter 9, vol. I, Ref. 6, p. 233.

[51] Poenaru, D.N., M.Ivaşcu, D.Mazilu, I.Ivaşcu, E.Hourani, and W.Greiner, 1989, invited talk, *1988 International Symposium on Developments in Nuclear Cluster Dynamics, Sapporo*, Proceedings edited by K.Akaishi, K.Kato, H.Noto, and S.Okabe (World Scientific, Singapore), p.76.

[52] Poenaru, D.N., M.Ivaşcu, I. Căta ,D.Mazilu, K.Depta, and W.Greiner, 1986, "Estimations of Cluster Emission Rates Based on 1988 Mass Tables" (Central Institute of Physics, Bucharest), Report NP–69–1989.

[53] Poenaru, D.N., M.Ivaşcu, D.Mazilu, R.Gherghescu, K.Depta, and W.Greiner, 1986, "Most probable cold fission fragments and heavy ion radioactivities" (Central Institute of Physics, Bucharest) Report NP–54–86.

Table 1: Cluster radioactivities of some alpha emitters.

				a		b		c		d		e		f		g	
Z	A	Z_e	A_e	lgT	-lgB	lgT	-lgB	lgT	-lgB	lgT	-lgB	lgT	-lgB	lgT	-lgB	lgT	-lgB
56	114	6	12	10.6	7.2	9.7	8.8	9.5	9.1			12.1	4.0	7.9	11.0	7.2	11.6
	115			14.7	6.4	15.2	5.0	13.6	8.9			15.8	3.2	12.3	11.0	11.6	12.0
	116			15.5	8.3	16.6	5.9	14.3	10.5	10.4	14.6	16.0	7.2	14.3	10.5	13.6	11.5
58	118	8	16	11.9	5.2	14.5	-16.7	10.6	5.6			12.3	8.5	11.0	-2.7	10.2	-2.2
	119			15.9	7.5	20.0	-16.5	15.4	5.4			16.5	9.1	15.3	-0.2	14.6	0.0
	120			16.6	5.5	20.8	-18.3	16.9	3.6	13.1	-0.8	17.3	4.7	16.6	0.2	15.9	0.3
	121			21.3	4.0	26.5	-	21.0	5.5	16.9	16.7	22.2	-0.8	21.2	4.4	20.7	6.9
	122			22.1	4.4	27.0	-	21.4	7.5			23.3	-2.8	21.9	5.3	21.5	7.1
	123			27.4	3.8			26.9	6.4			28.3	-2.2	26.9	6.6	26.6	8.0
	124			28.9	2.6	33.7	-	27.7	9.0			29.8	-4.1	27.9	7.8	27.7	8.7
	125			34.3	-2.9			33.6	2.8	31.3	14.1	34.9	-8.5	33.2	5.1	33.2	5.3
59	124	8	16	27.2	-7.3	33.2	-6.7	27.7	-3.9			28.2	0.6	26.0	5.7	25.5	6.1
	125			28.4	-3.4	34.7	-3.8	28.3	-1.3	22.7	6.4	29.4	5.4	27.1	2.8	26.7	3.6
	126			33.2	-4.9			33.8	-6.6			33.8	5.1	31.8	1.9	31.5	3.0
	127			34.5	-4.7			33.9	-2.1	26.6	13.8	34.7	9.5	32.7	3.2	32.6	4.2
62	127	14	28	20.9	6.1	24.9	7.4	20.8	3.3			21.2	9.5				
	128			21.7	8.8	25.4	9.6	21.3	5.0			22.0	12.7				
85	223	6	14					33.7	16.4	17.7	-12.2	29.0	17.3	28.9	15.9	27.9	16.7
86	223	6	14							19.2	2.1	24.9	16.5	23.6	-9.6	22.5	-6.0
	224					28.1	17.1	28.5	14.5	18.6	-1.0	25.1	14.6	24.8	-5.6	23.7	-3.0
	225					32.5	17.7	34.5	16.3	23.6	1.8	29.6	17.2	31.2	6.8	30.0	8.0
93	225	6	12	10.2	13.1	13.5	9.9	11.0	12.5	9.8	13.4	10.7	12.8	10.1	13.2	8.6	14.1
94	226	6	12	8.8	13.0	12.7	14.2	10.4	14.6	7.8	13.0	9.4	13.4	9.7	10.0	7.8	9.2

a-from Table 1; b-from Table 3;c-from Table 4; d-from Table 5; e-from Table 6; f-from Table 7;g-from Table 8; Ref.52.

Table 2: Cluster emission from some superheavy nuclei

Z	A	Z_c	A_c	From Table 7 Ref.52.					From Table 8 Ref.52.				
				E_α	lgT_α	E_k	lgT	$-lgB$	E_α	lgT_α	E_k	lgT	$-lgB$
110	282	28	74	7.8	5.6	162.9	17.9	12.3	8.2	4.1	163.5	16.9	12.8
112	272	4	8						11.65	-5.0	23.6	7.6	12.7
	304	28	78	6.07	13.7	161.6	24.2	10.5	6.70	10.3	162.0	23.6	13.3
	306			6.54	11.1	162.0	23.7	12.5	6.96	9.0	162.4	23.1	14.1
	308			6.23	12.8	162.1	23.8	11.0	6.61	10.7	162.3	23.4	12.6
119	299	4	8	11.55	-2.8	24.3	10.1	12.9	12.05	-3.9	25.2	8.1	12.1
120	300			12.43	-4.4	25.7	7.1	11.6	12.95	-5.5	26.7	5.2	10.8
	304			12.48	-4.5	24.9	8.6	13.2	13.04	-5.7	25.9	6.6	12.3
	305			12.08	-3.0	24.5	10.7	13.8	12.65	-4.3	25.5	8.7	13.0
	306			11.52	-3.2	23.9	10.5	13.7	12.09	-4.5	25.0	8.4	12.9
	307			10.48	-0.1	23.5	12.8	12.9	11.06	-1.6	24.6	10.6	12.2
	308			10.45	-0.5	22.9	12.8	13.4	11.03	-2.0	23.9	10.5	12.6
121	304			12.80	-3.8	25.9	9.1	13.0	13.35	-4.9	26.9	7.2	12.2
	305			12.32	-3.9	25.4	8.7	12.6	12.87	-5.0	26.5	6.7	11.8
	306			11.91	-1.5	25.0	10.8	12.4	12.46	-2.9	26.0	8.8	11.7
	307			11.26	-2.0	24.4	10.7	12.7	11.82	-3.3	25.4	8.6	11.9
122	302			13.38	-5.8	26.2	7.2	13.1	13.88	-6.7	27.2	5.4	12.1
	305			12.32	-2.9	26.9	9.2	12.1	12.86	-4.1	26.9	7.2	11.4
	306			12.41	-3.8	25.4	8.7	12.5	12.93	-4.9	26.4	6.7	11.6

Table 3: Cluster emission from some nuclides stable against α-decay

Z	A	Z_c	A_c	Q_α	Q	lgT	Mass code C	Q_α	Q	lgT	Mass code C
56	160	6	16	-5.47	13.5	31.9	2				
58	162	8	22	-5.74	23.6	30.0	2				
60	168	10	26	-6.81	30.8	34.8	2				
66	186	16	46	-9.44	72.8	17.8	2				
67	181			-4.53	65.4	34.2	6				
70	196	20	56	-10.50	87.0	29.7	2				
72	204	28	78	-10.44	118.7	20.5	2	-3.09	115.5	25.2	3
73	205			-8.77	117.6	27.1	2	-3.01	116.5	28.7	3
74	206			-7.20	117.5	30.7	2	-3.05	118.1	29.8	3
75	223	26	76	-10.79	119.4	23.3	3	-4.98	115.1	29.9	7
	224			-11.20	118.8	25.5	3	-5.53	116.1	29.6	7
76	211	28	78	-6.64	122.6	32.5	2	-4.12	122.4	32.9	3
	212			-7.34	123.5	29.6	2	-4.49	122.9	30.4	3
	222	26	76	-8.98	119.7	26.3	3	-3.51	115.3	33.1	7
	223			-9.59	119.9	27.5	3	-3.91	116.5	32.7	7
	224			-10.03	120.1	25.5	3	-4.50	118.2	28.4	7
	225			-10.54	119.6	27.7	3	-4.93	119.0	28.5	7
77	223	27	77	-8.08	122.7	30.5	3	-2.97	120.3	34.1	7
	224			-8.35	122.4	32.2	3	-3.31	120.9	34.4	7
	225			-8.88	122.5	30.3	3	-3.78	122.5	30.4	7
78	216	28	78	-6.07	126.9	32.4	2	-3.81	125.6	34.3	3
	224			-7.06	126.1	32.1	3	-2.58	125.7	32.7	7
	225			-7.44	125.9	34.0	3	-2.80	126.3	33.4	7

6 Figure Captions

Fig. 1. Regions of CR with estimated branching ratios relative to α - decay larger than 10^{-10} at least in one of the eight tables from Ref. 52.

Fig. 2. The most probable cluster emitted from parent nuclei according to Table 1, Ref. 52. $logT(s) \leq 35$, $logB < 18.5$. B=Be, C=C, M=Mg, N=Ne, O=O, P=P, S=Si, a=Ar, c=Ca, f=Fe, k=K, m=Mn, n=Ni, o=Co, r=Cr, s=S, t=Ti, v=V, – = Green approximation of the line of β - stability.

Fig. 3. The most probable clusters emitted from superheavy nuclei according to Table 7, Ref. 52. See the caption of Fig. 2.

Fig. 4. Lifetimes for some kinds of CR versus the neutron numbers of the daughter in the region of neutron rich nonα - emitters.

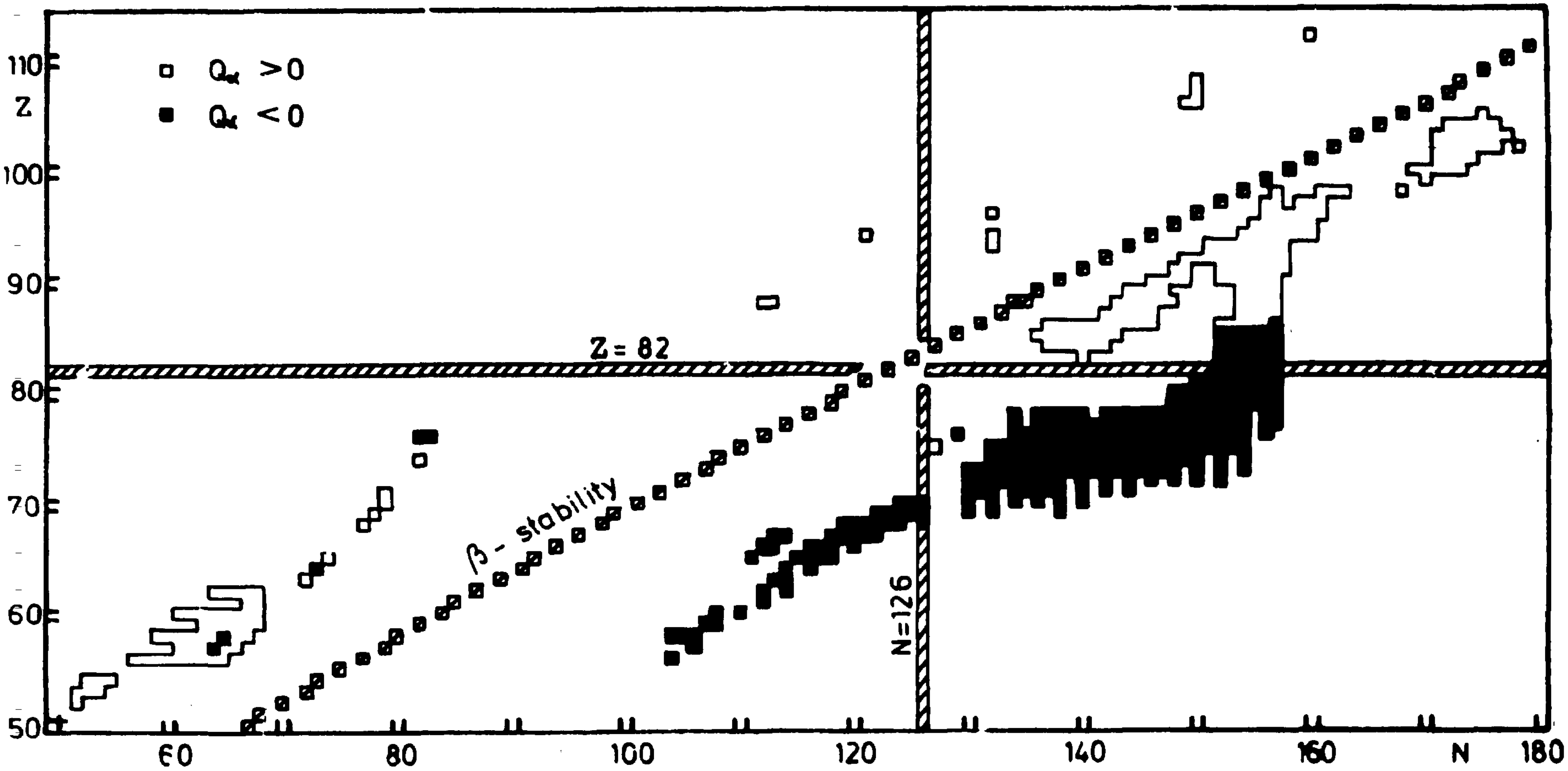
110
Z
100
90
80
70
60
50
60
80
100
120
140
160
N
180
□ $Q_\alpha > 0$
■ $Q_\alpha < 0$
Z = 82
N=126
β - stability

Fig.1

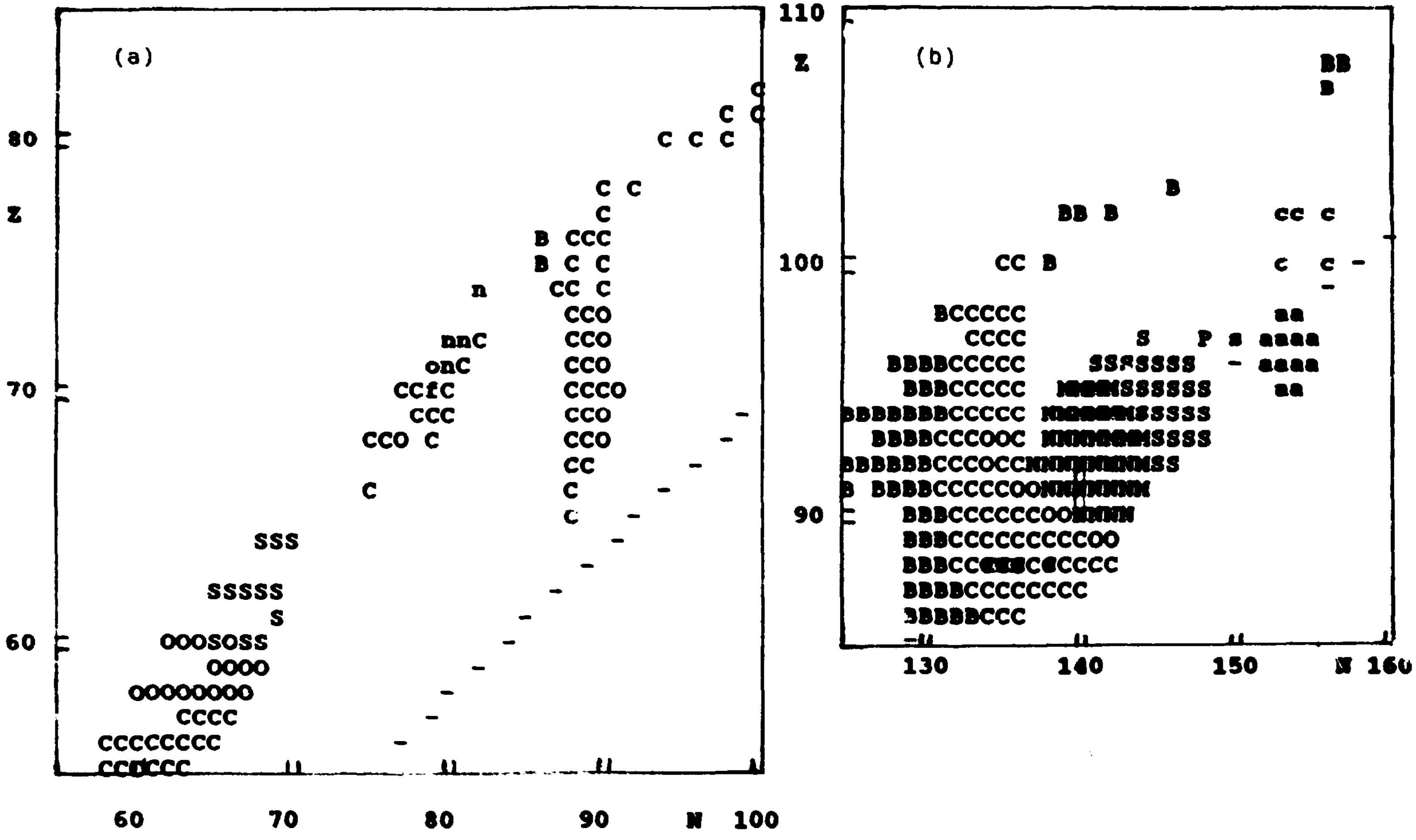

Fig. 2

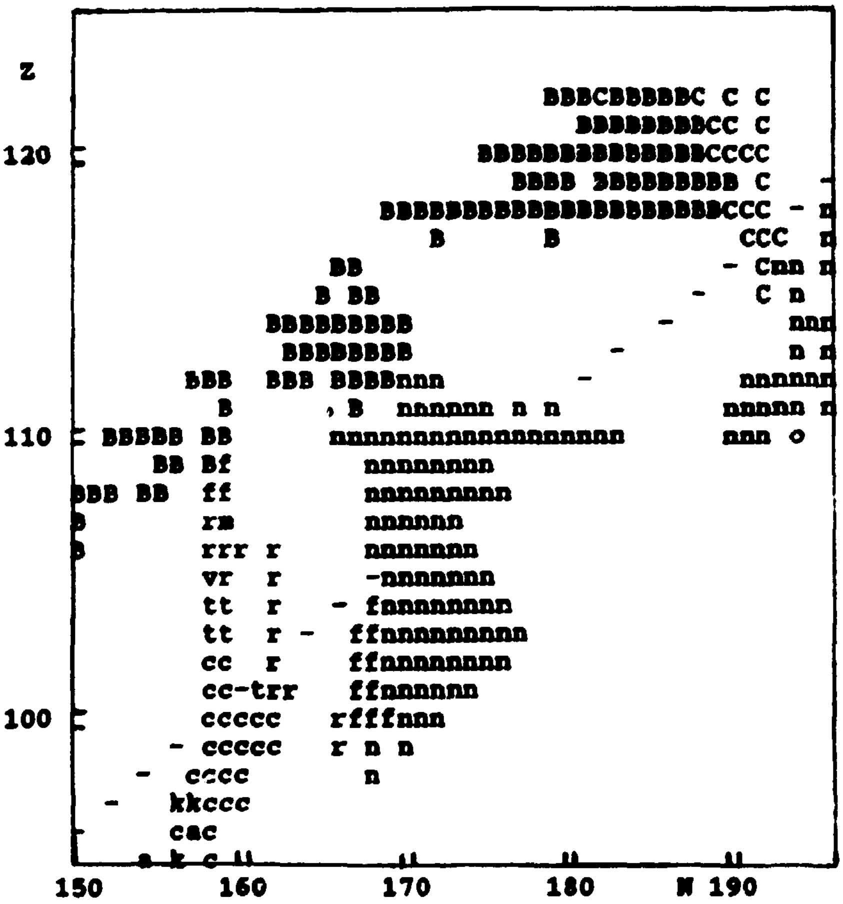

Fig. 3

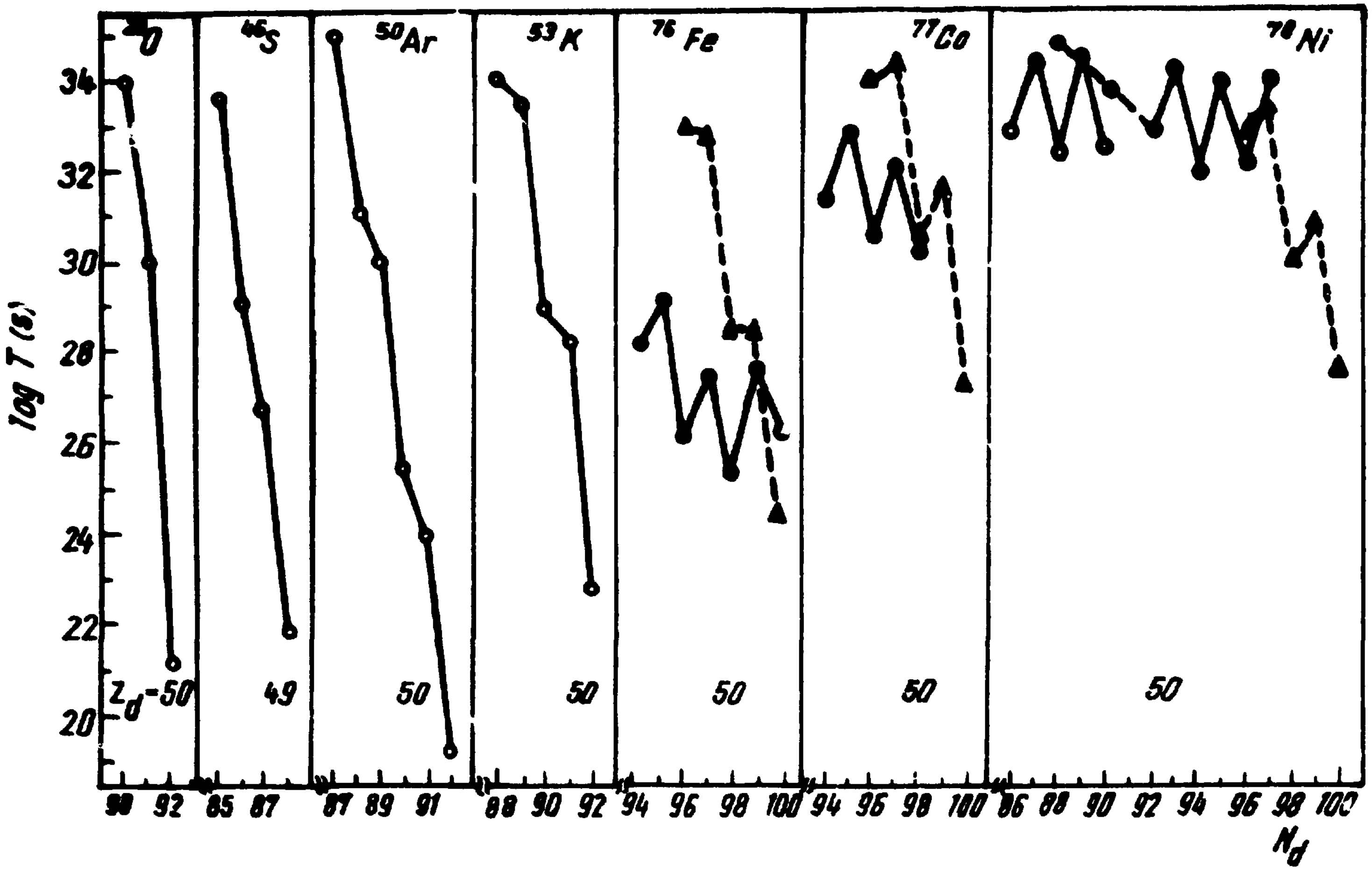
O
^{46}S
^{50}Ar
^{53}K
^{76}Fe
^{77}Co
^{78}Ni
log T (s)
34
32
30
28
26
24
22
20
Z_d=50
49
50
50
50
50
50
90 92
85 87
87 89 91
88 90 92
94 96 98 100
94 96 98 100
86 88 90 92 94 96 98 100
N_d

Fig. 4