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Target Fragment Mass Distribution
for the
Interaction of 245 MeV/A ^{139}La with ^{139}La

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ABSTRACT

The target fragment isobaric yield distribution was measured for the reaction of 245 MeV/A ^{139}La with ^{139}La using radiochemical techniques. The mass distribution shows two features not previously observed in high energy rare earth target fragment mass distributions. These features are (a) the appearance of a large fission fragment-like bump in the yield distribution centered at A $\sim$60, whose integrated cross section is $\sim$540 mb, indicating greatly enhanced fission of a target-like species (compared to p-La collisions where $\sigma_f \leqslant 1$ mb) (b) a low, integrated total residue production cross section of $\sim$3.9 b, possibly indicating the occurrence of a significant number of events that do not lead to the production of target fragments. These observations are compared to predictions of the nuclear firestreak and intranuclear cascade models. It appears the enhanced fission of the La-like species is due to significant angular momentum transfer in this reaction while the decreased residue yield is due to the large number of participant nucleons in this reaction.

NUCLEAR REACTIONS ^{139}La (^{139}La,X), E = 245 MeV/A; measured $\sigma(Z,A)$; deduced σ_f, σ_R

1. Introduction

The availability of very heavy ion beams at relativistic energies from the LBL Bevalac has stimulated interest in the study of high energy collisions of equal mass nuclei. In such collisions, it is believed that one can study compressional and high density stages of nucleus-nucleus collisions. In this paper we wish to report the results of some very simple single particle inclusive measurements of target fragmentation for one case of such a collision, the interaction of 245 MeV/A ^{139}La with ^{139}La. We believe that the reported measurement of the fragment isobaric yield distribution in this reaction can reveal some of the features seen in high energy (heavy nucleus-heavy nucleus) collisions not previously observed in high energy p-nucleus or light nucleus-heavy nucleus collisions. In particular, we shall report the observation of an unusually large fission cross section and an unusually low total fragment production cross section and shall try to suggest possible causes for these phenomena.

2. Experimental

The target fragment isobaric yield distribution was measured for the reaction of ^{139}La with ^{139}La at a "center of target" projectile energy of 245 MeV/A using the LBL Bevalac. A La metal target of thickness 402 mg/cm^2 was irradiated[1] with a ^{139}La $^{39+}$ beam for $\sim$2 days with a total particle fluence of 5.7 x 10^{11} ions. The beam intensity was monitored by a thin window ion chamber mounted in front of the target. This ion chamber had been calibrated[2] just prior to the experiment using a scintillator. The beam energy entering the target was 255 MeV/A and was 235 MeV/A as it left the target.

At the end of the irradiation, the target was cut in half, with one half being analyzed by direct γ-ray spectroscopy while the other half was separated into four chemical fractions prior to counting. The chemical fractions were an iodine fraction (containing I radionuclides), a rare earth fraction (containing Sc, Y, La, Ce radionuclides), a barium-strontium fraction (containing Ba, Rb, Cs, Sr, radionuclides) and an antimony fraction (containing Te, Sn, Sb and Tc radionuclides). In the chemical separation the La metal foil was dissolved in HNO_3, iodine carrier added and the iodine extracted into CCl_4. After backextraction, the iodine was precipitated as AgI for counting. The aqueous phase from the original extraction was evaporated to dryness and converted to 2N in HCl. This solution was contacted with anion exchange resin (BioRad AG1-X8) with the antimony fraction being adsorbed by the resin which was counted directly. H_2SO_4 was added to the eluant from the anion exchange procedure to precipitate the Ba-Sr fraction. The rare earth fraction was then precipitated as LaF_3 using HF.

The counting of the iodine fraction began $\sim$3 hours after end of bombardment, the Sb fraction 7 hours, the Ba-Sr fraction 8 hours and the rare earth fraction 9 hours after end of bombardment. The chemical yields for each of the elements in the fractions were determined by normalization to the radionuclide yields measured using the unseparated foils, making corrections for the original division of the target foil.

Assay of the unseparated foil fraction began $\sim$10 minutes after end of irradiation and assay of all fractions continued for $\sim$1 month. The assay of the target fragment radioactivities and the calculation of measured nuclidic production cross sections from them was done using standard techniques that have been described previously.[3] The results of these measurements for the interaction of $\sim$245 MeV/A ^{139}La with ^{139}La are summarized in Table I.

No correction was made for the loss of nuclei recoiling from the surface of the target because of a lack of knowledge of the ranges of the nuclei involved. Based upon previous studies[4] of the recoil properties of the light products from the reaction of 18.5 GeV ^{12}C with Gd, one would estimate that $< 2 - 3\%$ of the light fragments are lost due to recoil. No corrections were made for reactions induced by secondary particles because we do not have any information about the magnitude of the effect in our bombardment. If the secondary reaction effects were similar to those seen[5] for the reaction of 25 GeV ^{12}C with Ag, one might expect a uniform enhancement (independent of A for $\Delta A > 20$) of ∿10% in the product yields. In any case it does not seem likely that secondary particle effects could cause a reduction in the apparent total residue production cross section, one of the principal findings of this work. The other principal finding, an enhanced fission cross section, could, conceivably, be due to secondary low energy projectile fragments which fuse with the target nucleus with high transferred angular momentum and cause it to fission. But we can make some estimates that indicate that this process is not likely. If we remember that the multiplicity of charged particles produced in nucleus-nucleus collisions is roughly independent of the identity of the projectile and dependent only on the total kinetic energy of the projectile,[6] then the relevant comparison to this work would involve 34 GeV projectiles. But for 25 GeV ^{12}C, 36 GeV ^{40}Ar and 42 GeV ^{20}Ne interacting with targets of the more fissionable ^{165}Ho, of comparable thickness to those used in this experiment, Kraus et al.[7] find $\sigma_f < 10$ mb, whereas the reaction of 167 MeV α particles and ^{16}O ions with ^{165}Ho give $\sigma_f = 130$ and 440 mb, respectively. Also one can note[7] that 250 MeV/A ^{12}C interacting with ^{165}Ho gives $\sigma_f < 10$ mb. Although this evidence does not rigorously exclude the possibility that there were secondary particle induced fission events, it adds evidence to the argument that such effects were not a major factor.

The measured radionuclide production cross sections represent cumulative yields (which include contributions from nuclei produced by radioactive decay). These cross sections were corrected for decay feeding in a manner described previously[8] In making this correction, one assumes Gaussian charge distributions; i.e., the independent yield (yield before β decay) cross sections can be represented by a histogram that lies along a Gaussian curve, at constant mass number, A.

This is written as:

$$\sigma(Z,A) = \sigma(A) \left\{ [2\pi s_z^2 (A)]^{-\frac{1}{2}} \exp\left[\frac{(Z - Z_p(A))^2}{-2\, s_z^2(A)}\right]\right\} \qquad (1)$$

with the three parameters: σ (A) the total isobaric yield, s_z (A) the Gaussian width parameter, and Z_p (A) the most probable Z value for that isobar. By assuming that σ (A) varies smoothly and slowly as a function of A, and is roughly constant within a small A range, one can iteratively fit the measured data, determining Z_p (A) and s_z (A) for limited mass regions. The results of this fitting procedure are shown in Figure 1. From the generally reasonable fits of the data points to the Gaussian curves, one can conclude that the assumptions made in correcting for β decay have been satisfied for the case under study. The isobaric or mass yield for each data point in Figure 1 was calculated[8] and the resulting fragment mass distribution is shown in Figure 2 and Table I along with similar data for p-La collisions.

3. Results and Discussion

The isobaric distribution shows decreasing fragment yields from A ∿134 to A ∿80 followed by a large bump centered at A ∿60 (Figure 2). The former decrease is characteristic of decreasing yield patterns with increasing Δ A from the target nucleus characteristic of high energy spallation reactions. The "bump" is centered at about the same A value and has roughly the same shape as the fission fragment distribution from the interaction of 600 - 700 MeV protons with La.[9,10] Thus we conclude that these "bump" fragments result from the fission of a La-like species. However the magnitude of the fission cross section in the ^{139}La + ^{139}La reaction greatly exceeds that observed in the p + ^{139}La reaction. The value of the integrated cross section between A = 40 and A = 80 (divided by two) is

540 mb which is to be compared to $\sigma_f = 0.69 \pm 0.09$ mb[9] or $\sigma_f = 0.6$ mb[10] for the reaction of 600 and 660 MeV p with La, respectively.

The other unusual feature of the distribution is the magnitude of the total integrated residue cross section ($40 \leqslant A \leqslant 140$ with proper correction for fission) which is ∿3.9b , i.e., ∿70% of the total reaction cross section as calculated for this reaction with soft-spheres model.[11] In our previous experience [12] with nucleus -Ta and nucleus -Au collisions, the measured total integrated residue cross section is $\gtrsim$ 85% of the soft spheres estimate of the total reaction cross section.

To see if these new features of the fragment mass distribution are simple, expected consequences of using a large projectile, we compared our results to predictions of two phenomenological models of nucleus-nucleus collisons, the nuclear firestreak model[13] and the Yariv and Fraenkel intranuclear cascade model with cascade-cascade interactions.[14] The effect of de-excitation by fission or particle emission upon the primary fragment distribution as predicted by the firestreak model were calculated using a modification[15] of the DFF code suitable for highly excited fragments with modest angular momenta. (The "average" fragment in the primary distribution has A ∿110, E^* ∿370 MeV and J ∿12ħ). In the de-excitation calculation a_f/a_n was set equal to 1.02.[9] The results of this calculation are shown in Figure 2. No significant amount (<10 mb) of fission is predicted to occur and no significant amount of "missing cross section is expected.

The intranuclear cascade model has quite different predictions for the primary distribution. The "average" fragment in the primary distribution has A ∿135 and is more highly excited, E^* ∿590 MeV, with higher angular momentum, J ∿32ħ. Also there is a broad distribution of J values with the population standard deviation approximately equal to the mean value.

The effect of de-excitation by fission or particle emission for this primary distribution involving species with high E^* and high J was calculated using the JULIAN/PACE code.[16] The rotating liquid drop fission barriers of Cohen, Plasil and Swiatecki[17] were used with the barrier height being taken as 80% of the values given in Ref. 17. As before $a_f/a_n = 1.02$. A fission cross section of ∼400 mb was predicted along with a total (A >40) residue cross section of ∼2.7b, in qualitative, if not quantitative agreement with the data. In this calculation, the increased fission is due primarily to the larger values of J. To gain an appreciation of this effect, one can compare the de-excitation of the A = 134 and A = 135 members of the primary distribution. Both have similar excitation energies (∼630 MeV) but in the case of A=134, $\overline{J} = 24\hbar$ with $\sigma_J = 19\hbar$ while for A = 135 $\overline{J} = 36\hbar$, $\sigma_J = 35\hbar$.) In the de-excitation of the A = 134 primary fragments 1.4% fission while 8.6% of the A = 135 fragments are predicted to fission. In the calculation, the relatively low target residue cross section is a result of the fact that the average number of participants (i.e., struck nucleons) in the target nucleus was 127 while in the projectile it was 136. Thus in the model, there really were few "spectators" to the collision.

4. Conclusions

We conclude that in the reaction of 245 MeV/A ^{139}La with ^{139}La that significant amounts of angular momentum are imparted to the target-like fragment in the collision causing a larger fission cross section. The lower overall residue production cross section may indicate a very large number of both projectile and target "participants" in this reaction. This work was supported in part by the U.S. Department of Energy under Contract DE-AM06-76RL02227, Task Agreement DE-AT06-76ER70055, Mod A007, and DE-AC03-76SF00098 and the Swedish Natural Science Research Council. We gratefully acknowledge the generosity of L. S. Schroeder, G. F. Krebs, and the members of their collaboration who gave us their target following irradiation.

References

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1. The actual Bevalac experiment was that of L.S. Schroeder, G.F. Krebs, *et al*. designed to measure pion phenomena.
   These experimentors gave us their irradiated target immediately after the end of their experiment.
2. G.F. Krebs (private communication).
3. D.J. Morrissey, D. Lee, R.J. Otto and G.T. Seaborg, Nucl. Inst. Meth. 158 (1979) 499.
4. G.D. Cole and N.T. Porile, Phys. Rev. C25 (1982) 244.
5. N.T. Porile, G.D. Cole and C.R. Rudy, Phys. Rev. C19 (1979) 2288.
6. A. Sandoval, H.H. Gutbrod, W.G. Meyer, A.M. Poskanzer, R. Stock, J. Gosset, J.C. Jourdain, C.H. King, Ch. Lukner, Nguyen Van Sen, G.D. Westfall and K.L. Wolf, Phys. Rev. C21 (1980) 1321.
7. R.H. Kraus, W. Loveland and G.T. Seaborg (private communication).
8. D.J. Morrissey, W. Loveland, M. de Saint-Simon and G.T. Seaborg, Phys. Rev. 21 (1980) 1783.
9. G. Andersson, M. Areskong, H.A. Gustafsson, G. Hylten, G. Schrøder and E. Hagebø, Z. Phys. A293 (1979) 241.
10. A.K. Lavrukhina, L.D. Krasavina and A.A. Pozniakov, Doklady Akad. Nauk. SSSR 119 (1958) 56, trans. Sov. Phys. -Doklady 3 (1958) 283.
11. P.J. Karol, Phys. Rev. C11 (1975) 1203.

12. W. Loveland, C.P. Oertel, D.J. Morrissey, P.L. McGaughey, G.T. Seaborg, K. Aleklett, Z Phys. A (submitted for publication).

13. W.D. Myers, Nucl. Phys. A296 (1978) 177. For use of this model in connection with target fragmentation, see reference 15.

14. Y. Yariv and Z. Fraenkel, Phys. Rev. C24 (1981) 488.

15. P.L. McGaughey, Lawrence Berkeley Laboratory Report LBL-15325, November, 1982.

16. A. Gavron, Phys. Rev. C21 (1980) 230.

17. S. Cohen, F. Plasil and W.J. Swiatecki, Ann. Phys. (N.Y.) 82 (1974) 557.

TABLE I

Target Fragment Yields for 245 MeV/A $^{139}La + ^{139}La$

Nuclide	Measured Production Cross Section (mb)	Isobaric Yield (mb)	Nuclide	Measured Production Cross Section (mb)	Isobaric Yield (mb)
^{24}Na	42.6 ± 1.1	42.6 ± 4.3	^{77}Br	9.8 ± 0.8	13.8 ± 1.4
^{28}Mg	6.6 ± 0.2	7.8 ± 0.8	^{79}Kr	11.1 ± 2.3	19.0 ± 3.8
^{44m}Sc	4.2 ± 0.4	–[a]	^{83}Rb	22.2 ± 0.8	22.3 ± 2.3
			^{83}Sr	10.3 ± 2.3	18.7 ± 4.1
^{46}Sc	12.9 ± 0.8	19.0 ± 1.9	^{84}Rb	4.7 ± 0.5	39.4 ± 3.9
^{47}Sc	5.6 ± 0.4	13.5 ± 1.3	^{85}Sr	23.2 ± 5.9	23.4 ± 6.0
^{48}Sc	2.0 ± 0.1	18.4 ± 1.8	^{85m}Y	3.7 ± 0.7	–[a]
^{48}V	5.1 ± 0.2	24.0 ± 2.4	^{87m}Y	24.6 ± 1.2	–[a]
^{52}Mn	2.9 ± 0.1	40.2 ± 4.1	^{88}Y	13.3 ± 0.6	8.4 ± 0.8
^{54}Mn	19.5 ± 3.7	34.4 ± 6.4	^{88}Zr	27.7 ± 1.1	42.6 ± 4.3
^{67}Ga	9.7 ± 1.0	27.5 ± 2.7	^{89}Zr	23.2 ± 5.9	24.9 ± 6.3
^{69}Ge	15.9 ± 2.0	61.1 ± 7.9	^{90}Nb	15.4 ± 0.6	30.7 ± 3.1
^{69m}Zn	1.4 ± 0.1	15.8 ± 1.6	^{93m}Mo	7.8 ± 1.0	–[a]
^{73}Se	6.4 ± 0.6	14.9 ± 1.6	^{96}Tc	8.8 ± 0.2	19.1 ± 1.9
^{74}As	5.4 ± 0.4	16.4 ± 1.7	^{97}Ru	17.7 ± 0.6	23.6 ± 2.4
^{75}Se	11.8 ± 0.7	14.9 ± 1.6	^{99m}Rh	10.6 ± 0.7	–[a]
^{76}As	2.7 ± 1.9	38.2 ± 26.3	^{100}Pd	8.2 ± 0.4	27.0 ± 2.7
^{76}Br	7.8 ± 1.7	11.2 ± 2.4	^{101}Rh	24.4 ± 0.4	–[a]

TABLE I

Target Fragment Yields for 245 MeV/A ^{139}La + ^{139}La

Nuclide	Measured Production Cross Section (mb)	Isobaric Yield (mb)	Nuclide	Measured Production Cross Section (mb)	Isobaric Yield (mb)
^{101}Pd	16.2 ± 3.2	27.9 ± 5.6	^{123}Xe	38.0 ± 2.9	81.0 ± 8.1
^{105}Ag	27.1 ± 0.4	27.1 ± 2.7	^{125}Xe	63.8 ± 1.2	75.1 ± 7.5
^{106m}Ag	8.6 ± 0.2	–[a]	^{126}I	5.7 ± 1.0	103 ± 18
^{111}In	28.4 ± 0.6	28.4 ± 2.9	^{127}Xe	72.2 ± 1.8	84 ± 8
^{113}Sn	43.7 ± 5.5	44.2 ± 5.5	^{127}Cx	73.5 ± 3.0	107 ± 11
^{116}Te	18.1 ± 1.0	44.0 ± 4.4	^{128}Ba	37.2 ± 1.1	142 ± 14
^{117m}Sn	5.1 ± 0.6		^{129}Cs	103 ± 1.7	110 ± 11
^{117}Sb	29.4 ± 4.7	29.4 ± 4.7	^{129m}Ba	46.8 ± 9.4	–[a]
^{118m}Sb	6.9 ± 0.6	–[a]	^{131}Ba	97.1 ± 1.0	142 ± 14
^{119m}Te	16.5 ± 1.1	–[a]	^{132}Cs	22.0 ± 0.4	125 ± 13
			^{132}La	48.5 ± 0.4	141 ± 14
^{120}Sb	2.6 ± 0.1	56.7 ± 5.7	^{132}Ce	4.9 ± 4.7	197 ± 187
			^{133m}Ba	42.6 ± 1.3	
			^{132}Ce	33.3 ± 11.0	273 ± 91
^{121}I	55.5 ± 8.8	76.0 ± 12.1	^{135m}Ba	42.6 ± 2.2	–[a]
^{122}Xe	21.2 ± 2.3	81.3 ± 8.8	^{135}Ce	27.6 ± 1.0	124 ± 12
^{123}I	72.9 ± 5.5	74.2 ± 7.4	^{137m}Ce	34.3 ± 2.4	–[a]

TABLE I

Target Fragment Yields for 245 MeV/A ^{139}La + ^{139}La

Nuclide	Measured Production Cross Section (mb)	Isobaric Yield (mb)
^{139}Ce	23.5 ± 1.3	29.7 ± 3.0
^{140}La	5.9 ± 0.5	54.7 ± 5.5

Note: a Isobaric yield not computed because we believe a substantial fraction of isobaric yield is an unobserved member of isomeric pair

Figure Captions

Figure 1. The charge dispersion curves for the ∿245 MeV/A ^{139}La + ^{139}La reaction are shown as a function of the mass region of the products. The triangles indicate isomeric yields where it is known that part of the yield for that nuclide is "missing."

Figure 2. The target fragment mass distribution for the reaction of ∿245 MeV/A ^{139}La + ^{139}La is shown. The solid line is to guide the eye through the data. The histogram represents the prediction of the firestreak model.

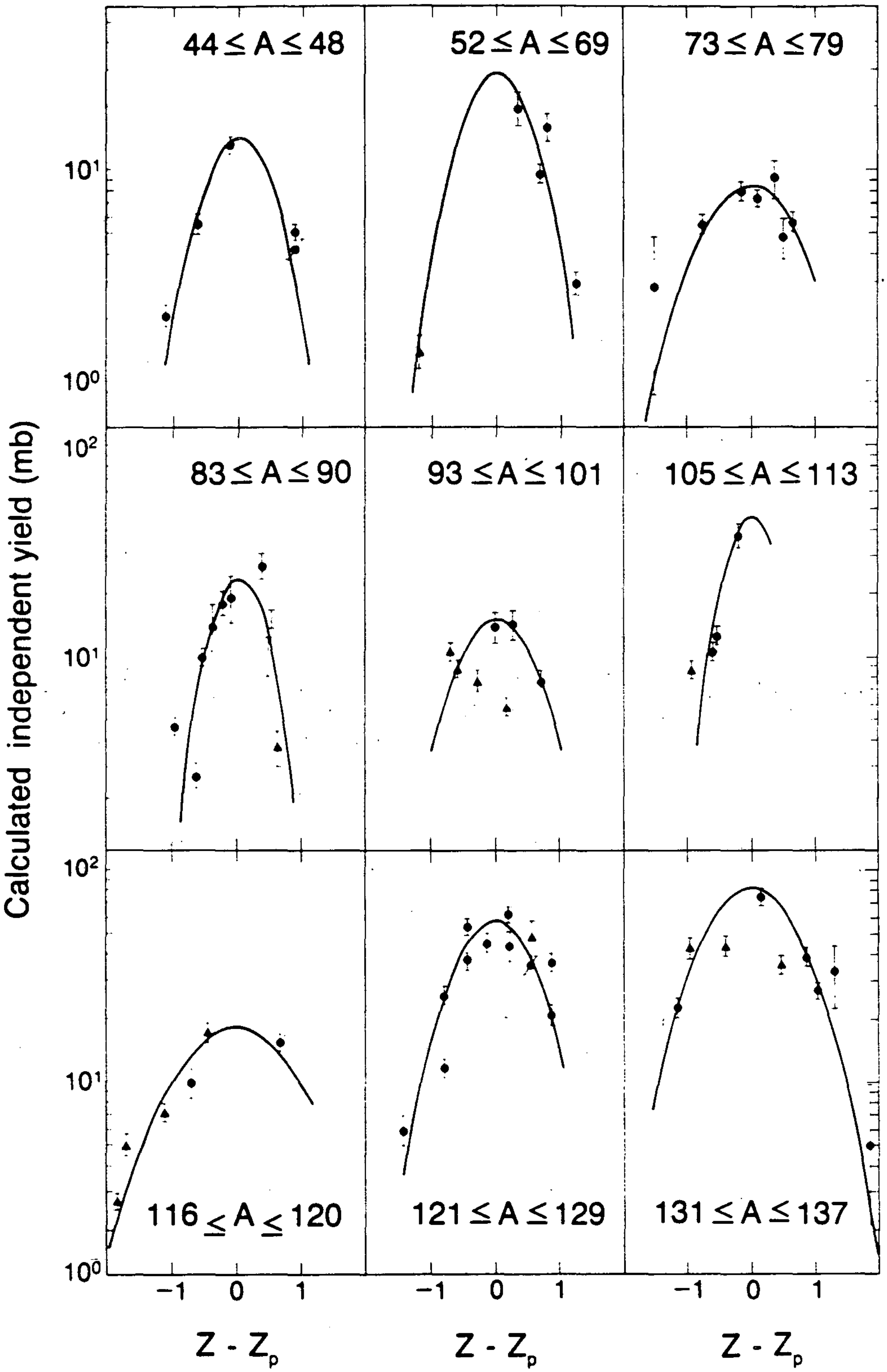

Fig. 1

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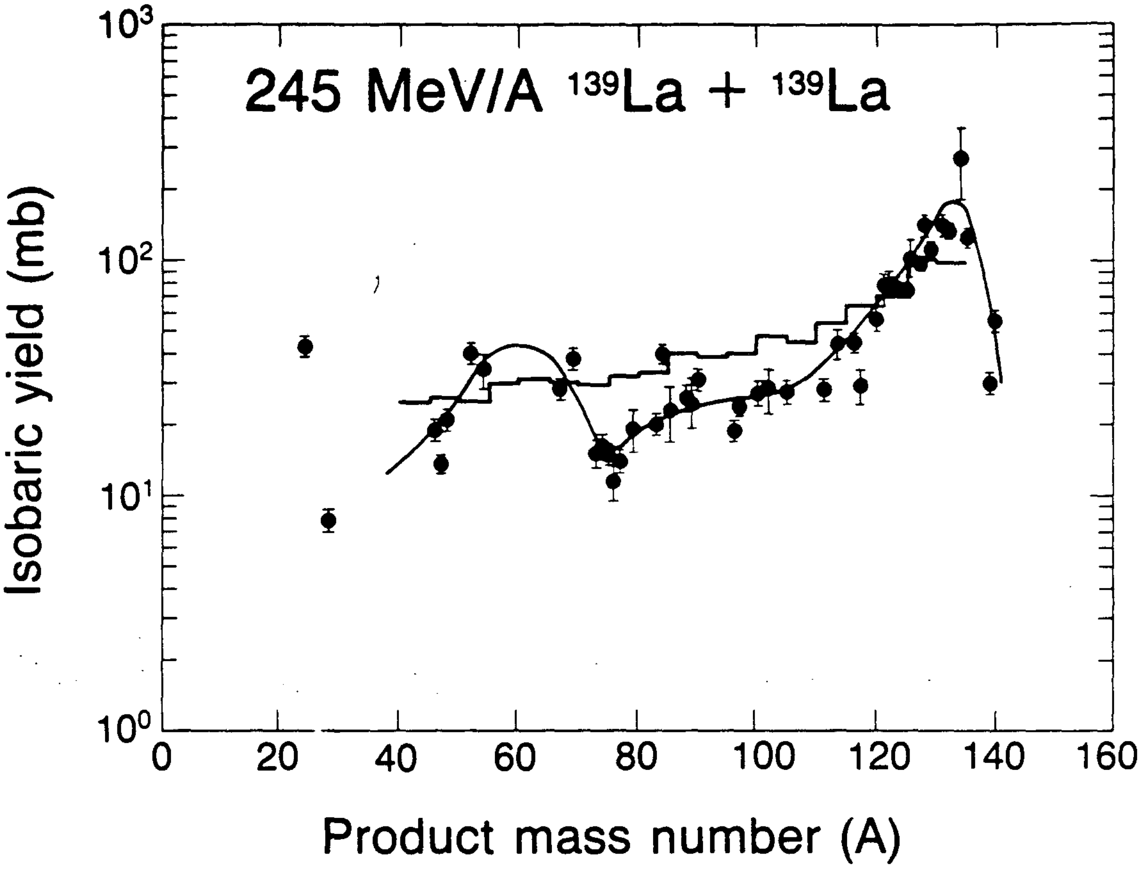

Fig. 2

XBL 8311-668

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