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Publication Date
1977-05-01

Submitted to Physics Letters

LBL-6522
Preprint c.1

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May 1977

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

DISCLAIMER

FURTHER STUDIES OF LARGE COLLISION RESIDUES IN RELATIVISTIC HEAVY ION REACTIONS WITH HEAVY NUCLEI*

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May 1977

ABSTRACT

Target residue mass and charge distributions have been measured radiochemically for the reaction of 25.2 GeV ^{12}C ions with Au and Pb. Enhanced product yields for A=140-170 are found that are not present in reactions of Pb with GeV protons. The shape of the mass distribution in this region is used to define a pre-equilibrium product mass distribution.

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Recent interest in relativistic heavy ion (RHI) reactions has been stimulated by the observations of Schröeder _et al._[1] and Westfall _et al._[2] that in RHI reactions with heavy targets, some encounters lead to large numbers of emitted charged particles (up to 100) and that these emitted particles show very "hard" energy spectra, uncharacteristic of evaporated nucleons. Of especial note, has been the successful description of these light particle data by the geometric-thermodynamic "fireball" model.[2] According to this model, a group of nucleons is cut out from the overlap region of the target and the projectile with the result that this group of nucleons forms a hot quasiequilibrated fireball which decays as an ideal gas. In a previous work, we have shown[3] that the target residue mass distribution from the reaction of 25.2 GeV ^{12}C with U has a peak in the mass distribution for $160 \leqslant A \leqslant 190$ that is quantitatively correlated with the survivors of the more central [(impact parameter $b \leqslant 0.7\ (R_t + R_p)$] projectile-target collisions. Nevertheless, the pre-evaporation mass distributions deduced from the experimental data in this work are somewhat uncertain because of the inherent difficulties in reconstructing the initial yields of species from A=200-240 from the fission product mass distribution.

In this paper, we report the results of radiochemical measurements of the yields of the target residues formed when 25.2 GeV ^{12}C ions interact with Au and Pb nuclei. This investigation was carried out as a complement to the previously reported study with a U target since the interpretation of the data was expected to be more straightforward for the case of the less fissionable Pb and Au targets.

Foils of Au and Pb (of thickness 25 and 480 mg/cm^2 respectively and surrounded by $\sim$15 mg/cm^2 Al catcher foils) were irradiated for 162 minutes in a beam of 25.2 GeV ^{12}C ions of intensity $\sim 2.5 \times 10^{10}$ particles/min at the BEVALAC. Gamma and x-ray spectroscopic measurements of the radioactivity induced in the target and catcher foils began one hour after bombardment and continued for about three weeks. Over 75 radionuclides were identified in this work on the basis of their γ-ray energy, half-life and radiation intensity. No corrections were made for the contributions to the foil activities from secondary induced reactions because comparison of the ratio of in-beam (Au, Pb) foil activity to out-of-beam (Au, Pb) monitor foil activity with similar ratios for U targets where secondary corrections are well-known,[3] revealed the secondary corrections for the (Pb, Au) experiments to be <7%. Recoil losses from the target were negligibly small although enough activity was found in the Al catcher foils surrounding the Au target to measure by x-ray spectrometry forward/backward (F/B) ratios of 1.5 ± 0.6, 2.7 ± 1.2 and 1.9 ± 1.0 for nuclei in the Xe-Pr, Dy-Yb and Pt-W regions, respectively.

The experimentally determined independent and cumulative yields for individual radionuclides from the Au and Pb targets are shown in Figures 1(a) and 2(a). Using the procedures briefly described by Otto et al.,[4] independent yield formation cross sections were calculated for all radionuclides, Gaussian charge dispersions [of the form $P(Z,A) = (2\pi\sigma^2)^{1/2}\exp(-(Z-Zp)^2/2\sigma^2)$] were fitted to the data, and the charge dispersions were integrated to give the isobaric yields for the reactions. Figures 1(b) and 2(b) depict the relative yield of species of given (Z,A) for the Au and Pb targets while Figures 1(c) and 2(c) show the mass yield distributions. As partially shown in Figures (1) and (2), Zp, the most probable fragment charge, moves to more neutron deficient values and the charge dispersion widths, σ, increase as the product mass decreases from A=208 to A=140. The mass yield curves for Au and Pb could be superimposed with no discernible difference except for (a) the position of the target peak and (b) the position of the steeply sloping region of the mass yield curve appears to start at $A \sim 140$ for the Au target and at $A \sim 150$ for the Pb target.

Also shown in Figure 2(c) is the mass yield curve for the reaction of GeV protons with Pb as deduced from a combination of data from Friedlander[5] and Grover.[6] Comparison of the two curves shows very similar shapes for the region $40 \leqslant A \leqslant 100$, with modest enhancements of the yield of the lightest products and enhanced product yields in the

$140 \leqslant A \leqslant 170$ regions in the RHI reactions. While there is no clear-cut separation of fission product yields from other reaction product yields in these RHI mass distributions, one can note a relatively broad charge dispersion (σ=1.5 Z units) for the A~100 products in the Pb mass distribution thus implying[3] an excitation energy of the fissioning system of 100-130 MeV.

Of most interest is the question of the origin of the enhanced product yields in the $140 \leqslant A \leqslant 170$ regions. We used a modified version of the computer code ALICE,[7] to trace the course of the neutron-fission-charged particle emission competition as the precursors of the $140 \leqslant A \leqslant 170$ products de-excited. By assuming various shapes for the initial precursor mass, charge and energy distribution, and tracing their de-excitation, we were able to set ranges on what the product distribution must have been at the end of the initial interaction-fast pre-equilibrium particle emission (i.e., pre-statistical evaporation) stage of the RHI reaction. Assuming the data are represented by curve C such precursor distributions are shown in Figure 1(c) and 2(c) as curve A. These precursor distributions are remarkably similar in shape to that inferred[3] for the reaction of 25.2 GeV ^{12}C with U. Since very different amounts of fission and neutron emission are involved in the de-excitation of products of the U, Pb, Au systems, we can now conclude, in a relatively model independent manner, that similar mechanisms are acting in the initial interaction of RHI's with Au, Pb and U targets, and that curve A is a proper representation of the initial product distribution. One further constraint that can be placed upon the mechanism of the initial projectile-target interaction and the de-excitation process is that products should be left with relatively low angular momentum. Table I shows isomeric yield ratios measured in RHI reactions. The lack of a preferential population of the high spin member of an isomeric pair must imply either low initial product angular momentum and/or removal of large amounts of angular momenta by photon and/or particle emission during the de-excitation process.

It is interesting to see what the geometrical "abrasion-ablation" ideas[8] used in the fireball model to describe the projectile-target interaction might predict for the product distribution from these reactions. Curve B in Figure 2(c) shows the result of such a calculation for the C + Pb reaction. The agreement between the calculation and the data is reasonable except for the events with $A<150$ which result from impact parameters $b \leqslant 5$ fm. It will be interesting to see what success more sophisticated approaches to RHI interactions have in treating our data.

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*Work supported in part by the Division of Physical Research of U.S. Energy Research and Development Administration.

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Table I.

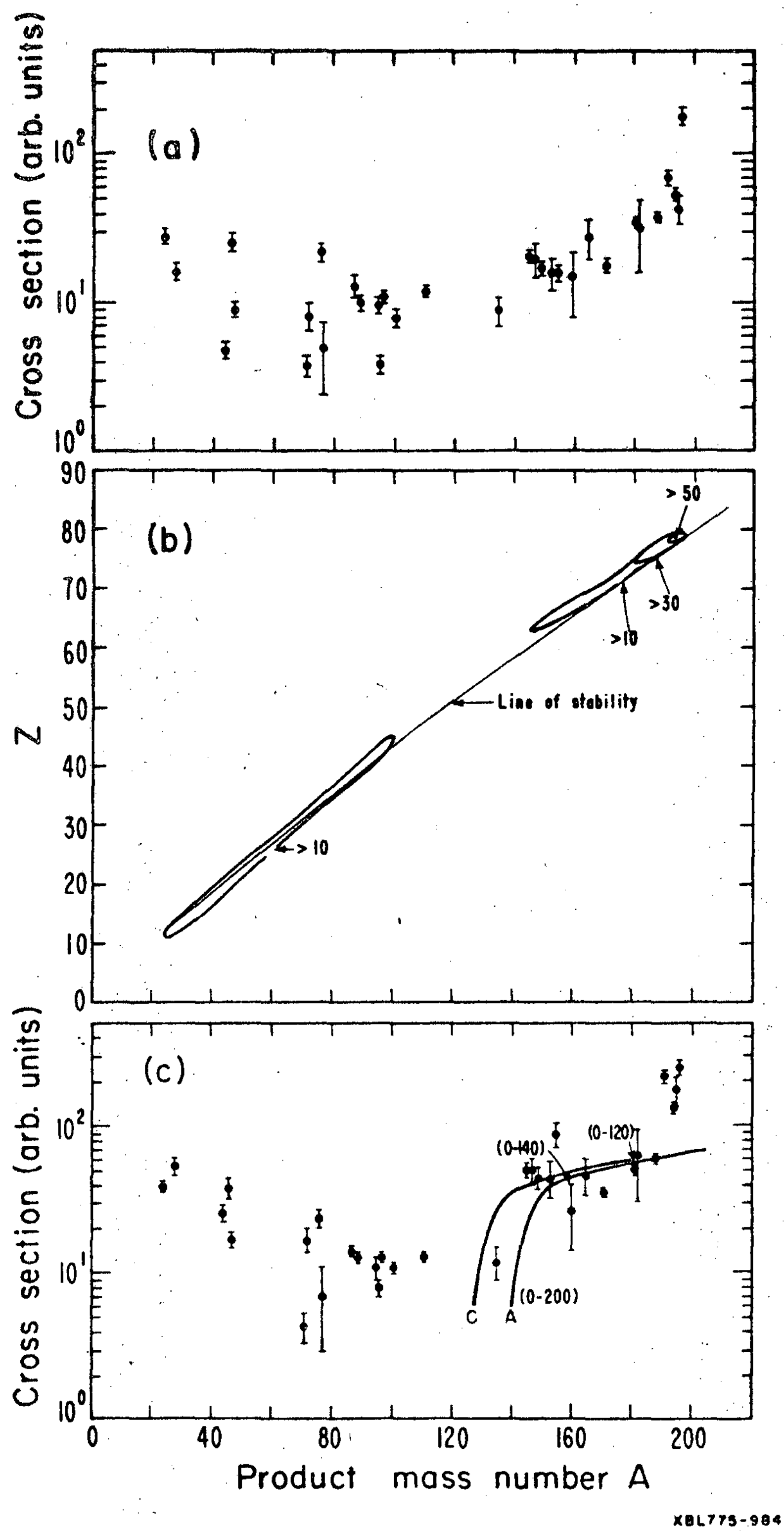
Isomer Ratios in RHI Reactions

Reaction	Isomer Ratio
25.2 GeV ^{12}C + Pb	$\frac{\sigma(^{198m}Tl(7+))}{\sigma(^{198}Tl(2-))} = 1.4 \pm 0.2$
25.2 GeV ^{12}C + Bi	$\frac{\sigma(^{196m}Au(12-))}{\sigma(^{196}Au(2-))} = 0.5 \pm 0.2$
	$\frac{\sigma(^{198m}Au(12-))}{\sigma(^{198}Au(2-))} = 0.3 \pm 0.2$
25.2 GeV ^{12}C + U	$\frac{\sigma(^{186}Ir(6-))}{\sigma(^{186m}Ir(2-))} = 0.09 \pm 0.03$

FIGURE CAPTIONS

Fig. 1. (a) Independent and cumulative yield formation cross sections for individual radionuclides for the reaction of 25.2 GeV ^{12}C with Au. (b) Contour lines for equal independent yields. (c) Total integrated mass yields. See text for explanation of curves. The numbers along curve A in parentheses represent the excitation energy in MeV for species of a given mass.

Fig. 2. Same as Figure 1 except target is Pb. The dashed curve in Fig. 2(c) is a combination of the data of Refs. 5 and 6. The dot-dashed curve (B) represents the prediction of the abrasion-ablation model.



Cross section (arb. units)
(a)
10^2
10^1
10^0
90
80
70
60
50
40
30
20
10
0
Z
(b)
> 50
> 30
> 10
Line of stability
> 10
Cross section (arb. units)
(c)
(0-140)
(0-120)
(0-200)
C
A
0
40
80
120
160
200
Product mass number A
XBL775-984

Fig. 1

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