Vol. 25(1994) *ACTA PHYSICA POLONICA B* No 3–4

NEUTRON AND PROTON FLOW BETWEEN THE COLLIDING ^{208}Pb AND ^{64}Ni IONS*

W.KRÓLAS, R.BRODA, J.GRĘBOSZ, A.MAJ, T.PAWŁAT

Niewodniczański Institute of Nuclear Physics
Radzikowskiego 152, PL-31-342 Kraków, Poland

AND

M.SCHRAMM, H.GRAWE, J.HEESE, H.KLUGE, K.H.MAIER, R.SCHUBART

Hahn-Meitner-Institut Berlin
Glienicker Strasse 100, W-1000 Berlin 39, Germany

(Received August 28, 1993)

The ^{208}Pb + ^{64}Ni reaction at 350 MeV energy was investigated using γ-γ coincidence technique and target radioactivity measurements. The determined distribution of products indicates a dominant role of deep-inelastic collisions. The flow of protons and neutrons between the colliding nuclei is discussed in terms of mass and charge equilibration processes.

PACS numbers: 25.70. -z, 25.70. Lm

Reactions induced by heavy ions with incident energies close to the Coulomb barrier have been intensively investigated using particle-gamma coincidence and charged particle spectroscopy methods. A different approach to use the γ-γ coincidence technique to study such collisions was recently demonstrated for ^{106}Cd + ^{54}Fe reaction [1]. In this presentation we describe initial results obtained from a similar study of ^{208}Pb + ^{64}Ni system using γ-γ coincidence and radioactivity measurements.

The 350 MeV ^{64}Ni beam energy was chosen, which at the surface of the target corresponds to a collision energy 11 % higher than the Coulomb barrier. A thick ^{208}Pb target (30 mg/cm^2, 98.7 % enriched) was used to stop the reaction products, consequently the data are integrated over

---

* Presented at the XXIII Mazurian Lakes Summer School on Nuclear Physics, Piaski, Poland, August 18–28, 1993.

the projectile energy range from the initial 350 MeV down to the Coulomb barrier. The ^{64}Ni beam from the VICKSI HMI Berlin accelerator was pulsed with 69 ns burst separation, which allowed to separate the in-beam and off-beam (isomeric and radioactive decay) events. The γ-γ coincidences were measured using the OSIRIS spectrometer (11 Compton suppressed germanium detectors) together with the multiplicity and sum energy from the 48 element BGO ball.

To study various processes that take place in the ^{208}Pb + ^{64}Ni collision we aimed to determine as complete as possible the distribution of the reaction products. Three techniques were employed. The relative production yields of long-lived radioactive isotopes were obtained from the measurements of the radioactivity collected in the thick target. These measurements started immediately after the end of the experiment at HMI Berlin, employing the OSIRIS array, and were continued for 5 months at the INP Kraków using a single germanium detector. A detailed analysis of the activity spectra led to the identification of about 120 isotopes produced and stopped in the target with lifetimes ranging from few hours to as long as 33 years (^{207}Bi).

From the quantitative analysis of the off-beam coincidence data we determined the production yields of short-lived radioactive isotopes with lifetimes in the range of seconds to few hours as well as the population of isomers living longer than a few nanoseconds. Additionally, the in-beam coincidence data analysis provided the production yields for isotopes that could not be seen using methods described above, *e.g.* stable isotopes.

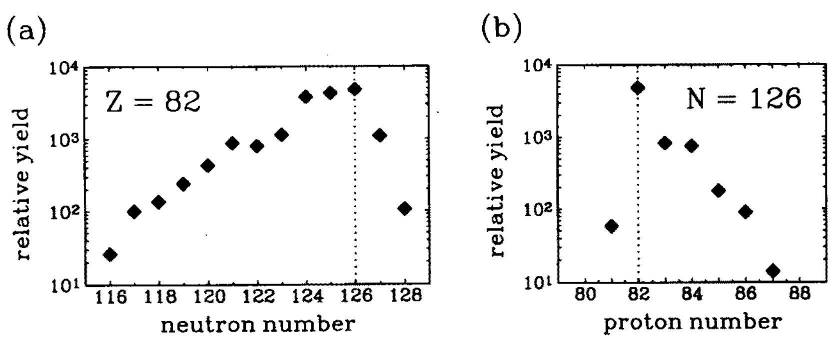

Fig. 1. Relative production yields for $Z = 82$ (a) and $N = 126$ (b) isotopes produced in the ^{208}Pb + ^{64}Ni reaction at 350 MeV. The dotted line indicates the target neutron (a) and proton (b) number. The production yield units are arbitrary but the same for both parts of the figure.

Most of the identified nuclei are target-like or projectile-like products. A very small contribution of fusion-fission products confirms that at our beam energy ($E_{\rm LAB}/A = 5.5$ MeV/u) almost no compound nuclei are formed [2].

The distribution of product nuclei emphasizes the dominant role of deep-inelastic processes for which often a large transfer of nucleons takes place. The most important feature of these processes is the trend towards equilibration of mass and charge of two colliding nuclei. The measured distribution corresponds to secondary products which arise after the evaporation of neutrons from the excited primary products.

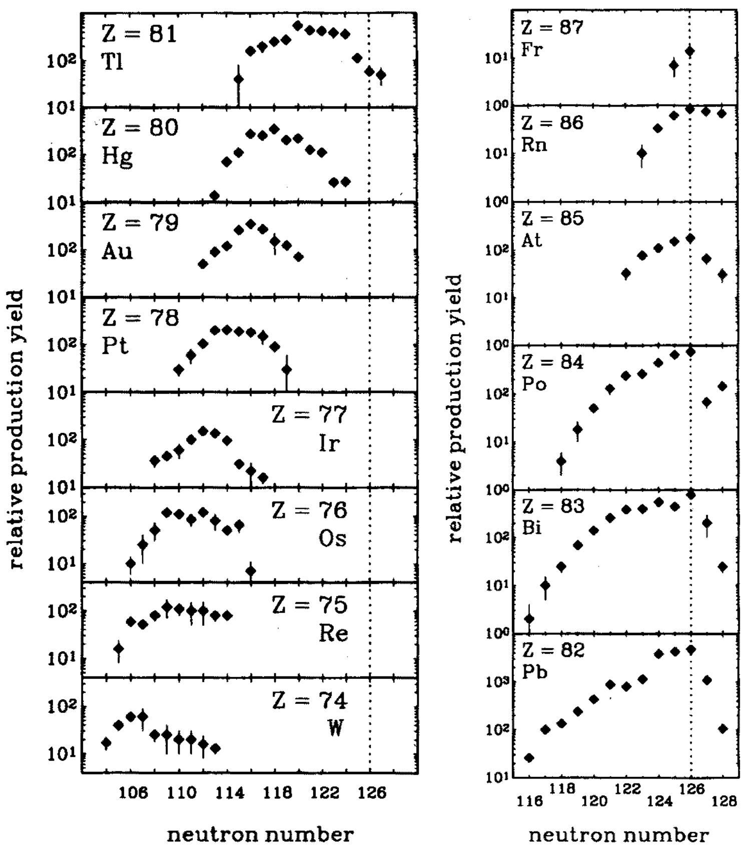

Fig. 2. Relative production yields for isotopes of $Z \geq 82$ (right part) and $Z < 82$ (left part) nuclei produced in the $^{208}Pb + {}^{64}Ni$ reaction at 350 MeV. The dotted line indicates the target neutron number $N = 126$. The production yield units are arbitrary but the same for all elements.

In Fig. 1 we show the productions yields obtained for nuclei with $Z = 82$ (target proton number) and $N = 126$ (target neutron number). As expected for the N/Z ratio equilibration, the protons are transfered from the ^{64}Ni projectile to ^{208}Pb target nucleus. Nuclei as proton rich as Fransium ($Z = 87$) are produced. The same trend is reinforced by the intense flow of neutrons in the opposite direction. Consequently, with additional evaporation of neutrons, the lead isotopes distribution extends to the ^{198}Pb isotope.

An extended set of results, including production yields for all $74 \leq Z \leq 87$ isotopes, is presented in Fig. 2. It is interesting to note that for $Z > 82$ nuclei the distribution becomes more symmetric with higher number of transferred protons. Apparently, the very neutron rich light nuclei that arise from the ^{64}Ni stripped of few protons can hardly accept additional neutrons. On the other hand it is clear that the stripping of protons from the ^{208}Pb is almost always accompanied by the stripping of several neutrons. Thus, the mass equilibration, realized by a large mass transfer for nuclei below $Z = 82$, results also in the lowering of the N/Z ratio towards the equilibrium value.

In another aspect the data are analyzed to obtain the population of different spin states in individual nuclei. This will allow to compare the angular momentum brought into final products of different reactions. In some cases the population of states with considerably high spins (up to 20 $\hbar$) was already established.

REFERENCES

[1] R. Broda, C.T. Zhang, P. Kleinheinz, R. Menegazzo, M. Lach, K.H. Maier, H. Grawe, M. Schramm, R. Schubart, S. Hofmann, IFJ Kraków Annual Report 1991, Kraków 1992, p. 67.

[2] R. Bock, Y.T. Chu, M. Dakowski, A. Gobbi, E. Grosse, A. Olmi, H. Sann, D. Schwalm, U. Lynen, W. Müller, S. Bjørnholm, H. Esbensen, W. Wölfli, E. Morenzoni, *Nucl. Phys.* **A388**, 334 (1982).