EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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MEMORANDUM
No 1

To : Those who are concerned with the "PROPOSAL FOR PARASITE STUDY OF HIGH-ENERGY FISSION AND SPALLATION IN THE SLOW EJECTED BEAM AT THE PS".

From : R. Brandt

Re : SOME FURTHER REMARKS IN CONNECTION WITH THE ABOVE-MENTIONED PROPOSAL.

When high-energy protons became available, their interactions with complex heavy nuclei (i.e. uranium) were studied. Many experimental details were known, however, one is still far from understanding all principal features of these reactions. One is still to a large extent in the stage of data collection and speculation about the possible reaction mechanism.

Nevertheless, it might be useful to summarize the present situation, and to describe some techniques and the results obtained so far. (Emulsion work is not considered in this memorandum.*).

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The oldest technique uses classical radiochemical methods in order to give the yield, energy and differential energy distribution forselected isotopes produced in the interaction. This method allows certainly the best fragment mass-determination possible, but its principal draw-back is that nothing can be learned aboutthe reaction partners which are produced in the same interaction. Besides, this method is very time-consuming, and only few nuclides have been studied. The results obtained so far are as follows:

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*) (Perfilov gave a summary of the emulsion experiments at the IAEA-Conference in Salzburg 1965 - Proceedings are published.)

1. Some reaction products are observed which seem to arise from fission reactions: the nucleus has received only little excitation energy from the incoming proton, an excited nucleus after the fast cascade fissions at some stage during its de-excitation.* The reaction products are the same as low-energy-induced fission reaction products. The yield of those fission reactions decreases with the increase of proton energies. Fission and non-fission interactions can be fairly well separated, even at high-energies, since both processes yield different final reaction products (CERN-work). The observation of fission products at high proton-bombarding energies is not suprising.

2. Aside from fission products one observes a new class of reaction products with the following characteristics (BNL and CERN):

   2.1 The non-fission products are mostly neutron-deficient; their isotopic-yield distribution resembles the isotopic-yield distribution obtained in typical 600-MeV spallation reactions (Rudstam).

   2.2 It might be possible to interpret those products in the I^{120}-region (from an uranium target) as spallation residuals (Rudstam). For lighter particles, such as n-deficient Sr^{83}, Br^{75}, Cu^{64} (possibly Mg^{28} and Sc^{44}), such a simple interpretation is not acceptable, since the rate of production is too high in order to be explained in the same way as the n-deficient I^{120}-isotope (Cumming (BNL), Brandt). At present no convincing model exists which can interpret the production of these isotopes.

   At this stage there exist some speculative models (fast fission, fragmentation). However, more experimental data are needed to clarify the situation, in particular one needs to know more about the different partners of one interaction. (This answer cannot be given with radiochemical methods principally).

   This situation forced the nuclear chemists to employ more advanced techniques:

   2.2.1 Mica: At CERN ** and BNL mica detectors can be used to study high-energy nuclear interactions. The pretended aim of this study was that one wants to measure the total fission cross-section, which is in itself not a too exiting number. But, as usual, a new technique gave unexpected results: The observation

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*) "Fission" is defined as a slow process, occurring essentially in the same manner as slow-neutron induced fission in U. "Spallation" is defined as a process where a high-energy particle initiates a "fast Cascade" whereafter an excited nucleus is left, de-exciting slowly by emission of n, α, etc. Strictly speaking, "fission" is just one decay mode in the de-excitation path of heavy and excited nuclei.

**) (CERN-Heidelberg-Naples-Warsaw Collaboration).

that the cross-section for ternary fission varies appreciably (factor of 20-60) even between 2 GeV and 30 GeV (BNL and Strasbourg). This is a first indication that some complex nuclear reaction cross-sections are not at all "flat" at high-energies.

2.2.2 Semi-conductorexperiments: This technique is the most promising of all. Historically, the first fission experiments which allowed a direct comparison with theory, used semi-conductor detectors (Thompson, Swiatecki, et al. in Berkeley). Therefore, high-energy laboratories in the USA started employing this technique. The aims are as follows:

1st stage: One measures the energy (E_1 and E_2) of two fission fragments at 180°. This allows the calculation of the masses of the fission fragment:

$$E_1 = \frac{m_1}{2} \times v_1^2 \qquad E_2 = \frac{m_2}{2} \times v_2^2 \tag{1}$$

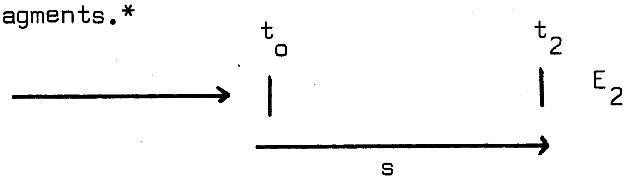
$$m_1 v_1 = m_2 v_2 \quad \text{(momentum conservation)} \tag{2}$$

$$m_1 + m_2 = m_o \quad (m_o \text{ - target nucleus}) \tag{3}$$

$$\frac{E_1}{E_2} = \frac{m_2}{m_o - m_2} \tag{4}$$

With this technique one can, essentially, only study fission and one can extract from this the excitation energy of the nucleus before fission in some cases. (Ph.D. thesis of R. Nix at Berkeley). It should be mentioned that equations (2) and (3) are only very approximately valid for high-energy reactions.

2nd stage: One will measure the time of flight and the energy of single fragments.*



(5)

flight-path s
flight-length ($t_2 - t_o$) } velocity v_2

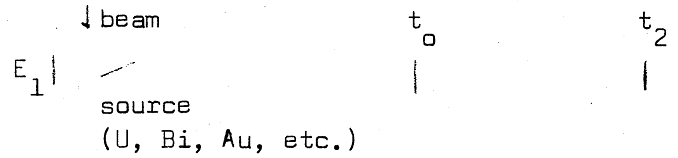
energy of particle determined with semi-conductor (E_2)

$$m_2 = \frac{E_2 \times 2}{v_2^2} \tag{6}$$

*) A suitable device has been developed by E. Haines (IPL-Pasadena) and will be employed at BNL and Argonne for this experiment. The mass range covered is estimated to be 30 to 170.)

This will allow a complete mapping of the yields of all masses and their energies. About the interpretation of thesedata one can only speculate at present.

By adding a second semi-conductor detector at 180° to the system mentioned under (5) one can learn which particles are fission fragments:



This is the experiment which we propose to do in 1967.

3rd stage: The experiments in the 2nd stage do not allow one to answer the essential question which are the reaction partners in non-fission type of interactions. Therefore, on might use two time-of-flight-plus-energy systems at angles between 20° and 180° with respect to each other. But it is premature to decide on this at present.

This is the general lay-out of the experimental plans at CERN and (with only minor changes) at BNL and Argonne in the USA. Finally, it seems useful to look at the situation in these two laboratories in the USA, since they are working on approved projects and our manpower and electronics requirements will be very similar.

BNL Situation:

Here essentially the same aims are pursued as those contained in our proposal. The experiments of the 1st stage (mentioned above) are essentially finished, and plans are made to go into the 2nd stage in the near future. They work at 2.9 GeV, however, the Cosmotron will be shut down next year. One can have doubts whether by that time the experiment will be sufficiently finished. Additionally one knows that there are differences between 2.9 GeV and 20 GeV in the non-fission type of interactions.

At BNL the group working on this problem needs:

- 2 full-time scientists
- occasional help of 1 or 2 other scientists
- some help by technicians
- one fission chamber
- 3 ADC's together with a magnetic-tape unit
- one two-parameter analyser
- further electronics for coïncidence set-ups, etc. (standard high-energy electronic equipments.)

ARGONNE Situation:

A group of about the same strength as at BNL is working there.. They work at 12 GeV with a beam intensity of 10^{10} p/burst at present. The focus is very bad as compared to CERN.

The counting rates, therefore, are very small.

CONCLUSION FOR THE CERN WORK:

CERN has the highest energy, highest intensity and best focused slow extracted high-energy proton beam. The experiments (everything else assumed to be equal) would have much better statistics than the work at Argonne.

R. Brandt.