TESTS OF A METHOD TO STUDY HIGH-ENERGY NUCLEAR FISSION

BY MEANS OF MICA DETECTORS

Part I.

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R. Brandt, Ch. Gfeller and J. Zakrzowski *

* Visiting Scientist from the Physics Department, University of Warsaw, Poland.
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ABSTRACT

Sheets of natural mica interleaved with metal foils have been exposed at the CERN PS to large doses of high-energy protons in order to test a method of studying high-energy nuclear fission. After processing, the mica sheets were examined under an ordinary optical microscope. It was found that the passage of the high-intensity proton beams through the mica did not affect its registration properties. The application of mica detectors in experiments of this kind may, however, be limited by the background of tracks produced in the mica itself. This background is tolerable for beam densities not exceeding about $10^{13}$ protons/cm$^2$. 

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I. INTRODUCTION

Recently, mica \(^*\) has found wide-spread use in the study of low-energy induced fission. As a detector which records single fission fragments, mica is superior to nuclear emulsion mainly in the following ways:

i) Nuclear emulsion cannot be used for fluxes of more than \(10^9\) protons/cm\(^2\), compared to about \(10^{13}\) protons/cm\(^2\) tolerable in mica, as will be shown later.

ii) Silver and bromine are necessary constituents of nuclear emulsion. When a nuclear emulsion is loaded with heavy nuclei such as uranium, the incident protons interact with the uranium as well as with silver and bromine. Therefore it is difficult to obtain a clear picture of the interactions which take place in uranium. Even for low sensitivity emulsion there is no clear mass cut-off below which tracks are not recorded. In mica, however, only charged particles with mass numbers \(A > 30\) are registered and the constituents of mica are nearly free of nuclei which can produce fission-like tracks. It seems therefore useful to extend investigations of fission processes by this technique to the high-energy region.

It has recently been proposed by the CERN-Naples-Warsaw collaboration\(^2\) to study high-energy induced fission and spallation-fragmentation reactions in different nuclei using mica detectors. Stacks of mica sheets interleaved with metal foils have been exposed at the CERN PS for studies of the feasibility of the technique.

This paper reports to what extent mica is insensitive to the passage of high-energy protons through it, and shows that the passage of these protons does not interfere with the known registration properties of mica with fission tracks. A subsequent paper will

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\(^*\) A summary of the present status in this field is given by Walker\(^1\).
contain more details on how one can try to estimate cross-sections for fission and spallation-fragmentation interactions by the method here described. Amongst others, the following problems can be studied with the proposed method:

a) The cross-sections at 0.6 and 20 GeV incident proton energy for fission and those spallation fragmentation reactions which give track-producing products for uranium as well as for lighter elements. It is not easy to carry out such a study with other techniques and consequently little is known about these cross-sections up to the present.

b) One can also use high-energy antiprotons and pions as bombarding particles and compare the results with those from the proton experiments. Such information is very valuable since little is known about the interactions in heavy nuclei of high-energy particles other than protons.

II. EXPERIMENTAL METHOD

Several exposures were made at the CERN PS to the internal proton beam and to the fast extracted proton beam. The details of the exposures as well as the stack compositions are set out in Table 1.

Stacks Nos. 1 to 7 and 9, 10 were mounted in the standard target holders used by the Nuclear Chemistry Group at CERN and were flipped into the internal proton beam. Stack No. 8 was mounted in an aluminium frame and placed in the fast extracted proton beam (see Fig. 1). The production of Na$^{24}$ from aluminium foils was used in each case (with the exception of stacks Nos. 1 and 4) to obtain an estimate of the total number of protons incident on the "working area" of the detectors (see below). In all exposures the proton beam was incident perpendicularly on the stack surface.
Natural mica was used as a detector in these tests. The mica sheets were first annealed for about one hour at 600°C to remove the fossil tracks and then cleaned to obtain fresh surfaces; no pre-etching in hydrofluoric acid was made. Their registration properties were tested by exposing them to the fission fragments from the spontaneous decay of $^{252}\text{Cf}$. The mica sheets used in the FS exposures were either glued with araldite to aluminium frames or fixed together at one side to form a "sandwich" composed of a pair of sheets. The sandwich was then placed in an aluminium "envelope" with a window defining the "working area" of the mica detectors.

As targets, either self-supporting metal foils or layers of metal evaporated into the inside surface of the mica sheets forming a sandwich were used. In the latter case the thickness of the layers was determined for several specimens from the chemical analysis\(^9\).

After exposure, the mica sheets were processed in the usual manner\(^3\) by immersing them for 20 to 30 minutes in 40% hydrofluoric acid at room temperature. They were then rinsed in water and alcohol, dried and examined under an ordinary optical microscope. Layers of evaporated metal were removed before processing by first dipping the mica sandwiches in 5n HNO$_3$ and rinsing in water.

\*RESULTS AND CONCLUSIONS\*

It was observed that the passage of the high-density proton beam through the mica sheets had no effect on the mica registration properties. Fission tracks recorded in mica prior to the proton exposure were not removed and could be revealed

\(^9\) We are very much indebted to Dr. E. Bruninx of the CERN Nuclear Chemistry group for making this analysis.
later on. This is illustrated in Fig. 2 which shows the tracks of fission fragments from the spontaneous decay of Cf$^{252}$ observed in mica after the irradiation in a proton beam. The use of the mica detectors for the high-energy fission studies may, however, be limited by the background of tracks produced in mica itself. It is presumably due to the recoiling spallation products arising in the interactions of high-energy protons with some of the mica constituents$^1$. The background does not seem to constitute a serious problem if the total proton dose does not exceed $10^{12} - 10^{13}$ protons/cm$^2$. Figure 3 shows the tracks recorded in a mica sheet adjacent to a 30 μm thick foil of lead exposed to a dose of a few times $10^{12}$ protons/cm$^2$. These tracks are due to the fission and spallation fragments produced in the proton interactions with lead nuclei. The track density is so high that one can actually see with the naked eye the spot through which the beam passed. Figure 4 shows the opposite surface of the same mica sheet that was adhering to another mica sheet: only a few "spots" can be seen in this case. When the proton dose is much greater than $10^{13}$ protons/cm$^2$, the density of tracks produced by the spallation recoils in the mica itself becomes prohibitively large as can be seen from Fig. 5. Figures 6 and 7 show tracks recorded in mica sheets adjacent to gold and silver foils, respectively. No differences were seen between the mica sheets facing an aluminium foil and those adhering to other mica sheets.

First attempts to find correlations among the tracks in the two mica sheets forming a sandwich were not successful. Further tests to study the feasibility of observing spatial coincidences of fission fragments by this method are in progress and will be reported in a forthcoming paper.

While several problems still remain to be solved (preparation of thin targets and observation of spatial coincidences), the present tests indicate that this approach may be useful in the high-energy fission studies.
ACKNOWLEDGEMENTS

We are very grateful to Dr. W.O. Lock and Dr. G. Rudstam for their support and interest in this work. We wish to thank the CERN staff, and particularly Dr. D. Dekkers and Dr. G. Plass for their co-operation in making the irradiations. Our thanks are due to Miss W. Riezler and Miss E. Tielsch for their assistance and to Mr. M.A. Roberts for making the microphotographs. Finally, one of us (J. Zakrzewski) acknowledges the Ford Foundation for the Fellowship at CERN.
REFERENCES

1) For summary of the present status in the field of the solid-state nuclear track detectors see, for example, R.M. Walker, Proc.Conf.Strasbourg (1963).


Note added in proof: Spatial coincidences of fission fragments resulting from the interactions of incident protons with uranium, bismuth and lead nuclei have been observed in mica sandwiches exposed recently at the PS. Details will be given in a forthcoming report.
<table>
<thead>
<tr>
<th>Exposure date</th>
<th>Stack No.</th>
<th>Stack composition</th>
<th>Beam</th>
<th>No. of pulses</th>
<th>No. of circulating protons</th>
<th>Total No. of incident protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.9.1964</td>
<td>1</td>
<td>4 mica sheets</td>
<td>internal circulating proton beam of 18.3 GeV</td>
<td>2</td>
<td>$6.1 \times 10^{10}$</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>1 mica sheet pre-exposed to $^{235}$U fission fragments</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>2</td>
<td>2 mica-Al (4.0 μm) - mica</td>
<td></td>
<td>1</td>
<td>$1.42 \times 10^{11}$</td>
<td>$6.6 \times 10^{12}$</td>
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<tr>
<td></td>
<td>3</td>
<td>1 mica-Pb (30 μm) - mica</td>
<td></td>
<td>1</td>
<td>$2.0 \times 10^{10}$</td>
<td>$1.5 \times 10^{12}$</td>
</tr>
<tr>
<td>8.9.1964</td>
<td>4</td>
<td>6 mica sheets</td>
<td>as above</td>
<td>10</td>
<td>$8.6 \times 10^{12}$</td>
<td>-</td>
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<tr>
<td></td>
<td>5</td>
<td>3 mica sandwiches with evaporated layers of U</td>
<td>as above</td>
<td>1</td>
<td>$0.76 \times 10^{13}$</td>
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<tr>
<td></td>
<td>6</td>
<td>2 mica sandwiches with evaporated layers of U</td>
<td>as above</td>
<td>5</td>
<td>$5.46 \times 10^{10}$</td>
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<td>1 mica sandwich with inserted Au foil (13 μm)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>mica-Al (4.0 μm) - mica</td>
<td>as above</td>
<td>1</td>
<td>$8.62 \times 10^{11}$</td>
<td>$3.3 \times 10^{13}$</td>
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<td>mica-Cu (57 μm) - mica</td>
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<tr>
<td></td>
<td></td>
<td>mica-Pb (30 μm) - mica</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>mica-Au (13 μm) - mica</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.9.1964</td>
<td>8</td>
<td>4 mica sandwiches with evaporated layers of Pb (785 μg/cm² ± 15%), Au (15 μg/cm² ± 15%), Ag (35 μg/cm² ± 20%), and Cu (43 μg/cm² ± 10%), respectively,</td>
<td>fast extracted proton beam of 23.7 GeV</td>
<td>1</td>
<td>$1.0 \times 10^{12}$</td>
<td>$8.8 \times 10^{11}$</td>
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<tr>
<td></td>
<td></td>
<td>mica-Ag (15 μm) - mica</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>mica-Pb (30 μm) - mica</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 mica sheets</td>
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<td></td>
</tr>
<tr>
<td>Exposure date</td>
<td>Stack No.</td>
<td>Stack composition (^x)</td>
<td>Beam</td>
<td>No. of pulses</td>
<td>No. of circulating protons (^y)</td>
<td>Total No. of incident protons (^+)</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
<td>---------------------------</td>
<td>------</td>
<td>--------------</td>
<td>-----------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>17.9.1964</td>
<td>9</td>
<td>2 mica sandwiches with evaporated layers of Bi (200 µg/cm²) mica - Pb (30 µm) - mica</td>
<td>internal circulating proton beam of 20.6 GeV</td>
<td>1</td>
<td>(8.2 \times 10^{11})</td>
<td>(6.5 \times 10^{13})</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>the same as that of target 9</td>
<td>as above</td>
<td>1</td>
<td>(7.8 \times 10^{11})</td>
<td>(5.6 \times 10^{13})</td>
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</tbody>
</table>

\(^x\) Three foils of Al (40 µm) were added to all the stacks, with the exception of those of No. 1 and 4, in order to make possible the determination of the total number of incident protons from the production of Na\(^{24}\).

\(^y\) Multiple traversals through the stack not taken into account.

\(^+\) Estimated from the production of Na\(^{24}\) from Al foils over the working area of 1 cm².
FIGURE CAPTIONS

Fig. 1. A stack of mica sheets and metal foils mounted in an aluminium frame (left) or in a standard target holder (right).

Fig. 2. Tracks of fission fragments from the spontaneous decay of C1252 recorded in mica before - and revealed by processing after - the irradiation in a proton beam.

Fig. 3. Tracks recorded in a mica sheet adjacent to a 30 μm thick foil of lead exposed to a dose of a few times $10^{12}$ protons/cm$^2$.

Fig. 4. The opposite surface of the same mica sheet as that shown in Fig. 3 adhering to another mica sheet.

Fig. 5. Tracks recorded in a mica sheet adjacent to another mica sheet exposed to about $10^{15}$ protons/cm$^2$.

Fig. 6. Tracks recorded in a mica sheet adjacent to a gold foil.

Fig. 7. Tracks recorded in a mica sheet adjacent to a silver foil.
Fig. 1. A stack of mica sheets and metal foils mounted in an aluminium frame, left, or in a standard target holder, right.

Fig. 2. Tracks of fission fragments from the spontaneous decay of Cr$^{232}$ recorded in mica before - and revealed by processing after - the irradiation in a proton beam.
Fig. 3. Tracks recorded in a mica sheet adjacent to a 30 μm thick foil of lead exposed to a dose of a few times $10^{17}$ protons/cm$^2$.

Fig. 4. The opposite surface of the same mica sheet as that shown in Fig. 3 adhering to another mica sheet.
Fig. 5. Tracks recorded in a mica sheet adjacent to another mica sheet exposed to about $10^{15}$ protons/cm$^2$.

Fig. 6. Tracks recorded in a mica sheet adjacent to a gold foil.
Fig. 7. Tracks recorded in a mica sheet adjacent to a silver foil.