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DISCRIMINATION OF TRACKS OF PHOTOFISSION FRAGMENTS WITH VERY HIGH BACKGROUND OF ALPHA PARTICLES AND ELECTRONS IN NUCLEAR EMULSIONS*

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S U M M A R Y

With common drugs used in photography such as Amidol, boric acid, sodium sulfite and potassium bromide, a developing bath was prepared which permits a full discrimination between tracks of highly ionizing particles, such as fission fragments, in the presence of strong background radiation such as that produced by the electrons from a 2000 Roentgen X-ray dose and a background of 10^9 alpha particles/cm^2.

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INTRODUCTION

In order to measure the anisotropy of photofission fragments from U-238[1] with Ilford nuclear emulsion D1 and KO as detectors, it was considered advantageous to search for a method of developing photoplates so that only the tracks from fission fragments were clearly visible in a background produced mainly by electrons from very high X ray doses and by alpha particle.

Methods that allow discrimination between fission fragments and alpha particle tracks by under-development[2] or by eradication of the latent image[3] are already known. However, the distinction between these tracks is sometimes difficult, mainly when the number of alpha particle tracks is much greater than the fission fragment tracks or when the alpha particle tracks form large angles with the plane of the emulsion.

The conventional processes of development do not take full advantage of the difference in the ionizing powers of the two kinds of particles that produce the tracks. A fission fragment has on the average, an ionizing power 30 times greater than that of an alpha particle; however, if a conventional development is used the tracks resulting are almost indistinguishable. A process of development, which takes advantage of the difference in ionizing power in such a way as to eliminate the development of undesirable tracks of a particle with less ionizing power, is advantageous for many reasons; in scanning it is not necessary to distinguish between numerous tracks from alpha particles and from those produced by fission fragment because the only tracks visible are those from the fission fragments. Moreover, the same process which eliminates the undesirable background tracks allows the use of greater doses of X-ray, yielding a greater number of fission fragment tracks with benefit to the time of scanning.

Frequently nuclear emulsion loaded with an alpha emiter is used both as the detector and target nuclide container. In this case the whole experiment, from the moment of the impregnation to the emulsion processing, is done as fast as possible (in a few hours), so as to prevent the undesirable accumulation of alpha particle tracks. When the technique that eliminates the alpha tracks is used, fading of the latent image is the only limiting factor on time. However fading can be slowed down in a dry, low temperature, nitrogen atmosphere.

METHOD

In a previous paper[4], it has been shown which factors influence the kinetics of development of tracks produced by charged particles and the equations that describe the rate of reaction. These equations indicate that it is possible to separate the curves completely; grain density versus development time of fission -fragment tracks from those of alpha particle tracks.

The rate of development of the latent image depends on several factors, such as the nature of the photographic emulsion (including the effect of the loading), the solarization produced by intense gamma radiation, the nature of the developing bath, the temperature and the ionization produced by the particle along its path.

It is possible to prepare a developing bath such that at a given temperature only fission tracks will be developable; alpha tracks remaining invisible because as has been said before, fission fragments ionize much more than alpha particles and thus, the number and size of the latent images produced in the grains by fission fragments are higher than those produced by alpha particles. When the developing power of the bath is so low as barely to develope the grains sensitized by a given charged particle, it is reasonable to assume a first order process for the mechanism of development; that is, the rate of development is proportional to the number of sensitized grains not yet developed, $(dD/dt) = k\ (D_\infty - D)$, where k is the specific rate of the process. D_∞ represents the total number of grains that may be rendered developed and D is the number of grains already developed at the time considered.

The integrated form of this equation is the following:

$$D = D_\infty \left\{ 1-\exp\ \left[-k(t-t_o)\right] \right\} \qquad (1)$$

where t_o is the induction period; that is, the time within which no development is observable.

Dealing with development of tracks, produced by two kinds of particles of very different powers of ionization, it is possible to adjust the time scale of the two processes so that the development induction period t_o of the tracks of the particles with less ionization is so long that it allows time enough for tracks of the particles with greater ionization, to be full developed.

Potassium Bromide, which is usually employed to increase the induction period, was used in a relatively large quantity. It also reduces the specific rate of development. Diluting by a factor of twenty the concentration of the developing agent, keeping a sufficient quantity of sulfite and a low pH with an adequate concentration of boric acid, and carrying the development at low temperature, it is possible to reduce considerably the specific rate of development, thus magnifying the time scale so as to obtain the desired discrimination. This developing solution diffuses in less than 2 hours in 200 micron plates, and is probably suitable for use in 600 micron pellicles.

Since the adequate time of development for a group of plates exposed under certain conditions depends on several factors, a device was used to determine the optimum time of development. This apparatus yields plates gradually developed in such a way that in just one operation a large time interval may be studied.

The apparatus (figure 1), consists of a plastic holder that may hold four 1"x3" plates, a graduated cylinder and the mechanism of an old clock. The support is dipped into the developing bath by the mechanism which is connected to several wheels of different radii, the one to be used, depending on the time interval to be investigated. The clock mechanism sinks the plate holder vertically at a uniform rate. Therefore, for each position on the plates there corresponds a particular developing time. The proper choice of time is made from a microscopic examination of the plates, choosing the region where the fission tracks are to be sharply visible in the full thickness of the emulsion and the background sufficiently weak so as to allow comfortable scanning.

A preliminary determination of the masimum tolerable gamma ray dose adequate for the U-238 photofission investigation was made, exposing natural uranium loaded plates to a calibrated Ra-Be source. Keeping the source and the plates inside a block of paraffin during the exposure, one gets neutron fission tracks and a background of gamma rays that vary with the distance from the source. In this way it is possible to determine with good approximation the ideal developing conditions.

When performing the actual experiments in photofission, one or more plates were developed gradually in the apparatus described above, during a time interval that contains the optimum time obtained in the previous experience with the Ra-Be source. Once the developing time for a given temperature was established the following method was used; loaded emulsions were washed in running distilled water at 5°C for 30 or 120 minutes (100 or 200 microns). Then the plates were kept for the optimum time previously determined in the following developing bath:

Boric Acid 5.5g
Sodium Sulfite 4.5g
Potassium Bromide 1.5g
Amidol 0.45g
Distilled water to make 2 liters

After the developing bath the plates were washed in running water at 8°C for 60 minutes, then put in a stop bath (0.7% acetic acid solution) at 5°C for 2 hours, washed again in running water and fixed in a 30% hypo solution which contained some silver. Fixation is done at a temperature of 5°C. The photoplates after the fixing process were washed in tap water at 8°C dehydrated in alcohol and dried at room temperature.

The time used for development at 10°C for Ilford KO 100 microns thick was between 50 to 70 minutes. For emulsions 200 microns thick, the time was 90 to 120 minutes, adjusted in each case to loading pH and X-ray doses. It was found that from batch to batch the proper time was different when the other conditions were the same. It is well known that the impregnation of uranyl salts in emulsion has a desensitization effect which is strongly affected by the pH of the solution used.

Nuclear emulsions exposed to high doses of X-rays suffer a fading of the latent image similar to the solarization in common photography and the overall effect is equivalent to a diminishing of the emulsion sensitivity[5]. This effect depends on the rate of irradiation, on the content of water of the emulsion and on the room temperature. The solarization effect of the dose and rate of X-ray exposure and of the uranyl salt at the loading pH is such that a 300 R dose given in 2 minutes' exposure at 20 Mev will require 9 hours in the developing bath to render the alpha tracks barely visible. With a dose of 600 R and the same rate, it was impossible to observe any alpha particle track with 24 hours of development.

When the X-ray dose is not too high and the development lasts too long the fission tracks become very dark with a density of grains so high that the screw structure resulting from too many grains in the trajectory is very well observed.

USES OF THE TECHNIQUE

The method of development described above may have many different uses in problems of nuclear physics where one has production of highly ionizing particles in the presence of a strong background of radiation. For instance, using Ilford KO type of nuclear emulsion to study problems involving fission fragments with high energy X rays it is possible to use exposures up to 2000 Roentgens. This permits the study of angular anisotropy, fissionability and tripartition with emission of fragments heavier than alpha particles. The method may be used to study spontaneous fission, or fission induced by very high intensity beams of neutrons or charged particles. Another possible use is the detection of high ionizing heavy cosmic ray primaries in exposures carried out for many hours in the Van Allen outer space belt of radiation.

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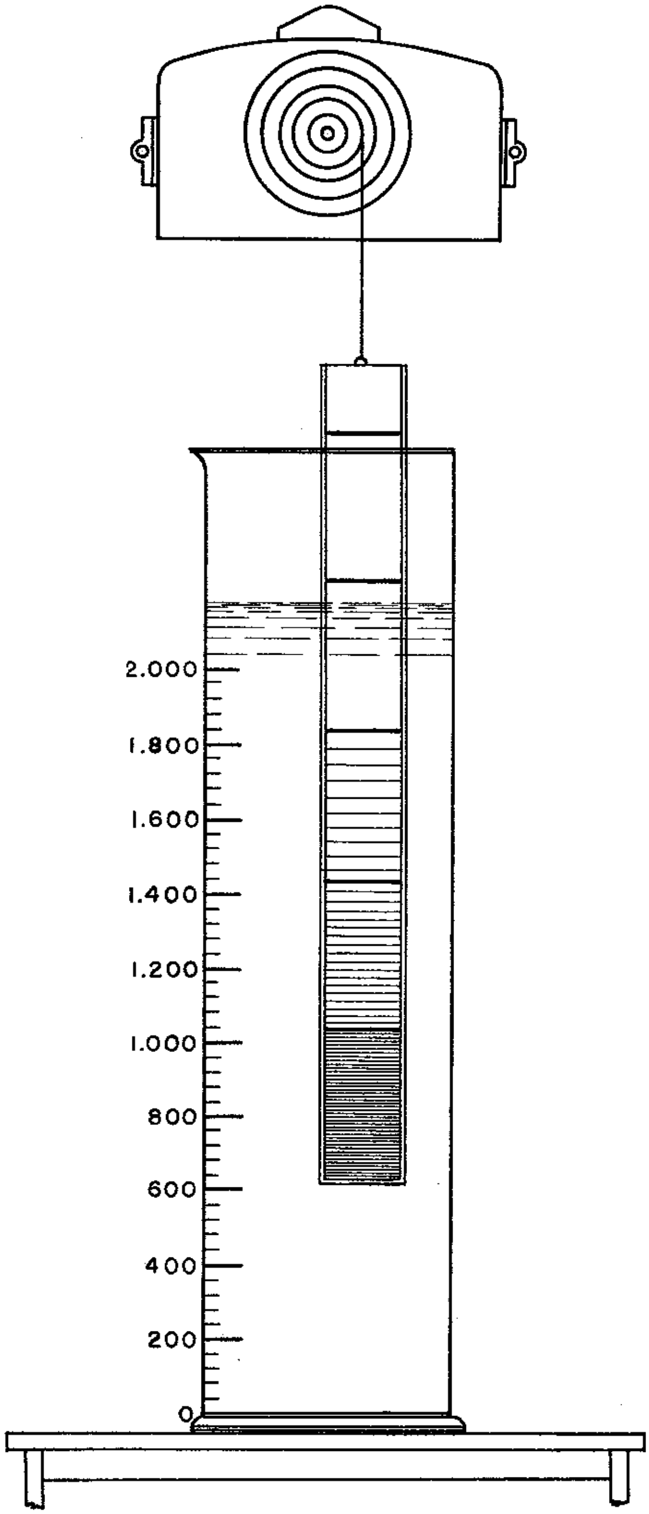

Fig. 1

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