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# Latest Developments in Nuclear Emulsion Technology

Kunihiro Morishima*

*Institute for Advanced Research, Nagoya University, Furo, Chikusa, Nagoya, Aichi, 464-8602, Japan*

**Abstract**

Nuclear emulsion is high sensitive photographic film used for detection of three-dimensional trajectory of charged particles. These trajectories are recorded as tracks consist of a lot of silver grains. The size of silver grain is about 1 μm, so that nuclear emulsion has submicron three-dimensional spatial resolution, which gives us a few mrad three-dimensional angular resolution. The important technical progress was speed-up of the read-out technique of nuclear emulsions built with optical microscope system. We succeeded in developing a high-speed three-dimensional read-out system named Super Ultra Track Selector (S-UTS) with the operating read-out speed of approximately 50 $cm^2$/h. Nowadays we are developing the nuclear emulsion gel independently in Nagoya University by introducing emulsion gel production machine. Moreover, we are developing nuclear emulsion production technologies (gel production, poring and mass production). In this paper, development of nuclear emulsion technologies for the OPERA experiment, applications by the technologies and current development are described.

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*Keywords:* nuclear emulsion, muon radiography, neutron, proton, fast ion, scanning system ;

## 1. Nuclear Emulsion

Nuclear emulsion is one of photographic films, which is able to detect three-dimensional tracks of charged particles with submicron spatial resolution (Fig. 1 (a)). The structure of nuclear emulsion is shown in Fig. 1 (b). Emulsion gel is poured on the supporting base material (Fig. 1 (d)). A lot of silver bromide (AgBr) crystals, which diameter is a few hundred nm, are dispersed in gelatin layer (Fig. 1 (e)). Fig. 1 (c) is electron microscope picture of AgBr crystals. A charged particle passes through emulsion layer, as a result, some crystals in the line of trajectory have latent image. After chemical development of nuclear emulsion, these latent images change to submicron silver particles (grains) (Fig. 1 (f)). From this principle, we can detect three-dimensional trajectory of charged particle

* Corresponding author. Tel.: +81-52-789-2541; fax: +81-52-789-2864.
*E-mail address:* morishima@flab.phys.nagoya-u.ac.jp

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(track). The optical microscope image of track is presented in Fig. 1 (g). Due to the excellent performance as a detector with submicron position accuracy in 4π solid angle, nuclear emulsion allowed to observe π and μ decays (Powell, Fowler and Perkinset (1959)), charmed particle (Niu et al. (1971)), tau neutrino (Kodama et al. (2002)), double hypernucleus (Takahashi et al. (2001)) and so on.

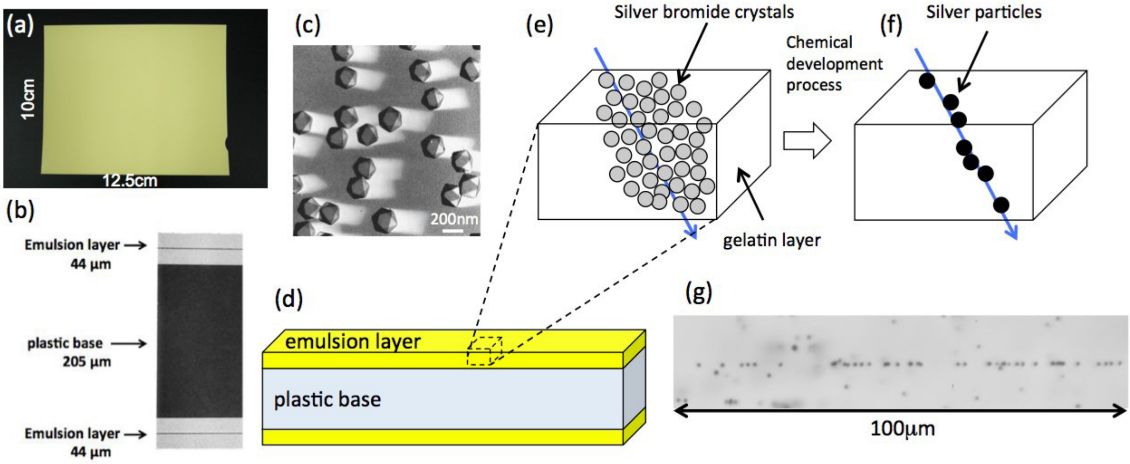


Fig. 1. (a) A picture of OPERA film; (b) An electro microscope image of cross section of OPERA film; (c) An electron microscope image of silver bromide crystals of OPERA film. The diameter of crystals is about 200 nm; (d) An Illustration of the structure of OPERA film; (e) and (f) The principle of detection of charged particle; (g) A microscope image of track of minimum ionizing particle in OPERA film.

## 2. Technical development for the OPERA experiment

The aim of the OPERA experiment is direct observation of tau neutrino appearance in a pure muon neutrino beam (Acquafredda et al. (2009)). The principle of the OPERA detector operation is the following. Neutrino has very small cross-section. In order to detect enough neutrino interactions for analysis and to realize this experiment, 1000 tons of target materials are needed. On the other hand, in order to identify tau neutrino, we need to observe tau decay. Tau decay scale is about 1mm, and decay kink angle is several 10 mrad. Thus, a detector with micron spatial resolution is needed. The only detector satisfying both requirements is Emulsion Cloud Chamber (ECC), which is stacking structure of nuclear emulsion and target material plates. OPERA ECC consists of 57 emulsion films interleaved with 1mm thick lead plates and the size of both plates is 10 cm × 12.5 cm. In order to realize this experiment, 8 million nuclear emulsion plates were necessary.

### *2.1. OPERA film*

8 million plates were produced by Fuji Photo Film Co., Ltd and were named OPERA film. OPERA film is first case of industrial machine production (Nakamura et al. (2006)). Fig. 1 (b) shows the nuclear emulsion cross section under the electron microscope. Emulsion layers, which are able to record trajectory of charged particle, are very uniformly poured on both sides of plastic supporting base and uniformity of thickness is less than 1 μm. The density of Ag grains per 100 μm of minimum ionization particle (MIP) track is 36. This value is the unit of sensitivity of nuclear emulsion called Grain Density (GD).

### *2.2. Automated scanning system "S-UTS"*

The OPERA experiment requires not only industrial production of nuclear emulsion but also a high-speed data analysis as well. The required speed is about 1000 $cm^2$/day. We have developed high-speed emulsion read-out