Development of high-sensitivity nuclear emulsions focusing on silver bromide crystal size and chemical sensitization

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Introduction

Cosmic ray imaging is a technology that uses cosmic ray muons to nondestructively visualize the interior of large structures. We use nuclear emulsion plates as detectors for cosmic ray imaging. Because the efficiency of muon track detection depends on the sensitivity of the emulsion, research has been conducted to improve emulsion sensitivity. The emulsion manufacturing process consists of three steps: crystal formation, desalting, and chemical sensitization. Previous research has shown that emulsion sensitivity is significantly dependent on the size of the silver bromide crystals. Therefore, efforts have been made to increase the size of the silver bromide crystals during the crystal formation process to improve sensitivity. Furthermore, during the chemical sensitization process, a certain amount of sodium thiosulfate and chloroauric acid are added as sensitizers, and gold and sulfur are attached to the silver bromide crystals, resulting in gold-sulfur sensitization. Because the total surface area of silver bromide crystals in an emulsion is inversely proportional to the crystal size, emulsions with larger crystal sizes have a higher amount of sensitizer attached per unit area. This makes the silver bromide crystals more susceptible to development, resulting in an increase in fog, or developed silver particles not derived from track formation. Fog becomes noise when detecting muon tracks, so to suppress the increase in fog, a sensitizer is added to large grain emulsions in an amount inversely proportional to the crystal size.

Experimental Procedures

(1) Silver Bromide Crystal Size Measurement

Particle sizes were measured using various methods, including turbidity distribution, electron microscope images, and centrifugal sedimentation, for multiple emulsions with different crystal formation process formulations, and the results were compared.

(2) Search for the Optimal Sensitizer Addition Amount

Several emulsions were prepared by sensitizing a 300 nm equivalent unsensitized emulsion with varying amounts of sensitizer. Nuclear emulsion plates were prepared using each emulsion and developed, and their performance was evaluated based on three indices.

(i) Grain Density (GD)

Grain density (GD) is an index of sensitivity defined as the number of developed silver grains per 100 μm of track. After irradiating the plates with cosmic rays for several days, the plates were developed, and the GD of the cosmic ray tracks was visually measured and compared using an optical microscope.

(ii) Fog Density (FD)

Fog density (FD) is an index of noise defined as the number of fog particles per 1000 μm^3. The plates were developed immediately after preparation, and the FD was visually measured and compared using an optical microscope.

The performance of the plates was compared using the above two indicators, and the optimal amount of sensitizer to be added was explored.