Muon radiography by nuclear emulsions: data acquisition and processing

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Nuclear emulsions used as tracking devices as have unique features that make them suitable for muon radiography of volcanic edifices. They are cheap and have excellent spatial and angular resolution, respectively about 0.3 micrometers and 1 mrad. They have no dead time, but on the other hand they have no time resolution. Such specific behaviours demand the use of specific techniques.

Once a nuclear emulsion-based detector is removed from its exposure site and the films are developed, data readout can start. Modern automatic microscopes acquire images stored in the emulsion thickness and convert them to sets of tracks of charged particles. Even very thin layers, of the order of 50 micron, can provide 3D information about the local flux of muons and/or other particles present in the showers initiated by primary cosmic rays. In the case of exposures that take several months and detector surfaces of the order of a few m2, data readout time is only a fraction of the data collection time.

The performances of the data readout system play a prominent role. Fast emulsion scanning speed means ability to acquire data on large areas; high statistics implies low statistical fluctuations of data, and hence good sensitivity to the variations of the integrated flux density. Track recognition efficiency is also crucial: since emulsion films are exposed in stacks to reduce the amount of fake tracks due to ambient radioactivity and not related to cosmic rays, the ability to reconstruct penetrating tracks depends on a power of the tracking efficiency. The basic architecture and working principle of the European Scanning System (ESS) are described. Such system is currently used by muon radiography research groups in Europe and Japan. The evolution of the system to scale up its speed and data quality are also presented.

The size of data sets from a typical exposure can be 10^{10} singlet tracks. Detectors for muon radiography are built of several small stacks of emulsion films (doublets, triplets, quadruplets or multiplets with or without absorbers to stop soft components). Single layer tracks are normally correlated in the films of the same stack to reconstruct penetrating tracks. This operation dramatically increases the signal-to-noise ratio to values that range from 100:1 to 10000:1. The resulting data sets of penetrating tracks provide detailed angular spectra of integrated rock thickness. Given the amount of data, specific algorithms have been developed and optimized.

Such processed data even allow a posteriori fine-tuning of the position, direction and inclination of the individual sub-stacks that build the detector, with a precision of a few degrees. Finally, selection of the quality of tracks allows filtering different components of the flux of charged particles that cross the detector, from electromagnetic showers to muons. The method is shown with examples from data analysis activities on exposures to Unzen and Stromboli.