COSMIC RAY TOMOGRAPHY

A feasibility study

Overview

- A look into past archeological uses
  - Alvarez Experiment
  - Pyramid of the Sun
  - Mayan Pyramid
- Attenuation Vs. Coulomb Scattering
  - Attenuation
    - A deeper look into the process of attenuaton
    - Detectors

  Coulomb Scattering
    - A deeper look into the process of Coulomb Scattering

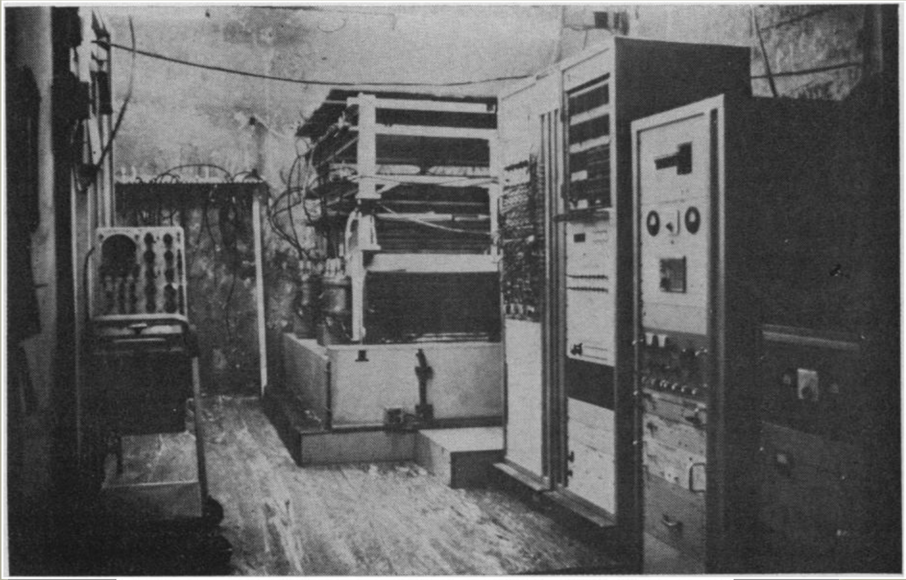
ALVAREZ[1]

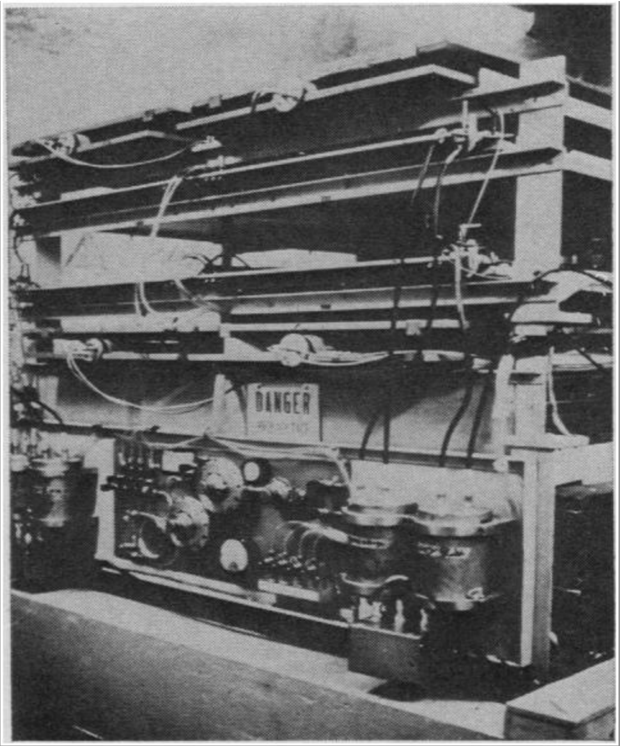
First to use muography to look into an ancient structure

Looked into the Pyramid of Khafre

Used a muon detector called a spark chamber

- Which could locate the position of object to within 1 m.
- New, more advanced detectors have now been produced
- Built underneath in a tunnel, could use muons coming from different zenith angles





Teotihuacan^2

- Pyramid of the sun
- Physicist Arturo Menchaca-Rocha and Archeologist Linda Manzanilla
- Needed a tunnel
  - Match the muon flux measured at different angles with the muon flux that would be expected from the depth of the pyramid

- Unlike the Pyramid of Khafre, this does not have a uniform density, so they have to calculate the average density by taking samples from inside the pyramid

Mayan Pyramid[3]

- University of Texas, Physicist Roy Schwitters
- Looking for any rooms or chambers inside a Mayan pyramid in Belize
- Detectors will be buried in shallow holes around the base of the pyramid
- Still possible without a tunnel:
  - With four or five smaller detectors spaced around the structure to get a three dimensional view

Two Methods

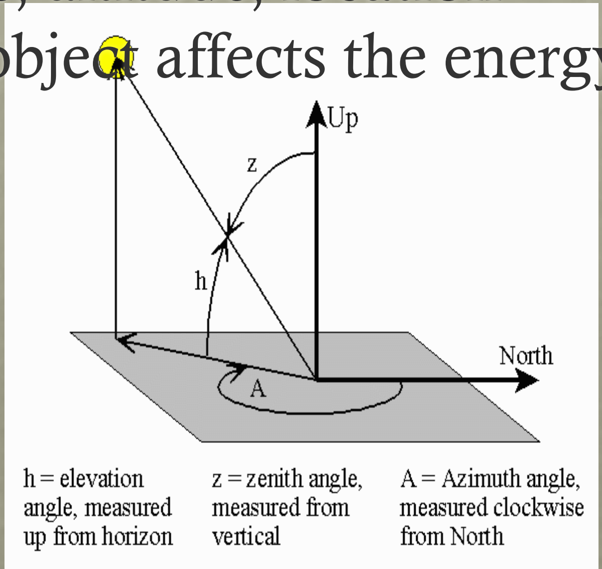
- Attenuation
  - The loss of Muon flux
- Columb Scattering
  - Measurement of the muon path’s angle deviations

Attenuation

- The change of muon flux can be useful in imaging larger areas
- can use a detector underneath the object to measure the attenuation
  - Muons with any zenith angle
  - Smaller detector can be used
- Can use a detector horizontal, on the side of the object
  - Muons with a zenith angle at almost 90°
  - Larger detector needed

MUON TRAJECTORY[4]

- Without an underground tunnel, we would strictly use muons that are coming in at a 90° zenith angle, θ
- The azimuth angle tells us what direction the muon is coming from, ϕ
- The azimuth angle, zenith angle, altitude, location (latitude and longitude) of the object affects the energy of the muon



LOOKING INTO VOLCANOES[4]

- Flux of cosmic ray muons can be calculated
  - Flux of Muon with an energy greater than E(c)=

$$N_{\mu}(E_c, \theta_z) = \int_{E_c}^{\infty} I_0(E, \theta_z)\, dE.$$

- Where I(o) is the intensity of high energy muons arriving at the zenith angle (θ), with corrections for the spherical nature of the earth, energy loss due to the air, and loss of intenstiy due to in-flight muon-decay

LOOKING INTO VOLACANOES[4]

- Energy loss of a charged particle through matter with a certain thickness in terms of density length of X can be written as

$$dE/dX = [1.88 + 0.077 \ln(E/M) + 3.9E] \times 10^{-6}\ (\mathrm{TeV\,g^{-1}\,cm^2}),$$

- Thus a relationship exists between X and the intensity of penetrating cosmic-ray muons
    - For a substance with an unknown X, a measurement of Muon flux penetrating through a substance with an angle θ determines its thickness

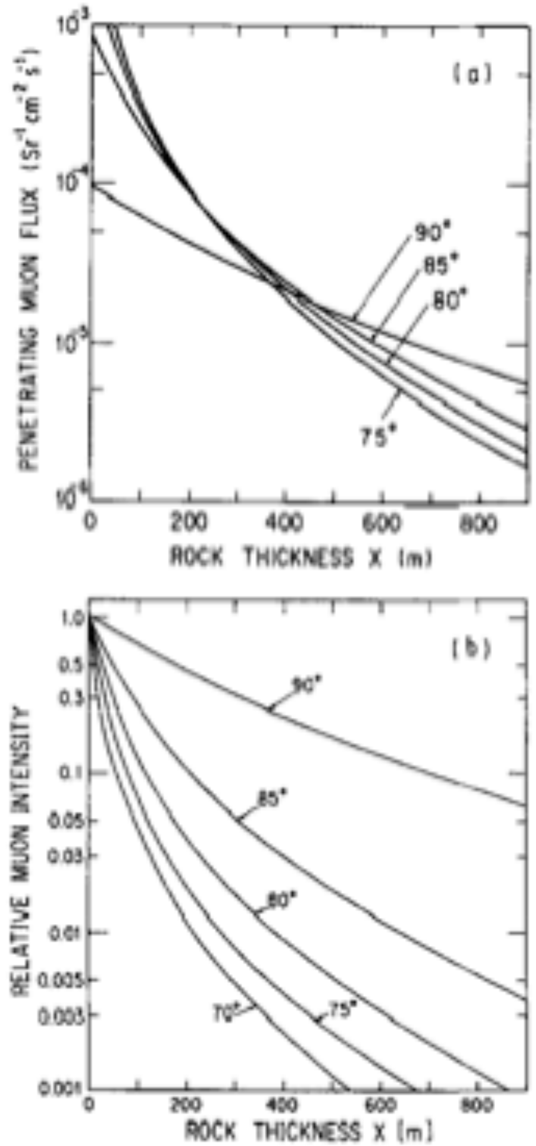
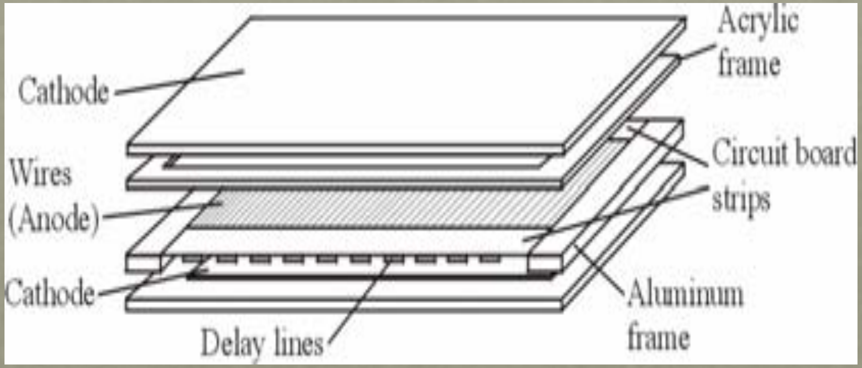


Fig. 2. (a) Integrated flux of cosmic-ray muons at various zenith angles (θ_z) penetrating through a given thickness of rock (m) with a density of 2.5 g/cm^3. (b) Relative intensity of these muons normalized by the value for zero thickness.

Detectors Underground[2]

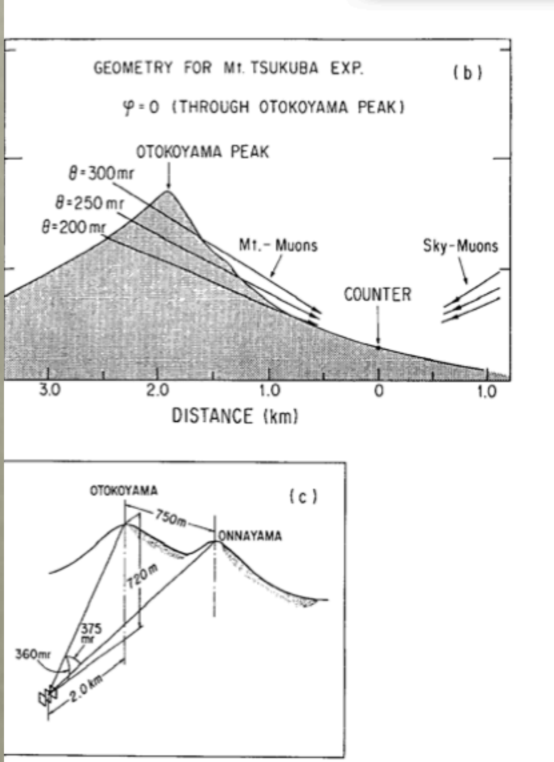
- Alvarez
  - Used a copper and acrylic chamber filled with gas
  - As the particles went through the gas, they slam into atoms with so much energy that they knock electrons free, producing an electric pulse
  - From these pulses, they could measure how many muons were going through different sections of the pyramid
  - This spark chamber is now an outdated detector and new more accurate have been engineered

- Menchaca's multi-wire detector
  - Two 1m X 1m scintillator planes for muon identification and backgrounds rejection
  - Six multi-wire chamber proportional chambers (MWPC's)
  - View of the MWPC



Detector used for Volcanoes[4]

- Scintillation counter telescope
  - Fe absorber inside detection system is useful to remove any low energy backgrounds, one between 1 and 2, one between 2 and 3



taken in the present measurement: (a) horizontal view, (b) vertical view

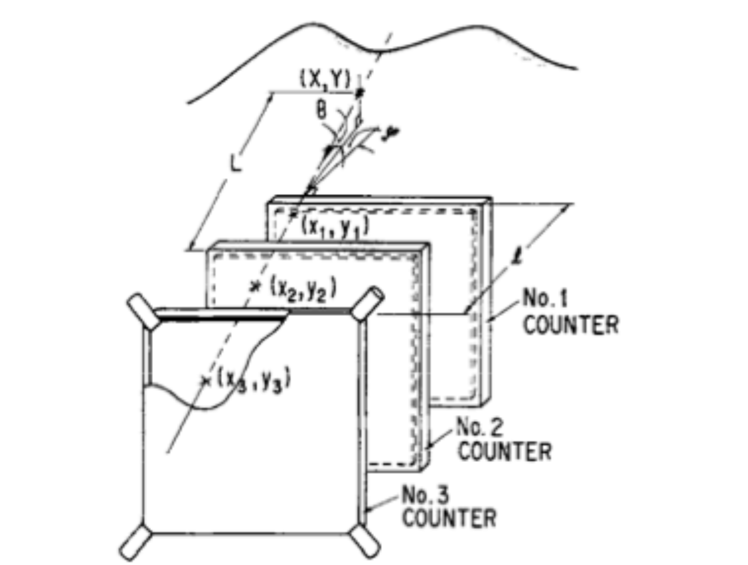


Fig. 3. Counter telescope comprising three plastic scintillators used for the Mt. Tsukuba measurement.

Electronics of Detector[4]

- The TDC circuit determines all the timing of the photo-multipliers
- Each plastic scintillator is 127 X 127 cm
- VAX 3200 computer took the data, which was converted to histograms of timing from counter to counter, spatial position, angles θ and φ, and timing from three scintillators

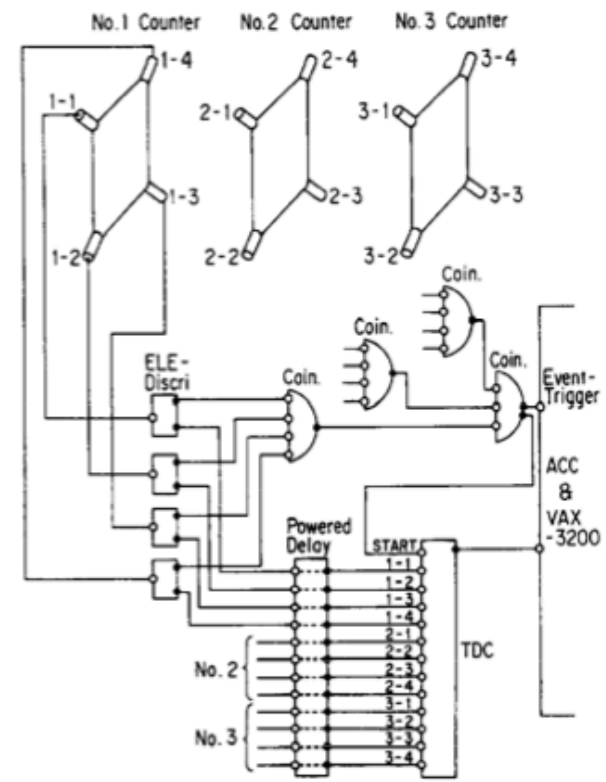


Fig. 4. Diagram of the electronics and computer system used for the Mt. Tsukuba measurement.

Coulomb Scattering[5]

- For thicker objects, it is better to use Coulomb Scattering
  - The many small interactions add up to yield an angular deviation, roughly follow gaussian distribution

$$\frac{dN}{d\theta_x} = \frac{1}{\sqrt{2\pi}\theta_0} e^{-\frac{\theta_x^2}{2\theta_0^2}}$$

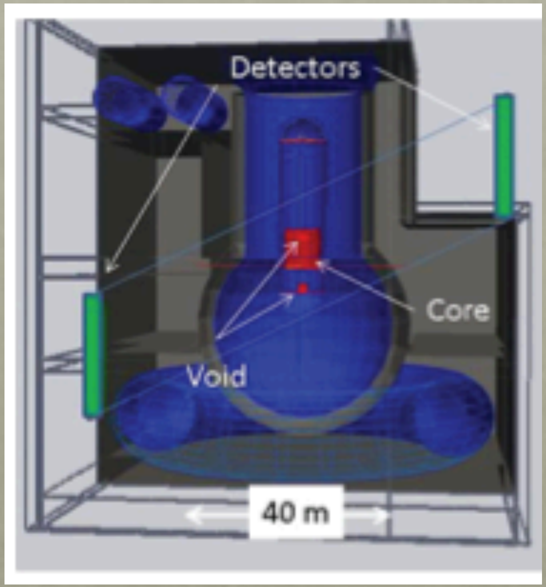
- Where θ (o) related to the scattering material through its radiation length, L(o) as follows:

$$\theta_0 = \frac{13.6}{\beta c p}\sqrt{\frac{L}{L_0}}[1 + 0.038\ln(L/L_0)]$$

- By tracking the scattering angles of individual particles, the scattering material can be mapped

DETECTOR[6]

- Muons pass through two position-sensitive detectors



- Works best if detectors are bigger than object being detected
- Uses similar scintillator based detectors

Benefit of Coulomb Scattering[6]

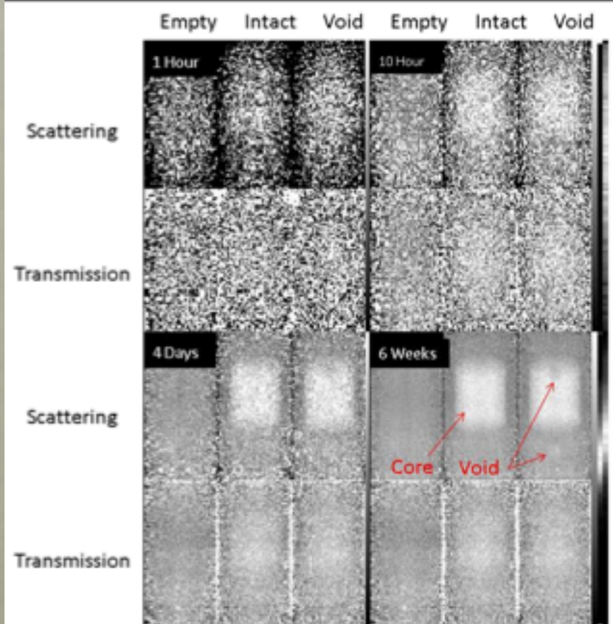


FIG. 3 (color online). Reactor reconstructions at different exposure times. In scattering radiography, the reactor core can be detected after about 10 hours of exposure. After four days, a 1 m diameter (1%) void can be detected when compared to an intact core. After 6 weeks, the void is clear and the missing material can [illegible]. With the attenuation method, the core can be observed [illegible] empty scene in four days. The void is undetectable even after 6 weeks of exposure.

Another Type of Detector[6]

- Scintillator detectors are not the only detectors out there
- One type is a cherenkov radiation detector
  - Particle goes through the chamber filled with selected gas with relativistic velocity
    - Leaves a track of Cherenkov Radiation
      - Radiation is reflected by a concave reflective mirror and detected by an array of photomultipliers

Citations

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