Cracks in the Cathedral of Santa Maria del Fiore, in Florence, popularly known as the Duomo, are the subject of research by scientists at Los Alamos National Laboratory. PETAR MILOŠEVIC

Muons in the cathedral

LANL technology used to study cracks in Florence's Duomo

By Elena Guardincerri
For The New Mexican

For traditional Christian architecture, the dome of a Renaissance cathedral represents Heaven. There is poetic symmetry today in using muons, the daughter particles of cosmic rays raining down from the stars, to scan the internal structure of a cupola atop a nearly 600-year-old Italian church in hopes of preserving it for centuries to come.

The lovely self-supporting dome of the Cathedral of Santa Maria del Fiore in Florence, Italy, was engineered by Filippo Brunelleschi, who figured out how to construct it from bricks and other masonry materials. Often called Brunelleschi's Dome and completed in 1436, it's actually two domes, one inside the other like Russian dolls.

The inner vault, 7 feet thick and nearly 150 feet across, bears all the weight onto the lower structure. The outer dome, about 31 inches thick, forms a weatherproof shell. Today, deep cracks in the domes have cast a pall of uncertainty over its future. Could it all come tumbling down?

In 2013, a group of experts on the cathedral came to Los Alamos National Laboratory to consult about fixing the cracks. That conversation led to bringing in muon-imaging technology as a tool to study the problem. Muon-imaging technology was developed for national security purposes, such as searching cargo shipments for nuclear materials — not quite cathedrals. As such, it would have to be adapted to prove useful in this unique architectural setting.

Muons are created when cosmic rays — mostly protons and helium nuclei streaming at nearly the speed of light toward Earth from all directions in space — strike Earth's atmosphere. Although muons have a lifetime of just 2.2 microseconds, something odd happens: because muons are traveling near the speed of light, an effect of Special Relativity called time dilation takes over.

Time appears to pass more slowly for objects traveling near light speed. So that 2.2 microseconds gets dragged out long enough for muons to streak down to the Earth's surface, where they penetrate the ground and any objects along the way. Every second, a handful of muons pass through your body; despite their high energy, their scarcity makes them harmless to people.

The penetrating nature of muons — far better than X-rays — makes them ideal for peering into thick, dense objects. Since the 1950s, scientists have been using muon transmission and attenuation with a single detector to create shadowy 2D images much like X-rays.

In the wake of the 9/11 terrorist attacks and the heightened anxieties over smuggled nuclear materials, two Los Alamos physicists brainstormed about muon tomography. It would create a 3D cross-section of, say, a shipping container by sandwiching it between two detectors. The device would measure the scattering angles of muons passing through it and computationally process the resulting image.

Muon tomography is especially good at spotting nuclear material, even encased in concrete. The work was a close fit with the lab's mission to protect the nation against nuclear threats by developing transformational technologies to better recognize nuclear and radiological threats and detect and prevent trafficking in nuclear materials.

Los Alamos has licensed muon scattering tomography to Decision Sciences International Corp., which has deployed it at shipping ports and collaborated with Toshiba on the construction of two trackers to locate nuclear fuel remnants inside the tsunami-ravaged Fukushima Daiichi nuclear reactor.

In Florence, cracks in the dome are causing consternation among the Opera del Duomo, the group that has maintained the cathedral since the 13th century, in part because no one knows how deeply the cracks penetrate or whether the wall is reinforced with iron bars or other materials. Brunelleschi withheld — or destroyed — his architectural drawings, leaving behind a set of puzzles.

Do iron chains wrap around the dome inside the masonry, holding it together against the outward-pressing strain of all that weight, like the bands around a barrel? Do "dog bones," short iron bars that appear on material manifests from the construction era, act like rebar tying segments together? Does rubble masonry fill the wall inside a brick veneer?

The architects and engineers intent on preserving the dome need answers to these questions so they can design a plan to reinforce it and prevent this world treasure from further cracking and — horror of horrors — tumbling down.

Muon tomography has emerged as a leading technology to reveal the hidden secrets. By suspending one muon tracker inside the cathedral and placing the other on the walkway between the dome's two shells, a team of Los Alamos scientists and others will create a computer image of the inner structure of the masonry wall. The "exposure" will take longer than two weeks, thanks to the rarity of muons, and will provide a partial 3D view of the interior.

Italian cathedrals aren't the only use for muon imaging. Besides determining the status of fuel inside the Fukushima reactor, other applications include checking structural reinforcements inside highway bridges and dams around New Mexico.

Tunnels, mines and volcanoes could all be scanned. In the realm of national security, the National Nuclear Security Administration's rapid-response teams could use a lightweight, portable muon scattering tomography unit when investigating a nuclear threat in the field.

The Los Alamos team is currently developing a smaller set of detectors and plans to work with Italian experts from the University of Parma and Florence to figure out how best to install them. The goal is to create an image of a vertical slice of the dome to reveal its structural secrets. Armed with this unique internal view, the preservation team can set to work keeping the dome aloft for another 600 years.

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