# First quantitative measure of radiation leaked from Fukushima reactor

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Atmospheric chemists at the University of California, San Diego, report the first quantitative measurement of the amount of radiation leaked from the damaged nuclear reactor in Fukushima, Japan, following the devastating earthquake and tsunami earlier this year.

Their estimate, reported this week in the early, online edition of the Proceedings of the National Academy of Sciences, is based on a signal sent across the Pacific Ocean when operators of the damaged reactor had to resort to cooling overheated fuel with seawater.

"In any disaster, there's always a lot to be learned by analysis of what happened," said senior author Mark Thiemens, Dean of the Division of Physical Sciences at UC San Diego. "We were able to say how many neutrons were leaking out of that core when it was exposed."

On March 28, 2011, 15 days after operators began pumping seawater into the damaged reactors and pools holding spent fuel, Thiemens' group observed an unprecedented spike in the amount of radioactive sulfur in the air in La Jolla, California. They recognized that the signal came from the crippled power plant.

Neutrons and other products of the nuclear reaction leak from fuel rods when they melt. Seawater pumped into the reactor absorbed those neutrons, which collided with chloride ions in the saltwater. Each collision knocked a proton out of the nucleus of a chloride atom, transforming the atom to a radioactive form of sulfur.

When the water hit the hot reactors, nearly all of it vaporized into steam. To prevent explosions of the accumulating hydrogen, operators vented the steam, along with the radioactive sulfur, into the atmosphere.

In air, sulfur reacts with oxygen to form sulfur dioxide gas and then sulfate particles. Both blew across the Pacific Ocean on prevailing westerly winds to an instrument at the end of the pier at UC San Diego's Scripps Institution of Oceanography where Thiemens' group continuously monitors atmospheric sulfur.

Using a model based on NOAA's observations of atmospheric conditions the team determined the path air took on its way to the pier over the preceding 10 days and found that it led back to Fukushima.

Then they calculated how much radiation must have been released. "You know how much seawater they used, how far neutrons will penetrate into the seawater and the size of the chloride ion. From that you can calculate how many neutrons must have reacted with chlorine to make radioactive sulfur," said Antra Priyadarshi, a post-doctoral researcher in Thiemens' lab and first author of the paper.

After accounting for losses along the way as the sulfate particles fell into the ocean, decayed, or eddied away from the stream of air heading toward California, the researchers calculated that 400 billion neutrons were released per square meter surface of the cooling pools, between March 13, when the seawater pumping operation began, and March 20, 2011.

Concentrations a kilometer or so above the ocean near Fukushima must have been about 365 times higher than natural levels to account for the levels they observed in California.

The radioactive sulfur that Thiemens and his team observed must have been produced by partially melted nuclear fuel in the reactors or storage ponds. Although cosmic rays can produce radioactive sulfur in the upper atmosphere, that rarely mixes down into the layer of air just above the ocean, where these measurements were made.

Over a four day period ending on March 28th, they measured 1501 atoms of radioactive sulfur in sulfate particles per cubic meter of air, the highest they've ever seen in more than two years of recordings at the site.

Even intrusions from the stratosphere – rare events that bring naturally produced radioactive sulfur toward the Earth's surface – have produced spikes of only 950 atoms per cubic meter of air at this site.

The nuclear reaction within the cooling seawater marked sulfur that originated in a specific place for a discrete period of time. That allowed researchers to time the transformation of sulfur to sulfur dioxide gas and sulfate particles, and measure their transport across the ocean, both important factors for understanding how sulfate pollutants contribute to climate change.

"We've really used the injection of a radioactive element to an environment to be a tracer of a very important process in nature for which there are some big gaps in understanding," Thiemens said.

The event also created a pulse of labeled sulfur that can be traced in the streams and soils in Japan, to better understand how this element cycles through the environment, work that Thiemens and colleagues in Japan have already begun.

Provided by University of California - San Diego

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