Quiet cables set to help reveal rare physics events

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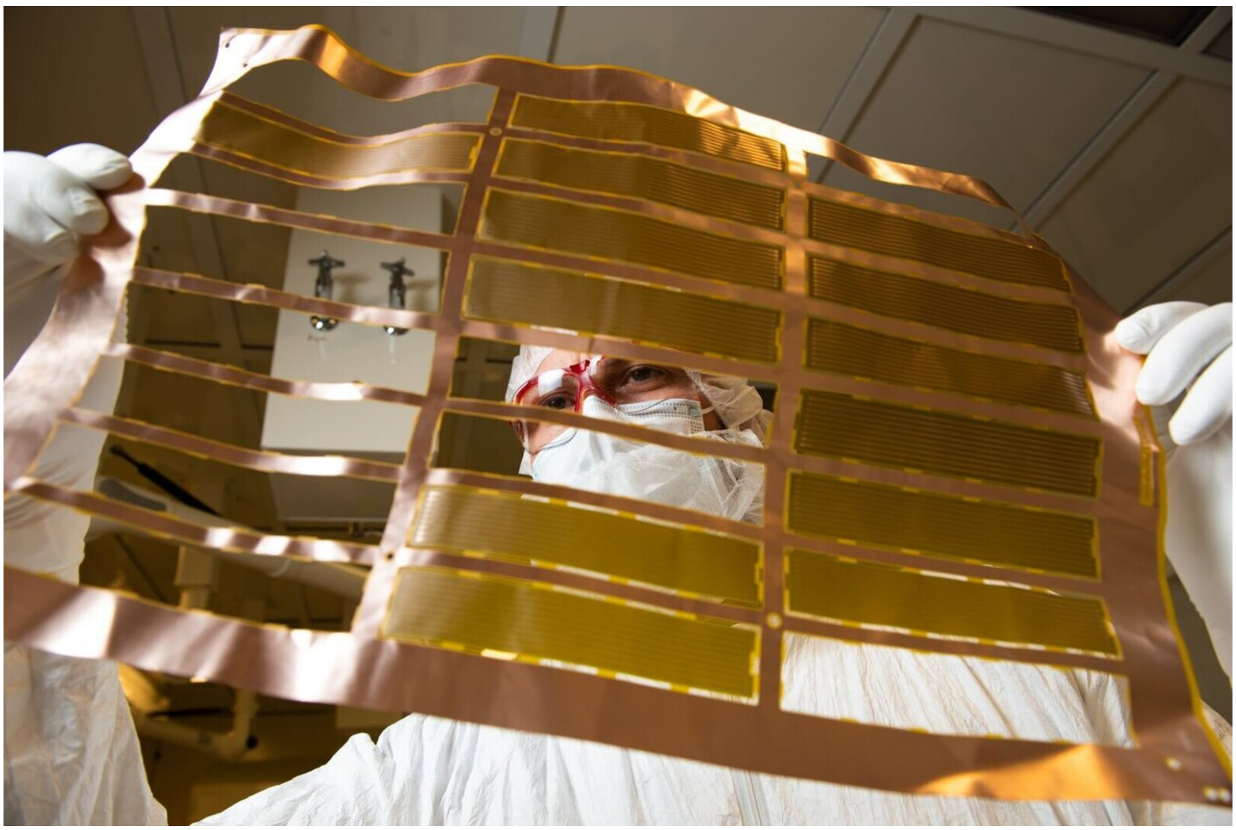


PNNL chemist Isaac Arnquist examines ultra-low radiation copper cables specially created for sensitive physics detection experiments. Credit: Andrea Starr | Pacific Northwest National Laboratory

Imagine trying to tune a radio to a single station but instead encountering static noise and interfering signals from your own equipment. That is the challenge facing research teams searching for evidence of extremely rare events that could help understand the origin and nature of matter in the universe. It turns out that when you are trying to tune into some of the universe's weakest signals, it helps to make your instruments very quiet.

Around the world more than a dozen teams are listening for the pops and electronic sizzle that might mean they have finally tuned into the right channel. These scientists and engineers have gone to extraordinary lengths to shield their experiments from false signals created by cosmic radiation.

Most such experiments are found in very inaccessible places—such as a mile underground in a nickel mine in Sudbury, Ontario, Canada, or in an abandoned gold mine in Lead, South Dakota—to shield them from naturally radioactive elements on Earth. However, one such source of fake signals comes from natural radioactivity in the very electronics that are designed to record potential signals.

Radioactive contaminants, even at concentrations as tiny as one part-per-billion, can mimic the elusive signals that scientists are seeking. Now, a research team at the Department of Energy's Pacific Northwest National Laboratory, working with Q-Flex Inc., a small business partner in California, has produced electronic cables with ultra-pure materials.

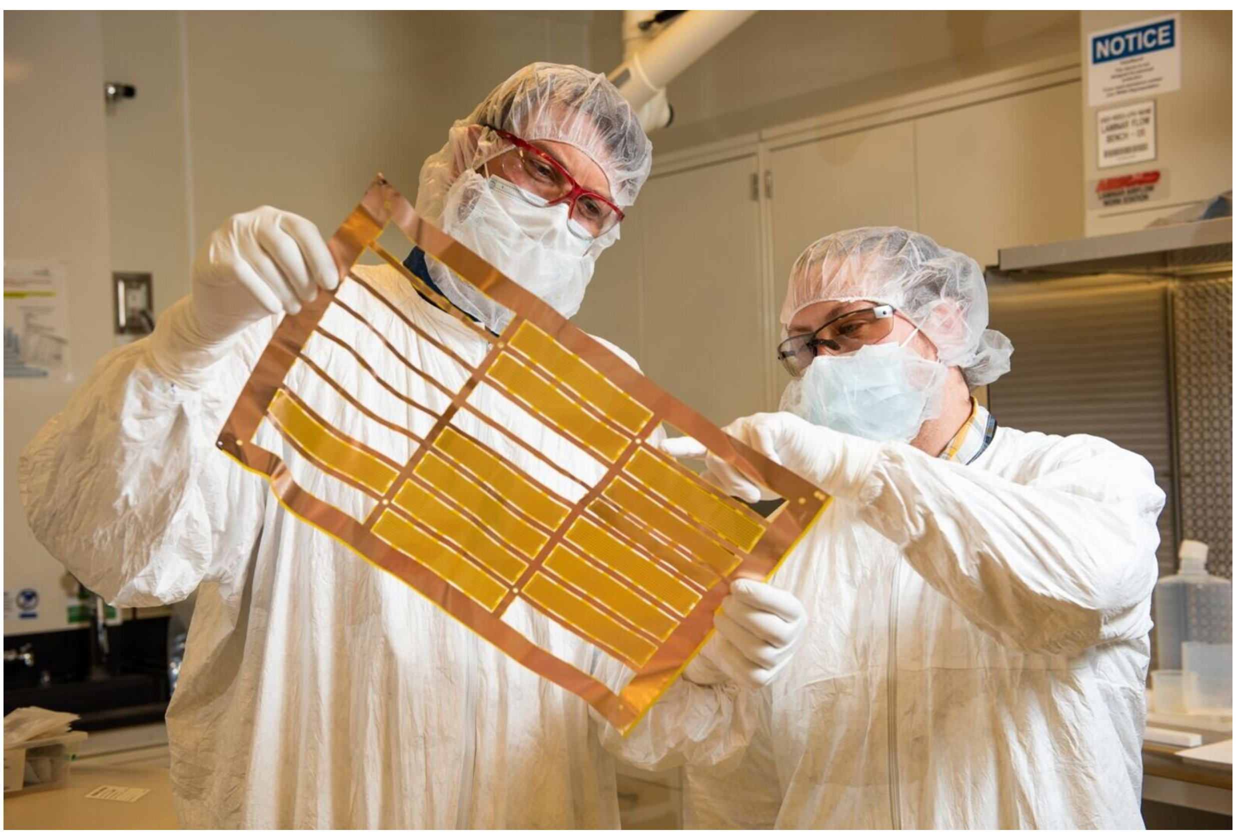
These cables are specially designed and manufactured to have such extremely low levels of the radioactive contaminants that they will not interfere with highly sensitive neutrino and dark matter experiments.

The scientists report in the journal *EPJ Techniques and Instrumentation* that the cables have applications not only in physics experiments, but they may also be useful to reduce the effect of ionizing radiation interfering with future quantum computers.

"We have pioneered a technique to produce electronic cabling that is a hundred times lower than current commercially available options," said PNNL principal investigator Richard Saldanha. "This manufacturing approach and product has broad application across any field that is sensitive to the presence of even very low levels of radioactive contaminants."

An ultra-quiet choreographed ballet

Small amounts of naturally occurring radioactive elements are found everywhere: in rocks, dirt and dust floating in the air. The amount of radiation that they emit is so low that they do not pose any health hazards, but it's still enough to cause problems for next-generation neutrino and dark matter detectors.



Chemist Isaac Arnquist and post-doctoral researcher Tyler Schlieder examine a sheet of ultra-pure copper cables designed for physics experiments. Credit: Andrea Starr | Pacific Northwest National Laboratory

"We typically need to get a million or sometimes a billion times cleaner than the contamination levels you would find in just a little speck of dirt or dust," said PNNL chemist Isaac Arnquist, who co-authored the research article and led the measurement team.

For these experiments, Saldanha, Arnquist, and colleagues Maria Laura di Vacri, Nicole Rocco and Tyler Schlieder evaluated the amount of uranium, thorium and potassium at each step of the dozen or so processing steps that ultimately produce a detector cable. The team then developed special cleaning and fabrication techniques to reduce the contamination down to insignificant levels. Working in an ultraclean, dust and contaminant-free laboratory, the researchers meticulously plan out their every move.

"I almost think of us as performance athletes because everything, every movement we make, is extremely thought out. It's almost like we're choreographed dancers," said Arnquist. "When we handle a detector sample material, there's no wasted extraneous motion or interaction with the sample because that interaction could impart some contamination that limits how well we can measure the materials."

After several years of work and hundreds of measurements, the resulting cables are now so free of contaminants that they will not impact the operation of next-generation dark matter and neutrino experiments such as DAMIC-M, OSCURA, and nEXO. The research team points out in their study that low-radioactivity cables can increase the sensitivity of the experiments and even allow more flexibility in detector design.

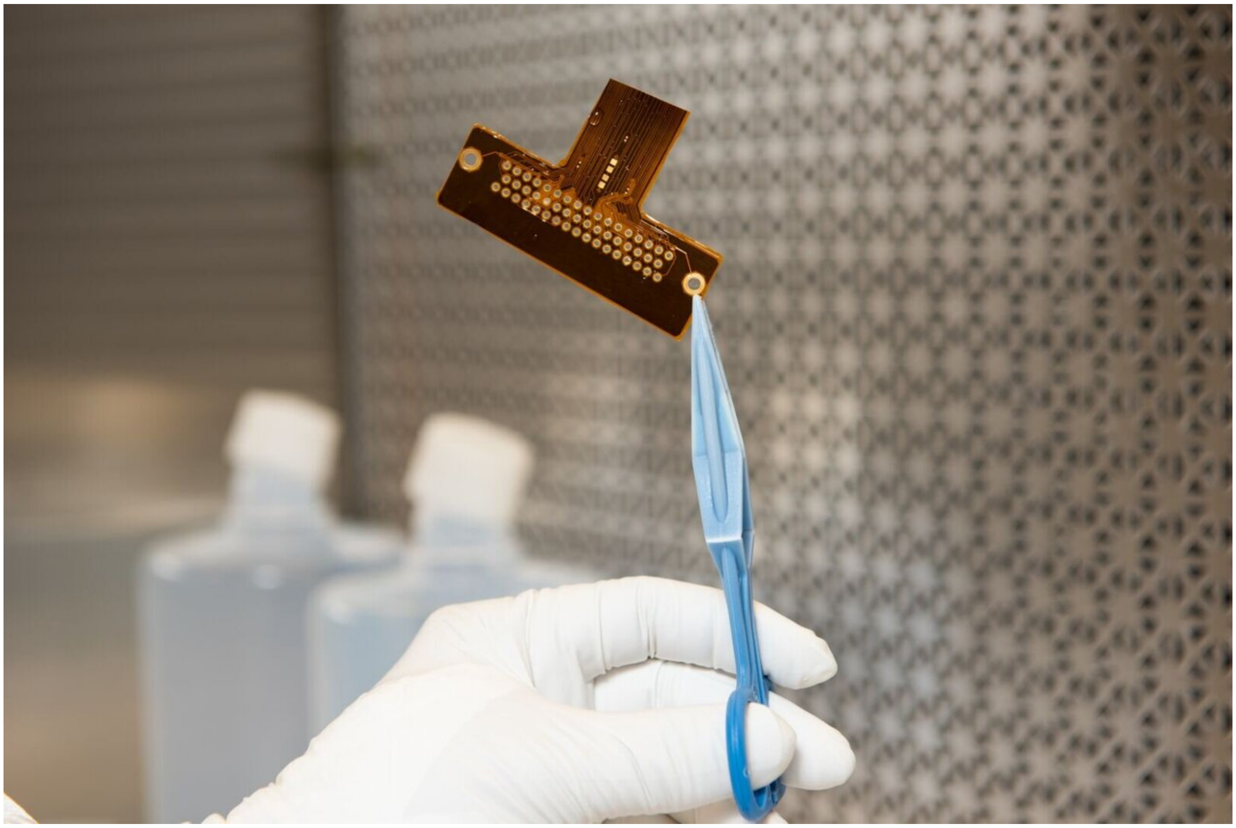
Getting closer to the 'a-ha' moment

So, exactly what are the researchers looking for in these experiments? In the case of both dark matter and neutrinoless double beta decay, they are hoping to record extremely rare events that could solve two key mysteries of the universe. Both of these mysteries pose fundamental questions about why the universe looks the way it does.

The galaxies that fill our universe would not have formed without the existence of dark matter. Dark matter makes up around 85% of the matter of the universe, and yet, we have never observed dark matter directly, only its gravitational imprint on the universe. Perhaps more intriguing, the question of why there is matter in the universe at all may hinge on a unique property of the smallest known particles of matter—the neutrino.

Unlike all other fundamental particles, neutrinos could possibly interact as both matter and anti-matter. If true, this could result in an extremely rare nuclear decay called neutrinoless double beta decay. Scientists are building large experiments consisting of many tons of sensitive material with the hope of finding the first evidence of neutrinoless double beta decay within the next decade.

"Every step we take to eliminate interfering radioactivity gets us closer to finding evidence for dark matter or neutrinoless double beta decay," said Saldanha.



Close up of an ultra-low radiation electronic cable with dozens of conductive circuitry pathways to monitor sensitive physics experiments. This sample cable allows the research team to assess radiopurity after production and cleaning. Credit: Andrea Starr | Pacific Northwest National Laboratory

"These flexible cables have many conductive pathways, which are needed to read out complicated signals," added Arnquist. "When, say, dark matter interacts with the detector or a neutrinoless double beta decay occurs, it's going to create an event that needs to be accurately recorded—read out—to make the discovery. We need to put a complex electronic part that is extremely clean of radioactive elements into the heart of the detector."

"Next generation searches for neutrinoless double beta decay will be among the lowest radioactivity experiments ever constructed," said David Moore, a Yale University physicist and PNNL collaborator.

"These detectors use such pure materials that even a small amount of normal cabling materials would overwhelm the radioactivity from the entire rest of the detector, so developing ultra-low-background cables to read out such detectors is a major challenge. This recent work from PNNL and Q-Flex is key to enabling these detectors and will reduce the cabling background to a small fraction of what was possible with previous technologies."

Planning is already underway to upgrade the highly sensitive DAMIC-M dark matter experiment and the new ultra-pure cables are one of the key improvements scheduled for installation in the detector.

"One component that we can't avoid in our detector are the cables that transmit the signals, which must be of very low radioactivity," said Alvaro E Chavarria, a physicist at the University of Washington and a collaborator on the DAMIC-M project.

"Prior to this recent PNNL development, the best solution was microcoax cables, which carry too few signals and would have required a significant redesign of our detector. This development is super exciting, since it enables the use of the industry-standard flex-circuit technology for low-background applications."

Recent research findings by PNNL scientists and other collaborators indicate that the performance of some quantum computing devices can be affected by the presence of trace radioactive contaminants. While radioactivity is not currently what limits the capabilities of existing quantum computers, it is possible that quantum devices of the future might need low-radioactivity cables to enhance their performance.

"We see the potential for these cables to find applications in a wide range of sensitive radiation detectors and perhaps other applications such as quantum computing," Saldanha said.

More information: Isaac J. Arnquist et al, Ultra-low radioactivity flexible printed cables, *EPJ Techniques and Instrumentation* (2023). DOI: 10.1140/epjti/s40485-023-00104-6

Provided by Pacific Northwest National Laboratory