Urgent measures are needed to shore up NIST's crumbling facilities

Researchers must cope with flooding, power surges, and other difficulties.

THE LENGTH-SCALE INTERFEROMETER at NIST remains one of the most accurate length-measurement instruments in the world after almost 60 years in use. Since 1983 the SI meter has been defined by fixing the speed of light in a vacuum, and it can be realized independently anywhere. The world's national metrology institutes compare the accuracy of their dimensional measurements about once a decade. The NIST lab in Gaithersburg, Maryland, houses the venerable instrument but lacks modern environmental controls.

In 2019 the definition of the kilogram was changed by international consensus from a cylindrical platinum–iridium object held in a Paris vault to a formula based on the Planck constant. (See "An atomic physics perspective on the kilogram's new definition," by Wolfgang Ketterle and Alan Jamison, Physics Today, May 2020, page 32.) In the US, a scale called a Kibble balance is used to precisely calibrate objects, known as artifacts, that represent the kilogram. There the gravitational force exerted on a mass is exactly offset by a force produced when an electrical current is run through a coil of wire immersed in a magnetic field.

To help define the kilogram value with a precision of one part in 10^9—one-fifth the mass of an eyelash, according to NIST scientist Darine El Haddad—NIST's Kibble balance is kept in a Faraday cage located three stories underground on the Gaithersburg, Maryland, campus. Housed inside a vacuum chamber, the instrument is mounted on a floating block to dampen vibration. In 2018 a combination of heavy downpours and a burst pipe overwhelmed the sump pumps and flooded the chamber. It took until March of this year to complete repairs and allow researchers to refloat the floor.

Since the flooding incident, NIST has been unable to investigate a mystery: why the uncertainty of its kilogram measurements nearly doubled from 13 micrograms that researchers had established on solid ground to the 25 micrograms El Haddad and colleagues obtained on the floating block before the flood. "We saw in 2018 that there was a systematic shift in the calibrated mass when the block is floated versus when the block was down," she says.

The next comparison of kilogram values among the world's national standards institutes will be made this fall at the International Bureau of Weights and Measures in Paris. The wider the uncertainty, the less weight is given to each individual nation's contribution to the consensus. El Haddad is hopeful that by that time NIST will be able to halve its uncertainty range back to 13 micrograms.

Flooding isn't the only facilities-related problem El Haddad has to cope with. "Every month we have to deal with something," she says. "If it gets too warm in here, we're going to have to break vacuum and bring fans to ventilate the lab. That happens a few times a year."

Hazardous conditions

Just down the hall from the Kibble balance, a different flood event destroyed a cesium clock in the lab where voltage standards are set. David Newell, group leader of the fundamental electrical measurements group, says the deluge also drenched racks of servers and capacitor banks, creating electrical hazards for personnel. "How do you not step on a land mine when you are going into the lab and powering everything down?" he says.

Newell's group, which includes El Haddad, employs superconducting magnets to establish the quantum Hall resistance standard. Repeated power surges have led to cryostat compressors shutting down and causing 15-tesla magnets to quench and suddenly stop superconducting. "Sometimes the magnets are okay, sometimes they're not," says Newell. On at least two occasions, magnets had to be sent to the manufacturer for repair, a process that can take up to a year.

In the Gaithersburg lab where an almost 60-year-old length-scale interferometer is used to calibrate lengths up to a meter to an uncertainty of only 50 nanometers, inadequate temperature and humidity controls can make such precision impossible, says John Kramar, deputy division chief of the microsystems and nanotechnology division of NIST's Physical Measurement Laboratory. A 1 °C temperature change will alter by 1 micrometer the measured length of a meter-long artifact made of Invar, a nickel–steel alloy often used in metrology because of its low coefficient of thermal expansion. "Every time the temperature control goes out, you can't make a measurement," says J. Alexander Liddle, scientific director of the microsystems and nanotechnology division.

Humid conditions can cause rusting of the artifacts that NIST uses to ensure the long-term stability and consistency of its calibrations, and high humidity also shifts the effective wavelength of the laser light used for interferometry. Portable dehumidifiers have been installed in the lab as a stopgap measure.

Deferred maintenance

Over an 11-month period ending in February 2022, 13 failures occurred in the vertical hot water pipes at the 10-story NIST headquarters building in Gaithersburg, flooding 40% of the offices and affecting 85% of staff. "It got to a point where I had to stop playing whack-a-mole and, out of my emergency reserve, fund a project for $5–6 million to replace all the hot water risers," says Skip Vaughn, chief facilities management officer. Buckets to catch dripping water are not an uncommon sight in lab hallways. A four-inch strainer in the high-pressure steam pipe at NIST's central utilities plant failed catastrophically in 2018. "If someone had been there at the time, they would have been severely injured or killed," Vaughn says.

Other mishaps caused by deficient facilities are detailed in a February report by a committee of the National Academies of Sciences, Engineering, and Medicine (NASEM). At NIST's campus in Boulder, Colorado, leaks in a 20-year-old roof destroyed a transmission electron microscope that will cost $2.5 million to replace. The delivery to national laboratories of radiation sensors important to homeland security was delayed by months due to the lack of humidity controls in a Boulder lab. Flooding caused by a corroded fitting in the hydronic system in a Gaithersburg lab building destroyed instrumentation valued at $5.2 million. That doesn't count the massive amount of research time that was lost, says Vaughn.

Scientists from "lots of other metrology institutes come and visit," says Vaughn. "We hear on a recurring basis that they can't believe the incredible results NIST produces, given how bad the facilities are. How many years of that before they start questioning our results?"

"What's happened at our facilities hasn't happened over a short period of time," Vaughn says. Most of the buildings at NIST's Gaithersburg campus date to the early to mid 1960s, when the institute, then known as the National Bureau of Standards, was relocated from Washington, DC.

The infrastructure problems were expected to be discussed at a House Science, Space, and Technology Committee hearing on NIST's fiscal year 2024 budget request. That hearing was scheduled for 10 May, after Physics Today went to press.

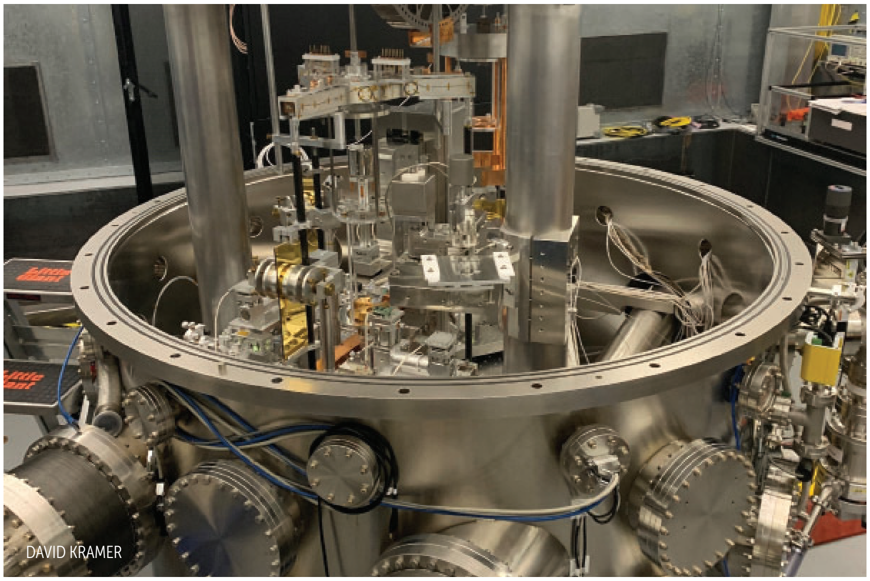
NIST's Boulder campus was completed in the 1950s. But it's far smaller than the Maryland campus, and it doesn't have nearly the number of issues, Vaughn says. Boulder also received funds from the 2009 American Recovery and Reinvestment Act to build a new central utility plant.

Vaughn says the design lifetimes of complex research buildings and central utility plants such as those at NIST are generally considered to be around 30 years. The vast majority of NIST's labs haven't been renovated since they were built.

The original 1962 lab buildings all have single-pane glass, uninsulated exterior walls, and original ductwork. "It's incredibly hard to do things like replacing air handlers and fixing those environmental control issues," Vaughn says.

Maintenance can only fix so much; some issues require full renovations. "The bigger the project, the cheaper the cost," says Vaughn. "Doing a lot of projects piecemeal costs more than doing a whole building, and you still haven't fixed everything."

For the past 20 years, NIST's Visiting Committee on Advanced Technology has warned Congress about "the poor and worsening physical condition and functionality of NIST's facilities, and the impact on its mission," according to the February NASEM report. More than two decades ago, the committee labeled the state of NIST labs alarming and said more funding was critical.


DAVID KRAMER

NIST'S KIBBLE BALANCE in Gaithersburg, Maryland, is used to define the SI kilogram. Housed in a vacuum vessel in a lab deep underground, the instrument can be floated to isolate it from vibration. Damage to the flotation mechanism caused by a 2018 flood was repaired in March 2023, allowing researchers to compare the mass values with and without flotation.

The NASEM report warns that deficient facilities "are preventing NIST from achieving its mission, that valuable researcher time is being wasted due to inadequate facilities, and that in many cases NIST facilities are no longer world class." Even if refurbished to their original condition, the report says, they wouldn't be capable of providing the dramatically increased environmental control requirements for metrology that have emerged since the buildings were constructed.

The NASEM report concludes that bringing NIST facilities to acceptable standards will require $300 million–400 million annually for major construction projects for at least 12 years. It recommends another $120 million–150 million each year over the same period for facility maintenance and major repairs.

In FY 2023, NIST received $130 million for maintenance and major repairs but nothing for major construction. President Biden's FY 2024 budget request pending before Congress would double the total for facilities to $260 million, including $50 million for a major renovation of the central utilities plant, $30 million to replace air handling systems in three Gaithersburg buildings, and $49 million for a building expansion in Boulder.

In addition to NIST's budget line for facilities maintenance and construction, a portion of the maintenance expense comes from an institutional support fund, into which NIST's lab programs pay 31% of their budgets. The fund also pays for administrative functions, such as human resources, finance, procurement, safety, and security. The scale of NIST's facility needs is so large that increasing the institutional support rate enough to make meaningful progress on NIST's deferred maintenance "would significantly reduce NIST's scientific and programmatic output to unacceptable levels," says Jason Boehm, NIST's chief of staff.

Construction costs soar

After Congress provided $60 million in both 2016 and 2017 for the modernization of NIST's radiation physics building, Vaughn commissioned an analysis of what else might be accomplished with that amount for annual major construction funding. The study showed that completing his office's top 11 priority projects alone would take "35 years to infinity," he says. That analysis assumed no inflation for five years, followed by 3% annually. If the inflation rate experienced between 2014 and 2019 was used instead, the 11 projects would never be completely funded, he says. In fact, construction costs generally have leapt nearly 50% just in the past two years.

Vaughn concedes that every federal agency could justifiably plead its case for inadequate facilities funding. "But what it really boils down to is what the impact is on your mission as an agency." While office staff can work from home if need be, that's not an option for scientists who conduct research that requires extreme controls and is mission critical. Around 80% of NIST's structures were built for that purpose, he says.

NIST's deteriorating infrastructure has caused a significant loss of productivity, with employees forced to devote much of their time and resources dealing with and designing workarounds to outages, leaks, and other deficient systems. "Everyone spends their research dollars to protect themselves," Newell laments. Using the salaries of affected staff and the amount of time they spend dealing with facilities issues, Vaughn calculates that $138 million worth of R&D is being lost annually. Based on that inefficiency, the funding needed for a complete renovation would be paid back in less than five years.

The situation also affects employee morale. Some researchers have left; others are threatening to quit. "The private sector has all nice new facilities. We're already hearing stories of people at NIST saying don't bother applying here, our facilities suck," says Vaughn.

Congressional staffers whom Vaughn has shown around the NIST campus are sympathetic, but they haven't been encouraging. They have suggested that he explore alternative funding sources, such as public–private partnerships and leasing modern lab facilities. But NIST's leasing authority requires the agency to pay for the entire lease term up front, making that option unaffordable.

The tiny agency's obscurity doesn't help. NIST's budget for lab programs this fiscal year is just under $953 million. "It's very easy for something to get lost in the huge federal bureaucracy," says Vaughn. Even the Department of Commerce, of which NIST is a part, has lots of other bureaus with different needs. "How do you make sure you're not lost in the noise?"

But the functions NIST performs are vital to industry, health care, consumers, and national defense. "NIST is the federal agency you've never heard of that probably has the most impact on your life," Vaughn says. "Pretty much anything you use goes back to NIST."

David Kramer