IEEE SPECTRUM

FOR THE TECHNOLOGY INSIDER | 05.15

Carbon Queen

IT'S ELEMENTAL: THANKS TO MILDRED DRESSELHAUS, CARBON MAY BE TO THE 21ST CENTURY WHAT SILICON WAS TO THE 20TH P. 46

IEEE

IEEE SPECTRUM

LUCAS LAURSEN

On the Cover **Photograph for *IEEE Spectrum* by Mike McGregor**


Who will industrialize
the Internet of Things?
You and NI will. From smart manufacturing to the smart grid, bridging the digital and physical worlds is one of the most significant engineering opportunities we face today. NI, together with other visionary companies, is ensuring the superior design and performance of the increasingly complex systems that will fuel the Internet of Things and drive industrial adoption. Learn more at ni.com.
NATIONAL INSTRUMENTS
©2015 National Instruments. All rights reserved. LabVIEW, National Instruments, NI, and ni.com are trademarks of National Instruments.
Other product and company names listed are trademarks or trade names of their respective companies. 19044

DEPARTMENTS_05.15

IEEE SPECTRUM

ADDITIONAL RESOURCES

Tech Insider / Webinars

Available at spectrum.ieee.org/webinar

- Simulation of Automotive Wireless RF System Performance—14 May
- Silicon, Software, and Open Source—19 May
- Modeling of Capacitive and Resistive Devices—Available on Demand
- Enabling the Maker of Things in the Internet of Things—Available on Demand
- **MASTER BOND RESOURCE LIBRARY** http://spectrum.ieee.org/static/master-bond-resource-library
- **NEW PRODUCT RELEASE LIBRARY** http://spectrum.ieee.org/static/new-product-release-library
- **WHITE PAPERS** http://spectrum.ieee.org/whitepapers

The Institute

Available 8 May 2015

- **UNDERWATER EXPLORERS** Read about students who are putting their systems engineering and marine robotics skills to the test as they design autonomous underwater vehicles that can drift, drive, or glide through the ocean without real-time control by human operators.

- **NAILING A VIRTUAL INTERVIEW** Because more employers are interviewing prospective candidates over Skype or similar video-chatting programs, candidates need to learn how to impress a hiring manager even if they're not in the same room.

- **LIGHTING THE WAY** Finding ways to inspire the next generation of power engineers is a priority at this year's IEEE Power & Energy Society general meeting, to be held in Denver from 26 to 30 July.

FROM LEFT: JOHN HARPER/CORBIS; NAVEEN PM; EVAN ACKERMAN

IEEE SPECTRUM
(ISSN 0018-9235) is published monthly by The Institute of Electrical and Electronics Engineers, Inc. All rights reserved. © 2015 by The Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, New York, NY 10016-5997, U.S.A. Volume No. 52, issue No. 5, International edition. The editorial content of IEEE Spectrum magazine does not represent official positions of the IEEE or its organizational units. Canadian Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40013087. Return undeliverable Canadian addresses to: Circulation Department, IEEE Spectrum, Box 1051, Fort Erie, ON L2A 6C7. Cable address: ITRIPLEE. Fax: +1 212 419 7570. INTERNET: spectrum@ieee.org. ANNUAL SUBSCRIPTIONS: IEEE Members: $21.40 included in dues. Libraries/institutions: $399. POSTMASTER: Please send address changes to IEEE Spectrum, c/o Coding Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855. Periodicals postage paid at New York, NY, and additional mailing offices. Canadian GST #125634188. Printed at 120 Donnelley Dr., Glasgow, KY 42141-1060, U.S.A. IEEE Spectrum circulation is audited by BPA Worldwide. IEEE Spectrum is a member of the Association of Business Information & Media Companies, the Association of Magazine Media, and Association Media & Publishing. IEEE prohibits discrimination, harassment, and bullying. For more information, visit http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html.

IEEE SPECTRUM | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

BACK STORY_

Keeping Up With Mildred

MIKE McGREGOR doesn't claim to make a specialty of photographing octogenarians. But the fact is, he has done it more than a few times. So when he was assigned to capture 84-year-old Mildred Dresselhaus, he prepared himself for a low-key, sedentary shoot in MIT's building 13, where Dresselhaus often works. Then the IEEE Medal of Honor recipient showed up with a suitcase stuffed with clothing, ready for anything.

"We did three changes of clothes in the conference room," says McGregor. And then he suggested taking the photo shoot outside. To get out, McGregor recalls, meant going up in one elevator, down a set of stairs, up in another elevator, and through a building and a half. "Building 13 was the craziest building I've ever been in," he says. "I knew it was a schlep, but she was totally game. She was there to make things happen." He was inspired by her willingness to make the most out of the hour they had together.

He was also impressed by her commitment to music. "She brought a selection of scarves with her, and one of them had musical instruments on it," he says, prompting him to mention that he plays the cello. "'I'm a violinist,' she told me, so I asked if she still played. 'Sadly, no,' she said. I asked how long it had been since she had played. 'Three weeks,'" was her reply.

Again McGregor marveled. Admitting sheepishly that he picks up his cello a couple of times a month, he says, "You know you're a hard-core musician if you think that if you haven't played in three weeks you're no longer playing." ■

CITING ARTICLES IN IEEE SPECTRUM *IEEE Spectrum* publishes an international and a North American edition, as indicated at the bottom of each page. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, And Now This... is in *IEEE Spectrum*, Vol. 52, no. 5 (INT), May 2015, p. 56, or in *IEEE Spectrum*, Vol. 52, no. 5 (NA), May 2015, p. 64.

05.15

PHOTOGRAPH BY Jared Kuzia

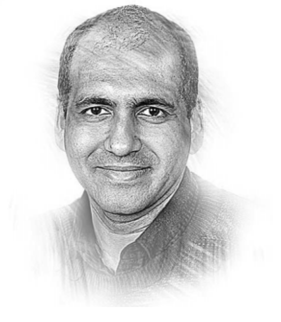
CONTRIBUTORS_

Mark Anderson

An *IEEE Spectrum* contributing editor, Anderson has covered advances in carbon nanotechnology for us and other publications. In this issue he profiles the field's doyenne, Mildred Dresselhaus [p. 46], recipient of this year's IEEE Medal of Honor. The 84-year-old Dresselhaus's seven-day-a-week work ethic is a true inspiration, Anderson says. "I arrived at her MIT office on the morning of a snowstorm to do the interview," he recalls, "and she was ready to go."

Lucas Laursen

Laursen is a freelance journalist based in Madrid. He wrote two articles in this issue: "Google's Year of Forgetting" [p. 12], about Google's expunging of search results in Europe, and "A Power Play in Nicaragua" [p. 34], for which he visited a number of small hydroelectricity plants in the country's northern mountains. "I was ready to hear praise for the power project," Laursen says, "but not ready for a plant operator who burst out in song about the arrival of electricity."



M.V. Ramana

Ramana is a researcher with the Nuclear Futures Laboratory and the Program on Science and Global Security at Princeton University. In this issue, he writes about small nuclear reactors of the past, many of which suffered from poor economics as well as technical problems [p. 40]. "There was a lot of hope attached to those reactors," Ramana says. "Given the claims being made about today's small reactor designs, the history of the earlier ones is worth revisiting."

Geetha Rao

A freelance writer based in Bangalore, India, Rao profiled Ashok Jhunjhunwala, a professor at IIT Madras, for this issue [p. 23]. She says the range of the engineer's work on affordable and robust technologies for rural India is "mind-blowing—a call center to help farmers, a telephone advisory service for moms-to-be, solar DC–powered homes to combat India's hot summers. Jhunjhunwala has left no stone unturned to help the poor lift themselves out of poverty."

Harold Reitsema

Reitsema is the mission director of Sentinel, the B612 Foundation's privately funded space telescope, which is designed to find asteroids that might threaten Earth [p. 28]. For many years, he led spacecraft design teams at Ball Aerospace. When he retired from Ball in 2008, he says, "I thought I had worked my last space science mission." But a chance to build Sentinel, which could discover hundreds of thousands of objects, was an opportunity too good to pass up.

05.15

IEEE

IEEE MEDIA
SENIOR DIRECTOR; PUBLISHER, IEEE SPECTRUM
James A. Vick, j.vick@ieee.org
ASSOCIATE PUBLISHER, SALES & ADVERTISING DIRECTOR
Marion Delaney, m.delaney@ieee.org
RECRUITMENT AND LIST SALES ADVERTISING DIRECTOR
Michael Buryk, m.buryk@ieee.org
BUSINESS MANAGER Robert T. Ross, r.ross@ieee.org
IEEE MEDIA/SPECTRUM GROUP MARKETING MANAGER
Blanche McGurr, b.mcgurr@ieee.org
IEEE MEDIA GROUP DIGITAL MARKETING SENIOR MANAGER
Ruchika Anand, r.t.anand@ieee.org
LIST SALES & RECRUITMENT SERVICES PRODUCT/ MARKETING MANAGER Ilia Rodriguez, i.rodriguez@ieee.org
REPRINT SALES +1 212 221 9595, EXT. 319
MARKETING & PROMOTION SPECIALIST Faith H. Jeanty, f.jeanty@ieee.org
SENIOR MARKETING ADMINISTRATOR Simone Darby, simone.darby@ieee.org
MARKETING ASSISTANT Quinona Brown, q.brown@ieee.org
RECRUITMENT SALES ADVISOR Liza Reich +1 212 419 7578
ADVERTISING SALES +1 212 705 8939

ADVERTISING PRODUCTION MANAGER Felicia Spagnoli
SENIOR ADVERTISING PRODUCTION COORDINATOR
Nicole Evans Gyimah
ADVERTISING PRODUCTION +1 732 562 6334

IEEE STAFF EXECUTIVE, PUBLICATIONS Anthony Durniak

IEEE BOARD OF DIRECTORS
PRESIDENT & CEO Howard E. Michel, president@ieee.org
+1 732 562 3928 FAX: +1 732 465 6444

PRESIDENT-ELECT Barry L. Shoop
TREASURER Jerry L. Hudgins **SECRETARY** Parviz Famouri
PAST PRESIDENT J. Roberto B. de Marca

VICE PRESIDENTS
Saurabh Sinha, Educational Activities; Sheila Hemami, Publication Services & Products; Wai-Choong "Lawrence" Wong, Member & Geographic Activities; Bruce P. Kraemer, President, Standards Association; Vincenzo Piuri, Technical Activities; James A. Jefferies, President, IEEE-USA

DIVISION DIRECTORS
Ellen J. Yoffa (I); Hirofumi Akagi (II); Harvey A. Freeman (III); William W. Moses (IV); Susan K. Land (V); Rob Reilly (VI); Wanda K. Reder (VII); John W. Walz (VIII); Marina Ruggieri (IX); Kazuhiro Kosuge (X)

REGION DIRECTORS
Vincent P. Socci (1); Timothy P. Kurzweg (2); Mary Ellen Randall (3); Robert C. Parro (4); J. Derald Morgan (5); Thomas Coughlin (6); Amir G. Aghdam (7); Costas M. Stasopoulos (8); Norberto M. Lerendegui (9); Ramakrishna Kappagantu (10)

DIRECTORS EMERITUS Eric Herz, Theodore W. Hissey

IEEE STAFF
EXECUTIVE DIRECTOR & COO James Prendergast
+1 732 502 5400, james.prendergast@ieee.org
PUBLICATIONS Anthony Durniak
+1 732 562 3998, a.durniak@ieee.org
CORPORATE ACTIVITIES Elena Gerstmann
+1 732 981 3452, e.gerstmann@ieee.org
EDUCATIONAL ACTIVITIES Douglas Gorham
+1 732 562 5483, d.g.gorham@ieee.org
ACTING CHIEF INFORMATION OFFICER Donna Hourican
+1 732 562 6330, d.hourican@ieee.org
MEMBER & GEOGRAPHIC ACTIVITIES Cecelia Jankowski
+1 732 562 5504, c.jankowski@ieee.org
HUMAN RESOURCES Shannon Johnston, SPHR
+1 732 562 6343, s.johnston@ieee.org
STANDARDS ACTIVITIES Konstantinos Karachalios
+1 732 562 3820, constantin@ieee.org
GENERAL COUNSEL & CHIEF COMPLIANCE OFFICER
Eileen M. Lach, +1 212 705 8990, e.m.lach@ieee.org
CHIEF MARKETING OFFICER Patrick D. Mahoney
+1 732 562 5596, p.mahoney@ieee.org
CHIEF FINANCIAL OFFICER Thomas R. Siegert
+1 732 562 6843, t.siegert@ieee.org
TECHNICAL ACTIVITIES Mary Ward-Callan
+1 732 562 3850, m.ward-callan@ieee.org
MANAGING DIRECTOR, IEEE-USA Chris Brantley
+1 202 530 8349, c.brantley@ieee.org
IEEE PUBLICATION SERVICES & PRODUCTS BOARD
Sheila Hemami, *Chair*; John Baillieul, Babak D. Beheshti, Herbert S. Bennett, Jennifer T. Bernhard, Eddie Custovic, Jean-Luc Gaudiot, Ron B. Goldfarb, Glenn Gulak, Lawrence Hall, Christofer Hierold, James M. Irvine, Hulya Kirkici, Carmen S. Menoni, Paolo Montuschi, Thrasos Pappas, Michael Pecht, Michael Polis, Sorel Reisman, Tariq Samad, Fred Schindler, Gianluca Setti, Gaurav Sharma, Curtis A. Siller, David Tian, Ravi Todi, H. Joel Trussell, Leung Tsang, Stephanie M. White, Steve Yurkovich

IEEE OPERATIONS CENTER
445 Hoes Lane, Box 1331, Piscataway, NJ 08854-1331 U.S.A.
Tel: +1 732 981 0060 Fax: +1 732 981 1721

PHOTO-ILLUSTRATIONS BY **Gluekit**


Enhancing entertainment
in everyday life
life.augmented
Experience by STMicroelectronics. Simulation by ANSYS.
ANSYS®

How to Stop Killer Asteroids

Only vigilance and ingenuity stand between Earth and oblivion

IN A WORLD OF ENDLESS THREATS, the most worrisome are those that can kill you. And a large asteroid hurtling toward a catastrophic collision with Earth tops the list.

Killer asteroids are part of a category of slow-emerging existential threats, such as global climate change, that, because they reveal themselves gradually, invite the attention of engineers, who are well suited to craft solutions from materials and technologies at hand.

Slow-emerging threats aren't easily thwarted, because there are honest disagreements about optimal responses. That's the situation with rogue asteroids and comets. A staple of science fiction, these near-Earth objects (NEOs) are real. In 2013, an 18-meter-wide asteroid exploded–without warning–above a remote part of Russia. In January, a larger asteroid passed within 1.2 million kilometers (745,000 miles) of Earth–close enough to allow the Jet Propulsion Lab, which leads NASA's NEO office, to learn a lot.

The stakes are high. An asteroid collision most likely extinguished the dinosaurs about 65 million years ago. David Morrison, a senior scientist at the Solar System Exploration Research Virtual Institute, at the NASA Ames Research Center, in Mountain View, Calif., thinks it's "reasonable to expect" that, if faced with a killer asteroid, "the spacefaring nations would find a way to deflect it and save the planet."

How? Space engineers believe they can fashion effective responses from existing technologies. The two most popular strategies involve destroying asteroids with explosives or nudging them into a new trajectory, to allow Earth to escape impact.

Experts from the United States' National Academy of Sciences, the Department of Defense, and NASA and specialized outfits such as the Asteroid Deflection Research Center, at Iowa State University, all agree that early warnings–years or even decades in advance of impact–are essential for effective protection.

Step one is to create an inventory of the many dangerous asteroids loose in deep space. NASA is behind in its task to identify and track them, partly because costs have exceeded the paltry sum (about US $40 million annually) budgeted by the U.S. government.

Fortunately, there are people in the private sector willing to pitch in. "You can't stop what you can't see," says Edward Lu, former astronaut, physicist, and cofounder of the B612 Foundation, which is devoted to tracking asteroids. Lu argues that the best way to accelerate tracking threats is to send a telescope–called Sentinel (see "A Sentinel in Space," in this issue)–into space that would identify previously unknown NEOs larger than 140 meters. He says his private foundation can assemble such data more quickly, and less expensively, than government can.

Once identified, killer asteroids will need to be diverted or destroyed. Hydrogen bombs, possessed in plentiful numbers by the United States and Russia, can smash NEOs into bits. If resorting to nukes in space proves impractical, "gravity tractors" and kinetic impactors (high-speed spacecraft that enter the path of an NEO in order to alter its trajectory) can deflect asteroids so that they miss Earth. We need only alter an asteroid's arrival time by 6 minutes to avoid a collision. Finally, advance warning would allow the target area to be evacuated; endangered people could at least move to safer ground.

The hitch, of course, is money. Responding vigorously to threatening asteroids ultimately could cost a fortune. With enough money, engineers would gain enormous new responsibilities and the chance to save untold lives or even the human species.

But what if avoidance systems fail altogether, or carry out a maneuver that spares damage to one country but results in harming another? Carl Sagan called this the "deflection dilemma." Even worse, what if bad guys hijack the technology and send an asteroid *toward* Earth, instead of nudging it away from us?

Then space engineers will be glad for another kind of preemptive action–political sanction and cover for their work–because their protection system might end up increasing risks to Earth's inhabitants. –G. PASCAL ZACHARY

G. Pascal Zachary is a professor of practice at Arizona State University and author of *Endless Frontier: Vannevar Bush, Engineer of the American Century* (MIT Press, 1999).

ANDRZEJ WOJCICKI/GETTY IMAGES

NEWS

$10,000 TO $25,000: COST OF A PERMIT TO ENTER THE EVEREST AREA VIA NEPAL

JOHN HARPER/CORBIS

WASTE-TO-ENERGY AT THE ROOF OF THE WORLD

Volunteer engineers hope to power a Nepalese village with human waste from Mount Everest

For many amateur climbers, summiting Mount Everest represents one of life's greatest challenges and achievements. But for the Nepalese and foreign professionals who work there, the larger challenge is figuring out how to keep the place clean.

Efforts to beautify what's frequently called "the world's highest garbage dump" have been under way for more than a decade, with mixed results. Spent oxygen canisters, empty beer bottles, and tattered tents recovered from the mountain can often be reused or recycled, but human waste is a messier problem. Each year, porters haul down some 12,000 kilograms of poop from base camps at Everest and the nearby Pumori, Lhotse, and Nuptse mountains. Getting the material off the mountain is one thing; however, properly disposing of it is another.

The waste is currently delivered on foot to Gorak Shep, the nearest village to Everest, sitting at 5,164 meters »

IT'S THE PITS: Human waste from Mount Everest climbers is brought down from base camps and dumped in pits like this one in the Nepalese village of Gorak Shep.

GARRY PORTER

(3.2 miles) above sea level. The porters drop the poop into unlined pits, leaving the raw excrement to slowly dehydrate and break down in the open air, which, at such high altitudes, can take years. In the meantime, the waste mars the landscape and potentially contaminates the town's water supply. Both the Nepalese government and the climbing community recognize that this method of disposal is a hazard to environmental as well as human health, but given the remoteness of the site and the magnitude of the problem, solutions have remained elusive.

A team of volunteer engineers might be just what Nepal needs, however. Members of the Mt. Everest Biogas Project, as it's called, say they have a potential fix: a specially designed biogas reactor that can transform Gorak Shep's fetid trenches into energy. Not only would it eliminate the need for the poop pits, it would also provide the village with a bountiful, free source of methane, which could be used as fuel for cooking and heating homes.

Garry Porter, a retired Boeing engineer based in Seattle, and his buddy Dan Mazur, a professional mountaineer, hatched the idea back in 2010. Mazur lives in Nepal and Tibet for half the year and regularly leads climbs up Everest, so he was well aware of the poop predicament. Porter became intimate with it in 2003, when he attempted to scale Everest. "The Nepalese consider this their sacred mountain, and we're defecating on it," he says.

Thousands of biogas reactors already operate at lower altitudes throughout Nepal, but temperatures at Gorak Shep prevent the needed waste-devouring bacteria from thriving. Recognizing this, Mazur asked Porter if he thought it would be possible to create a biogas digester that could function in the cold. Porter did, and the project was born.

After recruiting about a dozen other engineer volunteers, Porter and his team began brainstorming a solution, keeping in mind that they could use only materials that are readily available in Kathmandu, Nepal's capital. Rather than build something from scratch, they decided to figure out a way to insulate the preexisting design, a 6-cubic-meter model that, if kept warm enough, could process all the climber waste currently dumped in Gorak Shep.

Having worked through several iterations, the team settled on a relatively straightforward solution. The digester itself will be swaddled in R-50 (heavy) insulation, and a 200-watt resistor coil—similar to those found in water heaters—will deliver heat. The contents of the digester, which is buried in the ground, must remain at 30 °C or higher. Given the ground and air temperature, the engineers calculated that doing this would require an average of 100 W, a figure that they doubled to be safe.

There was another problem, of course: Gorak Shep has no access to electricity.

(A few telecom companies serving climbers have photovoltaic installations for their own needs.) Consulting meteorological databases, the team determined that–given the maximum summer and minimum winter temperatures, plus days of cloud cover and snow–an array of 16 photovoltaic solar panels would be able to produce the needed 200 W. A bank of Exide LMXT 2-volt batteries, which are designed for use with solar arrays, is also needed to keep the digester running at night and on overcast days. The whole thing will be topped off with a shelter, which the volunteer group Architects Without Borders has offered to design.

Porter and the other engineers recently submitted a 27-page "Basis of Design" for peer review to engineers not involved in the project. In February, it was returned with the reviewers' stamp of approval. The Nepalese government, residents of Gorak Shep, and the climbing community have all responded enthusiastically as well. Now the biogas team is working on estimating the price–certainly in the thousands of dollars, the engineers say–of building and installing the digester, which will be funded entirely by donations. Construction is tentatively slated for 2016. "Our intent is to build one, get it up and running, train local operators–and then the horses leave town," Porter says. "But we will have people in Seattle and Kathmandu who can provide technical support for the life of the system."

If successful, the project could be replicated in other locations that are too cold for traditional digesters. "In places like Alaska they have an expensive solution–they helicopter the waste out–but that's not available in a lot of developing countries where there aren't even treatment plants they can helicopter it to," Porter says. "If we can bring this technical solution to bear on a universal problem, then hey, that's great."
–RACHEL NUWER

WHILL

JAPANESE STARTUP REINVENTS THE WHEELCHAIR

Whill says its personal mobility device will appeal to tech-obsessed consumers. But will it sell?

WHILL TO RULE: A wheelchair designed with techies in mind can make tight maneuvers.

A Japanese startup founded by former automotive engineers wants to turn the wheelchair into an accessory for the tech savvy. Their company, Whill, is building a "personal mobility device" that it says is easier and more comfortable to use than conventional power wheelchairs. Whill's chair, called the Model A, features an advanced drive system that lets it take tight turns and ride on rough terrain. It also has a minimalist, sleek design that makes it look like it came from a science fiction movie.

This month, Whill plans to start selling the Model A in Japan and the United States (initially only in California, for US $9,500). The company is betting on what might seem like a strange thing: that the global market for wheelchairs will grow at a fast pace, and that users will demand more capable–and better-looking–offerings. Some demographic trends support this: The number of people 65 and older is expected to triple by 2050 to reach 1.5 billion, or about one in every six people on the »

NEWS

planet. And the older population is likely to help drive up the number of people with disabilities, which is at 15 percent today, according to the World Health Organization.

CEO and cofounder Satoshi Sugie, who left Nissan to start Whill, tells *IEEE Spectrum* that he got the idea for the startup when he met a disabled man who would no longer go to the grocery store in his wheelchair because of the way people looked at him. Although wheelchair users are often physically fit, the traditional chair can create the impression that its occupant is weak and helpless, he says.

With that in mind, Sugie and his colleagues set out to completely reenvision–and reengineer–the power wheelchair. One of the key innovations of the Model A is its two front wheels, whose rims are each wrapped with two dozen small rubber tires that turn independently. Designed by a retired Toyota engineer who is on staff at the startup, these omnidirectional wheels allow the chair to move in any direction more easily and with a tight turning radius.

The Model A also has a four-wheel-drive system and a motor controller that let users drive over almost any kind of surface. A lead-acid battery gives the chair a range of nearly 20 kilometers on one charge. To steer it, you can use either a joystick on the armrest or an app on your iPhone.

It's no coincidence that Whill was founded in Japan (just outside of Tokyo), where more than a quarter of the population is 65 or older, the highest proportion of any country. But Whill also has an office in Silicon Valley, which has a generation of gadget-loving people who are growing old. The initial market will be for the disabled, but the company, which has raised $11 million from Japanese and U.S. investors, hopes to ultimately broaden sales to anyone who has difficulty walking or standing.

The intent is to "create an image that, rather than a chair for the disabled, this is stylish transportation," says Sugie.

Of course, the big question for Whill is, will it sell?

History is not on the company's side. Both Toyota and Honda have demonstrated futuristic personal mobility prototypes but haven't yet commercialized them. In 1999, famed inventor Dean Kamen unveiled a robotic wheelchair called iBot. At $25,000, it was expensive, but it could climb curbs, allow users to raise the seat so that they would be at eye level with a standing person, and even go up and down stairs. The U.S. Food and Drug Administration approved it as a medical device, and insurers covered part of the cost. Still, its high cost was one of the reasons it was discontinued in 2009.

IEEE Fellow Rory A. Cooper, a professor in the Department of Rehabilitation Science and Technology at the University of Pittsburgh, says Whill's chair looks like a good product, but he doesn't think its technology is particularly innovative. He should know: Cooper, who has used a wheelchair for 30 years, is a world-renowned mobility expert and director of the Center of Excellence in Wheelchairs and Associated Rehabilitation Engineering, part of the U.S. Department of Veterans Affairs.

"Omnidirectional wheels have been around for 30 years, and four-wheel drive has been around for at least 15 years," he says.

He adds that if insurers can at least partially cover its cost, Whill may appeal to many adults today who have higher expectations for remaining active longer and are more accepting of technology than previous generations. After all, "today's 65-year-olds were early adopters of things like personal computers, PDAs, and mobile phones," he says.

–TAM HARBERT

WHILL

GOOGLE'S YEAR OF FORGETTING

Following a European court ruling, Google expunged more than half a million links

Google has gotten better at forgetting. A year ago, a European court ruled that Google search results in the European Union were subject to European data-protection rules. That meant that while private individuals might not be able to force a newspaper to retract an irrelevant or outdated story about them, they could ask Google to remove links to the story. Despite a slow start, the search giant has now caught up with the requests. In the meantime, Americans, Japanese, Koreans, and others around the world are proposing the adoption of similar privacy-protection policies.

Google–which can claim 93 percent of the European search market, according to StatCounter–began removing certain links from search results on its EU pages in June. The removals were in response to a 13 May 2014 ruling by the Court of Justice of the European Union that enables residents to request the removal of search engine results that point to prickly parts of their past. If it did anything, the ruling proved that personal privacy is popular: Google got over 41,000 requests in the first four days it accepted them. Requests later leveled off at around 1,000 per day.

The off-line analogy might be a guest asking a party host not to bring up an old, reputation-tarnishing story. It is still up to the host to decide whether to comply, and other guests may still whisper–or shout. But thanks to the CJEU ruling, search engine results in the EU are now subject to the same data-protection rules as other company-held personal data. It's as if party attendees could now ask the party host to keep mum, with the threat of appealing to a national agency.

Yet the ruling left open many questions about how to comply. Soon after removals began in June, for example, Google restored certain links when publishers argued that the stories in ques-

FORGET ABOUT IT: Google executives, government ministers, and other grandees try to figure out how the "right to be forgotten" should work.

tion were in the public interest. Individuals unhappy with the decisions of search engine providers–Google has rejected a little over 40 percent of requests so far–can still appeal to their national data-protection agencies.

The logic that the ruling follows is one of the things that makes it remarkable. The ruling skips altogether the mechanics of how search results are created from public third-party records. Instead, the court reasoned that the potential richness and accessibility of search results make them more of a threat to a person's privacy than the individual records themselves. Since Google (for now) is the main controller of that data in Europe, it has the same responsibility as other companies that control personal data in Europe, the court argued.

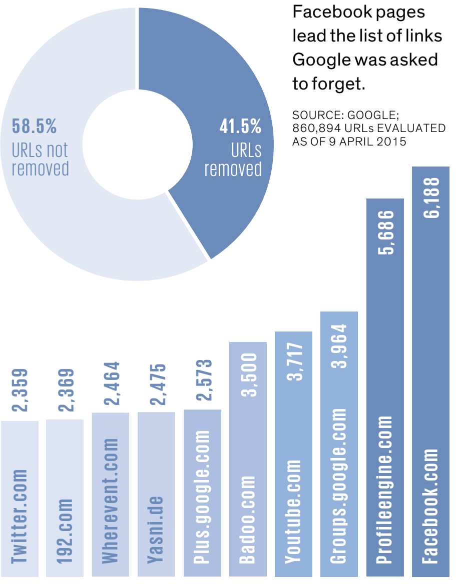
Yet some groups have questioned the court-imposed, company-implemented method of protecting the public's right to know: "We argue that it should be handled by a court, not a company," says Pam Cowburn, communications director for the Open Rights Group in London.

Wikipedia founder Jimmy Wales, who sat on an advisory council that Google convened about the issue, concurred in his comment on the council's report and added that "the recommendations to Google contained in this report are deeply flawed due to the law itself being deeply flawed." Google's advisory council conducted hearings in seven European cities in late 2014.

Another member of the advisory council, German federal justice minister Sabine Leutheusser-Schnarrenberger, argued that Google's current interpretation of the ruling does not go far enough. "Since EU residents are able to research globally, the EU is authorized to decide that the search engine has to delete all the links globally," she wrote in her comment on the report.

FORGOTTEN BUT NOT GONE: Facebook pages lead the list of links Google was asked to forget.

SOURCE: GOOGLE; 860,894 URLs EVALUATED AS OF 9 APRIL 2015



And globally is how the idea is spreading. A Japanese court ruled in October 2014 that Google must take down some personal information. Yahoo has already announced that it will extend its existing privacy takedown request system to its Japanese sites. Hong Kong's privacy commissioner for personal data, Allan Chiang Yam Wang, said late last year at the Asia Pacific Privacy Authorities Forum in Vancouver, B.C., Canada, that national privacy officials from many countries were considering how they might enact their own versions.

The question in all cases is whether unfettered search engine results are the same as free expression. There's good reason to think not. Governments limit the intrusiveness of credit reports, for example, treating them as business tools instead of a form of free expression. Evgeny Morozov asked in *The New Republic*, "If we don't find it troubling to impose barriers on the data hunger of banks and insurance companies [for composing credit reports], why should we make an exception for search engines?"

At a March debate presented by Intelligence², University of Chicago law professor Eric Posner argued that such information is now easier to find than in the past, when public records such as trial proceedings might have ended up in a courthouse basement–available, but not easily accessible to all. "What the 'right to be forgotten' does is it raises the cost for strangers to find out information about you. It doesn't make it impossible," he said. By making it inconvenient, but not impossible, for someone to find contested information, the right to be forgotten is effectively undoing some of the gains of the information age: re-creating the effect of paper's archival limitations with today's technology. –LUCAS LAURSEN

GONZALO ARROYO MORENO/GETTY IMAGES

SOGGY COMPUTING

Liquid-gated vanadium dioxide switches might match the brain's efficiency

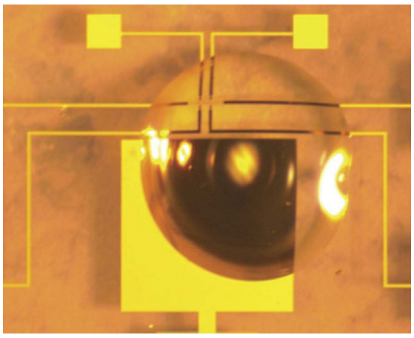
Stuart Parkin has a vision for the future of computing. Gone are the motherboards, the individual memory chips, the billions of speedy transistors. In their place is something strange: a brain-inspired box full of liquid-driven circuitry that swells and shrinks, with a clock speed that would make even a 40-year-old microprocessor look blazingly fast.

"The mantra [has been] 'Go smaller, go faster,' and I think the mantra is wrong," says Parkin, a longtime IBM researcher who is now director of the Max Planck Institute of Microstructure Physics, in Halle, Germany. "It turns out it costs a lot of energy to go faster," Parkin adds. By slowing down to more brainlike speeds, on the order of tens of hertz, he says, future computers–with likely very different architectures–might be able to accomplish a lot with very little energy.

Over the years, engineers have studied a range of candidates that might be used to make brainlike circuits. Parkin's focus is on vanadium dioxide, one of a class of materials called metal oxides that are capable of switching from an insulating state to a conductive, metallic one. Such materials could potentially be used to make very-low-power switches that retain their states even when no power is supplied to them. Since vanadium dioxide performs the transition from insulator to metal at fairly low energy–close to room temperature–it has long been considered an attractive candidate for an electrically driven switch.

But vanadium dioxide's switching performance isn't so simple. To maximize an applied voltage's ability to make the material switch states, Parkin and other researchers have redesigned the transistor. The design includes a thin film of vanadium dioxide, topped by a gate that consists of a droplet of ionic liquid, a salt with ions that are bound loosely enough to form a liquid instead of a solid.

When a voltage is applied to this liquid gate, positive and negative charges move to opposite sides of the droplet. Those that accumulate near the vanadium dioxide film, researchers thought, would enhance the electric field that is very close to the film, so it could be used to switch the state of the film from insulating to metallic.



WETWARE: A gate electrode, coupled with a droplet of ionic liquid, controls a switch made from vanadium dioxide. The channel of the device is 200 micrometers long.

This has worked, and some early results indicated the liquid gate could create a change in electrical state much like what takes place in today's silicon-based transistors. But recent research suggests that a different mechanism can cause the change. In 2013, Parkin and his colleagues reported that liquid gates might actually be pulling oxygen atoms out of the vanadium dioxide into the liquid, a form of electromigration.

Now, it seems that for some orientations of the film's crystalline structure, this effect can be quite physically dramatic, causing the material to swell in volume by as much as 3 percent. By contrast, when vanadium dioxide is heated so that it becomes metallic, it actually contracts slightly, by about 0.3 percent. Parkin and his colleagues reported the new observation in the *Proceedings of the National Academy of Sciences* in January.

The change is further evidence that liquid gates induce structural changes in the material, Parkin says. But he still hopes to put this unusual switch to use. At Max Planck, he's aiming to put his new research group to work on exploring what kinds of circuits can be built with multiple ionic-liquid vanadium dioxide devices, possibly constructed using 3-D printing.

The swelling is dramatic but not entirely a surprise, says Shriram Ramanathan, who studies metal oxides at Harvard University. "Many of these ionic crystals are what are called oxygen breathers," he says. They can hold a lot of oxygen in them and release it, sort of [like] a solid-state sponge."

Ramanathan's group is exploring a different direction for thin-film metal oxides. Last year, he and his colleagues used a solid instead of a liquid gate to apply a voltage to a compound of samarium, nickel, and oxygen. They used this gate to pump protons in and out of the material, demonstrating a 100 million-fold change in resistance. His team is also exploring how to use the material to make brainlike circuitry with liquid gates.

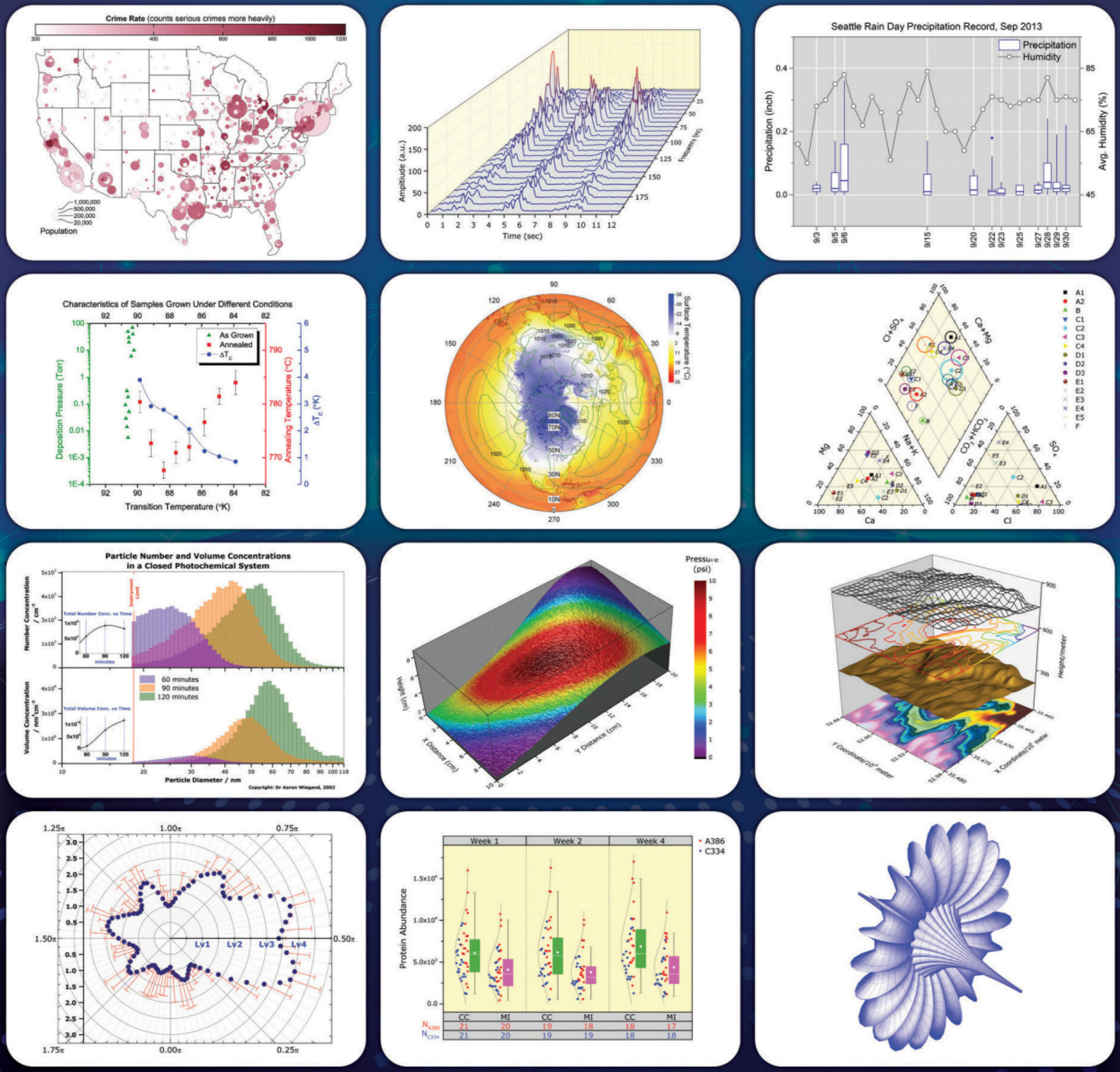
Unlike vanadium dioxide, nickelate-based materials switch from insulator to metal above 100 °C, and so they might lend themselves to more immediate applications alongside conventional electronics, which can run hot enough to trigger the vanadium dioxide transition on their own, Ramanathan says. But he adds that there will be multiple applications for this class of materials in electronics, and no one approach is likely to be universal. –RACHEL COURTLAND

MAX PLANCK INSTITUTE OF MICROSTRUCTURE PHYSICS

NEW VERSION

ORIGIN® 2015

Graphing & Analysis



Over 100 new features & improvements in Origin 2015!

FOR A FREE 60-DAY EVALUATION, GO TO ORIGINLAB.COM/DEMO AND ENTER CODE: 8547

Over 500,000 registered users worldwide in:

- 6,000+ Companies including 120+ Fortune Global 500
- 6,500+ Colleges & Universities
- 3,000+ Government Agencies & Research Labs

OriginLab®

20+ years serving the scientific & engineering community

PHOTOGRAPH BY Yves Herman/Reuters/Landov

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

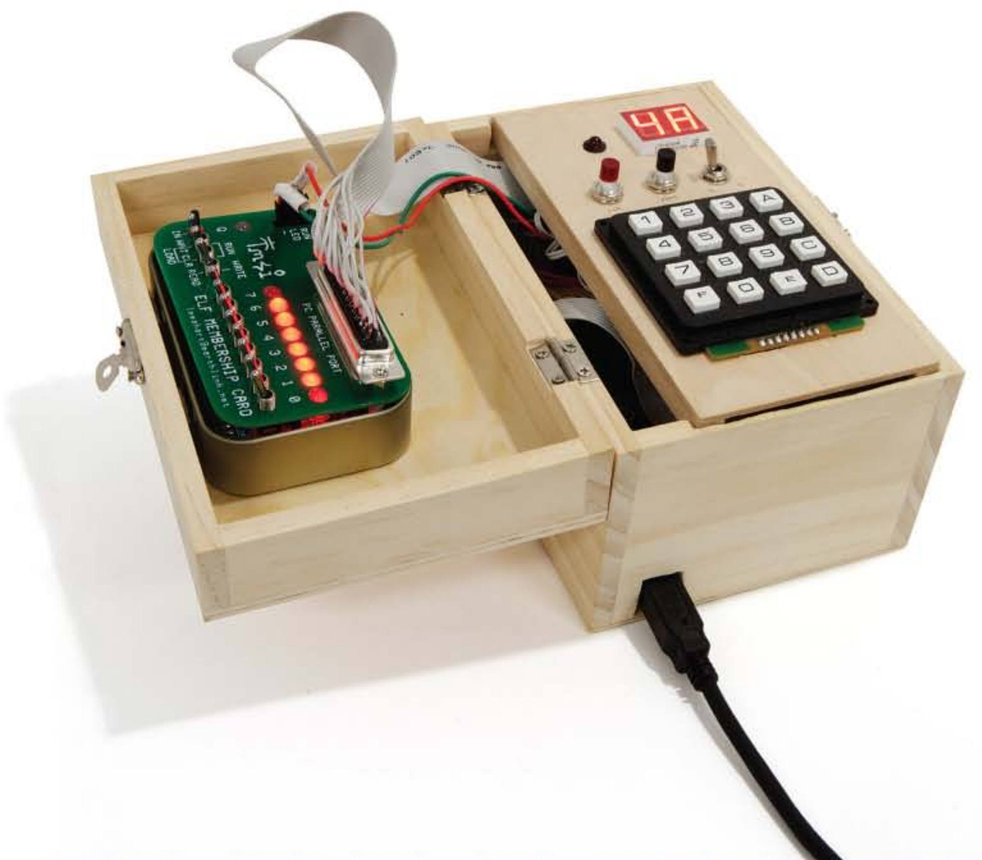
INSECT PSYCHOLOGY

ROACHES. The image of this one brings to mind an undifferentiated horde of invaders just like him, all with one thing in mind: annexing your space as their feeding and breeding grounds. But researchers at the Free University of Brussels say they have uncovered evidence that roaches have distinct personalities. (It still seems odd to imagine members of a group of roaches described as "the shy one," "the funny one," and "the go-getter.") To discover these differences, the scientists didn't sit the insects on the proverbial couch, says Isaac Planas-Sitjà, the behavioral ecologist who led the study. He and his colleagues glued tiny RFID chips to hundreds of roaches in order to track each one's behavior after it was placed in a new environment.


"Delightful" - Wired
"Robot heaven" - Mashable
Welcome to the world of
ROBOTS
For iPad
More Robots
ieee spectrum ROBOTS
FEATURED ROBOTS
Robonaut 2
Ekso
iCub
Nao
Geminoid DK
Hand Arm System
PR2
MakerBot
Rollin' Justin
BigDog
Baxter
VGo
Keepon
Asimo
Robots
Ratings
News
Play
Learn
About
Get the app now:
robotsapp.net
Download on the
App Store

RESOURCES

5,000: THE NUMBER OF TRANSISTORS IN A CDP1802 PROCESSOR. SMARTPHONE CPUs TYPICALLY HAVE 1 BILLION TO 2 BILLION TRANSISTORS



RESOURCES_HANDS ON

RETURN OF THE ELF

MAKING A 1976 MICRO-COMPUTER MORE USER FRIENDLY

A couple of months ago, I built the Membership Card, a remake of the 1976 Cosmac Elf microcomputer. Despite the vintage of its RCA CDP1802 processor, the Membership Card still has value as a low-power microcontroller, with an elegant instruction set that leverages a clever hardware design. However, only a masochist would attempt to do any serious programming with the Membership Kit alone: Entering a program via the Membership Card's front panel requires using toggle switches to enter bytes into memory, one bit at a time. ● What's needed is a way to upload programs written with the aid of those sops to human frailty, keyboards and screens. There are actually a number of ways to get such programs into the Membership Card, which is composed of one circuit board that is a complete microcomputer, with processor and memory, and another board stacked above it, which is the front panel that provides general input/output facilities. One way is to burn a program directly into an EEPROM chip and mount it on the microcomputer board. A more flexible option is to burn a small loader program onto an EEPROM and then upload programs as desired via a serial connection. ● To be sure, this is probably the best approach if you intend to use the Membership Card with shields created for the Arduino, for example. Bill Rowe has created a replacement board for the front panel—the Olduino—that allows exactly this, supplying an interface for modern shields that provide things like Ethernet connectivity. ● But these options require hardware modifications. Instead, I wanted to use the parallel port interface built into the existing front panel. With this I could build a programmer that would—electronically speaking—act like a human being ▸

PHOTOGRAPH BY Randi Klett

flipping switches and entering bytes, albeit a fast and error-free one.

The original Cosmac Elf used a bunch of chips and hard-wired logic to handle input from a keypad and display output via two hexadecimal digits and a "Q LED." (The Q LED was connected to a dedicated Q pin on the 1802 that could be turned on or off with a single machine code instruction.) I figured that a standard US $25 Arduino Uno would have enough processing oomph to replace most of those chips with software.

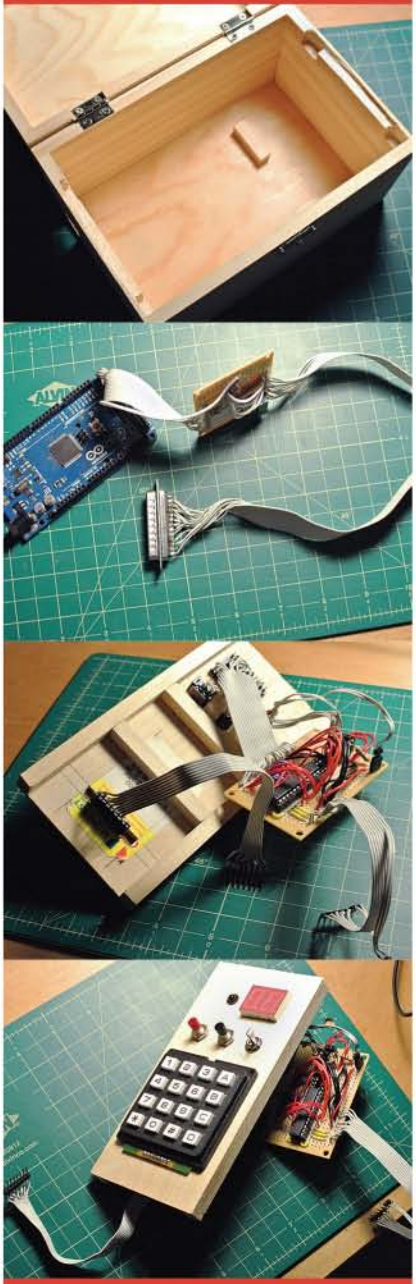
To drive the display, though, I used a MAX6971 chip. This let me send serial signals via three of my Arduino's pins to form numbers and the letters *A* to *F* on two seven-segment LEDs. Driving them directly would have required 14 of the Uno's 20 input/output pins.

But then I realized that even with the MAX6971's help, my input/output real estate woes weren't over: I would need eight pins to connect directly with the keypad, another eight pins to send the data bits for each byte of my program, and nine more pins to handle various control signals and the output from the 1802.

I initially thought that a set of shift registers—which convert parallel signals into serial ones and vice versa—would allow me to connect everything up with pins to spare, but with all the additional wiring, I would end up with something that was just as complex as the original Cosmac Elf circuitry.

So I decided to throw some money at the problem and step up to the Arduino Uno's big sister, the Arduino Mega. The Mega costs about twice as much as the Uno, but it has over three times as many input/output pins. All my real estate woes vanished. I still used the MAX6971 to handle the seven-segment LED displays (to avoid having the Mega handling the relatively large amounts of current that so many LEDs could require), but everything else was wired up directly, including the Q LED. I used resistors on the various input and output lines to act as pull-up resistors

INTERFACE IN A BOX



I CUT NOTCHES and holes in a box to create an enclosure [top] for the Arduino Mega and two interface boards. The first board connects the Mega to a 25-pin connector [second from top]. The second board [second from bottom] controls the LED display [bottom] .

STEPHEN CASS (4)

and current limiters, respectively. Interfacing with the Membership Card required wiring up 17 pins of a 25-pin parallel connector.

The basic operation of the Membership Card is controlled by three dedicated toggle switches on the front panel that reset the processor, switch it between run and programming modes, and so on. Using guidelines available on the Retrotechnology website, I was able to write software that manipulated various control lines to perform the functions of these switches.

I fitted the programmer into a wooden box that I picked up at an art supply store for a few dollars. My programmer operates in two modes—Load and Run. In Load mode, keying bytes in via the keypad and pressing an input button stores them in the Membership Card's memory. Pressing another button sends an entire prewritten program to the Membership Card. Currently, this program is coded into my Arduino software, but there's no reason the software couldn't be modified to accept programs from a host computer (perhaps one running the excellent TinyElf emulator, so as to fully debug programs before loading them into real hardware). In Run mode, the programmer starts the Membership Card executing whatever program is in memory and accepts output from it. (A confession: I haven't got the output part working perfectly yet, but I can at least extract and display the Q signal from programs running on the Membership Card.)

A supercapacitor in the Membership Card will preserve the contents of memory for several hours once disconnected from the programmer, giving me ample time to connect the Membership Card to another power supply for stand-alone use.

Once I perfect the programmer's operation, the next step will be to add a small LCD. This way I can emulate the action of the "Pixie" graphics chip used on later Elf computers, which provided a screen resolution of a whopping 64 by 128 pixels.

—STEPHEN CASS

TERABYTES ON TAP
WESTERN DIGITAL'S STORAGE IS PROSUMER FRIENDLY

Being told to back up your data is, in the words of one *IEEE Spectrum* editor, "about as impactful as your dentist telling you to floss." Backing up is not exciting, and there are rarely short-term consequences for failing to do it. You know what, though? Teeth are more replaceable than your data. *Back up your stuff.* And if you're looking for a place to start, Western Digital has some ideas.

In March, WD released four new NAS (network-attached storage) systems in its Expert line: Two are designed for prosumers, and two are designed for small businesses that have users inside and outside the network and need to run applications and so forth. A box containing at least one hard drive, a NAS sits on your network, acting as a file server. These have been around for a while and are boring, because lots of them exist. Single-disk NAS systems—such as Apple's Time Capsule—are common at the consumer end, while systems for businesses generally spread your data across multiple drives set up in a redundant array of independent disks (RAID) configuration. In all but the simplest RAID setup, a damaged drive's data can be reconstructed from information stored in the rest of the array.

SOME SIMPLE STORAGE: Western Digital's new RAIDs are easily managed via a browser [top]. If you prefer, you can fit your own drives into bays [below].

EVAN ACKERMAN (2)

What's nice about WD's new products is that they make it simple to get a NAS RAID up and running with a set of features that typically aren't easy for non-IT folks to set up. (I'm going to focus on the prosumer models, because they seem to be able to do almost all the stuff you're likely to care about, and they're cheaper.)

One of these models can handle two drives and the other, four. The four-drive version has a little screen to let you know how it's feeling, and there's an additional USB port on the front that we'll talk about in a bit.

Setup is trivial: You plug the RAID into your network and turn it on. The browser-based configuration tool takes maybe three clicks and 15 seconds to complete. In fact, all administration is through an easy-to-navigate browser interface. You can set up accounts for users and give them access to different folders, automate backups, enable media streaming and so on. The RAID supports most common networked file systems, including OS X's.

A feature worth highlighting is remote access, which is a way of creating your own "personal cloud." (I'm sorry, I tried to find a term less abused by marketers.) It's the same sort of thing as any other Internet-based personal cloud service, except it's free, and you retain control of all your stuff. You can share files by giving others selective access.

In another move that distinguishes these RAIDs, WD is encouraging third-party developers to make apps for them; some were available at launch. Nothing super interesting yet, except for Dropbox's, which lets you sync your Dropbox with the RAID. Additionally, you can back up the RAID to commercial clouds, including Amazon S3 and Elephantdrive.

The other feature I like is the aforementioned USB 3.0 port on the front of the four-drive model. You can set it up so that when you plug in, say, a camera, and press a button above the port, the RAID will copy all the camera's pictures, store them in a preselected folder, and then wipe the camera clean.

Pricing is, of course, based on capacity. For the two-bay EX2100, without drives, you're looking at US $250. If you want included drives, there are 4-, 8-, and 12-terabyte options, topping out at $750 for 12 TB. The four-bay EX4100 starts empty at $400, and you can add drives up to $1,450 for 24 TB (!).

Before we close, it's important to note that while a RAID is resilient to drive failures, it's not immune to anything that affects the array as a whole, like theft or fire. For that, you'll need to duplicate your data to a cloud service, or put a copy somewhere far away, like someone else's closet or garage. **—EVAN ACKERMAN**

A version of this article previously appeared online.

COPING WITH PROMOTION

ENGINEERS FACE SPECIAL CHALLENGES IN ADAPTING TO A MANAGEMENT ROLE

Being offered a promotion is typically cause for celebration. Apart from higher pay and maybe a better parking spot, it is a recognition of one's skill and dedication. But a promotion can bring its own headaches—especially for engineers. In addition to universal challenges, such as when you become the boss of friends (or rivals), the very skills that land an engineer the promotion may become a stumbling block in the new position.

Engineers pride themselves on the depth of their detailed technical expertise, and they distinguish themselves on the strength of the performance of the things they create. Once you become a manager, however, so-called soft skills become essential. You are evaluated in large part on the performance and creations of others. You will find yourself having to restrain yourself from wading in and fixing a problem that rightly belongs to a subordinate. And then there's the flip side of that last problem—having to accept that sooner or later your technical knowledge of some domain will be outstripped by someone working under you.

"People have a lot of trouble letting go," says Pablo Herrero, head of RF front-end systems for Intel and the chair of the IEEE's Student Activities Committee. Mauro Togneri, a management consultant who has founded and led numerous tech companies, agrees that engineers can struggle with the transition, saying, "The focus has to shift from designing things…to managing people. And that's usually a difficult shift."

Consequently, Intel runs career development workshops for employees moving into management. "We try to teach them how to look at the big picture," says Herrero. One common exercise in these workshops is to break participants into teams and provide each with a copy of the company's publicly stated overall goals for the year. "Then we ask them to break that down into pieces, until they reach 'What do I do every day, what e-mails do I answer, what meetings do I attend that help accomplish these goals?' "

Another focus of the workshops is to encourage participants to develop their networks with other managers within a company, because how you deliver to other teams will become a critical part of how your performance is measured once you are in a management position. "When you're an individual contributor, it's you and your problem and your equipment or your piece of code… but when you make this transition, it's all about the network, which teams you deliver to, which teams you get stuff from," says Herrero.

Getting the best from your team means remembering that the skills and decision processes are very different from the usual subjects of engineering, warns Togneri: "I always tell people when they become managers to keep in mind that while components such as transistors have predictable behavior, people's behavior can, and will, change. Think of it in terms of you're designing some electronic device and your transistors are able to become NPN or PNP at will. So you cannot craft a solution to something and expect it to stand forever."

Togneri also has some useful advice on coping with some of those more universal issues of promotion, saying that once someone is promoted, there is "the tendency to focus on 'What is my authority?' and 'Who am I boss of?'. . . . What the person who moves from a nonmanagement to a management position really needs to focus on is 'What is it that I need to do for the people who work for me and for the company?' "

Herrero's final advice is to learn how to say no when demands on you or your team threaten to become too much: "It can be very difficult for [new managers] to learn how to say no, but if you don't learn this then you are dead in three months, because you will be automatically swamped." —STEPHEN CASS

MARCELO SANTOS/GETTY IMAGES

ASHOK JHUNJHUNWALA
CREATING LOW-COST SOLUTIONS FOR RURAL INDIA REQUIRES SURPRISING SOPHISTICATION

The first time Ashok Jhunjhunwala and his team helped install an ATM in rural South India, around 2005, the villagers didn't like what they saw: They knew that the new bank notes it issued would be suspected as counterfeit, in contrast to soiled notes, considered authentic because they'd been in circulation.

It was an eye-opener for Jhunjhunwala, a professor of electrical engineering at the Indian Institute of Technology Madras (IITM), who heads the Telecommunications and Computer Networks (TeNet) group there. His goal was to develop a low-cost ATM that could run on solar power, to serve villagers who typically had limited or no access to financial services. Jhunjhunwala had to redesign the ATM to handle soiled notes, a difficult task because such notes are much less uniform than new notes. It was a good demonstration of how low-cost systems can require more sophisticated designs than conventional systems.

The ATM, Gramateller Duo, was built by Chennai's Vortex Engineering, guided by Jhunjhunwala and faculty from IITM. But it's only one of the 80-odd products Jhunjhunwala has fostered, many incubated at IITM's Rural Technology and Business Incubator (RTBI), where he's professor-in-charge of the IITM research park. He is also on the board of directors for numerous Indian tech companies.

Jhunjhunwala is currently busy combating blackouts by working on solar DC power for homes and offices. At his IITM office, he gestures toward the devices surrounding him, saying, "This room is powered on DC—all lights, fans, TV, laptop, charger. There is no AC power...DC-powered and energy efficient devices decrease power consumption by 50 percent."

He and his team are working on the concept of off-grid homes—in which individual homes run on solar power alone—and what they call GOA (green offices and apartments) for multiple dwellings, where each apartment can set the DC-power limits from 100 to 400 watts and solar power can be supplemented from the grid. "We have designed and commercialized these two concepts. The system can be expanded by using more solar panels," he says.

In India, 32 percent of homes receive no power. Decentralized-solar homes, generating an average of 500 W of solar power per home, could generate enough power to equal current total Indian domestic consumption, says Jhunjhunwala.

When power cuts occur today, there's a blackout. The AC power supply from the grid to homes is completely switched off. Instead, Jhunjhunwala and his colleagues, including Bhaskar Ramamurthi, IITM's director, suggest a brownout fallback that would use 10 percent of the normal power supply from a DC line.

Although solar powered, the DC system will have storage so that it can provide electricity around the clock. It can power three LED tube lights, two fans, and a cellphone charger or three lights, one fan, and one 24-inch TV. "This is done without any change in the power grid. The only change required is at the substation, where a brownout instead of a blackout is implemented, and at homes, where this box provides two lines," Jhunjhunwala explains.

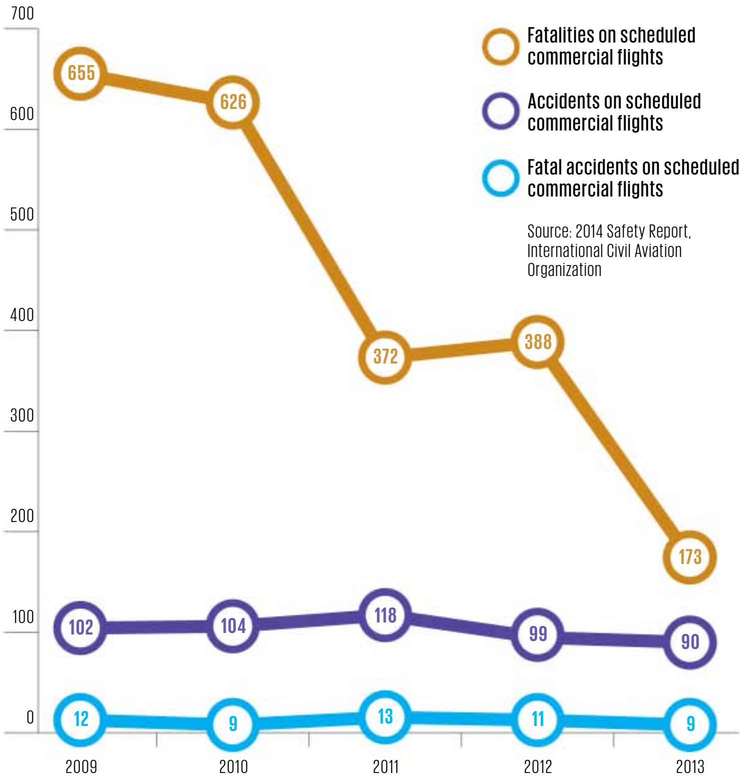
The system has been successfully tested at IITM, and it's now being tested at some homes in four states. It can certainly banish much suffering during the hot Indian summers.

A desire to help humanity has driven Jhunjhunwala ever since the late 1980s, when he worked on the idea of one telephone for every person to empower rural India. Back then, there were only 8 million domestic lines. The dream? To make it 100 million. For his contributions, he received India's prestigious Padma Shri award, in 2002.

Even today, Jhunjhunwala continues to believe in "training people to become wealth creators in India, where there is so much poverty—to get them out of it, give them opportunities to grow. That's the driving force of my life." **—GEETHA RAO**

PHOTOGRAPH BY Naveen PM

KEEP ON FLYING



YOU MIGHT THINK 2014 WAS A BAD YEAR FOR FLYING. There were four highly publicized accidents—the still-mysterious disappearance of Malaysia Airlines Flight 370 in March, the shooting down of Malaysia Airlines Flight 17 over Ukraine in July, AirAsia Flight QZ8501 falling into the Java Sea in December, and finally, in July, the Air Algérie Flight 5017 crash in Mali, for a total of 815 dead. ● But according to Ascend, the consulting branch of Flightglobal that monitors aircraft accidents, 2014 in fact had the best accident rate in history: one fatality per 2.38 million flights, compared to the previous best of one per 2.37 million in 2012. True, Ascend did not count the downing of MH Flight 17, which was an act of war, not an accident. ● In any case, it's better to personalize the problem by putting it in terms of the risk per passenger per hour of flight. The necessary data are in the annual safety report by the International Civil Aviation Organization, which covers large jetliners as well as smaller commuter planes. ● In 2013, 32.1 million domestic and international flights carried 3.1 billion people, logged 5.8 trillion passenger-kilometers, and experienced 90 accidents, causing 173 fatalities. With the mean flight time at about 2.2 hours, this implies roughly 6.8 billion of passenger-hours or 2.5×10^{-8} fatalities per person per hour in the air. For large jetliners—dominated by Airbuses and Boeings and regional jets made by Canada's Bombardier and Brazil's Embraer—the risk that year was just 1×10^{-8}. In 2014, large jetliner accidents (excluding the MH 17) would have pushed the latter rate to about 8×10^{-8}, but the mean for the past decade remains at historic lows.

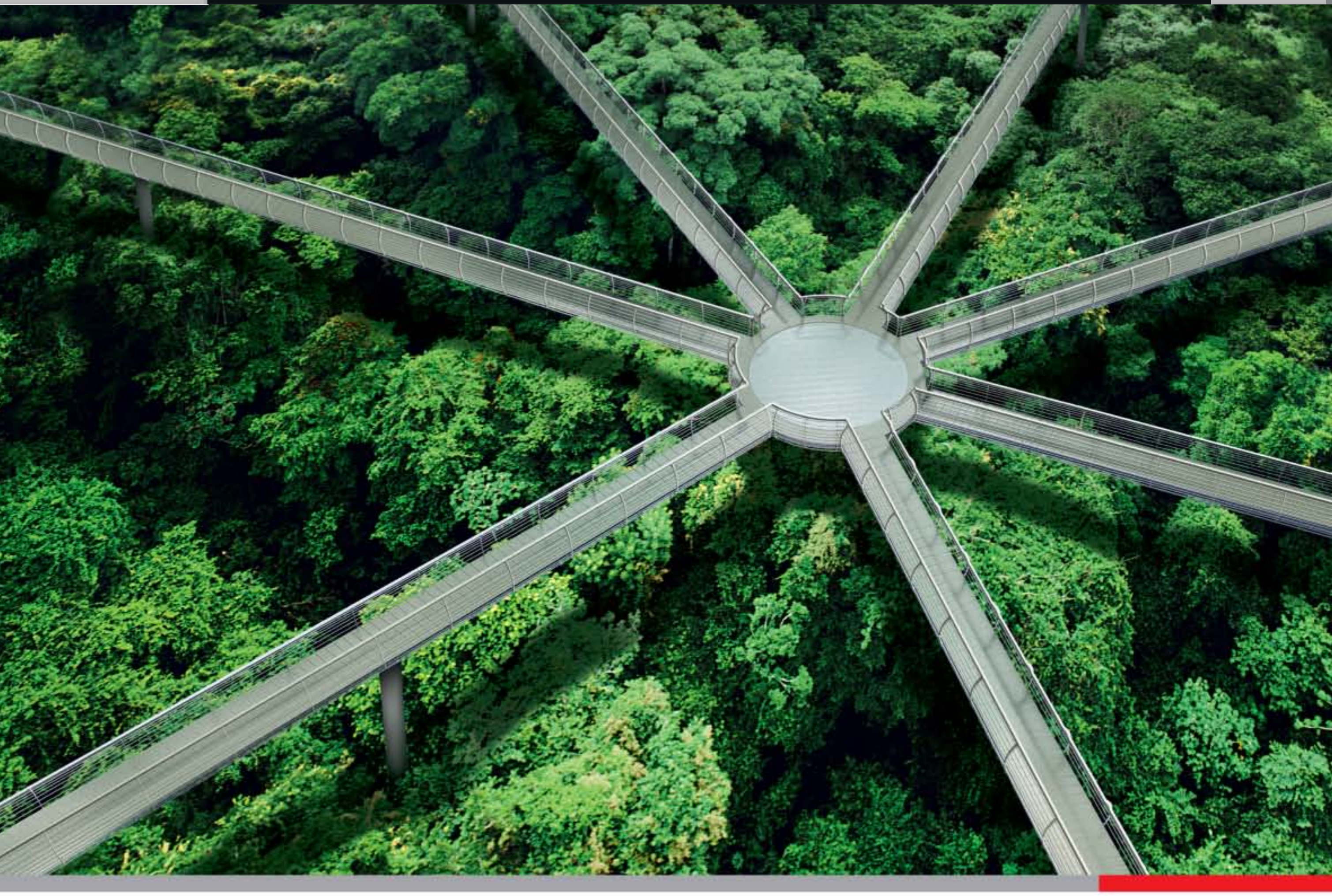
In short, flying has never been safer.

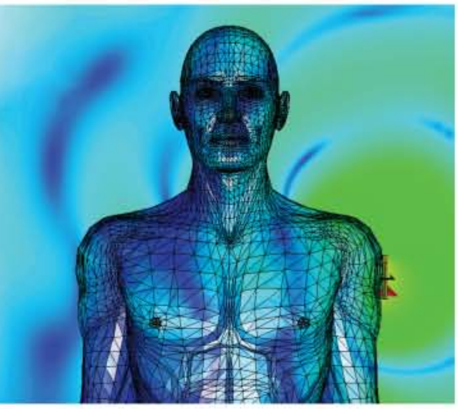
The obvious measuring stick is general mortality, the annual death rate per 1,000 people. In affluent nations that rate now ranges between 7 and 11; I will use 9 as the mean. Because the year has 8,760 hours, this average mortality prorates to 0.000001 or 1×10^{-6} deaths per person per hour of living. This means that the average additional chance of dying while flying is just 1/100th of the risk of simply being alive. Smoking risks are 100 times as high; ditto for driving in a car.

Obviously, age-specific mortality for older people is much higher. For individuals of my age group—I'm 71—it is about 25 per 1,000 or 3×10^{-6} per hour (that means that of a million of us, three will die every hour). In 2014, I flew more than 100,000 kilometers, spending more than 100 hours aloft in large jets belonging to four major airlines whose last fatal accidents were, respectively, in 1983, 1993, 1997, and 2000. In every hour aloft the probability of my demise wasn't even 1 percent higher than it would have been had I stayed on the ground.

Of course, I've had white-knuckle moments. The most recent one was in October 2014, when my Air Canada Boeing 767 headed into the turbulent fringes of a megatyphoon that was crossing over Japan.

But I never forget that quiet hospital rooms are what should really be avoided: The latest assessment shows that preventable medical errors push the risk of premature death to at least 5×10^{-5} and perhaps as high as 1×10^{-4} per every hour of hospital stay, easily more than doubling or even tripling the probability of dying for those of my age group who cannot stay out of a hospital. So keep on flying, and avoid hospitals! ■





SEEING RADIO

A novel refreshes the way I think about radio

AS AN ENGINEER, I FOUND THE CURRENT BEST-SELLING novel *All the Light We Cannot See* nostalgic and thought provoking. The story is about a young German boy, Werner, and a blind French girl, Marie-Laure, during the German occupation of France in 1939. • Before I read the book I assumed that the title had to do with the blindness of Marie-Laure, but instead the title refers to radio waves, as illustrated by this passage from the book: "What do we call visible light? We call it color. But the electromagnetic spectrum runs to zero in one direction and infinity in the other, so really, children, all of light is invisible." • The author, Anthony Doerr, has said that his original motivation was to "conjure up a time when hearing the voice of a stranger in your home was a miracle." The story portrays an era when families clustered around radios made by companies such as Philco and Grundig, when propaganda dominated broadcasts and radios were critical to both armies and resistance cells, when people twiddled the dials of shortwave receivers to search for voices from faraway cities, and when the music on the airwaves was Mozart and Bach. • The characterization of radio waves as invisible light interests me. Somehow I associate photons with visible light but not with radio waves. The very word "photons" seems to connote visible light. In most of classical electrical studies we deal instead with electrons–charged particles that have associated fields and, when they move, create waves. Maxwell's equations describe it all, so there is no need to mention photons. But it is true that both visible light and radio waves are electromagnetic waves, and the associated particle is the photon.

When Werner is 13, he studies radio waves from Heinrich Hertz's *The Principles of Mechanics*. (I'm impressed, since that classic text is dense with partial differential equations.) His affinity for the technology gains him a reputation for fixing radios, where he applies an unusual approach:

> He dismantles the machine, stares into its circuits, lets his fingers trace the journeys of electrons. Power source, triode, resistor, coil. Loudspeaker. His mind shapes itself around the problem, disorder becomes order, the obstacle reveals itself, and before long the radio is fixed.

Werner usually ends up repairing a broken wire. I'm a little dubious about this, since bad vacuum tubes, melted capacitors, or burned resistors are more likely than breaks in heavy copper wires. Furthermore, I can't imagine tracing circuits in an early radio by simply staring at the rat's-nest wiring under the chassis. However, I don't mean to quibble with the use of literary license. Tracing a circuit is a lot more impressive than replacing a vacuum tube.

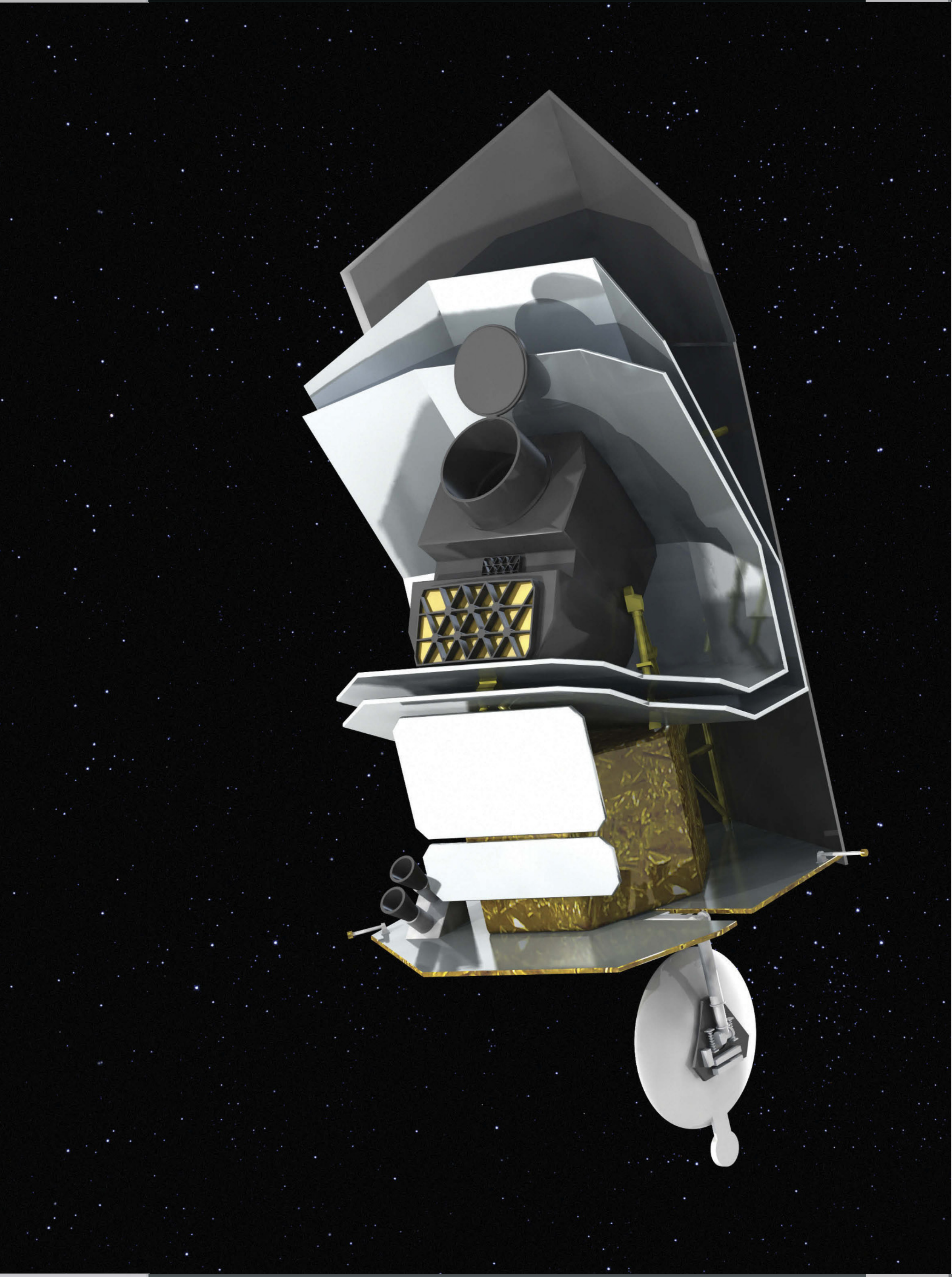
Later, Werner joins the German army and operates direction-finding radio equipment, looking for resistance transmissions, including those being sent by Marie-Laure from her attic transmitter.

The book closes with Marie-Laure as an old woman in contemporary times, thinking about what has become of the radio waves that were so important to her and Werner during the war:

> Marie-Laure imagines the electromagnetic waves…except now a thousand times more crisscross the air…maybe a million times more. Torrents of text conversations, tides of cell conversations, of television programs, of e-mail, vast networks of fiber and wire interlaced above and beneath the city, passing through buildings, arcing between transmitters…

What if our eyes were sensitive to radio frequencies? What a symphony of thrashing, undulating colors we might see! ■

ILLUSTRATION BY Brian Stauffer



IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

A SENTINEL FOR SPACE

To protect Earth from hazardous asteroids... we must first find them

HUMANKIND LIVES IN A COSMIC SHOOTING GALLERY. For evidence of that, we need look no further than the events of 15 February 2013. On that day, a medium-size asteroid was set to pass some 28,000 kilometers from Earth, unusually close and well within the orbits of geosynchronous satellites. Dubbed 2012 DA14, the rock was first spotted the previous year. Since then, astronomers had been eagerly anticipating the opportunity to take a closer look and measure such vitals as size, shape, and composition. ¶ But just as they were readying their telescopes, another asteroid took them completely by surprise. In the early morning hours of the 15th, a previously unknown piece of space flotsam entered Earth's atmosphere and streaked across the sky, breaking up over the Russian city of Chelyabinsk. Briefly exceeding the sun in brightness, the rock exploded with the equivalent of 500 kilotons of TNT. The shock waves damaged roofs and walls, blew out thousands of windows, and injured more than 1,500 people, primarily from shattered glass.

BY HAROLD REITSEMA

ILLUSTRATION BY John MacNeill

Why didn't we see this one coming? By scrutinizing the footage collected by dashboard cameras and building-security systems, scientists were eventually able to reconstruct details of the asteroid's entry and demise. The object came from the sunward side of Earth, meaning it was never visible in the nighttime sky as it made its final approach. And analysis of the blast energy revealed that the cosmic interloper was a modest 19 meters or so in diameter, which would have made it difficult to see even if it had been visible after dark.

We're fortunate that the asteroid was a small one. If it had been the size of 2012 DA14–some 30 meters–it's likely that astronomers would still have missed it, and the damage could have been much worse.

UNEARTHLY INTERLOPERS: An automobile dashboard camera captures the entry of a 19-meter-wide asteroid over the city of Chelyabinsk, in Russia [right]. Many more near-Earth asteroids have yet to be discovered than have been spotted to date [see chart, far right].

AP PHOTO

The good news is that such events need not take us by surprise. Our team of former astronauts and scientists at the B612 Foundation, a nonprofit planetary-defense group, as well as engineers at Ball Aerospace & Technologies Corp., have devised a space mission, called Sentinel, that could go a long way toward finding asteroids on collision courses before they pose a danger to Earth.

Sentinel is the first space telescope dedicated to asteroid hunting. During six and a half years of operation, it will be able to spot more than 500,000 objects orbiting in the vicinity of Earth, dozens of times more than have been found to date. Not only could this rapid rate of detection reveal serious threats to the planet, it could also give people enough advance notice to do something about it.

ASTEROIDS ARE SMALL ROCKY OBJECTS—leftover rubble from the formation of the planets–that for the most part orbit the sun in a zone between Mars and Jupiter called the main asteroid belt. Millions of asteroids reside in this belt and have done so since the solar system formed more than 4 billion years ago. But not all have stayed there. Thanks to gravitational encounters with Jupiter, other planets, and one another, a subset of asteroids have had their orbits disturbed and now swing through the inner solar system, where they can pass close to–or even collide with–Earth.

These wayward asteroids are often called near-Earth objects (NEOs), a term that includes the occasional near-Earth comet. In the past few decades, astronomers have spotted more than 12,000 of them. But based on the low rate of rediscovery (how infrequently we see the same objects over and over again), we know there are many more out there. If there were no NEOs left to find, we would see only ones we'd already found; instead, our surveys keep turning up new ones.

Relatively small objects dominate the NEO population. The numbers are a bit uncertain given the incompleteness of our current observations, but it's reasonable to expect that there are millions bigger than about 20 meters, more or less the length of a train car. Fewer than 1,000 are larger than 1 km.

Even a smaller NEO could create devastating loss of life and property if it were to strike a populated area. A 30-meter-wide asteroid hurtling through space can carry the kinetic equivalent of megatons of TNT, on the order of a hundred or more times the energy contained in the bomb dropped on Hiroshima. How that energy is released will depend on a variety of factors, including asteroid composition and angle of impact.

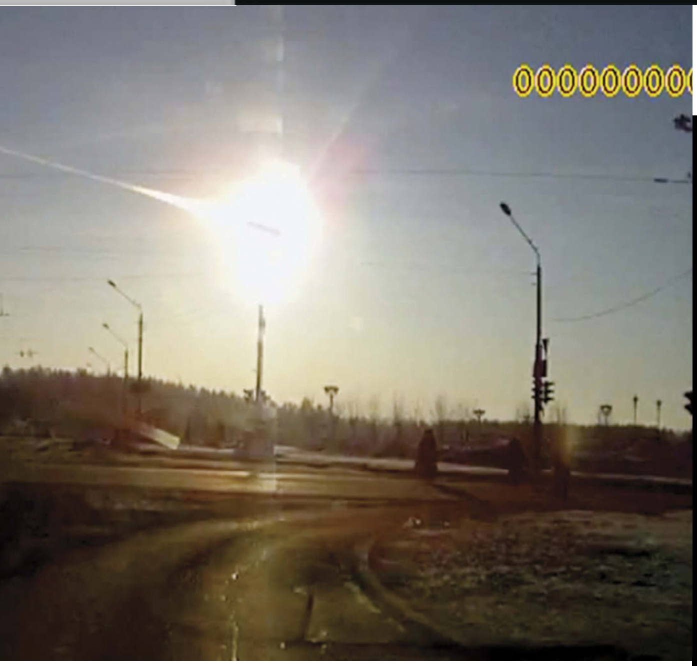
Impacts are more than a theoretical concern: There's ample evidence that Earth has been hit multiple times before and could be again. In the 1960s, astronomer and geologist Eugene Shoemaker raised awareness of the possibility after he showed that the 50,000-year-old Meteor Crater in Arizona was formed by an impact with an asteroid. It's now well established that the heavily eroded Chicxulub crater, in Mexico, was forged some 65 million years ago, when a 10-km-wide asteroid or comet slammed into Earth. The collision darkened the atmosphere and has long been thought to have led to the demise of the dinosaurs.

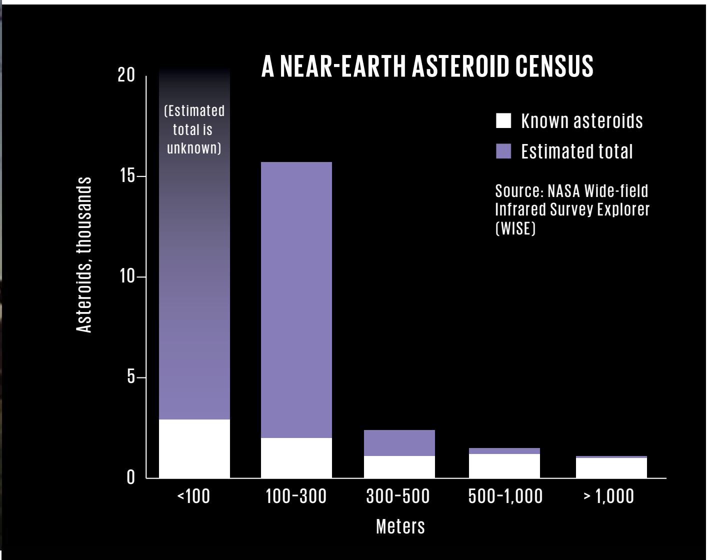
And it's not all ancient history. In 1908, a roughly 40-meter-wide object burst apart over Tunguska in Siberia, Russia, flattening thousands of square kilometers of forest–some 80 million trees. Recently, data collected by a global network of infrasound detectors used to monitor nuclear tests has revealed airbursts created by the dozens of small asteroids that enter the atmosphere each year.

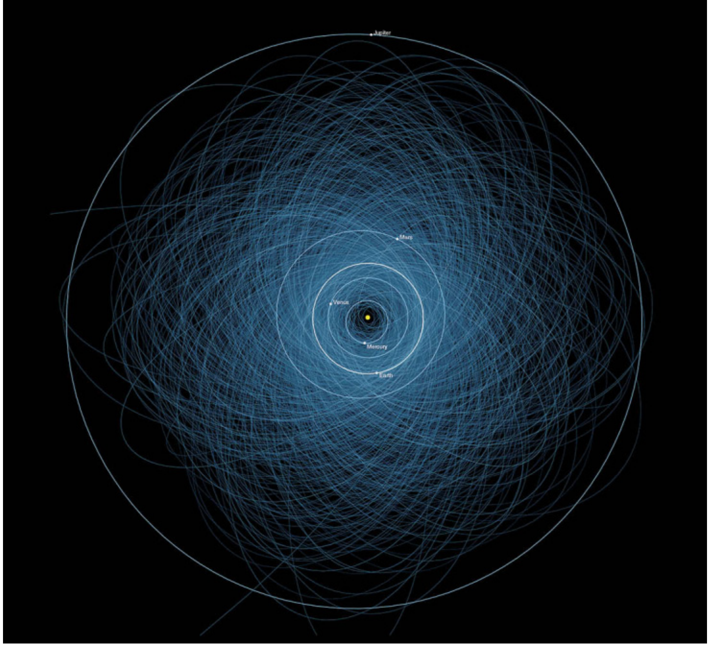
Based on the geologic record and what we know about the NEO population, the probability of a catastrophic event is quite low. A Tunguska-scale event might occur once every few centuries. Impactors as large as the 10-km-diameter object that finished off the dinosaurs very rarely collide with Earth, just once every 100 million years or so.

But of course, these are just average rates. The next asteroid with the potential to level a city might not hit Earth for hundreds of years; it could also arrive tomorrow. The only thing we can say with certainty is that there will be more collisions in our future.

Given enough advance warning, though, we should be able to protect ourselves. For a long time,







THE CELESTIAL SWARM: The orbits of potentially hazardous asteroids—near-Earth asteroids at least 140 meters in size and in orbits that pass quite close to Earth's—are shown here. More than 1,400 objects of this class had been discovered at the time this graphic was released in 2013.

the most dramatic and effective option seemed to be a nuclear bomb: Explode one near an asteroid and you could generate enough pressure to force the asteroid off course without breaking it into many Earth-threatening pieces.

But in 2002, astronauts Ed Lu and Rusty Schweickart, planetary scientist Clark Chapman, and astrophysicist Piet Hut joined forces to explore other ways to deflect or destroy a threatening asteroid–should one be discovered. By 2010, the B612 Foundation (named for the asteroidal home of the title character in Antoine de Saint-Exupéry's *The Little Prince*) and the rest of the space community had settled on a few ways that humankind could feasibly deflect all but the largest asteroids.

One option, devised by Lu and fellow astronaut Stan Love, is called the gravity tractor. It would take advantage of the small gravitational attraction between a hovering spacecraft and the threatening asteroid. Given enough time, the tug of the spacecraft could nudge the asteroid's orbit so that it would pass slightly ahead of or behind Earth. Another possibility is to send a robotic spacecraft on a high-velocity collision course, one that would transfer the craft's considerable momentum to the asteroid. These methods are attractive alternatives to the prospect of sending nuclear weapons into space. There's only one hitch: Because of the small changes in velocity these deflection approaches produce, any such mission would have to be launched years or even decades before the calculated date of impact.

Regardless of method, we can't deflect an asteroid if we don't know it's coming. Finding potential threats has been the prime focus of planetary defense research for the last 20 years or so, and it continues to be the area that requires the most effort.

BOTTOM: NASA

THE ORGANIZED ASTEROID HUNT began with the very biggest objects in 1998, when the U.S. Congress directed NASA to initiate the Spaceguard Survey, with the aim of finding 90 percent of NEOs larger than 1 km within 10 years. To reveal these objects, NASA mounted a ground-based campaign of telescopic observation from multiple sites. By 2011, the agency met its goal, finding more than 900 of the estimated 1,000 or so NEOs larger than 1 km. Happily, none of them seem poised to strike Earth anytime soon.

The remaining NEOs of this size are on long, elliptical orbits that will only occasionally pass by Earth and so may take decades longer to find. Extending the search to smaller objects that could also be quite dangerous was the next logical step. Even before the Spaceguard Survey was complete, Congress did just that, calling for NASA to find 90 percent of NEOs that are at least 140 meters in diameter by 2020.

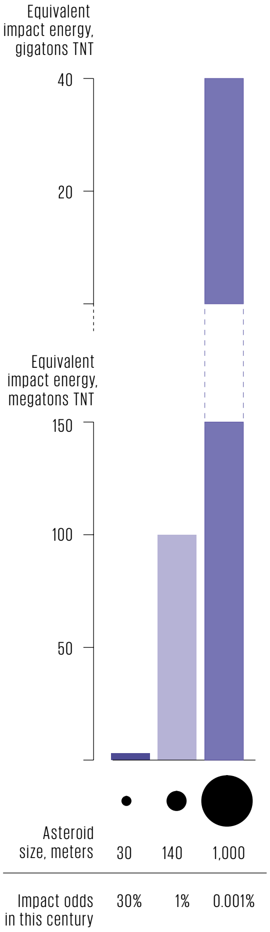
This goal is much more ambitious. NEOs aren't easy to observe. As a general rule, they're as dark as charcoal, absorbing most of the visible light that hits them. And the smaller they are, the less sunlight they reflect. Most can be detected only when they're very close and so can be tracked for just a few days as they zip past Earth. This in turn limits how precisely their orbits can be pinned down. Many objects that are known today fly away from Earth in orbits so poorly charted that the timing and location of their next return can't be accurately predicted. Indeed, the orbital parameters of nearly two-thirds of known NEOs are so uncertain that it will be difficult for astronomers to find them again when they return to Earth's vicinity.

On Earth, astronomers have initiated several programs that will make big contributions to NEO discovery. The most ambitious employ telescopes with large fields of view and massive cameras. One facility, called Pan-STARRS (for Panoramic Survey Telescope & Rapid Response System), has for years been operating one of four planned telescopes on the island of Maui in Hawaii, with a 1.4-gigapixel camera, one of the world's largest. And astronomers are currently moving forward with the Large Synoptic Survey Telescope (LSST), one of a new class of very large optical telescopes. LSST will start searching the heavens in 2022 from a mountain summit in northern Chile with an 8.4-meter-wide primary mirror and a 3.2-gigapixel camera.

These are powerful and sensitive tools. But they have their limitations. Because ground-based optical telescopes must operate at night, they're blind to objects that approach from regions of the sky near the sun. They're also limited by the need for good viewing conditions—a moonless and fairly turbulence-free sky, which might be on offer only a quarter of the time. But the most serious obstacle is water vapor in the atmosphere, which absorbs infrared light before it can reach the ground.

The infrared part of the spectrum happens to be where NEOs are easiest to see. Asteroids may be dark, but they're warmed by sunlight and absorb and re-emit that light at infrared wavelengths. Ground-based observatories are blind to the part of the spectrum where NEOs are at their brightest, which limits their sensitivity.

Today, astronomers find about 1,500 or so new NEOs a year. LSST should be able to boost that discovery rate significantly—perhaps by as much as a factor of 10. But even with new telescopes in the works, it could be 20 years or more from now before ground-based efforts locate the 140-meter-or-larger objects NASA has been charged to find by the end of this decade. And it will take even longer to home in on smaller ones.



SIZE MATTERS: The impact energy of an asteroid (rough, notional figures shown here) varies significantly with size. Fortunately, population dwindles with diameter. The largest asteroids have the smallest odds of impact with Earth.

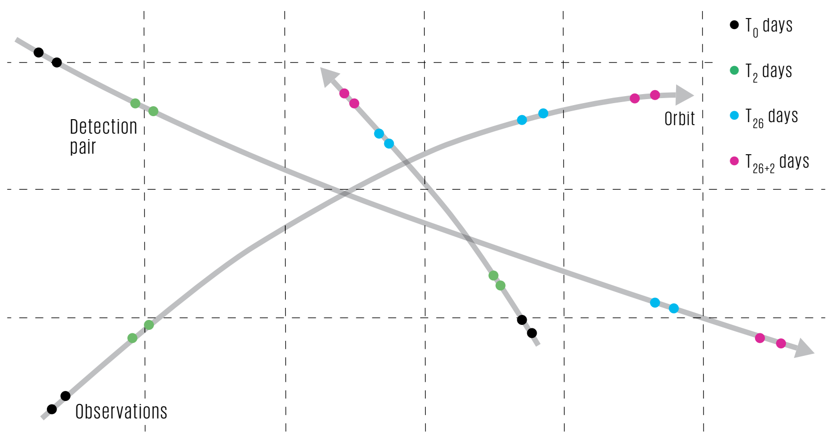
Eventually, these observatories could turn up an asteroid on a collision course with Earth. But we don't know when the next one will hit. If we want to give ourselves as much time as possible to defend the planet, we'll want to find any such hazards early. And the fastest way to find them is to go to space.

That's easier said than done. Tight budgets have made prospects slim for government-sponsored science spacecraft. Although there is a proposal for a NASA mission called NEOCam, which would look for near-Earth asteroids, it hasn't been picked up since scientists initially proposed it in 2006, and it's competing with dozens of other possible space missions for funding.

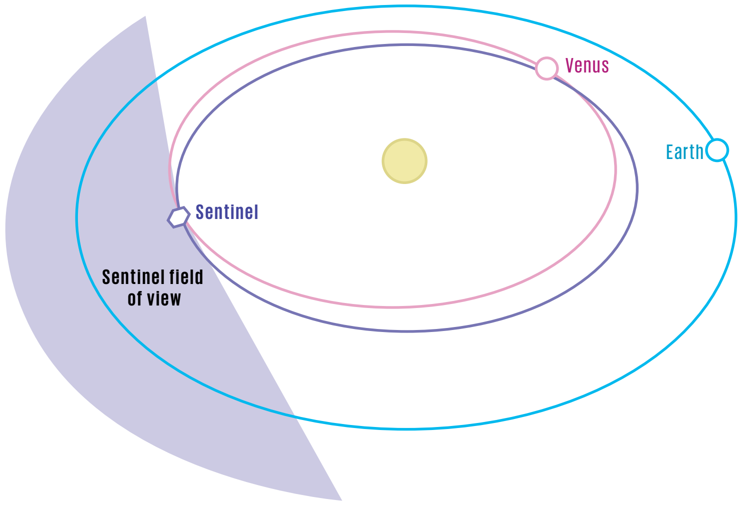
Given these constraints, the B612 Foundation decided to move forward on its own with an infrared telescope called Sentinel, which would be the first space telescope dedicated to hunting for NEOs. The mission concept got its start in 2006 at Ball Aerospace, in Boulder, Colo., where I worked until retiring in 2008. Ball built NASA's planet-finding Kepler Space Telescope as well as critical parts of NASA's Spitzer Space Telescope, an infrared observatory. My group at Ball based its scheme for an asteroid hunter in part on the technologies it developed for those two spacecraft. In 2011, B612 issued a request for proposals and selected Ball to build, launch, and operate the observatory. I joined B612 that same year.

We expect the mission will cost US $450 million in all, a figure that will cover development, launch, and 6.5 years of operation. B612 is funding Sentinel through philanthropic donations, much as astronomical observatories were funded in the early 20th century. So far, we have raised enough money to build our team, fabricate engineering versions of the infrared detectors, construct a performance model for Sentinel to help plan our observing strategies, and establish our management plans. This is the first time anyone has attempted to fund a scientific, deep-space mission this way, but it's quite possible it won't be the last.

WE PLAN TO PLACE SENTINEL in an orbit around the sun about 50 million km inside Earth's orbit and not far from the orbit of Venus. There, the telescope will effectively sit with its back to the sun, continually scanning for objects with its 0.5-meter aperture and 30-megapixel infrared camera. This placement will allow Sentinel to see NEOs when they are close to the sun, during a



FIND THE ORBIT: Sentinel will image the sky four times every 26 days. The telescope's computer will hunt for NEOs in pairs of snapshots taken an hour apart, by looking for images that show movement against the background of stars [see detection pair, above left]. Sentinel will revisit the same area of the sky after two days, then twice more after it has started its sky survey over again. If an object is found at all four opportunities, astronomers will be able to predict with fairly high accuracy where the object will go over the next century.



LOOKING OUT: Sentinel will hunt for NEOs over more than half the sky, slightly more than a hemisphere; the cross section extends over 200 degrees in the plane of the solar system. Because Sentinel's orbit is faster than Earth's, the telescope will be able to move ahead of Earth and find objects that will one day cross its orbit—long before they approach the planet.

time when they're at their hottest and therefore radiating strongly at infrared wavelengths.

Sentinel's proximity to the sun will let it generate twice as much power from its solar panels as it would in Earth orbit, but it will make thermal control more complicated. The spacecraft's electronics must be held near room temperature, but the telescope must be kept below -208 °C, some 65 degrees above absolute zero, so that it won't radiate heat at wavelengths that its camera would detect.

To keep things that cold, Sentinel will use a combination of techniques. The bulk of the cooling will come from a three-tiered cascade of sunshades. The first of these shades is the spacecraft's array of solar panels. Because the solar array itself will heat up to more than 100 °C, two highly reflective thermal shields will be inserted between the solar array and the telescope to intercept the heat radiated toward the spacecraft and deflect it to space. The Spitzer telescope uses this same approach.

This arrangement will get the telescope temperature down to what is needed. But the detectors have to be even cooler, just 40 degrees above absolute zero, to keep thermal noise to a minimum. For that, we plan to use a mechanical cryocooler, a smaller and less massive alternative to the tank of cryogen, such as liquid helium and solid hydrogen, used on previous infrared space telescopes.

A somewhat unusual aspect of Sentinel is its mirror design. Reflecting telescopes typically have two mirrors: a primary that reflects incoming light onto a secondary that hovers above it, which then focuses the light onto a detector or objective. This tried-and-true design turns out to be a tricky one for infrared telescopes. Light can bounce off the support structure holding up the secondary mirror, and the structure itself can radiate heat that can be picked up by the detectors. To circumvent these issues, Sentinel will use three mirrors instead of two, in an off-axis configuration that will eliminate the possibility of any telescope structure getting between the detector and its view of the sky.

All told, Sentinel will have an 11-square-degree field of view, more than 50 times the area the moon takes up in the sky when viewed from Earth. Sentinel's camera will take in this large field of view with a mosaic of 16 individual 1.8-megapixel CMOS detector chips. B612 has already gotten a start on these detectors, which are sensitive to wavelengths of infrared radiation from 5 to 10.2 micrometers, the range where NEOs emit most of their light. Raytheon Vision Systems, which is building the detectors, finished a prototype in 2013. The company is now building a full-scale engineering unit, a carbon copy of what will eventually fly on the telescope.

To hunt for NEOs, the Sentinel observatory will use its camera to look for objects that have moved relative to the background of stars between pairs of images. Sentinel's hunting strategy could be categorized as "step and stare," moving from one patch | CONTINUED ON PAGE 51

LIFELINE: Engineers from the Nicaraguan rural electrification group ATDER-BL walk along an access road near the 930-kilowatt El Bote hydroelectric plant, the largest of 30 such installations the group has built in northern Nicaragua.

A POWER PLAY IN NICARAGUA

How the country's northern highlands got electricity, lights, and a new sense of purpose

On a dirt road high in Nicaragua's northern mountains, a small knot of men and two precocious young boys uncoil electrical cable from the back of a pickup truck. Other workers swing machetes at overhanging tree branches. Along the cleared shoulder of the road, another crew tightens a cable on a freshly planted utility pole.

THE GRIND: Farmers process coffee berries using a hand-cranked machine. Access to electricity speeds up this labor-intensive work.

By Lucas Laursen

PHOTOGRAPHS BY Lucas Laursen

Verdant coffee plantations line the steep road, punctuated by wooden shacks where pigs orbit stakes in the mud. Placards on outhouses proclaim the names of aid organizations. Cinder-block evangelical churches mark even the tiniest clusters of homes.

This extension of the power grid will serve about 30 families in the San Ramón valley, about 200 kilometers northeast of Managua. "We've always lived in the dark here," says Salvador Gonzáles, a resident of the valley and one of the men volunteering on the line crew. For him, the arrival of electricity means a refrigerator and a leap in quality of life. "I'll have my soda cold, some chicken, some meat, a Popsicle," he says.

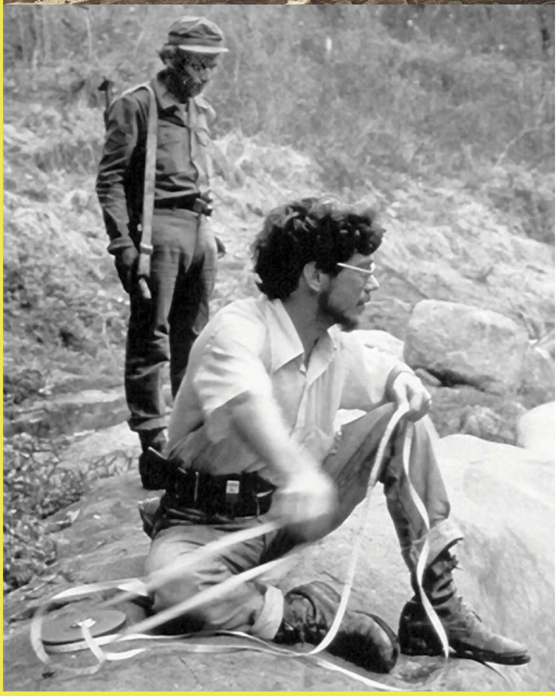
Rural electrification swept through the Western Hemisphere decades ago, but Nicaragua missed out: Electricity reaches barely a third of rural Nicaraguans like Gonzáles. The country's overall electrification rate of around 74 percent puts it ahead of Haiti and behind every other country in the hemisphere.

There is no physical reason for this impoverishment. Nicaragua is wet, windy, mountainous, volcanic, and tropical, meaning it is an excellent candidate for hydroelectric, wind, geothermal, and solar power. Estimates of its geothermal potential alone have put the figure at several thousand megawatts; for reference, the country's entire installed capacity is about 1,410 megawatts.

In recent years, investments in renewable energy projects have soared, thanks to generous tax breaks. But imported oil still accounts for half of the country's electricity generation.

The government in Managua, under the idiosyncratic rule of Daniel Ortega, the Sandinista who also led the country in the 1980s, has a plan to raise the electrification rate to 85 percent by 2016. But Nicaraguans in and around the San Ramón valley are tired of waiting. With the help of a local nonprofit group, the inhabitants are taking the electrification of their homes into their own hands. The electricity that Gonzáles will soon enjoy comes from a small hydroelectric plant in the nearby town of El Cuá. And that plant is part of a rich legacy that encompasses a small act of war, some stubborn and idealistic engineers, and a rare unity among fierce, independent people.

WATERWORKS: ATDER-BL's Abner Talen and José Luís Olivas Flores, director of the nonprofit Aprodelbo [pointing], stand at the dam that feeds the 185-kilowatt San José de Bocay plant.



STAYING POWER: In 1987, contra soldiers killed U.S. engineer Benjamin Linder [bottom, sitting]. Rebecca Leaf [top, plaid shirt] took over for Linder, leading the design and construction of the San José de Bocay hydroelectric plant.

IT'S HARD TO PICTURE NOW, but 30 years ago Nicaragua was an international hotbed of revolution and a Cold War proxy battleground between the United States and the Soviet Union. Many Nicaraguans sympathized with the socialist Sandinista National Liberation Front, which came to power in 1979 after toppling the U.S.-backed Somoza family. These tropical northern highlands saw some of the heaviest fighting between U.S.-backed contra guerrillas and Nicaraguan forces. Over the course of the decadelong war, tens of thousands of Nicaraguans died.

At the edge of the regional capital of Matagalpa, a road leads to the modest administrative office of the Association of Rural Development Workers–Benjamin Linder (known by its Spanish acronym, ATDER-BL). Benjamin Linder was a young American engineer who sympathized with the Sandinista movement and came

TOP: ATDER-BL (2); BOTTOM: LUCAS LAURSEN

A GROWING GRID

ATDER-BL has built 30 small hydroelectric plants and 225 kilometers of power lines, providing electricity to 40,000 people.

The grid operated by ATDER-BL and its partner Aprodelbo extends from Ayapal in the north to the intertie with Nicaragua's main power grid in the south.

to Nicaragua in 1983 to work on engineering projects. The first project he completed was a 100-kilowatt hydroelectric plant near El Cuá.

Hardworking, idealistic, and playful, Linder entertained the locals by riding his unicycle through town while juggling, sometimes dressed as a clown. At the time, El Cuá was a town of 2,000 that lacked electricity, running water, and sanitation. Despite the logistical challenges of operating in a war zone—contra guerrillas mined the road to El Cuá and sprang frequent ambushes—Linder supervised the completion of the El Cuá plant in 1985 and soon began work on another.

Then, on 28 April 1987, contra soldiers attacked and killed Linder and two Nicaraguans named Sergio Hernández and Pablo Rosales as they worked at the site of the new plant near the town of San José de Bocay. Linder, the only American civilian to be killed by the contras, was 27 years old. In 1988, the IEEE Society on Social Implications of Technology posthumously awarded Linder the Carl Barus Award for Outstanding Service in the Public Interest, in recognition of his "courageous and altruistic efforts to create human good by applying his technical abilities."

OTHER HANDS took up Linder's work. Shortly after he died, his family and friends began raising funds to complete the plant, and Bocay residents volunteered their labor. A colleague of Linder's named Rebecca Leaf was working at the time for the Nicaraguan Energy Institute in Managua. The MIT-educated engineer gave up her government job to lead the design and construction of the Bocay plant.

At times, progress ground to a halt, hampered by a U.S. trade embargo that limited the availability of parts. Even after the 1990 peace settlements, guerrilla groups continued to threaten the area. Still, Leaf and her team completed the 185-kW hydroelectric plant in 1994, and today the turbines in Bocay and El Cuá continue to generate electricity.

And 21 years later, Leaf is still here. These days, she is the director of ATDER-BL, which she founded after Linder's death, and she lives in El Cuá, working from the group's operations office here. Sunlight bathes the blue one-story building, which is set behind a chain-link fence just off the town's only paved road. Flocks of birds in nearby trees twitter and shriek, and a metallic screech rings out from the adjacent machine shop, one of the first buildings to get electricity. Visitors wander in, clutching electric bills.

Leaf emerges from her office with an armful of maps and spreadsheets that document the association's work. She speaks quietly despite the din. The Bocay project "left us with partially trained machinists, welders, masons, surveying crew, pipeline installation experts, and electricians," she recalls. The workers could have returned to their day jobs—farming, cutting hair, maintaining the town's fleet of Soviet jeeps and American school buses. Leaf, too, could have found work elsewhere.

But people from nearby communities "came looking for us, saying that they had a river and they wanted to have a hydro plant, too," she explains. And so she began canvassing international donors for funding. The money was there—but for drinking water systems, not hydroelectric plants. And so for several years, the team switched to constructing potable water systems, the basic piping of which wasn't too different from that of the hydropower plants they'd been building. "That was our bread-and-butter income," Leaf says.

As word of ATDER-BL's work spread, the group returned to building hydropower plants, ranging in size from pico-plants that generate just enough juice to charge a car battery and light a school, to microplants of 3 to 8 kW that local farmers can operate themselves, to one plant that's nearly a megawatt and now powers about 4,000 homes. In total the group, which now has a full-time staff of 40, has installed about 30 small hydroelectric plants throughout the region. It has consulted for Nicaragua's Ministry of Mines and Energy and the United Nations Development Programme on dozens more.

"ATDER-BL's work has improved the quality of life for thousands of Nicaraguans, from schoolchildren to farmers, with the support and help of local communities," says Laurie Guevara-Stone of the Rocky Mountain Institute, in Snowmass, Colo., who has worked on renewable energy in Nicaragua and other Central American countries. "Their approach could really serve as a model for rural electrification in other parts of the world."

DESPITE ITS INTERNATIONAL reputation, ATDER-BL has never lost its local focus. Just as the group had done in El Cuá and Bocay, it still leans heavily on local workers for the construction of each new hydroelectric plant, explains electrical engineer Abner Talen. The association asks each household to provide a volunteer to do the less technical work: branch clearing, pole hoisting, cable laying, concrete pouring. ATDER-BL's crew does the rest.

"The people have to be willing to work," Talen says. "They have to take on the project as their own." Countless other well-meaning development efforts don't follow that approach–and they fail, he adds. "There are lots of experiences where the population was given everything and then they don't take care of it like they should."

One of the smallest of ATDER-BL's hydropower plants is a 2-kW system owned and operated by a coffee grower named Martín Rivera and his neighbors. His house is nestled on a lush slope surrounded by bushes heavy with red, ripening coffee berries. Several years ago ATDER-BL advised him and his neighbors when they installed their plant. Now the generator hums in a closet-size shed downhill from Rivera's farm. Upstream, a tiny dam hidden in the thick forest captures the water to drive the small Pelton wheel turbine.

Twenty years ago, Rivera would have never worked with a group like ATDER-BL. He fought on the side of the contras, and during the worst of the fighting, he sent his son Álvaro to the lowlands to study. When the war ended, Rivera returned to farming. And his son, who'd gotten an agricultural engineering degree, came home and began working for ATDER-BL.

PEOPLE POWER: Workers from ATDER-BL and local volunteers haul a 25-kilowatt microturbine, which now powers three small villages.

ATDER-BL

Microhydroelectric systems like Rivera's run at full capacity only when there's enough rain. At drier times, they generate less power or none at all. But the bigger, newer sites need to operate continuously and sell their excess power to the grid to recoup their up-front cost, says Leaf. The cost of raw materials like copper has soared, and the increasing automation of the plants' control systems, which rely on more expensive components and software, has also driven up costs.

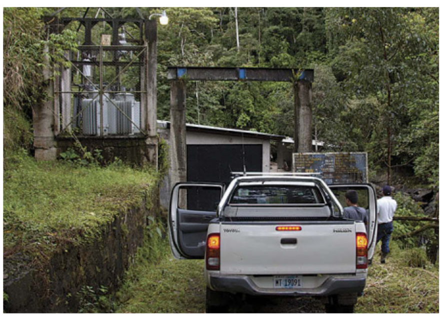
Ensuring a steady supply of water for its hydropower plants has been a challenge for ATDER-BL, and it has pushed its engineers into an unexpected new sideline: watershed conservation. In this regard, the association's biggest project to date, located at the foot of a steep rocky stream near the tiny town of El Bote, presented a thorny challenge.

The 930-kW plant, completed in 2008 and financed in part with a US $1.3 million loan from the World Bank and $400,000 from the nonprofit Green Empowerment, based in Portland, Ore., now generates about 5.8 gigawatt-hours per year, enough to power around 6,000 homes in the region. And the local community is thriving. "El Bote is a town of only 95 houses," Leaf says, "but as soon as there was electricity available, they started increasing the years of schooling...and they graduated the first class of high school students about three years ago."

But even as construction of the power plant got under way in 2002, the surrounding area was rapidly changing–for the worse. On Leaf's first visit to the Bosawás Biosphere Reserve, northeast of El Bote, she recalls, "It looked like a place for a Tarzan movie, with vines dangling down from the trees along the side of the river and flocks of red parrots flying overhead, the monkeys calling from the trees nearby, throwing things at you." But at the forest's edges, she says, "we saw the virgin forest smoldering. It was the slash and burn of poor people needing to establish agriculture."

Such wholesale land clearing is bad for hydroelectricity. Fields of corn and beans, which the poorest farmers plant because they offer a quick return on investment, are prone to soil erosion. During the rainy season, the sediment washes from deforested farmland, clogs streams, disrupts dams, and hobbles the hydropower generators. And without the shade of trees overhead, streambeds dry up.

Someone had to ensure the region has enough water to feed its hydropower plants, and that person turned out to be Boanerge Rocha Moreno. The agricultural engineer stands at the intersection of two dirt roads, where one-room wooden houses sport rooftop satellite dishes. He wears a Boston Red Sox cap, a spotless white polo shirt, jeans, and rubber boots.



RURAL WATTS: An ATDER-BL lineman runs a new line in the San Ramón valley [top]. ATDER-BL's Abner Talen and Boanerge Rocha Moreno inspect the El Bote plant [bottom].

"When I came for the first time to El Bote, this was naked earth. There were no trees," he says, as he hops into the association's shiny new Toyota Hilux. The truck dodges puddles and fords streams, and Rocha points to the roadside, which has been planted with a yellow-green grass that helps hold the soil. Growing coffee also helps, he says. Although it takes longer to mature than corn or beans, coffee can grow in the shade of trees that better protect the watershed's soil. And because coffee sells at higher prices, growers can afford to leave forested patches on their land. ATDER-BL has bought about 800 hectares of forest upstream from the El Bote and Bocay plants and has overseen the planting of thousands of trees.

"We try to inform people that we have to take care of the forest, that the water depends on the forest, and that water is life," Rocha says.

THAT MESSAGE is trickling down to the farmers, who have embraced it with varying degrees of enthusiasm. One of the more passionate is Luís Euxebio Irías Calderón. He farms in a valley so steep that horses move faster than motor vehicles, and he is also the part-time operator of a nearby micro-hydropower plant. Irías's smile gleams gold as he offers to sing a song he composed for the plant's recent inauguration in the Valley of the Olivas.

LUCAS LAURSEN (2)

"The song is kind of raw since we don't have a guitar," Irías says, before belting out the ballad: "The engineer Rosales / Hatched the plan / To bring the project / To the Valley of the Olivas." Midway through, he gets to "Got to plant trees / All over the range / So that tomorrow / We aren't unprepared."

The engineer in Irías's song is Félix Rosales, ATDER-BL's energetic young project manager and Leaf's protégé. Standing nearby, Rosales smiles as Irías croons. A graduate of the National University of Engineering in Managua, Rosales talks of the powerful ripples that emanate from electrification projects: The availability of electricity draws skilled workers to the region–high school teachers, doctors, merchants, all of whom have the disposable income to pay more for goods and services.

That is what happened in the mountain towns that ATDER-BL has helped electrify. No longer places from which parents send their children away, these towns are growing, and the people, having endured years of deprivation and violence, are hopeful.

But there is still work to do, Leaf says. Interconnecting El Cuá's regional power grid to the national grid has posed technical challenges. "The nearest point for the intertie was a decrepit rural circuit of Nicaragua's northern utility, Disnorte, with patched conductor wires and fissured porcelain insulators," Leaf says. The line's unreliable voltage frequently forces the hydro plants' generators to trip off-line, damaging the generators' main circuit breakers and the transformers' power interrupters. At its own expense, ATDER-BL installed a supervisory control and data acquisition (SCADA) system to help manage the problem and get the plants back on line faster after each trip event.

"For Disnorte, it's just another low-income rural circuit," says Leaf. "For us, it's fundamental to everything that we're doing."

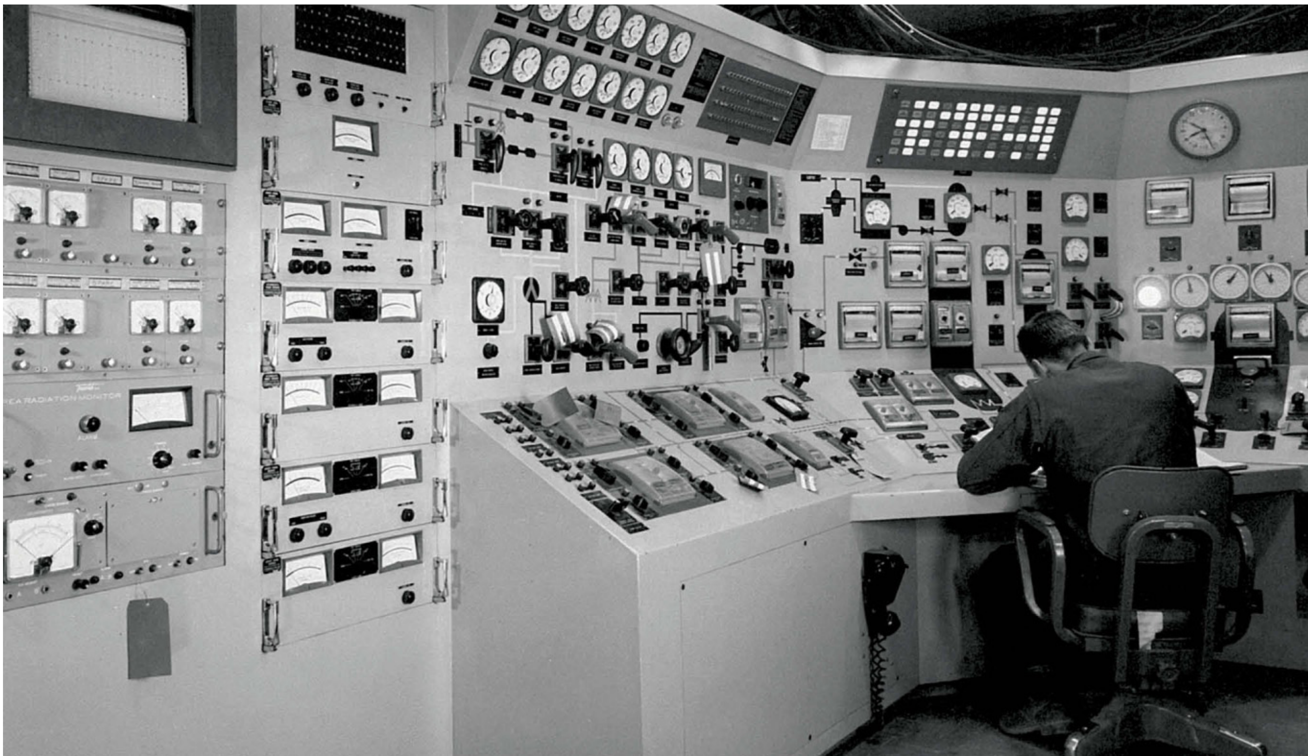
Meanwhile, in San José de Bocay, the population has been growing by about 8 percent a year. "There's a big demand for electrical service and basic services," says José Luís Olivas Flores, whom Leaf recruited to lead Aprodelbo, a nonprofit there that operates the plant and the local grid. "Now we have cellphones, cybercafés, cable TV. We could say the window has opened to the world due to having electricity." The 185-kW hydro plant that ATDER-BL completed in 1994 can no longer supply the 1,500 homes, farms, small businesses, schools, churches, gas stations, and municipal government office. Now there's talk of building an 820-kW hydroelectric plant, he says.

ATDER-BL must also contend with federal electricity regulations that allow Disnorte to charge the association retail rates for its electricity but to buy electricity from ATDER-BL at the lower wholesale rates. Nicaragua is in the process of reforming its renewable energy laws, and Leaf and her team are lobbying legislators for a more equitable arrangement.

Leaf may speak softly, but she has helped an entire region to speak for itself. And to sing. Irías laughs as he reaches the end of his song: "And with this I'll leave / Forgive the bad singing / Got to take care of the project / Which has cost us so much." ■

POST YOUR COMMENTS at http://spectrum.ieee.org/nicaragua0515

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®



THE FORGOTTEN HISTORY OF

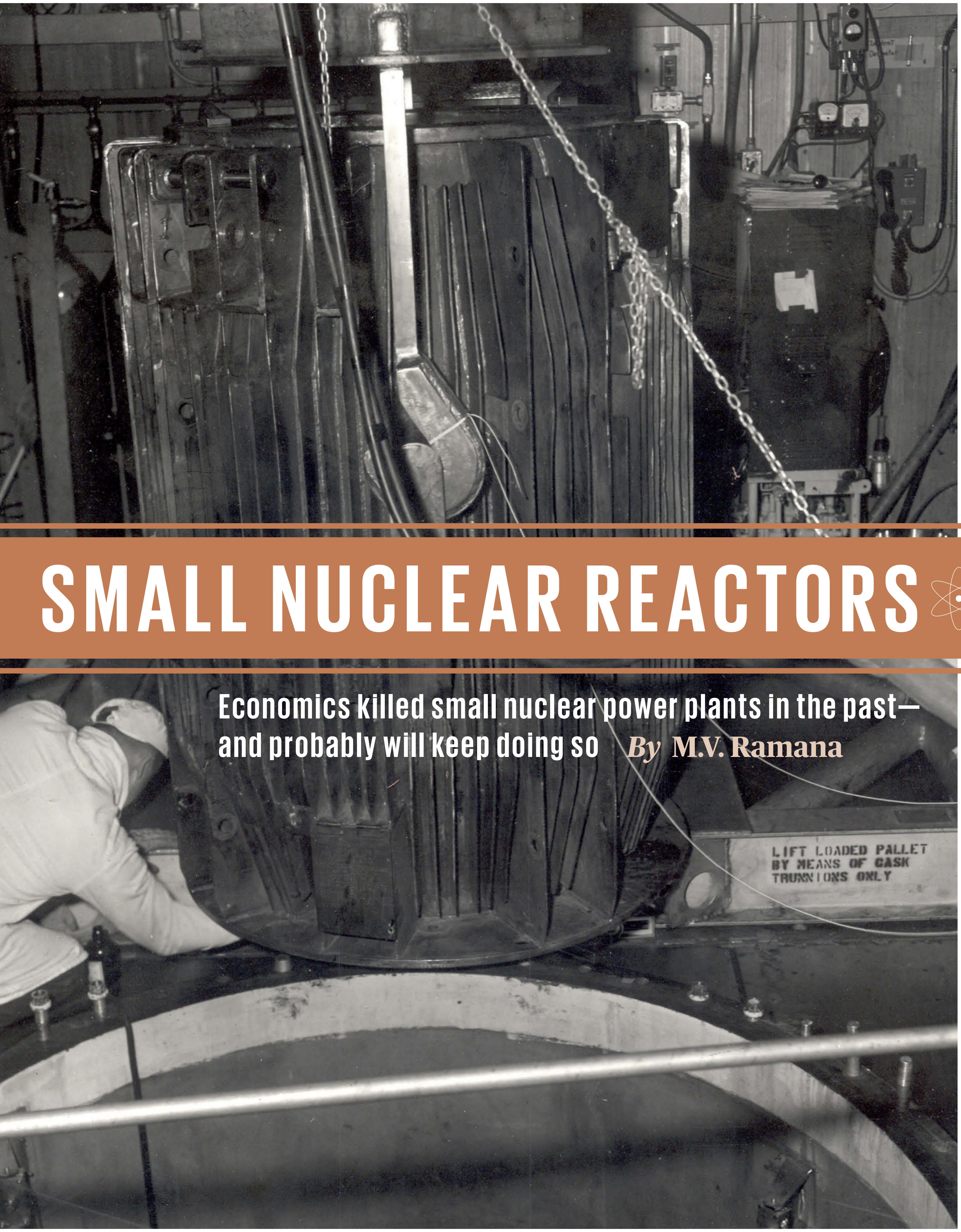
PM-3A • McMurdo Station, Antarctica

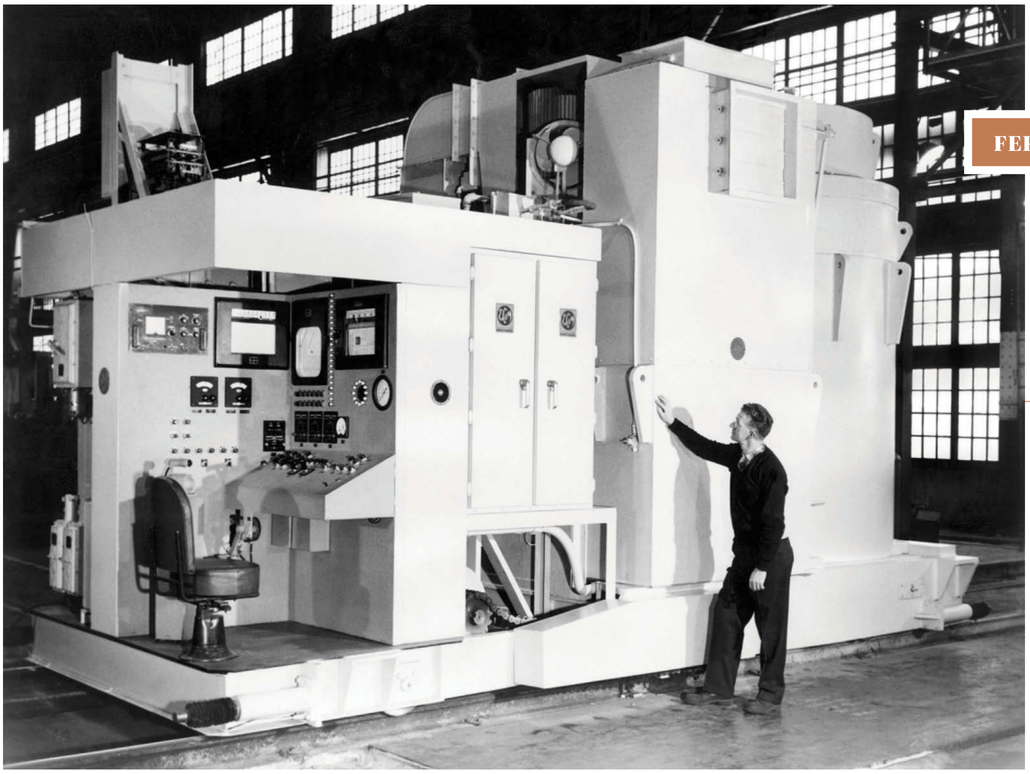
THE U.S. NAVY'S PM-3A NUCLEAR POWER PLANT WAS THE FIRST AND ONLY NUCLEAR REACTOR IN ANTARCTICA. IT WAS SHUT DOWN IN 1972, AFTER CRACKS AND LEAKS DEVELOPED IN THE CONTAINMENT VESSEL AND COOLANT PIPING. EVENTUALLY, THE CONTAMINATED COMPONENTS AND 14,400 METRIC TONS OF SOIL WERE SHIPPED TO CALIFORNIA FOR DISPOSAL.

SMALL NUCLEAR REACTORS

Economics killed small nuclear power plants in the past—and probably will keep doing so

By M.V. Ramana





FERMI-I • Newport, Mich.

THE ENRICO FERMI ATOMIC POWER PLANT, UNIT 1, WAS AN EARLY SMALL NUCLEAR REACTOR CONSTRUCTED WITH FUNDING FROM THE U.S. ATOMIC ENERGY COMMISSION. IT REACHED CRITICALITY IN 1963 AND OPERATED UNTIL 1972, DESPITE SUFFERING A PARTIAL MELTDOWN IN 1966.

A tantalizing proposition has taken hold again in the nuclear industry: that small nuclear reactors have economic and other advantages over the standard-size ones being built today. The idea is that by reducing the substantial financial risk of a full-scale nuclear project, small reactors are the best option for kick-starting a much-discussed revival of nuclear power.

Although concerns about climate change have led energy planners to retain nuclear power as an option, the technology remains in stasis or decline throughout the Americas and Europe. Two new nuclear projects now under way in the United States were the first to be awarded construction licenses in the country since the late 1970s. Globally, nuclear power produced about 11 percent of all electricity in 2013, down from its high of 17.6 percent in 1996, according to data from the *BP Statistical Review of World Energy 2014*. In the United States, the number of operating nuclear power plants has slipped below 100, with the recent shutdown of the Vermont Yankee plant.

A fundamental reason for this decline is indeed economic. Compared with other types of electricity generation, nuclear power is expensive. According to a 2014 report by the Wall Street advisory firm Lazard, the cost of generating a megawatt-hour of electricity from a new nuclear reactor (without considering government subsidies, including those for liability for severe accidents) is between US $92 and $132. Compare that with $61 to $87 for a natural-gas combined-cycle plant, $37 to $81 for wind turbines, and $72 to $86 for utility-scale solar. Nuclear's high costs result directly from the very high costs of building a reactor—estimated by Lazard at $5.4 million to $8.3 million for each megawatt. These per-megawatt costs translate into billions of dollars. For example, the latest estimate for one of the two U.S. projects mentioned above—a pair of 1,117-MW reactors being built near Jenkinsville, S.C.—is $11 billion.

These costs were acknowledged in a 2012 brochure for an industry conference devoted to what are called small modular reactors (SMRs). Noting the "huge billion dollar challenges" posed by traditional nuclear plants, the brochure declared that "Small Modular Reactors are the perfect solution to this problem by mitigating billions in financial risk, growing incrementally with power demand and offering shorter and easier construction schedules.... The SMR market is global and extremely vast.... In short the power industry is crying out for commercial SMR projects throughout the world."

If it is, the power industry is likely to be disappointed. Small reactors, in fact, date back to the earliest days of atomic power, and this long history shouldn't be overlooked as vendors tout new generations of the technology. As the history makes clear, small nuclear reactors would be neither

PREVIOUS PAGES: LEFT: U.S. NAVY/NATIONAL SCIENCE FOUNDATION (2); RIGHT: U.S. NAVY SEABEE MUSEUM. THIS PAGE: EVERETT COLLECTION/ALAMY as cheap nor as easy to build and operate as their modern proponents are claiming they would be.

SMRs HAVE OUTPUTS of anywhere from 10 to 300 MW. Compare that with the 860-MW average of the most popular reactor types now operating around the world and the 980-MW average of the reactors under construction. Although some of the dozens of new small reactor designs take novel approaches, many of them, especially the ones most likely to be licensed for construction first, are just variations on the familiar light-water reactor. The cost of SMRs can be kept low, proponents say, in part by using factory-fabricated modules, which would require only limited assembly at the site of the power plant itself.

The basic idea actually dates to the 1940s, when the U.S. Air Force, Army, and Navy each initiated R&D on various types of small reactors. From 1946 to 1961, the Air Force spent more than $1 billion trying to build a reactor to power long-range bombers–to no avail. In canceling the program, President John F. Kennedy wrote, "The possibility of achieving a militarily useful aircraft in the foreseeable future is still very remote."

The Navy had better success with developing nuclear power for its aircraft carriers and submarines. But these have quite different requirements from today's SMR proposals. A submarine reactor is designed to operate under stressful conditions–to provide a burst of power when the vessel is accelerating, for example. And unlike civilian power plants, naval nuclear reactors don't have to compete economically with other sources of power production. Their overwhelming advantage is that they enable a submarine to remain at sea for long periods of time without refueling.

Of the U.S. military's early small reactors, the ones that are most comparable to what's being discussed today came from the Army Nuclear Power Program. It led to the construction of eight small reactors. Several of these were located in the same types of isolated spots that are now being proposed as potentially attractive sites for SMRs: Antarctica, Greenland, and remote Army bases.

The experience at these sites was not encouraging. The PM-3A at McMurdo Station in Antarctica, for example, "developed several malfunctions, including leaks in its primary system [and] cracks in the containment vessel that had to be welded," according to the official history of the program by Lawrence H. Suid. The leaks from the plant (which was owned and operated by the U.S. Navy) resulted in significant contamination, and 14,400 metric tons of soil were removed and shipped to Port Hueneme, a naval base north of Los Angeles, for disposal.

Unlike the Navy's submarine reactors, the Army reactors could be displaced by conventional diesel generators, and in 1976 the Army canceled the program. As Suid writes, the Army concluded "that the development of complex, compact nuclear plants of advanced design was expensive and time consuming...that the costs of developing and producing such plants are in fact so high that they can be justified only if the reactor has a unique capability and fills a clearly defined objective backed by the Department of Defense...[and that] the Army and the Pentagon had to be prepared to furnish financial support commensurate with the AEC's [U.S. Atomic Energy Commission's] development effort on the nuclear side."

AS IT HAPPENED, the AEC (predecessor of the U.S. Department of Energy and the Nuclear Regulatory Commission) was keenly interested in small reactors. Starting in the 1950s, a number of civilian small reactors were proposed in the United States, and eventually 17 reactors with power outputs of less than 300 MW were commissioned. None of them are in operation today.

Many of these projects were supported by the AEC, which promoted nuclear power to U.S. utilities. Its first round of funding, announced in January 1955, went toward small units that could serve as "prototype reactors that would contribute to the development of large reactors," wrote Wendy Allen in her 1977 report *Nuclear Reactors for Generating Electricity: U.S. Development From 1946 to 1963*.

Of the four proposals submitted, the AEC funded three: the Yankee (not to be confused with the later and much larger Vermont Yankee), Dresden-I, and Fermi-I. Of these, Fermi is the best known, because it suffered a meltdown in 1966, which was colorfully described in John G. Fuller's 1975 book *We Almost Lost Detroit* and Gil Scott-Heron's song of the same title. The other two reactors were relatively successful in meeting the goals they aimed for. The 185-MW Yankee, also known as Yankee Rowe, operated for 31 years; its decommissioning, however, took 16 years and cost $608 million.

As mentioned, the AEC viewed these reactors as prototypes of bigger things to come. It preferred large reactors to small ones for a simple reason: economies of scale. Many of the expenses associated with constructing and operating a reactor do not change in linear proportion to the power generated. For instance, a 400-MW reactor requires less than twice the quantity of concrete and steel to construct as a 200-MW reactor, and it can be operated with fewer than twice as many people. Writing in *Science* in 1961, a senior member of the AEC worried that "competition [from fossil fuel plants] is indeed formidable" and suggested that "with current pressurized-water reactor technology, lower nuclear power costs can be achieved most readily with large plants."

Belief in scale economies was so strong within the electrical industry that in the early 1960s, some utilities banded together to absorb the output of a large nuclear power plant.

In the face of this prevailing wisdom, proponents of small reactors pinned their hopes on yet another popular commercial principle: "economies of mass production." For instance, Samuel B. Morris, the general manager and chief engineer of Los Angeles's Department of Water and Power, traveled all the way to Geneva in 1955 to attend the first International Conference on the Peaceful Uses of Atomic Energy. There, he made a case for small reactors, arguing that because the "number of small units...is many times the number of large units," there could be "economy in development and repetitive manufacture" of the small units.

ELK RIVER • Elk River, Minn.

ELECTRICITY FROM THE SHORT-LIVED 22-MEGAWATT ELK RIVER POWER REACTOR COST TWICE AS MUCH AS THAT FROM A COAL-FIRED PLANT. IT OPERATED FOR JUST THREE AND A HALF YEARS AND WAS SHUT DOWN FOR GOOD IN FEBRUARY 1968, AFTER CRACKS APPEARED IN THE COOLING SYSTEM PIPING.

NUCLEAR REGULATORY COMMISSION (2)

Meanwhile, representatives from the smaller electric utilities, including those in rural areas, argued that the AEC's focus on large reactors effectively excluded them.

CONFRONTED WITH SUCH ARGUMENTS and wanting to extend nuclear power to regions that could not support large reactors, the AEC announced in September 1955 a second round of funding. This time, small reactors were the goal, not a means to an end. The commission received seven proposals, of which it funded two: a 22-MW reactor in Elk River, Minn., about 50 kilometers northwest of Minneapolis, and a 12-MW reactor near the town of Piqua, Ohio. Two more reactors were later added to the program: the Boiling Nuclear Superheater (Bonus) reactor in Punta Higuera, Puerto Rico, and the La Crosse boiling water reactor in Genoa, Wis.

Elk River was heralded by its operator as "Rural America's First Atomic Power Plant." Much like the SMRs envisioned now, it was made from prefabricated components, and its reactor vessel was compact enough to be shipped to the site on a standard railroad flat car.

The reactor design was a variant of the boiling water reactor, which is the second most common reactor type today. But its fuel was unusual, consisting of a mixture of highly enriched uranium (which had more of the chain-reacting isotope uranium-235 than was typical for nuclear fuel) and thorium. Many experts considered thorium to be the hope for nuclear power in the long run, in part because they feared uranium would run out; to this day, some still believe thorium to be the answer to all of nuclear energy's problems.

At the congressional hearings on the power demonstration program, O.N. Gravgaard, president of the Rural Cooperative Power Association, which was building the plant, stated, "We in rural power started out from scratch, out of necessity. Power was not available several years ago.... We in rural power will do everything to make this reactor a financial success."

Construction of Elk River began in January 1959, and the reactor reached criticality in November 1962. But it wasn't declared as operating commercially until July 1964, three and a half years behind schedule. The lengthy delay resulted from various engineering problems, including cracks in some components. According to congressional hearings in 1967, Elk River's construction cost more than doubled, from $6.2 million to $16 million. To be sure, other reactors built then and later ended up costing at least three times their initial estimates; in comparison, Elk River looked pretty good.

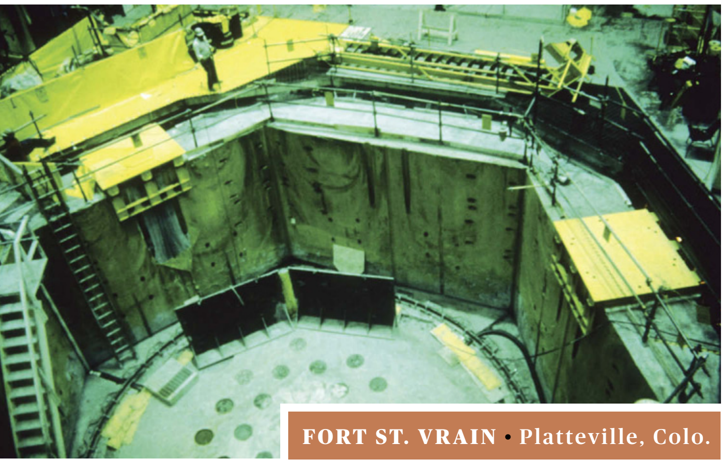
FOR A REACTOR THAT TOOK more than five years to complete, Elk River had a remarkably short operating life: just three and a half years. The reactor was shut down for good in February 1968 after cracks appeared in the cooling system piping. Faced with repair costs estimated at $1 million, the cooperative chose not to fix it. A spokesperson for the co-op told the *Chicago Tribune* that the group "didn't feel we wanted to spend the money, especially since the reactor has not been too economical because it is too small," adding that the reactor had produced power at twice the cost of power from coal-fired plants.

As noted by the nuclear physicist Walt Patterson in his 1976 book *Nuclear Power*, Elk River became the first demonstration power reactor to be decommissioned. Because the reactor vessel was quite radioactive, decommissioning required the development of new underwater torches that were manipulated remotely to cut up the thick steel structure. The process took three years and cost $6.15 million, which was almost the same figure as the initial estimate for construction.

Dealing with the irradiated uranium-thorium fuel proved difficult too. Eventually, the spent fuel was shipped to a reprocessing plant in southern Italy.

In 1968, the same year Elk River shut down, the last of the AEC's small reactors was connected to the grid: the 50-MW La Crosse boiling water reactor. That plant operated for 18 years; by the end, its electricity cost three times as much as that from the coal plant next door, according to a 2012 news account about the disposal of the plant's spent fuel. In the article, a former plant manager was quoted as saying that the La Crosse plant "had a great design. The only problem was it was too small."

Since then, not a single small reactor has been commissioned in the United States. Indeed, reactor size in the United States ballooned, reaching the 800- to 1,300-MW level by the mid-1970s.



FORT ST. VRAIN • Platteville, Colo.

THE 330-MEGAWATT FORT ST. VRAIN NUCLEAR GENERATING STATION HAD A HIGH-TEMPERATURE GAS-COOLED REACTOR DESIGN DEEMED TO BE "ULTRASAFE." HOWEVER, IT RARELY OPERATED AT FULL CAPACITY AND WAS SHUT DOWN IN 1989.

NUCLEAR REGULATORY COMMISSION

The one exception to this growth trend was an experimental 330-MW high-temperature gas-cooled reactor, the Fort St. Vrain plant in Platteville, Colo. It came on line in 1976, with a design promoted as being ultrasafe. But the reactor was a failure. A *New York Times* article about the 1988 decision to shut it down captured the gist of the problem: "Safest Reactor Is Closing Because It Rarely Runs." Data from the International Atomic Energy Agency showed that the plant produced about 15 percent of the electricity it would have if it had run at full capacity.

Small reactors were constructed in many other countries too, but all of them served as stepping-stones to larger reactors. The country with the most recent experience with small reactors is India, which until recently was still constructing 220-MW heavy-water reactors. These fit many of the characteristics of today's SMRs as envisioned by proponents: modest size and a relatively standardized design that was manufactured and operated by a single utility and its partners. Nevertheless, the Indian atomic energy establishment decided to scale these up to generate 700 MW or more. The bottom line: Economies of scale were not peculiar to the United States.

What was and is peculiar to the United States and explains the country's greater interest in small reactors is that its nuclear plants are operated by private utilities; in most countries, government-controlled organizations run the nuclear reactors. Private utilities have more stringent budgets and face tighter capital constraints, hence the attraction of a potentially cheaper nuclear reactor. To the extent that other countries have been interested in developing small reactors, it is mostly with an eye toward the export market.

THE DREAM OF SMALL NUCLEAR REACTORS did not die with the 1960s. In the 1980s, the nuclear industry was reeling from high cost and schedule overruns in reactor construction that had begun in the previous decade. And so, proponents of nuclear power circled back to the idea of going small.

A 1983 paper in the journal *Energy* by analyst Joe Egan offered his vision of small, prefabricated reactors. "A novel, factory-based approach to manufacturing reactors under 400-MWe size may alleviate many of the pragmatic constraints on nuclear business," he wrote, suggesting that "prefabrication and standardization of major plant components could lower dollar-per-kilowatt capital costs to levels now boasted by 1,000-MW models." Such factory assembly could further reduce costs, he wrote, by reducing regulation, shortening construction times, and avoiding quality issues with components.

"The reactors, once assembled on barges (or even railroad cars, in one case), would be floated across oceans, up rivers, or be carted cross-country to operating sites," Egan added. "There, purchasers would anchor the plants and simply 'turn the key' for 200–400 MWe of instant power."

This vision never materialized. No turnkey reactors were carted cross-country or floated up rivers. Then, as earlier, they were deemed too expensive.

Sadly, the nuclear industry continues to practice selective remembrance and to push ideas that haven't worked. Once again, we see history repeating itself in today's claims for small reactors—that the demand will be large, that they will be cheap and quick to construct.

But nothing in the history of small nuclear reactors suggests that they would be more economical than full-size ones. In fact, the record is pretty clear: Without exception, small reactors cost too much for the little electricity they produced, the result of both their low output and their poor performance. In the end, as an analyst for General Electric pronounced in 1966, "Nuclear power is a big-plant business: it is most competitive in the large plant sizes." And if large nuclear reactors are not competitive, it is unlikely that small reactors will do any better. Worse, attempts to make them cheaper might end up exacerbating nuclear power's other problems: production of long-lived radioactive waste, linkage with nuclear weapons, and the occasional catastrophic accident. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/smallnukes0515

THE QUEEN OF CARBON

Electronics made from nanoscale tubes, wires, and sheets of carbon are coming, thanks to pioneering researcher Mildred Dresselhaus

By Mark Anderson

BEFORE SILICON GOT ITS OWN VALLEY, THIS mild-mannered element had to vanquish many other contenders to prove itself the premier semiconductor technology. It did so in the 1950s and 1960s. Today, carbon is poised at a similar crossroads, with carbon-based technologies on the verge of transforming computing and boosting battery-storage capacities. Already, researchers have used these technologies to demonstrate paper-thin batteries, unbreakable touch screens, and terabit-speed wireless communications. And on the farther horizon they envision such carbon-enabled wonders as space elevators, filters that can make seawater drinkable, bionic organs, and transplantable neurons.

Whatever miracles emerge from Carbon Valley, its carbon-tech titans will surely think fondly upon their field's founding mother, Mildred Dresselhaus. This MIT professor of physics and engineering has, since the early 1960s, been laying the groundwork for networks of nanometer-scale carbon sheets, lattices, wires, and switches. Future

PHOTOGRAPH BY Mike McGregor

engineers will turn these things, fabricated from carbon-based materials such as graphene, into the systems that will carry computing into its next era.

Now, after a half century of quiet work, she is accumulating accolades. This past November, in a ceremony at the White House, President Obama awarded her the Presidential Medal of Freedom, the U.S. government's highest civilian honor. "Her influence is all around us, in the cars we drive, the energy we generate, the electronic devices that power our lives," Obama said.

And this June, the IEEE will confer upon Dresselhaus its highest accolade, the IEEE Medal of Honor, for her "leadership and contributions across many fields of science and engineering." She is the first female Medal of Honor recipient in the award's nearly century-long history. (Before the IEEE's formation, the Medal of Honor was presented by the Institute of Radio Engineers, which merged with the American Institute of Electrical Engineers in 1963 to form the IEEE.)

> "Her influence is all around us, in the cars we drive, the energy we generate, the electronic devices that power our lives"
> —Barack Obama

While Dresselhaus has blazed a path for researchers eager to exploit the magic of carbon computing, for most of her 84 years her own pathway has been anything but obvious. It was muddled by a world that had trouble accommodating a visionary engineering researcher who was also a caring and thoughtful mentor—as well as a mother of four (and today a grandmother of five).

The daughter of destitute Eastern European émigrés, a product of Great Depression and World War II–era New York City schools and their melting-pot culture, Dresselhaus (née Spiewak) as a child imagined that the only career open to her was that of schoolteacher. Even that was a bit of a stretch, given the time and place: The kids in her neighborhood and in her struggling primary school in the Bronx were mostly uninterested in their studies. But a mysterious force soon intervened. It was music.

Both her grandfather and great-grandfather served as town cantors in her father's ancestral village of Dzialoszyce, Poland. So when her older brother, Irving, began playing the violin with uncommon grace at age 4, his gift wasn't a complete surprise. Their parents secured a scholarship for him at New York City's prestigious Greenwich House music school. And when Mildred was herself 4 or 5, she began studying music there, too. Although she stopped taking lessons at Greenwich House at 13, she has never abandoned her beloved violin. Dresselhaus still plays every day. "I had his hand-me-down violin," she says. "I inherited all the things he left behind."

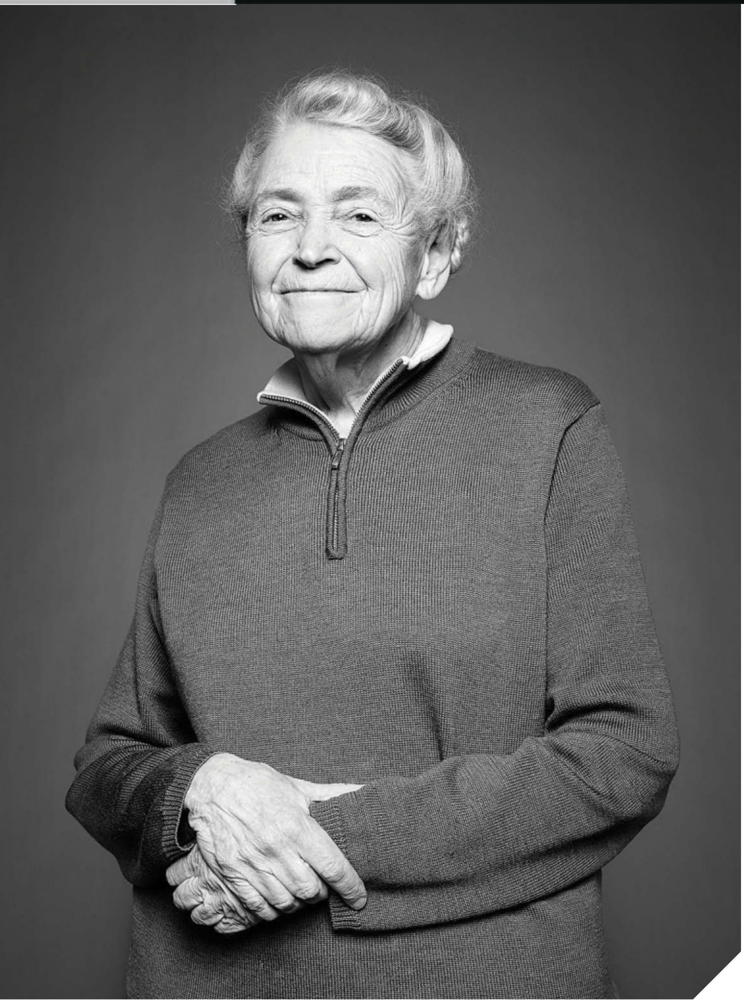
And it was music that brought her into contact with more ambitious peers at the Greenwich House school. "It was obvious—education was important," she says she realized not long after arriving at the school, in 1934 or '35. "That was the most important lifelong thing I learned at the music school."

She would probably have again followed her brother's footsteps several years later, into the legendary Bronx High School of Science, but in those days Bronx Science was for boys only. So she set her sights on Hunter College High School, a New York City preparatory school for girls. While studying for her entrance exam, she discovered to her delight how easily math came to her. "My interest was inspired by studying—by myself and motivated by myself—math for the entrance exam to Hunter High," she says.

At Hunter, she did so well in math and science that a poem in Dresselhaus's senior yearbook pays tribute to her abilities: "Any equation she can solve / Every problem she can resolve / Mildred equals brains plus fun / In math and science, she's second to none." She went on to study at Hunter College, where, during her second year, another important force entered into her life.

"Rosalyn Yalow's [physics] course got me more into focusing on the science profession," Dresselhaus says of the course she loved most at Hunter, which was taught by a medical physicist who would soon herself decamp for a research career and ultimately share the 1977 Nobel Prize in Physiology or Medicine. "That's where I really got started. And Rosalyn insisted that I go to graduate school. She was a person who used to tell you what you were doing."

Bolstered by Yalow's effusive letters of recommendation, Dresselhaus was admitted to Radcliffe College in 1951 for graduate studies, an admission deferred so that she could attend the University of Cambridge on a Fulbright fellowship.



"He was a methodical guy; he always did the same thing every day," Dresselhaus says. On the morning walks, for example, Fermi would talk about the issues on his mind–sometimes related to the day's lecture, sometimes not. And when Fermi gave his talks, he'd first hand the class copies of his notes. "He didn't want people taking notes while he [lectured]. He wanted people to listen. He'd give you the notes. The lecture [notes] didn't have many pages. Very concise."

Fermi, who died in November 1954, during Dresselhaus's second year at Chicago, still had an outsized influence on the young woman during her brief time in his orbit. "He developed in me the mind-set that we should be interested in everything," she says, "because we never know where the next big breakthrough in science will occur."

In the fall of 1955, Dresselhaus began her Ph.D. project, investigating the microwave properties of a superconductor in a magnetic field. The novel and hybrid nature of her investigation–involving low-temperature and solid-state physics, electrical engineering, and materials science–meant she couldn't just order the parts for her research out of a catalog.

She found much of what she needed, though, under the university's football stands, where more than a dozen years before, Fermi had led a group that had created the world's first man-made nuclear-fission chain reaction. There, a mountain of surplus equipment was free for the taking. Repurposing a warehouse worth of materials, she grew superconducting wire for her experiments, built microwave equipment, and even produced liquid helium.

Dresselhaus says she'd developed that kind of gumption because her primary school teachers were terrible. "They were sufficiently bad that if you wanted to learn something, you taught yourself," she says. "That was terrific training."

While at Chicago, she met her future husband, fellow graduate student Gene Dresselhaus. They married in May 1958 and moved to Ithaca, N.Y., where she was a National Science Foundation postdoctoral fellow and Gene had an entry-level faculty position in the physics department at Cornell University. There Dresselhaus also met another celebrity scientist, albeit one whose great fame would come years later–Richard Feynman. At the time, Feynman was developing the equations that would become the quantum theory of electrodynamics.

"He gave a lecture now and then," she says. "And if there's a Feynman lecture, you go to it. It's always interesting, looking at things you've heard about before but from a totally different perspective."

Also in 1959, the Dresselhauses welcomed their first child, Marianne. And despite the stimulating Feynman lectures Dresselhaus occasionally attended, Cornell wasn't exactly a female academic's dream in those days. Early on, a faculty

"Radcliffe had no [science] classes," Dresselhaus explains. "The classes were at Harvard. But the exams were at Radcliffe. Women didn't take their exams with the men. I had to take my exams by myself in a different room. It was a very complex situation and not a very comfortable one."

During her first year at Harvard, Dresselhaus realized she was growing weary of the university and a bit restless. She'd discovered that the best place in the country to study physics was at the University of Chicago, home to Manhattan Project veteran and Nobel laureate Enrico Fermi. So in 1953, after finishing her master's degree at Radcliffe, she was off to Illinois.

At Chicago, too, Dresselhaus was often the only woman in her classes. But the learning environment wasn't as stifling. And it was at Chicago, she says, where she first really began to learn to think like a physicist, thanks to Fermi himself. Although by then famous for his role in the Manhattan Project, Fermi headed up a small and intimate physics department. In Dresselhaus's incoming class in 1953, for instance, there were just 11 physics students.

Fermi was an early riser, as was Dresselhaus, and they lived along the same walking route to campus. So she, along with other students, faculty, and acolytes, timed their morning commute so they could stroll along with the legendary physicist.

PHOTOGRAPH BY Mike McGregor

member told her point blank that no woman would ever be permitted to lecture to his engineering students.

So in 1960 the two Dresselhauses went to MIT's Lincoln Laboratory. There she moved out of superconductors, her thesis topic, and began looking instead at magnetic and optical properties of graphite, bismuth, and other so-called semimetals. This field, she says, wasn't popular or very competitive at the time, which gave her the latitude she needed to have four children (one daughter and three sons) through 1964. As a working mother, however, she encountered some bumps in her career progress.

One Lincoln Lab colleague, H. Eugene Stanley (now a professor of physics, chemistry, biomedical engineering, and physiology at Boston University) recalls the day after Dresselhaus delivered her youngest child, Eliot, in 1964.

"When she had her fourth kid," recalls Stanley, "she brought him to work the day after he was born. She was there around noon or 1 o'clock with the baby in tow. But because Lincoln Lab was a government lab, you either had to have clearance or have a badge. They wouldn't let the kid in. She was furious! I didn't see her angry that often, but I saw her angry that day."

Dresselhaus crossed from Lincoln Lab to parent institution MIT in 1967, accepting a visiting professorship in electrical engineering, a position that became permanent the following year. She added a joint appointment in physics in 1983.

"When I first came to MIT, the [physics] department was only interested in high-energy physics," she says of a field that was then consumed with colliding subatomic particles at ever-higher energies. She adds that more quotidian fields of physics, from materials science to engineering physics, were on the back burner at the time. "It's all totally different now.... There's a big shortage of people [who] have a physics background and engineering also."

On a snowy day in the middle of one of Cambridge's harshest winters ever, Dresselhaus holds forth in her MIT office on her favorite topic. "Consider a simple sheet of carbon atoms, also known as graphite," she begins.

She pulls down a well-worn ball-and-stick-model from atop one of her cabinets. "Carbon's crystal structure is such that the in-plane force is the strongest in nature," she says. "But across the plane it's very weak. So it allows separation of layers very easily."

A pencil's graphite flakes off easily without disintegrating, and yet it can still cling to rough, fibrous surfaces like paper. Individual sheets of graphite, in other words, are as tough as diamond. But as a group they're as flaky as phyllo dough.

Throughout the 1960s, 1970s, and 1980s, Dresselhaus and her graduate students investigated the properties of both graphite and carbon intercalation compounds–that is, sheets of graphite sandwiching individual bromine or potassium atoms, which were captured like olives between slices of bread. Her group also laid the foundation for the discovery and exploitation of nanotechnological wonder materials, such as the tiny carbon spheres known as buckminsterfullerenes, the cylindrical carbon pipes called nanotubes, and the single-atom-thick sheets of carbon called graphene.

Variations or combinations of these carbon structures could yield body armor stronger than Kevlar, ultrathin membranes with pores small enough to filter the salt from seawater, and even bionic implants that can give new hope to those with serious spinal-cord or organ damage. Used as electrodes in batteries or capacitors, graphene and nanotubes offer promise as a kind of ultimate energy storage system. Their charge capacities would exceed those of traditional batteries, and their charge times (on, say, an electric-vehicle battery) would be shorter than the time it takes to pump a tankful of gasoline.

And as a possible substrate for next-generation electronics, graphene has few competitors today. Its high conductivity (better than silver's) and its single-atom thickness make robust, molecule-size graphene circuit components boasting terahertz computing speeds a tantalizing if far-future possibility. "Graphene is not going to replace silicon; it's going to do different things," Dresselhaus says.

Although well into her 80s, Dresselhaus is at her MIT office every day, including weekends and holidays, often as early as 6 a.m. Her enthusiasm for her work, which these days includes studying optical, electric, and vibrational properties of graphene, carbon nanotubes, and other nanomaterials seems undiminished. "I am excited by my present research and am not yet anxious to stop working," she says, simply.

As she has for much of her MIT career, Dresselhaus also mentors young people, especially women starting careers in STEM. She has supervised the theses of more than 60 doctoral students and shepherded many more colleagues and associates through career transitions and inflection points.

"One time at MIT, she told me she was working with this great [Ph.D.] student named Shirley Ann Jackson," says Laura Roth, Dresselhaus's former colleague at Harvard and Lincoln Lab. "And now she's president of Rensselaer Polytechnic Institute." (Jackson has herself earned 52 honorary degrees and been called by *Time* magazine "perhaps the ultimate role model for women in science.")

Says Gang Chen, head of the mechanical engineering department at MIT, "Four women from my own group...benefitted from Millie's support during their stay at MIT. On several occasions, Millie volunteered to talk to my female students, giving them individual career advice.

"On one hand, it seems to be quite late for the first woman to receive the IEEE Medal of Honor," Chen adds. "On the other hand, no one is more fitting than Millie, and she has set a truly high bar. I am sure Millie's receiving this honor will inspire more women in IEEE to strike high." ■

POST YOUR COMMENTS at http://spectrum.ieee.org/dresselhaus0515

A SENTINEL FOR SPACE

CONTINUED FROM PAGE 33 | of the sky to another 15 times an hour, collecting light for 3 minutes at each spot. This same observing sequence will be precisely repeated in the next hour. Then the telescope's computer will compare each pair of images of the same patch of sky.

An NEO won't look much different than a star on a given snapshot, but it will move many pixels in that 1-hour interval. When two images taken 1 hour apart indicate a change, the onboard computer will store the 5-by-5-pixel area surrounding the change in both images. The observatory will then move to a new set of 15 areas of the sky for the next 2 hours, and then on to another set after that.

We expect there to be numerous spurious detections due to variable stars, main belt asteroids, charge deposited by cosmic rays, and other noise sources. But the protocol we've devised for content-driven data compression–saving only those areas of an image that show a change–should allow us to cast the net wide and still be able to send data back to Earth on anything that could potentially be an NEO. A typical space telescope might compress data by a factor of two or three. We'll save only 1/1,000 of the data we collect. This reduction in data will help compensate for the paltry transmission rates you get with an antenna so far from Earth. It will also minimize how much time we'll need to listen on the ground. NASA has agreed to let the B612 Foundation use the agency's Deep Space Network, a global group of giant parabolic-dish antennas that are used to pick up spacecraft transmissions from all over the solar system. Time is a precious commodity on the network. With our image-processing strategy, we can store data for a week and then download it all (about 4 gigabytes) in a relatively economical 4 hours.

Astronomers at the University of Colorado Boulder's Laboratory for Atmospheric and Space Physics will be the first to comb through the data. They will examine the pairs of images taken an hour apart to hunt for moving objects. Then they'll compare these detections with ones taken two days later to see if any might correspond to physically possible orbits. Those detections that pass this test will be passed on to the Minor Planet Center of the Smithsonian Astrophysical Observatory, in Cambridge, Mass., which manages a huge database of all NEO observations. There astronomers will calculate an orbit for each object and send their results to the NEO Program Office at NASA's Jet Propulsion Laboratory, in Pasadena, Calif., which projects orbits forward in time to look for stuff that could hit Earth. If NASA finds something, its office will issue a notice, and professional and amateur astronomers will be able to follow up with ground-based observations to improve our knowledge of the object's orbit and get a better fix on the threat.

Sentinel will also be able to pause its planned survey to take a closer look at objects of interest.

SENTINEL IS STILL in the very early stages. This year, we'll finalize the engineering requirements for the Sentinel spacecraft and sign a firm fixed-price contract–one where all the costs are agreed upon up front–with Ball for spacecraft construction and operation. If our fund-raising efforts keep moving forward as they have, we will launch the spacecraft in 2019.

Once the mission begins, we should see a flood of new NEO detections. Based on Sentinel's position and sensitivity, we expect it to turn up 200,000 NEOs smaller than 30 meters, 200,000 between 30 and 50 meters, and some 100,000 that are 50 meters or larger. In less than seven years, the telescope will be able to meet NASA's goal of finding 90 percent of objects 140 meters or larger.

Of course, Sentinel's survey will be nowhere near complete. For the hundreds of thousands of NEOs larger than 30 meters Sentinel will find, there are many more that it won't. But any one of the NEOs that Sentinel does detect could easily be on a collision course with Earth. We calculate that there is about a 30 percent chance that Sentinel will find an impactor that will hit Earth sometime this century. And there will be others that will require detailed follow-up observations to know with certainty that they will miss us.

If Sentinel finds an object that looks likely to hit Earth, there are still many open questions about what we might do about it. Pushing or pulling on the object might divert it from a collision course, but even the most powerful form of deflection–a nuclear explosion–will require years of advance notice to engineer. Complicating matters is the fact that long-term predictions are difficult.

POST YOUR COMMENTS at http://spectrum.ieee.org/sentinel0515

NEOs move around as they are pushed by the sun's radiation and as they spin and reemit that radiation into space. These effects are hard to model precisely; the farther out in time we project an object's orbit, the more uncertain that projection becomes. We won't want to do anything to an asteroid's path until we can be quite certain that we won't risk making the situation worse. It may be that the best response is to monitor the object carefully and evacuate the area it will hit.

That said, the debate over these various courses of action will only be a theoretical exercise until we're faced with a real threat. And the only way to know whether there is a threat is to go out and find it–before it finds us. ■

IEEE

CANDIDATES IN 2015 ELECTION

THE IEEE BOARD OF DIRECTORS has received the names of the following candidates to be placed on this year's ballot. The candidates have been drawn from recommendations made by regional and divisional nominating committees. In addition, the names include candidates for positions in the IEEE Standards Association, IEEE Technical Activities, and IEEE-USA.

For more information on IEEE elections and candidates, please visit http://www.ieee.org/elections or e-mail election@ieee.org.

Electronic ballot access and paper ballot packages will be mailed on or before 17 August to all IEEE members who are eligible to vote as of 30 June. To ensure all ballot packages are delivered to the proper mailing address, please visit http://www.ieee.org/go/my_account and update your member profile if necessary.

IEEE PRESIDENT-ELECT, 2016
Karen Bartleson
Frederick "Fred" C. Mintzer

DIVISION II DELEGATE-ELECT/DIRECTOR-ELECT, 2016
Hulya Kirkici
F.D. "Don" Tan

DIVISION IV DELEGATE-ELECT/DIRECTOR-ELECT, 2016
John T. Barr
Jennifer T. Bernhard
Tapan K. Sarkar

DIVISION VI DELEGATE-ELECT/DIRECTOR-ELECT, 2016
John Y. Hung
Luke R. Maki

DIVISION VIII DELEGATE-ELECT/DIRECTOR-ELECT, 2016
Dejan S. Milojicic
Arnold N. Pears

DIVISION X DELEGATE-ELECT/DIRECTOR-ELECT, 2016
Toshio Fukuda
John R. Vig

REGION 1 DELEGATE-ELECT/DIRECTOR-ELECT, 2016–2017
Babak Dastgheib-Beheshti
Gim Soon Wan

REGION 3 DELEGATE-ELECT/DIRECTOR-ELECT, 2016–2017
John E. Montague
Gregg L. Vaughn

REGION 5 DELEGATE-ELECT/DIRECTOR-ELECT, 2016–2017
T. Scott Atkinson
Robert C. Shapiro

REGION 7 DELEGATE-ELECT/DIRECTOR-ELECT, 2016–2017
Xavier N. Fernando
Maike Luiken

REGION 9 DELEGATE-ELECT/DIRECTOR-ELECT, 2016–2017
Jose-Ignacio Castillo-Velazquez
Enrique A. Tejera M.

IEEE STANDARDS ASSOCIATION PRESIDENT-ELECT, 2016
Robert S. Fish
Forrest D. "Don" Wright

IEEE STANDARDS ASSOCIATION BOARD OF GOVERNORS MEMBER-AT-LARGE, 2016–2017
W.C. "Chuck" Adams
Philip B. Winston

IEEE STANDARDS ASSOCIATION BOARD OF GOVERNORS MEMBER AT-LARGE, 2016–2017
Stanley J. Krolikoski
Paul Nikolich

IEEE TECHNICAL ACTIVITIES VICE PRESIDENT-ELECT, 2016
Marina Ruggieri
Douglas N. Zuckerman

IEEE-USA PRESIDENT-ELECT, 2016
Keith D. Grzelak
Karen S. Pedersen

IEEE-USA MEMBER-AT-LARGE, 2016–2017
Eric S. Ackerman
Wole Akpose
Daniel N. Donahoe

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

Experimental Power Grid Centre
A*STAR

Experimental Power Grid Centre (EPGC), Singapore

Increased penetration of distributed energy resources such as solar and wind has resulted in the need for solutions to counter the intermittency issues and ensure a grid that is reliable and robust. The need for better management of assets and reduced system down-time highlights the importance of research in self diagnosis and condition monitoring. These are some of the problems that EPGC is addressing by maintaining key domain expertise in Power Systems and Power Electronics.

Coupled with advanced simulation capabilities and a unique experimental grid facility, EPGC provides a platform for industry to tap on, to locally develop solutions for a global market.

The Experimental Power Grid Centre is a world-class facility specially mandated to lead A*STAR's efforts in developing new technologies for the intelligent and decentralised power distribution, interconnection and utilisation. Opened on 1 Nov 2011, the facility is sited on Jurong Island with the following features:

- An experimental power grid that can operate in islanded, grid-connected or power grid emulator connected mode.
- Power network that is able to reconfigure to various topologies such as radial, serial or loop.
- Test bays to accommodate additional experimental stations.
- Fuel infrastructure for addition of novel energy sources.
- Power electronics laboratory for development of hardware prototypes.
- Real-time simulator with hardware-in-loop capabilities.
- Real-time monitoring and control of experimental power grid.

EPGC invites application for the position of Deputy Director with the following capabilities:

Candidates should have 10-12 years experience in field of research related to Power Systems in areas of planning and optimisation, transmission, distribution, of which 3-5 years should be in emerging areas, such as Smart Grids, Distribution System Automation.

Candidates with research experience in industry R&D or Research Institutes will be preferred.

Candidates should have demonstrated research leadership in one of the research areas listed above.

Job Description:

- Will lead a team of researchers in Power Systems.
- Will be responsible for skill development in core areas of the research team.
- Will lead a research programme in Power Systems.
- Will assist Programme Director in strategic planning and skill development.
- Will work with industry, A*STAR Research Institutes and Public Agencies and provide leadership in areas of Power Systems and Smart Grids.

Interested candidates are invited to apply online at

http://www.a-star.edu.sg/Careers/Career-Opportunities.aspx

by selecting SERC Careers and search under EPGC.

河北工業大学
HEBEI UNIVERSITY OF TECHNOLOGY

Faculty Position in Hebei University of Technology (Tianjin)

Located in Tianjin, Hebei University of Technology (HEBUT) is a key provincial university as well as one of the national universities under "Programme 211". The university was founded in 1903 in Tianjin. It specializes in all engineering and science disciplines studies with 42 disciplines authorized to award doctor degrees. HEBUT is the first engineering-based university to launch MBA program in China. Meanwhile, it is the only university in Hebei province that offers an EMBA education.

Academic Disciplines: The faculty positions are available in all disciplines of electrical and electronic engineering. The recruitment specially includes micro-nanoelectronics, electromagnetic and microwave, nanophotonics, communication, new energy, power engineering, computer engineering, big-data, and control engineering. The university also seeks the Director for Schools.

The positions are open at all levels from Assistant Professor to Distinguished Professor levels. Candidates with high qualification will be recommended for the National Talent Programme. All applicants are expected to have a PhD degree and high potential teaching and research. Salary and startup fund are highly competitive.

Applications with detailed CV, 3 representative publications and names of three referees to email: HR@hebut.edu.cn

By Oct 31, 2015. For more information, visit:

http://www.hebut.edu.cn

Faculty Openings in Electrical and Computer Engineering Texas Tech University

Texas Tech University. The Department of Electrical and Computer Engineering (ECE) is inviting applications for tenure track positions at the Assistant/Associate/Full Professor level. Our recruitment focus includes (a) **Computer Engineering** in the areas of **computer architecture**, **microprocessor** and **embedded systems** and (b) **Pulsed Power, Power Electronics, Power Systems, Transient Computational Electromagnetics,** or other closely related fields to complement a large existing Research Center.

Details can be found at **http://www.depts.ttu.edu/ece/department/jobs.php**. To be considered, all applicants must apply electronically through **http://www.texastech.edu/careers/**, Req. ID 3424BR for Computer Engineering position and Req. ID: 3422BR for Pulsed Power position. Copies of the applications should be emailed to search committee chairs: Andreas.Neuber@ttu.edu for the pulsed power position and Ranadip.Pal@ttu.edu for the computer engineering position.

As an Equal Employment Opportunity/Affirmative Action employer, Texas Tech University is dedicated to the goal of building a culturally diverse faculty committed to teaching and working in a multicultural environment. The university welcomes applications from minorities, women, veterans, persons with disabilities, and dual-career couples.

McMaster University

Tenure-stream Faculty Positions in Biomedical Engineering and Micro-Nano Systems

The Electrical and Computer Engineering Department at McMaster University invites applications for tenure-stream positions in Biomedical Engineering, and Micro-Nano Systems. The successful applicants will have an earned PhD in a relevant discipline, and the potential for excellence in both research and teaching.

For full position details, please visit **http://www.eng.mcmaster.ca/postings_fulltime.html**

All qualified candidates are encouraged to apply. However, Canadian citizens and permanent residents will be given priority for these positions. McMaster University is committed to employment equity and to recruiting a diverse faculty and staff.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Laboratory Program Manager – Grid Integration

Requisition #4219BR

The National Renewable Energy Laboratory (NREL) Laboratory is seeking a Laboratory Program Manager (LPM) to manage all of NREL's activities in support of the Office of Electricity Delivery and Energy Reliability (OE) and the Office of Energy Efficiency and Renewable Energy (EERE).

For more information and to apply, please visit: **www.nrel.gov/careers** and search for **Req #4219**

MCCI
Microelectronic Circuits Centre Ireland

Microelectronic Circuits Centre Ireland (MCCI) is an EI and IDA Ireland funded technology centre hosted at Tyndall National Institute in collaboration with the University of Limerick. Its mission is to carry out world-leading analogue mixed-signal and RF integrated circuit research in collaboration with its twenty five industry partners. Applications include biomedical, agri-food and communications in technologies from 0.35um to 16nm. For more information, please look at **www.mcci.ie**

There are currently open research positions at all levels within MCCI including:

Principal Investigator IC Circuit Design – Head of Group
The Principal Investigator will report directly to the MCCI Director, will drive their own research roadmap and will head up a research group of scale to implement their vision. They will grow the group with high calibre talent to create a world recognised centre of excellence in Analogue and Mixed-Signal microelectronic circuit design. The Principal Investigator and their team will carry out innovative integrated circuit research which will have impact internationally including publications in leading conferences such as ISSCC.

Analogue Mixed-Signal IC Research Fellow
The Analogue Mixed-Signal research fellow will report to a Principal Investigator. Successful candidates will lead multiple MCCI research projects including hiring, supervision and mentoring of staff. They will drive the technical direction and innovation of projects in their area of expertise aligned with one of the MCCI research topics of high speed communications, data-converters or power management.

Faculty Positions in Robotics and in Computer Science

NAZARBAYEV UNIVERSITY

Nazarbayev University is seeking highly qualified full-time faculty members at Assistant, Associate and Full Professor ranks to join its rapidly growing programs in Robotics and in Computer Science at the School of Science and Technology. Successful candidates must have an earned Ph.D. degree from a reputable research university, a demonstrated ability for research, excellent English-language communication skills and a commitment to graduate and undergraduate teaching.

Launched in 2010 as the premier national university of Kazakhstan, NU's mandate is to promote the emergence of Astana as the research and educational center of Eurasia. The strategic development of this English-language university is based on the Western model via partnerships with top-ranked world universities. NU is committed to become a world-class research university and is making significant investments in research infrastructure, equipment and personnel.

Applications are particularly encouraged from candidates with research interests in biomechatronics, unmanned aerial vehicles, computer-aided design, manufacturing, advanced machining and industrial automation for the **Department of Robotics** and in intelligent systems, high-performance computing, sensor networks, bio-informatics and big-data for the **Department of Computer Science**. Exceptional candidates with research interests in other topics of Robotics and Computer Science are also encouraged to apply.

Benefits include an internationally competitive salary, international health care coverage, free housing (based on family size and rank), child educational allowance, and home-leave travel twice per year.

Applicants should send a detailed CV, teaching and research statements, and list of publications to **sst@nu.edu.kz**. Review of applications will begin immediately but full consideration will be given to applications submitted no later than **May 15th, 2015**. For more information, visit **http://sst.nu.edu.kz** .

IEEE *Access*
The **journal** for rapid **open access** publishing

Become a published author in 4 to 6 weeks.

IEEE *Access* is a multidisciplinary journal that allows you to:

- Publish articles in 4 to 6 weeks
- Expect the IEEE trusted peer review with a typical **one-third** acceptance rate
- Reach millions of global users through the IEEE *Xplore*® digital library with free access to all
- Submit multidisciplinary articles that do not fit neatly in traditional journals
- Integrate multimedia and track usage and citation data for each published article
- Connect with readers through commenting
- Publish without a page limit for **only $1,750** per article

IEEE *Access*... a multidisciplinary open access journal that's worthy of the IEEE.

Learn more at: **www.ieee.org/ieee-access**

IEEE Advancing Technology for Humanity

14-PUB-246 12/14

上海科技大学 ShanghaiTech University

ShanghaiTech Faculty Search

ShanghaiTech University invites highly qualified candidates to fill multiple tenure-track/tenured faculty positions in the School of Information Science and Technology. Candidates should have exceptional academic records or demonstrate strong potential in cutting-edge research areas of information science and technology. English fluency is required and overseas academic connection or background is highly desired. ShanghaiTech is built as a world-class research university for training future generations of scientists, entrepreneurs, and technological leaders. Besides establishing and maintaining a world-class research profile, faculty candidates are also expected to contribute substantially to graduate and undergraduate education.

Academic Disciplines:
We seek candidates in all cutting-edge areas of information science and technology. Our recruitment focus includes, but is not limited to: computer architecture and technologies, nano-scale electronics, high-speed and RF circuits, intelligent/integrated signal processing systems, computational foundations, big data, data mining, visualization, computer vision, bio-computing, smart energy/power devices/systems, next-generation networking, as well as inter-disciplinary areas involving information science and technology.

Compensation and Benefits:
Salary and startup funds are highly competitive, commensurate with experience and academic accomplishment. We also offer a comprehensive benefit package to employees and eligible dependents, including housing benefits. All regular ShanghaiTech faculty members will be within its new tenure-track system with international practice for performance evaluation and promotion.

Qualifications:
- A detailed research plan and demonstrated record/potentials;
- Ph.D. (Electrical Engineering, Computer Engineering/Science, or related field);
- A minimum relevant research experience of 4 years.

Applications:
Submit (in English, PDF) a cover letter, a 2-page research plan, a CV plus copies of 3 representative publications, and names of three referees to sist@shanghaitech.edu.cn by June 30, 2015. For more information, visit **http://www.shanghaitech.edu.cn.**

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

AND NOW THIS...

WHEN INTEGRATED CIRCUITS COULDN'T BE TRUSTED

In the 1960s, microelectronics were often unreliable

Today, few equipment manufacturers feel compelled to peer inside the little black boxes that litter modern circuit boards. But in the early days of ICs, reliability problems were common, as shown by this September 1967 ad for a Picker X-Ray microelectronics inspection machine. The machine is pictured in operation, checking incoming ICs at Grumman Aircraft Engineering Corp., now Northrop Grumman Corp. The company was an appropriate choice because at the time, Grumman was building lunar landers as part of NASA's Apollo program. The Apollo program was responsible for large improvements in the quality of ICs overall, as NASA and its contractors tracked down manufacturing problems that would otherwise threaten the ability to fly astronauts safely. **—STEPHEN CASS**

PHOTOGRAPH BY Randi Klett


F-35
AA-1