

**Bulletin
of the
Atomic
Scientists**

Annual
Report
2016

**It is
two and
a half
minutes
to
midnight**

The Mission

The *Bulletin of the Atomic Scientists* engages science leaders, policy makers, and the interested public on topics of nuclear weapons and disarmament, climate change, and emerging technologies. We do this through our award-winning journal, iconic Doomsday Clock, public access website, and regular set of convenings. With smart, vigorous prose, multimedia presentations, and information graphics the *Bulletin* puts issues and events into context and provides fact-based debates and assessments. For more than 70 years, the *Bulletin* has bridged the technology divide between scientific research, foreign policy, and public engagement.

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Letter from the Chair

Lee Francis



In 2016, NASA reported the warmest year globally since modern record-keeping began. Worldwide nuclear tensions increased as relations between the United States and Russia continued to deteriorate, and North Korea conducted two underground nuclear tests. The divisive 2016 US presidential election was marked by reckless rhetoric about nuclear weapons, climate change denials, and confusion about cyber-technology and artificial intelligence.

Through it all, we at the *Bulletin of the Atomic Scientists* stepped up our programming and added features to our website attracting more visitors, subscribers, and donors than ever before in more than seven decades of service. Keenly aware of growing uneasiness and concern, we maintained a sharp focus on nuclear issues, climate and energy, and threats from emerging technology, bringing together the best scientific research and public policy analysis in the hope of creating a safer and healthier planet.

The precarious nature of that hope became increasingly clear by the end of 2016. Our Science and Security Board made the decision to move the Doomsday Clock to two and a half minutes to midnight, an unprecedented step that is described in the statement beginning on page 10.

On behalf of the Governing Board, the Science and Security Board, and the Board of Sponsors, I extend our gratitude to the stakeholders who increased their own support as our small but mighty staff worked tirelessly to meet the increased expectations of an anxious world, hungry for facts and reason.



In addition to pushing out a world-class bimonthly journal, and maintaining a highly-trafficked website, our leadership took to the road and engaged new audiences in cities across the United States and Europe. The *Bulletin* and the Clock were featured in news reports, social media postings, and the major network hit television show *Madam Secretary*.

We were pleased to welcome more Next Generation scientists and experts as authors and readers. We were also able to extend our outreach to outstanding educators and students from some of Chicago's leading public and private high schools by including them in our annual Clock Symposium and Annual Dinner.

None of what the *Bulletin* does would be possible without the generosity of major foundations, corporations, and a host of individuals listed at the end of this report. In our home base at the University of Chicago, we remain deeply grateful for the tremendous support provided by the Harris School of Public Policy.

I am inspired by the title of the latest book by renowned author and astrophysicist Lawrence Krauss, who serves as the Chair of our Board of Sponsors: *The Greatest Story Ever Told—So Far: Why Are We Here?*

I am appropriating his subtitle in asking you to read carefully the story in this report—to better understand why the *Bulletin* itself is here—and how much we depend on your participation and support to channel the great advancements of science and technology toward the peace and security of this planet.

Lee Francis, MD, MPH

Letter from the Executive Director and Publisher Rachel Bronson



What you will see in the pages that follow is evidence of a vibrant organization that is actively rethinking its mandate in the 21st century, a time in which scientific and technological advancements are moving faster than ever.

The security landscape darkened considerably in 2016, pushing to the forefront serious questions about the future health and safety of the planet. Political leaders from across the globe including Mikhail Gorbachev, William Perry, and key NATO leaders, warned of a dangerous drift toward a new Cold War. The current US administration's repeated assertions to augment the US nuclear arsenal, and to disregard expert advice, have only elevated concerns about our shared futures.

Citizens in large numbers are pushing back, showing a renewed interest in becoming agents of change and making their voices heard. This renewed civic engagement, around issues such as nuclear risk, climate change, and emerging technologies that have long been the focus of the *Bulletin*, provides enormous opportunities.

In the last few weeks alone, the *Bulletin* has received emails and letters from high school teachers, college students, professors, and individuals from around the world, including a 12-year-old boy, all asking how to help make the world a safer place. One writer concluded: "If you honestly think that average people like me can actually do something about the threats we face, then I have no reason not to try."

At this pivotal moment, large numbers are turning to the *Bulletin of the Atomic Scientists* as a credible fact-based source of information to help underpin their local efforts. The *Bulletin's* Twitter following outpaces most of its counterparts. We have seen a more than 500% increase in the number of weekly newsletter sign-ups, comparing calendar year 2015 to 2016. Traffic to the *Bulletin's* website remains on a strong upward trajectory, and its demographic reach is young and international; 50% of the *Bulletin's* audience is below the age of 35 with half coming from the United States, and half from abroad.

Coming Up

**"Turn Back the Clock"
Exhibit
Opening Event June 7, 2017
Museum of Science
and Industry, Chicago**

**Annual Clock Symposium
and Dinner
November 6, 2017
Chicago**



With Rachel at the Annual Dinner were Mathew Burrows from the Atlantic Council, left, and 2016 Honoree Bill Revelle.

To respond to increasing demand, the *Bulletin* is actively developing new platforms and applications for engaging and motivating new audiences. It has radically altered its approach to the annual Doomsday Clock announcement, and is investing in new data visualizations, building new partnerships, and intentionally targeting younger audiences through a variety of activities including mounting a major new exhibit at the exalted Museum of Science and Industry. Two years in the making, the exhibit will be visited by tens if not hundreds of thousands of school children.

What you will see in the pages that follow is evidence of a vibrant organization that is actively rethinking its mandate in the 21st century, a time in which scientific and technological advancements are moving faster than ever. The risks and opportunities of such advancements are considerable, and it is up to all of us to ensure that they are channeled toward peace and security. That has always been what the *Bulletin* has stood for, and in today's world I cannot think of a more important task.

We are doing our best to get out of our offices to meet those bringing new ideas and those seeking answers. Come see us in Chicago, or elsewhere around the country. Follow the *Bulletin* on whatever platform you get your news. Share with us your good ideas; support us at a level that is meaningful to you.

Together, we have a lot of work to do.

Rachel Bronson, PhD

2016: “In the pocket of Big Truth...”



1. The hit CBS television series *Madam Secretary* aired a special 2016 episode titled “On the Clock,” suggesting that rising tensions between India and Pakistan had prompted the *Bulletin* to consider moving the Doomsday Clock closer to midnight, a possibility that concerned “The President” in a tight election season. When he asked “Madam Secretary” to intervene with the Science and Security Board, an advisor counseled that the board was impervious to political pressure and “in the pocket of Big Truth.”

2. The *Bulletin’s* Clock Announcement on January 26, 2017 continued to generate discussion and major news coverage, including in *The New York Times*, which opened its lead editorial with this statement on February 6, 2017: “Scientists who study the risk of nuclear war recently moved the hands of the symbolic Doomsday Clock to 2½ minutes before midnight.”

3. London’s Bubble Theatre featured Editor-in-Chief John Mecklin as a character in “After Hiroshima” in a March production.

4. John Mecklin was a featured speaker at the Wired NextFest conference, a festival of innovation in Milan, Italy, last May.

5. From left, Natasha Egan, executive director of the Museum of Contemporary Photography at Columbia College Chicago, and Santa Fe mixed media artist Judy Tuwaletsiwa, at a workshop to discuss a new *Bulletin* arts initiative in which members of the creative community can present their work, interact with scientists, and help the *Bulletin* engage new audiences.

1. At a March dinner in Chicago featuring remarks by *Bulletin* columnist and nuclear strategy expert Adam Mount, Elena Bocchino, with Argonne National Laboratory, chatted with Governing Board member Mark Ratner.

2. Satiric journal *The Onion* reported in a spoof last May that the “*Bulletin of the Atomic Scientists* set the global Doomsday Clock to 11:59 p.m. following Arby’s threats to launch a 3-Cheese Jalapeño Beef ‘N Bacon Melt.”

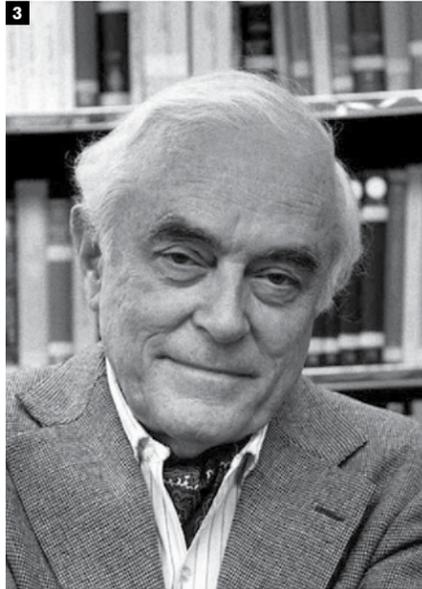
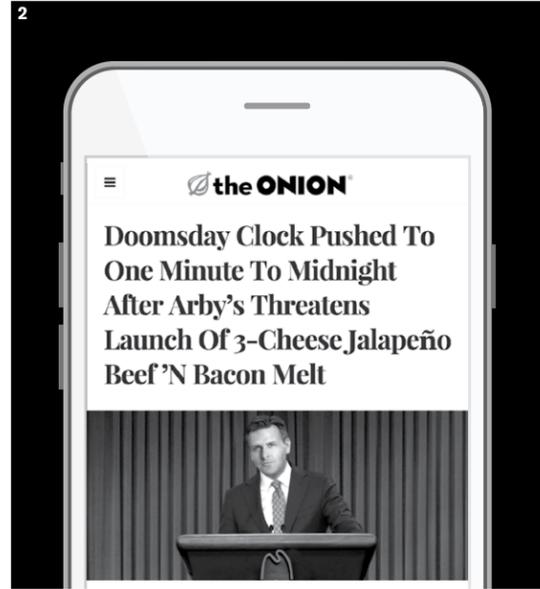
3. Also in the spring, the *Bulletin* announced the creation of the complete John A. Simpson Archive, a searchable collection of *Bulletin* articles containing every issue published since our founding in 1945. The archive is named in honor of John Alexander Simpson, a onetime chair of the Board of Sponsors.

4. At the Gene Siskel Film Center in October, Emma Belcher of the MacArthur Foundation, left, moderated a panel discussion including Rachel Bronson, right, and Eric Schlosser, author of *Command and Control*, which described a 1980 nuclear accident in Damascus, Arkansas. The discussion followed the Chicago premiere of the documentary based on Schlosser’s work.

5. Science and Security Board member Sivan Kartha, climate expert and senior scientist at the Stockholm Environmental Institute, delivered an address titled “Tick Tock” at the York Festival of Ideas in the United Kingdom last June.

6. After President Barack Obama visited Hiroshima in May and spoke about the grave threat that nuclear weapons still pose to the world, Executive Director and Publisher Rachel Bronson appeared on PBS’s News Hour with former Assistant Secretary of State for International Security and Nonproliferation Stephen Rademaker to discuss President Obama’s nuclear legacy.

7. Senior Editor Lucien Crowder, left, moderated a panel at the Atlantic Council in January, convened to discuss the danger that anti-satellite weapons pose to global security, the subject of a previous *Bulletin* roundtable.



Supporting the Next Generation

Leonard M. Rieser Award



For her essay, "The value in activism: Lessons from the Columbia University climate sit-in," a powerful examination of the eight days of the Columbia Divest for Climate Justice (CDCJ) sit-in, and the three years of prior campaigning, Nikita Perumal received the *Bulletin's* Leonard M. Rieser Award. A Fulbright Scholar now in Vanuatu, Perumal is conducting research on the intersections of human rights and climate change.

In her essay, Perumal describes some of the verifiable victories of the CDCJ campaign, but emphasizes that many achievements that result from successful activism aren't necessarily quantifiable. It is the cause of climate justice that keeps Perumal and her peers going: "We keep organizing because we realize that vulnerable communities, from the South Bronx to rural Appalachia to the small island nations of the Pacific, continue to face the devastation of climate impacts and fossil fuel extraction."

In selecting the Rieser Award winner, *Bulletin* editor John Mecklin praised the emotional impact of Perumal's work: "The best writing doesn't just convey information; it also provides the context and emotional detail that are vital if readers are to become interested—and then be inspired to act. And if I had to use a single word to describe Ms. Perumal's portrayal of more than three years of climate change protest at Columbia University, it would be 'inspirational.'"

Voices of Tomorrow

Among the 18 Voices of Tomorrow essays published in 2016 and therefore eligible to receive the Leonard M. Rieser Award were the outstanding contributions listed below and available at thebulletin.org.

Who killed the US-Russia plutonium agreement, and does it really matter?

Darya Dolzikova

The Kremlin's decision to suspend implementation of the Plutonium Management and Disposition Agreement is symptomatic of much deeper issues between Russia and the United States.

Climate science, nuclear strategy, and the humanitarian impacts debate

William Ossoff

New collaboration is needed between climate scientists and military strategists to assess the long-term effects of the most plausible scenarios of nuclear weapons use.

A brighter future for Iranian nonproliferation?

Farnaz Alimehri

Iran's cooperation with the Czech Republic on civilian nuclear energy is a good sign for the rest of the world.

The flawed analogy between nuclear and cyber deterrence

Patrick Cirenza

High-ranking officials draw dangerous parallels between nuclear and cyber warfare at a time when cyber weapons don't meet the criteria for a credible deterrent.

Anti-ship missiles: a dangerous gateway

Nolan Fahrenkopf

Sales of anti-ship missiles level the playing field for weaker countries, making it easier for them to develop advanced missiles.

Communications Workshops

In our ongoing series of workshops connecting experienced public communicators with emerging science and security experts, the *Bulletin* conducted a daylong session in May 2016 in Palo Alto with the Nuclear Science and Security Consortium at UC Berkeley and the Center for International Security and Cooperation at Stanford.

In July, David Sanger of *The New York Times*, below, delivered the keynote address titled "Communicating National Security" at the James Timbie Forum for Arms Control and Nonproliferation, during the morning session of our Washington, DC workshop conducted in partnership with the Stimson Center, the Elliot School of International Affairs at The George Washington University, and the US Department of State.



Chief Washington correspondent of *The New York Times* David Sanger spoke to communications workshops participants in July.

Extern and Interns



The *Bulletin* welcomed Hayeong Rho as a full-time extern serving as our Program Manager for Special Initiatives, supported by the government of the Province of Alberta, Canada.

Eight highly motivated university students were accepted for part-time internships to assist in communications, data collection, editorial research, and fundraising and development. The 2016 summer interns were supported by fellowships from the Metcalf Internship Program and the Institute of Politics, both at the University of Chicago.



1. Colette Ashley; 2. Alex Hearn; 3. Kirk Lancaster; 4. Nick Macius; 5. Delilah Marto; 6. Kiryl Puchyk; 7. Nick Reuter; 8. Sophia Weaver

What Role for Nuclear Power?

Engaging policy leaders and the public

Pro

Advocates maintain that nuclear power is essential to a low-carbon future because it emits no carbon dioxide and provides large amounts of baseload electrical generation.

Con

Critics point to nuclear power's costs and accident and proliferation risks as continuing drawbacks to large-scale nuclear reactor construction.

Debate about the future of nuclear power has evolved rapidly over the last 10 years, gathering momentum in the early 2000s when there was widespread belief in a "nuclear renaissance" and slowing considerably after the frightening events at Japan's Fukushima Daiichi nuclear power plant five years ago, and the collapse of the price of natural gas. With this important policy discussion in mind, *the Bulletin of the Atomic Scientists* prepared to add several new and important contributions to advance the debate.

The 2016 Clock Symposium: *The Bulletin* devoted its annual half-day gathering to the question of what role nuclear power can and should play in achieving the deep de-carbonization required to halt global warming. Members of our board—respected climate and nuclear scientists, security experts, and corporate leaders—and select guests were invited to explore whether and where the *Bulletin* can usefully focus its efforts on this topic, and thereby advance pressing public policy discussions about the future of the global energy landscape. Participants also looked at how technological innovations could affect the debate, financing issues, and navigating the political "briar patch" of this extraordinarily polarizing topic. The full Symposium report can be found at www.thebulletin.org.

Interactive website feature: *The Bulletin* also launched a brand-new interactive on the website: World Nuclear Power Reactor Construction 1951–2017. Built in partnership with the Pulitzer Center on Crisis Reporting, Visionscarto, and the World Nuclear Industry Status Report, this interactive enables users to find out about status and developments in nuclear power plant building, new and abandoned constructions, and reactor startups and shutdowns on a global scale through more than 60 years of nuclear industry history.

Special issue: *Bulletin* editors also prepared the January/February issue of the subscription journal to focus upon the question of whether nuclear power should be a major part of the world's response to global warming. This special issue was also produced in partnership with the Pulitzer Center on Crisis Reporting.



Mycle Schneider of the World Nuclear Industry Status Report made a presentation for *Bulletin* supporters at the University of Chicago in December

Letter from the Editor-in-Chief

John Mecklin



The *Bulletin* continued to expand its readership and influence significantly over the past year, in ways that were powered by many factors, including authoritative special journal issues, additions to an extensive stable of expert columnists and authors, new multimedia offerings, and inventive coverage related to Donald Trump's election as US president. As we grew our audience, the *Bulletin* also continued to garner attention from thought-leading publications and top-tier think tanks like *The New York Times*, *The Atlantic*, the *Los Angeles Times*, the Council on Foreign Relations, and Harvard's Belfer Center for Science and International Affairs.

On the quantitative front, readership of our open website grew by about 20 percent over the previous year. The site drew 312,000 more pageviews than in 2015, and many of our new readers continued to come from the Web-native social media and news aggregation sites that tend to attract younger audiences. And as analysis of our website traffic in 2016 showed, the *Bulletin*'s audience is young, indeed, with more than half of our readers below age 35, and nearly two-thirds under 45.

These increases in readership and impact came as we continued to emphasize top experts and quality writing about the most pressing issue of our time—the preservation of humanity in the face of potentially catastrophic technological threats.

The 2016 presidential campaign was the backdrop for renewed public interest in two issues that we cover most heavily—nuclear weapons and climate change—bringing a surge in attention to the *Bulletin* itself. On both our open website and in our subscription journal, we offered readers a wide variety of expert policy commentary and analysis as the campaign unfolded, including questions for both presidential candidates from Princeton's Frank von Hippel and Zia Mian, Stanford's Sig Hecker, Center for Strategic and International Studies nuclear expert Sharon Squassoni, and many other *Bulletin* experts.

Almost from the minute Donald Trump's surprising election was confirmed, the *Bulletin*'s connection with the public has expanded and strengthened. From November 9, 2016 through February 2017, traffic to our website surged almost 40 percent above the preceding year's—in no small part because of extraordinary worldwide interest in the Science and Security Board's decision to move the Doomsday Clock 30 seconds closer to midnight, a move related in significant ways to Trump's statements and actions during and after the presidential campaign. And since the election, articles on the *Bulletin* site with the word "Trump" in the headline have been viewed some 33,000 times.

Just the same, the *Bulletin*'s strong showing in 2016 was multidimensional, with most of our content having no direct connection to Trump.

In the nuclear realm, the *Bulletin* published a special issue on US-Russia relations that included "Putin: The one-man show the West doesn't understand," an authoritative profile of the Russian president by noted Brookings Institution senior fellow Fiona Hill. Since our last annual report, we have also produced a wide swath of distinguished climate change coverage, including a comprehensive special issue focused on whether nuclear power should be a major part of the world's response to climate change. And early in 2017, we published "Coming to grips with emerging technological threats," an expert survey of technologies—from artificial intelligence to swarming drones—that could endanger humanity's future, if not properly governed.

Through the last half of 2016, the *Bulletin* marshalled the resources to create its newest interactive multimedia offering, the Global Nuclear Power Database, which provides an extraordinary wealth of information on all commercial nuclear power reactors begun since the dawn of the Atomic Age—at the click of a computer mouse. This interactive was built via a partnership among: the *Bulletin*, the Pulitzer Center on Crisis Reporting, Visionscarto data design firm, and the Paris-based World Nuclear Industry Status Report. And even before that database was launched, the *Bulletin*'s major interactives—including the Doomsday Dashboard, the Nuclear Notebook, and the Nuclear Fuel Cycle Cost Calculator—exhibited remarkable growth, garnering some 233,000 pageviews in 2016, up about 80 percent over the preceding year.

Looking to the future, we will add a pair of columnists this year to cover events as diplomats from around the world descend on UN headquarters in New York to negotiate what would be a true (and truly controversial) landmark of the Atomic Age—a treaty to ban nuclear weapons. We are working on a special issue on the US nuclear modernization program and continuing our coverage of the world's efforts to turn the climate change promises of the Paris Accord into reality.

And although it is hardly the only subject we will cover, thanks to your continued support—for which the entire staff thanks you—the *Bulletin* is well positioned to continue to give the international security implications of Trump administration nuclear and climate policies the nonpartisan and rigorously expert attention they deserve.

John Mecklin

It is two and a half minutes to midnight

From: The *Bulletin of the Atomic Scientists* Science and Security Board
To: Leaders and citizens of the world
Date: January 26, 2017
Re: Annual Clock Statement

Editor's note: Founded in 1945 by University of Chicago scientists who had helped develop the first atomic weapons in the Manhattan Project, the *Bulletin of the Atomic Scientists* created the Doomsday Clock two years later, using the imagery of apocalypse (midnight) and the contemporary idiom of nuclear explosion (countdown to zero) to convey threats to humanity and the planet. The decision to move (or to leave in place) the minute hand of the Doomsday Clock is made every year by the *Bulletin's* Science and Security Board in consultation with its Board of Sponsors, which includes 16 Nobel laureates. The Clock has become a universally recognized indicator of the world's vulnerability to catastrophe from nuclear weapons, climate change, and new technologies emerging in other domains.

Over the course of 2016, the global security landscape darkened as the international community failed to come effectively to grips with humanity's most pressing existential threats, nuclear weapons and climate change.

The United States and Russia—which together possess more than 90 percent of the world's nuclear weapons—remained at odds in a variety of theaters, from Syria to Ukraine to the borders of NATO; both countries continued wide-ranging modernizations of their nuclear forces, and serious arms control negotiations were nowhere to be seen. North Korea conducted its fourth and fifth underground nuclear tests and gave every indication it would continue to develop nuclear weapons delivery capabilities. Threats of nuclear warfare hung in the background as Pakistan and India faced each other warily across the Line of Control in Kashmir after militants attacked two Indian army bases.

The climate change outlook was somewhat less dismal—but only somewhat. In the wake of the landmark Paris climate accord, the nations of the world have taken some actions to combat climate change, and global carbon dioxide emissions were essentially flat in 2016, compared to the previous year. Still, they have not yet started to decrease; the world continues to warm. Keeping future temperatures at less-than-catastrophic levels requires reductions in greenhouse gas emissions far beyond those agreed to in Paris—yet little appetite for additional cuts was in evidence at the November climate conference in Marrakech.

This already-threatening world situation was the backdrop for a rise in strident nationalism worldwide in 2016, including in a US presidential campaign during which the eventual victor, Donald Trump, made disturbing comments about the use and proliferation of nuclear weapons and expressed disbelief in the overwhelming scientific consensus on climate change.

The *Bulletin of the Atomic Scientists Science and Security Board* takes a broad and international view of existential threats to humanity, focusing on long-term trends. Because of that perspective, the statements of a single person—particularly one not yet in office—have not historically influenced the board's decision on the setting of the Doomsday Clock.

But wavering public confidence in the democratic institutions required to deal with major world threats do affect the board's decisions. And this year, events surrounding the US presidential campaign—including cyber offensives and deception campaigns apparently directed by the Russian government and aimed at disrupting the US election—have brought American democracy and Russian intentions into question and thereby made the world more dangerous than was the case a year ago.

For these reasons, the Science and Security Board of the *Bulletin of the Atomic Scientists* has decided to move the minute hand of the Doomsday Clock 30 seconds closer to catastrophe. It is now two minutes and 30 seconds to midnight.

The board's decision to move the clock less than a full minute—something it has never before done—reflects a simple reality: As this statement is issued, Donald Trump has been the US president only a matter of days. Many of his cabinet nominations are not yet confirmed by the Senate or installed in government, and he has had little time to take official action.

Just the same, words matter, and President Trump has had plenty to say over the last year. Both his statements and his actions as president-elect have broken with historical precedent in unsettling ways. He has made ill-considered comments about expanding the US nuclear arsenal. He has shown a troubling propensity to discount or outright reject expert advice related to international security, including the conclusions of intelligence experts. And his nominees to head the Energy Department and the Environmental Protection Agency dispute the basics of climate science.

In short, even though he has just now taken office, the president's intemperate statements, lack of openness to expert advice, and questionable cabinet nominations have already made a bad international security situation worse.

Last year, and the year before, we warned that world leaders were failing to act with the speed and on the scale required to protect citizens from the extreme danger posed by climate change and nuclear war. During the past year, the need for leadership only intensified—yet inaction and brinkmanship have continued, endangering every person, everywhere on Earth.

Who will lead humanity away from global disaster?

Nuclear Weapons

A dangerous situation on multiple fronts

Predictability and continuity are often prized when it comes to nuclear weapons policy, because the results of miscommunication or miscalculation could be so catastrophic. Last year, however, the nuclear weapons continuity most in evidence was negative: North Korea's continuing nuclear weapons development, the steady march of arsenal modernization programs in the nuclear weapon states, simmering tension between nuclear-armed India and Pakistan, and stagnation in arms control.

North Korea conducted two more nuclear weapons tests, the second, in September, yielding about twice the explosive power of the first, in January. Pyongyang also relentlessly tested missiles, achieving a rate of about two launches per month in 2016. In his 2017 New Year's statement, Kim Jong-un declared he would soon test a missile with an intercontinental range. The UN Security Council passed new sanctions against North Korea in November 2016 to further limit the country's access to cash, but there is no guarantee those sanctions will succeed where others have failed.

Meanwhile, Russia is building new silo-based missiles, the new Borei class of nuclear ballistic missile submarines, and new rail-mobile missiles as it revamps other intercontinental ballistic missiles. The United States forges ahead with plans to modernize each part of its triad (bombers, land-based missiles, and missile-carrying submarines), adding new capabilities, such as cruise missiles with increased ranges. As it improves the survivability of its own nuclear forces, China is helping Pakistan build submarine platforms. And Pakistan and India continue to expand the number of weapons in and the sophistication of their nuclear arsenals.

Elsewhere, nuclear volatility has been (and remains) the order of the day. While the US president-elect engaged in casual talk about nuclear weapons, suggesting South Korea and Japan acquire their own nuclear weapons to compete with North Korea, other countries voted in the UN to move forward toward a treaty to ban nuclear weapons, passing Resolution L41. In 2017, those states will convene to consider a nuclear weapons ban, presumably without the 38 countries—including the US and a number of its allies—that voted against the ban. A ban would be merely symbolic without the participation or input of countries that have nuclear weapons. But this approach—which circumvents traditional, often glacial efforts like the Conference on Disarmament—reflects long-held frustration with the slow pace of progress toward nuclear disarmament. The world saw the 20th anniversary of the first signature on the Comprehensive Nuclear Test Ban Treaty pass in 2016; the treaty still awaits its entry into force.

The Iran nuclear deal has been successful in accomplishing its goals during its first year, but its future is in doubt under the Trump administration. No firm plans have been made to extend the nuclear security summit process. Disputes over Ukraine, Syria, ballistic missile defenses in Europe, and election interference have the United States and Russia at loggerheads, with little if any prospect that nuclear arms reduction negotiations will resume.

Progress in reducing the overall threat of nuclear war has stalled—and in many ways, gone into reverse. This state of affairs poses a clear and urgent threat to civilization, and citizens around the world should demand that their leaders quickly address and lessen the danger.

Climate Change

The clear need for climate action

Global efforts to limit climate change have produced mixed results over the last year. The Paris Agreement went into effect in 2016, and countries are taking some actions to bring down emissions of greenhouse gases. Global annual emissions were flat this past year, though there is no assurance this heralds a break point. If the global economy has weaned itself from exponentially growing emissions rates, that would indeed be a major accomplishment.

But because carbon dioxide persists in the atmosphere for centuries, net emissions must eventually be put on a trajectory to reach zero if global warming is to be stemmed. The longer it takes to shift toward that trajectory, the greater the warming—and consequences—that current and future generations will face. The true success of the Paris Agreement should be measured against a strict criterion: Do the next steps in its implementation bring about the reductions of carbon dioxide emissions necessary to keep world temperatures from reaching levels that: threaten catastrophic sea level rise; change rainfall patterns and therefore threaten agriculture; increase storm severity; reduce biodiversity; and alter ocean chemistry (among the many negative impacts that unchecked global warming will cause)?

The continued warming of the world measured in 2016 underscores one clear fact: Nothing is fundamentally amiss with the scientific understanding of climate physics. The burning of fossil fuels adds carbon dioxide to the atmosphere; carbon dioxide is a greenhouse gas, inhibiting the radiation of heat into space. The relationship between increased atmospheric carbon dioxide levels and increased terrestrial temperature has been researched for decades, and national science academies around the world agree: Human activity is the primary cause of climate change, and unless carbon dioxide emissions are dramatically reduced, global warming will threaten the future of humanity.

In 2016, however, the international community did not take the steps needed to begin the path toward a net zero-carbon-emissions world. The Marrakech Climate Change Conference, for instance, produced little progress beyond the emissions goals pledged under the Paris Accord.

The political situation in the United States is of particular concern. The Trump transition team has put forward candidates for cabinet-level positions (especially the Environmental Protection Agency and Energy Department) who foreshadow the possibility that the new administration will be openly hostile to progress toward even the most modest efforts to avert catastrophic climate disruption.

Climate change should not be a partisan political issue. The well-established physics of Earth's carbon cycle is neither liberal nor conservative in character. The planet will continue to warm to dangerous levels so long as carbon dioxide continues to be pumped into the atmosphere—regardless of who is chosen to lead the United States or any other country.

International leaders need to refocus their attention on achieving the additional carbon emission reductions that are needed to capitalize on the promise of the Paris Accord. In the United States, as a very first step, the Trump administration needs to make a clear, unequivocal statement that it accepts climate change, caused by human activity, as a scientific reality. No problem can be solved, unless its existence is recognized.

Nuclear Power

An option worth careful consideration

During the last half of the 20th century, the most profound existential threat facing the world was the prospect of global nuclear holocaust, sparked by decisions made under the pressure of the very short time required for intercontinental ballistic missiles to reach their targets. In the 21st century, another existential threat looms: global warming caused by greenhouse gas emissions from more than 100 years of fossil fuel use.

Ironically, the nuclear forces used in weapons of mass destruction can also be harnessed as a carbon-free source of energy. Splitting the atom provides a million-fold increase in energy over the simple chemical reactions that convert fossil fuels to carbon dioxide and energy. The scale of the energy potential of nuclear fission—and its capacity to reduce the greenhouse gas emissions that cause global warming—make nuclear power a tempting part of the solution to the climate change problem. Some 440 nuclear power plants already generate 11 percent of the world's electricity.

In addition to its promise, however, nuclear power has safety, cost, waste, and proliferation challenges. One can argue that the number of deaths and adverse health effects caused by nuclear power has been minimal, even when major accidents have occurred. But a single accident can change governmental policy and public attitudes toward nuclear power. That single accident can also affect multiple countries and produce effects that stretch over decades—as the Chernobyl and Fukushima disasters have shown.

Although new nuclear power plants are being built, mainly in Asia, the scale of the effort does not match the need for clean energy. Today's 400-plus nuclear power plants are, on average, 30 years old. They displace some 0.5 to 0.7 gigatons of carbon each year, as compared to the 10 gigatons discharged annually from the use of fossil fuels.

To achieve just 6 percent of needed reductions in greenhouse gas emissions, nuclear power would have to increase in capacity at least threefold during the next 50 years. This would mean adding 2,000 megawatts of capacity per month, the equivalent of a new 1 gigawatt-electric nuclear power plant every several weeks. Such growth in the use of nuclear power would also require concomitant commitments to nuclear safety, security, and waste management that are politically, technically, and intergenerationally responsible.

In the short and medium terms, governments will need to discourage the premature closure of existing reactors that are—as determined on a case-by-case basis—safe and economically viable. In the longer term, entrepreneurs will have to design and test new types of reactors that can be built quickly, and they will then have to prove to regulators that those new reactors are at least as safe as the commercial nuclear plants now operating.

It is likely that leaders in different parts of the world will make different decisions on whether their countries will or will not include nuclear power in their efforts to combat climate change. Where nuclear power is used, at a very minimum, leaders must ensure that truly independent regulatory systems and safe geological disposal repositories are created.

Emerging Technologies

Potential threats multiply

In December, US intelligence agencies concluded that Russia had intervened in the 2016 US presidential campaign to help Donald Trump in ways that highlight the vulnerability of critical information systems in cyberspace. Information monocultures, fake news, and the hacking and release of politically sensitive emails may have had an illegitimate impact on the US presidential election, threatening the fabric of democracy, which relies on an informed electorate to decide the direction of public policy—including policy relating to existential threats such as nuclear weapons and climate change. If not controlled, these types of electoral attacks could be launched against democracies around the world, undermining belief in representative government and thereby endangering humanity as a whole.

Such attacks on the democratic process, however, represent just one threat associated with the modern world's increased reliance on the internet and information technology. Sophisticated hacking—whether by private groups or governmental entities—has the potential to create grave and large impacts, threatening financial activities and national electrical power grids and plants (including nuclear power plants) and the personal freedoms that are based on the privacy at the core of democracy.

Beyond cybersecurity, the increasing potential of autonomous machine systems—which could, for example, allow the development of efficient, self-driving cars—also opens up a new set of risks that require thoughtful management. Without good governance, including appropriate regulation, these threats could emerge in coming decades as existential—that is, dangerous to the whole of humanity or to modern civilization as we know it. Lethal autonomous weapons systems that make “kill” decisions without human input or supervision, for example, would be particularly worrisome. Advances in synthetic biology, including the Crispr gene-editing tool, also have great positive potential—and a dark side that includes the possible creation of bioweapons and other dangerous manipulations of genetic material.

Technological innovation is occurring at a speed that challenges society's ability to keep pace. While limited at the current time, potentially existential threats posed by a host of emerging technologies need to be monitored, and to the extent possible anticipated, as the 21st century unfolds.

Recommendations

Reducing risk: Expert advice and citizen action

Technology continues to outpace humanity's capacity to control it, even as many citizens lose faith in the institutions upon which they must rely to make scientific innovation work for rather than against them. Expert advice is crucial if governments are to effectively deal with complex global threats. The Science and Security Board is extremely concerned about the willingness of governments around the world—including the incoming US administration—to ignore or discount sound science and considered expertise during their decision-making processes.

Wise men and women have said that public policy is never made in the absence of politics. But in this unusual political year, we offer a corollary: Good policy takes account of politics but is never made in the absence of expertise. Facts are indeed stubborn things, and they must be taken into account if the future of humanity is to be preserved, long term.

Nuclear weapons and climate change are precisely the sort of complex existential threats that cannot be properly managed without access to and reliance on expert knowledge. In 2016, world leaders not only failed to deal adequately with those threats; they actually increased the risk of nuclear war and unchecked climate change through a variety of provocative statements and actions, including careless rhetoric about the use of nuclear weapons and the wanton defiance of scientific truths. We call on these leaders—particularly in Russia and the United States—to refocus in the coming year on reducing existential risks and preserving humanity, in no small part by consulting with top-level experts and taking scientific research and observed reality into account.

Because we know from experience that governmental leaders respond to public pressure, we also call on citizens of the world to express themselves in all the ways available to them—including through use of the powerful new tools of social media—to demand that:

- US and Russian leaders return to the negotiating table to seek further reductions in nuclear arms and to limit nuclear modernization programs that threaten to create a new nuclear arms race. The world can be more secure with much, much smaller nuclear arsenals than now exist—if political leaders are truly interested in protecting their citizens from harm.
- The United States and Russia reduce the alert levels of their nuclear weapons and use existing crisis stability mechanisms to avoid inadvertent escalation of conflict. Provocative military exercises increase the possibilities for accidental war and should cease.
- Governments around the world sharply reduce their countries' greenhouse gas emissions and fulfill the Paris Accord promise of keeping warming to 2 degrees Celsius above preindustrial levels, or less. This temperature target is consistent with consensus views on climate science and is eminently achievable and economically viable, provided that poorer countries are given the support they need to make the post-carbon transition.

- The Trump administration acknowledge climate change as a science-backed reality and redouble US efforts to limit carbon dioxide emissions and support carbon-free energy sources, including, when economically reasonable and safe over the long term, nuclear energy. It is well past time to move beyond arguments over the reality of climate change and on to solutions, including fiscal measures—such as carbon markets and carbon taxes or fees—that encourage efficiency and put a price on carbon emissions.
- The United States, China, Russia, and other concerned nations engage with North Korea to reduce nuclear risks. Neighbors in Asia face the most urgent threat, but as North Korea improves its nuclear and missile arsenals, the threat will rapidly become global. As we said last year and repeat here: Now is not the time to tighten North Korea's isolation but to engage seriously in dialogue.
- Leaders of countries with commercial nuclear power programs deal responsibly with safety issues and with the commercial nuclear waste problem. Top experts disagree on whether an expansion of nuclear-powered electricity generation can become a major component of the effort to limit climate change. Regardless of the trajectory of the global nuclear industry, there will be a continuing need for safe and secure interim and permanent nuclear waste storage facilities and for ever-safer nuclear power plants.
- The countries of the world collaborate on creating institutions specifically assigned to explore and address potentially malign or catastrophic misuses of new technologies. Scientific advance can provide society with great benefits. But as events surrounding the recent US presidential election show, the potential for misuse of potent new technologies is real. Governmental, scientific, and business leaders need to take appropriate steps to address possibly devastating consequences of these technologies.

For the last two years, the minute hand of the Doomsday Clock stayed set at three minutes before the hour, the closest it had been to midnight since the early 1980s. In its two most recent annual announcements on the Clock, the Science and Security Board warned: "The probability of global catastrophe is very high, and the actions needed to reduce the risks of disaster must be taken very soon."

In 2017, we find the danger to be even greater, the need for action more urgent. It is two and a half minutes to midnight, the Clock is ticking, global danger looms. Wise public officials should act immediately, guiding humanity away from the brink. If they do not, wise citizens must step forward and lead the way.

2016: A Terribly Interesting Year

Bulletin editors produced a remarkable array of array of content in 2016—ranging from brief columns, multimedia presentations, and interactive features to roundtable discussions and long-form articles. A healthy segment of our material appears in our subscription-based journal, which has won numerous honors through the years, including the 2007 National Magazine Award Society for General Excellence from the American Society of Magazine Editors.

By any measure, the annual subscriptions, offered through our publishing partners Taylor & Francis, are a bargain for individuals and institutional subscribers. Also, we normally "lift the paywall" for several articles in each issue, providing free access to the special issues, interviews, analysis, and graphics that have garnered international respect for more than seven decades.

Every issue also includes open access to installments of the renowned Nuclear Notebook, an authoritative accounting of world nuclear weapons arsenals produced by Federation of American Scientists experts Hans M. Kristensen and Robert S. Norris.

And since May 2016, an additional bonus of an annual subscription is access to the John A. Simpson Archive—a fully searchable cache of every single article published by the *Bulletin* since it was founded in 1945. It is a unique chronicle reflecting the belief of our founders that the atom bomb would only be the first of many dangerous presents from "Pandora's box of modern science." It remains a record of the *Bulletin's* sustained efforts to educate people about the realities of the scientific age.

(Above, the photo shows the Lizard Island section of Australia's Great Barrier Reef, before and after the recent coral bleaching event. Image courtesy of the XL Catlin Seaview Survey.)

Key special journal issues

January–February 2016: In the first special issue of the new year, "Nuclear Energy in the Middle East," Executive Director and Publisher Rachel Bronson wrote the lead article "Power shift in the Middle East."

May–June 2016: This special issue discussed many aspects of US-Russia relations, including arms control, current statistics on the Russian nuclear arsenal, and the geostrategic significance of Russia's oil and gas exports.

July–August 2016: This special issue illustrated the rapidly changing power equations on display across—and beneath—the world's oceans and how those changes could soon affect everything from global internet access to the nuclear deterrent strategies of the world's nuclear powers.

November–December 2016: International security in the age of renewables was the focus of the final special issue for calendar 2016, which included articles on Saudi Arabia, the impact on relations between Russia and the European Union, and complex financing issues.

2016: Journal Highlights

Interviews and Long-form articles

Editor-in-Chief John Mecklin published two key interviews in 2016: one with **former covert CIA operations officer Valerie Plame**, who spoke on how millennials can be encouraged to become active in dealing with the threat posed by nuclear weapons and nuclear proliferation, and the other with **former US ambassador to Russia Michael McFaul**, who discussed how US-Russia relations might be improved, given Russian President Vladimir Putin's suspicious views of US intentions.

Associate Editor Dan Drollette talked to **Steven Chu, former US Secretary of Energy** about his latest research; the reasoning behind the decisions he made in office; and how to make progress in the current, anti-regulatory political environment.

Edward Moore Geist argued that an **Artificial Intelligence (AI) arms race** is already well under way, due to the historical connection between AI research and defense applications, despite campaigns for an agreement to ban autonomous weapons before they become the next domain of military competition.

In **Putin: The one-man show the West doesn't understand** by Fiona Hill, the director of the Center for the United States and Europe at The Brookings Institution explained what the world is missing when it deals with the Russian president.

And a bevy of top experts—including Princeton's Frank von Hippel and Stanford's Sig Hecker—suggested a series of penetrating questions about nuclear weapons that should have been asked of the 2016 presidential candidates. And should now be put to the winner of the election.



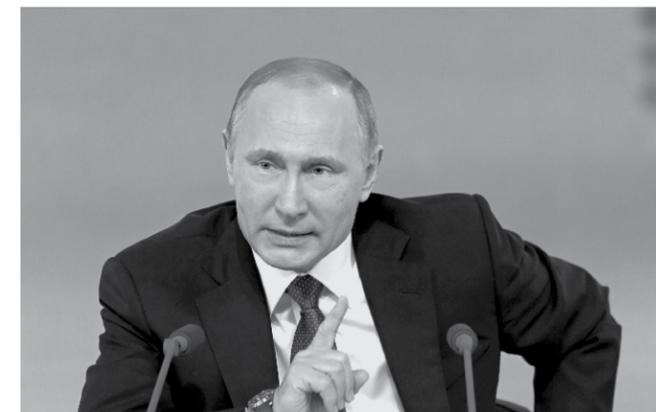
Steven Chu



Valerie Plame



Michael McFaul



Vladimir Putin

2016: At thebulletin.org

Nuclear Weapons

Below are some of the *Bulletin's* best website articles on nuclear weapons from 2016, during which, in countries around the world—from North Korea to Pakistan to India to Russia and on to the United States—people who ought to know better suggested that more nuclear weapons should be built, and some might be used.

On tickling the dragon's tail

Victor Gilinsky

The moral restraints that prevent Armageddon are flimsier than one might think, because humans have a self-destructive defect. They like to tickle the dragon's tail.

The experts, and the Trump administration

John Mecklin

Top experts on nuclear weapons, climate change, and other existential threats to humanity comment on how they think the expert community can best respond to Donald Trump's election.

Preparing the country for nuclear terrorism

Jerome M. Hauer

The presidential candidates must do more than accept the possibility of a terrorist attack with an improvised nuclear device. They need to plan an effective response that reduces the mass morbidity and mortality such an attack inevitably will cause.

The double-edged sword: US nuclear command and control modernization

Andrew Futter

Even in this digital age there are many reasons to be careful about what we wish for when it comes to modernizing the nuclear command and control system. More technological capability will not necessarily create a more secure world.

Climate

2016 was a lot like 2015, only more so: It was an even hotter year for average global temperatures. The rate of melting of sea ice increased. And climate change deniers seemed to come out in greater force than ever before, resulting in the election of a US president who says he thinks climate change is "a hoax." Here are a few stories from the past year.

The climate change generation gap

Dana Nuccitelli

One specific demographic strongly correlates to climate science denial: age. But money, gender, ethnicity, and status also come into play. A climate scientist—who also writes for the UK paper *The Guardian*—explains what may be going on.

Kashmir, climate change, and nuclear war

Zia Mian

A new source of conflict between Pakistan and India has emerged—centered, once again, on Kashmir. It is a struggle over access to, and control over, the water in the rivers that start as snow and glacial meltwater in the Himalayas.

Thanksgiving advice: How to deal with climate change denying Uncle Pete

Richard C.J. Somerville

"Why is Uncle Pete so stubborn and so resistant to overwhelming scientific evidence on climate change?" That's a very good question, and here is the answer.

"We'd have to finish one new facility every working day for the next 70 years"

Andy Skuce

Carbon capture and storage, or CCS, has been touted as a way to reduce atmospheric CO₂. Recently, researchers in Iceland seemed to make a breakthrough, turning this gas into stone, using what is essentially soda water. But how realistic is it to build CCS facilities on a scale large enough to combat climate change?

Columns

Of special interest this year were the addition of new columnists Michael Horowitz and Julia Macdonald of The Perry World House at the University of Pennsylvania and Jodi Lieberman from Argonne National Laboratory. Lieberman's daily Nuclear Roundup is a compilation of quality nuclear policy news published around the world.

Who will want artificially intelligent weapons? ISIS, democracies, or autocracies?

Michael C. Horowitz

If you're a dictator who can't trust your own people in the military, you can still trust a machine to do your dirty work.

What it really means to fight climate change like a war

Dawn Stover

Environmental activists and political leaders have called on us to fight climate change as though we were fighting a war. But doing so calls for more than a massive deployment of industrial technology. It calls for actual personal sacrifice.

US-Russian rift threatens science ties that keep us safe

Siegfried S. Hecker

For two decades, Russian and American nuclear scientists cooperated to avoid catastrophe. Can they do it again?

From Flint to Yucca Mountain, politicized regulators are doing harm

Jeff Terry

When officials charged with protecting the public act based on politics rather than science, they undermine trust and endanger citizens.

2016: By the Numbers*

*Calendar 2016 through January 2017,
following the Clock Announcement

2,400,000

website visits

+20%

3,700,000

page views

+26%

Nearly half of the *Bulletin's* audience is from outside the United States

53% of the *Bulletin's* audience in 2016 was under 35 years old. 70% was under 45

Our interactive tools were used more in 2016 than ever before

Doomsday Dashboard
Nuclear Notebook
Nuclear Fuel Cycle Cost Calculator
Doomsday Clock Timeline
Global Nuclear Power Database

+80%

2016: By the Numbers*

+259%

Facebook likes



+84%

Twitter followers



+2,500,000

viewers watched

When the *Bulletin* announced that the Doomsday Clock was set thirty seconds forward to two and a half minutes to midnight.

- +10,000 news, radio, and tv stories
- Top 10 most viewed online in the *New York Times*, *Washington Post*, *Reuters*, and the *BBC*.

+55%

increase in weekly newsletter subscribers

Financials

Ordinary Income/Expense	2015	2016
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Income

Foundation Grants	332,638	154,983
Individual & Corporate Contributions	448,958	508,678
In-kind Contributions	507,433	535,968
Earned Revenue	214,890	165,612

Total Revenue before Restrictions	1,503,919	1,365,241
Released from Restriction	421,817	623,137
Total Unrestricted Revenue	1,925,736	1,988,378

Temporarily Restricted

Temporarily Restricted Revenue	1,171,602	127,455
Released from Restriction	(421,817)	(623,137)

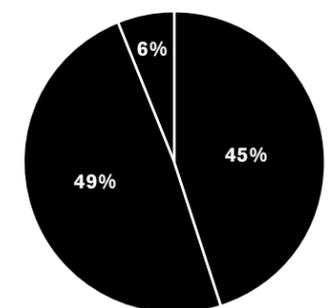
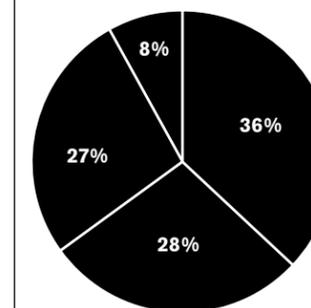
Total Revenue after Release of Restrictions	2,675,521	1,492,696
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Expense

Salaries and Benefits	747,750	882,155
Program Expenses	1,023,085	975,210
Administrative Expenses	112,026	123,458

Total Expense	1,882,862	1,980,823
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Net Operating Income before Restrictions	42,874	7,555
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Income

Foundation Grants	36%
Individual & Corporate Contributions	28%
In-kind Contributions	27%
Earned Revenue	8%

Expenses

Salaries and Benefits	45%
Program Expenses	49%
Administrative Expenses	6%

2016: Annual Dinner Highlights



1 We welcomed another sold-out crowd for the second year in a row to the *Bulletin's* 2016 Annual Dinner on November 14 at the Chicago Cultural Center. Keynote speakers were Career Ambassador and Board of Sponsors member Thomas Pickering, who has served as US ambassador to the United Nations, El Salvador, India, Israel, Jordan, Nigeria, and the Russian Federation, and award-winning climate scientist and member of the Science and Security Board Richard Somerville of the Scripps Institution of Oceanography at the University of California San Diego.



The highlight of the evening came when former Vice President Al Gore delivered a videotaped tribute to honorees William and Eleanor Revelle for their early recognition that climate change poses a threat to humanity, and for their long-standing commitment to the *Bulletin*.



“The Revelles have never stopped working to make the world a safer and healthier place.”



1. Annual Dinner keynote and SASB member Richard Somerville; **2.** Eleanor and Bill Revelle 2016 honorees; **3.** Board of Sponsors member, Career Ambassador, and Keynote Speaker Thomas Pickering; **4.** Crowd at Annual Dinner at Chicago Cultural Center; **5.** left, Jennifer Smyser of the Stanley Foundation, Theodore Kalionzes from the MacArthur Foundation, and Sharon Squassoni, from the Science and Security Board; **6.** Former Vice President Al Gore; **7.** Invenergy's Patrick Whitty, Suzanna Torres, and Michael Blazer; **8.** Alan Schriesheim, Marilyn Diamond, Terry Diamond, Kay Torshen, and Avi Porat; **9.** Board of Sponsors Chair Lawrence Krauss; **10.** 2016 Annual Dinner Honoree Eleanor Revelle with *Bulletin* supporter Brian Hanson



2016: With Gratitude

For more than seven decades, a dedicated network of board members, advisors, foundations, and donors have sustained the *Bulletin of the Atomic Scientists*. We extend our deepest gratitude to the board leaders, individuals, and institutions who made contributions between January 1 and December 31, 2016. Their names are listed here, with our sincere thanks for making everything we do possible.

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Evanston Township High School Renewable Energy Lab Teacher Ellen Fierer with Governing Board member John Balkcom and Carol Balkcom

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With sadness we noted the passing of Helen Thom Edwards, an outstanding physicist who was known the world over, and who was a generous friend to the *Bulletin*.

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