

**Bulletin
of the
Atomic
Scientists**

It is two and a half minutes to midnight

2017 Doomsday Clock Statement

Science and Security Board
Bulletin of the Atomic Scientists

Editor, John Mecklin

IT IS TWO AND A HALF MINUTES TO MIDNIGHT®



Statement from the executive director

This year marks the 70th anniversary of the Doomsday Clock, a graphic that appeared on the first cover of the *Bulletin of the Atomic Scientists* as it transitioned from a six-page, black-and-white newsletter to a full-fledged magazine. For its first cover, the editors sought an image that represented a seriousness of purpose and an urgent call for action. The Clock, and the countdown to midnight that it implied, fit the bill perfectly. The Doomsday Clock, as it came to be called, has served as a globally recognized arbiter of the planet's health and safety ever since.

Each year, the setting of the Doomsday Clock galvanizes a global debate about whether the planet is safer or more dangerous today than it was last year, and at key moments in recent history. Our founders would not be surprised to learn that the threats to the planet that the Science and Security Board now considers have expanded since 1947. In fact, the *Bulletin's* first editor, Eugene Rabinowitch, noted that one of the purposes of the *Bulletin* was to respond and offer solutions to the “Pandora's box of modern science,” recognizing the speed at which technological advancement was occurring, and the demanding questions it would present.

In 1947 there was one technology with the potential to destroy the planet, and that was nuclear power. Today, rising temperatures, resulting from the industrial-scale burning of fossil fuels, will change life on Earth as we know it, potentially destroying or displacing it from significant portions of the world, unless action is taken today, and in the immediate future. Future technological innovation in biology, artificial intelligence, and the cyber realm may pose similar global challenges. The knotty problems that innovations in these fields may present are not yet fully realized, but the *Bulletin's* Science and Security Board tends to them with a watchful eye.

This year's Clock deliberations felt more urgent than usual. On the big topics that concern the board, world leaders made too little progress in

the face of continuing turbulence. In addition to the existential threats posed by nuclear weapons and climate change, new global realities emerged, as trusted sources of information came under attack, fake news was on the rise, and words were used in cavalier and often reckless ways. As if to prove that words matter and fake news is dangerous, Pakistan's foreign minister issued a blustery statement, a tweet actually, flexing Pakistan's nuclear muscle—in response to a fabricated “news” story about Israel. Today's complex global environment is in need of deliberate and considered policy responses. It is ever more important that senior leaders across the globe calm rather than stoke tensions that could lead to war, either by accident or miscalculation.

I once again commend the board for approaching its task with the seriousness it deserves. *Bulletin* Editor-in-Chief John Mecklin did a remarkable job pulling together this document and reflecting the in-depth views and opinions of the board. Considerable thanks goes to our supporters including the Carnegie Corporation of New York, MacArthur Foundation, Ploughshares Fund, David Weinberg and Jerry Newton, as well as valued supporters across the year.

I hope the debate engendered by the 2017 setting of the Clock raises the level of conversation, promotes calls to action, and helps citizens around the world hold their leaders responsible for delivering a safer and healthier planet.

Rachel Bronson, PhD
Executive Director and Publisher
26 January, 2017
Chicago, IL

It is two and a half minutes to midnight

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 15 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. A printable PDF of this statement, complete with the executive director's statement and Science and Security Board biographies, is available [here](#).

To: Leaders and citizens of the world

Re: It is 30 seconds closer to midnight

Date: January 26, 2017

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.

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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 brinksmanship have continued, endangering every person, everywhere on Earth.

Who will lead humanity away from global disaster?

A dangerous nuclear 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 in an effort to further limit the country's access to cash, but there is no guarantee those sanctions will succeed where others have failed.

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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 United Nations 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 United States 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.

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. There are encouraging signs that 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.

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The political situation in the United States is of particular concern. The Trump transition team has put forward candidates for cabinet-level positions (especially at 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

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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.

Potential threats from emerging technologies.

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.

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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.

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.

Science and security board biographies

Lynn Eden (Co-Chair) is co-chair of the *Bulletin's* Science and Security Board and senior research scholar (Emeritus) at Stanford University's Center for International Security and Cooperation. Eden is also co-chair of U.S. Pugwash and a member of the International Pugwash Council. Her scholarly work focuses on the military and society; science, technology, and organizations; and US nuclear weapons history and policy. Eden's *Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation* won the American Sociological Association's 2004 Robert K. Merton award for best book in science and technology studies.

Rod Ewing is the Frank Stanton Professor in Nuclear Security in the Center for International Security and Cooperation in the Freeman Spogli Institute for International Studies and a Professor in the Department of Geological and Environmental Sciences in the School of Earth Sciences at Stanford University. Ewing's research focuses on the back end of the nuclear fuel cycle, mainly nuclear materials and the geochemistry of radionuclides. He is the past president of the International Union of Materials Research Societies. Ewing has written extensively on issues related to nuclear waste management and is co-editor of *Radioactive Waste Forms for the Future* and *Uncertainty Underground: Yucca Mountain and the Nation's High-Level Nuclear Waste*. He received the Lomonosov Medal of the Russian Academy of Sciences in 2006.

Sivan Kartha is a Senior Scientist at SEI whose research and publications for the past twenty years have focused on technological options and policy strategies for addressing climate change, concentrating most recently on equity and efficiency in the design of an international climate regime. He is a co-Leader of SEI's Gender and Social Equity Programme, and co-Director of the Climate Equity Reference Project. His current work deals primarily with the economic, political, and ethical dimensions of equitably

sharing the effort of an ambitious global response to climate change. Dr. Kartha has also worked on mitigation scenarios, market mechanisms for climate actions, and the environmental and socioeconomic impacts of biomass energy. His work has enabled him to advise and collaborate with diverse organizations, including the UN Climate Convention Secretariat, various United Nations and World Bank programs, numerous government policy-making bodies and agencies, foundations, and civil society organizations throughout the developing and industrialized world. He served as a Coordinating Lead Author in the preparation of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change released in 2014, co-leading the chapter on Equity and Sustainable Development.

Lawrence Krauss (Chair-Board of Sponsors, ex officio SASB) is the director of the Origins Project at Arizona State University and Foundation Professor at ASU's School of Earth and Space Exploration and Physics Department. Krauss is an internationally known theoretical physicist with wide research interests, including the interface between elementary particle physics and cosmology, where his studies include the early universe, the nature of dark matter, general relativity and neutrino astrophysics. He has written 10 books, including the international best-sellers, *The Physics of Star Trek*, and *A Universe from Nothing*, and his upcoming book, *The Greatest Story Ever Told--So Far* due out in March. He writes regularly for magazines and newspapers including the *New York Times* and the *New Yorker*, and frequently appears on radio and television, as well as, most recently, in several feature films. Among his numerous awards for research and outreach, he was awarded the 2012 Public Service Award from the National Science Board for his contributions to the public understanding of science.

Herb Lin is senior research scholar for cyber policy and security at the Center for International Security and Cooperation and Research Fellow

Biographies (continued)

at the Hoover Institution, both at Stanford University. He is particularly interested in the use of offensive operations in cyberspace, especially as instruments of national policy.

Suzet McKinney is the Executive Director of the Illinois Medical District Commission. She is the former Deputy Commissioner of the Bureau of Public Health Preparedness and Emergency Response at the Chicago Department of Public Health, where she oversaw the emergency preparedness efforts for the department and coordinated those efforts within the larger spectrum of Chicago's public safety activities. A sought-after expert in her field, McKinney also provides support to the US Department of Defense, Defense Threat Reduction Agency, to provide subject matter expertise in biological terrorism preparedness to international agencies.

Steve Miller is the Director of the International Security Program at Harvard University's Belfer Center for Science and International Affairs, and he is a Fellow of the American Academy of Arts and Sciences where he co-chairs the Committee on International Security Studies (CISS). Miller is also Co-Chair of the US Pugwash Committee, and is a member of the Council of International Pugwash. Miller co-directs the Academy's project on the Global Nuclear Future Initiative with the *Bulletin's* Science and Security Board Co-Chair, Robert Rosner.

Raymond Pierrehumbert is Halley Professor of Physics at the University of Oxford. He was a lead author on the IPCC Third Assessment Report, and a co-author of the National Research Council report on abrupt climate change. He was awarded a John Simon Guggenheim Fellowship in 1996, which was used to launch collaborative work on the climate of Early Mars with collaborators in Paris. He is a Fellow of the American Geophysical Union (AGU), a Fellow of the American Academy of Arts and Sciences, and has been named Chevalier de l'Ordre des Palmes Académiques by

the Republic of France. Pierrehumbert's central research interest is how climate works as a system and developing idealized mathematical models to be used to address questions of climate science such as how the earth kept from freezing over: the faint young sun paradox. Current interests include climate of extrasolar planets.

Ramamurti Rajaraman is an emeritus professor of physics at Jawaharlal Nehru University and a co-chair of the International Panel on Fissile Materials. His research areas include particle physics, quantum field theory, and solitons. He has written about fissile material production in India and Pakistan and the radiological effects of nuclear weapon accidents.

Robert Rosner (Co-Chair) is the co-chair of the *Bulletin's* Science and Security Board. Rosner is the William E. Wrather Distinguished Service Professor in the department of Astronomy and Astrophysics and Physics at the University of Chicago. Rosner recently stepped down as director of Argonne National Laboratory, where he had also served as Chief Scientist. His research is mostly in the areas of plasma astrophysics and astrophysical fluid dynamics and magnetohydrodynamics (including especially solar and stellar magnetic fields); high energy density physics; boundary mixing instabilities; combustion modeling; applications of stochastic differential equations and optimization problems; and inverse methods.

Jennifer Sims is currently a senior fellow at the Chicago Council on Global Affairs and is writing a book on intelligence in international politics. She is also a consultant on intelligence and homeland security for private corporations and the US government. In 2008, the president of the United States appointed her to the Public Interest Declassification Board, which advises the president on the declassification policies of the US government. Sims received her MA and her PhD from Johns Hopkins University's School of Advanced International Studies. In 1998, Sims

Biographies (continued)

received the intelligence community's highest civilian award, the National Distinguished Service Medal.

Susan Solomon is the Lee and Geraldine Martin Professor of Environmental Studies at the Massachusetts Institute of Technology and was the Founding Director of the MIT Environmental Solutions Initiative from 2014-2015. She is well known for pioneering work that explained why there is a hole in the Antarctic ozone layer and is the author of several influential scientific papers in climate science. Solomon received the 1999 US National Medal of Science, our nation's highest scientific award, in 1999. She has also received the Grande Medaille of the French Academy of Sciences, the Blue Planet Prize in Japan, the BBVA Frontiers of Knowledge Award, and the Volvo Environment Prize. She is a member of the US National Academy of Sciences, the French Academy of Sciences, and the Royal Society in the UK. She served as co-chair for the Intergovernmental Panel on Climate Change (IPCC) fourth climate science assessment report, released in 2007. Time magazine named Solomon as one of the 100 most influential people in the world in 2008.

Richard Somerville is Distinguished Professor Emeritus and Research Professor at Scripps Institution of Oceanography, University of California, San Diego. His research is focused on critical physical processes in the climate system, especially the role of clouds and the important feedbacks that can occur as clouds change with a changing climate. His broader interests include all aspects of climate, including climate science outreach and the interface between science and public policy. He was a Coordinating Lead Author of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC); the IPCC shared the 2007 Nobel Peace Prize equally with Al Gore. Somerville is a Fellow of both the American Association for

the Advancement of Science and the American Meteorological Society. He received the Climate Communication Prize of the American Geophysical Union as well as awards from the American Meteorological Society for both his research and his popular book, *The Forgiving Air: Understanding Environmental Change*.

Sharon Squassoni currently directs the Proliferation Prevention Program at the Center for Strategic and International Studies in Washington, DC. She has specialized in nuclear nonproliferation, arms control and security policy for three decades, at the Arms Control and Disarmament Agency, the State Department, and the Congressional Research Service. She has also held positions at the Institute for Defense Analyses, the Carnegie Endowment for International Peace, and Newsweek magazine. She received a Bachelor of Arts degree from the State University of New York at Albany, a master's in public management from the University of Maryland, and a master's in national security strategy from the National War College.

David Titley is a Professor of Practice in Meteorology and a Professor of International Affairs at the Pennsylvania State University, and the founding director of Penn State's Center for Solutions to Weather and Climate Risk. He served as a naval officer for 32 years and rose to the rank of rear admiral. Dr. Titley's career included duties as commander of the Naval Meteorology and Oceanography Command; oceanographer and navigator of the Navy; and deputy assistant chief of naval operations for information dominance. He also served as senior military assistant for the director, Office of Net Assessment in the Office of the Secretary of Defense. While serving in the Pentagon, Dr. Titley initiated and led the US Navy's Task Force on Climate Change. After retiring from the Navy, Dr. Titley served as the deputy undersecretary of commerce for operations, the chief operating officer position at the National Oceanic and Atmospheric

Biographies (continued)

Administration. Dr. Titley serves on numerous advisory boards and National Academies of Science committees, including the CNA Military Advisory Board and the Science and Security Board of the *Bulletin of the Atomic Scientists*. Dr. Titley is a fellow of the American Meteorological Society and was awarded an honorary doctorate from the University of Alaska, Fairbanks.

Editor

John Mecklin is the editor-in-chief of the *Bulletin of the Atomic Scientists*. Previously, Mecklin was editor-in-chief of Miller-McCune (since renamed Pacific Standard), an award-winning national magazine that focused on research-based solutions to major policy problems. Over the preceding 15 years, he was also: the editor of High Country News, a nationally acclaimed magazine that reports on the American West; the consulting executive editor for the launch of Key West, a regional magazine start-up directed by renowned magazine guru Roger Black; and the top editor for award-winning newsweeklies in San Francisco and Phoenix. In an earlier incarnation, he was an investigative reporter at the Houston Post and covered the Persian Gulf War from Saudi Arabia and Iraq. Writers working at his direction have won many major journalism contests, including the George Polk Award, the Investigative Reporters and Editors certificate, and the Sidney Hillman Award for reporting on social justice issues. Mecklin holds a master in public administration degree from Harvard's Kennedy School of Government.

About the *Bulletin of the Atomic Scientists*

The *Bulletin of the Atomic Scientists* engages science leaders, policy makers, and the interested public on topics of nuclear weapons and disarmament, the changing energy landscape, 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 70 years, the *Bulletin* has bridged the technology divide between scientific research, foreign policy and public engagement.

The *Bulletin* was founded in 1945 by Manhattan Project scientists who “could not remain aloof to the consequences of their work.” The organization’s early years chronicled the dawn of the nuclear age and the birth of the scientists’ movement, as told by the men and women who built the atomic bomb and then lobbied with both technical and humanist arguments for its abolition.

Today, the *Bulletin* is an independent nonprofit 501(c)(3) organization. With our international network of board members and experts, we assess scientific advancements that involve both benefits and risks to humanity, with the goal of influencing public policy to protect our planet and all its inhabitants.

The *Bulletin*’s website is a robust public and research-oriented source of detailed reports and cogent analysis from the scientists and experts who are directly involved. It receives an average of over 160,000 visits per month. The bimonthly magazine, which can be found in over 15,000 leading universities and institutions worldwide, attracts a large number of influential readers. About half of the *Bulletin*’s website and journal readers reside outside the United States. Half of the visitors to its website are under the age of 35.

The *Bulletin*’s signature strength is its capacity to synthesize and inform by linking critical issues, treaty negotiations, and scientific assessments to threats represented by the iconic Doomsday Clock. The Clock attracts more daily visitors to our site than any other feature, and commands worldwide attention when the *Bulletin* issues periodic assessments of global threats and solutions.

In 2007 the *Bulletin* won the National Magazine Award for General Excellence, the magazine industry equivalent of an Oscar for Best Picture. The *Bulletin* also was named one of four 2009 finalists for the Lumity Technology Leadership Award, presented by Accenture to a nonprofit organization that is effectively applying innovative technologies. Today, the *Bulletin* supplements its cutting-edge journalism with interactive infographics and videos, and amplifies its messages through social media platforms.

To advance the *Bulletin* as a thriving public forum over the next 70 years, we are opening more channels between scientific and policy leaders as we increase our outreach to supporters all over the world. Two partnerships are key to these efforts—one with the University of Chicago’s Harris School of Public Policy and the other with Routledge, our publishing relationship that began in January 2016.

See more at: <http://thebulletin.org>

Timeline of doomsday clock changes



2016 IT IS STILL 3 MINUTES TO MIDNIGHT

“Last year, the Science and Security Board moved the Doomsday Clock forward to three minutes to midnight, noting: ‘The probability of global catastrophe is very high, and the actions needed to reduce the risks of disaster must be taken very soon.’ That probability has not been reduced. The Clock ticks. Global danger looms. Wise leaders should act—immediately.” See the full statement from the Science and Security Board on the 2016 time of the Doomsday Clock.



2015 IT IS 3 MINUTES TO MIDNIGHT

Unchecked climate change, global nuclear weapons modernizations, and outsized nuclear weapons arsenals pose extraordinary and undeniable threats to the continued existence of humanity, and world leaders have failed to act with the speed or on the scale required to protect citizens from potential catastrophe. These failures of political leadership endanger every person on Earth.” Despite some modestly positive developments in the climate change arena, current efforts are entirely insufficient to prevent a catastrophic warming of Earth. Meanwhile, the United States and Russia have embarked on massive programs to modernize their nuclear triads—thereby undermining existing nuclear weapons treaties. “The clock ticks now at just three minutes to midnight because international leaders are failing to perform their most important duty—ensuring and preserving the health and vitality of human civilization.”



2012 IT IS 5 MINUTES TO MIDNIGHT

“The challenges to rid the world of nuclear weapons, harness nuclear power, and meet the nearly inexorable climate disruptions from global warming are complex and interconnected. In the face of such complex problems, it is difficult to see where the capacity lies to address these challenges.”

Political processes seem wholly inadequate; the potential for nuclear weapons use in regional conflicts in the Middle East, Northeast Asia, and South Asia are alarming; safer nuclear reactor designs need to be developed and built, and more stringent oversight, training, and attention are needed to prevent future disasters; the pace of technological solutions to address climate change may not be adequate to meet the hardships that large-scale disruption of the climate portends.



2010 IT IS 6 MINUTES TO MIDNIGHT

International cooperation rules the day. Talks between Washington and Moscow for a follow-on agreement to the Strategic Arms Reduction Treaty are nearly complete, and more negotiations for further reductions in the U.S. and Russian nuclear arsenal are already planned. Additionally, Barack Obama becomes the first U.S. president to publicly call for a nuclear-weapon-free world. The dangers posed by climate change are still great, but there are pockets of progress. Most notably: At Copenhagen, the developing and industrialized countries agree to take responsibility for carbon emissions and to limit global temperature rise to 2 degrees Celsius.



2007 IT IS 5 MINUTES TO MIDNIGHT

The world stands at the brink of a second nuclear age. The United States and Russia remain ready to stage a nuclear attack within minutes, North Korea conducts a nuclear test, and many in the international community worry that Iran plans to acquire the Bomb. Climate change also presents a dire challenge to humanity. Damage to ecosystems is already taking place; flooding, destructive storms, increased drought, and polar ice melt are causing loss of life and property.



2002 IT IS 7 MINUTES TO MIDNIGHT

Concerns regarding a nuclear terrorist attack underscore the enormous amount of unsecured—and sometimes unaccounted

Timeline of doomsday clock changes (cont.)

for--weapon-grade nuclear materials located throughout the world. Meanwhile, the United States expresses a desire to design new nuclear weapons, with an emphasis on those able to destroy hardened and deeply buried targets. It also rejects a series of arms control treaties and announces it will withdraw from the Anti-Ballistic Missile Treaty.

 **1998 IT IS 9 MINUTES TO MIDNIGHT**
India and Pakistan stage nuclear weapons tests only three weeks apart. “The tests are a symptom of the failure of the international community to fully commit itself to control the spread of nuclear weapons--and to work toward substantial reductions in the numbers of these weapons,” a dismayed *Bulletin* reports. Russia and the United States continue to serve as poor examples to the rest of the world. Together, they still maintain 7,000 warheads ready to fire at each other within 15 minutes.

 **1995 IT IS 14 MINUTES TO MIDNIGHT**
Hopes for a large post-Cold War peace dividend and a renouncing of nuclear weapons fade. Particularly in the United States, hard-liners seem reluctant to soften their rhetoric or actions, as they claim that a resurgent Russia could provide as much of a threat as the Soviet Union. Such talk slows the rollback in global nuclear forces; more than 40,000 nuclear weapons remain worldwide. There is also concern that terrorists could exploit poorly secured nuclear facilities in the former Soviet Union.

 **1991 IT IS 17 MINUTES TO MIDNIGHT**
With the Cold War officially over, the United States and Russia begin making deep cuts to their nuclear arsenals. The Strategic Arms Reduction Treaty greatly reduces the number of strategic nuclear weapons deployed by the two former adversaries. Better still, a series of unilateral initiatives remove most of the intercontinental

ballistic missiles and bombers in both countries from hair-trigger alert. “The illusion that tens of thousands of nuclear weapons are a guarantor of national security has been stripped away,” the *Bulletin* declares.

 **1990 IT IS 10 MINUTES TO MIDNIGHT**
As one Eastern European country after another (Poland, Czechoslovakia, Hungary, Romania) frees itself from Soviet control, Soviet General Secretary Mikhail Gorbachev refuses to intervene, halting the ideological battle for Europe and significantly diminishing the risk of all-out nuclear war. In late 1989, the Berlin Wall falls, symbolically ending the Cold War. “Forty-four years after Winston Churchill’s ‘Iron Curtain’ speech, the myth of monolithic communism has been shattered for all to see,” the *Bulletin* proclaims.

 **1988 IT IS 6 MINUTES TO MIDNIGHT**
The United States and Soviet Union sign the historic Intermediate-Range Nuclear Forces Treaty, the first agreement to actually ban a whole category of nuclear weapons. The leadership shown by President Ronald Reagan and Soviet Premier Mikhail Gorbachev makes the treaty a reality, but public opposition to U.S. nuclear weapons in Western Europe inspires it. For years, such intermediate-range missiles had kept Western Europe in the crosshairs of the two superpowers.

 **1984 IT IS 3 MINUTES TO MIDNIGHT**
U.S.-Soviet relations reach their iciest point in decades. Dialogue between the two superpowers virtually stops. “Every channel of communications has been constricted or shut down; every form of contact has been attenuated or cut off. And arms control negotiations have been reduced to a species of propaganda,” a concerned *Bulletin* informs readers. The United States seems to flout the few arms control agreements in place by seeking an expansive, space-based anti-ballistic missile capability, raising worries that a new arms race will begin.

Timeline of doomsday clock changes (cont.)



1981 IT IS 4 MINUTES TO MIDNIGHT

The Soviet invasion of Afghanistan hardens the U.S. nuclear posture. Before he leaves office, President Jimmy Carter pulls the United States from the Olympics Games in Moscow and considers ways in which the United States could win a nuclear war. The rhetoric only intensifies with the election of Ronald Reagan as president. Reagan scraps any talk of arms control and proposes that the best way to end the Cold War is for the United States to win it.



1980 IT IS 7 MINUTES TO MIDNIGHT

Thirty-five years after the start of the nuclear age and after some promising disarmament gains, the United States and the Soviet Union still view nuclear weapons as an integral component of their national security. This stalled progress discourages the *Bulletin*: “[The Soviet Union and United States have] been behaving like what may best be described as ‘nucleoholics’--drunks who continue to insist that the drink being consumed is positively ‘the last one,’ but who can always find a good excuse for ‘just one more round.’”



1974 IT IS 9 MINUTES TO MIDNIGHT

South Asia gets the Bomb, as India tests its first nuclear device. And any gains in previous arms control agreements seem like a mirage. The United States and Soviet Union appear to be modernizing their nuclear forces, not reducing them. Thanks to the deployment of multiple independently targetable reentry vehicles (MIRV), both countries can now load their intercontinental ballistic missiles with more nuclear warheads than before.



1972 IT IS 12 MINUTES TO MIDNIGHT

The United States and Soviet Union attempt to curb the race for nuclear superiority by signing the Strategic Arms Limitation Treaty (SALT) and the Anti-Ballistic Missile (ABM) Treaty. The two treaties force a nuclear parity of sorts. SALT limits the number

of ballistic missile launchers either country can possess, and the ABM Treaty stops an arms race in defensive weaponry from developing.



1969 IT IS 10 MINUTES TO MIDNIGHT

Nearly all of the world’s nations come together to sign the Nuclear Non-Proliferation Treaty. The deal is simple--the nuclear weapon states vow to help the treaty’s non-nuclear weapon signatories develop nuclear power if they promise to forego producing nuclear weapons. The nuclear weapon states also pledge to abolish their own arsenals when political conditions allow for it. Although Israel, India, and Pakistan refuse to sign the treaty, the *Bulletin* is cautiously optimistic: “The great powers have made the first step. They must proceed without delay to the next one--the dismantling, gradually, of their own oversized military establishments.”



1968 IT IS 7 MINUTES TO MIDNIGHT

Regional wars rage. U.S. involvement in Vietnam intensifies, India and Pakistan battle in 1965, and Israel and its Arab neighbors renew hostilities in 1967. Worse yet, France and China develop nuclear weapons to assert themselves as global players. “There is little reason to feel sanguine about the future of our society on the world scale,” the *Bulletin* laments. “There is a mass revulsion against war, yes; but no sign of conscious intellectual leadership in a rebellion against the deadly heritage of international anarchy.”



1963 IT IS 12 MINUTES TO MIDNIGHT

After a decade of almost non-stop nuclear tests, the United States and Soviet Union sign the Partial Test Ban Treaty, which ends all atmospheric nuclear testing. While it does not outlaw underground testing, the treaty represents progress in at least slowing the arms race. It also signals awareness among the Soviets and United States that they need to work together to prevent nuclear annihilation.

Timeline of doomsday clock changes (cont.)



1960 IT IS 7 MINUTES TO MIDNIGHT

Political actions belie the tough talk of “massive retaliation.” For the first time, the United States and Soviet Union appear eager to avoid direct confrontation in regional conflicts such as the 1956 Egyptian-Israeli dispute. Joint projects that build trust and constructive dialogue between third parties also quell diplomatic hostilities. Scientists initiate many of these measures, helping establish the International Geophysical Year, a series of coordinated, worldwide scientific observations, and the Pugwash Conferences, which allow Soviet and American scientists to interact.

magazine’s founders--and the broader scientific community--are trying to convey to the public and political leaders around the world.



1953 IT IS 2 MINUTES TO MIDNIGHT

After much debate, the United States decides to pursue the hydrogen bomb, a weapon far more powerful than any atomic bomb. In October 1952, the United States tests its first thermonuclear device, obliterating a Pacific Ocean islet in the process; nine months later, the Soviets test an H-bomb of their own. “The hands of the Clock of Doom have moved again,” the *Bulletin* announces. “Only a few more swings of the pendulum, and, from Moscow to Chicago, atomic explosions will strike midnight for Western civilization.”



1949 IT IS 3 MINUTES TO MIDNIGHT

The Soviet Union denies it, but in the fall, President Harry Truman tells the American public that the Soviets tested their first nuclear device, officially starting the arms race. “We do not advise Americans that doomsday is near and that they can expect atomic bombs to start falling on their heads a month or year from now,” the *Bulletin* explains. “But we think they have reason to be deeply alarmed and to be prepared for grave decisions.”



1947 IT IS 7 MINUTES TO MIDNIGHT

As the *Bulletin* evolves from a newsletter into a magazine, the Clock appears on the cover for the first time. It symbolizes the urgency of the nuclear dangers that the