Bulletin
of the
Atomic
Scientists

It is 2 minutes to midnight

2018 Doomsday Clock Statement

Science and Security Board
Bulletin of the Atomic Scientists

Editor, John Mecklin

Statement from the President and CEO

The year just past proved perilous and chaotic, a year in which many of the risks foreshadowed in our last Clock statement came into full relief. In 2017, we saw reckless language in the nuclear realm heat up already dangerous situations and re-learned that minimizing evidence-based assessments regarding climate and other global challenges does not lead to better public policies.

Although the *Bulletin of the Atomic Scientists* focuses on nuclear risk, climate change, and emerging technologies, the nuclear landscape takes center stage in this year's Clock statement. Major nuclear actors are on the cusp of a new arms race, one that will be very expensive and will increase the likelihood of accidents and misperceptions. Across the globe, nuclear weapons are poised to become more rather than less usable because of nations' investments in their nuclear arsenals. This is a concern that the *Bulletin* has been highlighting for some time, but momentum toward this new reality is increasing.

As you will see in the discussion that follows, the *Bulletin*'s Science and Security Board has once again assessed progress—actually, lack thereof—in managing the technologies that can bring humanity both relief and harm. It is my hope that the statement focuses world attention on today's dangerous trajectory and urges leaders and citizens alike to redouble their efforts in committing to a path that advances the health and safety of the planet. The Board has provided recommendations for how we might go about achieving this end, and it is urgent that we take heed.

I commend the members of the Science and Security Board for the work they undertake every day to put us on a safer footing. As always, John Mecklin's talented pen has helped pull together wide-ranging contributions and allowed a large group of engaged experts to speak with one voice. The *Bulletin* couldn't serve its proper role without financial support from the Carnegie Corporation of New York, the MacArthur Foundation, and the many other foundations, corporations, and individuals who contribute regularly to the *Bulletin*'s mission. We are deeply grateful for this ongoing support.

It is urgent that, collectively, we put in the work necessary to produce a 2019 Clock statement that rewinds the Doomsday Clock. Get engaged, get involved, and help create that future. The time is now.

Rachel Bronson, PhD
President & CEO
25 January, 2018
Chicago, IL

It is now two 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 President and CEO's statement and Science and Security Board biographies, is available here.*

To: Leaders and citizens of the world
Re: Two minutes to midnight
Date: January 25, 2018

In 2017, world leaders failed to respond effectively to the looming threats of nuclear war and climate change, making the world security situation more dangerous than it was a year ago—and as dangerous as it has been since World War II.

The greatest risks last year arose in the nuclear realm. North Korea's nuclear weapons program made remarkable progress in 2017, increasing risks to North Korea itself, other countries in the region, and the United States. Hyperbolic rhetoric and provocative actions by both sides have increased the possibility of nuclear war by accident or miscalculation.

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But the dangers brewing on the Korean Peninsula were not the only nuclear risks evident in 2017: The United States and Russia remained at odds, continuing military exercises along the borders of NATO, undermining the Intermediate-Range Nuclear Forces Treaty (INF), upgrading their nuclear arsenals, and eschewing arms control negotiations.

In the Asia-Pacific region, tensions over the South China Sea have increased, with relations between the United States and China insufficient to re-establish a stable security situation.

In South Asia, Pakistan and India have continued to build ever-larger arsenals of nuclear weapons.

And in the Middle East, uncertainty about continued US support for the landmark Iranian nuclear deal adds to a bleak overall picture.

To call the world nuclear situation dire is to understate the danger—and its immediacy.

On the climate change front, the danger may seem less immediate, but avoiding catastrophic temperature increases in the long run requires urgent attention now. Global carbon dioxide emissions have not yet shown the beginnings of the sustained decline towards zero that must occur if ever-greater warming is to be avoided. The nations of the world will have to significantly decrease their greenhouse gas emissions to keep climate risks manageable, and so far, the global response has fallen far short of meeting this challenge.

Beyond the nuclear and climate domains, technological change is disrupting democracies around the world as states seek and exploit opportunities to use information technologies as weapons, among them internet-based deception campaigns aimed at undermining elections and popular confidence in institutions essential to free thought and global security.

The *Bulletin of the Atomic Scientists* Science and Security Board believes the perilous world

security situation just described would, in itself, justify moving the minute hand of the Doomsday Clock closer to midnight.

But there has also been a breakdown in the international order that has been dangerously exacerbated by recent US actions. In 2017, the United States backed away from its long-standing leadership role in the world, reducing its commitment to seek common ground and undermining the overall effort toward solving pressing global governance challenges. Neither allies nor adversaries have been able to reliably predict US actions—or understand when US pronouncements are real, and when they are mere rhetoric. International diplomacy has been reduced to name-calling, giving it a surrealistic sense of unreality that makes the world security situation ever more threatening.

Because of the extraordinary danger of the current moment, the Science and Security Board today moves the minute hand of the Doomsday Clock 30 seconds closer to catastrophe. It is now two minutes to midnight—the closest the Clock has ever been to Doomsday, and as close as it was in 1953, at the height of the Cold War.

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The Science and Security Board hopes this resetting of the Clock will be interpreted exactly as it is meant—as an urgent warning of global danger. The time for world leaders to address looming nuclear danger and the continuing march of climate change is long past. The time for the citizens of the world to demand such action is now: #rewindtheDoomsdayClock.

The untenable nuclear threat. The risk that nuclear weapons may be used—intentionally or because of miscalculation—grew last year around the globe.

North Korea has long defied UN Security Council resolutions to cease its nuclear and ballistic missile tests, but the acceleration of its tests in 2017 reflects new resolve to acquire sophisticated nuclear weapons. North Korea has or soon will have capabilities to match its verbal threats—specifically, a thermonuclear warhead and a ballistic missile that can carry it to the US mainland. In September, North Korea tested what experts assess to be a true two-stage thermonuclear device, and in November, it tested the Hwasong-15 missile, which experts believe has a range of over 8,000 kilometers. The United States and its allies, Japan and South Korea, responded with more frequent and larger military exercises, while China and Russia proposed a freeze by North Korea of nuclear and missile tests in exchange for a freeze in US exercises.

The failure to secure a temporary freeze in 2017 was unsurprising to observers of the downward spiral of nuclear rhetoric between US President Donald Trump and North Korean leader Kim Jong-un. The failure to rein in North Korea's nuclear program will reverberate not just in the Asia-Pacific, as neighboring countries review their security options, but more widely, as all countries consider the costs and benefits of the international framework of nonproliferation treaties and agreements.

Nuclear risks have been compounded by US-Russia relations that now feature more conflict than cooperation. Coordination on nuclear risk reduction is all but dead, and no solution to disputes over the INF Treaty—a landmark agreement to rid Europe of medium-range nuclear missiles—is readily apparent. Both sides allege violations, but Russia's deployment of a new ground-launched cruise missile, if not addressed, could trigger a collapse of the treaty. Such a collapse would make what should have been a relatively easy five-year extension of the New START arms control pact much harder to achieve and could terminate an arms control process that dates back to the early 1970s.

For the first time in many years, in fact, no US-Russian nuclear arms control negotiations are

under way. New strategic stability talks begun in April are potentially useful, but so far they lack the energy and political commitment required for them to bear fruit. More important, Russia's invasion and annexation of Crimea and semi-covert support of separatists in eastern Ukraine have sparked concerns that Russia will support similar "hybrid" conflicts in new NATO members that it borders—actions that could provoke a crisis at almost any time. Additional flashpoints could emerge if Russia attempts to exploit friction between the United States and its NATO partners, whether arising from disputes on burden-sharing, European Union membership, and trade—or relating to policies on Israel, Iran, and terrorism in the Middle East.

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In the past year, US allies have needed reassurance about American intentions more than ever. Instead, they have been forced to negotiate a thicket of conflicting policy statements from a US administration weakened in its cadre of foreign policy professionals, suffering from turnover in senior leadership, led by an undisciplined and disruptive president, and unable to develop, coordinate, and clearly communicate a coherent nuclear policy. This inconsistency constitutes a major challenge for deterrence, alliance management, and global stability. It has made the existing nuclear risks greater than necessary and added to their complexity.

Especially in the case of the Iran nuclear deal, allies are perplexed. While President Trump has steadfastly opposed the agreement that his predecessor and US allies negotiated to keep Iran from developing nuclear weapons, he has never successfully articulated practical alternatives. His instruction to Congress in 2017 to legislate a different approach resulted in a stalemate. The future of the Iran deal, at this writing, remains uncertain.

In the United States, Russia, and elsewhere around the world, plans for nuclear force modernization and development continue apace. The Trump administration's Nuclear Posture Review appears likely to increase the types and roles of nuclear weapons in US defense plans and lower the threshold to nuclear use. In South Asia, emphasis on nuclear and missile capabilities grows. Conventional force imbalances and destabilizing plans for nuclear weapons use early in any conflict continue to plague the subcontinent.

Reflecting long decades of frustration with slow progress toward nuclear disarmament, states signed a Treaty on the Prohibition of Nuclear Weapons, commonly known as the ban treaty, at the United Nations this past September. The treaty—championed by the International Campaign to Abolish Nuclear Weapons, which has been awarded the Nobel Peace Prize for its work—is a symbolic victory for those seeking a world without nuclear weapons and a strong expression of the frustration with global disarmament efforts to date. Predictably, countries with nuclear weapons boycotted the negotiations, and none has signed the ban treaty. Their increased reliance on nuclear weapons, threats, and doctrines that could make the use of those weapons more likely stands in stark contrast to the expectations of the rest of the world.

An insufficient response to climate change. Last year, the US government pursued unwise and ineffectual policies on climate change, following through on a promise to derail past US climate policies. The Trump administration, which includes avowed climate denialists in top positions at the Environmental Protection Agency, the Interior Department, and other key agencies, has announced its plan to withdraw from the Paris Agreement. In its rush to dismantle rational climate and energy policy, the administration has ignored scientific fact and well-founded economic analyses.

These US government climate decisions transpired against a backdrop of worsening climate change and high-impact weather-related

disasters. This year past, the Caribbean region and other parts of North America suffered a season of historic damage from exceedingly powerful hurricanes. Extreme heat waves occurred in Australia, South America, Asia, Europe, and California, with mounting evidence that heat-related illness and death are correspondingly increasing. The Arctic ice cap achieved its smallest-ever winter maximum in 2017, the third year in a row that this record has been broken. The United States has witnessed devastating wildfires, likely exacerbated by extreme drought and subsequent heavy rains that spurred underbrush growth. When the data are assessed, 2017 is almost certain to continue the trend of exceptional global warmth: All the warmest years in the instrumental record, which extends back to the 1800s, have—excepting one year in the late 1990s—occurred in the 21st century. https://climate.nasa.gov/news/2655/october-2017-was-the-second-warmest-october-on-record/

Despite the sophisticated disinformation campaign run by climate denialists, the unfolding consequences of an altered climate are a harrowing testament to an undeniable reality: The science linking climate change to human activity—mainly the burning of fossil fuels that produce carbon dioxide and other greenhouse gases—is sound. The world continues to warm as costly impacts mount, and there is evidence that overall rates of sea level rise are accelerating—regardless of protestations to the contrary.

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Especially against these trends, it is heartening that the US government's defection from the Paris Agreement did not prompt its unravelling or diminish its support within the United States at large. The "We Are Still In" movement signals a strong commitment within the United States—by some 1,700 businesses, 250 cities, 200 communities of faith, and nine states, representing more than 40 percent of the US population—to its international climate commitments and to the validity of scientific facts.

This reaffirmation is reassuring, and other countries have maintained their steadfast support for climate action, reconfirmed their commitments to global climate cooperation, and clearly acknowledged that more needs to be done. French President Emmanuel Macron's sober message to global leaders assembled at December's global climate summit in Paris was a reality check after the heady climate negotiations his country hosted two years earlier: "We're losing the battle. We're not moving quickly enough. We all need to act." And indeed, after plateauing for a few years, greenhouse gas emissions resumed their stubborn rise in 2017.

As we have noted before, the true measure of the Paris Agreement is whether nations actually fulfill their pledges to cut emissions, strengthen those pledges, and see to it that global greenhouse gas emissions start declining in short order and head toward zero. As we drift yet farther from this goal, the urgency of shifting course becomes greater, and the existential threat posed by climate change looms larger.

Emerging technologies and global risk. The Science and Security Board is deeply concerned about the loss of public trust in political institutions, in the media, in science, and in facts themselves—a loss that the abuse of information technology has fostered. Attempts to intervene in elections through sophisticated hacking operations and the spread of disinformation have threatened democracy, which relies on an informed electorate to reach reasonable decisions on public policy—including policy relating to nuclear weapons, climate change, and other global threats. Meanwhile, corporate leaders in the information domain, including established media outlets and internet companies such as Facebook and Google, have been slow to adopt protocols to prevent misuse of their services and protect citizens from manipulation. The international community should establish new

measures that discourage and penalize all cross-border subversions of democracy.

Last year, the Science and Security Board warned that "[t]echnological 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."

If anything, the velocity of technological change has only increased in the past year, and so our warning holds for 2018. But beyond monitoring advances in emerging technology, the board believes that world leaders also need to seek better collective methods of managing those advances, so the positive aspects of new technologies are encouraged and malign uses discovered and countered. The sophisticated hacking of the "Internet of Things," including computer systems that control major financial and power infrastructure and access to more than 20 billion personal devices; the development of autonomous weaponry that makes "kill" decisions without human supervision; and the possible misuse of advances in synthetic biology, including the revolutionary Crispr gene-editing tool, already pose potential global security risks. Those risks could expand without strong public institutions and new management regimes. The increasing pace of technological change requires faster development of those tools.

The increasing pace of technological change requires faster development of strong public institutions and new management regimes.

How to turn back the Clock. In 1953, former Manhattan Project scientist and *Bulletin* editor Eugene Rabinowitch set the hands of the Doomsday Clock at two minutes to midnight, writing, "The achievement of a thermonuclear explosion by the Soviet Union, following on the heels of the development of 'thermonuclear devices' in America, means that the time, dreaded by scientists since 1945, when each major nation will hold the power of destroying, at will, the urban civilization of any other nation, is close at hand."

The Science and Security Board now again moves the hands of the Clock to two minutes before midnight. But the current, extremely dangerous state of world affairs need not be permanent. The means for managing dangerous technology and reducing global-scale risk exist; indeed, many of them are well-known and within society's reach, if leaders pay reasonable attention to preserving the long-term prospects of humanity, and if citizens demand that they do so.

This is a dangerous time, but the danger is of our own making. Humankind has invented the implements of apocalypse; so can it invent the methods of controlling and eventually eliminating them. This year, leaders and citizens of the world can move the Doomsday Clock and the world away from the metaphorical midnight of global catastrophe by taking these common-sense actions:

- US President Donald Trump should refrain from provocative rhetoric regarding North Korea, recognizing the impossibility of predicting North Korean reactions.
- The US and North Korean governments should open multiple channels of communication. At a minimum, military-to-military communications can help reduce the likelihood of inadvertent war on the Korean Peninsula. Keeping diplomatic channels open for talks without preconditions is another common-sense way to reduce tensions. As leading security expert Siegfried Hecker of Stanford University recently wrote: "Such talks should not be seen as a reward or concession to Pyongyang, nor construed as signaling acceptance of a nuclear-armed North Korea. They could, however, deliver the message that while Washington fully intends to defend itself and its allies from any attack with a devastating retaliatory response, it does not otherwise intend to attack

North Korea or pursue regime change." https://thebulletin.org/time-insert-control-rods-north-korea11198

- The world community should pursue, as a short-term goal, the cessation of North Korea's nuclear weapon and ballistic missile tests. North Korea is the only country to violate the norm against nuclear testing in 20 years. Over time, the United States should seek North Korea's signature on the Comprehensive Nuclear Test Ban Treaty—and then, along with China, at long last also ratify the treaty.
- The Trump administration should abide by the terms of the Joint Comprehensive Plan of Action for Iran's nuclear program unless credible evidence emerges that Iran is not complying with the agreement or Iran agrees to an alternative approach that meets US national security needs.
- The United States and Russia should discuss and adopt measures to prevent peacetime military incidents along the borders of NATO. Provocative military exercises and maneuvers hold the potential for crisis escalation. Both militaries must exercise restraint and professionalism, adhering to all norms developed to avoid conflict and accidental encounters.
- US and Russian leaders should return to the negotiating table to resolve differences over the INF treaty; to seek further reductions in nuclear arms; to discuss a lowering of the alert status of the nuclear arsenals of both countries; to limit nuclear modernization programs that threaten to create a new nuclear arms race; and to ensure that new tactical or low-yield nuclear weapons are not built and that existing tactical weapons are never used on the battlefield.
- US citizens should demand, in all legal ways, climate action from their government. Climate change is a real and serious threat to humanity. Citizens should insist that their governments acknowledge it and act accordingly.
- Governments around the world should redouble their efforts to reduce greenhouse gas emissions so they go well beyond the initial, inadequate pledges under the Paris Agreement. The temperature goal under that agreement—to keep warming well below 2 degrees Celsius above preindustrial levels—is consistent with consensus views on climate science, is eminently achievable, and is economically viable, provided that poorer countries are given the support they need to make the post-carbon transition. But the time window for achieving this goal is rapidly closing.
- The international community should establish new protocols to discourage and penalize the misuse of information technology to undermine public trust in political institutions, in the media, in science, and in the existence of objective reality itself. Strong and accountable institutions are necessary to prevent deception campaigns that are a real threat to effective democracies, reducing their ability to enact policies to address nuclear weapons, climate change, and other global dangers.
- The countries of the world should collaborate on creating institutions specifically assigned to explore and address potentially malign or catastrophic misuses of new technologies, particularly as regards autonomous weaponry that makes "kill" decisions without human supervision and advances in synthetic biology that could, if misused, pose a global threat.

The failure of world leaders to address the largest threats to humanity's future is lamentable—but that failure can be reversed.

The failure of world leaders to address the largest threats to humanity's future is lamentable—but that failure can be reversed. It is two minutes to midnight, but the Doomsday Clock has ticked away from midnight in the past, and during the next year, the world can again move it further from apocalypse. The warning the Science and Security Board now sends is clear, the danger obvious and

imminent. The opportunity to reduce the danger is equally clear.

The world has seen the threat posed by the misuse of information technology and witnessed the vulnerability of democracies to disinformation. But there is a flip side to the abuse of social media. Leaders react when citizens insist they do so, and citizens around the world can use the power of the internet to improve the long-term prospects of their children and grandchildren. They can insist on facts, and discount nonsense. They can demand action to reduce the existential threat of nuclear war and unchecked climate change. They can seize the opportunity to make a safer and saner world.

They can #rewindtheDoomsdayClock.

Science and security board biographies

Rachel Bronson (ex officio SASB) is the President and CEO of the *Bulletin of the Atomic Scientists,* where she oversees the publishing programs, the management of the Doomsday Clock, and a growing set of activities around nuclear risk, climate change, and disruptive technologies. Before joining the *Bulletin*, she served as vice president for Studies at The Chicago Council on Global Affairs, adjunct professor of "Global Energy" at the Kellogg School of Management, and senior fellow and director of Middle East studies at the Council on Foreign Relations, among other positions. Her book, *Thicker than Oil: America's Uneasy Partnership with Saudi Arabia* (Oxford University Press, 2006), has been translated into Japanese and published in paperback. Her writings and commentary have appeared in outlets including *Foreign Affairs, The New York Times, The Washington Post, "PBS NewsHour," "Charlie Rose,"* and *"The Daily Show*." Bronson has served as a consultant to NBC News and testified before the congressional Task Force on Anti-Terrorism and Proliferation Financing, Congress's Joint Economic Committee, and the 9/11 Commission.

Lynn Eden is Senior Research Scholar (Emeritus) at Stanford University's Center for International Security and Cooperation. Eden is also co-chair of US 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. Her current research and writing (mostly historical) ask how a specific US military planning organization has enabled very good people to plan what, if put into action, could or would result in the deaths of tens or hundreds of millions of people. In other words, how do US military officers make plans to fight and prevail in nuclear war?

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 Sciences in the School of Earth, Environmental and Energy 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.

Daniel Holz is an Associate Professor in Physics, Astronomy & Astrophysics, the Enrico Fermi Institute, and the Kavli Institute for Cosmological Physics, at the University of Chicago. His research focuses on general relativity in the context of astrophysics and cosmology. He is a member of the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration, and was part of the team that announced the first detection of gravitational waves in early 2016. He received a 2012 National Science Foundation CAREER Award, the 2015 Quantrell Award for Excellence in Undergraduate Teaching, and the Breakthrough Prize in Fundamental Physics in 2016, and was selected as a Kavli Fellow of the National Academy of Sciences in 2017. Holz received his PhD in physics from the University of Chicago and his AB in physics from Princeton University.

Sivan Kartha is a Senior Scientist at Stockholm Environmental Institute whose research and publications for the past 20 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

Biographies (continued)

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.

Elizabeth Kolbert has been a staff writer at *The New Yorker* since 1999 and has written extensively on science and climate change to great acclaim. Her most recent book, *The Sixth Extinction*, won the 2015 Pulitzer Prize for general nonfiction. Kolbert is also known for her book *Field Notes from a Catastrophe*, based on her three-part series on global warming, "The Climate of Man," which won the 2006 National Magazine Award for Public Interest and the AAAS Advancement of Science Journalism Award. She is also a recipient of a Heinz Award (for educating the public about environmental issues) and a Guggenheim Fellowship.

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 bestsellers *The Physics of Star Trek*, *A Universe from Nothing*, and his latest book, *The Greatest Story Ever Told—So Far,* which was released last year. 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. Krauss is the only physicist to have been awarded the three major awards from the American Physical Society, the American Institute of Physics, and the American Association of Physics Teachers.

Herb Lin is Senior Research Scholar for Cyber Policy and Security at the Center for International Security and Cooperation and Research Fellow 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 CEO/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. She is the author of the forthcoming text: *Public Health Emergency Preparedness: Practical Solutions for the Real World*, published by Jones & Bartlett Publishers (2018).

Biographies (continued)

Steve Miller is the Director of the International Security Program at the Belfer Center for Science and International Affairs in Harvard University's Kennedy School of Government, and he is a Fellow of the American Academy of Arts and Sciences, where he is chair of 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 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 the use of fundamental physical principles to elucidate the behavior of the present and past climates of Earth and other planets, including the growing catalog of exoplanets. He leads the European Research Council Advance Grant project EXOCONDENSE.

Ramamurti Rajaraman is an emeritus professor of physics at Jawaharlal Nehru University. He is a founding member and former co-chair of the International Panel on Fissile Materials. He is also currently a member of the Asia Pacific Leadership Network, Council of the Pugwash Conference on Science & World Affairs, the Permanent Monitoring Panel on Mitigation of Terrorist Acts, World Federation of Scientists (Erice, Italy), the Editorial Board of "Science and Global Security," and of the Board of Governors of the Centre for the Study of Developing Societies (New Delhi). His research areas in pure physics include nuclear theory, particle physics, quantum field theory, quantum Hall systems, anomalous gauge theories, and Soliton physics. He has also worked on areas of public policy including higher education, nuclear energy and disarmament. The latter body of work was recognized by the 2014 Leo Szilard Lectureship Award by the American Physical Society. His work covers nuclear weapon accidents, civil defence, India's nuclear doctrine, minimal deterrence and anti-missile and early warning systems. He has analyzed the Indo-US nuclear agreement and its impact on both India's civilian nuclear program and its nuclear arsenal. He has written about fissile material production in India and Pakistan and the radiological effects of nuclear weapon accidents.

Robert Rosner (Chair) is the chair of the *Bulletin*'s Science and Security Board and is the William E. Wrather Distinguished Service Professor in the Departments of Astronomy & Astrophysics and Physics, and the Harris School of Public Policy Studies at the University of Chicago. Rosner served as Director of Argonne National Laboratory, where he had also served as Chief Scientist. His current scientific research is mostly in the areas of plasma astrophysics and astrophysical fluid dynamics and magnetohydrodynamics; high energy density physics; boundary mixing instabilities; and computational physics. His policy-oriented work has focused on the future of nuclear power and the back end of the nuclear fuel cycle, as well as various aspects of electrifying the transport sector.

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

Biographies (continued)

her PhD from Johns Hopkins University's School of Advanced International Studies. In 1998, Sims 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, the 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 the American Association for the Advancement of Science, the American Geophysical Union, and the American Meteorological Society. He has received both the Climate Communication Prize and the Ambassador Award 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 is Research Professor at the Institute for International Science and Technology Policy, Elliott School of International Affairs, at the George Washington University. Previously, she directed the Proliferation Prevention Program at the Center for Strategic and International Studies and was a senior scholar at the Carnegie Endowment for International Peace, both in Washington, DC. She has specialized in nuclear nonproliferation, arms control and security policy for three decades, serving in the US government at the Arms Control and Disarmament Agency, the State Department, and the Congressional Research Service. 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

Biographies (continued)

operations, the chief operating officer position at the National Oceanic and Atmospheric 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.

Jon Wolfsthal is Director of the Nuclear Crisis Group, an independent project of Global Zero. Wolfsthal served previously as Special Assistant to the President of the United States for National Security Affairs and senior director at the National Security Council for arms control and nonproliferation. During his time in government he was involved in almost every aspect of US nuclear weapons, arms control, nonproliferation and security policy. Previously, Wolfsthal was the Deputy Director of the Center for Nonproliferation Studies at the Monterey Institute of International Studies, and served for three years as special advisor to Vice President Biden on issues of nuclear security and nonproliferation. He served in several capacities during the 1990s at the US Department of Energy, including an on-the-ground assignment in North Korea during 1995-96. With Joseph Cirincione, he is the author of *Deadly Arsenals: Tracking Weapons of Mass Destruction*. He is a non-resident fellow with the Carnegie Endowment for International Peace and with the Managing the Atom Project at Harvard University.

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 the topics of nuclear risk, climate change, and disruptive 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.

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 more than 230,000 visits per month. The bimonthly magazine, which can be found in more than 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, publisher of our digital journal since January 2016.

See more at: https://thebulletin.org

Timeline of Doomsday Clock changes

2017 IT IS TWO AND A HALF MINUTES TO MIDNIGHT

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 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."

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.

Timeline of Doomsday Clock changes (cont.)

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 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.

Timeline of Doomsday Clock changes (cont.)

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.


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 Olympic 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

Timeline of Doomsday Clock changes (cont.)

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.

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.

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