

## Science and Global Security

### From Nuclear Weapons to Cyberwarfare and Artificial Intelligence



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# Science and Global Security

## From Nuclear Weapons to Cyberwarfare and Artificial Intelligence

Alexander Glaser

**Tuesdays and Thursdays, Bowl 016, 1:30–2:50 p.m.**

### Course description

Advances in science and technology over the past century have created many unprecedented and still unresolved global security challenges for policy makers and the public. The invention of nuclear weapons during World War II led Einstein to conclude that “the unleashed power of the atom has changed everything save our modes of thinking.” Security concerns and government-sponsored research programs later combined to shape the Cold War arms race between the United States and Soviet Union. Many military and technical innovations resulted; these include precision-guided intercontinental ballistic missiles, spy satellites, and the global positioning system (GPS), but also the modern electronic computer and computer networks, which became the basis for the internet. Recent developments in biotechnology and digital communication and control raise the prospect of possible new kinds of warfare.

This course will provide students with a basic technical understanding of some of the critical technologies that are relevant to national and global security and will equip students with the skills to better assess the challenge of developing effective policies to manage such technologies. Case studies will *inter alia* include nuclear weapons and their proliferation, delivery systems for weapons of mass destruction, biotechnology and biosecurity, new media and crowdsourcing, autonomous weapons, superintelligence, and cyberwarfare.

While the emphasis of this course will be on the security challenges posed by many of these technologies, it will also explore the application of science to arms control and disarmament. Examples covered in class will include the potential of open-source satellite imagery, which has been effectively used for crowd-sourcing purposes, and internet-enabled approaches to encouraging anonymous reporting.

For revisions and updates, go to  
[nuclearfutures.princeton.edu/courses/wws353](http://nuclearfutures.princeton.edu/courses/wws353)

**WWS/MAE 353: Science and Global Security: From Nuclear Weapons to Cyberwarfare (Spring 2017)**  
 Alexander Glaser, Syllabus, Revision 1b, February 7, 2017

Course Overview

Week	Date	ID	Topic	Concept/Guest	DUE
1	02/07		Setting the Stage		
	02/09	11	Nuclear Weapons 1: Principles		
2	02/14	12	Nuclear Weapons 2: Effects	Scaling laws	Handout
	02/16	13	Nuclear Weapons 3: Acquisition		
3	02/21	14	Negotiating a Treaty Banning Nuclear Weapons	(w/ Ray Acheson)	PS1
	02/23	21	Biological (and Chemical) Weapons		
4	02/28	22	Biotechnology, Biosecurity, and Bioterrorism	(w/ Andy Leifer)	PS2
	03/02	23	Dynamics of Infectious Diseases	Modeling I	
5	03/07	24	Expert Briefings: Biosecurity and Modeling	(w/ Fefferman and Chyba)	PS3
	03/09	31	Nuclear Energy and Nuclear Proliferation 1		
6	03/14	32	Nuclear Energy and Nuclear Proliferation 2 (Case study)	Making Sense of Equations I	PS4
	03/16		Midterm exam (in class)		Midterm
<b>SPRING BREAK</b>					
7	03/28	41	Delivery Systems 1: mostly Missiles	Making Sense of Equations II	
	03/30	41	Delivery Systems 2: mostly Missiles (continued)		
8	04/04	42	Nuclear Strategy and Deterrence 1		Handout
	04/06	43	Nuclear Strategy and Deterrence 2: Wargame		
9	04/11	51	Verification 1: Satellites		PS5
	04/13	52	Verification 2: Emerging Technologies and Virtual Reality	(w/ Tamara Patton)	
10	04/18	61	The Future 1: Cyberwarfare		
	04/20	62	The Future 2: Cyberwarfare (Kinetic Pwnage)	(w/ Ed Skoudis)	
11	04/25	63	The Future 3: Machine Learning and Superintelligence	Modeling II	
	04/27	63	The Future 4: Machine Learning and Superintelligence		
12	05/02		Team Presentations		
	05/04		Team Presentations		

### Assignments

Weekly readings, regular blog posts or comments; five problem sets (mostly in the first half of the semester); midterm exam in class; team projects and presentations (in the second half of the semester); and final exam.

Problem sets are due Tuesdays before class. A 24-hour delay carries a 20% penalty, a 48-hour delay carries a 40% penalty; we do not accept problem sets afterwards. Students can work together on problem sets in groups of up to three students, but submit separate problem sets and draft individual answers to all questions. When working in groups, list names of the other team members on the first page.

### Prerequisites

No prerequisites

### Grading (tentative breakdown)

Problem sets:	20%
Midterm exam (in class):	15%
Team projects:	15%
Final exam (closed book):	25%
Blog posts, comments, annotated syllabus:	10%
Class/precept participation:	15%

### Readings; Blog posts and comments; Annotated syllabus

Most readings and media required for this course are available online, either directly (with open access) or through Princeton University. All other readings are or will be available on Blackboard; these are marked with **(BB)** below. Each week, two students take the lead on blogging, due Mondays, 9:00 a.m., and all others can respond by Wednesday, 9:00 a.m. For a maximum blog score, 5 contribution points are needed by the end of the semester (1 point for each blog comment; 2 points for posting an initial entry). Up to 3 additional points will be awarded at the end of the semester for particularly thoughtful contributions. Students are encouraged to annotate a hardcopy of the syllabus with short comments on the usefulness of the readings; this will help us improve the assignments for next year (2 points).

## Weekly Schedule and Readings

### Setting the Stage: Science, Technology, and the Doomsday Risk (Feb. 7)

Advances in science and technology have always played an important role in shaping the nature of warfare, but a fundamentally new dimension emerged with the invention of nuclear weapons in the 1940s and, as the nuclear arsenals expanded, the respective capability for nearly-instant global devastation. Since the end of Cold War, many global security challenges have evolved but, as former President Obama pointed out in 2009, “in a strange turn of history, the threat of global nuclear war has gone down, but the risk of a nuclear attack has gone up.” New technologies are now emerging that could again transform the conditions of global security. These developments can be disruptive (as with the invention of nuclear weapons) or gradual as with the increasing significance of autonomous weapons and artificial intelligence. The dual-use nature of many relevant technologies further highlights the complexity of sound policy-making. To set the stage for the topics and issues covered this semester, we will briefly explore the different types of security threats today, the perception and prioritization of relevant risks, and the resulting challenges for effective policy making.

#### Readings (for today, only recommended):

- *It is Two and a Half Minutes to Midnight, 2017 Doomsday Clock Statement*, Science and Security Board, Bulletin of the Atomic Scientists, January 26, 2017, [thebulletin.org](http://thebulletin.org).

#### More to explore:

**Here and below, “more to explore” readings and videos are not required!**

- [Remarks by President Obama at Hiroshima Peace Memorial, Hiroshima Peace Memorial](#), Hiroshima, Japan, May 27, 2016.
- Figures 1–3 and Sections 3.1 and 3.2 in Part 3 (Emerging Technologies) in *Global Risks 2017, 12th Edition*, World Economic Forum, Geneva, 2017, [reports.weforum.org/global-risks-2017](http://reports.weforum.org/global-risks-2017) and [www3.weforum.org/docs/GRR17\\_Report\\_web.pdf](http://www3.weforum.org/docs/GRR17_Report_web.pdf).
- *Welcome to 2035 ... The Age of Surprises*, United States Air Force, Center for Strategy and Technologies, Video/Commercial, 2 min, 2012, [www.youtube.com/watch?v=9Xpu2QqLnHY](http://www.youtube.com/watch?v=9Xpu2QqLnHY).

### Unit 1: Nuclear Weapons (Feb. 9, Feb. 14, Feb. 16, and Feb. 21)

Shortly after the discovery of nuclear fission in the late 1930s, it became clear that the process could, in principle, unfold in an explosive chain reaction and release large amounts of energy. At the time, it was unknown, however, just how hard it would be to make the fissile material (highly enriched uranium or plutonium) needed for a nuclear weapon. During World War II, the U.S. Manhattan project demonstrated the technical basis of large-scale fissile material production (including the feasibility of operating nuclear reactors) and led to the development and use of the first nuclear weapons in 1945. The Soviet Union demonstrated its nuclear capability in 1949, and military planners on both sides began to integrate these weapons into their war-fighting arsenals. The emerging arms race between the superpowers further escalated in scale with the invention of the hydrogen bomb, which would increase the yield of nuclear weapons several hundred-fold. The destructive effects of nuclear weapons remain unparalleled; they involve air blast, heat, and nuclear radiation.

*Keywords: Nuclear fission process; radioactivity; effects of nuclear weapons; medical and climatic impact of nuclear war; nuclear reactors, nuclear fuels, uranium enrichment, plutonium production.*

**Nuclear Weapons 1: Principles (Feb. 9).** In this unit, we explore the principles of nuclear fission and the concept of a nuclear chain reaction, estimate the time scale of the processes involved, and determine the amount of energy released in a nuclear explosion. We can then also estimate the so-called critical mass and the approximate amount of material needed to make a nuclear bomb.

#### Readings:

- Henry Stimson (Secretary of War), *Memorandum Discussed with the President*, April 25, 1945, [nsarchive.gwu.edu](http://nsarchive.gwu.edu).
- Jonathan Fetter-Vorm, *Trinity: A Graphic History of the First Atomic Bomb*, Hill and Wang, 2012, pp. 39–61. **(BB)**
- Kosta Tsipsis, “The Physics of a Nuclear Explosion,” Chapter 2 in *Arsenal: Understanding Weapons in the Nuclear Age*, Simon and Schuster, New York, 1983. **(BB)**

#### ALTERNATIVELY:

- “Nuclear Physics” (C.2) in Appendix C (“Basic Nuclear Physics and Weapons Effects”), *Nuclear Matters Handbook 2016*, U.S. Department of Energy, Washington, DC, 2016, [www.acq.osd.mil/nbcdp/nm/NMHB](http://www.acq.osd.mil/nbcdp/nm/NMHB).

More to explore:

- Richard Rhodes, *The Making of the Atomic Bomb*, Simon & Schuster, 1995.
- S. Glasstone and L. M. Redman, *An Introduction to Nuclear Weapons*, WASH-1037 Revised, U.S. Atomic Energy Commission, Washington, DC, June 1972.
- Robert Serber, *The Los Alamos Primer: The First Lectures on How to Build an Atomic Bomb*, University of California, Berkeley, 1992.

**Nuclear Weapons 2: Effects (Feb. 14).** What happens if the energy equivalent of 20,000 tons of high explosive is released within one millionth of a second in a volume of one cubic foot? In this session, we will examine the effects of nuclear explosions, which involve air blast, heat, and nuclear radiation, and discuss the consequences of regional and global nuclear war.

Readings:

- *Statement by the President of the United States*, White House Press Release, August 6, 1945. **(BB)**
- J. Robert Oppenheimer, *Recollection of the Trinity Test ("Now I am become Death, the destroyer of worlds")*, Television Broadcast, 1 min, 1965, [www.youtube.com](http://www.youtube.com).
- RETRO Report, "Nuclear Winter," *New York Times*, April 4, 2016, [www.nytimes.com](http://www.nytimes.com).
- Alan Robock and Owen B. Toon, "Local Nuclear War, Global Suffering," *Scientific American*, 302, January 2010, pp. 74–81. **(BB)**
- Kosta Tsipis, "Blast, Heat, and Radiation," Chapter 4 in *Nuclear Almanac: Confronting the Atom in War and Peace*, Addison-Wesley, Reading, Massachusetts, 1984. **(BB)**

ALTERNATIVELY:

- "The Effects of Nuclear Detonations" (C.4) in Appendix C ("Basic Nuclear Physics and Weapons Effects"), *Nuclear Matters Handbook 2016*, U.S. Department of Energy, Washington, DC, 2016, [www.acq.osd.mil/ncbdp/nm/NMHB](http://www.acq.osd.mil/ncbdp/nm/NMHB).

Web:

- NUKEMAP, by Alex Wellerstein, [nuclearsecrecy.com/nukemap](http://nuclearsecrecy.com/nukemap).

Video:

- *The House in the Middle*, Federal Civil Defense Administration, 12 minutes, 1954, [www.youtube.com](http://www.youtube.com).
- Isao Hashimoto, *1945–1998*, Multimedia Artwork, 14 minutes, 2003, [www.ctbto.org](http://www.ctbto.org) or [www.youtube.com](http://www.youtube.com).

More to explore:

- *White Light, Black Rain: The Destruction of Hiroshima and Nagasaki*, Documentary directed by Steven Okazaki, 86 minutes, 2007. **(BB)**
- Jill Lepore, “The Atomic Origins of Climate Science,” *The New Yorker*, January 23, 2017, [www.newyorker.com](http://www.newyorker.com). **(BB)**
- S. Glasstone and P. J. Dolan, *The Effects of Nuclear Weapons*, U.S. Government Printing Office, Washington, DC, 1977, [www.ipfmlibrary.org/gla77.pdf](http://www.ipfmlibrary.org/gla77.pdf).
- A. A. Broyles, “Nuclear Explosions,” *American Journal of Physics*, 50 (7), July 1982, pp. 586–594. **(BB)**
- Leo Sartori, “Effects of Nuclear Weapons,” *Physics Today*, March 1983. **(BB)**

**Nuclear Weapons 3: Acquisition (Feb. 16).** How hard is it to make a nuclear weapon? Harold Agnew, director of Los Alamos National Laboratory from 1970 to 1979, once said: “Those who say that building a nuclear weapon is easy, they are very wrong, but those who say that building a crude device is very difficult are even more wrong.” Today, it is widely acknowledged that the production of the nuclear explosive material remains the most significant technical hurdle in the process of making a (simple) nuclear weapon or explosive device. In this unit, we will explore the technologies and infrastructure needed to make plutonium or highly enriched uranium in quantities that are sufficient for a weapons program. We will also examine the risk of nuclear terrorism, which became a particular concern after 9/11. In this scenario, a non-state actor would acquire existing nuclear material to fabricate an “improvised nuclear device.” Such a device may have a much lower yield than a typical nuclear weapon, but still be hundreds or thousands of times more destructive than conventional explosives.

Readings:



- H. A. Feiveson, A. Glaser, Z. Mian, and F. von Hippel, "Production, Uses, and Stocks of Fissile Materials," Chapter 2 in *Unmaking the Bomb: A Fissile Material Approach to Nuclear Disarmament and Nonproliferation*, MIT Press, Cambridge, MA, 2014. **(BB)**
- "Amateur A-Bomb," *Time Magazine*, May 13, 1974. **(BB)**
- William Langewiesche, "How to Get a Nuclear Bomb," *The Atlantic*, December 2006, [www.theatlantic.com](http://www.theatlantic.com). **(BB)**
- Peter Zimmerman and Jeffrey Lewis, "The Bomb in the Backyard," *Foreign Policy*, October 16, 2009, [foreignpolicy.com](http://foreignpolicy.com). **(BB)**

More to explore:

- Steve Coll, "The Unthinkable: Can the United States be Made Safe from Nuclear Terrorism?," *The New Yorker*, March 12, 2007, [www.newyorker.com](http://www.newyorker.com). **(BB)**

**Nuclear Weapons 4: Negotiating a Ban on Nuclear Weapons (Feb. 21).** In October 2016, the First Committee of the United Nations General Assembly, which deals with disarmament and international security matters, adopted a resolution to begin negotiations on a treaty banning nuclear weapons: 123 countries voted in favor, 16 abstained, and 38 voted against this resolution, including most nuclear weapon states (except China, Pakistan, and North Korea) and most member states of NATO. Negotiations are set to begin in New York in March 2017. Today, we will have an opportunity to learn about the origins and prospects of this initiative.

**Guest Lecture: Ray Acheson**

*Ray Acheson is the Director of Reaching Critical Will (reachingcriticalwill.org). She provides reporting, analysis, and advocacy across a range of international disarmament and arms control issues and forums, including those related to nuclear weapons, explosive weapons, the arms trade, armed drones, and autonomous weapons, and gender and disarmament. Ray is also on the Board of Directors of the Los Alamos Study Group, represents the Women's International League for Peace and Freedom (wilpf.org) on several coalition steering groups, and previously worked with the Institute for Defense and Disarmament Studies. She has an Honors BA from the University of Toronto in Peace and Conflict Studies and an MA in Politics from The New School for Social Research.*

Readings:

- Ray Acheson, Thomas Nash, and Richard Moyes, *A Treaty Banning Nuclear Weapons: Developing a Legal Framework for the Prohibition and Elimination of Nuclear Weapons*, Reaching Critical Will of the Women's International League for Peace and Freedom and Article 36, May 2014, [reachingcriticalwill.org](http://reachingcriticalwill.org) and [article36.org](http://article36.org).
- *Taking Forward Multilateral Nuclear Disarmament Negotiation*, United Nations General Assembly, First Committee, Seventy-first Session, A/C.1/71/L.41, October 14, 2016, [reachingcriticalwill.org](http://reachingcriticalwill.org).

More to explore:

- Alexander Kmentt, "The Development of the International Initiative on the Humanitarian Impact of Nuclear Weapons and Its Effect on the Nuclear Weapons Debate," *International Review of the Red Cross*, 97 (899), 2015, [www.icrc.org](http://www.icrc.org).

**Unit 2: Biotechnology, Biosecurity, and Bioterrorism (Feb. 23 and 28, Mar. 2 and 7)**

The Biological Weapons Convention (BWC) bears a superficial similarity to the NPT, but in fact differs greatly in scope and monitoring. The traditional concern over biological weapons was with state programs; this has now been supplemented by both the threat of terrorist use and, perhaps most disturbingly, the extraordinary growth of biotechnology that places increasing potential power for dangerous biological modifications in the hands of the technically competent.

*Keywords: Biological and chemical weapons conventions; wedge model; dynamics and control of infectious diseases; epidemics and pandemics; anthrax, smallpox; biotechnology; biosecurity; bioterrorism; disease surveillance.*

**Biological Weapons 1: Principles (Feb. 23).** In this first session, we will introduce the fundamental principles and effects of biological and chemical weapons. In particular, we will also characterize the similarities and differences between the different types of weapons of mass destruction (nuclear, biological, chemical) and how these weapons are (or can be) captured in arms control regimes.

Readings:

- Jeanne Guillemin, "Introduction" and "Biological Agents and Disease Transmission," in *Biological Weapons: From the Invention of State-Sponsored Programs to Contemporary Bioterrorism*, Columbia University Press, 2006, pp. 1–39. **(BB)**

- Edwin D. Kilbourne, “Plagues and Pandemics: Past, Present, and Future,” in Nick Bostrom and Milan Cirkovic, eds., *Global Catastrophic Risks*, Oxford University Press, 2008, pp. 287–307. **(BB)**

Video:

- *Contagion*, directed by Steven Soderbergh, 106 minutes, 2011. **(BB)**

More to explore:

- The Biological and Toxin Weapons Convention (BTWC or, more often, just BWC), available at [www.opbw.org](http://www.opbw.org).

**Biological Weapons 2: Acquisition (Feb. 28).** Especially since the 2001 anthrax-letter attacks (following 9/11), concerns over the possible development and use of biological weapons has shifted from state-sponsored programs to efforts that a non-state actor might be able to launch. In this unit, we will examine how recent advances in biotechnology, especially the growing capabilities to sequence and synthesize DNA (including the DNA of pathogens) exacerbate these concerns, ask how the scientific community can or should conduct “experiments of concern,” and explore strategies to mitigate some of the present and emerging security risks.

**Guest Lecture: Andy Leifer**

*Andy Leifer is an Assistant Professor in the Department of Physics and the Princeton Neuroscience Institute, where he directs the LeiferLab. Previously he was a Lewis-Sigler Fellow and Principal Investigator. He received his doctorate in Biophysics from Harvard University under the supervision of Professor Aravi Samuel. As an undergraduate, he attended Stanford University where he graduated with degrees in Physics and Political Science and interdisciplinary honors in international security studies. He grew up out west in sunny California and Colorado.*

Readings:

- “Science of Synthetic Biology,” Chapter 2 in *New Directions: The Ethics of Synthetic Biology and Emerging Technologies*, Presidential Commission for the Study of Bioethical Issues, December 2010.
- Heidi Ledford, “CRISPR, The Disruptor,” *Nature*, 522, June 4, 2015, pp. 20–24.
- John Bohannon, “Biologists Devise Invasion Plan for Mutations,” *Science*, 347 (6228), March 20, 2015, p. 1300.

- Heidi Ledford, “Life Hackers,” *Nature*, 467, October 7, 2010, pp. 650–652.
- Ali Nouri and Christopher F. Chyba, “Biotechnology and Biosecurity,” in Nick Bostrom and Milan Cirkovic, eds., *Global Catastrophic Risks*, Oxford University Press, 2008, pp. 450–480. **(BB)**

More to explore:

- *Biotechnology Research in an Age of Terrorism*, Committee on Research Standards and Practices to Prevent the Destructive Application of Biotechnology, National Research Council, Washington, DC, 2004, [www.nap.edu/catalog.php?record\\_id=10827](http://www.nap.edu/catalog.php?record_id=10827), Executive Summary and Chapter 1 (“Introduction”), pp. 1–40. **(BB)**
- Ali Nouri and Christopher F. Chyba, “Proliferation-resistant Biotechnology: An Approach to Improve Biological Security,” *Nature Biotechnology*, 27 (3), 2009, pp. 234–236.
- Richard Danzig et al., *Aum Shinrikyo: Insights Into How Terrorists Develop Biological and Chemical Weapons*, Center for a New American Security, Washington, DC, July 2011.

**Biological Weapons 3: Dynamics of Infectious Diseases (Mar. 2).** The effects of biological weapons can be greatly amplified if the disease caused by the agent is contagious and leads to an epidemic in the targeted population. In this session, we will develop a simple mathematical model to describe the dynamics of infectious diseases (“SIR model”). This will enable us to assess the effects of a disease outbreak and the effectiveness of different control options.

Readings:

- Duncan J. Watts, “Epidemics and Failures,” Chapter 6 in *Six Degrees: The Science of a Connected Age*, Norton & Company, February 2004. **(BB)**
- P. Munz, I. Hudea, R. J. Smith, “When Zombies Attack: Mathematical Modeling of an Outbreak of Zombie Infection,” J. M. Tchenche and C. Chiyaka (eds.), *Infectious Disease Modeling Research Progress*, Nova Science Publishers, Inc., 2009. **(BB)**

Video game:

- *Plague Inc.*, [www.ndemiccreations.com](http://www.ndemiccreations.com), on iOS and Android.

More to explore:

- R. M. Anderson and R. M. May, *Infectious Diseases of Humans: Dynamics and Control*, Oxford University Press, 1991.

**Biological Weapons 4: Expert Briefings (Mar. 7).** We will conclude this unit with two expert briefings. Professor Nina Fefferman will provide some additional insights into mathematical modeling of infectious disease dynamics, especially how individual behaviors can cause different outcomes at the level of the population. Professor Christopher Chyba will share with us the findings from a recent study on biosecurity by the President's Council of Advisors on Science and Technology, co-chaired by Chyba, offering “guidance about how the United States can take advantage of its strong scientific community to prepare for and respond to pathogens of all kinds.”

**Guest lectures: Nina Fefferman (via Skype) and Christopher Chyba**

*Nina Fefferman is Associate Professor in the Department of Ecology & Evolutionary Biology at the University of Tennessee, Knoxville. Her research focuses on the mathematics of epidemiology, evolutionary and behavioral ecology, and self-organizing behaviors, especially of systems described by networks. While the research in the Fefferman Lab frequently focuses on disease in human and/or animal populations, and how disease and disease-related behavioral ecology can affect the short-term survival and long-term evolutionary success of a population, people in the lab have worked on problems as diverse as computer network security to social behaviors in grass-roots organizations that make the movement susceptible to radicalization.*

*Christopher Chyba is Professor of Astrophysical Sciences and International Affairs at Princeton University. His security-related research emphasizes nuclear and biological weapons policy, arms control, and nonproliferation. His scientific research focuses on solar system exploration and the search for life elsewhere. From 2009 through 2016, he was a member of the President's Council of Advisors on Science and Technology (PCAST). Dr. Chyba co-chaired the PCAST study “Action Needed to Protect Against Biological Attack” in 2016.*

Readings:

- Eric Lofgren and Nina Fefferman, “The Untapped Potential of Virtual Game Worlds to Shed Light on Real World Epidemics,” *The Lancet: Infectious Diseases*, 7 (9), September 2007, pp. 625–629. **(online and BB)**

- “Letter Report to the President on Action Needed to Protect against Biological Attack,” *President's Council of Advisors on Science and Technology (PCAST)*, Washington, DC, November 2016, [obamawhitehouse.archives.gov](http://obamawhitehouse.archives.gov). **(BB)**

### Unit 3: Nuclear Energy and Nuclear Proliferation (Mar. 9 and Mar. 14)

A basic understanding of nuclear reactor and fuel-cycle technologies will be important in allowing us to appreciate the differences between various technical and non-technical choices for civilian nuclear-energy use. To a large extent, these choices determine the proliferation risks associated with nuclear power. Since the 1970s, many countries have abandoned nuclear weapon programs, but some others have emerged, and concerns about the nature of nuclear activities, sometimes part of civilian nuclear power program, persist. This week, we will explore the fundamentals of various nuclear technologies and examine the strategies that have been proposed or implemented to prevent the diversion of civilian nuclear power programs for military purposes. To complement this discussion, we will explore and assess some relevant case studies.

*Keywords: Nuclear fuel-cycle options; civilian and military use of nuclear power; technical and non-technical dimensions of nuclear proliferation, nuclear safeguards, nuclear non-proliferation treaty, multilateral approaches to the nuclear fuel cycle; Pakistan, Libya, North Korea, Iran.*

**Nuclear Energy and Nuclear Proliferation 1 (Mar. 9).** This lecture will provide an introduction to the basic technologies and processes underlying the peaceful use of nuclear energy—and how some of them can be used for military purposes.

#### Readings:

- H. A. Feiveson, A. Glaser, Z. Mian, and F. von Hippel, “Fissile Materials, Nuclear Power, and Nuclear Proliferation,” Chapter 5 in *Unmaking the Bomb: A Fissile Material Approach to Nuclear Disarmament and Nonproliferation*, MIT Press, Cambridge, MA, 2014. **(BB)**
- Robert H. Socolow and Alexander Glaser, “Balancing Risks: Nuclear Energy & Climate Change,” *Daedalus*, 138 (4), Fall 2009, pp. 31–44, [mitpressjournals.org](http://mitpressjournals.org).
- Scott Sagan, “Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb,” *International Security*, 21, Winter 1996/97, pp. 54–86. **(BB)**
- Anonymous, *IAEA Super Inspectors*, February 2012, [www.youtube.com/watch?v=kE-0pdlx5Jk](http://www.youtube.com/watch?v=kE-0pdlx5Jk).

Video:

- *A is for Atom*, Documentary, BBC, 46 min, 2011,  
[www.bbc.co.uk/blogs/adamcurtis/2011/03/a\\_is\\_for\\_atom.html](http://www.bbc.co.uk/blogs/adamcurtis/2011/03/a_is_for_atom.html) or  
[www.youtube.com/watch?v=-FDrA7yUdFc](http://www.youtube.com/watch?v=-FDrA7yUdFc)

**Nuclear Energy and Nuclear Proliferation 2: Iran and North Korea (Mar. 14).**

Iran and North Korea have dominated the domestic and international nonproliferation debate over the past few years. While fundamentally different, both are among the hardest nonproliferation challenges of the past few decades, and every recent U.S. Administration has pursued different policies toward these nuclear programs. In the case of Iran, the EU3+3 (France, Germany, and the United Kingdom plus China, Russia, and the United States) signed a landmark agreement with Iran. The new U.S. Administration may however stop supporting this deal, which could rapidly lead to its collapse. The regional and global consequences of such a breakdown are hard to anticipate. North Korea on the other hand has successfully proliferated, testing its first nuclear device in 2006 after the 1994 Agreed Framework had collapsed in 2002/2003. North Korea has since carried out a number of additional weapon tests, probably weaponized a warhead, and it is on the verge of demonstrating credible ICBM capability, i.e., missiles that could eventually reach U.S. territory. It is hard to see how the North Korean weapons program could be rolled back, and it is unclear what the regional implications of North Korea's capabilities over the next years will be. In this unit, we will explore in more depth one of these programs pending developments in the coming weeks.

Readings:

- PLACEHOLDER READING #1: [Joint Comprehensive Plan of Action](#), Vienna, 14 July 2015.
- PLACEHOLDER READING #2: *The Iran Nuclear Deal, The Definitive Guide*, Harvard Kennedy School, Belfer Center for Science and International Affairs, Cambridge, MA, August 2015.
- PLACEHOLDER READING #3: [38north.org](http://38north.org).
- PLACEHOLDER READING #4: Daryl Kimball and Kelsey Davenport, "Recalibrating U.S. Policy Toward North Korea," *Issue Briefs*, 9 (1), February 2017, [www.armscontrol.org](http://www.armscontrol.org).

**SPRING BREAK**

#### Unit 4a: Delivery Systems and Ballistic Missiles (Mar. 28 and 30)

The importance of a delivery system for nuclear weapons has been recognized from the very beginning. In his famous 1939 letter to President Roosevelt, Einstein assumed that nuclear weapons would be powerful but gigantic and speculated that bombs would therefore have to be “carried by boat” and “might very well prove to be too heavy for transportation by air.” Nuclear warheads turned out much smaller, and delivery became possible not only by aircraft but also by ballistic missiles. The invention of the intercontinental ballistic missile equipped with guidance systems in the late 1950s and the development of de-facto invulnerable submarine-launched missiles critically shaped nuclear postures during the Cold War. The spread of missile technology continues to be a challenge for the nuclear nonproliferation regime. In this unit, we will review the basic phenomena and constraints underlying the delivery of warheads over intercontinental distances and the implications for nuclear strategy.

*Keywords: Rocket equation; ballistic missile trajectories; nuclear triad.*

#### Readings:

- Dietrich Schroer, “Intercontinental Ballistic Missiles,” Chapter 6 in *Science, Technology and the Nuclear Arms Race*, Wiley & Sons, New York, 1984. **(BB)**
- Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, MIT Press, Cambridge, MA, 1990, Chapter 1 (“A Historical Sociology of Nuclear Missile Guidance”) and Chapter 8 (“Patterns in the Web”). **(BB)**

#### More to explore:

- Lynn Davis and Warner R. Schilling, “All You Ever Wanted to Know about MIRV and ICBM Calculations but Were Not Cleared to Ask,” *Journal of Conflict Resolution*, 17 (2), June 1973, pp. 207–242. **(BB)**
- Albert D. Wheelon, “Free Flight of a Ballistic Missile,” *ARS Journal*, 29 (12), 1959, pp. 915–926.
- James N. Constant, *Fundamentals of Strategic Weapons: Offense and Defense Systems*, Martinus Nijhoff Publishers, The Hague, 1981.

#### Unit 4b: Nuclear Strategy, Deterrence, and the Last 30 Minutes (Apr. 4 and 6)

As the Cold War arms race accelerated in the 1950s, military planners in the United States and elsewhere began to develop and then refine the concept of nuclear deterrence, which included massive retaliation, flexible response, and mutual assured destruction (based on a “secure second-strike capability”). Along the way,



the superpowers also began to embrace (nuclear) arms control, which is based on the shared understanding that it can be preferable for all parties not to engage in costly and potentially destabilizing arms races. Arms control regulates, limits, reduces, or prohibits particular classes of weapons and has remained a critical tool to support global security to the present day. Arms-control agreements are often enshrined in treaties, which usually require verification mechanisms to confirm compliance. In this unit, we will examine the basic concepts of nuclear strategy and arms control. We will also examine, the contributions that established and emerging technologies can play in treaty verification.

*Keywords: Massive retaliation; mutual assured destruction; no-first use, second-strike capability.*

Readings:

- Thomas M. Nichols, "Nuclear Strategy, 1950–1990: The Search for Meaning," Chapter 1 in *No Use: Nuclear Weapons and U.S. National Security*, University of Pennsylvania Press, Philadelphia, 2014. **(BB)**
- Carol Cohn, "Sex and Death in the Rational World of Defense Intellectuals," *Signs: Journal of Women in Culture and Society*, 12 (4), 1987. **(BB)**

More to explore (including some classics):

- Alexander L. George and Richard Smoke, *Deterrence in American Foreign Policy, Theory and Practice*, Columbia University Press, New York, 1974, Chapter 1. **(BB)**
- Robert Jervis, "Deterrence and Perception," *International Security*, 7 (3), Winter 1982/83. **(BB)**
- Lawrence Freedman, *The Evolution of Nuclear Strategy*, 3rd Edition, Palgrave MacMillan Press, London, 2003. **(BB)**
- Jeffrey Knopf, "The Fourth Wave in Deterrence Research," *Contemporary Security Policy*, 31 (1), April 2010. **(BB)**
- Eric Schlosser, *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*, Penguin Press, 2013.

**WARGAME: The Last 30 Minutes (Apr. 6)**

Readings:

- Bruce Blair, “What Exactly Would It Mean to Have Trump’s Finger on the Nuclear Button?,” *Politico Magazine*, June 11, 2016, [www.politico.com](http://www.politico.com).
- “Nuclear Command and Control,” Chapter 6 in *Nuclear Matters Handbook 2016*, U.S. Department of Energy, Washington, DC, 2016, [www.acq.osd.mil/ncbdp/nm/NMHB](http://www.acq.osd.mil/ncbdp/nm/NMHB).

### **Unit 5: Science and Technology for Arms Control and Verification (Apr. 11 and Apr. 13)**

Arms-control agreements are meaningful only insofar as they also include provisions to demonstrate compliance with the agreement through a set of agreed reporting and verification provisions. In this unit, we will explore the political and technical challenges of verification in the context of arms control, with a particular emphasis on the role of satellites and the potential of social media, which may provide fundamentally new ways to detect or report non-compliance with treaty obligations.

**Verification 1 (Apr. 11).** This lecture introduces the basic concepts underpinning the politics and technology of verification. As a case study, we will examine satellites, which were first developed and deployed by the superpowers during the Cold War for threat assessment and war planning. When the first arms-control treaties were negotiated in the early 1970s, however, they (also) became a critical tool to enable verification of these agreements without the need for onsite inspections. Many countries and now also private companies operate satellites today, and they have begun to sell imagery of unprecedented quality, sometimes on a first-come first-serve basis. In this session, we will discuss why satellites are where they are, determine the resolution limits of the imagery that can be obtained with them, and explore what future roles satellites could play given that “quasi real-time imagery for everyone” may soon become a reality.

*Keywords: Satellite orbits; satellite imagery; optical resolution.*

#### Readings:

- PLACEHOLDER READING #1: Amy F. Woolf, *Monitoring and Verification in Arms Control*, Report R41201, Congressional Research Service, December 23, 2011.  
**(BB)**
- PLACEHOLDER READING #2: D. Wright, L. Grego, and L. Gronlund, “The Basics of Satellite Orbits” and “Types of Orbits, or Why Satellites Are Where They Are,” Sections 4 and 5 in *The Physics of Space Security: A Reference Manual*, American

Academy of Arts and Sciences, Cambridge, MA, 2005, [www.amacad.org](http://www.amacad.org).

## Verification 2: Emerging Technologies and Virtual Reality (Apr. 13).

### Guest Lecture: Tamara Patton

*Tamara Patton is a Doctoral Student in Science, Technology and Environmental Policy (STEP) at the Woodrow Wilson School of Public and International Affairs. Prior to coming to Princeton, Tamara worked as a researcher at the Vienna Center for Disarmament and Non-Proliferation (VCDNP) and at the Stockholm International Peace Research Institute (SIPRI). She has an MA in nonproliferation studies from the Middlebury Institute of International Studies and a BA in international studies from the University of Washington.*

#### Readings:

- Tamara Patton, Jeffrey Lewis, Melissa Hanham, Catherine Dill, and Lily Vaccaro, *Emerging Satellites for Non-Proliferation and Disarmament Verification*, Vienna Center for Disarmament and Non-Proliferation (VCDNP), Vienna, Austria, January 2016, [nonproliferation.org](http://nonproliferation.org).
- Tamara Patton, Bernadette Cogswell, Moritz Kütt, and Alexander Glaser, “Full-Motion Virtual Reality for Nuclear Arms Control,” *57th Annual INMM Meeting*, July 24-28, 2016, Atlanta, Georgia. **(BB)**

## Unit 6: The Future (Apr. 18, Apr. 20, Apr. 25, and Apr. 27)

In this unit, we will explore (often more qualitatively than quantitatively) emerging technologies and their possible ramifications for global security.

***The Future 1: Cyberwarfare (Apr. 18).*** The discovery in mid 2010 of “Stuxnet,” a sophisticated computer worm developed by the United States and Israel to destroy uranium enrichment equipment in Iran brought into international focus the emerging strategic capabilities of cyberattacks, including the possibility of “kinetic military action. In mid 2011, the Whitehouse released its own cyber-strategy, declaring that “when warranted, the United States will respond to hostile acts in cyberspace as we would to any other threat to our country.” Many other countries are actively expanding their cyber capabilities. In this lecture, we will explore the fundamental elements of cyberwarfare, as far as they can be identified and anticipated today; consider the similarities and differences between cyberwarfare and “physical” warfare; and examine if and how traditional security concepts

(including crisis stability, attribution, escalatory control, and minimization of collateral damage) and strategies apply to cyberwarfare.

Readings:

- Seymour M. Hersh, “The Online Threat: Should We Be Worried About a Cyber War?,” *The New Yorker*, November 1, 2010, [www.newyorker.com](http://www.newyorker.com).
- Joseph Nye, “Deterrence and Dissuasion in Cyberspace,” *International Security*, 41 (3), Winter 2016/2017. **(BB)**
- PLACEHOLDER #1
- PLACEHOLDER #2

More to explore:

- *International Strategy for Cyberspace*, The President of the United States, White House, Washington, DC, May 2011.
- *Department of Defense Strategy for Operating in Cyberspace*, U.S. Department of Defense, Washington, DC, July 2011.

***The Future 2: The Internet of Things and Kinetic Pwnage (Apr. 20).***

**Guest Lecture: Ed Skoudis**

*Ed Skoudis is the founder of Counter Hack, an organization that designs, builds, and operates popular “infosec challenges” and simulations including CyberCity, NetWars, Cyber Quests, and Cyber Foundations. As director of the CyberCity project, Ed oversees the development of missions that help train “cyber warriors” in how to defend the kinetic assets of a physical, miniaturized city. Ed’s expertise includes hacker attacks and defenses, incident response, and malware analysis, with over fifteen years of experience in information security. Adapted from: [www.sans.org/instructors/ed-skoudis](http://www.sans.org/instructors/ed-skoudis).*

Readings:

- Robert O’Harrow Jr., “CyberCity Allows Government Hackers to Train for Attacks,” *Washington Post*, November 26, 2012, [washingtonpost.com](http://washingtonpost.com) **(BB)**
- PLACEHOLDER READING #1: Hacked Cameras, DVRs Powered Today’s Massive Internet Outage (“2016 Dyn Cyberattack”), October 21, 2016,

[krebsonsecurity.com](http://krebsonsecurity.com).

- PLACEHOLDER READING #2: G. Conti, M. Weigand, E. Skoudis, D. Raymond, T. Cook, and T. Arnold, "Towards a Cyber Leader Course Modeled on Army Ranger School," *Small Wars Journal*, April 2014. **(BB)**

***The Future 3: Machine Learning and Superintelligence (Apr. 25 and 27)***. Recent years have seen unprecedented progress in the field of machine learning, which gives computers the ability to learn from data. Two major types of machine learning are currently being distinguished: In supervised machine learning, a program is trained on a set of ("labeled") training data to reach conclusions about new ("unlabeled") data, effectively making predictions about the future. In unsupervised machine learning, a program is given unlabeled data and must find patterns and relationships therein, i.e., discover hidden structures in a dataset. With regard to military applications, the pace of progress in machine learning has already to an important debate about the possibility of autonomous weapons, which, once activated, would select and engage targets without further intervention by a human operator. Some experts consider this development inevitable; others consider it highly problematic and see autonomous weapons as violating principles of humanity. Looking further ahead, and currently in the realm of science fiction, there may be autonomous systems that match and eventually exceed human-level intelligence and achieve what some call "superintelligence." If such systems should be developed at all and, if they are, how to ensure that they remain benevolent once they exist, has been considered one of the "most momentous questions that our species will ever confront." In this unit, we will explore the security implications of these (possible) developments.

Readings:

- E. Ackerman, "We Should Not Ban 'Killer Robots,' and Here's Why," *IEEE Spectrum*, July 29, 2015, [spectrum.ieee.org](http://spectrum.ieee.org).
- S. Russell, M. Tegmark, and T. Walsh, "Why We Really Should Ban Autonomous Weapons: A Response," *IEEE Spectrum*, August 3, 2015, [spectrum.ieee.org](http://spectrum.ieee.org).
- Nick Bostrom, "Get Ready for the Dawn of Superintelligence," *New Scientist*, 5 July 2014, pp. 26–27. **(BB)**
- PLACEHOLDER READING #1: Nick Bostrom, "Past developments and Present Capabilities" and "Paths to Superintelligence," Chapters 1 and 2 in *Superintelligence: Paths, Dangers, Strategies*, Oxford University Press, 2014. **(BB)**

- PLACEHOLDER READING #2: Stuart Russell, Daniel Dewey, Max Tegmark, "Research Priorities for Robust and Beneficial Artificial Intelligence," *AI Magazine*, 36 (4), 2015, [futureoflife.org](http://futureoflife.org).
- PLACEHOLDER #3
- PLACEHOLDER #4

Video:

- *Ex Machina*, directed by Alex Garland, 108 minutes, 2015. **(BB)**

**Team Presentations (May 2 and May 4)**

TBD.



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