Princeton School on Science and Global Security

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Book of Abstracts

SCIENCE & GLOBAL SECURITY
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The Princeton School on Science and Global Security

The Princeton School on Science and Global Security, launched in 2020, trains next-generation scientists and engineers from around the world in technical perspectives on understanding, reducing, and ending the threat from nuclear weapons. The goal is to provide skills and insights that participants can use in their own research, encourage and inspire them to investigate new ideas to advance global security and a safer and more peaceful world and to foster an international community of such researchers. The School is organized by Princeton University's Program on Science and Global Security (SGS), part of the School of Public and International Affairs.

The meeting includes presentations by invited graduate students, post-doctoral researchers and established researchers on topics such as fissile materials, verification, emerging technologies, and missile defense. It also includes interactive learning experiences and tutorials on nuclear policy.

History

The Princeton School on Science and Global Security traces its origins to the international School on Science and World Affairs organized by the forerunner of the Program on Science and Global Security and the Moscow Institute of Physics and Technology held over eight days in September 1989 outside Moscow. Princeton hosted the second International Summer School on Science and World Affairs in August 1990. The schools focused on nuclear disarmament and global environmental issues. The two schools grew out of discussions between the U.S. physicist Frank von Hippel and the Soviet physicist Roald Sagdeev about the lack of a younger generation of Russian scientists knowledgeable about arms control issues. These discussions also led to the publication of a new international journal, *Science & Global Security,* with an initial editorial board of U.S. and Soviet scientists.

The third Summer School was hosted in Moscow by the newly established Center for Arms Control, Energy, and Environmental Studies at Moscow Institute of Physics and Technology in 1991. The

1992 Summer School was held in Shanghai, hosted by the Center for American Studies (CAS) at Fudan University. It was organized together with the Union of Concerned Scientists (UCS) which took lead responsibility for future meetings. These meetings became known as the International Summer Symposium on Science and World Affairs. Since the first meeting in 1989, these gatherings have hosted over 500 scientists and researchers from over 40 countries.

Program on Science and Global Security

Princeton University's Program on Science and Global Security (SGS), based in the School of Public and International Affairs, conducts scientific, technical and policy research, analysis and outreach to advance national and international policies for a safer and more peaceful world. The Program was founded in 1974 by Harold Feiveson and Frank von Hippel.

Throughout its history, SGS has worked on nuclear arms control, nonproliferation, and disarmament to reduce the dangers from nuclear weapons and nuclear power. The control and elimination of fissile materials (the key ingredients for nuclear weapons) is a major part of the SGS agenda. SGS works to understand and reduce the risks from nuclear weapons and the strategies, postures, forces and policies of the nine nuclear armed states. SGS also helps develop confidence-building measures to reduce the risks of crisis, arms racing and nuclear weapons use in the US-NATO-Russian region, South Asia, the Middle East, East Asia, and the Pacific.

SGS does research to support the 2017 United Nations Treaty on the Prohibition of Nuclear Weapons and the goal of the verified and irreversible elimination of all nuclear weapons and weapon programs. SGS is home to *Science & Global Security*, the leading academic peer-reviewed journal for technical arms-control analysis. The journal covers nuclear, biological, chemical, space, and cyber technologies and programs and related security issues. Its goals are to help develop the technical basis for new policy initiatives to reduce the risks from these technologies to international peace and security and to provide a resource for further scholarship and policy analysis.

SGS provides training opportunities for post-doctoral and senior scientists interested in science and security policy. It has helped train technical nuclear arms control and nonproliferation researchers from around the world.

Participants and Abstracts

Curtis T. Asplund (he/him)
San José State University

U.S. Plutonium Pit Policy in 2022

Abstract: Modern thermonuclear weapons rely on plutonium pits for their primary detonation. These pits are hollow spheres of plutonium that, though modest in size (10 to 20 cm in diameter), contain multiple kilograms of plutonium metal and are difficult, expensive, and hazardous to produce. The difficulty and hazards are attested to by the notorious incidents at and closure of the Rocky Flats Plant in 1992. Since then, various proposals and policies for resuming large scale production have been put forward, and standing U.S. policy requires the production of 80 pits per year by 2030. However, many have questioned the need for this production goal, which would apparently require the construction of a new facility, at the Savannah River Site in South Carolina, at the cost of billions of dollars and with significant risks to the surrounding community.

I will present arguments that the justification for these production goals is not commensurate with the costs and risks. In particular, the United States already has many thousands of pits, including many surplus beyond those in deployed warheads. The current state of the publicly available science on pit aging does not clearly indicate that they need to be replaced in the next fifty or more years, or that we clearly need new ones for new warheads. Thus, better and more

transparent science on this topic is called for and should be required before more public money is spent on pit production. I will further discuss the effort by Rep. Garamendi (D-CA) and others in the U.S. Congress to pass an amendment to the current (Fiscal Year 2023) National Defense Authorization Act, that will require a more detailed, independent study of pit aging, and a public briefing on the environmental impact of pit production at the Savannah River Site.

On my own time, and in collaboration with colleagues and other grass-roots organizations, I have advocated for this amendment by communicating with members of Congress and their staff. I will mention some takeaways from that effort and prospects for the future of U.S. plutonium pit policy. I welcome feedback and comments from participants in this program.

Biography: Curtis T. Asplund is an assistant professor in the Physics & Astronomy department at San José State University. Prior to this, he was a visiting faculty member at Franklin & Marshall College, and earlier was a high school teacher for several years near Washington, DC. He completed postdocs at Columbia University and KU Leuven, and he earned his PhD from UC Santa Barbara, where he studied theoretical aspects of black holes and entanglement in quantum field theory. His interests in ethics, public policy, and the role of scientists in society emerged in his original stomping grounds of Southern California and were developed further in the liberal arts climate of his alma mater, Oberlin College. His concerns about American military power are also informed by growing up on and around U.S. military bases and having close family serving in the Marine Corps. He began his serious engagement with nuclear weapons policy as a Next-Generation Fellow with the Physicists Coalition for Nuclear Threat Reduction, beginning January 2022. With the guidance of his fellowship mentor, Frank N. von Hippel, he has been engaged with the current state of U.S. policy on plutonium pits.

Sarah Bartley (she/her)
North Carolina A&T University

Plutonium Pit Production at the Savannah River Site and Environmental Justice Implications for Georgia and South Carolina

Abstract: The Savannah River Site (SRS) is currently owned by the U.S. Department of Energy (DOE), and it was originally owned by Dupont Company in 1951. In 1951, the Atomic Energy Commission constructed the SRS on 200,000 acres in Aiken, Barnwell, and Allendale counties. The SRS has historically been associated with the production of plutonium and tritium for nuclear weapons. There is a long history of accidents, leaks of radionuclides in the environment and the Savannah river, and outdoor waste dump. There is an unaddressed history of environmental racism against the SRS workers. There are records of Black workers sent into high radiation areas without proper safety equipment. Class action lawsuits with former SRS workers have largely been unsuccessful and claimants must file individually. So far over 10,000 former SRS workers have filed claims and received $1 billion in payout.

As of 2018, a billion-dollar plan to build a Mixed-Oxide Fuel Fabrication Facility was canceled after $8 billion were already spent by the U.S. government. The United States plans to produce 80 plutonium pits by 2030. The government plans to split the production of plutonium pits between Los Alamos Lab in NM and the SRS in SC. The DOE/NNSA proposed to transform the Mixed-Oxide Fuel Fabrication facility into a new pit production plan, for an additional $11.2 billion. The question remains on the environmental impact of plutonium on the surrounding communities.

With an inspection of the past, Rocky Flats was ill-fated by neglecting the impacts of the location of the plutonium pit production site on the surrounding communities. The lack of protocols for loads of plutonium in gloveboxes resulted in hundreds of fires between 1952 and 1992. The firefighters were not given proper procedures to halt the plutonium fires. This resulted in increased fumes for the residents of Denver. Citizens in the area were not informed or evacuated.

To prevent the creation of another Rocky Flats crisis, the following objectives have been created.

Our objective is to analyze and reevaluate the environmental impact of plutonium conducted by the DOE in 2020. The impact statement doesn't state that potential accidents (including fires and criticality accidents) could release plutonium and fission products into the atmosphere. The consequences of the plutonium facility would disproportionately impact minority and low-income communities. There is a current lawsuit by local community groups asking for the delay of the pit production in SC and a more comprehensive impact assessment. The current lawsuit suggests existing impact assessment may not capture fully the consequences of producing pits at the SRS. There are questions about source terms and modelization.

Our general strategy is to produce atmospheric dispersion and deposition calculations using HYSPLIT for hypothetical releases of plutonium fires to the SRS in Aiken, SC. These results may play a role in finding the average areas impacted by possible plutonium fires in the area over the year 2021. Additionally, there are plans to update the wind roses for the SRS. This will assist with emergency evacuation responses for the SRS.

Rocky Flats is a cautionary tale. Without the proper protocols to extinguish fires and emergency evacuations, the SRS has the possibility to produce pollutants that can impact citizens as far as Michigan. From the HYSPLIT models, the pollutants can drift into North Carolina, Tennessee, Georgia, and the Atlantic ocean. This is a potential multistate problem for unnecessary plant development. Pit production is neither urgent nor a requirement for deterrence. Starting production at the SRS is a policy choice and there are alternatives. The financial resources that are needed to complete and start this new plant in SC could be used to finish the clean-up at the SRS and address legacy justice and compensation issues faced by former workers at the plant instead.

Biography: Sarah Bartley obtained her B.S. in Physics from Agnes Scott College and an M.S. in Physics from the University of Central Florida. She is a PhD student in the Department of Nanoengineering at North Carolina A&T State University. She accepted an IBIEM (Integrative Bioinformatics for Investigating and Engineering Microbiomes) fellowship for the year 2020–2021 to focus on microbiome research. She has accepted the Chancellor Fellowship for the years 2021–2025. She is also the host of a podcast called "Funding is the Matter". For the first series, she is investigating the lack of funds to Historically Black Colleges and Universities (HBCUs).

Sarah Marie Bruno (she/her)
Johns Hopkins University

The Environmental and National Security Implications of the Proliferation of Commercial Satellites

Abstract: Space is becoming increasingly commercialized with satellite technology promising technological advancements such as low-cost global internet access. Satellite constellations will likely boost the global economy and increase internet accessibility worldwide, narrowing the digital divide. However, they will also contribute to congestion in the near-Earth space environment with the potential for far-reaching impacts. Solar reflections off satellites can interfere with planetary defense (detection of near-Earth asteroids) as well as compromise the United States missile defense system. The crowding of low-Earth orbits also increases the risk of collisions between satellites, potentially putting U.S. military satellites at risk. Satellite brightness (both in the optical regime and in radio frequency uplink and downlink transmissions) also introduces foreground contamination which may greatly impede astronomical observations from the ground in optical, infrared, radio, and microwave wavelengths. Satellites and satellite debris also contribute to diffuse night sky brightness, which negatively impacts human health and harms wildlife. Thus, commercial satellite proliferation is an environmental issue with significant implications for national security and beyond. The time is now to develop policy measures to regulate commercial satellites.

Biography: Sarah Marie Bruno is a postdoctoral fellow at the Johns Hopkins University department of Physics and Astronomy, working on the Cosmology Large Angular Scale Surveyor (CLASS) telescope array. Bruno primarily focuses on the construction of integrated detector and readout hardware for CLASS. She is also a member of the American Astronomical Society's Committee on Light Pollution, Radio Interference and Space Debris, which engages in advocacy surrounding the impact of commercial satellites on astronomy. Bruno earned her PhD in Physics at Princeton University in 2021.

Matt Caplan
Illinois State University

Effective Popular Communication for Nuclear Weapons Issues

Abstract: The nuclear dimensions of the war in Ukraine have renewed public interest in nuclear weapons issues. However, there is a shortage of media at a level suitable for popular audiences and misconceptions are numerous given the complexities of these issues. With Kurzgesagt GmbH, I write scripts for fully animated educational videos to inform the public about the dangers of nuclear weapons. I will present two short videos on nuclear weapons, one targeting audiences of all ages and one specifically targeting a teenage demographic, and discuss some best practices for effectively communicating with these audiences. (This work is supported in part by the Physicists Coalition for Nuclear Threat Reduction).

Biography: Matt Caplan is currently a professor of physics at Illinois State University where he studies white dwarf and neutron star interiors. Prof. Caplan received his PhD from Indiana University and his BS from the University of Virginia. From 2017 to 2019 he was a CITA National Fellow at McGill University and in 2021 he was a Next-Generation Fellow of the Physicists Coalition for Nuclear Threat Reduction. Beyond academia, he is a scriptwriter for PBS Digital Studios and Kurzgesagt.

Bárbara Cruvinel Santiago (she/her/hers)
Columbia University

Brazil Shouldn't Let Bolsonaro Stand in the Way of the Ban Treaty

Abstract: Brazil was the first nation to sign the Treaty on the Prohibition of Nuclear Weapons (TPNW), also known as the ban treaty, in 2017 under President Michel Temer. Bolsonaro was elected in 2018, and his political stance regarding militarization and nuclear weapons stalled the entire ratification process of the TPNW in Brasilia. In my talk, I will give my perspective on how Brazil could benefit from and contribute to the TPNW if it were to ratify the ban treaty, based on research I did as a Next-Generation Fellow of the Physicists Coalition for Nuclear Threat Reduction.

Brazil is one of the biggest nations that have signed the TPNW, and it could make the treaty stronger by ratifying it. Brazil has played a huge role in disarmament and nuclear policy over the years, and it could further solidify its diplomacy status, especially in the global south, by ratifying the TPNW. It is also the only BRICS country that has signed the treaty so far other than South Africa. Moreover, given that Brazil has strong nuclear research despite being a non-nuclear weapon state, signing the TPNW could strengthen scientific collaborations between Brazil and other signing members of the treaty. Brazil in fact has several commissions, institutes and universities working on nuclear research, potentially making it the country with the most nuclear capabilities among signatory states. Hence, Brazil can be a crucial player doing safety checks in other countries and transferring technology to other nations for peaceful use. Additionally, Brazil's experience with a nuclear accident in the city of Goiania could be key in helping other countries dealing with nuclear contamination.

Brazil and Argentina have a bilateral agency (ABACC) that has done trustworthy verification work over the years alongside IAEA to make sure both countries are utilizing nuclear resources solely for peaceful purposes. This means that Brazil has a lot of expertise in nuclear control and the technology that would be involved in

similar endeavors. Thus, Brazil signing the TPNW would benefit other state parties that need technology available in Brazilian soil and would also strengthen Brazilian science due to the vast potential for technological exchange and scientific collaboration with other signatories.

In the talk, I will also address how one could educate the Brazilian public, in particular scientists, about nuclear issues in the country. I will do so by talking about my Next-Generation Fellowship follow-up project that aims to create a bilingual educational platform, so Brazilian citizens can be informed of their own nuclear history and current issues.

Biography: Bárbara Cruvinel Santiago is a physics PhD candidate at Columbia University working on astronomical instrumentation under a NASA fellowship. Born and raised in Brazil, she got her B.S. in physics at Yale, after which she worked at the Nobel-Prize-winning MIT-LIGO lab and got her master's at Columbia. She was one of the inaugural fellows of the Next-Generation Fellowship from the Physicists Coalition for Nuclear Threat Reduction, and she received the 2021 American Physical Society 5 Sigma Physicist Award for congressional advocacy in nuclear disarmament.

Roohi Dalal (she/her/hers)
Princeton University

Space Debris and Nuclear Strategic Stability

Abstract: Space-based assets, such as early warning and communications satellites, form an important part of the United States National Nuclear Command, Control, and Communications (NC3) system. However, the U.S. 2018 Nuclear Posture Review notes that in recent years, states including Russia and China have been developing counterspace military capabilities to target these satellites. Such anti-satellite weapons aim to deny the United States the ability to conduct NC3 in addition to space-based intelligence, surveillance, and reconnaissance; as well as positioning, navigation and timing.

In addition to threats of intentional interference, space-based assets also face hazards from their orbital environment, particularly the growing amount of space debris. This novel web of threats raises several questions, including whether satellite failures due to debris impacts could be mistaken for intentional counterspace operations. This possibility is particularly worrisome, as the United States has maintained the option of a nuclear response to non-nuclear attacks on its NC3.

I evaluate whether the growing population of space debris could destabilize nuclear strategic stability by first determining the probability of debilitating debris collisions with NC3 satellites, and then assessing existing technological capabilities to attribute satellite failures to either debris impacts or intentional interference.

I characterize the threat to NC3 systems from debris in geostationary orbit (GEO) in terms of both the expected collision frequency and the potential damage caused by such collisions, focusing on the impact of debris pieces smaller than the limits of U.S. tracking systems (1 meter in GEO). The expected frequency of collisions between GEO satellites and a debris object larger than 1 cm is at least one per every four years. I then use the NASA Standard Breakup Model to show that such collisions could severely damage the satellite without fully fragmenting it, i.e., cause the satellite to fail without clear evidence of a breakup that one would be able to detect with existing systems.

Upon concluding that cratering events due to debris collisions are

both likely and able to cause irreparable and unobservable damage to satellites, I then discuss other possible observational signatures of debilitating debris impacts to assess whether such impacts could be distinguished from intentional attempts to incapacitate satellites, such as cyber attacks and directed energy weapons. I show that the expected satellite displacement after a debris collision is much smaller than the uncertainties associated with U.S. Space Surveillance Network orbit predictions. Instead, I recommend observational methods to detect changes in the satellite attitude due to collisions, including Satellite Laser Ranging and Inverse Synthetic Aperture Radar imaging. I also recommend the improvement of the modeling of satellite orbits to reduce uncertainties associated with non-gravitational forces.

Noting that the U.S. Space Force is beginning to phase out the use of GEO satellites for early warning, instead moving to large satellite constellations in low earth orbit (LEO), I similarly evaluate the threat from debris in LEO and our ability to attribute satellite failures in this orbit. While the debris population in LEO is much higher than in GEO, and satellites in LEO are more vulnerable to attacks from directed energy weapons, our debris tracking capabilities for this closer orbit are much better, and observational follow-up after satellite failures would be much quicker and easier. I suggest that it is unlikely that a debris impact could be mistaken for a counterspace attack against a satellite in LEO, i.e., LEO debris is not as destabilizing as the debris in GEO.

Considering the expected exponential growth in the amount of debris in the coming years, one might also ask whether debris could be leveraged as a deterrent against developing, testing, and employing destructive anti-satellite weapons. I study this possibility and note that states or non-state actors with very little reliance on space-based assets could instead engage in intentional debris production to weaken other states. In light of this, I recommend strengthening The Convention on International Liability for Damage Caused by Space Objects to be a stronger deterrent against debris creation.

Biography: Roohi Dalal is a fourth-year PhD student in the Department of Astrophysical Sciences at Princeton University. She received a B.S. in Astrophysics and History from Caltech, and was a Fulbright scholar at Leiden University in the Netherlands. In addition to her thesis research on characterizing dark energy and dark matter with the Hyper Suprime-Cam galaxy survey, she is a member of the policy subcommittee of the American Astronomical Society's Committee on Light Pollution, Radio Interference and Space Debris.

Daine Danielson
University of Chicago

Can a Neutrino Nonproliferation Detector Be Fooled?

Abstract: Neutrino detectors represent a promising new technology for the detection and verification of nuclear activities. The nature of neutrinos allows these devices to be non-invasive, and extremely robust against signal manipulation due to the fundamental physical properties of neutrinos. Naturally, however, before any novel technology can be employed for national security purposes it must be proven to be at least as robust against deception as existing techniques.

Neutrino radiation is a necessary product of nuclear beta decay, and therefore neutrinos are produced in abundance by nuclear fission reactions. Unlike gamma, neutron, or beta radiation, neutrinos cannot be shielded, because the low interaction strength of the Weak Nuclear Force renders all forms of ordinary matter highly permeable to neutrinos. Furthermore, the production of large neutrino fluxes is highly characteristic of nuclear fission alone, as opposed to any other ordinary process. Hence, the existence of neutrino radiation in a region presents a unique signature of the presence of fissile material which cannot be shielded. Therefore, there is a great deal of interest in the ongoing development of neutrino-based technologies for various detection and verification use cases in nuclear nonproliferation.

For the verification of agreed-upon nuclear activities, the deployment of a neutrino detector on the site of a nuclear reactor facility can provide a less-invasive alternative to present-day verification methods. Such a neutrino detector, deployed at short distances (< 200 m) from the reactor core, would be sensitive to the total power status of the reactor as well as the relative abundances of radioactive isotopes in the core, as different isotopes produce neutrinos at different rates. Proposed use cases at short distances include monitoring for the clandestine removal of weapons-grade plutonium as it is produced in the core, and the verification of the burn-up of reclaimed weapons-grade plutonium which has been inserted into the core for disarmament purposes. In addition, it has been proposed that a neutrino detector—one which is sensitive to coherent neutrino-nucleus

interactions—deployed at short distances from a reactor core can be used to detect the presence of a breeding blanket by observing the anomalous production of low-energy neutrinos by the blanket. Even at large distances from a nuclear reactor, large-scale neutrino detectors have been proposed as useful tools for the discovery of hidden reactors, and the verification of the on-off power cycle of the core which can differentiate weapons-production from energy production.

Given the appeal of neutrino detection as a non-invasive tool for nonproliferation monitoring, it is natural to ask how a nonproliferation monitoring deployment based on neutrino technology might be lead to an incorrect conclusion by a reactor operator working in bad faith—in short, how a neutrino monitor might be "fooled." To stimulate discussion of this topic, we discuss several methods by which a reactor operator might "mock up" a desired reactor neutrino signature in the above use cases, despite covertly running the nuclear reactor in violation of the agreed-upon operating procedure, which the neutrino monitor is tasked with verifying. In each case, we discuss possible countermeasures by which the monitoring program might be strengthened, so as to render it impervious to the hypothetical evasion technique, while minimizing the invasiveness of the monitoring as much as possible.

Countermeasures include the independent monitoring of reactor power, or of fission gas production, and exploiting sensitivity to neutrino directionality. The goal of this talk is not to give the final word on this issue, but rather to stimulate discussion on this important topic, and to encourage awareness and feedback from the broader security community.

Biography: Daine L. Danielson is an Eckhardt Graduate Scholar in the Enrico Fermi Institute and Department of Physics at the University of Chicago. He is also a Hertz Fellow. Daine's research explores the fundamental physics of elementary particles and quantum fields, and their applications to nuclear nonproliferation, using novel technologies such as neutrino-based nuclear surveillance. Recently, his research has focused on the phenomena of quantum entanglement and decoherence, and the fundamental limits on the sensitivity of detectors, which exploit these phenomena. He is dedicated to the pursuit of interdisciplinary solutions to problems in nuclear energy and defense that integrate policy and scientific perspectives. Daine holds a BS in Computational Physics with a minor in Mathematics from UC Davis.

Jan Geisel-Brinck (he/him)
University of Hamburg

Decommissioning of Military Nuclear Reactors in the Context of the TPNW

Abstract: The Treaty on the Prohibition of Nuclear Weapons (TPNW) requires states parties that own nuclear weapons not only to destroy their nuclear weapons, but also to eliminate their nuclear weapons program. This includes the decommissioning of military nuclear reactors for plutonium production. The treaty also requires the elimination to be irreversible.

By now, a lot of experience has been gained in the decommissioning of civil nuclear reactors. However, military nuclear reactors of nuclear weapon states have never been monitored by the International Atomic Energy Agency (IAEA). The talk will discuss the options for implementing verified decommissioning under the TPNW, the difficulties that may arise along the way, and lessons that can be learned from previous dismantlement projects. Building on experience from the civil sector, nuclear decommissioning in general is illustrated. Afterwards, the similarities and differences to the decommissioning process of military nuclear facilities are discussed.

The decommissioning of the French nuclear reactors Marcoule G1, G2, and G3 is used as a case study. The dismantling operations have been in progress since 1969 for G1, and since 1986 for G2 and G3. As with many reactors for plutonium production, they were among the country's first nuclear reactors built. Thus, at the beginning of the decommissioning process, detailed decommissioning legislation did not exist and many technical challenges had to be resolved.

A major limitation to the pace of decommissioning was and still is the lack of an appropriate treatment facility for irradiated graphite. This is a typical problem for nuclear weapon states, since graphite is often used as a moderator in plutonium-producing reactors. However, decades of dismantling like in the Marcoule case are not in the TPNW's interest. Hence, support or the transfer of know-how by more experienced states in dismantlement technologies can greatly contribute to the successful implementation of the TPNW.

A key requirement of the TPNW is the irreversibility of the elimination. Decommissioning projects of nuclear power plants rarely take less than 10 years, usually much longer. During such time periods, political situations can change significantly. It is therefore advisable to optimize the process in order to achieve an irreversible state as early as possible. Of course, radiation protection should not be neglected for this purpose.

The failed attempt of verified decommissioning of North Korea's Nyŏngbyŏn reactor can serve as a negative example: As a result of the six-party talks, North Korea agreed to shut down its major nuclear facility Nyŏngbyŏn. Initial demolition work began in 2008. Following a breakdown of the six-party talks agreement, dismantling operations were halted and IAEA inspections suspended. Not having reached an irreversible state of dismantling, the reactor was reconditioned and resumed operation a few years later.

To determine whether a civil nuclear power plant can be considered decommissioned for safeguards purposes, the IAEA uses a so called 'essential equipment' list that is prepared for every nuclear facility. A similar approach could be used to verify the successful implementation of the terms of the TPNW. This requires inspectors to have access to the facility and to facility design plans. Also, the dismantling process should focus on the central components first in order to achieve irreversible results as early as possible. Once an irreversible decommissioning state of the nuclear power plant is established, the TPNW objective is accomplished. From that point on, further work can be carried out without time pressure and even be delayed by – for example – 50 years to make use of the natural decay of short-lived radionuclides.

Biography: Jan Geisel-Brinck studied in Cologne and Hamburg and holds a master's degree in physics. He specialized in medical physics and scientific peace research. In his thesis he investigated measurement methods for the verification of nuclear disarmament using Geant4 Monte Carlo simulations. In addition to his studies, he was on the organizing team for the 2019 international NuDiVe exercise. The exercise dealt with the practical implementation of nuclear disarmament verification. In particular, Jan was responsible for the detailed planning of disarmament steps and the deployment of radiation detectors. He is currently working in the field of nuclear power plant decommissioning, conducting clearance measurements for the release of non-radioactive waste.

Jake Hecla (he/him)
UC Berkeley

Limiting Factors in Mobile Nuclear Power Plant Development and Deployment

Abstract: Mobile nuclear power plants (MNPPs) have been described as a potentially transformative means of improving the availability and durability of electrical power at remote military facilities. These reactors are promoted as compact and robust alternatives to diesel generators, producing 1–5 MWe of continuous electrical power regardless of environmental conditions. In response to perceived fuel-availability challenges and the increasing energy intensity of warfare, the Department of Defense has invested heavily in this concept, and is pursuing plans to build and test a prototype at the Idaho National Laboratory by 2024. A variety of designs are under development by private companies, and testing of non-nuclear components is ongoing in the United States and Canada. However, despite the enthusiasm for these systems, the case for their deployment is relatively weak on grounds of cost, logistical complexity, and safety under attack.

Claims regarding the scale of cleanup needed in a post-strike environment are likewise concerning. Public claims of performance under attack seem to be based on a fundamental misunderstanding of the concept of fuel integrity, failing to differentiate between fission product retention and core integrity. When questioned about the safety of the reactor should the containment be breached, the program manager for Project Pele has presented tri-structural isotropic (TRISO) fuels as nearly invulnerable, stating that the fuel material is a "real game-changer" and that "even in the case of an attack, [the reactor] is not going to be a significant radiological problem."

Regardless of fission product retention, fuel fragments ejected from a strike on a MNPP will not self-shield, and will remain lethally radioactive. The physical dispersal of the fuel resulting from an attack will create a punishing radiological environment in the vicinity of the reactor, with high dose rates likely extending for many hundreds of meters. TRISO fuels do not solve this: Both graphite and SiC have low fracture toughness, and the pulverization and dispersal

of the core is unavoidable in the case of a significant kinetic attack. This may make such reactors exceptionally valuable targets, as the reactor debris can act as an area-denial weapon that renders several square kilometers an instant no-man's-land. This is likely to prevent the use of materiel and force a protracted shelter-in-place. In the eyes of the adversary, the area-denial effect of a strike on a reactor core may make MNPPs exceptionally valuable targets in comparison with the diesel generators they replace.

Further, it is unclear what storage and basing options would exist to enable the DoD to deploy such reactors where they are needed on short notice. While mobile nuclear power plants may offer benefits to supply-line robustness and electrical reliability in some installations, the publicly available information on project Pele fails to address major safety, cost and logistical issues. Further, the foundational rationale for the development of these systems is incoherent, portraying an inconsistent and poorly described set of use-cases. While the challenges outlined here are not inherently disqualifying to the goal of developing mobile reactors, they have not been sufficiently addressed for the academic and national security communities.

Biography: Jake Hecla is a PhD candidate in the Department of Nuclear Engineering at the University of California, Berkeley where he holds a Nuclear Science and Security Consortium fellowship. His work focuses on the development of detection technologies for nuclear nonproliferation. Currently, his research focuses on neutrino detection for nonproliferation, and applications of coded-aperture imaging for radiation mapping. He earned an undergraduate degree in nuclear science and engineering from MIT in 2017, where he focused on technologies for arms control and verification. Hecla additionally works as a scientific advisor to Clean Futures Fund, a nonprofit pursuing projects in the Chernobyl Exclusion Zone.

Jihye Jeon
Princeton University

Superheated Droplet Detectors for Zero-Knowledge Verification

Abstract: In arms control treaty verification, the Host, whose weapons are under inspection, will require high confidence that no information is revealed about the configuration or composition of their warheads. On the other hand, the Inspector will want to confirm with high confidence whether or not inspected items are real nuclear warheads. To address these concerns, our group previously introduced a Zero-Knowledge Protocol (ZKP) differential radiography approach for warhead verification and showed that superheated emulsion, droplet or bubble detectors, can be used for this purpose. Bubble detectors record information non-electronically, which reduces security concerns, and they can be preloaded prior to a measurement, as required in the ZKP protocol.

In this study we are both extending this technique for higher spatial resolution and also developing the ZKP technique to verify fissile material in presented objects, using the new EXCALIBUR (EXperiment for CALIBration with URanium) neutron source available at the Princeton Plasma Physics Laboratory (PPPL).

First, we developed a new technique for measuring the spatial resolution of bubble detectors, requiring the careful alignment of the neutron source and attenuating materials. To test higher-resolution differential radiography with 14 MeV neutrons from EXCALIBUR, we placed test-tube-shaped bubble detectors transverse to the direction of the neutron flux and across a jump in neutron opacity in the test object.

We found a corresponding jump in the bubble number density along the axis of the detector, indicating an achievable spatial resolution. Using this technique, we made the first quantitative measurements of the spatial resolution attainable with these detectors, finding for our parameters a resolution in the range of 2 mm. This has direct implications for the precision of Zero-Knowledge Protocol differential radiography, potentially for details of the protocol, and for the alignment of test objects and preloads required in this protocol.

Secondly, for fissile material detection, we plan to use bubble de-

tectors with an energy threshold at 1 MeV to detect fission neutrons driven by sub-MeV neutrons, as can be provided by the EXCALIBUR neutron source when its neutrons are moderated by a thick cylinder of steel.

A key requirement is that this neutron spectrum should result in a dramatically reduced bubble count rate compared with the 14 MeV spectrum, with the result that bubbles measured in the presence of fissile material should come predominantly from fission events, not from the small fraction of higher-energy neutrons emitted by EXCALIBUR. The required drop in bubble count rate was measured, consistent with MCNP calculations taking into account both the neutron moderation in EXCALIBUR and the energy response of the detectors provided by Yale University.

Based on what we found, we could demonstrate the functionality of the collimated, moderated, and filtered modes of the PPPL neutron source, EXCALIBUR, for the purpose of fissile material detection. The combined moderator and bubble detector systems worked as expected, giving about 50 times less signal than under direct exposure to 14 MeV neutrons in collimated mode. This promising result will enable bubble detectors to measure predominantly fission neutrons coming from fissile material, rather than neutrons coming from the source.

Biography: Jihye Jeon is a PhD student in the Department of Mechanical and Aerospace Engineering at Princeton University. Prior to coming to Princeton, Jihye worked at the Korea Institute of Nuclear Nonproliferation and Control (KINAC), analyzing international nuclear safeguards and security policy. Jihye graduated from Seoul National University with a BS in Nuclear Engineering and a BA in English Language and Literature, and from Sejong University with an MS in Nuclear Engineering focused on radiation measurement and applications. Her research interests are in developing verification technologies for special nuclear materials. She is also interested in radiation detection application in various scenarios for nuclear disarmament and nonproliferation purposes.

Manuel Kreutle (he/him)
Princeton University

NuDiVe 2022:
Verification Procedures and Technologies in Practice

Abstract: A widely discussed approach to the elimination of the nuclear threat is the establishment of a framework of scientific verification measures that includes technologies and procedures to ensure the integrity of the disarmament process on the one hand while meeting nonproliferation and security concerns on the other. There have been efforts to develop adequate verification technologies since the Cold War. However, most verification procedures have been unilateral, or bilateral between nuclear weapon states but under the cover of secrecy.

Only few nuclear disarmament verification initiatives pursued the idea of multilateral or international control. This includes the 1989 Black Sea experiment between Russia and the United States, the Trilateral initiative between Russia, the United States, and the IAEA, but also the UK-Norway initiative or the QUAD exercise (involving the UK, Norway, Sweden, and the United States).

In this talk, the latest international nuclear disarmament verification exercise "NuDiVe 2022" (successor to the "NuDiVe" exercise held in 2019) will serve as an example. Technologies and procedures will be presented while demonstrating how they could be used in a potential nuclear disarmament scenario.

Organized by France and Germany, the NuDiVe 2022 exercise could rely on the expertise of participants from 11 countries and high-level verification technologies. This included the Trusted Radiation Identification System (TRIS) provided by Sandia National Laboratory for presence measurements. A Compton camera provided by the Japanese Atomic Energy Agency (JAEA) and portal monitors as well as handheld detectors from the German Federal office for radiation protection were used to conduct absence measurements. Furthermore, modern sealing technology as used by the IAEA and a cryptographic hashing algorithm for data transfer were applied.

The technologies were embedded into a framework of procedures

to ensure a mutually-agreed inspection process before and after the dismantlement of a (notional) nuclear warhead. In the framework, the safety, security, and nonproliferation interests of an inspected nuclear weapon state as well as the interests of an inspecting non-nuclear weapon state were taken into account. Through this framework, the first steps of a "general and complete" disarmament process are sketched, building trust between the different parties. The documents and results of both NuDiVe exercises were made available to the scientific community and the public so they could contribute to the discussion on nuclear disarmament.

Biography: Manuel Kreutle has been working in the field of nuclear disarmament verification since 2018, mainly conducting neutron transport Monte Carlo simulations with Geant4. As a member of the Carl Friedrich von Weizsäcker Centre for Science and Peace Research, he was co-organizer of "NuDiVe" and "NuDiVe 2022," two Franco-German nuclear disarmament verification exercises held in 2019 and 2022 at Forschungszentrum Jülich, Germany. Currently he is doing his PhD at Princeton University as part of the Program on Science and Global Security. He holds a Bachelor of Science in Physics from the University of Heidelberg and a Master of Science from the University of Hamburg, Germany.

Emily Kuhn (she/her)
Yale University

Practicality of Aegis as an Underlayer in United States Ballistic Missile Defense

Abstract: Ballistic missile defense is a growing piece of the United States nuclear strategy. Recently, the Missile Defense Agency has been considering the use of the naval defense system Aegis to serve as an underlayer in U.S. ballistic missile defense. This project focuses on the practicality of such a proposal, exploring the technical capabilities of Aegis in this context, and considering the political dimensions.

Following the United States' withdrawal from the Anti-Ballistic Missile (ABM) treaty in 2002, a Ground-Based Midcourse Defense (GMD) was constructed. This system, which forms the basis for U.S. missile defense and which Aegis would augment, consists of ground-based radars and 44 intercept vehicles spread between Alaska and California. During operation, an incoming ICBM will be detected by the early-warning system and tracked by the GMD radars until its trajectory is well established, at which point intercept vehicles would be launched on trajectories that collide with the ICBM, destroying the weapon through a head-on collision.

There exists disagreement about the level of protection the GMD system provides, but it is well understood that it does not defend against attacks from Russia and China, and is intended mainly as a defense against North Korea. This has important ramifications for arms control: If adversaries were to perceive U.S. defense as capable against an attack, they might accelerate weapons build up and increase their own stockpiles. After all, posturing has been a core tenant of arms control, and if arsenals run the risk of being obsolete or defended against, a natural reaction is to grow them. Thus, many in the arms control community remain cautious about a build up in defense systems, including the use of Aegis to bolster the GMD capabilities.

Aegis is a ship-based system of interceptors, sensors, and computation resources. Existing work has shown that Aegis can provide full

coverage of the lower 48 states with just a few sites if its interceptors are launched as soon as sensors (including those in the GMD system) establish the ICBM trajectory. Recently, Aegis has been floated as an underlayer in the current missile defense system, meaning that it will only launch interceptors if the GMD has been launched and verified to miss its target (sometimes described as a "shoot-look-shoot" doctrine). However, this capability of Aegis to serve as an underlayer has not yet been explored technically.

To address the practicality of Aegis as an underlayer in U.S. ballistic missile defense, we must determine when we will know if the GMD has failed, and then understand geographical regions Aegis can protect within the limited time window available after that point. This will be done using Matlab and Python programs from Ted Postol and David Wright to compute series of missile trajectories, including trajectories of ICBMs launched from North Korea that target U.S. soil, and trajectories of Aegis interceptors, considering primarily the newly developed Block IIA interceptor. The talk will discuss the trajectory models, including assumptions and early results, as well as the technical challenges and political dimensions to the problem.

Biography: Emily Kuhn is an NPP Fellow at NASA's Jet Propulsion Laboratory. Her research primarily focuses on developing calibration hardware for next-generation radio telescopes. She has TA-ed several courses at the intersection of science and public policy, with a particular focus on the history and legacy of the U.S. nuclear program, and she has enjoyed challenging young scientists to think about the broader societal implications of their own work. Emily holds a BS in physics from Duke University and a PhD in physics from Yale University.

Dory Peters
Cornell University

US and EU Imports of Russian Uranium and Enrichment Services Could Stop. Here's How

Abstract: Due to Russia's invasion of Ukraine, the United States, the European Union, and other nations want to impose economic sanctions on Russia as a deterrent. Recently, stopping Russian uranium and enrichment services has been discussed as part of the sanctions. Currently, the United States purchases approximately 14% of uranium from Russia, while the EU buys 20%. Meanwhile, the United States purchases 28% of enrichment services while the EU buys 26% of the services. This study discusses potential alternative sources for the aforementioned Russian imports and their associated costs. It can be seen that if forgoing the uranium and enrichment services from Russia, as large as a 50% increase in uranium and SWUs (separative work units) would only increase the retail cost of the U.S. nuclear power plants by two percent. Alternative sources of uranium supply could include Canada and Niger, while the United States and its allies could seek enrichment services from the reopening plant of a large U.S. plant, ConverDyn, in Metropolis, Illinois, which had shut down in 2017—largely because of Russian competition. This analysis states that both the United States and the EU could switch to fueling their reactors with uranium and enrichment work purchased from sources other than Russia.

Biography: Dory Peters received her BA in Physics and Math in 2021. Her previous research spans three different institutions, Montclair State, Rutgers-Newark, and Caltech, and was concentrated in the area of fluid dynamics. Currently, she is pursuing a PhD in Mechanical Engineering at Cornell University applying machine learning concepts to computational solid mechanics. Peters is a 2022 Next-Generation Fellow of the Physicists Coalition for Nuclear Threat Reduction.

Lindsay Rand (she/her)
University of Maryland; Carnegie Endowment for International Peace

Re-Inventing Accuracy:
Quantum Sensing Implications for Nuclear Deterrence

Abstract: This research aims to determine the extent to which new quantum sensing technologies will impact nuclear deterrence and force structure decision-making. Quantum sensing is currently the most developed branch of technologies in the new wave of quantum information science and quantum engineering, which has been referred to as the "second quantum revolution." Thus, compared to quantum computing and quantum communication, quantum sensing is the most likely of the three branches of quantum technology to be deployed in nuclear-adjacent activities in the near term. For this reason, and as quantum technologies continue to garner interest among policymakers, it is important to analyze the applications that are most likely to impact nuclear deterrence in the near and medium term in order to anticipate the level of disruption they may have on strategic stability and nuclear force structure decision-making.

Perhaps the most prominent applications in the context of nuclear security are the projected improvements to positioning, navigation, and timing (PNT) technologies, which could improve missile targeting accuracy, and subsurface detection, which could enable better detection and tracking of nuclear submarines. Together, these two applications have catalyzed concern that quantum technologies, along with various other emerging technologies, may undermine assured retaliatory or second-strike capabilities, and therefore cast doubt over a vital pillar of deterrence.

In my research, I survey socio-technical elements of quantum sensor technologies and the assured second-strike deterrence requirement to investigate the likely impact of quantum sensing to nuclear force structure decision-making in the near-, medium-, and long-term futures. First, I survey recent experimental results to identify sensitivities of currently available quantum sensors relevant to PNT and subsurface detection applications. In addition to this survey, I also review theoretical literature to determine projected perfor-

mance gains for these technology categories at iterative stages of R&D progression. Using these findings and projections, as well as basic calculations related to use-case requirements, I find that quantum sensor innovations will likely serve as extensions in the gradual improvement to accuracy that has long occurred in these application areas, rather than signify a paramount shift or introduce dramatically new capabilities. Yet, through analysis of the socio-technical and organizational dimensions of second-strike strategic planning, I also find that there have historically been instances where force structure planning deviates from adherence to recommendations guided strictly by technical estimates, and instead also reflects predilections driven by organizational pressures and politics. Thus, I propose recommendations to respond to quantum sensing implications that both incorporate the technical analysis conducted and that have the potential to evade the organizational structure and prioritization system biases which have historically guided decision-making on similarly disruptive technologies.

The underlying objective of this research, and the significance of circumscribing the hype over emerging technologies and understanding the social phenomena that drive hype, is to re-evaluate the narrative that technological disruptions undermine nuclear deterrence and thus disincentivize arms control or cooperative risk reduction efforts. The methodologies applied in this research will demonstrate empirical approaches that can be used to predict the disruption of emerging technologies while avoiding social and political biases that may feed into hype in periods of technological uncertainty.

Biography: Lindsay Rand is Stanton pre-doctoral fellow in the Nuclear Policy Program at the Carnegie Endowment for International Peace. She is also a doctoral candidate at the University of Maryland School of Public Policy. Rand uses her interdisciplinary background to explore both social and technical dimensions of emerging technology disruption, with specific emphasis on consequences for nuclear security and arms control. Her dissertation analyzes implications for nuclear deterrence due to quantum sensing. Rand has an MPP from University of Maryland, an MS in nuclear health physics from Georgetown University, and a BA in physics and classical studies from Carleton College.

Elaine Rhoades (she/her)
Sandia National Laboratories

The Impacts of Emerging High Performance Computing Technologies on Nuclear Weapons Proliferation and Testing

Abstract: The Nuclear Nonproliferation Treaty entered into force in 1970 and has one primary objective of preventing the spread of nuclear weapons. A crucial step towards attaining this goal is to reduce, and eventually eliminate, test explosions of nuclear weapons; the Partial Test Ban Treaty and the Comprehensive Test Ban Treaty signify international cooperation in pursuit of that necessary step (although the latter has not yet entered into force). Testing is considered critical because it has historically been regarded as the benchmark for a nation declaring nuclear weapons capabilities, though recent studies suggest this benchmark may no longer be applicable. This paper examines two emerging technologies within the field of high-performance computing that could enable a state to confidently declare possession of nuclear weapons that have hollow-shell boosted pits without needing a nuclear weapons test: exascale supercomputers and quantum computing. A qualitative index called the Proliferation Risk Score was developed to describe the risk of horizontal proliferation in light of various motivational and technological indicators. The Proliferation Risk Score incorporated seven willingness variables that might contribute to a nation's decision to pursue development of nuclear weapons and seven technological indicators of their potential to use high performance computing technologies to declare confidence in a nuclear weapon design without requiring testing. Indicators were identified using established literature on proliferation. To calculate the Proliferation Risk Score, weights for different categories of indicator were modeled after Jo and Gartzke's Log-Likelihood Ratio (LR) test for the nuclear weapons possession model which indicates the relative significance of omitting certain sets of variables. Nine of the fourteen indicators were held constant (all willingness and two technological) and the other five indicators were evaluated on the time scales of present (c. 2020), short-term (c. 2030) and long-term (c. 2050) for twelve states: Brazil, DPRK (North

Korea), Egypt, Germany, Iran, Israel, Japan, The Netherlands, South Africa, South Korea, Syria, and Venezuela.

Analysis suggests that such declarations based on the use of these technologies are not currently possible, but may be possible for some states (Egypt, Germany, Israel, Japan, South Korea) considered in this study by 2050. Potential destabilizing effects of such declarations are investigated, but suggest that many states that may have the requisite computing capacity in the future also have protective factors in place against proliferation. Policy recommendations for the United States are provided, namely recommending proactivity in establishing export controls on relevant high-performance computing technologies. Future extensions to this work will be discussed and include re-evaluating the operationalization and surrogate variable definitions for some of the technological indicators; additionally, the impact of changing different willingness variables in concert with relevant technological indicators could yield valuable insight into a combination of technological and political changes facing each state in the coming years.

Biography: Elaine Rhoades is a postdoctoral researcher in the Radiation Effects Experimentation group at Sandia National Laboratories. She received a Bachelor of Science in Space Physics from Embry-Riddle Aeronautical University in 2014. Elaine earned a Doctorate in Physics from the Georgia Institute of Technology, defending her dissertation titled "Semiconductor Particle Detector based on Work Function Modulation" in November 2021. In the 2019–2020 academic year, she participated in the Sam Nunn Security Program at Georgia Tech, studying national security and policy issues, and completing an independent research project investigating the impact of high-performance computing technologies on nuclear weapons proliferation.

Khiloni Shah (she/her/hers)
University of Texas at Austin

Implications of ^{37}Ar Production on Nuclear Explosion Monitoring

Abstract: An important aspect of underground nuclear explosion monitoring is searching for peaks in signatures of interest from nuclear explosion tests above the natural background levels. The detection of radioactive noble gases, such as radioargon and radioxenon, is important to underground nuclear explosion monitoring efforts because noble gases are more mobile in soil than many other signatures from underground nuclear weapons tests. Radioargon detection is especially important because the argon isotopes, ^{37}Ar and ^{39}Ar, have longer half-lives than most of the radioxenon isotopes and thus, have longer detection windows. Furthermore, the ^{37}Ar background is relatively minimal as it is mainly produced from cosmic neutrons interacting with ^{40}Ca in shallow sub-surface rock and soil or cosmic neutrons interacting with ^{40}Ar in the atmosphere. As a result, radioactive noble gas detection systems can detect radioargon almost 300 or more days longer than radioxenon.

^{37}Ar is formed via the (n,α) reaction with ^{40}Ca, the dominant isotope in natural Ca, which is found in many common soil types. Thus, it is important to understand the production rates of ^{37}Ar because it is a signature of interest for underground nuclear explosion monitoring and has a high enough activity to be detected by current detection systems.

The thermal (low energy) neutron microscopic cross section for the ^{40}Ca(n,α)^{37}Ar reaction is poorly characterized with various nuclear data libraries disagreeing on what occurs at low energies. While the Evaluated Nuclear Data File (ENDF) model shows the thermal neutron cross section for this reaction to follow a "1/v" pattern, the Japanese Evaluated Nuclear Data Library (JENDL) model shows the cross section to be zero below 0.3 MeV. The differing cross section models will impact the predicted yield of ^{37}Ar from underground nuclear explosions depending on the probability of thermal and epithermal neutrons interacting with the ^{40}Ca. Furthermore, different rock

types will produce different quantities of ^{37}Ar from the ^{40}Ca(n,α) reaction. The elemental composition of the different rock types, including the impurities found in different rocks, will dictate the number of thermal neutrons available to interact with ^{40}Ca. Thus, understanding the impact of the microscopic cross section and the elemental rock composition on predicted ^{37}Ar yield from an underground detonation is important.

Biography: Khiloni Shah is a third year PhD student at The University of Texas at Austin (UT) in the Nuclear and Radiation Engineering program. Khiloni graduated with her B.S. in radiation physics from UT in 2020. Her research, supported by the National Science Foundation Graduate Fellowship Program, aims to improve data for noble gas production from underground nuclear explosions to support monitoring efforts. Outside of research, Khiloni is the president of the UT chapter of the American Nuclear Society. In this role, she has restarted a nuclear engineering seminar series to support students' professional development and enhance understanding of nuclear topics.

Owen Webster (he/him/his)
North Carolina State University

AUKUS as an Impetus for an Eventual LEU Naval Reactor Treaty

Abstract: A trilateral security pact composed of Australia, the United Kingdom, and the United States, AUKUS, represents a concerning geopolitical development in the Indo-Pacific region. Of particular interest to nonproliferation experts, the deal centers around provisioning Australia, a non-nuclear-weapon state (NNWS), with no fewer than eight nuclear-powered attack submarines over the coming decades. The United States has offered up its Virginia-class model, with the UK looking to export the Astute-class. Of the six countries currently possessing naval reactors, only the United States and the United Kingdom are believed to use HEU fuel with uranium-235 composition well above 90% "weapons-grade" threshold. Moreover, France and China operate their naval reactors on LEU, with France's levels as low as 6%. Previous literature has repeatedly demonstrated the technical feasibility of converting the U.S. naval reactor fleet to exclusively LEU fuel at this enrichment level. However, American policymakers have largely ignored the issue, even as a replacement to the Virginia-class featuring a LOS sealed reactor core moves forward. Failure to make a transition away from HEU naval reactors would commit the United States to restarting indigenous production of HEU by 2060, in direct opposition to its historic goals to minimize global stockpiles of fissile material.

At the same time, proponents of AUKUS have even pushed for its expansion to other states as part of a larger anti-China alliance in the Indo-Pacific. Considering current geopolitical dynamics in Northeast Asia, this work aims broadly to chart the path ahead for U.S. policy on AUKUS. Degradation of nonproliferation norms are highlighted specifically through the case study of South Korea. This extends beyond simply explaining its current impacts on South Korean attitudes, but also considers the future possibilities of how South Korea might acquire a nuclear submarine. Special concern is directed towards the preservation of critical aspects of the South Korean Section

123 Agreement, all while balancing the country's real security concerns. Policy prescriptions are provided for how the United States, and by extension the United Kingdom, Australia, and South Korea, might better live up to their nonproliferation obligations going forward. In the case of the United States, a primary recommendation offered herein is the conversion from HEU to LEU naval reactor cores across its fleet. With the development of the SSN(X) successor to Virginia-class in its early stages, the United States stands at a crossroads. Engineering decisions made now regarding the design of American submarines will set the stage for fissile material stockpiles throughout this century. Accordingly, this work includes a rough analysis of the technical feasibility of using high-density LEU fuel to create a compact LOS core. Specifically, estimates are made regarding the weight increase required to change the enrichment level in a hypothetical naval reactor. This calculation is intended to supplement existing open-source reports on the practicality of such a change. With this quantitative knowledge in hand, the effects of an LEU-fueled U.S. fleet on AUKUS and South Korea's submarine aspirations are discussed, alongside the broader implications for the global nonproliferation regime.

Biography: Owen Webster is a PhD candidate in nuclear engineering at North Carolina State, and is also pursuing a graduate certificate in Nuclear Nonproliferation Science and Policy. He holds a B.S. in Mechanical Engineering, B.S. in Economics, and B.A. in Chinese Studies, including a year spent at Tsinghua University on a Boren Scholarship. Owen performs materials research on next-generation semiconductors for safeguards detection applications as an NNIS fellow. He volunteers with the International Campaign to Abolish Nuclear Weapons (ICAN) and was selected to participate in the 2021 Hiroshima ICAN Academy. Most recently, Owen spent the summer in Daejeon, South Korea at KAIST as a NEREC fellow. In his spare time, he enjoys beekeeping, growing cactus, and spending time with his cats.

School Lecturers & Organizers

Sara Al-Sayed
Princeton University

Sara Al-Sayed is a Postdoctoral Research Associate in the Program on Science and Global Security (SGS) at Princeton University. She received her B.Sc. degree from the German University in Cairo, Egypt, M.Sc. degree from Universität Ulm, Germany, and PhD degree from Technische Universität Darmstadt, Germany—all in communications engineering, with the focus of her PhD dissertation being on statistical data processing. After an appointment as a postdoctoral research and teaching associate at Technische Universität Darmstadt, she picked up an M.A. program in philosophy of technology at the same university.

Nancy Burnett
Princeton University

Nancy Burnett is the Program Manager of the Program on Science and Global Security. Previously, she held administrative positions in Princeton's Firestone Library, the Office of the Dean of Undergraduates, and the Department of Economics. She oversees the day to day operations and financial processes of the Program. Nancy received a Bachelor's degree from Southern Illinois University.

Bernadette Cogswell
Virginia Tech

Neutrino Physics and Nuclear Nonproliferation
Discovery Skills for Solving Global Security Problems

Bernadette Cogswell is a Research Scientist at the Center for Neutrino Physics, Virginia Tech University. She was previously a Dame Kathleen Ollerenshaw Fellow at the University of Manchester's School of Physics and Astronomy and a Postdoctoral Research Associate at Princeton University's Program on Science and Global Security. She works on scientific and technical issues at the intersection of particle physics and nuclear nonproliferation and disarmament, and on policy and social issues surrounding nuclear threat reduction. She has undergraduate degrees in both Psychology and in Physics, graduate degrees in Physics and in English, and a PhD in Physics from Vanderbilt University. Bernadette is an associate editor for the journal *Science & Global Security.* Her research, policy, and outreach efforts focus on fostering cross-disciplinary research teams made up of social and physical scientists along with great communicators and visualizers to understand and improve nuclear threat reduction initiatives such as nuclear monitoring and nuclear policy reforms. This goal is also served by her website insightfulscientist.com. She has served as a member of the N Square Advisory Forum (2021–present), the APS Physicists' Coalition for Nuclear Threat Reduction Next Generation Fellowship Committee (2021), and APS Bridge Program National Advisory Board for Enhancing Diversity in Physics Graduate Education (2012–2014).

Alex Glaser (he/him)
Princeton University

*Nuclear Arms Control and Verification:
Past, Present, and Future*

Alexander Glaser is associate professor in the School of Public and International Affairs and in the Department of Mechanical and Aerospace Engineering. Alex has been co-directing the Program on Science and Global Security since 2016. Along with Harold Feiveson, Zia Mian, and Frank von Hippel, he is co-author of Unmaking the Bomb (MIT Press, 2014). For Princeton's work on nuclear warhead verification, Foreign Policy Magazine selected him as one of the 100 Leading Global Thinkers of 2014. In September 2020, Alex was elected a Fellow of the American Physical Society. Along with Tamara Patton and Susanna Pollack, he is one of the Executive Producers of the VR documentary *On the Morning You Wake.* Alex holds a PhD in Physics from Darmstadt University, Germany.

Lisbeth Gronlund
Massachusetts Institute of Technology (MIT)

The Future of U.S. Nuclear Warheads

Lisbeth Gronlund holds a PhD in theoretical physics from Cornell University. She has worked on technical and policy issues related to nuclear weapons, missile defenses, and space weapons for over three decades. From 1992 to 2020 she worked at the Union of Concerned Scientists' Global Security Program, first as a Senior Scientist and, beginning in 2002, as Co-director of the program. Prior to joining UCS, she was a research fellow at the MIT Defense and Arms Control Studies Program and at the Center for International Security Studies at the University of Maryland.

Lisbeth helped establish and was a primary organizer of the International Summer Symposiums on Science and World Affairs, which each year from 1989 through 2019 brought together around 40 young scientists from around the world to learn how to apply their expertise to nuclear weapons policy and related security issues. These meetings helped foster a new generation of independent scientists with expertise on security issues.

Lisbeth is a fellow of the American Association for the Advancement of Science and the American Physics Society (APS). She is the co-recipient of the 2001 Joseph A. Burton Forum Award of the APS "for creative and sustained leadership in building an international arms-control-physics community and for her excellence in arms control physics."

Geralyn McDermott
Princeton University

Geralyn McDermott joined the Program on Science and Global Security as Administrative Assistant in 2012. She provides administrative and research support to the Program's faculty, staff, and graduate students. In addition, Geralyn coordinates logistics for domestic and international conferences, arranges travel, and is responsible for expense reporting, and purchasing.

Zia Mian
Princeton University

The Treaty on the Prohibition of Nuclear Weapons

Zia Mian is a physicist and co-director of Princeton University's Program on Science and Global Security. His research interests include issues of nuclear arms control, nonproliferation, and disarmament and international peace and security. Mian is the co-author of Unmaking the Bomb (MIT Press, 2014) and a co-editor of *Science & Global Security,* the international peer-reviewed technical journal of arms control, nonproliferation, and disarmament. He co-chairs the International Panel on Fissile Materials (IPFM) and is a co-founder of the Physicists Coalition for Nuclear Threat Reduction. Mian serves on the Boards of the Arms Control Association and of the Union of Concerned Scientists. In 2022, he was appointed to the UN Secretary-General's Advisory Board on Disarmament Matters.

Igor Moric
Princeton University

Igor Moric is a Postdoctoral Research Associate in the Program on Science and Global Security. Previously, he worked as a postdoctoral researcher on the MIMAC and PandaX dark matter detectors at Tsinghua University in Beijing and SJTU in Shanghai, respectively. During his PhD at CNES and Paris Sorbonne he worked on the space atomic clock PHARAO. He has an advanced master in "Space Systems Engineering" from ISAE-SUPAERO in Toulouse.

Sébastien Philippe (he/him)
Princeton University

Modeling the Radiological Impact of Nuclear Explosions

Sébastien Philippe is Associate Research Scholar at the Program on Science and Global Security, and associate faculty at Sciences-Po, Paris. His research focuses on nuclear arms control, disarmament, and justice issues. He is the co-author of *Toxique* (French University Press, 2021), an investigation into the legacy of French nuclear testing in the Pacific and a book finalist for the Albert Londres Prize. He holds a PhD (2018) in Mechanical and Aerospace Engineering from Princeton, was a Stanton Nuclear Security Postdoctoral Fellow at the Harvard Kennedy School, and has served as a nuclear weapon system safety engineer in France. Philippe is associate editor of the journal *Science & Global Security* and a member of the International Panel on Fissile Materials.

Stewart Prager
Princeton University

The Physicists Coalition for Nuclear Threat Reduction

Stewart Prager is a professor of astrophysical sciences at Princeton University, and an affiliated faculty member with the Program on Science and Global Security. From 2009–2016, he was director of the Princeton Plasma Physics Laboratory.

Previously, he was professor of physics at the University of Wisconsin-Madison, where he was director of the Madison Symmetric Torus experimental program and director of the Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas, a multi-institutional NSF Physics Frontier Center. From 2012–2019, he co-directed the Max-Planck/Princeton Center for Plasma Physics.

Prager received the Dawson Award for Excellence in Plasma Physics from the American Physical Society (APS) and the Leadership and Distinguished Career awards from Fusion Power Associates. His service has included chair of the Department of Energy Fusion Energy Sciences Advisory Committee, President of the University Fusion Association, Chair of the APS Division of Plasma Physics. He is currently vice-chair of the APS Forum on Physics and Society and a co-founder of the Physicist Coalition for Nuclear Threat Reduction. He holds a PhD in plasma physics from Columbia University.

Alan Robock
Rutgers University

Global Famine After Nuclear War

Alan Robock is a Distinguished Professor of climate science in the Department of Environmental Sciences at Rutgers University. He graduated from the University of Wisconsin, Madison, in 1970 with a B.A. in Meteorology, and from the Massachusetts Institute of Technology with an S.M. in 1974 and PhD in 1977, both in Meteorology. Before graduate school, he served as a Peace Corps Volunteer in the Philippines. He was a professor at the University of Maryland, 1977–1997, and the State Climatologist of Maryland, 1991–1997, before coming to Rutgers in 1998. Prof. Robock has published more than 490 articles on his research in the area of climate change, including more than 280 peer-reviewed papers.

His areas of expertise include climate intervention, climatic effects of nuclear war, and effects of volcanic eruptions on climate. He serves as Associate Editor of Reviews of Geophysics. His honors include being a Fellow of the American Geophysical Union, the American Meteorological Society (AMS), and the American Association for the Advancement of Science, and a recipient of the AMS Jule Charney Medal. Prof. Robock was a Lead Author of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (awarded the Nobel Peace Prize in 2007). In 2017 the International Campaign to Abolish Nuclear Weapons was awarded the Nobel Peace Prize for "for its work to draw attention to the catastrophic humanitarian consequences of any use of nuclear weapons and for its groundbreaking efforts to achieve a treaty-based prohibition of such weapons" based partly on the work of Prof. Robock.

Anne Stickells (she/her)
Princeton University

Anne Stickells is a PhD candidate in Security Studies at Princeton's School of Public and International Affairs. Prior to coming to Princeton, Anne worked at RAND as a research assistant, where a number of her projects were related to nuclear policy. Anne graduated from Stanford in 2015 with a BA in Science, Technology, and Society, and a minor in Creative Writing.

Frank von Hippel
Princeton University

Arms Control: We Can and Should End Production of Highly-Enriched Uranium and Separation of Plutonium for Any Purpose

Frank von Hippel is a senior research physicist and professor of public and international affairs emeritus with Princeton's Program on Science & Global Security which he co-founded. He received a D.Phil. in theoretical physics in 1962 from the University of Oxford, where he was a Rhodes Scholar and held research positions at the University of Chicago, Cornell University, and Argonne National Laboratory, and served on the physics faculty at Stanford University. From 1983 to 1991, he was chairman of the Federation of American Scientists (FAS) and partnered with the Committee of Soviet Scientists for Peace and Against the Nuclear Threat to help provide technical support for initiatives to achieve a Comprehensive Test Ban, the Intermediate-range Nuclear Forces and Strategic Arms Reductions Treaties. He was assistant director for national security in the White House Office of Science and Technology Policy (1993 to 1994) and played a major role in developing what is now called the International Nuclear Materials Protection and Cooperation Program. Von Hippel's awards include the American Physical Society's (APS) 2010 Leo Szilard Lectureship Award; the American Association for the Advancement of Science's 1994 Hilliard Roderick Prize; and a MacArthur Foundation Prize Fellowship. His books include Advice and Dissent, Scientists in the Political Arena (1974); "Citizen Scientist" (1991) published in the American Institute of Physics "Masters of Modern Physics" series; "Unmaking the Bomb" (2014); and, Plutonium: How Nuclear Power's Dream Fuel Became a Nightmare (2019).

Sharon Weiner (she/her)
American University

U.S. Nuclear Modernization

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David Wright received his PhD in theoretical condensed matter physics from Cornell University in 1983 and worked as a research physicist until 1988. Since then he has worked on arms control and international security issues, researching technical aspects of nuclear weapons policy, missile defense systems, missile proliferation, hypersonic weapons, and space weapons. From 1992 to 2020 he was a researcher with the Global Security Program at the Union of Concerned Scientists, serving as co-director of the program from 2002 to 2020. He also held research positions in the Defense and Arms Control/Security Studies Program at MIT, the Center for Science and International Affairs at Harvard's Kennedy School of Government, and the Federation of American Scientists.

From 1990 to 2019, he was a primary organizer of the International Summer Symposiums on Science and World Affairs, which fostered cooperation among scientists around the world working on arms control and security issues. In 2001, he was a co-recipient of the American Physical Society's Joseph A. Burton Forum Award for his arms control research and his work with international scientists. He is a Fellow of the American Physical Society.

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Chinese Nuclear Policy and Development

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