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EnergyTechnologyVisualsCollectionETVC@hq.doe.gov

Accelerating the Implementation of Holistic Advanced Manufacturing to Meet US Nuclear Enterprise Needs

By Kathryn Dura

Executive Summary

The US nuclear enterprise is under strain like never before. More than half of the nuclear infrastructure is over 40 years old, and a significant portion dates back to the era of the Manhattan Project.[1] Now, these crumbling facilities, like Building 9204-2, which is responsible for lithium operations despite its 1943 construction date,[2] are being asked to rapidly develop modern nuclear weapons to meet executive demands for great power competition. Therefore, there is a dire need to accelerate the modernization of existing US systems. By examining current initiatives and emerging technologies, this paper seeks to answer the following policy question: how can the US nuclear weapons development and storage facilities efficiently implement a holistic approach toward advanced manufacturing to meet increased nuclear demand?

The report answers this question by first providing an explanation of the assumptions inherent in the question, namely, (1) the current state and demands of US nuclear infrastructure, (2) the definition of advanced manufacturing and the benefits of its holistic application, (3) the current support of advanced manufacturing in executive policymaking, (4) the current state of advanced manufacturing adoption in US industry, and (5) the current state of advanced manufacturing adoption in the US nuclear enterprise.

The report then provides three broad recommendations to solve the policy problem. The proposed solutions advocate for international collaboration facilitated by a public-private US research institute to accelerate American advanced manufacturing adoption in the nuclear context. First, the United States should conduct intellectual exchanges with those international organizations and

Sandia National Laboratory's Center for Integrated Nanotechnology (CINT) is tasked with establishing scientific principles on the design and integration of nanoscale materials. In this photo, a CINT technician works with a transmission electron microscope. (US Department of Energy/Donica Payne)

countries that have developed solutions to difficulties faced by the United States. For example, international organizations have already developed preliminary standards for aspects of advanced manufacturing, while Germany has successfully implemented the suite of technologies in a holistic manner. Second, the United States should expand its public-private manufacturing institute initiative to include an institute dedicated to helping the general US industry and the nuclear enterprise apply holistic advanced manufacturing by acting as the central organization for international collaboration. Third, the United States should leverage its existing nuclear maintenance and development collaboration with the United Kingdom to (a) adapt the broad international standards to a nuclear weapons context and (b) split the trial and error associated with implementing the suite of technologies to minimize cost in terms of time and money. To illustrate how these three recommendations synthesize into a viable path forward, the report provides a preliminary concept of employment.

Finally, this paper acknowledges the security and safety concerns inherent in attempting to bring the nuclear industry into the digital age by realizing advanced manufacturing. It addresses problems such as the quality and safety of the new weapons and tools and the risks inherent to applying nuclear information to digital streams and storage methods. The report concludes with a discussion on how the concept of employment can mitigate these baseline risks.

Introduction

For decades, the aging US nuclear enterprise has continued to crumble despite various efforts to curb the decline, including executive guidance and congressional funding. The system is now further strained by new requirements to build modern nuclear weapons and munitions to provide adequate flexibility in the current and future international security environments. Therefore, there is a dire need to accelerate the backlogged modernization of the US nuclear enterprise. This can be accomplished by utilizing advanced manufacturing: the implementation of a suite of emerging technologies, including big data and analytics, autonomous robots, the industrial Internet of Things, and additive manufacturing. By holistically implementing this method of industrial production rather than applying a select few aspects of advanced manufacturing in a piecemeal approach, the US nuclear enterprise can achieve efficient modernization, increasing nuclear production and safety while reducing costs in terms of time and money.

This paper therefore seeks to answer the following policy question: how can US nuclear weapons development and storage facilities efficiently implement a holistic approach toward advanced manufacturing to meet increased nuclear demand? The rest of this section provides the paper's scope, considers background information on the current state of US nuclear infrastructure, defines advanced manufacturing, and examines the extent to which the US government, industry, and nuclear enterprise have realized advanced manufacturing. It will conclude with actionable policy recommendations and a review of concerns regarding the application of advanced manufacturing to nuclear weapons facilities.

Research Scope

To examine the intersection of US nuclear infrastructure and advanced manufacturing, this report adopts a high-level, strategic focus that analyzes the organizational shortcomings permeating America's manufacturing industry. While it surveys general American and nuclear-specific advanced manufacturing applications, it tailors the recommendations to the latter. By creating an influx of best practices from proven implementers, all of American manufacturing can improve its adoption practices; by leveraging intimate collaboration of trusted allies, the US nuclear enterprise can accelerate its advanced manufacturing implementation. However, this issue is multifaceted, facing human resource barriers to retaining specialized personnel, technical hurdles to networking advanced technologies with nuclear facilities, and cooperation obstacles between private sector companies and the US nuclear enterprise. Therefore, this paper will address one strategic component of the broader policy problem, but, to fully realize the ultimate goal, policymakers would need to comprehensively address each aspect.

The Problem

Current State of and Demands on US Nuclear Infrastructure

In March 2017, the Subcommittee on Oversight and Investigations of the House Armed Services Committee held a hearing to investigate the infrastructure needs and projects ready for immediate implementation in the nuclear enterprise.[3] Multiple representatives described the current state of US nuclear infrastructure—consisting of buildings, facilities, and laboratories that develop and store nuclear weapons—as antiquated and known to experience "crumbling ceilings and flooded hallways." This is partially due to the infrastructure's vintage; more than half of the facilities are over 40 years old, and about a quarter were built in the era of the Manhattan Project.[4] This, combined with the $3.7 billion "backlog of deferred essential repairs, rehabilitation, and replacement construction,"[5] creates a strained financial situation; not only must day-to-day funding requirements function, but the growing maintenance needs must also be addressed. Delays and financial strain are not unusual for the US government, but in the context of nuclear security, it takes on a new urgency.

Or so one would think. Back in 2009, the Congressional Commission on the Strategic Posture of the United States delivered its final report, which raised the same concerns.[6] In the report, the commission recommended reorganizing the oversight of the nuclear stockpile and allocating adequate funding to address the crumbling infrastructure while maintaining standard function. Additionally, the commission grappled with the problem of aging nuclear warheads. The international security environment was one where the predominant nuclear threat was no longer apocalypse, but terrorism and proliferation. Therefore, the executive branch sought a balance: the United States would pursue arms treaties to reduce the number of strategic weapons worldwide while maintaining a reliable strategic deterrent. To accomplish this, the United States would maintain its stockpile without creating new weapons with new military capabilities. Therefore, the commission recommended that the warheads receive service-life extensions, with the degree of refurbishment varying case by case. The 2010 *Nuclear Posture Review* (NPR) concurred with these recommendations and began their implementation.[7]

However, changes in the security environment and to US policy have placed a new strain on the system. In 2018, the Trump administration released its *Nuclear Posture Review*, citing Chinese and Russian aggression and describing the need for "a flexible, tailored nuclear deterrent strategy" derived from a "diverse set of nuclear capabilities."[8] Specifically, it outlines various life-extension programs for current arms in addition to the development of low-yield nuclear weapons and nuclear-armed, long-range, standoff cruise missiles. Such programs represent a marked shift from Obama administration policies and will require extensive development and verification. For example, scientists must first determine the impact of age on performance prior to extending the weapons' service lives. As a result, the National Nuclear Security Administration (NNSA) must further increase efforts to meet the president's objectives, further straining the office and the nuclear infrastructure.

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Notably, the NNSA is receiving an increase in funding due to its critical need, and the growth of the deferred maintenance backlog has stopped. President Donald Trump requested $19.8 billion for the NNSA in fiscal year 2021, increasing the office's funding by almost 20 percent. However, as the *NPR* states, "There now is no margin for further delay in capitalizing the physical infrastructure needed to produce strategic materials and components for U.S. nuclear weapons."[9] If the threats and uncertainties outlined in the document are indeed as urgent as described, then the United States must accelerate its nuclear enterprise efforts with more than money.

Advanced Manufacturing

Many are familiar with concepts such as big data and analytics, cloud computing, cybersecurity, and 3D printing. Fewer are familiar with their convergence that, when combined with additional technologies, have the potential to revolutionize US manufacturing. While scholars and practitioners vary slightly on the exact technology categories encompassed in this system and its terminology, advanced manufacturing (or Industry 4.0) as a general concept is fairly consistent. A 2016 US policy document and a study from the Massachusetts Institute of Technology define advanced manufacturing as the novel products manufactured using emerging technologies and the innovative manufacturing system that comes from combining these emerging technologies.[10]

For this paper, the emerging technologies that make up advanced manufacturing are big data and analytics, autonomous robots, simulation, the industrial Internet of Things (IoT), cybersecurity, cloud computing, additive manufacturing, augmented reality, and nanotechnology.[11] By applying these technologies, the US manufacturing industry can reduce costs and inefficiencies. For example, sensor data from product testing can be analyzed in large data sets and stored on the cloud, allowing the results to dynamically impact future iterations of additively manufactured products. In particular, this system of production reduces the number of prototypes required, which will increase the manufacturer's flexibility and allow for smaller, custom production. By incorporating all of these technologies into a single system, manufacturing evolves from a largely stepwise transformation of raw materials to finished goods to an integrated system that couples physical goods with value-added services and software through ultraefficient processes.[12]

Given the systematic nature of advanced manufacturing, achieving the maximum benefits will require a complete implementation of the technology suite. For example, nanotechnology could add synthetic materials to raw materials, increasing their strength and endurance. High-precision sensors could detect this and feed the data back into a larger data set stored on the cloud. The data set could then be analyzed to improve the initial fabricated product, which would feed back into the nanotechnology design. Once the product is assembled satisfactorily, it could be integrated with service software to provide continued feedback to developers. While the implementation of one aspect of advanced manufacturing like nanotechnology would still result in some degree of product improvement, the full benefits would not be realized.

Current State of US Government Initiatives

The two most recent presidential administrations have identified advanced manufacturing as a solution for reinvigorating America's manufacturing sector. President Barack Obama set the foundation for developing US advanced manufacturing in 2011 when executive branch advisers wrote a groundbreaking report proclaiming the need for a coherent US innovation strategy.[13] A 2012 working group answered the call by publishing *A National Strategic Plan for Advanced Manufacturing*, which outlined the nation's principles and objectives, including creating partnerships, coordinating investment, and raising awareness of advanced manufacturing research and development.[14] The Obama administration also began to foster public-private partnerships with the Advanced Manufacturing Partnership, a national effort linking universities, industry, and the government to create quality manufacturing jobs and enhance US global competitiveness by investing in emerging technologies.[15]

Following the initial success of a pilot additive-manufacturing institute created in 2012, the Advanced Manufacturing National Program Office proposed a preliminary design for the National Network for Manufacturing Innovation, a system of manufacturing institutes accelerating US advanced manufacturing.[16] Shortly after the passing of the 2014 Revitalize American Manufacturing and Innovation Act, the newly named National Network for Manufacturing Innovation (NNMI), also known as Manufacturing USA, was created in 2016.[17] It comprises fourteen specialized, national manufacturing institutes meant to catalyze "the development of new technologies, educational competencies, production processes, and products via shared contributions from the public and private sectors and academia."[18] For example, MxD equips manufacturers with the necessary digital tools while America Makes aims to accelerate the use of additive manufacturing and 3D printing.[19]

As the Obama administration drew to a close, it outlined a path forward for future administrations to continue to develop American advanced manufacturing. For example, the Subcommittee for Advanced Manufacturing of the National Science and Technology Council wrote *Advanced Manufacturing: A Snapshot of Priority Technology Areas Across the Federal Government*. As the title suggests, this document summarizes existing and emerging priority areas within the manufacturing sector ripe for future, tailored federal efforts.[20] Through this body of policy documents, the Obama administration laid the necessary framework to further US advanced manufacturing.

When the Trump administration took office in January 2017, it modified the previous administration's narrative but continued the advanced manufacturing initiatives. For example, it released a modified advanced manufacturing strategy in October 2018 with policy goals that largely aligned with those of the Obama administration.[21] The main alteration is a shift from focusing on the advanced manufacturing business climate to expanding the capabilities of the domestic manufacturing supply chain. Regardless, the national manufacturing institutes continue to experience tangible success. Several have won million-dollar government contracts and awards for achievement.[22]

Over the past two administrations, there has been broad policy and funding continuity to further US advanced manufacturing adoption. These efforts demonstrate the importance of implementing the technologies and suggest a high level of support when applying the advanced manufacturing system to the US nuclear enterprise.

Current State of Advanced Manufacturing in US Industry

US industry, typically associated with cutting-edge innovation and growth, is lacking both when it comes to realizing advanced manufacturing. In December 2018, the Brookings Institution published a study on the state of advanced manufacturing productivity in regional and national sectors from 2007 to 2016.[23] It found that productivity in the advanced manufacturing sector sharply increased between 2008 and 2010 but plateaued from 2010 to 2016. Overall, the study attributes the sluggish growth to small and medium-sized firms struggling with weak innovation, foreign competition, and a glacial embrace of the digital era despite large firms flourishing and innovating.

This stagnant development seems at odds with US industry goals. In a 2016 study, the Boston Consulting Group (BCG) found that two-thirds of US company respondents associated reduced costs and increased productivity with advanced manufacturing.[24] Additionally, 43 percent of respondents associated revenue growth with the technologies' application. However, only 16 percent of surveyed US companies have implemented full advanced manufacturing (holistic) or at least preliminary measures (piecemeal). This should come as no surprise since only 29 percent of US companies developed first concepts for holistic implementation and an overall 41 percent of respondents stated that their company was unprepared to do so.

To better understand why US manufacturers are struggling to implement advanced manufacturing, BCG conducted a follow-on study in 2016. After surveying 280 US-based manufacturers of various sizes and industries, BCG again determined that adopting this new manufacturing concept was a priority but not an imperative.[25] Similarly, it found that 89 percent of respondents saw an opportunity to improve their manufacturing productivity with advanced manufacturing, but only 28 percent viewed it as an avenue to generate increased revenue.

Most interesting, within the suite of technologies that encompass advanced manufacturing, US manufacturers have focused on its digital aspects, with 65 percent implementing cybersecurity, 54 percent applying big data and analytics, and 53 percent using cloud computing.[26] Meanwhile, more physically connected technologies like additive manufacturing, advanced robotics, and augmented reality are the least implemented, with 34 percent, 32 percent, and 28 percent respectively. This is likely the result of several trends, including the relatively low startup cost to develop software as opposed to physical hardware or the expanding possibilities for digital applications in the consumer market. Thus, the data suggests that while US manufacturing companies prioritize the implementation of advanced manufacturing and have begun this process, they are doing so unevenly across the technologies within advanced manufacturing. This piecemeal approach fails to realize the full potential benefits of the innovation, such as increasing process efficiency and reducing cost in terms of time and money.

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Current State of Advanced Manufacturing in US Nuclear Enterprise

The NNSA is well aware of advanced manufacturing's potential in the nuclear enterprise. Its fiscal year 2020 *Stockpile Stewardship and Management Plan* details the activities of its Advanced Manufacturing Development Program, an initiative that "develops, demonstrates, and deploys next-generation production processes and manufacturing tools."[27] It is divided into three subprograms: Component Manufacturing Development, Additive Manufacturing, and Process Technology Development. These subprograms focus on modernizing the manufacturing technology processes, developing and incorporating 3D printing, and supporting uranium processing respectively.

To meet the presidential directives outlined in the *NPR*, the NNSA outlined priorities, accomplishments, statuses, and challenges for implementing advanced manufacturing.[28] For example, it seeks to replace conventional polymer processes with additive manufacturing by 2023 to reduce the number of steps, decrease the amount of required space, increase the production quantity, and curb waste. It also includes broader goals such as mitigating supply chain risk, leveraging industry advancements, and creating an integrated digital manufacturing network to utilize artificial intelligence and machine learning.

The NNSA has also experienced initial success in its implementation. For the first time, the nuclear enterprise additively manufactured a war reserve component in 2018.[29] Similarly, the Kansas City National Security Campus saved over $124 million by 3D printing more than 63,000 tools, fixtures, and molds. Within the US nuclear enterprise as a whole, approximately 10 percent of all fixtures, molds, and tools and about 90 percent of prototype fixtures and tools are additively manufactured.

These strides within the Advanced Manufacturing Program demonstrate the practicality and effectiveness of advanced manufacturing tools within the US nuclear enterprise. However, despite the goal of implementing a holistic approach to advanced manufacturing, the reported accomplishments predominantly feature one aspect—additive manufacturing—which will not provide sufficient benefits to meet current and future national security demands. By limiting its field of view to US development methods, the NNSA will likely perpetuate the piecemeal approach; by expanding its intellectual horizon, the NNSA can accelerate its holistic implementation of advanced manufacturing.

Recommendations

Introduction: A New Form of Burden Sharing

To optimally conduct nuclear enterprise modernization, America must look outside of its borders. After all, the United States is not alone in its awareness of or desire to leverage advanced manufacturing. By collaborating with international organizations and countries examining similar problems, American nuclear facilities can accelerate their adoption. Obviously, the level of collaboration will vary based on the national security implications of the topics. For example, international partners like Germany can provide broad frameworks for understanding and implementing advanced manufacturing. Meanwhile, the United States and the United Kingdom, with their long-standing relationship around nuclear weapons development, can work more closely, applying the general best practices to a nuclear context and dividing the trial-and-error costs of application. The rest of this section details the arguments for these recommendations and concludes with a comprehensive concept of employment.

A Strategic, Intellectual Exchange: International Organizations and the German Model

Given the benefits offered by advanced manufacturing, many organizations and countries outside of the United States are also facing the challenges of optimal integration and standardization. For example, the International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM) International signed an agreement to adopt and jointly develop global marketplace standards for additive manufacturing in 2011.[30] These two organizations recognized the potential redundancy in efforts and resources and sought to streamline international definitions and concepts. The collaboration has resulted in 14 requirements, guidelines, and recommendations pertaining to additive manufacturing general principles, standard terminology, purchaser requirements, and design guidelines.[31] Tapping into this effort and others like it can accelerate general US adoption by providing a ready-made, broadly applicable framework for understanding and regulating the implementation of advanced manufacturing technologies.

Aside from leveraging the knowledge of international organizations to improve general manufacturing efficiency, the United States should also look outside of its borders for concrete methods of implementation. For this, Germany is the ideal role model. First, Germany is "a world leader in high-technology manufacturing and imports,"[32] with approximately 21 percent of its economy relying on manufacturing. Second, it is a close US economic partner and NATO ally. Most importantly, Germany is applying advanced manufacturing in a holistic manner. One BCG study compared the current adoption rates of advanced manufacturing in the United States and Germany and found that both countries have demonstrated a similar pace of adoption.[33] However, the survey suggests that German industry is adopting advanced manufacturing comprehensively; roughly half of the surveyed industry has developed its primary, holistic advanced manufacturing concepts, while only 29 percent of US companies have developed first concepts. Worse, 41 percent of US companies (as opposed to 18 percent of Germany respondents) stated that their companies were unprepared to introduce advanced manufacturing technologies. Germany's comprehensive adoption may be due to its industry's long-standing advanced industrial-manufacturing capabilities. For example, German companies lead their American counterparts by 78 percent for the rate of robotics penetration in the manufacturing industry.

Additionally, there is precedent for leveraging Germany's model. The US system of manufacturing institutes, NNMI, is based on the Fraunhofer-Gesellschaft model, an umbrella organization begun in 1949 that now has 72 institutes and research units throughout Germany.[34] Each institute focuses on applied research topics for individual technologies, including those within advanced manufacturing. These institutes are national public-private initiatives funded in varying degrees by industry contracts, public research projects, and the German government.[35] Additionally, the network has international components; in 1994, Fraunhofer USA was established to conduct applied research and development and learn about American scientific advancements.[36]

If the United States has already adopted and begun to implement the Fraunhofer model, why is it failing to achieve the same results? From the outside, the most obvious difference between the two networks is their respective maturities. Germany has developed the optimal relationships and best practices necessary to coordinate its expansive public-private network over approximately 70 years, whereas America has only just begun. Therefore, the United States should go beyond translating the German model to an American context; it should deepen the countries' relationship by holding regular intellectual exchanges with Germany. This will help the United States learn best practices for its industries as a whole. Overall, by harnessing international collaboration, such as with the ISO/ASTM International and Germany, American manufacturing could reorient its organizational thinking in the long term. However, in the short term, this particular recommendation is limited in its ability to accelerate advanced manufacturing implementation for nuclear facilities.

Means of Collaboration: The Fifteenth Institute

International organizations and foreign governments offer US manufacturing the opportunity for an ideological acceleration of advanced manufacturing implementation. However, those benefits remain high level, largely focusing on standards development and broad best practices. This leaves not only the nuclear enterprise but the general manufacturing industry with limited assistance in tailoring application to individual industry needs.

To mitigate this shortfall and accelerate the adoption of advanced manufacturing, the existing institute structure within Manufacturing USA should be expanded to include a fifteenth institute focused on applying holistic advanced manufacturing. While the current structure provides businesses with tailored assistance regarding specific emerging technologies, there is no institute providing the same public-private support for companies to integrate those technologies. Given that this implementation style is currently lacking in American industry, the new institute can leverage the existing institute structure and resources to help US manufacturers develop specific adoption plans for their needs.

The additional institute will also provide foreign entities and the US nuclear industry a central hub with which they can partner. For example, when seeking to collaborate, the American nuclear enterprise would have a domestic liaison through which it could reach counterparts at the ISO/ASTM International or the Fraunhofer institutes. Streamlining such conversations not only increases communication efficiency but accelerates adoption by providing all parties with an entity through which sensitive trade secrets and best practices can be shared. Overall, this institute would provide a means through which general American manufacturing can holistically adopt more-efficient practices while offering the nuclear industry a potential American point of contact with international best practices.

Close Collaboration: The US-UK Special Relationship

While an intellectual exchange between international bodies and American institutes would be valuable for general US advanced manufacturing adoption, the highly specialized field of nuclear development and storage will require tailored suggestions. However, sharing sensitive nuclear enterprise information is rightly restricted. The optimal situation involves close collaboration with a trusted partner. Luckily, this level of cooperation already exists with the United Kingdom's Atomic Weapons Establishment (AWE).

AWE is the UK equivalent of the NNSA, with the mission to build, maintain, and certify the UK nuclear weapons stockpile and ensure good nuclear weapons stewardship.[37] Its long-standing, collaborative research relationship with US nuclear weapons laboratories began with the 1958 US-UK Mutual Defense Agreement, and its implementation has since deepened nuclear integration between these allies. The United Kingdom's Vanguard-class SSBN submarines, the source of its strategic nuclear deterrent at sea, carry Trident II D5 submarine-launched ballistic missiles designed and manufactured by Lockheed Martin in the United States.[38] When not deployed, UK Trident missiles are held in King's Bay, Georgia, at the US Strategic Weapons Facility. Even the warheads on the UK variants are purported to be similar to the 100-kiloton W76 US warhead. Aside from the submarine-launched nuclear missiles, the UK nuclear warhead storage and fitting facility in the Royal Navy Armaments Depot is managed jointly by Lockheed Martin, UK-based Babcock, and AWE. American companies even own more than a 75 percent stake of AWE's managing consortium. These examples of existing development and storage integration demonstrate the precedent for US-UK nuclear collaboration and the joint need to leverage holistic advanced manufacturing.

> To optimally conduct nuclear enterprise modernization, the United States must look outside of its borders.

This existing relationship should be deepened to efficiently test and implement advanced manufacturing. AWE and the NNSA could develop specific standards to apply advanced manufacturing in nuclear facilities based on the framework provided by the previously discussed international groups and institutes. This could be taken further by splitting the technology suite testing to reduce the potentially lengthy trial-and-error period. By systematically implementing advanced manufacturing in a nuclear context, both countries in the special relationship stand to accelerate adoption and reduce the individual cost of such an undertaking.

Concept of Employment

Applying the recommendations above into the US nuclear enterprise should be done in a deliberate, structured manner. First, the US nuclear enterprise would seek all available information by contacting the newly created fifteenth NNMI institute and determining if there are any relevant advanced manufacturing standards or broad implementation strategies from international sources. The institute would then contact organizations such as the ISO/ASTM International or the Fraunhofer institutes and relay the findings back to the nuclear industry. If more information or further collaboration is required, the NNMI could facilitate this exchange by acting as a liaison and connecting the correct counterparts.

Once the required information is obtained, the US nuclear enterprise would develop an implementation plan by applying the imported information to the nuclear context. With an initial plan, small accelerator teams in the NNSA and AWE would divide the experimental technology load and conduct preliminary testing.

By having smaller teams refine the technologies prior to facility application, the process can avoid disastrous attempts to use flawed systems for managing nuclear weapons. Similarly, BCG recommends the creation of cross-functional innovation teams to "conduct bold experiments, iterate quickly, and scale up new solutions across the organization as soon as they are validated."[39] Once the teams complete testing, the NNSA and AWE would compare results and hone best practices. These successes would then be implemented into the nuclear infrastructure and continuously refined to increase overall safety.

Potential Drawbacks

While the implementation of advanced manufacturing holds the promise of increased productivity and efficiency at a lower cost, the cutting-edge technology suite also brings risk in terms of safety and security. Its potential application to the US nuclear enterprise sets the stakes significantly higher. The rest of this section acknowledges potential concerns regarding the technologies' realization and provides reassurance of the effort's overall promise.

Safety

A key driver for recommending the application of advanced manufacturing in the nuclear industry context is its potential to increase the enterprise's overall safety. Instead of an already outdated infrastructure system struggling to manufacture modern equipment, the emerging technologies within advanced manufacturing could increase situational awareness of each weapon's status while streamlining its development. However, this implies that the weapons, tools, and prototypes that are created through these means meet the same quality standards. Revamping the nuclear infrastructure is useless if the technology is poor, fails to function, or creates a higher threat. Aside from the detrimental safety implications, even the potential existence of this concern could limit how the concept is applied on the ground.

The aforementioned concept of employment mitigates these concerns by allowing the US nuclear enterprise to examine established standards and methods from expert international sources. By analyzing the entire body of leading advanced manufacturing knowledge, the nuclear industry stands the best chance of maintaining safety. Similarly, the accelerator laboratory teams that conduct the initial testing prior to implementation provide another check against hasty action.

Security

Another immediate concern when seeking to implement a suite of emerging technologies in the nuclear enterprise is the protection of the vast amounts of digital information and system access from bad actors. By having electronic streams of data and locations where such information comes to ground for the employment of IoT, cloud storage, and big data and analytics, there is an inherent risk to the information's security and accuracy. In the nuclear context, this potential vulnerability risks nuclear proliferation. Similar to the safety concerns above, the recommended process in the previous section mitigates the preemptive application of flawed information systems. However, to some extent, the dangers of cybersecurity are fundamental to the technology and can never be completely eliminated.

Conclusion

While the concerns detailed above are inherent to the digital nature of advanced manufacturing, the pursuit of the system's holistic implementation is still worthwhile when appropriate checks are applied to mitigate risk. On the positive side, the ubiquity of the emerging technologies within advanced manufacturing can prove to be an unexpected boon; the safety and security concerns for applying the advancements to the nuclear enterprise are also problems faced by industry writ large. Therefore, all parties, domestic and international, possess aligned incentives to seek the fundamentally similar safety and security goals. This provides the foundation for intellectually importing from or closely collaborating with trusted international partners.

The very existence of an industry dedicated to developing and storing nuclear weapons is inherently risky. Holistically implementing advanced manufacturing to meet increased nuclear demand offers the best chance for the US nuclear enterprise to do so in a safe and secure manner during the digital age. Maintaining the crumbling infrastructure from the era of the Manhattan Project is no longer an option.

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About the Author

Kathryn Dura graduated summa cum laude from the University of Pennsylvania in 2018 with a double major in international relations and modern Middle Eastern studies and a minor in mathematics. As a student, she served as an inaugural Perry World House Student Fellow. She also conducted research on the proliferation of emerging technologies and developed a game theory model exploring how unmanned aerial vehicles impact escalation. After graduating, she worked as a Joseph S. Nye Jr. Technology and National Security Research Intern at the Center for a New American Security. Dura currently is an intelligence analyst for the US Navy and an inaugural member of the Stanley Center for Peace and Security Accelerator Initiative cohort.

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Kathryn Dura is a 2019 participant in the Stanley Center for Peace and Security's Accelerator Initiative. The Accelerator Initiative is a unique mentorship and career-development opportunity for a small cohort of early career women working in nuclear, international security, or technology policy. Participants chosen to be part of the Accelerator Initiative join the center's policy dialogues, hone and demonstrate their expertise, expand their networks, elevate their profiles, and deepen their interest in issues at the intersection of emerging technologies and nuclear weapons policy. Each "accelerator" develops a research question over the course of the year, to be expanded into a policy paper with support and feedback from an expert adviser of her choice. Accelerators are chosen through a rigorous application process each December. For more information: stanleycenter.org/accelerator.

Analysis and New Insights are thought-provoking contributions to the public debate over peace and security issues. The views expressed in this brief are those of the author and not necessarily those of the Stanley Center for Peace and Security. Cover photo: High Flux Isotope Reactor (HFIR) pool at Oak Ridge National Laboratory. The HFIR was built in the 1960s to produce "heavy" elements like plutonium. (EnergyTechnologyVisualsCollectionETVC@hq.doe.gov)

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6/20