Additive Manufacturing: A Review of Export Controls and Nuclear Nonproliferation Challenges

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INTRODUCTION

Additive manufacturing (AM) represents an emerging technology within the manufacturing sector that is gaining in global popularity as a mechanism to reduce lead time and cost, while improving availability and manufacturability of complex parts. Although the potential prospects – especially economic – for this technology, equipment, and associated processes may be great, the resulting proliferation risk may also be substantive. This summary outlines the current state and progress in AM development, focusing on United States' interests and the civilian nuclear industry; identifies how AM-related technology, equipment, and processes are covered under current export control regulations in the United States and the Nuclear Suppliers Group (NSG); summarizes the potential proliferation risk through historical example; and, discusses the AM supply chain and recommendations for how export controls may evolve to better mitigate the proliferation concerns. An overall understanding of the AM technology and how the industry is progressing is critical to both identifying the proliferation concerns and assessing how multilateral regime guidelines and national export control regulations can evolve to effectively address them.

State of the Additive Manufacturing Industry

Additive manufacturing is defined as the process of joining materials to make objects from 3-dimensional model data, usually layer by layer. The AM process as a whole includes the requisite data input or part design, the raw material usually in powder form, the technical knowhow to both create the data input and operate the system at the required parameters, the AM unit, and any post-processing work.

The market growth for additive manufacturing technology has increased at an extraordinary rate in the past few years. It is estimated that by the end of 2015 there were more than 278,000 worldwide shipments of desktop AM machines alone. The industry continued to grow with over 97 manufacturers producing new additive manufacturing systems in 2016, a 40% increase from the previous year, and achieving $6.063 billion in revenue [1]. 25% of the total amount of AM machines shipped fall within an affordable price range of $1-$1,000 for an average consumer, and this is likely to grow to 40.7% by 2019. Given these approximations, there will be about 2,249,689 units sold worldwide to average consumers. State-of-the-art printers and materials are also available for purchase for slightly more than $1 million.

At present, many traditional manufactures are interested in the possible applications to nuclear technology, especially the production of parts with complex geometries that are difficult to manufacture using traditional methods; advanced or new reactor components; and legacy or ageing parts that are no longer being manufactured. According to a Nuclear Regulatory Commission public meeting on the topic of AM in the nuclear industry, several nuclear suppliers are underway additively manufacturing non-critical fuel assembly related components and materials testing to qualify these parts for eventual regulatory approval [2]. The focus of industry thus far is primarily on stainless steel, zirconium, and nickel alloys, but is likely to expand to other metal alloys, as production techniques progress. AM metal production methods include the following: Powder Bed Fusion, Directed Energy Deposition, Sheet Lamination, and Binder Jetting, all of which are being studied by various industry stakeholders [2]. However, each of these has distinct limitations that influence their effectiveness and capabilities. Some key challenges to the advancement of AM in the nuclear industry include the lack of standards and codes for nuclear components; part qualification processes for regulatory approval; limitations in the precision of AM machines; and post-processing requirements needed to meet specified performance and surface finish parameters [2].

Proliferation Challenge

The United States Department of State has moved to amend the International Traffic in Arms Regulations, the regulatory mechanism for the Arms Export Control Act, to add additive manufacturing data (the information posted online that can be downloaded and used for 3D printing) to the list of items to be controlled and monitored. However, the plans for how to build 3D weapons and quality high-strength metals is currently publically available to all those wishing to access them online. Additionally, the scope of these regulations is limited to conventional munitions. In practice, 3D printing has tested the regulations. Cody Wilson created a completely 3D printed one-shot handgun, the Liberator, and posted the design information online. The United States Department of State ordered the removal of the Liberator files, however, Wilson has stated that he plans to release the information for how to create an Ak-47 online. It is difficult to control the dissemination of these files online. Before the Liberator files were removed, the weapon's designs were downloaded over 100,000 times.

Similar conventional weapons cases, such as Yoshitomo Imura in Japan, have also been reported.

These reflect conventional proliferation threats, many of which involve the use of affordable 3D printers, providing individuals access and the capability to create their own homemade firearms. There is also a significant unconventional proliferation threat. More expensive models of 3D printers with more extensive or precise capabilities have the potential to be used in the advancement of weapons of mass destruction (WMD). Though it is still unclear whether or not the quality of the 3D printed centrifuges or other materials would be useable for nuclear components of nonproliferation concern due to requisite properties and performance, AM technology is advancing every day. States willing to advance their weapons programs are always adapting different types of technology to accommodate their needs, and it should be assumed that they will be able to use functioning AM materials in the future.

Individuals and states can access additive manufacturing technology and use it to build weapons with little difficulty. A 3D printer and its filament (available in plastic, metal, nylon, glass, and other materials) can all be purchased online. Furthermore, one can easily access the appropriate information online and import printing plans for whole/or parts of weapons into their printers.

Additive manufacturing technology poses a proliferation problem for both conventional and unconventional weapons for many reasons:

- Technology and materials for the use of this technology are already affordable and accessible worldwide and
- The data available online could vary between plans for small weapons to parts used to construct centrifuges or rocket engines, giving individuals and states access to possible illegal materials and weapons.

ANALYSIS

This analysis of export controls is focused on the limitations and challenges posed by each part of the AM process, including feedstock or raw materials, data files and technical know-how, AM machines, and fabricated products and their components. This summary emphasizes the controls and possible limitations, as they apply to nuclear fuel cycle and weaponization. The export controls discussed reflect the guidelines from the Nuclear Suppliers Group (NSG) and related U.S. domestic regulations. The NSG issues guidelines for the transfer of nuclear items through the Trigger List and nuclear-related items through the Dual-Use List. The former is designed to include especially designed and prepared items and is comprised of "(i) nuclear material; (ii) nuclear reactors and equipment, therefore; (iii) non-nuclear material for reactors; (iv) plants and equipment for the reprocessing, enrichment and conversion of nuclear material and for fuel fabrication and heavy water production; and (v) technology associated with each of the above items".[3] The latter list includes guidelines concerning the export of nuclear-related dual-use items, or items that have nuclear fuel cycle or weaponization applications AND non-nuclear, commercial uses.

The NSG Trigger List is designed to incorporate items that trigger nuclear safeguards. In the U.S., the national regulations concerning trigger list items are divided among the Nuclear Regulatory Commission (NRC), Department of Commerce (DOC) and Department of Energy (DOE). In general categories i, ii, iii, and certain items under iv are controlled by the NRC, while the DOC controls exports for iv. The DOE governs exports of category v, or the technology related to the development, production or use of any of the Trigger List items. The NSG Dual-Use List is controlled by the DOC under the Export Administration Regulations.

Certain nuclear-grade materials and AM feedstock that meets specified properties, such as purity, density, etc., are currently covered under NSG guidelines. In the U.S., nuclear-grade materials (nuclear grade graphite, deuterium and heavy water, e.g.) are controlled by the NRC, while dual-use materials (hafnium, zirconium, maraging steel, e.g.), are controlled by DOC. These materials often are dual-use and have legitimate commercial and nuclear end uses. A determined proliferant could obtain materials for a legitimate end use and utilize an AM process to produce components required in the nuclear fuel cycle or weaponization processes. At this time, most studies of AM capabilities report that AM machines are unlikely to reproduce critical components and are more likely to provide alternative means of producing non-critical components. This is not to say that future advances in AM will be bound by the same limitations. In a rather short period of type, AM developed from a technique for producing plastic and resin products to one that could print metals. Advances have also brought about many distinct types of AM that each has its own capabilities and limitations. Consequently, controlling the feedstock materials alone may reduce the risk of diversion of materials, but may be insufficient as a standalone control, particularly if the materials involved have other legitimate commercial uses.

The data files used in AM are detailed computer aided design drawings and models that allows a computer to direct the AM machine to print a part layer by layer. The DOE controls especially designed and prepared nuclear technology in addition to dual-use technology under 10 CFR 810. For AM technology, these export controls include both data files, information associated with controlled AM units, and the technical expertise required to additively manufacture certain parts or components. As demonstrated by the historical examples of conventional munitions designs being publically released online, the data or technology may be quite difficult to effectively control even with an existing export control framework.

The Nuclear Suppliers Group guidelines cover the exports of some metal filaments, including maraging steel, which can be used in powdered form in extrusion methods of 3D printing; however, similar constraints have not been applied to the 3D printers themselves. Models that are currently able to print metal filament are: the EOS M series, the Matsuura Lumex Avance-25, Renishaw AM250, SLM 280, SLM 500, and Concept Laser Machines. Other existing NSG guidelines do apply to select materials with properties sufficient for nuclear applications, such as nuclear-grade graphite, maraging steel, and low-hafnium content zirconium. They also apply to the fabricated product or components of the product, independent of the manufacturing mechanism.

Controls associated with the fabricated product or its components are also limited in scope. Such controls only take effect if the final product is being exported. As such, a determined proliferant could acquire the raw materials, the data file, and an AM unit to print the part directly. That eliminates the need for the part to cross State boundaries and introduces a scenario that makes export controls less effective. It also adds to the overall proliferation threat introduced by emerging AM technologies. One approach to address this threat is to supplement existing export controls with controls on the AM processes not currently covered for an all-inclusive set of controls–the AM units themselves that meet some specified parameters relevant to the production of controlled nuclear commodities. This is just one possible option that may help improve the chances of preventing the diversion of goods for illicit purposes.

NOMENCLATURE

AM = Additive Manufacturing
DOC = Department of Commerce
DOE = Department of Energy
ITAR = International Traffic in Arms Regulations
NRC = Nuclear Regulatory Commission
NSG = Nuclear Suppliers Group

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