HPM technology will continue to advance, creating more opportunities to place these systems on different platforms, new and old. Having more platforms and options will help to legitimize the technology for operational units. Currently, AFRL and industry partners create these systems to demonstrate their potential and feasibility of the technology. Once these systems become more readily available, more training can occur. Having access to these systems at the operational level will provide an opportunity to showcase their capability and get the required buy-in so they can deploy in future conflicts.

HPM Intelligence Support Requirements

Operationalizing HPM weapons will require significant intelligence support to ensure these systems can prosecute targets effectively. Organizations operating HPMs will need to have intelligence professionals that can identify and breakdown frequencies of enemy target radars and systems. Having accurate intelligence on the target set will drive the requirement for the type of band the HPMs transmit through. Knowing what band to transmit through is essential because HPMs are most effective when they employ high pulsed power that is in-band with the target frequency using narrowband transmissions. Having accurate intelligence on the target set will ensure that maximum power is delivered to the target electronics, providing a functional kill. Intelligence support to HPM employment will be critical for them to succeed in operational missions.

Intelligence professionals will need to identify what they know about the target set. By doing this, it helps to determine the type of band to transmit in. If the intelligence professionals know detailed information about the target, then a narrowband transmission should be used. Using narrowband transmissions ensures the maximum energy delivery to the target. If little to no information is known, then ultrawideband transmissions should be used. This method does

not deliver as much energy to a target and may only degrade the electrical components. Degradation could be intentional or unintentional. If the degradation of the target was unintentional, the target would need reengagement to achieve the desired effects. Knowing what band to transmit is critical because it will determine the effects it will have on the target. Having the capability to determine intended effects on targets will help to normalize HPMs and help to add them to the vast lists of weapons that commanders have at their disposal to attack targets of interest.

HPMs as a Coercive Instrument

HPM weapons allow the US to reexamine coercion through conventional means. The use of HPMs, as mentioned earlier, can be used across the range of military operations in an attempt to change an adversary's behavior. Employing a countervalue strategy enables a coercive strategy by targeting things that are vital to an adversary nation. Having the means to strike targets like this provides a unique opportunity to look at how to use HPMs across the "coercion continuum."[37] The continuum ranges from deterrence to total war. HPMs can be employed across it to attempt to coerce adversaries to do what the US wants. Coercion is defined by AF Doctrine 3-0, "is convincing an adversary to behave differently than it other otherwise would through the threat or use of force."[38] HPMs give leaders conventional options that will affect the behavior of adversary nations.

When the US wants to affect the behavior of its adversaries, there has to be a capable and credible threat. Gerson explains that in order for the US to change an adversary' s behavior, there needs to be military capability and political willpower.[39] Military capability is established by conducting demonstrations of the weapons system and being broadcasted in open source videos. Much like the US currently does with other weapons systems. Political willpower could be more

challenging to demonstrate. Problems with HPMs and political support stems from a lack of understanding of systems capabilities. The Active Denial System is a perfect example and encountered these problems. Many people in the human rights arena became severe critics of the system. Their overarching concerns stemmed from possible misuse causing short-term pain but not leaving any physical evidence as well as unknown long-term effects.[40] For other HPMs, the process of socialization needs to occur now. New technologies bring about many unknowns causing fear within the people, which ultimately affects the ability of politicians to support these systems. Without the political willpower, the credibility of these systems would not exist.

Once the credibility of these weapons becomes established in the international system, then the US can begin to use them to affect the decisions of adversary countries. The US could deploy HPMs in situations that are below the threshold of war, like Iran's 2019 attack on the Saudi oil refinery. Open-source reporting indicated that the US responded to these attacks with a cyber-attack. If HPMs were operational, they could have deployed against Iran and conducted strikes against valuable targets to the Iranian Regime. Similarly, the US could respond to North Korea's belligerent behavior, nuclear weapons tests and ballistic missile launches, with an HPM. The US could threaten to launch an HPM to deliver effects on targets of value to deter future behavior. If deterrence failed, then the US could launch these assets to strike targets to compel them to stop their behavior. Using HPMs to compel an enemy would most likely have to employ a risk strategy where the US slowly imposes costs against the adversary country.[41] The idea is that eventually, the cost will become too high, and the adversary country will change their behavior. HPMs can be used on the lower end of the ROMO to coerce the enemy, but they can coerce adversaries in high-end conflicts.

HPMs can also deliver coercive effects while engaged in operations on the opposite end conflict continuum. If the US were to go to war with a near-peer, China, or Russia, these weapons could strike countervalue targets. In this type of conflict, HPMs could use all four of Pape's strategies: punishment, risk, decapitation, and denial to coerce the enemy.[42] Punishment would come in the form of attacking the critical infrastructure of a nation to attempt to get the people to revolt against their leadership, forcing them to terminate the war. As mentioned earlier, the bombing campaign in Tokyo was a punishment campaign that did not yield the intended results. Risk would look very similar as it does in the previous paragraph, attempting to raise the cost, so the country abandons its efforts. Decapitation would be severing communication nodes in a country. Doing this would be extremely useful in hieratical nations where lower echelons cannot act without leadership direction. Destroying electrical components in command and control nodes would limit communications in the country and affect their ability to conduct operations. A denial strategy for HPMS would look at conducting strikes against targets that preventing the country from defending itself. HPMs can dismantle these targets sets in several ways, from striking strategic surface-to-air missile systems to shutting down command and control nodes. Striking these nodes would affect the ability of the country to collectively defend the nation, making it easier for other conventional assets to strike the country. All 4 of these coercive strategies are ways to change an adversary behavior making conditions more favorable for the US.

HPMs provide the US with options to affect the behavior of adversary nations across the ROMO and continuum of conflict. These weapons have to perceived as a capable threat by adversary countries, or they will not have the ability to alter their behavior. Establishing credibility will come from continued testing and demonstrations as well as achieving political

support. HPMs employed using Pape's coercive airpower strategies will have the ability to deter or compel the adversary. Coercive instruments, like HPMs, can deliver effects before or during conflicts below the threshold of war or during the war itself. HPMs add to the plethora of weapons and options the US has should it need to engage in military action to coerce an enemy.

HPM Countervalue Targeting

Introducing HPMs into the operational inventory on several different platforms provides new and innovative ways of delivering non-kinetic effects on targets of value. Civilians and AF leaders will have to change how they look at problem sets. HPMs provide a unique opportunity to adjust how the US prosecutes targets. There is going to need to be a shift in thinking from "counterforce to countervalue."[43] Countervalue targeting was a strategy used by the US in the 1950s with nuclear weapons employment against the Soviet Union. The US countervalue doctrine involved targeting "the enemy's cities, destroying its civilian population and economic base."[44] Countervalue targeting with HPMs would not focus on destroying population centers or killing large amounts of civilians. It would focus on targeting the enemy's "national strength."[45] These targets could include command and control nodes, economic production, power plant control systems, and nuclear weapons facilities. These types of targets are at the center of a countries national power. Often, these targets are highly protected, but HPMs can get to these targets through both front and back doors. These doors are what link these facilities to the outside world. As conversations continue about how to employ HPMs properly, individuals need to be cautious when using countervalue terminology. Even though the concept is from nuclear weapons strategy, the effects will not be the same. The premise is to give leaders options to employ these weapons across the range of military operations. These weapon systems allow

the US to prosecute targets in retaliation for belligerent behavior to striking at the heart of a nation's military and economic strength.

Transitioning to a countervalue strategy for HPM employment provides the US with options to affect the potential adversary decision mechanisms. The US can now prosecute targets that have historically been off-limits because of collateral damage concerns. This approach is very similar to what Max Smeets proposes for offensive cyber operations. He is proposing that offensive cyber operations can successfully strike countervalue targets like critical infrastructure.[46] Critical infrastructure is at the heart of a nation's power, and delivering non-kinetic effects on them could affect an enemy's decision making. Degrading or destroying a nation's critical infrastructure could raise the cost of the conflict to a point where the adversary decides the pursuit of their objectives are not worth it. HPMs would use the same targeting strategy to gain a strategic advantage. Depending on the target and number of electrical components intended to be destroyed or degraded, achieving the desired effects could be achieved with one or more shots from the HPM.

Employing HPMs toward non-military targets could cause visceral reactions from some members of the US and the AF. These reactions may stem from the historical employment of airpower in World War II, where the US firebombed Tokyo in an attempt to coerce Japan into surrendering. In this bombing campaign, the US destroyed 16 square miles around the Japanese capital and killed somewhere between 80,000 and 130,000 Japanese.[47] The US claimed that the purpose of firebombing Tokyo was to destroy military targets. What many people around the World seen as punishment through a countervalue attack on the civilian populace. HPM attacks on critical infrastructure could have unintended consequences. These second- and third-order effects must be considered before launching a countervalue strike on critical infrastructure.

Considerations like this must be made and openly discussed to ensure it does not adversely affect the will of the American people.

Furthermore, HPMs allow combatant commanders to engage some of the most challenging problems sets the US faces today, HDBTs.[48] HDBTs are locations where countries store assets that are vitally important to their security. HPMs can get after these targets because they can gain access through "airshafts, power cabling, heating, ventilation, and air conditioning (HVAC) surface ducts and access architecture."[49] Not only are HPMs capable of entering through "back doors" as described above, but they can also enter through "front doors."[50] Front door targeting occurs when the indigenous antennas and receivers of a system become the point of entry for the microwave energy that will affect the system controlling it. Having these capabilities is what provides the flexibility to the commander. It also allows the commander to take actions against another country, overtly or covertly depending on what message the US is trying to send. HPMs should not replace conventional weapons but act as a force multiplier giving commanders and politicians options to combat threats to US national security using a countervalue strategy.

Conclusion

HPM technology, while not new, is a revolutionary technology that will provide the US unique capabilities. HPMs are the type of technology that the US will need to maintain its competitive advantage of its adversaries. This technology has been in a perpetual state of evolution and has seen significant advances in capability. HPM weapons come in two types, continuous-wave and pulsed-wave, and each provides unique capabilities. This study focused on how the US could take pulsed-wave HPMs from the laboratory setting and operationalizing them to prepare for tomorrow's fight. Employing these types of weapons systems will require some

changes to how intelligence professionals support the platforms to how the US conducts targeting. This study proposes that HPMs can be used to strike countervalue targets that will affect the adversaries' decision calculus. Having the ability to hold these types of targets at risk or conducting strikes against them provides the US with a new tool to coerce potential adversaries. HPM weapon systems should not replace any weapon or electronic warfare system. These systems provide alternative options when and if the US decides it needs to use the military instrument of power.

[1] Mac Thornberry, "Text - H.R.2810 - 115th Congress (2017-2018): National Defense Authorization Act for Fiscal Year 2018," webpage, (December 12, 2017), doi:/bill/115th-congress/house-bill/2810/text.
[2] Dr. Julie Lawrance, "High Power Electromagnetics Core Technical Competency Overview" (Kirtland AFB, NM, October 30, 2019).
[3] United States Air Force, "Air Force Directed Energy Weapon Flight Plan" (USAF, May 2017).
[4] Dr. Julie Lawrance, "High Power Electromagnetics Core Technical Competency Overview."
[5] Dr. Kelly Hammet, "Directed Energy Directorate," August 14, 2019.
[6] John P. Geis II, "Directed Energy Weapons on the Battlefield: A New Vision for 2025" (Center for Strategy and Technology, April 2003), https://pdfs.semanticscholar.org/ee49/5858df34ac957db318f06144beb55df66a31.pdf?_ga=2.214794519.1264551470.1576617461-1049598089.1576617461.
[7] John P. Geis II, "Directed Energy Weapons on the Battlefield: A New Vision for 2025" (Center for Strategy and Technology, April 2003), https://pdfs.semanticscholar.org/ee49/5858df34ac957db318f06144beb55df66a31.pdf?_ga=2.214794519.1264551470.1576617461-1049598089.1576617461.
[8] "Directed-Energy-Weapons," accessed December 19, 2019, https://www.lexingtoninstitute.org/wp-content/uploads/directed-energy-weapons.pdf.
[9] Ibid.
[10] Dr. Anil Kumar Maini, "Directed Energy Weapons: High-Power Microwaves," October 4, 2016, https://advance-lexis-com.aufric.idm.oclc.org/document/?pdmfid=1516831&crid=fc178cef-e5ef-4b29-b90a-712d9ade85de&pddocfullpath=%2Fshared%2Fdocument%2Fnews%2Furn%3AcontentItem%3A5KW1-TDF1-JB5M-W52W-00000-00&pddocid=urn%3AcontentItem%3A5KW1-TDF1-JB5M-W52W-00000-00&pdcontentcomponentid=390063&pdteaserkey=sr0&pditab=allpods&ecomp=sp79k&earg=sr0&prid=ddcef73e-2009-4c24-815b-c5b08580e1bc.
[11] John P. Geis II and Theodore C. Hailes, "Deterring Emergent Technologies," *Strategic Studies Quarterly* 10, no. 3 (Fall 2016): 47–73.
[12] Ibid.
[13] Ibid.
[14] Al Watters, *Aviation Week & Space Technology* 127, no. 23 (December 7, 1987), https://catless.ncl.ac.uk/Risks/6/01.
[15] "A Report on Non-Ionizing Radiation," *Microwave News*, February 1988; Sharon Weinberger, "High-Power Microwave Weapons Start to Look Like Dead-End," *Scientific American*, September 12, 2012, https://www.scientificamerican.com/article/high-power-microwave-weapons-start-to-look-like-dead-end/.
[16] "Non-Lethal Weapons Program > About > Frequently Asked Questions > Active Denial System FAQs," accessed April 13, 2020, https://jnlwp.defense.gov/About/Frequently-Asked-Questions/Active-Denial-System-FAQs/.
[17] Ibid.
[18] Noah Shachtman, "U.S. Testing Pain Ray in Afghanistan (Updated Again)," *Wired*, June 19, 2010, https://www.wired.com/2010/06/u-s-testing-pain-ray-in-afghanistan/.
[19] "Boeing: Boeing Awarded Contract to Develop Counter-Electronics HPM Aerial Demonstrator," *MediaRoom*, accessed December 22, 2019, https://boeing.mediaroom.com/2009-05-15-Boeing-Awarded-Contract-to-Develop-Counter-Electronics-HPM-Aerial-Demonstrator.
[20] Ibid.
[21] "High Powered Microwave Advanced Missile Project (CHAMP)," *Global Security.Org*, accessed December 21, 2019, https://www.globalsecurity.org/military/systems/munitions/champ.htm; Air Force Research Labratory, "AFRL Directed Energy Directorate," December 2016, http://www.kirtland.af.mil/AFRL_rd/index.asp.
[22] "Boeing: Boeing CHAMP Missile Completes 1st Flight Test," *MediaRoom*, accessed December 22, 2019, https://boeing.mediaroom.com/2011-09-22-Boeing-CHAMP-Missile-Completes-1st-Flight-Test.
[23] "Boeing: CHAMP - Lights Out," accessed December 22, 2019, https://www.boeing.com/features/2012/10/bds-champ-10-22-12.page; "Raytheon EMP Weapon Tested by Boeing, USAF Research Lab," *Military Embedded*

Systems, accessed December 22, 2019, http://mil-embedded.com/news/raytheon-emp-missile-tested-by-boeing-usaf-research-lab/.
[24] James Drew, "The U.S. Air Force Has a Computer-Killing Cruise Missile," *Medium*, April 1, 2015, https://medium.com/war-is-boring/the-u-s-air-force-has-a-computer-killing-cruise-missile-6a0bcf481ce1.
[25] "Raytheon EMP Weapon Tested by Boeing, USAF Research Lab."
[26] Mr Jack L Blackhurst, "Air Force Science and Technology Program," April 14, 2017, https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2017/science/Blackhurst.pdf.
[27] Dr. Julie Lawrance, "High Power Electromagnetics Core Technical Competency Overview" (Kirtland AFB, NM, October 30, 2019).
[28] Joseph Trevithick, "This Is What the US Air Force Wants You To Think Air Combat Will Look Like in 2030," *The Drive*, accessed December 22, 2019, https://www.thedrive.com/the-war-zone/19636/this-is-what-the-us-air-force-wants-you-to-think-air-combat-will-look-like-in-2030.
[29] "AGM-158 JASSM (Joint Air-to-Surface Standoff Missile)," *Airforce Technology*, accessed December 22, 2019, https://www.airforce-technology.com/projects/agm-158-jassm-standoff-missile/.
[30] Trevithick, "This Is What the US Air Force Wants You To Think Air Combat Will Look Like in 2030."
[31] Dr. Julie Lawrance, "High Power Electromagnetics Core Technical Competency Overview."
[32] "AFRL Showcases Game-Changing Technologies at DOD Lab Day," *Wright-Patterson AFB*, accessed April 15, 2020, http://www.wpafb.af.mil/News/Article-Display/Article/1190148/AFRL-showcases-game-changing-technologies-at-dod-lab-day.
[33] "Kratos XQ-58 Valkyrie (XQ-222) Unmanned Combat Aerial Vehicle (UCAV)," accessed April 15, 2020, https://www.militaryfactory.com/aircraft/detail.asp?aircraft_id=1755.
[34] "(SBIR) Navy - Compact Source for Focused and Tunable Narrowband Radio Frequency," accessed April 14, 2020, https://www.navysbir.com/n20_1/N201-010.htm.
[35] Joseph Trevithick, "This Containerized Launcher For The XQ-58A Valkyrie Combat Drone Could Be A Game Changer," *The Drive*, accessed April 14, 2020, https://www.thedrive.com/the-war-zone/30474/this-containerized-launcher-for-the-xq-58a-valkyrie-combat-drone-could-be-a-game-changer.
[36] Michael Green, Ernest Bower, and Center for Strategic and International Studies, *Asia-Pacific Rebalance 2025: Capabilities, Presence, and Partnerships : An Independent Review of U.S. Defense Strategy in the Asia-Pacific*, 2016, https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/160119_Green_AsiaPacificRebalance2025_Web_0.pdf, 121.
[37] Secretary of the Air Force, "Air Force Doctrine Annex 3-0: Operations and Planning" (Curtis E. Lemay Center, November 4, 2016), 1.
[38] Ibid.
[39] Michael Gerson, "Conventional Deterrence in the Second Nuclear Age" (Carlisle Barracks, Pa. : U.S. Army War College, Autumn 2009), 42.
[40] Benjamin Buch and Katherine Mitchell, "THE ACTIVE DENIAL SYSTEM: OBSTACLES AND PROMISE," n.d., 22.
[41] Robert A. Pape, *Bombing to Win: Air Power and Coercion in War* (Ithaca, N.Y: Cornell University Press, 1996), 19.
[42] Ibid.
[43] Dr. Julie Lawrance, "High Power Electromagnetics Core Technical Competency Overview."
[44] "Counterforce Doctrine | Nuclear Strategy," *Encyclopedia Britannica*, accessed April 18, 2020, https://www.britannica.com/topic/counterforce-doctrine.
[45] William A. Stewart, "Counterforce, Damage-Limiting, and Detterence" (RAND Corporation, July 1967), https://www.rand.org/pubs/papers/P3385.html.
[46] Max Smeets, "The Strategic Promise of Offensive Cyber Operations," *Strategic Studies Quarterly* 12, no. 3 (2018): 90–113.
[47] History com Editors, "Firebombing of Tokyo," *HISTORY*, accessed April 18, 2020, https://www.history.com/this-day-in-history/firebombing-of-tokyo.
[48] "High Powered Microwave Advanced Missile Project (CHAMP)."
[49] Russell J. Hart Jr., "DEFEATING HARD AND DEEPLY BURIED TARGETS IN 2035" (Air University (U.S.). Air War College., February 15, 2012), https://apps.dtic.mil/dtic/tr/fulltext/u2/1018630.pdf.
[50] John T Tatum, "HIGH-POWER RADIO FREQUENCY/MICROWAVE (HPM) DIRECTED-ENERGY WEAPONS (DEWs) AND THEIR EFFECTS," *DSIAC Journals* 4, no. 3 (Summer 2017): 22.