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ATTACKING THE UNITED STATES WITH UNMANNED AERIAL VEHICLE-BORNE RADIOLOGICAL WEAPONS IN 2035: FEASIBILITY AND DETERRENCE

by

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A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

17 February 2010

DISCLAIMER

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Biography

Mr. Mark Krause, National Geospatial-Intelligence Agency, is an imagery analyst with 24 years experience. His most recent assignment was as an imagery analyst at NGA-St Louis as the Unmanned Aerial Vehicle (UAV) Research & Development (R&D) Team Lead in the Office of Counter-Proliferation. At NGA he has worked as an imagery analysis instructor, and in positions as a senior imagery analyst specializing in air forces and R&D issues in Washington, DC. Prior to NGA, he was an imagery systems analyst with Hughes Aircraft Company assigned to the National Photographic Interpretation Center (NPIC) in Washington, DC. Mr. Krause was an active duty imagery intelligence officer in the USAF for seven years with assignments at Offutt AFB, NE, Osan AB, South Korea, and Washington, DC. He is currently an Air Force reservist. He has a B.A. in geography from the University of Wyoming.

Introduction

June 2035: the sky was clear and the ocean was calm. It was a perfect night to attack the United States. A fishing trawler rested peacefully on the smooth Atlantic Ocean about 150 miles due east of Washington DC. The trawler was not alone; a recreational craft was 50 yards off the trawler's starboard side. The trawler was devoid of a crew, which had left for the luxury craft about 15 minutes before. On board the trawler were two metal frames, one fore and one aft, each supporting a twin-boom unmanned aerial vehicle (UAV) with a 15 foot wingspan. The unmanned aerial vehicles were pre-programmed to fly to downtown Washington, DC whereupon a payload of radioactive material would be discharged via an explosion. Three more trawlers waited; one about 200 miles south of this one, one off the Gulf Coast and one off the Pacific Coast, each with similar unmanned aerial vehicles and payloads. All were ready to launch at the exact same time. At the planned time, a switch was toggled and the unmanned aerial vehicles rocketed from their launchers. The recreational boat pulled away. This was no suicide mission, and the crews would be available again if they could avoid capture.

The US is vulnerable to such an attack today. Delivering a radiological payload by unmanned aerial vehicle avoids smuggling the materials into the US, or relying on suicide tactics, saving experienced personnel to attack again at a later date.[1] In 2035, unmanned aerial vehicles are technologically advanced, reliable and plentiful. These unmanned aerial vehicles are available on the open market, and are not controlled because of their small size, limited range, and limited payload. The radioactive material is not controlled adequately, and is readily available. A large area antiaircraft defense probably is not available because of the expense. Antiaircraft point defenses are impractical because there are too many high value targets, such as large population centers and special-purpose facilities. If the payload was a nuclear weapon, then the damage potential would increase from possibly a few fatalities, millions of dollars in clean-up, and short-term psychological trauma on a national level to tens of thousands of fatalities, billions in clean-up, and severe psychological trauma on a national level.

This paper evaluates the possibility of a small non-state group attacking the US homeland with a nuclear-related payload on an unmanned aerial vehicle in 2035, and what the US can do to deter such an attack. Twenty-five years in the future, nuclear technology and unmanned flying technology are very familiar, and the equipment is easily managed by a small group. Launching unmanned aircraft from maritime platforms is not a new idea.[2] Also, using radiological materials in a bomb has been done before.[3]

A 2008 RAND study concluded that while using unmanned aerial vehicles as attack platforms may be "attractive" to some, "alternative attack modes are similar or even superior."[4] If alternative attack modes are superior because of limited exposure to unmanned aerial vehicle and nuclear technology due to current proliferation controls or the newness of the technology itself, then deterrence through denial may be working. However, unmanned aerial vehicles are being proliferated, nuclear energy is enjoying a renaissance, both technologies are being exposed to more people, and deterrence will only get harder in the future.

Unmanned Aerial Vehicles

There is a continuing debate about the differences between unmanned aerial vehicles and cruise missiles. The primary discriminators between cruise missiles and unmanned aerial vehicles are speed, flight profile, and payload. Typically, cruise missiles are warhead carrying, faster, one-way systems with a limited loitering capability[5] as compared to their unmanned aerial vehicle counterparts, which are payload diverse, slower, reusable, and loiter-capable.[6]

In 2035 unmanned aerial vehicles are ubiquitous. The unmanned aerial vehicle industry is projected to double in growth during 2007-2017 with most of the projected market in the military sector, and slight growth in the civilian market during the same timeframe.[7] One projection states that unmanned aerial vehicles could move from primarily military to civilian usage within 5-10 years, and routinely operate in commercial air space in the next 10-20 years.[8] The US Department of Defense projects unmanned aerial vehicle integration into national airspace by 2025.[9] Tactical unmanned aerial vehicles, like the ones in the scenario, will be available from a variety of companies worldwide.[10]

In 2035, the US, like most countries, has integrated civilian and military unmanned aerial vehicles into the national airspace, which has stimulated unmanned aerial vehicle usage and proliferation,[11] and spawned secondary unmanned aerial vehicle-related businesses such as flight training and maintenance. Users include all levels of government and the private sector, performing a wide range of activities such as surveying, agriculture, and law enforcement.[12] Also, there may be some private unmanned aerial vehicle hobbyist/enthusiasts in a small niche market. Unmanned aerial vehicles perform every mission that manned aircraft perform except passenger transport, and are viewed as cost/labor-saving machines.[13] Smaller unmanned aerial vehicles are not regulated by established counter-proliferation treaties such as the Missile Technology Control Regime (MTCR); they are excluded because of their short range, small size and payload.[14]

Unmanned aerial vehicles are simple to operate and maintain. To label them as “low tech” is an oversimplification; unmanned aerial vehicles have advanced technology albeit uncomplicated technology. For example, the flight control and navigation systems may be advanced in the same way an automobile GPS is advanced in design and concept, but easy to understand and operate. Many of these types of systems are modular, and can be plugged-in. The propeller-driven engines and composite airframes are also straight-forward in construction, and are easily repaired in field conditions. In addition, no special fuel is required.

Unmanned aerial vehicles can be customized to their purpose. The most expensive items on most unmanned aerial vehicles are the payloads and sensors. Preprogrammed unmanned aerial vehicles that are used as one-way weapons delivery platforms do not require sensors -- a big cost savings. Purchasing the unmanned aerial vehicles without sensors will not appear unusual because airframes and sensors can be, and are, regularly mixed and matched.

Many unmanned aerial vehicles can be flown from anywhere enabling a low-profile for the non-state group while flight training. Because many systems do not require a runway for take-off and landing, or any kind of human control if preprogrammed for flight, specialized flight facilities are unnecessary. Transport is easy because unmanned aerial vehicles can be broken down into components and placed into a container small enough and light enough for two or three people to handle without special equipment.

Tactical unmanned aerial vehicles are difficult to detect using radar because of their size and composite material construction. In addition, tactical unmanned aerial vehicles fly straight and level at low altitudes, between about 500-15,000 feet, and at low speeds, giving them flight characteristics which may be confused with birds. Because of their slow speeds, however, it takes these unmanned aerial vehicles a few hours to fly distances similar to those in the scenario, which increases the chances for detection and in-flight complications.

A "flying boat" unmanned aerial vehicle could be used instead of launching the unmanned aerial vehicles from a boat platform. The advantage is that only one boat would be needed to transport the flying boat unmanned aerial vehicles to the launch area. A getaway boat would be unnecessary. The main disadvantage is that the flying boat unmanned aerial vehicle may be part of a very small niche market, and therefore much easier to trace if purchased. This disadvantage is erased if an existing unmanned aerial vehicle model is modified, or the flying boat unmanned aerial vehicle is scratch-built. A flying boat unmanned aerial vehicle, called the Gull, was being developed in 2007 by a British company. Its size, endurance, and payload are comparable to the boat-launched unmanned aerial vehicles in the scenario.[15]

Weapons Payloads

The nuclear landscape of 2035 and the potential for acquiring a radiological payload depend in part on the number of nuclear-weapons states. The assumption made here is that the number of nuclear-weapons states has remained stagnant at ten (including Iran) for 20 years, because the international desire to get nuclear weapons has subsided. Should the number of nuclear-weapons states increase, the chances of getting materials and expertise to develop and use a radiological payload on an unmanned aerial vehicle probably also will increase. This is especially true if the states are either less politically stable, like Pakistan, or insular and self-deterministic, like Iran and North Korea.

In 2035, international demand for nuclear weapons may be flat, but nuclear power plant construction is booming as part of a worldwide effort to limit greenhouse gas emissions through alternative sources of electricity generation.[16] The increasing number of nuclear power plants increases the demand for nuclear fuel, thereby increasing the risk of nuclear materials falling into the wrong hands. Radioactive isotopes used for industrial and medical purposes are still widespread, however slightly better tracking procedures have been implemented after governments and manufacturers recognized the weapons potential for these materials at the turn of the century.[17] Also, equipment manufactured in the 1970s and 1980s, prior to tougher controls, has ceased to be a threat because their radioactive isotopes have exceeded their half-lives, decreasing their usefulness as a dangerous source of radiation.

The payload for a radiological-weaponized unmanned aerial vehicle would consist of either a nuclear warhead, manufactured by one of the nuclear-armed states or manufactured by the specific non-state group as an improvised nuclear device (IND), or a radiological dispersion device (RDD). Of the two, the nuclear weapon would cause, by far, the most destruction. Because of the size limitations on the delivery vehicle, the yield of the nuclear warhead probably would not exceed the low single-digit kiloton range.[18] Still, the detonation of an improvised nuclear device would produce a devastating explosion and radioactive fallout, which could last for years.[19] The amount of destruction is directly related to the target. Urban targets offer more destruction potential than do rural targets.

Radiological dispersion devices are known and feared more for their secondary and tertiary effects as weapons of "mass disruption." [20] A radiological dispersion device would cause less physical destruction, but "enormous psychological and economic impacts."[21] Technically, a radiological dispersion device is not a "nuclear weapon" because the radioactive material does not itself explode. Instead, the radioactive material is spread via an explosion, and becomes a hazard in the area in which it is located. Prolonged exposure to the material can be lethal or cause health problems later, depending on the nature of the material.[22] A radiological dispersion device may cause only a few casualties. However, because the public may not differentiate a radiological attack from a nuclear attack, the resultant confusion would threaten to overwhelm local, state and federal governments.[23] Also, casualties may not be immediately apparent because damage from exposure to these radioisotopes may take years to appear.[24]

Of the two nuclear payload options, using a state-manufactured nuclear warhead is the least likely option.[25] In 2035, nuclear arsenals for all the nuclear states probably will be secure through adequate storage and handling procedures, and individual warhead security measures based on the trend to seek more stringent safeguards.[26] Even if nuclear warheads had been obtained during the tumultuous times of the break-up of the Soviet Union, these warheads would be at least 50 years old by 2035, and probably wouldn't function as desired since they would have long exceeded their shelf-life.[27]

The second option for the non-state group is to build a nuclear warhead from scratch, which seems to be the option that national security experts believe to be the most likely.[28] The most important ingredient is plutonium or highly enriched uranium (HEU).[29] The general rule is the more enriched the uranium, the less needed to make a nuclear weapon.[30] Neither of the two available nuclear weapon designs are likely to fit onto an unmanned aerial vehicle comparable to the size used in the scenario; both designs would probably result in a warhead that was too bulky or too heavy. [31]

On the other hand, a radiological dispersion device is more flexible in design and can be sized to fit into the payload compartment of the unmanned delivery vehicle. No special configurations with relation to the explosives and the radiological material are necessary, and there is no minimum required amount of radiological material. In addition, building a radiological dispersion device is easier for a non-state group because the materials are readily accessible and the technology is known.[32]

The two types of radiological material most at risk for incorporation into a radiological dispersion device are spent nuclear fuel and other radioisotopes used in industry. Both types of radiological materials are abundant and not rigorously controlled.[33] In 2035, spent nuclear fuel quantities are probably growing because of the growth in the nuclear power industry. However, "because spent fuel tends to be highly radioactive, it provides a lethal barrier against acquisition by terrorists who do not have special protective handling equipment;" the quality that makes spent nuclear fuel desirable is the same quality that makes it deadly to handle. [34] Radioactive isotopes are easier to handle because they usually come in smaller protectively-sealed quantities or pre-molded forms.[35] Any of these radioisotopes would fit easily into a payload compartment, possibly with the radioactive shielding intact. While the shielding would protect the launch crew from prolonged radiation exposure, the radioactive shielding may also act as a blast shield, which would limit the spread of the radioisotope, and require more explosives to overcome the dampening effects of the shielding. Alternatively, the shielding could be removed, or the pre-molded radioisotope form placed inside the airframe minutes before launch, thereby limiting exposure to the launch crew and maximizing dispersal upon detonation of the payload.

In summary, the airframe size limits the type of nuclear-associated payload assuming that nuclear warheads are not smaller and lighter in 25 years. Based on availability, size, weight, and shape, the radiological dispersion device is a more likely payload than the nuclear weapon. The trade-off is in destructive potential. While the radiological dispersion device is a much less destructive weapon than an improvised nuclear device or nuclear warhead, it is still expensive to clean-up, and results in psychological damage. The psychological damage is increased with the realization that the population is at risk of further attacks, and the psychological damage is multiplied even more with each successful attack.[36]

Deterrence Strategy

In 2035, the United States can deter an airborne radiological through dissuasion, denial, or threat. Preparedness is critical for dissuasion.[37] If would-be attackers see the US as ready to respond in such a way that the effects of the attack are diminished, they may abandon their plans.[38] Denial offers the most effective deterrence. Stricter proliferation controls would limit distribution of critical materials.[39] Also, effective substitutes are available for some radiological materials, which decrease supply and potential misuse of these materials.[40] An active defense against unmanned airborne delivery vehicles may be too costly and unmanageable, but new technology available in 2035, such as directed energy, may provide a solution.[41] Finally, as a threat option, laws can be enacted, setting up the mechanisms to apprehend and punish perpetrators and their sponsors.

As the most likely attack modality, a radiological attack is attractive to non-state groups because the real damage occurs after the attack; widespread panic and costly clean-up.[42] Therefore, planning, exercising, and equipping for radiological disasters at all levels of government, and publicizing the fact, severely lessens an attack's outcome and consequences, possibly dissuading the attackers by forcing them to consider and select other alternatives.[43]

If the technology can be denied to the attacker, then the attack can't happen. The Missile Technology Control Regime, the Treaty on the Nonproliferation of Nuclear Weapons (NPT), and related programs for controlling radiological material proliferation are already in place. However, the attack scenario exploits the lower end of both sets of proliferation controls. The Missile Technology Control Regime does not adequately control smaller unmanned aerial vehicles[44] as emphasized by the growing unmanned aerial vehicle market.[45] The Treaty on the Nonproliferation of Nuclear Weapons does not control radioisotopes.

Based on the reasoning that the nuclear component is more destructive than the airborne platform component, more effort probably should be taken to strengthen the Treaty on the Nonproliferation of Nuclear Weapons-related controls. Radioisotope and other nuclear material production for military and civilian applications is a very limited field because of the specialized equipment required for production.[46] Radioactive materials can be controlled through closely monitoring all production facilities. Furthermore, steps have been taken to close the gap on accounting for disused or orphaned radioactive materials.[47] In addition, alternates to radiological materials have been found for some applications.[48] It is possible that by 2035 some radioisotopes will have disappeared from civilian use because of effective substitutes.[49] Regulation of radioisotopes "could contribute significantly to reducing the overall dangers posed by radioactive commercial sources." [50] However, not all nuclear-armed states have signed the Treaty on the Nonproliferation of Nuclear Weapons, and full participation would increase effectiveness.

Another aspect of denial is a viable anti-aircraft system. According to one estimate, "a limited defense [covering a large geographical area] against offshore cruise missiles would cost $30-$40 billion."[51] The same report documents other challenges such as persistent surveillance, communication between sensors and interceptors, enemy threat identification, and system redundancy.[52] In 2035, available technology might enable a practical defensive system. Stopping an unmanned aerial vehicle requires detection a few minutes after launch. As a maturing technology in 2035, directed energy weapons probably are the best single-system for defending against unmanned aerial delivery platforms.[53] The "fast-as-light" speed permits extra minutes for target identification, and fire control coordination as compared to a surface-to-air missile (SAM) system. However, the expense is probably a limiting factor. Smaller directed-energy or surface-to-air missile systems for defending specific targets would also work well, however placement at the right facility/city would be almost impossible without advanced warning.

In 2035, the groups that view the US as an adversary and have the capacity to attack the homeland using unmanned aerial vehicles with radiological payloads probably are varied in interests and goals, so it is impossible to determine specific threats to deter these groups. However, some threat actions are universal, such as establishing national and international laws that address procedures for handling attackers. One example is the International Convention for the Suppression of Acts of Nuclear Terrorism.[54] Though more effective as a state deterrent, these laws may serve notice to the hostile non-state group, hostile states, and states that knowingly or unknowingly permit nuclear terrorism activity.

Conclusion

Combining unmanned aerial vehicles and nuclear materials is an attractive possibility for any group wanting to attack the US homeland in the future. The airborne platform offers a greater chance for dispersal of the nuclear-related material over a wider area than a terrestrially-based timer-equipped device. Physical destruction is not dramatic. However, sanitizing the contaminated area is costly in time and resources. In addition, smuggling the materials into the country is unnecessary because the bomb is flown in. Moreover, using radiological material "taps into the public's nuclear fear." [55]

The technology for such an attack is well-established, widely understood, and easy to use. Most small groups would have the capability to employ one or several unmanned aerial vehicles as one-way bomb carriers. Depending on the size of the airframe, personnel requirements would be small. Two of three individuals could transport, assemble, arm and launch multiple unmanned aerial vehicles at one time. In 2035, purchasing an unmanned aerial vehicle system will be commonplace because of their widespread use throughout the world. Unmanned aerial vehicle system practice can be performed almost anywhere. Flight training is probably unnecessary for a one-way mission, but requires only a small open area to launch and recover the airframe, if desired. As for the weapons payload, if inadequately controlled, radiological materials will be available from a variety of sources. A radiological dispersal device is easy to construct, consisting of the radioactive material and an explosive to disperse the material.

In 2035, the United States is vulnerable to attack from a radiological dispersion device delivered by an unmanned aerial vehicle unless stricter controls are placed on the materials needed for such an attack. Unmanned aerial vehicle bombs do not pose a significant or recurring threat, and point- or large-area air defenses are very costly for such a small threat. The best defense is deterrence through denial in the form of proliferation controls, which have been, thus far, unevenly and selectively applied allowing the proliferation of unmanned aerial vehicles and nuclear-related materials. Some components of an unmanned aerial vehicle system, such as high-performance engines and autonomous flight control systems, can be regulated, but basic unmanned aerial vehicle systems are still available. No unmanned aerial vehicle-specific control mechanism exists. The Missile Technology Control Regime limits larger unmanned aerial vehicles, but was originally designed to limit ballistic missile proliferation. Radiological materials could be controlled more stringently at the source of production and in the specialized equipment in which they are used through established control methods like the Treaty on the Nonproliferation of Nuclear Weapons, or with a new radiological material-specific control. Ultimately, weak proliferation oversight will enable the attack scenario.

Endnotes

[1] Brain A. Jackson, David R. Frelinger, Michael J. Lostumbo, and Robert W. Button, *Evaluating Novel Threats to the Homeland: Unmanned Aerial Vehicles and Cruise Missiles*, RAND National Defense Research Institute (Santa Monica, CA: RAND, 2008), xv, http://www.rand.org.

[2] FDCH Congressional Testimony, "Dennis M. Gormley: Missile Technology Export Controls", in *Testimony to House Subcommittee on National Security, Emerging Threats, and International Relations Committee on House Government Reform*, Washington, DC: FDCH e-Media, Inc, 9 March 2004, 3. The 2002 National Intelligence Estimate on the ballistic missile threat mentions the possibility of launching a cruise missile from a shipping container still on-board the ship.

[3] Graham T. Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe,* (New York, NY: Henry Holt and Co., 2004), 31. Chechen separatists placed a package containing cesium-137 and dynamite in a Moscow city park in 1995 as a demonstration to the government.

[4] Jackson, Frelinger, Lostumbo, and Button, *Evaluating Novel Threats to the Homeland: Unmanned Aerial Vehicles and Cruise Missiles*, 3.

[5] *Dictionary of Military Terms*, *US Department of Defense,* (New York, NY: Skyhorse Publishing, Inc, 2009), 137. A cruise missile is defined as a "guided missile, the major portion of whose flight path to its target is conducted at approximately constant velocity; depends on the dynamic reaction of air for lift and upon propulsion forces to balance drag."

[6] Ibid, 577. An unmanned aerial vehicle is "a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload." There is some overlap between UAVs and cruise missiles; a category known as "lethal UAV" is essentially a very slow cruise missile.

[7] Ian Kemp, "Soaring Growth: Industry Assesses TUAV Market", *Unmanned Vehicles* 13, no. 1 (February 2008): 13. The UAV industry is projected to double in growth from $3.4 billion spent worldwide in 2007 to $7.3 billion spent in 2017 with most of the projected market in the military sector, and slight growth in the civilian market from 13% in 2007 to 17% in 2017.

[8] David Vos, "Integrating UAVs into Commercial Air Space", *Unmanned Systems* 24, no. 5 (November/December 2006): 33. This projection is from a company specializing in UAV flight control and navigation systems.

[9] Department of Defense, *Airspace Integration Plan for Unmanned Aviation*, (Washington, DC: Office of the Secretary of Defense, November 2004), 49.

[10] Kemp, "Soaring Growth: Industry Assesses TUAV Market", *Unmanned Vehicles* 13, 13.

[11] Department of Defense, *Airspace Integration Plan for Unmanned Aviation*, (Washington, DC: Office of the Secretary of Defense, November 2004), 49.

[12] Jackson, Frelinger, Lostumbo, and Button, *Evaluating Novel Threats to the Homeland: Unmanned Aerial Vehicles and Cruise Missiles,* 3.

[13] Department of Defense, *Airspace Integration Plan for Unmanned Aviation*, 45. Japan has used rotary UAVs to spray and plow rice fields since the early 1990's to compensate for an aging farm labor force.

[14] Arms Control Association, *Missile Technology Control Regime (MTCR) Equipment and Technology Annex 11 June 1996*, http://www.armscontrol.org/documents/mtcr (accessed 23 November 2009).

[15] Peter Donaldson, "Unmanned Renaissance for the Flying Boat", *Unmanned Vehicles* 12, no. 7 (September 2007): 31-32. The Gull 24 is an amphibious UAV approximately 12 feet long with a wingspan of 13 feet. Operational range varied depending on the weight of the payload, and was anywhere from 100 nautical miles with a 22 kilogram payload and a three hour endurance to 600 nm with an eight kg payload and 12-hour endurance. The Gull featured folding wings for easier transport.

[16] Stephen M. Francis, "Diversion of Nuclear Materials for Terrorist Use", in *Terrorism and Weapons of Mass Destruction: Responding to the Challenge*, ed. Ian Bellany. (New York, NY: Routledge, 2007), 223.

[17] Greg Van Tuyle and James E. Doyle, "Radiological Dispersal Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, ed. James E. Doyle (Burlington, MA: Butterworth-Heinemann, 2008), 471.

[18] Graham T. Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe*, 49. Comparably sized systems include the US Davy Crockett tactical nuclear weapon with a 50 pound warhead and a 0.25 kiloton yield, and the Russian Navy's RA-115-01 with a 65 pound warhead and a 0.5-2 kiloton yield.

[19] US Government Accountability Office, *Highlights:Combating Nuclear Terrorism*, GAO-09-996T (Washington, DC: 14 September 2009), 1-2.
[20] US House. "Preventing Nuclear Terrorisim, in *Combating Terrorism: Preventing Nuclear Terrorism: Hearings before the Subcommittee on National Security Veterans Affairs and International Relations of the Committee on Government Reform,* 107th Cong., 2nd sess., 2002, 46.
[21] US Government Accountability Office, *Highlights:Combating Nuclear Terrorism*, 1.
[22] Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (Monterey, CA: Monterey Institute, 2004), 262. Some of the more common and dangerous radioisotopes include cobalt-60, cesium-137, iridium-192, strontium-90, americum-241, californium-252, plutonium-238, and in larger amounts radium-226.
[23] US Government Accountability Office, *Highlights: Combating Nuclear Terrorism,* 10. These governments may have response and recovery plans, but no experience in plan execution.
[24] Ian Bellany, "Material Dangers", in *Terrorism and Weapons of Mass Destruction: Responding to the Challenge*, 41.
[25] Charles D Ferguson and William C. Potter, "Nuclear Terrorism and Improvised Nuclear Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, ed. James E. Doyle (Burlington, MA: Butterworth-Heinemann, 2008), 433; and Stephen M. Francis, "Diversion of Nuclear Materials for Terrorist Use", in *Terrorism and Weapons of Mass Destruction: Responding to the Challenge*, 216. There is no evidence that nuclear weapons were ever available on the black market. Furthermore, no attempt has been made by a terrorist group to use a state-manufactured nuclear weapon thus far.
[26] Charles D Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism*, 61-63. China, India, and Pakistan reportedly have asked for, or received, help from the US and Russia for assistance in better security methods for their respective nuclear arsenals. Also, India, Israel, North Korea, and Pakistan probably have procedures in place to prevent unauthorized use of their nuclear weapons.
[27] Graham T. Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe,* (New York, NY: Henry Holt and Co., 2004), 89.
[28] Graham T. Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe,* 92; and Siegfried S. Hecker, Why We Need a Comprehensive Safeguards System to Keep Fissile Materials Out of the Hands of Terrorists, in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, ed. James E. Doyle (Burlington, MA: Butterworth-Heinemann, 2008), 405.
[29] Charles D Ferguson and William C. Potter, "Nuclear Terrorism and Improvised Nuclear Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, 435. By definition, "HEU refers to uranium that has been processed to increase the portion of one isotope of uranium, uranium-235, from the naturally occurring level of 0.7% to the highly enriched level of 20% or more, at which use for weapons becomes practicable."[29] Weapons grade uranium is at least 90% enriched.
[30] Ibid. The International Atomic Energy Agency (IAEA) states that at least 25 kilograms of HEU or 8 kilograms of plutonium are needed to achieve a nuclear explosion. By some estimates, these numbers have been characterized as "conservative".
[31] Charles D Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism*, 135. The two available weapon designs are: the gun-type, where one mass of HEU is shot down a tube to impact another mass of HEU which results in an explosion; or the implosion-type where a concentrated mass of HEU or plutonium is surrounded by explosives which are detonated at the same time to compact the mass of nuclear material, resulting in the desired effect. The gun-type is the simplest to build from a technical standpoint; the implosion-type would be a "daunting technical challenge."
[32] Charles D Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism*, 259.
[33] Charles D Ferguson and William C. Potter, "Nuclear Terrorism and Improvised Nuclear Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, 451; and Van Tuyle and Doyle, "Radiological Dispersal Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, 471.
[34] Charles D Ferguson and William C. Potter, "Nuclear Terrorism and Improvised Nuclear Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, 436.
[35] Theodore E. Liolios, *The Effects of using Cesium-137 Teletherapy Sources as a Radiological Weapon (Dirty Bomb),* Occasional Paper. Hellenic Arms Control Center (Thessaloniki, Greece: 2008), 5, http://www.armscontrol.info; and Charles D. Ferguson, Tahseen Kazi, and Judith Perera. *Commercial Radioactive Sources: Surveying the Security Risks*, Occasional Paper No. 11, Center for Nonproliferation Studies, Monterey Institute of International Studies, (Monterey, CA, January 2003), 30. For example, one of the worst radiological

materials disasters happened in Goiania, Brazil where a sealed canister containing 93 grams of Cesium-137 in salt form, was responsible for causing four deaths and millions of dollars in clean-up and lost revenue when the canister was compromised. Cobalt-60 used for industrial radiation may come in an 11mm diameter cylinder up to 450mm long, or 23mm diameter by 36mm long cylinders when used for medical radiography.

[36] Charles D Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism*, 330.

[37] US Government Accountability Office, *Highlights: Combating Nuclear Terrorism,* preface.

[38] Graham T. Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe,* 198.

[39] Dennis M. Gormley, "Globalization and WMD Proliferation Networks: The Case of Unmanned Air Vehicles as Terrorist Weapons", *Strategic Insights* V, no. 6 (July 2006): 5; and Siegfried S. Hecker, Why We Need a Comprehensive Safeguards System to Keep Fissile Materials Out of the Hands of Terrorists, in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, 414.

[40] Greg Van Tuyle and James E. Doyle, "Radiological Dispersal Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, ed. James E. Doyle. (Burlington, MA: Butterworth-Heinemann, 2008), 468.

[41] FDCH Congressional Testimony, "Dennis M. Gormley: Missile Technology Export Controls", in *Testimony to House Subcommittee on National Security, Emerging Threats, and International Relations Committee on House Government Reform,* Washington DC:FDCH e-media, Inc., 9 March 2004, 3.

[42] US House. "Preventing Nuclear Terrorism", in *Combating Terrorism: Preventing Nuclear Terrorism: Hearings before the Subcommittee on National Security Veterans Affairs and International Relations of the Committee on Government Reform*, 47.

[43] Charles D Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism*, 330-331.

[44] Dennis M. Gormley, *Testimony to House Subcommittee on National Security, Emerging Threats, and International Relations Committee on House Government Reform, Missilie Technology Export Controls*, 4.

[45] Ian Kemp, "Soaring Growth: Industry Assesses TUAV Market", *Unmanned Vehicles*, 13.

[46] Greg Van Tuyle and James E. Doyle, "Radiological Dispersal Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, 461. Specialized equipment includes nuclear reactors or particle accelerators and chemical processors.

[47] Ibid, 461-471.

[48] Ibid, 451. For example, replacing radiological material-dependent teletherapy machines used for cancer treatment with electron accelerators, which require no radiological materials.

[49] Greg Van Tuyle and James E. Doyle, "Radiological Dispersal Devices", in *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy*, 468-470.

[50] Charles D. Ferguson, Tahseen Kazi, and Judith Perera. *Commercial Radioactive Sources: Surveying the Security Risks*, 62.

[51] Dennis M. Gormley, *Testimony to House Subcommittee on National Security, Emerging Threats, and International Relations Committee on House Government Reform, Missilie Technology Export Controls*, (9 March 2004), 4.

[52] Ibid, 4.

[53] Air Force Research Laboratory Directed Energy Directorate, *Directorate Overview* (briefing, AFRL, Kirtland AFB, NM, 25 August 2009).

[54] US Senate, *International Convention for Suppression of Acts of Nuclear Terrorism*, 110th Cong., 1st sess., 2007, Treaty Doc. 110-4, VI. This treaty "provides a legal basis for international cooperation in the investigation, prosecution, and extradition of those who commit offenses involving radioactive material or a nuclear device."

[55] Charles D Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism*, 259.

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