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THE PERFECT STORM AHEAD?

AN EXPLORATION OF THE RISK OF NUCLEAR TERRORISM

By John R. Haines

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THE PERFECT STORM AHEAD?
AN EXPLORATION OF THE RISK OF NUCLEAR TERRORISM

By John R. Haines

> *"Today, the elements of a perfect storm are in place around the world: an ample supply of weapons-usable nuclear materials, an expansion of the technical know-how to build a crude nuclear bomb, and the determination of terrorists to do it. This should be a grave concern for all of us. Terrorists don't need to go where there is the most material; they are likely to go where the material is most vulnerable. That means the future of the nuclear enterprise, including the future of the nuclear power industry, requires that every link of the nuclear chain be secure—because the catastrophic use of atoms for terrorism will jeopardize the future of atoms for peace."*
>
> Senator Sam Nunn
> 11 November 2013

I. INTRODUCTION

The international community has for some time been alarmed by the prospect of a terror or criminal organization acquiring possession of fissile material with the intent to weaponize it in a nuclear explosive device.[1] A potential malefactor has two options for the acquisition of fissile material: first, to steal or divert the material from a state; or second, to manufacture the material. Of these, the former is considered more likely though the latter cannot, and should not be discounted.

For reasons explored later, it is more likely a terrorist or criminal organization would seek to move fissile material across transnational borders rather than attempt to transport a fully assembled nuclear explosive device, since the former is comparatively difficult to detect when properly shielded and concealed whereas the latter is susceptible to discovery. This being the case, nuclear smuggling more likely involves the movement of illicit fissile material than illicit nuclear explosive devices. Once illicit fissile material reaches its intended destination and is in a malefactor's possession, the malefactor can leverage its disruptive effect by means of an adequately supported claim simply to have such material in-country, without necessarily having taken the additional step to weaponize the selfsame material. However, fabricating an

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[1] An underappreciated variation with an argued comparable disruptive effect is where such an organization credibly claims to have acquired possession of fissile material, and its claim cannot be discredited or challenged with sufficient confidence.

actual explosive nuclear device[2] allows a malefactor to leverage both the disruptive and the destructive effects.

This paper explores the nature of weapons-usable fissile material; the several options by which a malefactor could gain possession of it; and the method and effect of weaponizing fissile material in an explosive nuclear device. That discussion is preamble to an exploration of the phenomenon of nuclear smuggling and detecting the movement of illicit fissile material for the purpose of interdiction.

II. FISSILE MATERIAL, MALEFACTORS, AND IMPROVISED NUCLEAR DEVICES

A Guide to Acronyms

HEU - high-enriched uranium
IND - improvised nuclear device
SNM - special nuclear material
VNSA - violent non-state actor

A. ***What Is Fissile Material?*** Fissile material is matter that can sustain an explosive fission chain reaction. Two types— high-enriched uranium, i.e. to at least 80% ^{235}U (HEU), and plutonium containing less than 80% ^{238}Pu— are distinguished as *Special Nuclear Material* (SNM) because they constitute the primary ingredients of nuclear explosives. The degree of complexity to fabricate a crude, relatively small-yield *Improvised Nuclear Device* (IND) is greater than the technical demands of making its conventional analogue, an *Improvised Explosive Device* (IED). This being said, however, obtaining a sufficient mass of SNM remains the only absolute barrier preventing a determined malefactor from building a gun-type IND since the relevant know-how has been in the public domain for several decades. As one team of analysis put it:

> "In the chain of causation, the most difficult challenge for a terrorist organization would most likely be obtaining the fissile material necessary to construct an IND. Terrorists could attempt to exploit many acquisition routes."[3] "Most physicists and nuclear weapons analysts have concluded that construction of a gun-type IND would pose few technological barriers to technically competent terrorists."[4]

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[2] Such a device is properly characterized as an *Improvised Nuclear Device* (IND) to distinguish it from a military-grade device. An IND is defined as an illicit nuclear weapon fabricated from illegally obtained fissile material. If it achieves nuclear yield, an IND will produce the same physical and medical effects as any other nuclear weapon explosion, though in all probability, at reduced scale. If it "fizzles" and fails to achieve nuclear yield, the result would most likely resemble a *Radiological Dispersal Device*, dispersing radioactive material locally. See: http://www.remm.nlm.gov/nuclearexplosion.htm#ref2

[3] Ferguson & Potter (2004), p. 8.

[4] Ibid., p. 12.

INDs release kinetic, thermal and ionizing radiation, making them far more lethal than conventional explosives of equivalent yield. They are far easier to build than military-grade nuclear weapons, and designed for delivery into populated areas by means of civilian transport modes, e.g., vessel, railcar or vehicle, that militaries are not deployed to defend.

B. ***Is the Distribution of Fissile Material Widespread?*** The good news is that by the end of 2011, twenty nations had eliminated all weapons-usable fissile material on their soil.[5] Hungary is the most recent to do so and the twelfth since 2009, returning (in its case, to Russia) a total of 190kg of HEU in a multi-year effort coordinated with Russia, the United States, and the International Atomic Energy Agency. Commenting on this event, U.S. Secretary of Energy Ernest Moniz stated:

> "We know that in the wrong hands, just small amounts of these materials could be used to create a weapon of mass destruction. This operation in Hungary and our ongoing partnerships with countries around the world help to ensure that terrorists never obtain a nuclear weapon."[6]

Less comforting are warnings like one Moldovan authorities issued in September 2011, *viz.*, that one Black Sea crime syndicate was believed to possess a 1kg (2.2 lbs.) quantity of ^{235}U. The material was purportedly secreted outside Moldova and offered for sale to "non-Western buyers."[7] Moldovan officials subsequently issued an alert for one suspect, a prospective buyer identified only as "a resident of a country of North Africa." Fifteen months earlier, Moldovan officials arrested six persons claiming to posses a 9kg quantity of ^{235}U for which they sought USD30 Million. They possessed at the time of their arrest a cylindrical lead vessel containing 4.4g of ^{235}U-enriched uranium oxide, which experts believed was a sample of a larger quantity enriched in Russia, and transited by air to Transnistria and thence on ground to Moldova.[8]

C. ***When Is Fissile Material Weapon-Usable?*** Weapon-usable fissile material can be either: (a) the element *uranium* with a fissile isotopic (^{233}U or ^{235}U) content of 20 percent or more; or (b) the element *plutonium* of any isotopic composition. Detecting the physical presence of this material is challenging because inherently low radiation emissions makes it easy to shield. The United States Nuclear Regulatory Commission uses a synonymous term, *Special Nuclear*

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[5] United States National Nuclear Security Administration, December 2011, cited in Bunn & Harrell (2012), p. 13.

[6] United States Department of Energy (2013).

[7] According to a Associated Press (2011) report, this quantity of ^{235}U is material was valued at the time at USD$20 million.

[8] United States Senate Foreign Relations Committee (2011). In August 2010, Moldovan officials interdicted a 7g quantity of ^{238}U, which though not fissile, can be used to create fissile plutonium. These seizures along with earlier ones in Rouse, Bulgaria (1999) and Paris, France (2001) shared similarities: all were represented as "samples" of a larger quantity; each used a similar container to hold the sample; and each used paraffin wax inside the container to shield the material from radiologic detection. Similar uses of sample-sized quantities occurred in Georgia in 2003, 2006 and 2010. Source: Nuclear Threat Initiative (2011).

Material,[9] the formula quantity (called *Category I*) of which is designated *Strategic Special Nuclear Material*.

Three types of weapon-usable fissile material are used most often in fission-based explosive nuclear devices:

- *High-enriched uranium*. HEU is bred by isotopically separating the only naturally occurring fissile isotope of uranium, ^{235}U, to increase its concentration in a mass of uranium to at least 20 weight-percent (the remainder being ^{238}U). The process of increasing the concentration of an isotope of a given element by means of gaseous diffusion or centrifugation is called *enrichment*. HEU in practice is the only weapons-usable form of ^{235}U, the Category I quantity of which is 5kg.[10] To reach the higher *weapons-grade*, HEU must be at least 80 weight-percent^{235}U, with ^{238}U comprising the remainder. [11]

- *Uranium-233*. ^{233}U is a man-made fissile isotope bred by means of neutron irradiating fertile[12] naturally occurring Thorium-232 (^{232}Th) then separating the produced ^{235}U from the irradiated target. While this production system generates nearly pure ^{233}U, the generally accepted[13] definition of weapons-usable[2] requires as little as 12 weight-percent ^{33}U, the remainder[14] being ^{238}U. The Category I quantity of ^{233}U is 2kg.

- *Weapon-grade plutonium*. Any mass of the element plutonium containing less than 80 weight-percent of the isotope ^{238}Pu and less than 10 weight-percent of the isotopes ^{241}Pu and ^{242}Pu is considered weapon-grade. The Category I quantity of plutonium is 2kg. Its most common form, the fissile isotope ^{239}Pu, is produced by means of neutron irradiating the fertile isotope ^{238}U in special purpose production reactors. Achieving weapon-grade requires a 93 weight-percent or greater concentration of ^{239}P, the remainder consisting of ^{240}P (itself a fissile isotope, but one that complicates weapons-physics because of its high rate of spontaneous fission).

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[9] *Special nuclear material* is defined by Title I of the Atomic Energy Act of 1954 [42 UNITED STATESC. § 2011 et seq.]. An analogous term used by the International Atomic Energy Agency, *special fissile material*, is based in the 1957 European Atomic Energy Community (EURATOM) treaty. Materials meeting the definition of SNM and/or SFM are of the quality used to make fission weapons.

[10] The distinction between high- and low-enriched uranium reflects considerations other than weapons-physics: it is possible to use low-enriched ^{235}U as a component in a fission weapon though impractical to do so because of its effect on a weapon's physical size, i.e., the lower the ^{235}U enrichment, the greater the quantity required.

[11] This is the minimum weight-percent for an improvised nuclear device. See footnote (30) in Pluta & Zimmerman (2006). The generally accepted minimum for non-IND explosive nuclear devices is 90 weight-percent.

[12] A *fertile isotope* is one that is not itself fissile but is converted into a fissile isotope, either directly or after a short decay process following neutron absorption.

[13] http://web.ornl.gov/~webworks/cpr/pres/105448.pdf

[14] Deplete uranium (DU), i.e., uranium greater than 99.3 weight percentage ^{238}U, is used to isotopically dilute ^{233}U, converting it into a non-weapons usable fissile material. Fosberg, et al. (1998), p. 2.

All three types are classified *Category I Strategic Special Nuclear Materials*, which means that "in specified forms and quantities, each can be used to construct an IND capable of producing a nuclear explosion."[15]

Most IND designs utilize HEU: ^{233}U is relatively difficult to produce and requires special techniques to control the radiation levels associated with impurities[16] from the production process; and the relatively high rate of spontaneous neutron emission by weapon-grade plutonium limits its use to an implosion-type[17] device, which minimizes pre-detonation risk but is relatively difficult to build.[18] While pre-detonation would limit explosive yield, fractional yield is not an absolute disqualifier since a plutonium-based IND could still be sufficiently destructive to achieve its intended purpose.[19] This is so especially where a violent non-state actor[20] (VNSA) seeks to leverage an IND's disruptive as much as its destructive effect.

D. ***How Might a VNSA Acquire Fissile Material?*** According to the United States Department of Defense, "90 percent of the overall difficulty in making a nuclear weapon lies in the production of special nuclear material."[21] If acquiring fissile material is the principal rate-limiting factor to fabricating an IND, how might a VNSA come into possession of it? There are three options:

- Transfers (covert or overt) from a proliferator-state.
- Theft or diversion.
- Direct manufacture.

There is abundant open-source discussion about the risk of state-proliferation, so that option requires no further exploration here. Consider, then, the remaining pathways to acquiring fissile material of theft or diversion, and the direct manufacturing of fissile material for use in an IND.

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[15] United States Government Accountability Office (2007).

[16] Contaminant ^{232}U has a decay chain producing penetrating gamma radiation that increase in intensity for about a decade after the uranium is synthesized, at levels sufficient to become hazardous. See Kemp (2005), p. 185.

[17] An implosion-type nuclear weapon is a device in which high explosive surrounding a subcritical configuration of fissile material compresses the material into a condition of super-criticality to produce an explosion.

[18] Kemp, p. 184.

[19] Similarly, where ^{233}U is generated (rather than theft or diversion) by or on behalf of a malefactor, the co-generation of highly radioactive ^{232}U during the production process "is not considered an adequate barrier to prevent a terrorist from making an improvised nuclear device." See: Alvarez (2013), p. 58.

[20] Though varied by type, all violent non-state actors exhibit three shared qualities: (1) *Autonomy,* or distance from the state and the international state system; (2) *Representation,* or a common identity through which it retains members and regenerates by attracting new ones; and (3) *Influence,* or the capacity and capability to exert policy change on the international environment through "agile stateless and resourceful networks" [Moses (2003), p. 29)]. VNSAs include such actors as insurgents and other domestic militant groups; warlords, urban gangs and private militias; and terrorist and criminal organizations. See: Aydinli (2013).

[21] United States Department of Defense (1998), p. II-5-60.

1. *Theft or Diversion.* The obvious pathway to acquire fissile material illicitly is to divert it from a state that fails to protect its stockpile adequately.[22] This includes: (a) theft of fissile material from the state that manufactured it; (b) diverting fissile material in transit from the manufacturing-state to a recipient-state; or (c) theft from a recipient-state. Witting transfers by a state in possession of licit fissile material are less likely (though not inconceivable) given the likelihood of forceful retaliation against a proliferator if (or more realistically, when) the material is traced back to its program-of-origin.

There have been persistent attempts by VNSAs in the past two decades to acquire the ability to build INDs and other crude nuclear devices:

> “Their main constraint is expected to remain having access to sufficient nuclear explosive material for a nuclear explosive or to a complete, operational nuclear weapon…Given the sheer quantity of such materials in the world and the inadequate controls over them in some countries, the constraint of lack of access is not strong enough to eliminate the possibility of a terrorist group acquiring enough fissile material for a nuclear explosive.[23]

Case in point, the Nuclear Threat Initiative reported in January 2014:

> "The security of Pakistan's fissile materials has been a leading security concern for the United States for some time. While outside experts believe it would be difficult for terrorists to seize an entire nuclear warhead, they say it would be easier for insiders working at one of Pakistan's many nuclear weapon sites to gradually smuggle out enough weapon-grade material to build a rudimentary atomic device."[24]

Defending fissile material from theft or diversion is complicated by the role of supply-side intermediaries[25] operating within so-called "nuclear smuggling chains," especially criminal

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[22] Ibid., 137.

[23] Albright, et al. (2013), p. 5.

[24] "Indian Terror Group Leader Reportedly Sought Nuclear Bomb." *Global Security Newswire*, 2 January 2014. http://www.nti.org/gsn/article/indian-terror-group-leader-reportedly-sought-nuclear-bomb/

[25] Zaitseva & Hand (2003), p. 827, define *intermediaries* as "individuals, groups, and organizations that find a potential buyer for the stolen material, negotiate a deal (middlemen), and deliver it to the end-user (traffickers)." While "so far, there have been more small criminal groups involved in nuclear smuggling rather than large organized crime syndicates, " the authors write (p. 830):

> "Resourceful and powerful organized crime groups in Russia, Central Asia, the Caucasus, and Eastern and Southern Europe have established smoothly running mechanisms for smuggling drugs and weapons that could be easily adapted to nuclear material trafficking…Networks trafficking in drugs, weapons, and other illicit commodities are well suited for nuclear smuggling. Their experience in avoiding detection, knowledge of safe routes, protection by

organizations with expertise in the transnational movement of contraband. The World Customs Organization noted a decade and a half ago a "shift from individuals to organized crime, and also an increasing number of cases in which scientists are involved."[26] Nevertheless, while "suppliers and traffickers may divert or acquire material based on a real or perceived market demand, ultimately the concern and threat lies in the end-user of the smuggled material.'[27] The term *end-users* includes terrorist organizations, criminal groups, and others seeking to engage in *nuclear malevolence*—the credibly threatened or actual use of INDs or non-weaponized fissile material in acts of physical destruction, blackmail, extortion, and deliberate exposures— to achieve some desired end.

The observable black market is (and has for some time been) supply-driven,[28] reflecting such factors as the presence of intermediaries that employ sophisticated smuggling schemes; states that possess loosely-guarded fissile material; overreliance on physical interdiction as a fail-safe measure[29]; and states concealing acts of illicit diversion of their fissile material. VNSA interest in acquiring weapons-usable fissile material implies a demand-driven market also may exists (or at least the conditions for one to emerge do) though it remains opaque.

2. *Spotlight: HEU Theft or Diversion from Research Reactors.* A *research reactor* is a nuclear reactor employed primarily for the generation and utilization of the neutron flux and ionizing radiation.[30] It is designed to achieve high performance in production of neutrons for research rather than the production of energy for electricity.[31] Typical research reactor fuel assemblies are plates or cylinders of uranium-aluminum alloy clad with pure aluminum. Only a few kilograms of uranium are needed, albeit more highly enriched than for a power reactor. Many research reactors through the late 1970s[32] used HEU (state-of-the-art ones used 93%-enriched fuel[33]) because it allowed more compact cores with high neutron fluxes and longer times between refueling.

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corrupt authorities, and established infrastructures can be utilized for trafficking in nuclear and other radioactive material."

[26] Ercan Saka of the World Customs Organization, quoted by Arieff (1998).

[27] Zaitseva & Hand (2003), p. 832.

[28] In this context, a *supply-driven market* means where someone diverts FM on h/his own initiative and offers it for sale to potential end-users rather than doing so as the agent of a given end-user. Zaitseva & Hand (2003), p. 840.

[29] "It is generally accepted that the security of radioactive materials has to be based on three components: (1) prevention of the loss of control of these materials, (2) detection of their loss of control; (3) response after the detection of any loss of control." Gayral, p. 273. *Interdiction* is one element of component (3.), post-loss response, though as the author cautions, "A universal solution does not exist to the problem of detecting radioactive materials that are no longer under control."

[30] IAEA (2005), fn(4) on p. 2.

[31] http://www.ansto.gov.au/AboutANSTO/WhatANSTOdoes/FAQ/OPALandresearchreactors/ Last accessed 16 January 2014.

[32] Since 1978 only one research reactor, the FRM-II at Garching, Germany, was built with HEU fuel. World Nuclear Association (2011).

[33] Ibid.

The use of HEU to fuel research reactors leads directly to a set of inevitable and obvious proliferation risks associated with diversion or theft.[34] The IAEA reported 245 research reactors in operation worldwide, 86 in developing countries and 159 in developed countries.[35] Of these, 135 are HEU-fueled (almost all of United States or Soviet/Russian origin[36]) accounting in aggregate for some 18 tons of HEU.[37] Particularly problematic as a proliferation risk are the ca.120 HEU-fueled research reactors located in universities and other academic centers. These reactors:

> "[A]re in a number of cases much less well protected [than military storage sites]. Some are badly in need of better security than a chain-lock at the gates and a single night watchman on duty. There have been some twenty known cases of theft of plutonium and highly enriched uranium since 1990 and many more of other radioactive materials."[38]

Two types of research reactor, *critical assemblies* and *pulse*, contain large quantities of HEU but do not consume HEU fuel. Their use has long been rendered obsolete by inexpensive and highly accurate computer simulations.[39] Russia's profile here is even greater, accounting for two-thirds of critical assemblies and pulse reactors worldwide.[40]

The IAEA estimates 20,723 research reactor HEU fuel assemblies are distributed worldwide, the vast majority (>85%) supplied by the United States or Russia.[41] While most research

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[34] Glaser (2005), p. 1.

[35] http://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx

[36] Of these, about a third fulfill at least one of the following three conditions: (1) they are located within the United States; (2) they are of UNITED STATES origin but located outside the United States; and/or (3) they do not use UNITED STATES-supplied fuel. The remainder is Soviet or Russian origin. These data are accurate as of 2004, the most recent year for reliable open-source data are available.

[37] Russia operated the largest number of research reactors (60) that use HEU fuel or targets and over half that reactor-class' worldwide total, accounting for three-quarters of worldwide research reactor HEU (13.5 tons[37]). Cited in Bunn & Harrell (2012), p. 29.

[38] Schmidt & Spencer-Smith (2012), p. 117.

[39] http://www.armscontrol.org/act/2006_01-02/JANFEB-HEUFeature

[40] Data believed accurate as of December 2011. See Bunn & Harrell (2012), p. 27.

[41] The large number of HEU-fuel research reactors produced and supplied by the Soviet Union and, later, Russia, a particular proliferation concern. Ca. 2004, more than 20 research facilities in in 17 countries used Soviet/Russian- supplied HEU, including Belarus, Bulgaria, China, Czech Republic, Egypt, Germany, Hungary, Kazakhstan, Latvia, Libya, North Korea, Poland, Romania, Ukraine, Uzbekistan, Vietnam, and Yugoslavia. [Dedik (2003)] Of these, there were 14 operational reactors located in the Czech Republic, Germany, Hungary, Kazakhstan, Libya, North Korea, Poland, Ukraine, Uzbekistan, Vietnam, and Yugoslavia. Programs such as the UNITED STATES Department of Energy's *Reduced Enrichment for Research & Test Reactor*s are intended to convert, remove and/or protect vulnerable civilian radiological and nuclear material., especially by reducing the use of HEU fuel in research reactors by means of converting them to LEU fuel. Uranium fuel below 20% enrichment virtually eliminates the possibility that the material could be directly used for the construction of an IND. [Glaser, 18] Some 76 research reactors have been converted so far, 20 of which are located within the United States. Similar efforts are being pursued with respect to Russian-supplied research reactors. For example,

reactors contain less than 15 kg of weapons-grade HEU[42], all of this material is nevertheless weapons-usable (enriched ≥20% ^{235}U) and nearly half is weapons-grade (enriched ≥85% ^{235}U).[43] Assuming each fuel assembly contains 40g of ^{235}U, aggregate fuel assemblies worldwide contain some 384kg (847lbs.) of HEU, or 7.7 times one critical mass.

3. ***VNSA-Manufactured Fissile Material: Is it Plausible?*** The conventional response to this question has been to say that no, on balance, it is not plausible that a VNDA could manufacture weapon-usable fissile material in sufficient quantity, *viz.*:

> "Given [the] underlying physical realities, it is virtually inconceivable that a terrorist group would be able to produce separated plutonium or HEU on its own."[44]

However, this peremptory response fails to take full account of one key observation: a technologically unsophisticated malefactor need only succeed in producing a single crude IND, given which it has the option to choose technologies that may not scale well and/or may be considered too inefficient for large-scale production[45]

a. Manufacturing with Centrifuges. While it is generally accepted that terrorists "may be capable of building a limited number of low-end centrifuges…the production of enough weapon-grade uranium for one nuclear weapon would require a large number of centrifuges. As a result, this scenario is thought unlikely, unless a terrorist group can establish itself securely and safely for years inside a host state."[46] The unlikelihood that a VNSA would succeed in doing so reflects that the "detection of such a plant by the outside world would likely trigger an immediate military or other firm response aimed

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in July 2013, the United States and Russia assisted Vietnam to return (to Russia) nearly 16kg (35lbs.) of HEU from its Dalat Nuclear Research Institute. There are also efforts to convert Chinese-designed HEU reactors, two of which remain in operation in China, as well as a reactor each in Ghana, Nigeria, Iran, Pakistan and Syria. It is fair to note that efforts to recoup research reactor HEU have been executed unevenly: according to a Wikileaks cable dated 27 May 2009, an unknown quantity of HEU from a research reactor in Pakistan languished awaiting removal and disposal by the United States for three years because the Pakistan failed to conclude an agreement on the matter. Cited by Schmidt & Spencer-Smith (2012), p. 156.

[42] Bunn & Braun (2003), p. 717. The IAEA defines 25k) of ^{235}U (which amounts to about 28kg of HEU enriched to 90%) as the amount for which, taking into account unavoidable losses during fabrication, "the possibility of manufacturing a nuclear device cannot be excluded." There is no current comprehensive, authoritative inventory of civil HEU globally. http://www.nti.org/analysis/reports/civilian-heu-reduction-and-elimination/

[43] Excluding nuclear weapons states, there were research reactors with more than 20kg of 90% HEU content in Argentina, Belarus, Belgium, Germany, Italy, Japan, and Ukraine (2003). One research reactor in Belarus had more than 370kg of HEU, including enough enriched to 90% to make several bombs. Another in the Ukraine also contained large amounts of 90% HEU. In December 1999, a Russian inspection team determined that 2kg of 90% HEU was missing from the I.N. Vekua Physics & Technology Institute (located in Sukhumi, in the Abkhazia region of former Soviet Georgia) research reactor, amidst a period of Abkhazian-Georgian civil conflict.

[44] Bunn & Wier (2006), p. 137.

[45] Kemp (2005), p. 184.

[46] Albright, et al. (2013), pp. 28-29.

at immediately destroying the facility and the effort."[47] This pathway can therefore be discounted (though not fully dismissed) as a means to acquire fissile material.

b. ***Manufacturing with Particle Accelerators.*** A more intriguing question is whether a VNSA could manufacture fissile material using a machine know as a *particle accelerator*[48] that, as its name implies, accelerates elementary particles to extremely high energies. It has long been known that particle accelerators can be used to produce fissile material; that terrorists have not yet exploited this capacity may reflect the method's relative obscurity and/or the difficulty heretofore of acquiring appropriate accelerator technology.[49]

These considerations may be changing, however. A substantial body of literature serves to inform anyone seeking guidance on the method, and the last decade has seen many advances in the commercial availability of accelerators as well as the development of inexpensive, high-current accelerators for applications such as cancer therapy.[50] From this emerges a new, albeit minority perspective that particle accelerators *may* represent a plausible route to acquiring fissile material (though their benefits are situation-specific):

> "Considering then the ease with which these advanced accelerators can be acquired from foreign sources, the reduced reprocessing complexity afforded by non-multiplying transmuters, and the simplicity of constructing a ^{233}U gun-type weapon…[M]any of the natural barriers to proliferation can be lifted by employing particle accelerators, even for the most primitive of proliferators."[51]

While reprocessing is required to separate freshly produced fissile material from fertile material and waste products, the associated chemical processes are thoroughly described in the open literature and the requisite materials are available on the open market. Studies attempting to gauge the level at which reprocessing becomes a barrier have concluded that for even an entry-level proliferator, it is "a relatively simple process that might be operated by an adversarial group in a makeshift or temporary facility."[52] Similarly, for particle accelerators of the small size contemplated here, there

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[47] Ibid., 28.

[48] Machines that accelerate elementary particles over a long, straight line are called *linear accelerators*, and those that use powerful magnets to bend a particle's path into a circle are called *circular* accelerators or *cyclotrons*.

[49] Kemp, 186. This section draws heavily upon his arguments.

[50] Ibid., 186.

[51] Ibid., 201.

[52] Hinton, et al. (1996), pp. 4.3-4.9. Cited in Kemp, 197.

> is no publicly known detection method in use that is reliably immune to simple countermeasures.[53]

E. ***What Type of IND Might a VNSA Build?*** It is claimed that some critiques underrate the threat of nuclear terrorism by conflating (a) the technical barriers to manufacturing fissile material with (b) the lower barrier to fashioning an IND once one is in possession of fissile material of suitable type and quantity. Other critiques fail to distinguish adequately between building safe, reliable, and efficient military-grade nuclear weapons intended for delivery by a missile or fighter aircraft, and the far simpler task of making a single crude, unsafe, and unreliable IND— which after all, is a weapon of terror, not warfare— for delivery by boat, railcar motor vehicle, or human carrier.[54] The United States Department of Defense reflected on the question and concluded:

> "A terrorist with access to >50 kg of HEU would almost certainly opt for a gun-assembled weapon despite the inherent inefficiencies of such a device, both because of its simplicity and the perceived lack of a need to test a gun assembly. Building an effective gun assembly is certainly easier than demonstrating that a simple "implosion system" will actually work. The disadvantage of a gun design is that it needs significantly more fissile material than an efficient implosion device of similar yield. This may be important to a subnational group intending to explode a series of devices, but would be of much less importance if only one blast were contemplated..."
>
> "If the subnational group had only ^{239}Pu or needed to be economical with a limited supply of HEU, then it would likely turn to an implosion assembly. The simplest design of an implosion weapon places a solid plutonium (or HEU) pit at the center of a sphere, surrounded by a certain amount of tamper material such as ^{238}U, to be compressed by the large amount of high explosive filling the sphere..."
>
> "The technical problems confronting the designer of an implosion-assembled IND are relatively simple in comparison to obtaining special nuclear materials, particularly if the IND does not have to be very safe or predictable in yield."[55]

F. *Is a VNSA-Built IND Plausible?*

1. ***How Robust Are the Technical Barriers to Weaponization?*** There is no serious disagreement as to whether a crude explosive nuclear device lies within the capability of a motivated VNSA: the United States National Research Council concluded over a decade ago,

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[53] Kemp, p. 199.

[54] Bunn & Wier (2006), pp. 138-139.

[55] United States Defense Department (1998), p. II-5-61-2.

"crude weapons could be fabricated without state assistance."[56] So troubling as it may seem, the correct phrasing of the question is, "*How low are the barriers to weaponization*?" To this:

> "Congress's Office of Technology Assessment…concluded that an appropriate technical team for building an improvised nuclear device was two people, one of whom was a skilled machinist and the other a physicist. If the fissile fuel for the device is uranium enriched to 50% or more, this is a plausible, if stressing, scenario…The report concludes emphatically that low-technology devices can have militarily useful yields, and can reach into the several-kiloton region."[57]

2. ***Is a Small-Yield IND Destructive?*** Consider the detonation of a crude "fizzle" weapon— a very small-yield[58] IND in which a nuclear explosion takes place but the yield is sufficiently low that the resulting destruction and contamination is limited to an area of a few urban blocks.[59]

> "A bomb built by a terrorist need not be especially reliable, and it certainly need not be particularly predictable. Most importantly, it will be perceived as nuclear, and it will contaminate a very large area with radioactive fallout (some, of course, being the un-fissioned nuclear material itself)."[60]

A single critical mass[61] is not alone sufficient to cause an explosion since it does not cause

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[56] National Research Council (2002), p. 45.

[57] UNITED STATES Congress Office of Technology Assessment (1977), p. 140. Cited by Pluta & Zimmerman (2006), p. 61.

[58] *Explosive yield* is the amount of kinetic energy discharged when the weapon is detonated, expressed in terms of the equivalent mass of TNT.

[59] The scenario suggested here is one in which some of the material fissions, yielding an explosive energy of a few ton of TNT. See Joint Working Group (2008), p. 4. Another type of *fizzle* is a complete nuclear failure in which the chemical explosives of the device disperse radiological material in the vicinity of ground zero. Liolios (2002) offers a detailed examination of the two scenarios.

[60] Pluta & Zimmerman (2006), p. 61.

[61] The term *critical mass* means the minimum quantity of a given fissile material required to sustain a chain reaction. The exact mass varies with the particular fissile isotope present; its concentration and chemical form; and the material's geometrical arrangement. The bare-sphere (unreflected) critical mass of select fissile materials is shown in the table below:

Material	Bare critical sphere
^{235}U metal*	50 kg
^{239}Pu metal	
Weapon Grade (94 % ^{239}Pu alpha phase)	10 kg
Weapon Grade (94 % ^{239}Pu delta phase)	17 kg
Reactor Grade (65 % ^{239}Pu delta phase)	20 kg

fission multiplication. However, as little as 1.1 critical masses can produce an explosion in the 10T to 20T (0.01-0.02Kt) yield range. While the blast effect of a nuclear explosion in this range would be limited (though in an urban area, possibly quite destructive), intense radiation would be emitted: measured from burst point, a 20T fission explosion produces lethal 1350 REM to a radius of 300 meters, and highly dangerous 500 REM radiation out to 400 meters. By one authoritative estimate, "even a small nuclear detonation in an urban area could result in over one hundred thousand fatalities (and many more injured)."[62] Further sobering is the likely damage to critical infrastructure: a study of the effect of an IND detonation on the downtown Washington, D.C., electric power grid concluded that a total of five substations and greater than sixty miles of underground distribution would be damaged in a small-yield nuclear explosion, with an associated direct cost of USD$310 to USD$800 Million.[63]

3. ***Have Small-Yield Nuclear Explosive Devices Been Built?*** To contextualize the idea of an IND, consider the low-yield tactical fission weapons manufactured by the United States and the Soviet Union in the 1960s-1980s[64], starting with the United States' W-51/W-54 warhead. This class produced small but nonetheless powerful yields— 22T (0.022Kt) for the W-51 and 250T (0.22Kt) for the W-54. One version, designated the Mk-54, was configured as a projectile for the "Davy Crockett" M-388 recoilless rifle. Two variants of this very light and compact spherical implosion plutonium warhead produced yields of 10T (0.01Kt) and 20T (0.02Kt), respectively. The Mk-54 was sufficiently compact and lightweight[65] to allow its configuration as the backpack-carried Mk-54 SADM (for *Special Atomic Demolition Munition*). The lethality of the W-51/W-54 class should not be underrated: a simulated detonation of the 20T (0.02Kt) Mk-54 in President's Park, Washington D.C. (an area encompassing the White House) causes an estimated 3,830 fatalities plus an additional 3,070 injuries from blast, thermal radiation, and prompt gamma radiation as well as not-quantified fallout effects.[66]

Other Fissionable Materials:	
^{233}U	15 kg
^{237}Np	60 kg
^{241}Am	100 kg

Source: O'Neill (1997), p. 4

The critical mass of uranium increases sharply as enrichment decreases, with direct effect on the material's weapon-usability. Likewise, isotopic composition and the respective critical mass simultaneously affect other properties relevant to weapon-usability. See: Glaser (2005), p. 4.

[62] UNITED STATES Federal Emergency Management Agency (2008), p. NUC-6.

[63] Barrett (2013), p. 7.

[64] This subject is covered in Graham Allison's 2004 *Nuclear Terrorism: The Ultimate Preventable Catastrophe* (New York: Owl Books).

[65] The Mk-54 measured 11inches x 16 inches (28cm x 41cm) and weighed 51lbs. (23 kg).

[66] The simulator can be accessed at http://www.nuclearsecrecy.com/nukemap/

Another small-yield nuclear device is the W-79, a plutonium linear implosion artillery shell with an explosive yield of 100T-1.1Kt. One variant manufactured in the early 1980s, the W-82, is a very compact[67] lightweight airburst artillery shell generating up to a 2Kt yield blast. According to open-source literature, the smallest fission device developed and tested by the United States was the SWIFT, an ultra compact[68] plutonium linear implosion weapon[69] that generated a 190T (0.19Kt) yield blast when it was tested in May 1956.

4. ***Would an IND Detonation Cause Serious Harm?*** Even a very small yield IND can produce blast effects (ground shock, air blast, thermal radiation), external and penetrating radiation, and radiation contamination at levels sufficient to cause hundreds to thousands of casualties, and require a major response. These effects at different explosive yields are summarized in the table below.[70]

Table

IND Nuclear Explosive Effects as a Function of Yield:
Initial & Secondary Radiation and Ground Shock Effects[71]

	Radius for Indicated Effect (meters)			
IND Explosive Yield in tons of TNT equivalent (surface burst)[72]	500REM Prompt Gamma Radiation	Fallout from surface blast [500REM total dose]	Severe Blast Damage [10psi]	Moderate to Light Blast Damage (3psi)
1 ton	45	30-100	33	65
10 tons	100	100-300	71	140
100 tons	300	300-1,000	150	300
1 kiloton	680	1,000-3,000	330	650

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[67] The W-59 measured 6.1 inches x 34 inches (15.5cm x 86.3cm) and weighed 95lbs (43kg).

[68] SWIFT measured 5 inches by 24.5 inches (12.7x62cm) and weighed 96lbs. (43.5kg). The Soviet Union produced an even lighter "suitcase" device, the RA-155, weighing just 30kg and yielding 0.5Kt-2.0Kt

[69] SWIFT used using an explosive charge of OCTOL-76/24, a form of castable TNT-based binary explosive. OCTOL is a generic term used to describe mixtures of TNT and HMX (*High Melting eXplosive*). Gibbs & Popolato, eds. (1980), p. 61. While SWIFT was a boosted asymmetric warhead, when tested in May 1956, its yield was insufficient to ignite the fusion reaction and it failed to boost.

[70] Though its effect is not quantified here, thermal radiation produced by an IND could cause widespread fires if detonated in an urban area. Eden (2003).

[71] Ferguson & Potter (2004), p. 5.

[72] Compounding the challenge of mounting an effective public safety response is the observation that it might take longer to determine that a nuclear explosive device was used in the case of an IND that produced very little nuclear explosive yield (fizzle).

Beyond the immediate physical damage wrought by an IND detonation:

> "[T]he psychological, economic and sociological impacts of such an attack would be devastating. Unlike natural disasters, a nuclear attack may occur without warning, leaving little chance for preparation. An attack in an urban area would not only kill large numbers of people, it also could render the area virtually uninhabitable for a long period of time. Survivors may have to be relocated; hospitals and shelters would quickly become filled with displaced persons, many of them injured or suffering from radiation exposure. The trauma of such an attack would leave lasting psychological and emotional scars on the survivors. The clean up task would no doubt rival even the largest efforts undertaken following comparable natural disasters, such as hurricanes, and would require long-term commitments from local, state and federal relief programs."[73]

G. *The IND as a Weapon of Mass Disruption.*

1. *Terrorism-as-Disruption.* Terrorism is both an objective reality— the destruction it leaves behind is observable and quantifiable[74]— and a subjective interpretation— it is a social construct for acts to destabilize the state and/or to disrupt the social order.[75] A major component of any traumatic event is disruption of the experience of safety,[76] such that while the physical destruction wrought by an act of terrorism is geographically confined, the social disruption is more extensive. Indeed, it is argued, terrorism seeks explicitly to alter the behavior of a target population by surrounding the small zone of physical destruction with a much larger zone of fear and social disruption.[77]

2. *The Concept of "Nuclear Malevolence"*. The term *crisis* is defined elsewhere as:

> "Disruptions (or threats of disruption to be taken seriously) to the routines of at least two social institutions. In modern states, most frequent are crises related to the polity-economic nexus."[78]

The end-goal of *nuclear malevolence* is to provoke a crisis by means of marshaling the disruptive and destructive effects of fissile material as a threat- and violence-based

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[73] O'Neill (1997), p.6.

[74] Karaffa (2012).

[75] For example, Article 4 of the counterterrorism law approved by the Tunisian National Constituent Assembly in 2003 includes as *terrorism* "to disturb the public order" and "to sow terror amidst a population, with the design of influencing the policies of the state, to force it to do what it does not intend to do or to refrain from doing what it intends to do."

[76] Fullerton, et al. (2003), p. 4.

[77] Engel, et al. (2003), p. 287.

[78] Stallings (1997), p. 13.

communication process, with the intent of creating a crisis in order to achieve some set of political and/or social objectives.[79] The scale of nuclear malevolent acts includes:

- *Warnings*:
    - *Hoaxes*- dupes or tricks.
    - *Threats*- expressions of intent.

- *Thefts or Diversions* (of fissile material).

- *Employment*:
    - *Dispersal*- the deliberate release, or credibly threatened release, of radioactive fissile material into a public domain.
    - *Fabrication*- the use of fissile material to fashion an improvised nuclear device with which to endanger, or threaten to endanger, public safety.
    - *Deployment*- the detonation of an IND in a public domain.[80]

3. ***Social Disruption as a Target-Set.*** INDs have an inherent and obvious mass-effect potential as destructive weapons. They also have a sometimes underrated but nonetheless salient potential to cause widespread enduring socio-economic disruption. The impact of an IND in its *weapon of mass disruption* embodiment is a function of two factors, the *threshold of effect* and the *target-set to be influenced*, respectively.[81]

The first factor, *threshold of effect*, is the consequential tipping point where an IND detonation (or an open credible threat to do so) causes critical socio-economic disruption that does not trace directly to physical destruction caused by its detonation. What distinguishes INDs from their conventional counterparts, IEDs, is that INDs <u>always</u> cross the *threshold of effect* for criticality, while the latter may fail to do so even if the IED detonation causes physical damage. Public reaction to any malicious nuclear explosion ensures the disruptive effect exceeds the critical threshold: indeed, given its characteristically low explosive yield, an IND more often than not will have a far greater disruptive than destructive effect. INDs uniquely exert a super-critical disruptive effect even in the absence of a destructive one, i.e., where a credible malefactor threatens openly to detonate an IND in a public domain. This claimed absolute property of INDs— super-critical disruptive effect— goes to the root of why

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[79] The definition is the author's, who traces the concept traces to at least the early 1970s, *cf*. DeNike & Conrad (1974) and Taylor & Willrich (1974). As defined, *nuclear malevolence* is a variant of *terrorism*, a good working definition of which is "a doctrine about the presumed effectiveness of a special form or tactic of fear-generating, coercive political violence, and a conspiratorial practice of calculated, demonstrative, direct violent action without legal or moral restraints, targeting mainly civilians and non-combatants, performed for its propagandistic and psychological effects on various audiences and conflict parties." [Schmid (2012), p. 158]

[80] Adapted from Karber & Mengel (1977), p. 12.

[81] Bunker (2007), p. 41.

INDs are highly effective as weapons of terror despite having at most marginal utility as a weapon of warfare. It is the simple fact that an IND *is* a nuclear explosive device, not a conventional one, that makes the difference.

The second factor, *target-set to be influenced* for the disruptive effect, consists of social bonds and relationships—e.g., loss of confidence in governmental competency and heightened perceptions of insecurity by citizens who view themselves in imminent danger[82]— as well as economic targets— the interruption of ordinary commerce, financial market dislocations, and so on. The socio-economic disruption and physically destructive effects of an IND are additive, such that in its *disruptive* embodiment, an IND possesses two organic characteristics: first, inherent destructive potential (whether actualized or not) over an operational space; and second, socio-economic disruption whether the device is actually detonated or a credible malefactor openly threatens to do so.[83]

The near-impossibility of intentionally detecting the physical presence of concealed illicit fissile material in transit, as well as the straightforward pathway to weaponizing the material, serves to amplify an IND's disruptive effect, since civil authorities cannot with confidence disestablish a well-framed and detailed (i.e., what, where, how much) claim by a credible malefactor:

> "Unfortunately, even an IND that detonated with no yield or one that was never used but whose existence was disclosed could cause consequences of historic proportions, because terrorists could use the threat of a successful future nuclear detonation to blackmail target governments. Given the stakes, target-state leaders would be hard pressed not to give into the demands presented. Indeed, it is possible that a terrorist organization might be able to credibly threaten a nuclear detonation merely by demonstrating its possession of the requisite nuclear-weapon material, a possibility that underscores the critical importance of ensuring such fissile materials do not fall into the hands of such groups."[84]

4. ***Understanding Complex Adaptive Systems of Nuclear Malevolence.*** While *nuclear malevolence* is a *strategy* or an end, the asymmetric threat it presents is a *complex adaptive system*[85] or means to that end. A defining characteristic of *nuclear malevolence* is that it is a

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[82] Ibid., p. 44.

[83] Ibid.

[84] Ferguson & Potter (2004), p. 3. The *disruption* risk was raised a decade earlier by O'Neill (1997), p. 6.

[85] A *system* is a collection of interacting parts. A given system said to be *complex* if its interacting elements interact in a non-simple way, i.e., such that "the entire system exhibit[s] properties and behaviors that are different from those of the parts." [Jervis (1997), p. 6, in Lichtblau, et al. (2006), p. 12] A given system's degree of complexity is a function of the number of interacting entities.

complex adaptive system itself comprised of multiple, concatenated complex adaptive systems, e.g., global terror groups, transnational smuggling syndicates, and criminal patronage networks such as drug smugglers and organized crime.[86]

Two important conclusions derive from the claim that *nuclear malevolence* is a complex adaptive system: first, its total eradication is practically impossible; and second, taming strategies that selectively interfere with targets are likely to be more effective than all-out assaults on the entire network.[87] Here, *targets* are the complex elements of a system of nuclear malevolence, i.e., subsystems that perform specific functions required for the whole system to survive organizationally; and *survivability* is a function of subsystems' proper and aligned functioning.[88] The argument for applying analytic and simulation tools to complex adaptive systems of nuclear malevolence is to presage terrorist behavior that is both novel (and thus, most likely unpredictable) and amenable to detection in the physical world,"[89] both of which are conditions of *nuclear malevolence*.

5. ***Asymmetric Technologies Favor Malefactors.*** The asymmetry of simple technologies confers meaningful advantage to malefactors. For example, monitoring to detect

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Complex systems "are inherently non-linear, that is, characterized by extreme sensitivity to initial conditions, subject to abrupt changes in macro-level behavior, and inherently non-predictable." [Lichtblau, 12] They are *non-predictable* because "[t]here is little to no control— the collective action of the complex adaptive system is a result of a near infinite number of decisions made concurrently by the constituent agents from which it is comprised." [Langford (2012), p. 108]

Complicated behavior can, however, be analyzed to detect and map *emergent patterns*, i.e., non-predictable behavior patterns that emerge from the observation of multiple interacting agents operating in parallel, each following relatively simple rules of behavior. Care should thus be taken not to conflate *complex* and *chaotic*: a terrorist network can exhibit *dynamic complexity*, i.e., it changes according to nonlinear dynamics functions, without necessarily being chaotic, i.e., acts in a way that is deterministic yet not predictable. That *complex adaptive systems of nuclear malevolence* are not chaotic allows for taming counterterrorism (CT) strategies that selectively interfere with targets inside these systems. This being said, the optimal (from a violent non-state actor's perspective) complex adaptive system "exists on the edge of chaos." [Langford, 109-110]

Analogous to the use of INDs by *complex adaptive systems of nuclear malevolence*, Langford [109-110] cites the example of IED networks in Iraq and Afghanistan as "a complex adaptive system at the edge of chaos." Confronted by "a counter-system that was conventionally superior in almost every way," the IED networks evolved and adapted (i.e., it was non-deterministic) "at an ever increasing cycle that eventually generated a tempo superior to that of their adversary, resulting in a capability overmatch." Surely, the same pattern of evolution-and-adaptation would apply to *nuclear malevolenc*e.

CT's mission, once targeting priorities are clarified, is to inject non-linear complexity into the network in order to induce chaos and ‘entropy’. [Langford, 114] CT seeks to exploit the fact that terrorist networks are composed of a large number of nonlinearly interacting parts: sources of nonlinearity include feedback loops in the command & control chain, adaptation to CT actions, and elements of chance. [Ilachinsky, 7] It does so by first determining the set of relevant non-linearities, e.g., choke points, failure thresholds and second-order effects, and then creating these non-linearities internal to the network. [Langford, 117]

[86] Langford (2012), pp. 108-109.

[87] Ahmed, et al. (2008), p. 5.

[88] Adapted from Celebi, p. 9.

[89] The author applies this general observation about complex adaptive systems by Lichtblau, p. 16, to the specific case of *complex adaptive systems of nuclear malevolence.* As used here, *novel* means behavior that is unexpected and/or beyond that which is readily understood. Ibid.

the presence of concealed Special Nuclear Material requires extremely high sensitivities since the since the isotopes in question emit weak gamma signatures. These signatures are easily diminished or blocked altogether by the use of simple shielding techniques that do not themselves raise suspicion. Eliciting a detectable signature from such material requires the application of technically sophisticated, imperfect interrogation and detection techniques.[90] The challenge of detecting special nuclear material is compounded by a recent finding that at least one VNSA possesses "a particular container to put enriched uranium in as samples" that "block isotopes" in order to "get past [radiation] detectors." According to an unnamed security expert:

> "It's not wholly new technology but it has been tightly held…[T]he IAEA has at least one incident where this box evaded detection but then was found in a search. But there must be other intelligence that there are more containers out there."[91]

III. SOME CONCLUDING THOUGHTS

The potential for illicit Special Nuclear Material to move within normal land, sea, and air commerce is a significant ongoing national and international security concern. Indispensable and ubiquitous in international commerce, the modern intermodal container[92] is an ideal vector for the covert movement of illicit Special Nuclear Material. Then Commissioner of the United States Customs Service, Robert C. Bonner, called containers "the potential Trojan horse of the 21st century."[93] Such concerns are not new, however, but rather go back to the predawn of the atomic era: Albert Einstein wrote President Roosevelt on 2 August 1939 that, “A single bomb of this type, carried by boat or exploded in a port, might well destroy the whole port with some of the surrounding territory.”[94]

Technical means and systems are required to permit the routine, nonintrusive, nondestructive inspection of intermodal containers. Today’s detection architecture relies on fixed inspection portals at national borders and seaports; fixed radiation detectors positioned at traffic choke-

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[90] Schmitzer, C. (1998), p. 299.

[91] McElroy (2012).

[92] Intermodal freight containers are reusable transport and storage units used to move products and raw materials between locations. Intermodal containers can be transported by ships, semi-trailer trucks, and freight trains as part of a single journey, and often are transferred between modes several times before arriving at their ultimate destination. They have given rise to a multitude of specialized road and rail carriers, a fleet of some three thousand modular container vessels, and the emergence of a global network of over 430 highly automated port handling facilities. Organization for Economic Co-operation and Development, Directorate for Science, Technology and Industry. *Security in Maritime Transport: Risk Factors and Economic Impact*. July 2003. http://www.oecd.org/dataoecd/63/13/4375896.pdf Last accessed 21 March 2014.

[93] http://query.nytimes.com/gst/fullpage.html res=9B0DE0DD1339F936A15756C0A9639C8B63&sec=&spon=&pagewanted=all. Last accessed 1 August 2010.

[94] http://www.atomicarchive.com/Docs/Begin/Einstein.shtml. Last accessed 1 August 2010.

points within the national interior; and handheld detectors used by government agents or nuclear emergency search teams when specific intelligence is available. While the United States has invested heavily[95] in container security to address the inherent vulnerability of marine and land transportation modes, the predominant modes deployed so far consists of radiation monitors[96] installed at foreign ports of interest. While effective at detecting material that might be used in a "dirty bomb" Radiological Dispersal Device,[97] radiation monitors are not especially effective at detecting Special Nuclear Material, both because the emitted radiation signal is low and because the material is easily shielded to evade detection. However effective a detection architecture is, it is an error to assume that intermodal containers will be the sole, let alone, preferred, means by which a determined malefactor chooses to move illicit Special Nuclear Material. Accordingly, routine nonintrusive nondestructive inspection of intermodal containers is only an element, albeit a critical one, of a larger defense against this threat, which requires deployment of a far more robust, deep and dispersed detection matrix and interdiction capability than has been contemplated so far.

Going forward, the United States much develop a robust, field-deployable detection and interdiction architecture that measures up to the depth, complexity, and fluidity of the real-world threat-matrix associated with nuclear terrorism and the transnational movement of illicit fissile material. False confidence in "Maginot Line" type configurations risks potentially catastrophic failure. Accepting the constant that malefactors will persist in attempting to find ways to divert weapon-usable fissile material to illicit uses, the suggested emergence on the scene of (a) purpose-manufactured material for use in nuclear malevolence, and/or (b) proliferator-states knowingly or purposefully allowing material to be diverted to illicit uses, compounds the complexity and the magnitude of the threat of nuclear terrorism. As in life, to quote Mae West, "if you do it right, once is enough."

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[95] In FY 2006, $125 million or over half of DNDO's requested budget was proposed for next generation detection portals.

[96] As part of its Second Line of Defense Program, the United States Department of Energy targeted 330 high priority sites in Russia and 21 neighboring countries for nuclear detection equipment to be located at border crossings and high transit sites. After several years, however, the fraction of the identified set of priority border crossings that were provided with appropriate equipment and trained personnel was in the range of 25%. See: Matthew Bunn. *Securing the Bomb: The New Global Imperatives.* Nuclear Threat Initiative (May 2005) 45-46. http://www.nti.org/e_research/report_cnwmupdate2005.pdf Accessed 15 August 2010.

[97] An RDD combines conventional explosives with radioactive material to purposefully disseminate radioactive material without a nuclear detonation by producing radioactive and nonradioactive shrapnel and radioactive dust.

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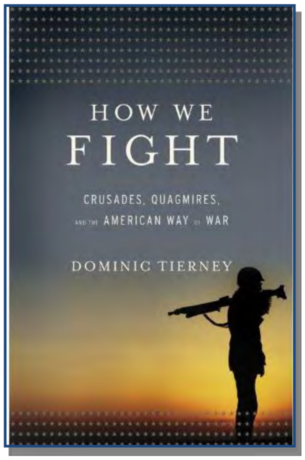

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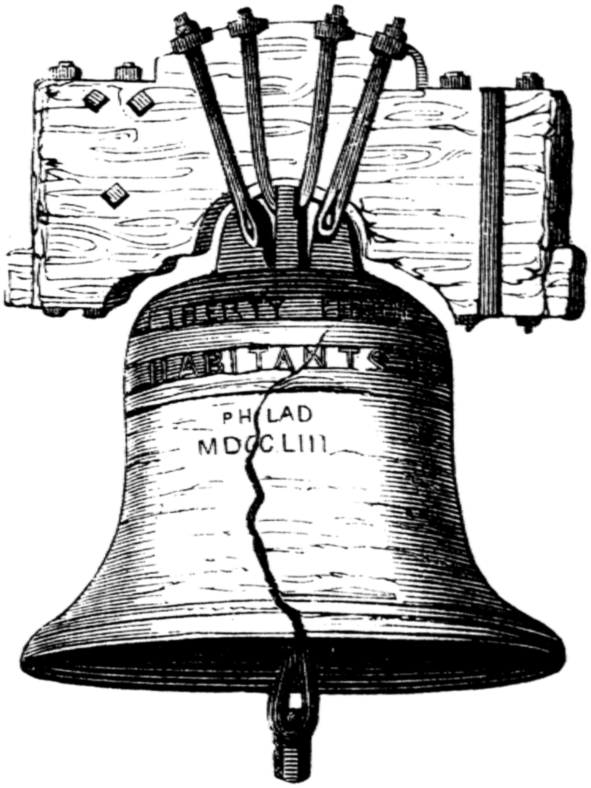

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