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"A nation must think before it acts." - Robert Strausz-Hupé

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"DIRTY BOMBS": REASON TO WORRY?

Explosive Radiological Dispersal Devices and the Distribution of Dangerous Radiological Material Worldwide

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"*Everybody is exposed to radiation.*
A little bit more or a little bit less is of no consequence."

-Dixie Lee Ray, Chair
US Atomic Energy Commission

"*Politics is more difficult than physics.*"

-Albert Einstein (1946)

A. INTRODUCTION

The recent report that the jihadist group *Islamic State of Iraq and the Levant* (ISIL) seized a quantity of heretofore unreported material from a university laboratory in Iraq sparked much commentary about the possibility of a malefactor fashioning and detonating a so-called "dirty bomb"—formally, an *explosive radiological dispersal device* or "Erdd." Knowledge of three recent incidents involving the theft or attempted theft of radiologic material in Mexico further amplified discussions about the risk that such material could be moved covertly into the United States and fashioned into an eRDD for detonation in a major American city. The purpose of this essay is to further explore recent incidents involving the theft or attempted theft of radiologic material, and to assess whether, and if so what, threat such material may pose.

B. DID ISIS SEIZE SADDAM-ERA RADIOLOGIC MATERIAL?

In early July the International Atomic Energy Agency disclosed that in June, militants linked to the group *Islamic State of Iraq and the Levant* (ISIL) seized a large quantity (88 lbs./40kg) of "uranium compounds" from Mosul University in northern Iraq.[1] The unspecified material was described by the IAEA as "low grade" nuclear material.

[1] It is therefore with no small sense of irony that on 7 July Iraq acceded to the United Nations *Convention on the Physical Protection*

There is informed speculation that the material originated from Iraq's former al-Jazirah conversion plant, which was located about 48km (30m) west of Mosul and 385km (240m) northwest of Baghdad. This conclusion is supported by, among other things, the large quantity of material ISIS reportedly seized. Prior to the 1990-1991 Gulf War, al-Jazirah was a uranium feedstock facility that produced "yellowcake," the solid form of mixed uranium oxides produced from uranium ore in the uranium recovery or "milling" process. Al-Jazirah sent its yellowcake to the nearby Jaber bin al-Hayyan facility for conversion into pure uranium hexafluoride (UF6). UF6 is used in gaseous diffusion or gas centrifuge enrichment processes to produce weapon-grade uranium-235. Al-Jazirah also produced uranium tetrachloride (UCl4), a feedstock in the electromagnetic isotope separation process of uranium enrichment. Pre-Gulf War, the Iraqi government planned to expand Al-Jazirah to allow on-site production of UF6 feedstock.

The likely source of the material ISIL seized from Mosul University is al-Jazirah's analytical laboratory, which may have transferred all or part of its inventory of samples from the conversion processes. It is known that some equipment and instrumentation from al-Jazirah was taken to Mosul University after 1991, and that Iraq failed to declare whatever material was transferred as required under its 1979 IAEA safeguards agreement.

The sample inventory may have been sizeable, and could have included reagents such as uranyl acetate (both radioactive and highly toxic if ingested, inhaled as dust, or by skin contact) as well as uranium oxide "yellowcake"; ammonium diuranate (an intermediate chemical form of uranium produced during yellowcake production); uranium trioxide (UO3) and dioxide (UO2); and possibly, gram-quantity samples of uranium tetrachloride.

C. RADIOLOGIC MATERIAL THEFT CLOSER TO HOME

In just the seven-month period from December 2013 through July 2014, there were three acknowledged incidents in Mexico involving the theft of radiologic material. The first occurred on 2 December 2013 when a vehicle transporting a decommissioned teletherapy[2] unit was stolen in Tepojaco, near Mexico City. According to Mexico's *Comisión Nacional de Seguridad Nuclear y Salvaguardia*s, the unit, formerly used for cancer treatment, was in transit from a hospital in Tijuana to a Mexican radioactive waste storage center some 1800 miles away. The teletherapy unit held a small capsule containing some 3000 curies of cobalt-60, a Category-1 radiation source. The International Atomic Energy Agency (IAEA) rates Category-1 as the most dangerous of the five categories it uses to rank radioactive materials.

The second incident occurred on 8 June 2014 in the city of Tultitlán, a municipality located in the northeastern part of the state of México, adjacent to the northern tip of the Distrito Federal and part of the Greater Mexico City urban area. A group of unidentified armed gunmen stormed a research building at Mexico's National Construction Laboratory and seized a device containing an unspecified quantity of cesium-37 and americium-241/beryllium (Am/Be). The material has not been recovered so far. Cesium-137 is a gamma radiation source with a 30-year half-life that is widely used in the construction industry for level, moisture, and thickness gauging applications. It is also used in oil exploration to characterize rock strata; and in pellet and seed form, in brachytherapy to treat certain cancers. Am/Be is used as a neutron-emitting source for industrial applications including oil well logging, material analysis, and thickness gauging. It has a 432-year half-life. These materials are usually contained in a sealed capsule, typically a small (7"x1") stainless steel cylinder.

The most recent incident occurred on 3 July 2014 and involved the theft of an unspecified quantity iridium-192 from a truck in Tlalnepantla de Baz, north of Mexico City. Iridium-192 is used as a gamma radiation source in industrial gauges that inspect welding seams, and in brachytherapy to treat certain cancers. Industrial gauges hold pencil-like metal sticks of solid iridium-192 or small stainless steel cylinders that contain iridium-192 pellets; iridium-192 in brachytherapy is in the form of small seeds, each about the size of a grain of rice. Iridium-192 has a 73.8-day half-life.

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of Nuclear Material.

[2] *Teletherapy* is the use of gamma radiation to treat diseases such as cancer. Also known as *external beam radiotherapy*, the modality uses ionizing radiation to control or kill malignant cells. The radiation source is the radionuclide cobalt-60 housed in a steel capsule within the unit.

D. EXPLOSIVE RADIOLOGICAL DISPERSAL DEVICES

For many years, the acronym *CBRN* has been shorthand for four classes of *toxic weapons*—chemical, biological, radiological, and nuclear. The etymology of the term is "firmly embedded with scale" in terms of the effect of these weapons on people and property. With the development of modern Type-E chemical high explosives,[3] the letter *e* has been appended to the acronym, now *CBRNe*. This makes an *explosive radiological dispersal device* or "eRDD" something of a hybrid as it combines *R* radiological material and *e* high explosives in a single device.

Sometimes called a *dirty bomb*, an eRDD is designed to cause the purposeful dissemination of radioactive material without a nuclear detonation.[4] It is important to understand what an RDD is not: it is not a nuclear device, that is, an eRDD releases energy from the detonation of a chemical explosive to disperse radioactive material, not from fission events, even if it contains fissile material.[5] Nor is an eRDD a military-type weapon; it is, rather, a coercive weapon with potentially potent social and psychological effects. While inhaling dispersed radioactive material does not necessarily lead to an acute radiation syndrome, the intent in detonating an eRDD is to cause panic as a result of radiation contamination as much as to cause acute physical injury.[6]

An eRDD can cause four types of damage: (1) *deterministic injuries* that are an immediate or near-immediate biological response to a known exposure,[7] e.g., radiation sickness or radiation burns, or from the blast effects of the explosion itself; (2) *stochastic injuries* which are a longer-term biological response (e.g., cancer) to a specific radiation dose; (3) *property damage* from the detonation's blast, shock and thermal effects; and (4) *contamination of buildings and property*. The precise types and extents of damage are contingent upon several factors: the radionuclide(s) released in the detonation; the amount of material released; the aerosol properties of the released particles; wind speed and wind direction at the blast site; and in an urban area, the location and size of buildings in the area. Somewhat counter-intuitively, a malefactor may purposely minimize the blast effect: the quantity of radioactive materials carried in a rising plume reaches the greatest values in a pinpoint explosion, which would maximum inhalation doses around the blast site.[8] This consideration may also steer a malefactor to detonate inside a building rather than outdoors.

While an eRDD is a *mass effect*[9] weapon, it is not a *weapon of mass destruction*[10] in any context other than a strict

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[3] High explosives are explosive materials that *detonate*, meaning the explosive shock front passes through the material at a supersonic speed.

[4] An RDD is one of three methods of exposing civilian populations to radioactive material. The other two are a *non-explosive RDD* (nRDD) or the dispersal of radioactive material by non-explosive means, such as food, water or air; and a *radiological exposure device* (RED), which is a passive device used to expose persons to a highly radioactive (usually gamma or neutron) source but that does not cause contamination.

[5] Uranium would have little physical effect if used in an eRDD. Technical experts rarely if ever consider uranium as a suitable eRDD material because the radiation emitted per gram is extremely small. Plutonium-238 might be used in an eRDD because of the biological hazards from inhaling alpha particles; however, a malefactor would likely find it easier to obtain other radionuclides. See: Medalia, p. 9.

[6] The radioactivity emitted by a radiological weapon is unlikely to present an acute health hazard: by some estimates, a person would have to spend 100 hours at an eRDD detonation site to have a 5% likelihood of developing symptoms of acute radiation sickness. This makes it practically impossible to accumulate a radiation dose high enough to suffer radiation sickness or death. See: Wirz & Egger (2005), pp. 505-506.

[7] It should be noted that a low radiation dose does not produce deterministic effects.

[8] Reshetin (2005).

[9] The United States Department of Homeland Security defines *weapons of mass effect* (WME) as "weapons capable of inflicting grave destructive, psychological and/or economic damage to the United States. These include chemical, biological, nuclear, radiological, or explosive weapons." See: USDHS (2006), p. 3. A WME has two key dimensions: first, the non-traditional or unconventional use of conventional means (here, high explosives); and second, mass effects, as measured separately or by the combination of a high number of fatalities in a rapid period of time, disabling or destruction of critical infrastructure, significant economic impact, and inducing high shock and awe as well as widespread panic and disruption. See: Defense Threat Reduction Agency (2008), p. [1-1] 2.

[10] WMD are defined in 18 United States Code §2332a as:

> "(A) any destructive device as defined in section 921 of this title (i.e. explosive device);
> (B) any weapon that is designed or intended to cause death or serious bodily injury through the release, dissemination, or impact of toxic or poisonous chemicals, or their precursors;

legal one. The intent of an eRDD detonation is to leverage the disruptive effect of social reaction to the dispersion of radioactive material in a local area. This has been described, somewhat sophistically, as "misplaced panic"[11] from an "irrational public fear of radiation." Here, *irrational* is meant to convey a degree of "fear, panic and social disruption" that is disproportionate to the (usually small) number of deterministic and (again, usually small) stochastic injuries.[12] This may well be so; however, it fails to take full measure that fear is irrational only when one is in full possession of the relevant facts. Even among the stoic, some element of "fear and panic" is likely in the period between an eRDD detonation, and the point when civil authorities can identify and contain the source of radioactivity. Moreover, the likely economic disruption from a well-placed eRDD detonation would be highly consequential. Contamination in the detonation's aftermath could prevent the use of critical economic assets, e.g., a seaport, building and/or subway line, for an extended period of time.

As one analyst noted, "Removal of urban radioactive contamination has never been performed on a large scale because no one has ever had to deal with the consequences of a radiological attack."[13] The intentional release of a relatively small amount of radioactive material using a conventional explosive has the potential to cause radiation exposure, but the spatial extent of the area within which high exposures might occur is minimal. The extent and degree of radiation contamination will be dependent on particle size, the height of release and local weather conditions, among other factors.

That being said, some analysts see the eRDD threat as more theoretical than real, in that no acknowledged incident has occurred so far in which an eRDD was successfully detonated. The reasons for this are speculative, but may include difficulties in handling radioactive material; lack of sufficient expertise to fabricate it into an effective weapon; a shift to simpler attacks using standard weapons and explosives; and improved security.[14] There is no particular reason to think that past is prologue, however, given demonstrable interest in mass effect weapons among malevolent, and increasingly, transnational actors.

While not impossible, it is unlikely that even a capable malefactor would attempt to manufacture sufficient quantities of a radionuclide, nor would it make sense to do so given ample opportunity for the theft, purchase, or transfer of material from a sympathetic party. The IAEA annually summarizes incidents reported to it voluntarily by participating states. During calendar year 2013, 5 incidents were reported involving IAEA Category 1-3 sealed radioactive sources, 4 of which were theft. An additional 1461 incidents were also reported, 6 involving possession and related criminal activities; 47 involving theft or loss; and 95 involving other unauthorized activities.[15]

E. THE EFFECT ON HUMANS OF RADIATION FROM AN ERDD DETONATION

When explosives are combined with radioactive material and detonated, the result is radioactive and nonradioactive shrapnel, and a radioactive plume. The plume is an aerosol of fine particles of radioactive material, the size of which will influence how far they are carried by the wind and how easily people inhale them. *Ground shine* is the deposit of radioactive aerosols out of the plume downwind from the detonation. *Cloud shine* is the passage of the radioactive plume, during which there is an external gamma hazard as well as an acute inhalation hazard due to the aerosol concentration of alpha- and beta-radiating particles. Radioactive particles may also be carried away on people's clothes, and spread by vehicles, e.g., ambulances and other first-responders, that pass through a contaminated area.[16]

The dispersed radioactive material causes *radiological contamination*—the physical distribution of radioactive material over a localized area—and *radiation exposure*—the irradiation of persons exposed to the blast or to radiological contamination[17]—in the affected geographic area, both of which result from the explosive ejection of

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(C) any weapon involving a biological agent, toxin, or vector (as those terms are defined in section 178 of this title)(D) any weapon that is designed to release radiation or radioactivity at a level dangerous to human life."

[11] Muller (2004).

[12] For example, see: Barnaby (2005), p. 5.

[13] Levi & Kelly (2002), p. 80.

[14] Medalia (2011), p. 2.

[15] http://www-ns.iaea.org/security/itdb.asp. Last accessed 23 July 2014.

[16] Pellérdi & Grósz (2007), p. 203.

[17] Inhaling radioactive aerosols results in internal irradiation. Contamination can spread through means that are obvious, e.g., wind, and less obvious, e.g., moving injured persons to hospitals.

radioactive material. Radiological contamination can be either *fixed contamination* that strongly adheres to a surface; or *loose contamination* deposited on a surface that is relatively easy to remove. The adherence of loose contamination is increased by the presence of oily films, grease, grime, and/or chemical vapors of the types found, for example, inside air ducts. Since ventilation systems usually operate at negative pressures, they tend to draw in dust and aerosols, including material that is radioactive.[18]

Radiation exposure can be external (skin surface) and/or internal (inhalation, ingestion, and wound contamination[19]). Inhalation is the primary route of exposure for internalized radionuclides, the end result of which depends on the size of the inhaled particles and the solubility of the radionuclide. About one-quarter of inhaled particles are immediately exhaled. Of the remainder, those less than 5μm in diameter can reach the alveolar space while particles greater than 10μm tend to remain in the upper areas of the lung.[20] Once in the lung, the particle's solubility becomes important: rapidly soluble radionuclides such as cesium-137 will enter the circulatory system, while less soluble radionuclides such as cobalt-60 will remain in the lung and irradiate the surrounding tissue until eventually removed by phagocytosis. Inhaled particles too large to enter the alveolar space are eventually removed from the lung via muccocilliary clearance; however, many of these particles are then swallowed and enter the gastrointestinal tract. Once ingested, their absorption again depends upon factors like chemical form and solubility.[21]

It is unlikely that an eRDD detonation would expose a significant number of persons to critical radiation doses; indeed, the physical injuries sustained in a detonation may well be limited to the blast effect of the explosion. However, misinterpretation of the explosion as a nuclear detonation may induce fear similar to that produced from a true nuclear detonation. These psychological effects may be significant: mass psychosomatic symptoms due to fear of the effects of radioactive material may be pervasive and severely overload medical support operations.[22]

F. RADIONUCLIDES: A PRIMER

A *radionuclide* (also called a *radioactive isotope* or *radioisotope*) is an atom with an unstable nucleus that becomes more stable by emitting radiation. This process is called *radioactive decay* and is associated with the emission of ionizing radiation. *Ionizing radiation*—alpha and beta particles, gamma rays and x-rays, and neutrons—is more energetic than non-ionizing radiation: it breaks molecular bonds and causes electron displacement when it passes through material, creating electrically-charged particles or *ions* that may damage living cells. Humans, of course, have no sense organs to detect ionizing radiation.

Some thirty radionuclides are in common use in medical and industrial application; however, only nine (9) are available widely and in concentrated amounts. They are (in alphabetical order):

- Americium-241 (Am-241)
- Californium-252 (Cf-252)
- Cesium-137 (Cs-137)
- Cobalt-60 (Co-60)
- Iridium-192 (Ir-192)
- Plutonium-238 (Pu-238)
- Polonium-210 (Po-210)
- Radium-226 (Ra-226)
- Strontium-90 (Sr-90)

Four types of ionizing radiation are relevant to eRDDs: alpha, beta, gamma, and neutron radiation. All

[18] Demmer, et al. (2014), p. 3.
[19] Wound contamination can occur when radionuclides enter an open wound as dust, or are embedded as radioactive shrapnel. As with other routes of exposure, the properties of the radionuclides are of prime important when determining the health effects on the victim.
[20] See: Bates, et al. (1966), Morrow (1967). Cited in Mickelson (2013).
[21] Mickelson (2013), pp. 74-75.
[22] Visger (2004), p. 25.

radionuclides emit at least one type of ionizing radiation.

G. SELECTING A RADIONUCLIDE FOR MISUSE

Two metrics are most important in selecting a radionuclide for misuse in an RDD: *specific activity* and *half-life*. Specific activity is the radionuclide's radioactivity per unit mass. Half-life is the period of time in which the number of radioactive atoms is reduced to one-half of its original amount; as a general rule, an isotope remains radioactive for seven to ten half-lives. A radionuclide's specific activity is inversely proportional to its half-life, such that the higher its specific activity, the shorter its half-life and the more radioactive it is compared to one with lower specific activity. Table 1 shows the half-life and the primary radiation type for nine (9) radionuclides that are good candidates for misuse in an eRDD.

Table 1.
Potential eRDD Radionuclides.[23]

Radionuclide (1)	Half-life (2)	Primary radiation type (3)	IAEA Category-2 *Quantity of Concern* (grams)[24] (4)
Americium-241[25]	432 years	Alpha + neutrons	4.73
Californium-252	2.6 years	Neutrons + alpha	0.01
Cesium-137	30.2 years	Beta + gamma	0.31
Cobalt-60	5.3 years	Gamma + beta	0.007
Iridium-192	74 days	Beta + gamma	0.002
Plutonium-238	87.8 years	Alpha	0.95
Polonium-210	138 days	Alpha	n/a
Radium-226	1,600 years	Alpha + gamma	10.93
Strontium-90	28.6 years	Beta	1.98

The ideal material strikes a balance between persistence and radiation emission. Three radionuclides have suitably long half-lives—cobalt-60, strontium-90, and cesium-137—making them effective radiation sources for an eRDD. Two others are strong radiation emitters—iridium-192 and polonium-210—but this is compromised by relatively

[23] See: Richardt, et al. (2013), p. 161.
[24] The threshold for IAEA Category-1 sources is 100 times that for Category-2 sources.
[25] A compressed mixture of americium-241 powder and beryllium powder doubly encapsulated in welded stainless steel is used in industrial gauges. The mixture is a strong neutron-emitter also known as "Am/Be": alpha particles emitted from Am-241 decay are absorbed in the beryllium, which then emits a neutron.

short (≤20 weeks) half-lives.[26]

Of the nine radionuclides under consideration, cobalt-60, cesium-137, and iridium-192 emit both gamma and beta radiation; americium-241 (as Am/Be) is a neutron emitter. These four are all potentially effective RDD materials based on their respective persistence and radiation emission, with the caveat that iridium-192 is limited by its short half-life.

The next gate is whether the radionuclide can be readily dispersed. Gamma and neutron emitters pose a handling danger that requires them to be shielded inside a sealed source that encapsulates the radionuclide in some durable metal (e.g., stainless steel, titanium, platinum) or dense attenuating metal (e.g., lead). This allows the material to be safely handled and transported; it also unintentionally makes it easier for a malefactor to incorporate it in an explosive device. All four radionuclides under consideration are commonly found in sealed sources. Selecting a mission-appropriate one is important, as the nature and the intensity of the radioactive material within them varies considerably.[27] In addition, eRDD design-and-build is a critical determinant of the real particle size distribution achieved in a detonation: small particles present mainly an inhalation risk, while intermediate ones become airborne in the detonation and the aerosol disperses downwind. Large particles also become airborne but deposit more quickly to contaminate the ground; likewise, non-aerosol fragments behave ballistically in an eRDD detonation and contribute to enhanced ground shine around the detonation point.

Of the four radionuclides under consideration, cesium-137 and americium-241 (as Am/Be) are normally supplied in powder form, which is the most effective form for purposes of widespread dispersal; however, a properly designed and built eRDD also will disperse cobalt-60 (metal slugs or pellets) and iridium-192 (metal discs or pellets) as aerosol dust.[28] Each of the four radionuclides is also an *exploitable radioactive source*, meaning that it can be sourced from material supplied routinely for industrial and medical applications.

Based on the foregoing, the four radionuclides can be ranked, each of which is an effective eRDD material:

- *Best:* cobalt-60 and cesium-137.
- *Better:* iridium-192.
- *Good:* americium-241 (as Am/Be).

H. COBALT-60: A MALEFACTOR'S CHOICE RADIONUCLIDE?

Cobalt-60 is an ideal eRDD radionuclide because of its relatively short half-life and the resulting high radioactivity (specific activity).[29] It is a man-made isotope of the element cobalt produced in a nuclear reactor by bombarding another isotope, cobalt-59, with neutrons.

1. *Exploitable Cobalt-60 Sources*

There are two readily exploitable sources of cobalt-60: sealed-source cobalt-60 capsules inside medical teletherapy units; and sealed-source cobalt-60 "pencils" used in food and industrial irradiation.

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[26] The very short half-lives of iridium-192 (74 days) and polonium-210 (138 days) make each less well suited for an eRDD given the likelihood of decaying to low radiation levels before the material could be used.

[27] Magill, et al. (2007), p. 108.

[28] As a general rule, the radiological risk coefficient associated with inhaling radioactive dust from the aerosol produced by an eRDD detonation is higher than other means of exposure. This consideration is simplified by an eRDD: the device's detonation and explosion negates key physical properties by turning solid metals into smaller particles that become airborne; likewise, chemical explosives can alter some of a radionuclide's chemical properties.

[29] A plausible case can be made as well for cesium-137, which is more commonly used in eRDD attack simulations. However, the likely sources of divertible cesium-137— cesium chloride-based blood product irradiators— are mostly located in Western hospitals. There is a concerted effort in Japan, Western Europe, and the United States to replace these irradiators with x-ray irradiators, and failing that, to substitute a less dispersible form of radioactive cesium. Moreover, cobalt-60 blood product irradiators were developed in the 1980s in response to difficulties experienced in the supply of cesium-137. Beyond blood product irradiators, however, there are over 100 research irradiators worldwide, many of which use cesium-137.

a. ***Cobalt-60 Teletherapy***

Teletherapy units use sealed-source cobalt-60 inside a small (2cm by 5cm) capsule, each containing about 7.4x-10^{13}Bq (2000 curie), which corresponds to a mass of about 1.8 grams. Although less common today in developed countries (where they have been replaced by linear accelerators), cobalt-60 teletherapy was an important advancement in radiotherapy delivery and thousands of units remain in service around the world. This factor alone makes thefts like the recent ones in Mexico likely to occur in the future. There are many cobalt-60 radiotherapy units in politically unstable developing states as well as in failed states. Some teletherapy units are being replaced by linear accelerators when a unit reaches the end of their useful life. This suggests two concerns, the first related to securing sealed-source cobalt-60 in teletherapy units that are in active use; and the second, to removing and securing cobalt-60 capsules from decommissioned units.

b. ***Cobalt-60 Food Irradiation***

Another potential cobalt-60 source that could be exploited by malefactors is food irradiation facilities. Food irradiation is the process of exposing boxes or pallets of food products to radiation in order to destroy insects, bacteria and microorganisms. Cobalt-60 gamma irradiation is the method most common worldwide. In this application, cobalt-60 is contained in sealed-source "pencils," which are small[30] double-encapsulated sealed stainless steel tubes that house cobalt-60 pellets or a stack of small, cylindrical cobalt-60 slugs. The pencils have a useful life of approximately twenty years.[31] Cobalt-60 in this embodiment is considered something of a self-protecting source because of the radionuclide's high activity, which to be handled safely requires 4cm-10cm of lead shielding to reduce the gamma emission, making it cumbersome for a single person to move unaided. Any effort to process a cobalt-60 pencil for weaponization—for example, grinding pellets or slugs into a power to more readily disperse the material—would be hazardous to all involved or exposed. Again, however, the combination of modern high explosive and the psychological impact of an eRDD detonation, let alone one in which the malefactor uses a cobalt-60 pencil, must be given serious consideration.

c. ***Cobalt-60 Industrial Irradiators***

The use of ionizing radiation as a method of sterilization is widespread and growing for disposable medical products, pharmaceutical and cosmetic raw materials, and other uses. A decade-old IAEA report indicated that there were over 200 gamma irradiators worldwide, of which 40 to 50 percent were located outside the United States and Europe. There also are an unknown number of, respectively, cobalt-60 mobile irradiators, research laboratory irradiators, and seed irradiators at unspecified locations around the world.

The largest industrial sterilization units use cobalt-60 sources.[32] The facilities typically use hundreds of cobalt-60 pencils to deliver high doses of gamma radiation. The Los Alamos National Laboratory in 2004 ranked industrial irradiators as posing the greatest concern "regarding usage in a large and damaging RDD."[33]

2. ***Cobalt-60 Exposed to Terrorism Risk***

The United Kingdom-based risk consultant Maplecroft annually publishes its well-respect *Terrorism Risk Index* rating nations the based on the frequency and lethality of terrorist incidents occurring there in the preceding twelve-month period. The IAEA publishes a *Directory of Radiotherapy Centers* (DIRAC), which reports the number, type and location of radiotherapy centers by-nation based on voluntary self-reporting. The agency also maintains jointly with the United Nations Food and Agriculture Organization a *Food Irradiation Treatment Facility Database* that identifies facilities by type and location.

The *Terrorism Risk Index* identifies eighteen (18) countries at "Extreme Risk" of terrorism with another eleven said to be at "High Risk". There are 768 cobalt-60 teletherapy units located in *Extreme Risk* states, and another 69 teletherapy units located in *High Risk* states. Other states selected by the author based on a perceived elevated risk

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[30] A typical cobalt-60 pencil measures 0.5-1.0" diameter by 12" active length, and weighs some 3 pounds (1400 grams).

[31] Note: cobalt-60 has a half-life of 5.3 years but remains very radioactive for some time thereafter.

[32] Smaller units that are sometimes mobile use cesium-137, which is easier to shield.

[33] VanTuyle, et al. (2004), pp. 16-17.

of terrorism also posted significant numbers. Table 2 shows the number of radiotherapy centers and the number of cobalt-60 teletherapy units by country for Extreme Risk, High Risk, and select at-risk states.

Table 2.
States Deemed at a Heightened Risk of Terrorism:
Number of Radiotherapy Centers, Co-60 Teletherapy Units,
and Co-60 Food Irradiation Treatment Facilities.

Ranking[34] (1)	Nation (2)	No. R/T Centers[35] (3)	No. Co-60 Units[36] (4)	No. Co-60 Food Irradiation Facilities[37] (5)	No. Co-60 Sterilization Facilities (No. Irradiation Units)[38] (6)
EXTREME RISK: (*rank*)					
1	Yemen	1	2		
2	Somalia	0	0		
3	Afghanistan	0	0		
4	Pakistan	26	28	1	
5	Iraq	8	2		
6	DR Congo	0	0		
7	Nigeria	9	5	1	
8	Philippines	34	10	1	1 (1)
9	Colombia	55	35		
10	Sudan	2	6		
11	Thailand	29	28	3	3 (3)*
12	Kenya	4	2		
13	India	314	333	16	3 (5)*
14	Turkey	94	59	2	2 (2)*
15	Russia	129	248		5 (5)
16	Algeria	7	10		
	subtotal	**712**	**768**	**21**	**14 (16)**
HIGH RISK					
	Kazakhstan	21	35		
	Ethiopia	1	2		
	Egypt	34	23	1	1 (1)*
	Peru	18	9	1	1 (1)*
	Honduras	5	6		
	Burma	4	7		
	Nepal	5	3		
	Indonesia	23	19	3	1 (1)
	subtotal	**90**	**97**	**5**	**3 (3)**
AT-RISK					
	El Salvador	4	3		
	Mexico	91	61	3	1 (1)*
	Guatemala	8	3		
	Syria	2	6	1	1 (1)
	Lebanon	9	3		
	Jordan	5	1		1 (1)
	Libya	4	4		
	Mali	1	0		
	Ukraine	56	89		1 (1)
	Greece	27	11		1 (1)

34 Source: Maplecroft Terrorism Risk Index (2013).
35 Source: IAEA Directory of Radiotherapy Centers.
36 Ibid.
37 Source: IAEA Food Irradiation Treatment Facilities Database.
38 Source: IAEA Directory of Gamma Processing Facilities in Member States (2004). An asterisk indicates that a facility may also handle food products.

These numbers are on their face disturbing. In some instances, these are states with legacy proliferation challenges attributable to nuclear weapon programs; for example, Russia (*Extreme Risk*), Kazakhstan (*High Risk*), and Ukraine, which account collectively for an aggregate of 372 cobalt-60 teletherapy units and 6 industrial irradiation facilities. In other cases, acute civil conflicts make the proliferation risk more acute, for example, in Syria, Lebanon and Jordan, where there are 10 cobalt-60 teletherapy units and 2 industrial irradiation facilities; in Central America [Honduras, El Salvador & Guatemala], where there a twelve cobalt-60 teletherapy units; and in Egypt, Libya and Algeria, where there are 37 cobalt-60 teletherapy units and 1 industrial irradiation facility.

The theft of cobalt-60 capsules from active or decommissioned teletherapy units outside the United States poses a meaningful risk simply based on the number of units located in states deemed at an extreme or a high risk of terrorism. While the health effects resulting from the detonation of an eRDD containing one or more cobalt-60 teletherapy capsules might be minimal, the resulting disruptive effect would not, particularly in a campaign to detonate multiple bombs serially. The relatively straightforward requirement to shield cobalt-60 for undetected movement transnationally also raises the risk of such material being used in an eRDD detonation in the United States.

While on a strict numeric basis cobalt-60 food irradiation facilities present fewer (and more challenging) targets for the theft or diversion, they represent high-value ones to a malevolent actor given the concentration of highly radioactive cobalt-60 present there. Decade-old data regarding their distribution show a surprisingly high number of facilities—26 food irradiation facilities and 17 industrial irradiation facilities—in states deemed at extreme or high risk of terrorism. To put this into some context, a decade-old simulation of the theft and subsequent detonation in Manhattan of an eRDD containing a single cobalt-60 pencil concluded it would contaminate a one thousand square kilometer area extending across three states, causing long-term contamination and a 1-in-10 risk of death from cancer for persons living within 300 city blocks of the detonation site.

I. CONCLUDING THOUGHTS

Rating the probability that a malevolent actor will at some point succeed in detonating an eRDD requires that one assess two factors, *the will to kill*—whether the actor is sufficiently motivated to cause a mass effect—and *operational capability*—whether the actor possesses the organizational capacity and the technical knowledge to plan and execute a detonation. The former can be taken as a given; the latter is up for discussion, but the direction of change is unfavorable and unsettling.

This should come as a surprise to no one: it was known a decade ago that al-Qa`ida's central leadership decided to acquire radiological weapons as a means of deterring the United States. There is some evidence in the public domain that al-Qa`ida operatives quickly attempted to act on this decision; for example, the May 2002 arrest of Abdullah al-Muhajir (José Padilla), who attempted to acquire radiological material in Canada. Further evidence includes reports in early 2004 that the Egyptian chemist and weapons expert (and al-Qa`ida affiliate) Midhat Mursi al-Sayid Umar (*a/k/a* Abu Khabab al-Masri) constructed an eRDD; the June 2004 arrest of eight men by British law enforcement after discovering information on explosives, chemicals, and radiological materials as well as building plans[39]; and late 2004 reports that an al-Qa`ida affiliate, Mustafa Hamid (*a/k/a* Abu Walid al-Misri) revealed information about an effort to purchase radiological material from al-Qa`ida contacts in Chechnya.

Further evidence in this direction is found in a document titled "Instances of Radiation Pollution from 1945-1987," which was posted on a prominent Jihadi operational website in 2005. It emphasized the desire to exact severe economic losses on the United States and its allies, and specifically encouraged attacks on western cities, stating "The important thing is to disperse radioactive material in a large commercial area so the government is forced to shut down this area which will cause this country massive economic disruption." The author, Abu al-Usood al-Faqir, suggested targeting (in order of priority) Las Vegas, New York, London, Sydney, Tokyo and Moscow, followed by "other large tourist cities and commercial capitals of all infidel nations."[40]

Given the ample supply of suitable radiologic material available to divert to malevolent uses, it is reasonable to

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[39] British officials recovered building plans to the New York Stock Exchange and the Citigroup building in New York; the International Monetary Fund in Washington, D.C.; and the Prudential building in Newark.
[40] al-Faqir (2005).

speculate that a concerted effort by a competent malefactor would involve (at least the intent of) serial detonations, probably following an initial demonstration detonation against a soft target. The initial detonation may face a low bar, since it may well be intended as a transcendent political act simply to achieve recognition for the perpetrator. A serial bombing campaign would, with each iteration, amplify the disruptive mass effect: further, there may well be no direct cause-and-effect connection between individual detonations and some intended tangible result.[41] Rather, each is intended as a political act.

It could be a costly one at that. The consulting firm Risk Management Solutions last year published findings regarding the effects of several postulated terrorism events in the United States. One involved the detonation of a cesium-137 eRDD in Manhattan. RMS estimated that while there would be "few" casualties, property damages would amount to USD127 billion.[42] The selection of the locus of the simulated attack was neither accidental nor tendentious: to achieve the greatest mass effect possible, the best suited targets are located in densely populated urban areas with relatively high cost of living, especially areas in which a key economic node can be compromised.[43]

Helmreich wrote a decade ago that the United States "seems the most attached to the limited view of terrorism…It is a view that violence is not an end in itself, but for advancing a goal." His suggested alternate view was that "Many terrorists seem to act out of a transcendent, if evil, idealism that is, at most, incidentally related to its political or strategic outcomes."[44] Pursuing this theme, another commentator observed, "These terrorists have transcended the need to connect their acts of terror directly with a political demand," and thus, "Given the trend toward transcendental terrorism, it is only a matter of time before terrorists move from creating carnage exclusively through the use of high explosives to creating destruction through the use of biological, chemical, or radiological agents."[45]

An eRDD is a paradigm weapon of transcendental terrorism:

> **"For terrorists seeking an asymmetric advantage against the United States, radiological weapons offer unique opportunities; discrete, lethal, requiring only limited technology to employ, and with radioactive material readily available they contain an awesome potential for psychological disruption."[46]**

It is true that the United States has erected defenses intended to detect and intercept radiologic material entering the country illicitly. It is also true that these, like all defenses, are not seamless and can be circumvented, especially with patience and persistence. After all, the vigilant application of tools to interdict the flow of illegal narcotics into the United States has by no means succeeded in achieving that end. There are ample avenues through which a determined adversary could move radiological material, and the possibility of acquiring a sizeable amount of this material would allow, for example, multiple cobalt-60 capsules to be moved separately, decreasing the odds that all are detected, interdicted and confiscated. This is a distinct advantage over fissile material, which is unlikely to move in parts. No serious analyst postulates that a single cobalt-60 capsule removed from a teletherapy unit would pose serious population health risks if detonated in an eRDD. The same cannot be said, however, for the mass psychological or economic effect of an eRDD detonation in a major American city. The United States is not immune from the effects of terrorism events carried out in other nations and would clearly bear some effect from the economic and social disruption associated with an eRDD detonation elsewhere. An aspect of the asymmetric advantage accruing to radiological weapons is that a demonstration detonation in one place can be leveraged to create a disruptive effect far away.

An eRDD detonation overseas linked to a malevolent actor's credible claim to have radiologic material in its possession somewhere within the United States would establish a classic paradox: how to prove a negative? Restated, would the public accept at face value the assertion that, contrary to the malevolent actor's credible claim (credible perhaps the actor already detonated an eRDD elsewhere), no such material exists within the United States? There are, admittedly, limited analogues from which to reason, but Brazil's 1987 experience in Goiania is

[41] Suggested by Helmreich (2001).
[42] RMS (2013), p. 10.
[43] Hanson (2008), p. 43.
[44] Helmreich (2001).
[45] Brown (2006), pp. 20, 40.
[46] Brown, op cit., 38.

instructive. After an accidental release of cesium-137 (which took 15 days to establish), 140,000 residents sought medical attention and the Brazilian government spent an estimated $20 Million on cleanup. It was ultimately determined that only 249 people were exposed, of which 49 were serious enough to warrant hospitalization and 5 died. As one commentator noted in retrospect, “From a psychological perspective, this should be no scarier than the crash of a jet airliner. However, the psychological impact was far more significant.”[47]

So, what are we to do? This discussion purposefully omitted a detailed treatment of the in-place detection architecture deployed in the United States (and elsewhere) to detect the movement of radioactive materials: within any competent treatment of that subject, approaches to evading detection would be at least implied, to the benefit of a malevolent actor who happens to be paying attention. The objective of the discussion was to focus attention on the widely dispersed supply of radiological material suitable for use in an eRDD. The presence of a significant number of units of such material in states deemed at an extreme or a high risk of terrorism ought to be sobering.

The author suggests that the bar defining what constitutes an “effective” eRDD is usually set too high: the seriousness of *any* eRDD detonation *anywhere* ought to be understood on its face. Acquiring suitable radiological material is not beyond the grasp of a reasonably competent malevolent group: incorporating this material into a workable improvised explosive device is not beyond the capability of a reasonably competent bomb maker with access to modern high explosives. Reducing or eliminating altogether personal concerns about radiation exposure among the members of a transcendental terror cell further simplifies the proposition.

The capsule stolen in Mexico in December 2013 contained compression-fused cobalt-60 metal pellets confined within a capsule made of titanium and stainless steel. Had this material—or the as-yet unrecovered and undisclosed quantity of cesium-37 (Cs-137) and americium-241/beryllium, or the unspecified quantity iridium-192—all stolen in Mexico within the past seven months founds its way into the hands of a determined malevolent actor, would public reaction be assuaged by assurances that the material is less dangerous than they thought?

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[47] *Ibid*.

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