WHEN TERRORISTS FIGHT DIRTY:
THE LIKELY MAGNITUDE OF A TERRORIST RADIOLOGICAL ATTACK
IN THE UNITED STATES

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By

Jessica Satterfield, A.B.J.

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Jessica Satterfield, A.B.J.

Thesis Advisor: Genevieve A. Lester, M.A.

ABSTRACT

This study examines the threat of a radiological dispersal device (RDD) attack against a major US city, and explores the various methods for measuring the scale of the threat to determine which best applies to a real world scenario. First, the research will examine past terrorist and lone actors’ attempts to construct an RDD, compared to an overview of the types and amounts of radioactive material currently missing in the United States. An analysis of these two datasets will allow for a determination on the most likely type and scale of RDD attack that could be carried out in the United States using currently available materials. This type and scale of attack will then be compared to existing methods of RDD measurability, and will propose additional sub-categories to these scales to more effectively address the most likely real-world scenario.
The research and writing of this thesis
is dedicated to my mother and teacher, Dianne Jackson Satterfield.
Thank you for teaching me all I know.

With love,

JESSICA
# Table of Contents

I. Introduction .................................................................................................................. 1  
II. Defining the ‘Dirty Bomb’ Threat .............................................................................. 2  
III. Assessing Terrorist Intent .......................................................................................... 7  
    Other Radiation Threats: The Lone Actor ............................................................... 11  
    From Malicious Intent to Radiological Attack ......................................................... 15  
IV. Acquiring Radioactive Material .............................................................................. 19  
    Terrorist RDD Rule #1: Target materials that are easy to find......................... 21  
    Terrorist RDD Rule #2: Target materials that make officials worry most .......... 27  
V. Building a Radiological Weapon ............................................................................... 36  
    Considering Weapon Scale..................................................................................... 37  
VI. Conclusion and Recommendations........................................................................... 41  

Appendix A: Radiation Primer ....................................................................................... 46  
Appendix B: Chart: Al-Qa’ida’s RDD Activities............................................................ 47  
Appendix C: Definitions of IAEA Radiation Source Categories 1-5 ............................ 48  
Bibliography .................................................................................................................. 49
I. INTRODUCTION

On June 10 2002, former US Attorney General John Ashcroft announced to the American public that an al-Qa’ida operative, known as Jose Padilla, was arrested for allegedly planning to attack the United States with a bomb designed to disperse radiation upon detonation.\(^1\) Ashcroft called this device a ‘dirty bomb.’\(^2\) For many Americans, this was the first they had heard of a possible dirty bomb terrorist attack, but for security experts across the country, the threat of a radiological bomb was nothing new. Known in security circles as a Radiological Dispersal Device, or RDD, this type of weapon is recognized less for its danger to human life and more for the psychological and economic damage that it would inflict on a targeted population. Due to these “terrorizing” effects, an RDD could be deemed attractive to terrorists. In the years following those first sweeping ‘dirty bomb’ headlines, al-Qa’ida has been reported to either possess or be working toward a radiological capability on at least nine different occasions.\(^3\) Although the organization is not believed to currently possess a radiological weapon, it is clear that al-Qa’ida has been active in conducting research on building and operationalizing an RDD. In addition to global jihadists, malicious actors the world over – from terrorists in Chechnya to white supremacists in the United States – have displayed both the intent and the capability to obtain radioactive material for malicious purposes. But, the question remains – How difficult would it be for a terrorist to successfully turn radioactive material into a ‘dirty bomb?’

1 “Ashcroft statement on 'dirty bomb' suspect,” CNN, 10 June 2002.
2 Ibid.
The current research on radiological weapons provides an overview of the threat, including RDD definitions and terrorist intent, but does not provide meaningful insight into the scale of the threat using real-world data. This study will fill this gap by analyzing past terrorist RDD attempts, along with cumulative reports of lost or stolen radioactive materials in the United States, to determine the magnitude of RDD – Small, Large, or Super weapon – that terrorists or other malicious actors would probably be able to construct. Based on the magnitude of attack deemed most likely, this analysis will determine the extent of the RDD threat against the US homeland and whether the most likely scale of radiological attack would pose a significant threat to national security.

II. DEFINING THE ‘DIRTY BOMB’ THREAT

In the years since Attorney General Ashcroft’s well-publicized definition of a ‘dirty bomb,’ a hand-full of researchers have attempted to gauge the threat level associated with a terrorist RDD attack. A radiological dispersal device has been defined as an exploding conventional bomb that “not only kills victims in the immediate vicinity, but also spreads radioactive material that is highly toxic to humans and can cause mass death and injury.” The Environmental Protection Agency defines an RDD as “a device that spreads radioactive material by exploding a conventional (non-nuclear) explosive, such as dynamite.” In the article “Dirty Bombs: The Threat Revisited,” Peter Zimmerman and Cheryl Loeb discuss the types and amounts of radioactive material that

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4 This will be taken from the Nuclear Regulatory Commission Website listing of lost/stolen radioactive materials licensed in the United States, listed under Event Notification Reports, <http://www.nrc.gov/reading-rm/doc-collections/event-status/event/>, last accessed on 13 March 2011.
5 “Ashcroft statement on 'dirty bomb' suspect,” CNN, 10 June 2002.
would be needed to construct an RDD, grouping the weapon types into three categories: Small, Large and Super weapons. In *Weapons of Mass Disruption: Radiological Devices*, A. Oppenheimer asserts that the likely impact of an RDD attack would be one of mass disruption, as opposed to large-scale destruction.

In 2010, the US government interagency Radiation Source Protection and Security Task Force submitted to the President and Congress a report on the progress made toward ensuring effective security of radiation sources in the US. One important provision included in this report is a US interagency agreed-upon definition of what constitutes a “Significant RDD.” According to the Task Force report, a Significant RDD is defined as:

“The combination of radioactive material and the means (whether active or passive) to disperse that material with malicious intent, without a nuclear detonation, that could (1) impact national security, national economy, national public health and safety, or any combination thereof or (2) require a robust, coordinated Federal response to save lives, minimize damage, and/or provide the basis for long-term community and economic recovery (which includes the cost for decontamination and environmental cleanup efforts).”

The Task Force report goes on to specify that a Significant RDD refers to “a device with sufficient radioactive materials to contaminate approximately 1 square kilometer (approximately 250 acres, or 0.386 square miles) of the environment to both the US Environmental Protection Agency (EPA) and

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10 Ibid.
DHS/Federal Emergency Management Agency (FEMA) Protective Action Guides relocation guideline of 2 rem in the first year.”  

To ensure the most inclusive discussion of radiological weapons, this study will consider both Significant RDDs, as defined above, as well as less significant radiological weapons that fall short of this threshold. At the lower end of the spectrum, this study will consider attack plans to utilize radioactive materials in a manner that is intended to cause health effects due to radiation exposure or contamination to a crowd of people. The scope of this study excludes consideration of nuclear materials, improvised nuclear devices, or other uses of fissile materials for a radiological event, and focuses strictly on non-fissile radioisotopes considered useful for an intended RDD.

The malicious use of radioactive material for the targeted murder of an individual is not considered an RDD, as defined in this study. For example, some analysts have deemed the November 2006 murder in London of former Russian spy Alexander Litvinenko with radioisotope polonium(Po)-210 as a successful small-scale dirty bomb attack. However, the definition of an RDD used here excludes incidents of this type. The Litvinenko event is better categorized as a targeted murder by poison.

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13 A crowd of people is considered here to be a group of at least 50 individuals.
There are two basic types of radiological weapons: active and passive devices.\textsuperscript{15} Active weapons consist of radioactive material wrapped around a conventional explosive that is designed to disperse radiation upon detonation. Active weapons are what most people think of when they hear the term dirty bomb. Passive weapons, on the other hand, do not involve the use of a conventional explosive and could be successfully carried out against a crowd of people without their knowledge. To carry out a passive attack, a malicious actor would need to acquire a significant source of radiation, remove this source from its shielding, and covertly place the unshielded source in a crowded area. Anyone walking near the unshielded radiation source would be exposed to radiation and, depending on the source strength and length of exposure time, could experience severe health effects and, in extreme cases, eventual death. A passive radiological weapon is commonly referred to as a Radiation Exposure Device (RED).\textsuperscript{16} Some analysts point to the 1995 discovery of a 30 lb container of radioisotope cesium(Cs)-137 buried in the snow near the entrance to Izmailovsky Park in Moscow as a successful RED attack.\textsuperscript{17} The cesium source was discovered after Chechen terrorist leader Shamil Basayev gave instructions to Russian TV reporters leading them to the location of the radiation source.\textsuperscript{18} Basayev claimed that the Chechen terrorist group “had already smuggled four such parcels into Russia, and that at least two were packed in explosives and hidden

somewhere in Moscow where they could be detonated at any time.” Based on the definition outlined above, the Izmailovsky Park event falls outside the scope of a radiological attack because it did not seek to cause severe health effects in a crowd of people. If Basayev had not told reporters where the cesium source was located but instead claimed to have placed a passive radiological device somewhere in Moscow, then this incident might be considered a successful RED event. However, since Basayev led authorities to the device, and since his claims of three additional smuggled containers with cesium were never confirmed, this event was not intended to harm the population and does not qualify as a radiological attack. It does, however, point to a gap in the security of radioactive material and underscores the possibility that an effective RED attack could be carried out.

In addition to active RDDs and passive REDs, other types of radiological weapons utilizing smaller amounts of radioactive material have been explored. In the article “Beyond the Dirty Bomb: Re-thinking Radiological Terror,” James M. Acton, M. Brooke Rogers and Peter D. Zimmerman introduce a third class of radiological weapons involving inhalation, ingestion and immersion (I3) attacks. Although the past literature had largely overlooked radiological attacks involving the ingestion, inhalation or full immersion of victims in radioactive material, the authors assert that this type of attack might cause more physical injury than the traditional dirty bomb. Furthermore, because

any type of radiation sources – including alpha, beta, and gamma – could be employed in a successful I3 attack, the number of potentially vulnerable sources is multiplied. However, a successful I3 attack would require high levels of technical proficiency to successfully alter radioactive material into a form suitable for dissolving in large bodies of water or dispersing as an aerosol over even a small crowd. Full immersion of victims in radioactive material would be even more difficult to accomplish. Although the physical health effects of internal exposure to radiation would be much greater than short-term external exposure, the high level of difficulty coupled with the likelihood of failure for I3 attacks make this form of radiological weapon less likely to occur than a “traditional” RDD or RED.

III. Assessing Terrorist Intent

Since at least 2002, when the threat of a radiological weapon came into the forefront of media reports and security assessments, al-Qa’ida and associated actors have displayed an active intent to acquire radioactive materials for use in a dirty bomb attack against the United States. The threat of a radiological attack against the US homeland came into the limelight in June 2002 when authorities arrested a suspected al-Qa’ida operative known as Abdulla Al Muhajir, born as Jose Padilla, on allegations that he had planned to build and detonate a radiological dispersal device in the United States. Although Padilla’s arrest brought the terrorist RDD threat into the spotlight, Padilla was

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21 See Appendix A for a description of radiation, and a definition of alpha, gamma and beta sources.
never formally charged with attempting to build, or otherwise plotting to use, a radiological explosive. In August 2007, Padilla was found guilty of “plotting to kill people overseas and of supporting terrorism.”

Al-Qa’ida’s interest in using radioactive material in a terrorist attack did not end with Padilla’s arrest. In 2004, the UK Metropolitan Police in London arrested eight men connected to al-Qa’ida for their involvement in planning attacks against financial institutions in the United States and the United Kingdom. Upon searching the detainees’ houses, UK authorities discovered research on radioactive materials and plans to build a crude RDD. In documents labeled “Final Presentation,” “HAZARDS,” and “Rough Presentation for Radiation (Dirty Bomb) Project,” which were recovered from the suspects’ homes, authorities found details on radioactive materials, including a comparison of different radioactive isotopes and their effects, and the types of material that would be most useful for an RDD. The documents, which were written by terrorist Dhiren Barot, provided information on commercially available devices that contain radiation sources, such as moisture density gauges, smoke detectors, and exit signs. One of the documents appears to be a proposal for a project to construct an RDD using 10,000

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25 Ibid.
28 Ibid.
smoke detectors containing “Am-147.”³⁰ (Note that the unstable isotopes of americium are Am-241, Am-242 and Am-243. Barot’s characterization of Am-147 represents either poor spelling or analysis that is scientifically incorrect.) The proposal called for an estimated team of 10 men to accumulate the devices and three men to carry out the attack, at an estimated cost of GBP 70,000³¹ (approximately USD 132,000, based on 2004 exchange rates³²). Barot estimated the casualty count at 500 victims in the long-term, if the radiation were dispersed in a busy metropolitan area.³³

The research conducted by Dhiren Barot on how to carry out a radiological terrorist attack represents the most extensive terrorist RDD writings widely distributed in the open press to date. Although these reports exhibit a low level of technical understanding and accuracy – points that will be examined in more detail in Chapter IV – these plans do show an active interest on the part of Barot, and by extension al-Qa’ida, in using RDDs to carry out a mass casualty attack. Barot’s research also includes a discussion of the economic and psychological effects of a dirty bomb, demonstrating that terrorists have taken note of the disruptive effects that radiological weapons can cause.³⁴

In addition to the widely publicized RDD attempts by Padilla and Barot, there have been numerous other terrorist dirty bomb plots reported in the open press. According to the Center for Nonproliferation Studies, there were a total of nine reports

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³¹ Ibid.
³³ Ibid.
between 1997-2004 alleging al-Qa‘ida’s attempts to acquire an RDD. Some of these claimed that the terrorist organization already possesses a radiological dispersal device, or is in possession of sufficient radioactive material to build a dirty bomb. For example, in 2003 BBC News reported that undercover British intelligence officers had evidence that Osama bin Laden “had acquired radioactive isotopes from the Taliban to (develop a weapon of mass destruction)” and “development work on the ‘dirty bomb’ had been going on in a nuclear laboratory in the Afghan city of Herat.” The same intelligence information allegedly shows that al-Qa‘ida has developed training manuals giving instruction on how to use a radiological device most effectively.

In the academic article “Does intent equal capability? Al-Qaeda and Weapons of Mass Destruction,” Sammy Salama and Lydia Hansell provide a comparison of al-Qa‘ida instructions for building chemical, biological, radiological and nuclear weapons as displayed in actual al-Qa‘ida and other Jihadi literature and manuals. According to this assessment, al-Qa‘ida instructions for producing an RDD have focused on Cs-137 as a useful radioisotope and have provided vague and unspecific instructions that could nevertheless succeed in making a crude device with very low potential of causing a mass

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37 Ibid.
casualty event. This assessment is consistent with Dhiren Barot’s misguided attempts to procure material from smoke detectors and construct an RDD of insignificant effect.

The available information clearly establishes that al-Qa’ida and its affiliates have maintained an interest in constructing radiological weapons for at least the last decade. However, the group’s past attempts to construct an RDD, along with instructions outlined in seized training manuals and dirty bomb studies, all point to a low level of technical understanding and tactics that would not result in an attack reaching levels of “mass disruption.” While there are compelling British intelligence reports that al-Qa’ida may have possessed a radiological weapon in Afghanistan as of 2003, the absence of an al-Qa’ida radiological attack since that time indicates that, if the group did have an RDD program in Herat, this program was either interrupted or unsuccessful. The absence of an RDD attack to date provides the most convincing evidence that al-Qa’ida does not possess a radiological capability.

**Other Radiation Threats: The Lone Actor**

In addition to the terrorist RDD threat from al-Qa’ida, the most extensive domestic RDD threats in the United States have involved lone criminals who have acquired small amounts of radioactive materials for unknown purposes. As with al-

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39 Ibid, p 634.
41 Note: For the purposes of this study, terrorism is defined as “Premeditated, politically motivated violence perpetrated against noncombatant targets by subnational groups or clandestine agents.” (United States Code, Title 22, Chapter 38) The lone actors discussed in this section are not considered terrorists because, in most cases, there is no evidence that their collection of radioactive material was intended for use in an attack against noncombatants. In the one exception to this rule – the case of James G. Cummings – his alleged plans to perpetrate a radiological attack at the inauguration of President Obama admittedly blurs the line between a lone actor and a terrorist. However, since Cummings did not carry out such attack and the accuracy of his alleged plans are dubious, he is included in this section vice the section on terrorist activities.
Qa’ida RDD attempts, these cases have involved small amounts of widely available radiation sources commonly used in industry that would not cause mass casualties if weaponized. However, the occurrence of these events poses a cause for concern and offers insights on how a malicious actor might go about acquiring radioactive materials for nefarious purposes. Three case studies of US citizens found to possess radioactive materials, as outlined below, together provide an overview of the types of radiological seizures that have most commonly occurred in the United States.

- **James G. Cummings.** In December 2008, authorities investigating the homicide of James G. Cummings at a residence in Belfast, Maine discovered radioactive materials inside his home. Cummings was killed in his sleep when his wife, Amber, shot him twice in the head. During the investigation and court trial, it was alleged that Cummings was a right-wing extremist who had been abusive toward his wife and 9-year-old daughter. Cummings was allegedly building a ‘dirty bomb’ at the time of his murder, and “told his wife and daughter how he planned to set off his bombs and kill his family during an attack in Washington, D.C., at the inauguration of President Barack Obama.” A report by the Maine Department of Environmental Protection provides that a hazardous materials team was dispatched to the Cummings residence during the investigation and found “a specific jar which contained a radioactive substance. No reading was detectable inches away from the jar,

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indicating it was a very low level radiation source.” No further information was officially released about the type of radioactive material contained in the jar. However, state Public Safety Commissioner Anne Jordan told reporters that federal officials determined that “the items seized could be purchased legally and that there was not sufficient quantity or quality to pose an immediate threat or hazard to the health and safety of the public.”

Cummings’ wife pleaded guilty to manslaughter and walked away from Waldo County Superior Court in January 2010 with a suspended sentence and six years’ probation.

- **Justin Sheridan.** In November 2007, authorities arrested Justin Sheridan in Urbandale, Iowa, for extracting radioactive materials from smoke detectors. Authorities searched his residence in response to a phone call received by the FBI office in West Des Moines providing information that Sheridan was trying to build “some kind of explosive device.” During a search of his residence, police found “an assault rifle, two non-functioning grenades, about 20 smoke detectors and materials used to grow psilocybin mushrooms.”

- **David Hahn.** Hahn, 31, was arrested in August 2007 by authorities in Detroit, Michigan, for stealing 16 smoke detectors containing radioactive materials.

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50 Ibid.
51 Ibid.
Although it is unknown why Hahn was collecting radioactive smoke detectors, authorities suspect he planned to experiment with the radioactive material contained inside the devices. Hahn was found guilty on charges of attempted larceny and sentenced in Macomb County Circuit Court in October 2007. Previously, Hahn was arrested in 1994 after police found “radioactive materials, chemicals, rocks, plastic and glass bottles and two exploded pipes in his car.” When questioned, then 18-year-old Hahn told authorities that he was attempting to make a nuclear reaction in his back yard in hopes of earning his Eagle Scout badge.

The cases of Cummings, Sheridan and Hahn show that the radiological threat to the United States is not a one-dimensional threat coming only from international terrorists based overseas, but is alive and well in our own backyard. Here at home, American citizens with no known connections to international terrorist organizations have collected commercially available radioactive materials for possibly nefarious purposes. As with past al-Qa’ida attempts to construct an RDD, possible attempts by American lone actors to construct a radiological weapon have been crude and technically ineffective. In the cases of Sheridan and Hahn, where the type of radioactive material is known, both individuals may have been influenced by UK convicted terrorist Dhiren Barot’s tactic of targeting radiation sources contained in smoke detectors. Although the amount of radioactive material contained in commercially available smoke detectors is negligible

53 Ibid.  
and would not be suitable for an RDD, the repeated targeting of radioactive smoke detectors by both al-Qa’ida operatives and lone actors in the United States is worth further examination.

**From Malicious Intent to Radiological Attack**

In the book *The Four Faces of Nuclear Terrorism*, Charles D. Ferguson and William C. Potter consider the steps that a terrorist group would have to take to carry out a radiological attack. These steps include: (1) forming extreme objectives, (2) making the decision to engage in radiological terrorism, (3) acquiring radioactive materials, (4) using these materials to construct a radiological device, (5) transporting the radiological weapon to a high-value target, and (6) detonating the RDD. (See Figure 1) Ferguson and Potter judge that the most challenging step in this chain of causation would be that of acquiring the radioactive materials.

![Figure 1: The six steps terrorists would have to take to construct a ‘dirty bomb,’ as defined by Charles Ferguson and William Potter.](image)

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58 Ibid.
59 Ibid.
60 Ibid.
The six steps outlined by Ferguson and Potter provide a provoking academic framework for considering the terrorist RDD threat; however, a review of terrorist activities shows that some groups have taken many of these steps already. For example, al-Qa’ida ideology is built on extreme objectives and past al-Qa’ida attempts to acquire an RDD show that the decision has already been made to engage in radiological terrorism. While reporting indicates that both terrorists and lone actors have succeeded in acquiring minute quantities of commercially available radioactive material, the types and quantities of material acquired would not be useful for a successful RDD. However, the terrorists acquiring these materials either did not know this or intended to perpetrate an unsuccessful dirty bomb detonation wholly for its disruptive effects. Considering this, the level of difficulty in successfully completing the third step should be viewed on a spectrum -- obtaining small amounts of radioactive material that would not cause massive health effects is relatively easy and has been done, while obtaining large amounts of highly radioactive material that causes a direct threat to human health is very difficult and requires scientific understanding, adequate shielding, and carefully timed lengths of exposure. Terrorists and malicious actors have not, to date, acquired large radiation sources that would require advanced technical skill for safe handling. For those radioactive materials that terrorists have acquired, as stated previously the absence of a terrorist RDD attack strongly suggests that they have not successfully used those radioactive materials to construct a radiological weapon.
According to Ferguson and Potter, once a terrorist has successfully acquired adequate types and amounts of radioactive material and has fashioned this material into an RDD, they would then face the challenge of transporting this material to the attack location. Although this step may at first appear difficult, it need not be. The Global Nuclear Detection Architecture, which is the US system that ensures a network of radiation detection devices are in place at border checkpoints around the world, does make it difficult to import any radioactive material into the United States. However, the fact remains that the need for international transport of an RDD is a myth. The United States, like every other large industrialized nation, is home to over a million radiation sources used in industry, medicine and research. As evidenced by the known activities of lone actors in the United States, some of these domestic industrial sources have already been targeted for possibly nefarious purposes. There is no reason to dismiss the possibility that malicious actors might target larger, more dangerous radiation sources in

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the future. A terrorist aimed at perpetrating a radiological attack against a major US city could acquire the necessary materials in the United States, construct the RDD near its target, and completely sidestep the hurdle of transporting the device across national borders. If a device did need to be transported domestically within the United States, this would not likely pose a problem since vehicles traveling from one state to the next are not required to pass through radiation portal monitors or any other type of vehicle inspection. Although some cities – such as New York – have dispatched radiation detection equipment to many popular locations, adequate shielding would ensure that an intact RDD remained undetected until the time of attack.  

![Diagram](image)

**Figure 3:** Considering steps terrorists have already taken, and those that could be easily sidestepped, only three remaining steps are required for a radiological capability.

Considering the steps that terrorist organizations and malicious actors have already successfully taken, as well as those that could easily be sidestepped, the number of steps that would remain toward constructing an RDD are few in number. A more accurate construct, based on today’s reality, includes three simple steps: (1) acquire radioactive materials, (2) construct an RDD, and (3) detonate the RDD. The remainder of

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this study will consider the hurdles and likely results associated with the first two of these steps. Assuming that an RDD is constructed effectively, the challenges associated with the third step would be comparatively small and are thus excluded from discussion.

**IV. ACQUIRING RADIOACTIVE MATERIAL**

It has been established that the first phase of building a radiological weapon – that of collecting adequate types and quantities of radioactive material – is the most difficult of the three steps toward an RDD. As noted in the previous discussion, while terrorists and lone actors have succeeded in acquiring some radiation sources, the types and quantities of materials they have obtained in the past would not be sufficient for a radiological weapon of consequence. For example, in his widely publicized RDD study Dhiren Barot suggested collecting smoke detectors containing the radioisotope americium and burning or exploding these smoke detectors to cause a mass casualty event.\(^\text{64}\) As evidenced by more recent reports of US lone actors who collected radioactive materials from smoke detectors, acquiring these devices is not difficult. Smoke detectors containing Am-241 can be purchased at most home improvement stores and do not require a license.\(^\text{65}\) Barot estimated that a dirty bomb attack using radioisotopes collected from 10,000 smoke detectors would cause approximately 500 casualties in the long term.\(^\text{66}\)

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\(^\text{66}\) Ibid.
According to the Environmental Protection Agency, a smoke detector made with the radioisotope Am-241 contains on average 1 microCurie of radiation.\(^\text{67}\) A microCurie is one-millionth of a curie.\(^\text{68}\) While Barot’s research was correct in identifying Am-241 as a radioisotope of concern, the NRC places a quantity of concern for americium at 16 curies.\(^\text{69}\) Thus for Dhiren Barot to acquire enough americium to concern federal officials, he would have to purchase or steal at least 16 million smoke detectors. Barot’s plan to acquire 10,000 smoke detectors would have provided him with 0.01 curie of americium, which is far too little material to cause a health threat to one person, let alone 500.

If Barot and his team corrected their faulty math and determined the correct number of smoke detectors needed for a radiological quantity of concern, this method of constructing an RDD would still be impossible. After collecting the 16 million smoke detectors over probably a number of years, the group would then have to dis-assemble each device and remove the Am-241. After repeating this step 16 million times and collecting all of the radiation sources from inside the smoke detectors, Barot would then face the challenge of modifying the americium into a form suitable for an RDD or RED. This entire process would need to be conducted in a manner that would avoid the attention of neighbors and friends. Clearly, the most extensive terrorist RDD research uncovered to date outlines inefficient tactics that would not work.


\(^{68}\) Ibid.

The above examination might lead one to conclude that the threat of radiological terrorism is negligible; however, this is a faulty conclusion. The previous chapter established that terrorist groups have already displayed an intent to build an RDD, and they have taken action toward acquiring radioactive materials. Though past attempts were misguided, intent followed by action can be a deadly combination when carried out by a competent actor. It is only a matter of time before a capable terrorist takes on the dirty bomb challenge.

For those charged with protecting the American public against this threat, there are two important lessons that can be learned from past failed attempts. First, all of the past RDD attempts, misguided as they were, have one thing in common – they all targeted radioactive materials that are commonly used in industry and are available for purchase on the open market. Terrorist RDD Rule #1: Target materials that are easy to find. Second, confiscated terrorist training manuals and studies provide an overview of which commercially available radioisotopes would be most useful for an RDD, and past RDD attempts have targeted these material types.\(^7\) This leads us to Terrorist RDD Rule #2: Target the commercially-available radioisotopes that make government officials worry the most. These two rules together provide significant insight on the materials that a moderately competent terrorist might target.

**Terrorist RDD Rule #1: Target materials that are easy to find**

In the comprehensive study *Commercial Radioactive Sources: Surveying the Security Risks*, Charles Ferguson, Tahseen Kazi and Judith Perera address the potential

that terrorists could acquire radiation sources commonly used in commercial, medical and industrial applications and use these sources to construct a radiological weapon.\textsuperscript{71} The potential that commercially available radiation sources might pose a security risk is a relatively new consideration. Due to the widespread use of these sources – there are more than two million radiological devices licensed for commercial applications in the United States alone\textsuperscript{72} – ensuring effective security of this material requires a clear understanding of what does and does not pose a radiological threat. While securing all radioactive materials would be ideal, the Ferguson et al study provides a ranking of radiation sources that pose the greatest security risk.\textsuperscript{73} This “high risk” list includes cobalt(Co)-60, Cs-137, Am-241, californium(Cf)-252, plutonium(Pu)-238, iridium(Ir)-192, and strontium(Sr)-90.\textsuperscript{74}

In addition to this conservative “high risk” list, the NRC provides a more liberal listing of 15 radioisotopes considered “Radioisotopes of Concern,” along with the quantity of concern for each material type.\textsuperscript{75} To ensure the most comprehensive review of potential terrorist targets, the remainder of this study will focus closely on the materials included in the more liberal NRC listing. The NRC list includes all of the radioisotopes deemed “high risk” by Ferguson, et al, as well as additional radioisotopes Am-

\textsuperscript{73} Charles Ferguson, Tahseen Kazi and Judith Perera, Commercial Radioactive Sources: Surveying the Security Risks, Monterey Institute of International Studies, Center for Nonproliferation Studies Occasional Paper No. 11, January 2003.
\textsuperscript{74} Ibid.
241/berryllium(Be), curium(Cm)-244, gadolinium(Gd)-153, promethium(Pm)-147, Pu-239/Be, selenium(Se)-75, thulium(Tm)-170 and ytterbium(Yb)-169.\textsuperscript{76}

After defining the radiation sources of highest risk, the Ferguson study goes on to consider the large number of high-risk sources that are reported as lost or stolen in the United States each year. The study notes that, “Because the amount of radioactivity in each orphan source is unknown, determining the exact number of orphan sources that pose a potential high security concern is impossible.”\textsuperscript{77}

However, an in-depth review of the NRC website shows that what was once considered impossible is, in fact, well within reach. The NRC provides a daily listing of all radiation sources licensed within the United States that have become “orphaned” (meaning lost or stolen).\textsuperscript{78} Included in this daily listing is the type and amount of radioactivity involved. While Ferguson, et al, are correct in stating that “determining the exact number of orphan sources that pose a potential high security concern is impossible,”\textsuperscript{79} a quantitative review of NRC reporting on orphan sources over the last year can provide insight into the approximate number of orphan sources that pose a potential security concern.

According to careful analysis of daily NRC event reports, between January and December 2010 a total of 262 industrial devices containing radioactive material, or

\textsuperscript{76} Ibid.
medical radioisotopes, were reported as lost or stolen in the United States.\textsuperscript{80} Nineteen of these devices were subsequently recovered. Of the 243 devices that remain missing, only 48 contained radioactive materials that are considered “radioisotopes of concern,” as defined by the NRC. These 48 missing devices contained a combined total of 70 sources of radioisotopes Am-241, Am-241/beryllium(Be), Cs-137, Ir-192, Pu-239 and Se-75. A breakdown of the missing radioisotopes is shown in Figure 4.

\textbf{Figure 4: Radioisotopes Missing in the US, based on NRC Event Reports from January-December 2010}

Examining how many medical and industrial sources are currently missing in the US can help determine which of these sources would be easiest for a terrorist to acquire; however, some caveats must be included here. First, this study provides an analysis of lost and stolen radiation sources reported during a representative timeframe from January to December 2010. A larger analysis of the full NRC dataset – spanning from 1999 to 2010 – is recommended as a future study to provide a complete assessment and comparison of NRC event reports. Although the dataset provided here gives a

representative sample, considering the full number of NRC reports could reveal modified patterns of analysis.

Second, as mentioned above, some of the missing devices were subsequently reported as recovered. It cannot be ruled out that additional recoveries of missing devices occurred that were never reported. NRC licensing agreements require licensees to report to federal authorities if a source is lost or stolen, but do not require that licensees report the subsequent recovery of missing material. As such, it’s possible that the estimated 48 radiological devices assessed to be missing in the US is an overstated estimate.

Finally, in contrast to the potential overstatement of the number of missing devices, it must be noted that this study includes only those NRC events that involved lost, stolen or missing materials. Additional events occurred in 2010 that involved the discovery of orphan sources that were never reported as missing. These events were excluded from consideration here because the radiation sources have been secured and no longer pose a potential security risk. However, the occasional discovery of orphan sources that were never reported as missing indicates the potential that additional radiological thefts and losses have occurred that remain unreported.

Acknowledging that it is not possible to determine the exact number of radiological devices currently missing in the United States, the 48 devices reported to the NRC in 2010 as lost or stolen and never recovered provides the best possible estimate. These missing devices include 26 industrial gauges containing Am-241/Be and Cs-137,

81 “Reports of theft or loss of licensed material,” Code of Federal Regulations, Title 10, Section 20.2201.
17 radiation sources used for medical procedures, two Pu-239 calibration sources, one X-Ray analyzer containing Am-241/Be, one radiography camera containing Ir-192, and one shipment of a Se-75 radiation source. A review of event types shows that in 2010, industrial gauges were exclusively targeted for theft, and medical sources were most often reported as missing. Other types of commercially available radiation sources were reported as lost or missing on a less frequent basis.

![Radiological Devices Missing in the US by Device Type](chart.png)

*Figure 5: Radiological Devices Missing in the US by Device Type, based on NRC Event Reports from January-December 2010*

Based on the NRC data, one could rightly conclude that “high risk” sources of Cs-137 and Am-241 are most frequently lost or stolen in the United States. Furthermore, Cs-137 and Am-241 are found in industrial gauges, which are most often targeted for theft. While these conclusions are accurate, they do not provide much real insight into the most significant radiological risk. As exhibited by the mistakes of Dhiren Barot, it is not only the type of radioactive material but also the *quantity* of material that determines its
effectiveness for an RDD. Considering both the types and quantities of radioisotopes missing will provide a very specific matrix of the current radiological threat.

**Terrorist RDD Rule #2: Target materials that make government officials worry most**

As noted in the previous section, the Nuclear Regulatory Commission has specified a list of 15 radioisotopes considered “Radioisotopes of Concern,” along with the Quantity of Concern (QoC) for each material type.83 A QoC represents the minimum amount of each specified radioisotope that would pose concern to federal officials if applied toward malicious purposes. A licensee possessing an amount of the specified material that is equal to or greater than a QoC must provide increased controls for this material.84 These increased controls can include closely monitoring which individuals have access to the radioactive material, quickly reporting a security breach or theft, and ensuring secure transportation of radioactive material when necessary.85 A list of the NRC “Radioisotopes of Concern” and corresponding Quantities of Concern is included in Figure 6. This list represents the most openly available specification of radioactive materials that may pose a security concern, along with the associated material quantities. The open publication of this list, and its easy access to the average citizen, is necessary to ensure proper regulation of licensed materials.

In addition to the NRC list of radioisotopes and quantities of concern, the International Atomic Energy Agency, as part of its Safety Standards Series, produced in

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84 Attachment B: Increased Controls For Licensees that Posses Sources Containing Radioactive Material Quantities of Concern, Federal Register, Vol 70 No 230, 1 Dec 2005, pp 72130-72132.
85 Ibid.
2006 a handbook titled “Dangerous quantities of radioactive material (D-values).” The handbook specifies the quantities of radioactive materials that should be considered dangerous – designated its “D-value” – and calculates this value for all commonly used radioisotopes. The IAEA D-value represents a lower threshold for what qualifies as a “dangerous” source than the NRC list. A listing of IAEA D-values for each “Radioisotope of Concern” is also displayed in Figure 6.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Isotopic Half-Life*</th>
<th>NRC Quantity of Concern (Ci)</th>
<th>IAEA D-Value (Ci)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am-241</td>
<td>432.2 y</td>
<td>16</td>
<td>1.622</td>
</tr>
<tr>
<td>Am-241/Be</td>
<td>432.2 y**</td>
<td>16</td>
<td>1.622</td>
</tr>
<tr>
<td>Cf-252</td>
<td>2.6 y</td>
<td>5.4</td>
<td>0.5405</td>
</tr>
<tr>
<td>Cm-244</td>
<td>18.1 y</td>
<td>14</td>
<td>1.351</td>
</tr>
<tr>
<td>Co-60</td>
<td>5.3 y</td>
<td>8.1</td>
<td>0.8108</td>
</tr>
<tr>
<td>Cs-137</td>
<td>30.1 y</td>
<td>27</td>
<td>2.703</td>
</tr>
<tr>
<td>Gd-153</td>
<td>8 m</td>
<td>270</td>
<td>27.03</td>
</tr>
<tr>
<td>Ir-192</td>
<td>73.8 d</td>
<td>22</td>
<td>2.162</td>
</tr>
<tr>
<td>Pm-147</td>
<td>2.62 y</td>
<td>11,000</td>
<td>1081</td>
</tr>
<tr>
<td>Pu-238</td>
<td>87.7 y</td>
<td>16</td>
<td>1.622</td>
</tr>
<tr>
<td>Pu-239/Be</td>
<td>24,200 y**</td>
<td>16</td>
<td>1.622</td>
</tr>
<tr>
<td>Se-75</td>
<td>119.8 d</td>
<td>54</td>
<td>5.405</td>
</tr>
<tr>
<td>Sr-90 (Y-90)</td>
<td>28.8 y (2.6 d)</td>
<td>270</td>
<td>27.03</td>
</tr>
<tr>
<td>Tm-170</td>
<td>128.6 d</td>
<td>5400</td>
<td>540.5</td>
</tr>
<tr>
<td>Yb-169</td>
<td>32 d</td>
<td>81</td>
<td>8.108</td>
</tr>
</tbody>
</table>

** Figure 6: Listing of the NRC Radionuclides of Concern, along with the half-life for each isotope, the NRC QoC, and the IAEA D-Value.

* Times are denoted in d (days), m (months) and y (years).
** Because the isotope of beryllium is not specified, the half-life of the primary radionuclide is used here. For reference, there are two unstable isotopes of beryllium: Be-7 has a half-life of 53.2 days and Be-10 has a half-life of 1.36 million years.

87 Ibid.
The IAEA’s lower threshold for what qualifies as a “dangerous” quantity is due to the wide range of scenarios considered. For example, the D-value is the smallest amount of radioactive material that could cause severe deterministic effects if uncontrolled.\(^88\) To determine the lowest possible D-value, the IAEA study considered two scenario types: (1) External exposure scenarios, which include carrying an unshielded source in your pocket for one hour or being in a room with an unshielded source for a period of time.\(^89\) The amount of material needed for an external exposure scenario would most closely correspond to the amount needed for a targeted RED weapon designed for use against one person. (2) Exposure to dispersed radioactive material including inhalation, ingestion, skin contamination and immersion.\(^90\) The amount of material included in this second scenario type would correspond to what would be needed for a small RDD or I3 weapon. The D-value for each radioisotope corresponds to the smallest quantity needed to perpetrate either an external exposure or dispersal event.\(^91\)

A second international guiding document on the security of radiation sources is the IAEA “Categorization of Radioactive Sources” published in 2005.\(^92\) This IAEA Safety Guide is designed to provide regulatory authorities with a “simple, logical system for ranking radiation sources in terms of their potential to cause harm to human health.”\(^93\) The document defines five categories of radiation sources and the corresponding risk to human health for each category. The categories are ranked from 1 to 5, with a Category

\(^88\) Ibid.
\(^89\) Ibid.
\(^90\) Ibid.
\(^91\) Ibid.
\(^93\) Ibid, p 2.
(Cat) 1 source being the most dangerous and a Cat 5 source being the least dangerous.\textsuperscript{94}

An in-depth definition of each IAEA category is described in Appendix C.

Both the IAEA D-Value and the Categorization of Radioactive Sources serve as supporting documents to the internationally agreed-upon “Code of Conduct on the Safety and Security of Radioactive Sources.”\textsuperscript{95} Member States endorsed the Code of Conduct at the September 2000 IAEA General Conference as a document that “serves as guidance to States for – \textit{inter alia} – the development and harmonization of policies, laws and regulation on the safety and security of radiation sources.”\textsuperscript{96} The Code of Conduct calls on all IAEA Member States to ensure enhanced regulation for the most dangerous Cat 1 and Cat 2 sources.\textsuperscript{97}

The NRC uses the IAEA Code of Conduct as a guide to determine which licensed sources should require enhanced security regulations within the United States. Consistent with the standing international guidance, current US regulatory requirements outline enhanced security assurances for Cat 1 and Cat 2 radiation sources.\textsuperscript{98} The NRC QoCs reflect this, as each quantity represents the smallest amount of the given radioisotope that could be considered an IAEA Cat 2 source.\textsuperscript{99}

\textsuperscript{94} Ibid.
\textsuperscript{96} Ibid.
\textsuperscript{97} Ibid.
\textsuperscript{99} Ibid.
Alternatively, the IAEA D-Value represents the smallest amount of each radioisotope that would fall into the IAEA Cat 3 ranking.\textsuperscript{100} Cat 3 sources are not addressed in the IAEA Code of Conduct. Overall, the current guidance for the international community calls for enhanced regulation for Cat 1 and Cat 2 sources, but not for Cat 3 sources. Since the D-value represents the \textit{smallest} amount of material that could be considered dangerous, some quantities of material included in the IAEA D-value calculus would probably cause effects that are too limited to meet our definition of a radiological attack. Although using a radiation source to cause harm to an individual by, for example, placing an unshielded source in a victim’s pocket without his/her knowledge does pose a real risk, a single occurrence of this type does not meet the threshold of a radiological attack as defined in this study. However, the repeated malicious use of radioactive material in this manner, resulting in internal health effects to a group of at least 50 individuals, would meet threshold for consideration here. Since the NRC quantity of concern provides the best definition of how much material would make US officials worry if used in an attack, and is consistent with standing international guidelines, the remainder of this study will use the NRC-defined quantities of concern as the best estimated quantity that terrorists might target.

Having established the quantities of radioisotopes that would cause general concern among government officials if used in a radiological attack, the analysis can now return to the types of materials that were reported missing in the United States in 2010.

\textsuperscript{100} The IAEA D-Value is used as the basis for calculating the IAEA Category for any given quantity of material. The IAEA Category is determined by dividing the given quantity of material by the D-Value for that material. If the result of that calculation is 1, then the source is always a Cat 3 source. As such, the D-Value should be considered the threshold quantity for Cat 3 sources. Visit Appendix C for more details on how to calculate the correct category for any given source.
As established in the previous section, NRC data shows that “high-risk” sources of Cs-137 and Am-241 accounted for the material types that were most frequently lost or stolen in the US last year.\textsuperscript{101} The majority of these stolen sources were contained inside industrial gauges commonly used in construction.\textsuperscript{102} However, to truly establish the missing sources that would be most useful for terrorists or malicious actors seeking a radiological capability, the\textit{quantity} of missing materials must be considered.

The majority of the NRC event reports specify the quantity of material involved in each loss or theft. For those reports that do not specify the amount of material, the quantity can be determined by researching the make and model of the commercial device involved in the event.\textsuperscript{103} It is important to note that, for all device types, the number of curies most often cited corresponds to the amount of radiation present at the date of manufacture. However, every radiation source decays over time, and the rate of decay varies by source type and is denoted by the source’s half-life. Taking this into account, the quantity of missing material cited here is probably inaccurate because the figures reported to the NRC likely do not account for radioactive decay. However, by adding together the individual reported quantities of all missing radiation sources, by source type, it is possible to determine the largest\textit{potential} quantity of radioactive materials

\textsuperscript{102} Ibid.
\textsuperscript{103} The NRC Event Reports that did not specify the amount of material involved the loss or theft of Troxler gauges. The amount of material contained in Troxler gauges may be determined by viewing the Operation Manuals for the make and model of gauge. To determine this, the author reviewed the Troxler operation manuals for the specified equipment. The Guides reviewed are: “Troxler 3411-B Advanced Control Unit,” Manual of Operation and Instruction, Troxler Electronic Laboratories, Inc., 2006.; “Model 3430 (and Model 3430-M) Surface Moisture-Density Gauge,” Manual of Operation and Instruction, Troxler Electronic Laboratories, Inc., 2006.; “Model 3440 Surface Moisture-Density Gauge,” Manual of Operation and Instruction, Troxler Electronic Laboratories, Inc., 2009.
currently outside regulatory control and most vulnerable to malicious use. This represents
the best possible estimate, not the exact quantity in real terms. The sum quantity of
missing material for each radioisotope is detailed in Figure 7.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Quantity Missing in 2010 (Ci)</th>
<th>NRC QoC (Ci)</th>
<th>Percentage QoC Missing</th>
<th>No. of Devices Missing</th>
<th>IAEA Cat of Missing Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am-241</td>
<td>0.85</td>
<td>16</td>
<td>5%</td>
<td>12</td>
<td>4, 5</td>
</tr>
<tr>
<td>Am-241/Be</td>
<td>0.68</td>
<td>16</td>
<td>4%</td>
<td>17</td>
<td>4, 5</td>
</tr>
<tr>
<td>Cs-137</td>
<td>0.56</td>
<td>27</td>
<td>2%</td>
<td>37</td>
<td>4, 5</td>
</tr>
<tr>
<td>Ir-192</td>
<td>7</td>
<td>22</td>
<td>32%</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Pu-239</td>
<td>0.12</td>
<td>16</td>
<td>0.75%</td>
<td>2</td>
<td>4, 5</td>
</tr>
<tr>
<td>Se-75</td>
<td>8</td>
<td>54</td>
<td>15%</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

*Figure 7: Missing Radionuclides of Concern in 2010, along with the missing quantities, shows that a Quantity of Concern was not reported missing for any given radioisotope.*

The analysis shows that, although 37 sources containing Cs-137 were reported as
missing in 2010, the sum total of missing Cs-137 equals only 2% of a quantity of
concern. A terrorist seeking to acquire a quantity of concern of Cs-137 would need to
steal more than 1,000 additional devices of this type in order to obtain the necessary 27
curies of material. Am-241 and Am-241/Be accounted for the other source types most
commonly lost or stolen in 2010. According to available data, a terrorist intent on
acquiring a significant quantity of these radioisotopes would need at least 200 additional
industrial devices.

While the quantities of material associated with device types most often reported
missing do not pose a security risk, the quantities associated with less common events do
pose a potential concern. From January to December 2010, one Cat 3 source of Ir-192
was reported missing. Compared to the number of missing Cs-137 and Am-241 sources,
this single event does not seem significant. However, the quantity of Ir-192 associated with that single event accounts for nearly one-third of a QoC. A terrorist intent on acquiring an amount of radioactive material that would concern federal officials would need to steal only three additional Ir-192 sources of the same type, and use them within 74 days’ time.\textsuperscript{104} In a similar vein, only 6 additional Cat 3 Se-75 sources would be needed to reach a QoC.

Considering the missing radioactive material types \textit{and} quantities leads to some conclusions. First and most importantly, if a terrorist or malicious actor were to somehow acquire every single one of the 70 radioisotopes of concern reported missing and not recovered in 2010, he or she still would not have a quantity of concern for any one source type. Second, the industrial devices that are most often stolen and lost contain quantities of material that are too small to be of use in building a radiological device. Furthermore, the fact that industrial devices with larger amounts of radiation are lost infrequently indicates that current security standards for potentially harmful sources are more effective.

The vast majority of sources lost or stolen in 2010 were Cat 4 and 5 sources, according to the IAEA Categorization of Radioactive Sources.\textsuperscript{105} These are the two least dangerous radiation source categories. Only two missing sources were Cat 3 materials, and there were no reports of Cats 1 or 2 sources that went missing in 2010 that were not

\textsuperscript{104} Note that the half-life for Ir-192 is 74 days. Therefore, depending on the date of manufacture for the missing source as well as how long it has been missing, the quantity of missing radioactive material may have been reduced significantly or fully decayed away.

subsequently recovered.\textsuperscript{106} This points to effective US regulatory control of the most dangerous Cat 1 and Cat 2 sources, moderate to effective regulatory control of Cat 3 sources, and less effective regulatory control of Cat 4 and Cat 5 sources. Taking this into consideration, a moderately capable terrorist intent on acquiring a high risk quantity of concern would most likely target devices containing Cat 3 sources, accumulating three or more devices holding these sources, and then removing each source from its shielding and combining them together for use in a radiological attack.

Cat 3 sources are judged here to be the most likely target for a successful radiological attack for several reasons. As shown by the NRC reports of recently missing radioactive materials, and further exhibited by reviewing NRC regulatory requirements, Cat 3 sources represent the material type that is easiest to acquire in amounts that could quickly accumulate to a quantity of concern. These two qualities meet the requirements of Terrorist RDD Rule #1 and Terrorist RDD Rule #2, as previously described. Although NRC regulations do require licensees to provide elevated security assurances if they possess collocated quantities of radioactive material that together accumulate to a QoC, these same security assurances are not required of individuals who possess only one or two Cat 3 sources.\textsuperscript{107} It cannot be ruled out that a terrorist or malicious actor could steal the required number of Cat 3 sources from a few different locations in order to acquire a QoC. Using the example of the Ir-192 source reported lost in 2010, a terrorist would need

\textsuperscript{106} There was one report of a stolen Cat 2 source, involving 40 curies of Ir-192 inside a vehicle that stolen in Utah. Because this source was recovered immediately after the theft, this incident is not considered to exhibit a regulatory failure of concern. See NRC Event No. 46380, <http://www.nrc.gov/reading-rm/doc-collections/event-status/event/2010/20101105en.html#en46380>, last accessed 13 March 2011.

to steal three additional devices from different facilities to possess the desired amount of material.

In addition, as previously shown in Figure 2 (see page 17), handling Cat 3 sources would require some technical skill, but would not require advanced technical skill. The past terrorist attempts have exhibited very poor levels of technical understanding. Assuming terrorists intent on conducting radiological terror will improve along a progressive learning curve, the most likely future successful attack will exhibit moderate advancement along this curve. The use of Cat 3 sources in a radiological attack represents the highest likely level of technical capability located near the center of this progressive learning curve.

V. BUILDING A RADIOLOGICAL WEAPON

Having determined the radiation source types and quantities that a moderately capable terrorist could acquire domestically in the United States, let us now consider the next step toward a dirty bomb attack – that of building a radiological weapon. Although it is true that acquiring sufficient amounts of radioactive material may pose the most difficult step toward building a radiological weapon, the challenge does not end once a sufficient amount of material has been allocated. Next, the terrorist group would need to determine what form the radioisotope they possess is in, and the most effective way of weaponizing the material to ensure its successful dispersal. The form of radioactive material, the physics of dispersal, and details of weapon design are intrinsic to the success of a radiological attack. However, this study will not detail the steps that a terrorist group
would need to take to construct the most effective device possible using currently missing materials. Doing so would run the risk of assisting terrorist groups, which is counter to the purposes of this study. Instead, this study will assume only that a terrorist group that has acquired a QoC of radioactive material will use this material to perpetrate an attack. The most likely attack would cause a release of radiation less than or equal to the relevant QoC. For example, a terrorist group that has acquired a QoC of Ir-192 will perpetrate a radiological attack that would release between 0 and 22 curies of Ir-192. Therefore, the highest likely scale of attack will equal one NRC QoC for the radioisotope involved. It is important to note that the real dispersal rate for any given radioisotope would depend on many different factors and would almost certainly be less than the full amount of material used. So even though the QoC will be used here to signify the most likely potential exposure rates following a dirty bomb attack, this estimate is moderately to significantly higher than what would result from a real-world attack using this amount of material.

**Considering weapon scale**

In the article “Dirty Bombs: The Threat Revisited,” Peter D. Zimmerman and Cheryl Loeb define three categories of radiological devices.\(^{108}\) These three categories are a Small RDD containing 1-100 curies of a gamma-emitting isotope, a Large RDD containing 1,000-10,000 curies of radioactive material, and a Super RDD containing more than 10,000 curies of radioactive material.\(^{109}\) These three weapon scales have provided a construct for emergency response planners and WMD specialists, allowing them to define what qualifies as a radiological weapon of mass effect. Without doubt, a


\(^{109}\) Ibid.
successful terrorist attack resulting in the dispersal of >10,000 curies of radiation would be devastating. However, past terrorist attempts do not display the technical capability to perpetrate a Super or Large RDD attack. In fact, the past attempts barely exhibit the level of sophistication needed for a Small RDD attack.

Zimmerman and Loeb go on to assert that more attention has been focused on the Small Device type and additional analysis is needed on maximum credible events. The analysis presented here establishes that past terrorist tactics and likely material availability indicate the maximum credible radiological event will be on the scale of a Small RDD weapon type. However, there is a significant difference between a 1 curie source of radiation and a 100 curie source. It is clear that the range of the Small RDD weapon type in its present form is too broad to maintain meaning. This begs the question: At what magnitude does a Small Device pose concern?

This can be determined by applying the data reviewed in previous sections. As already established, the IAEA D-Value represents a quantity of material that is 10 times smaller than the NRC Quantity of Concern, but that represents the amounts of common radioisotopes that could be considered dangerous. However, the use of this quantity to perpetrate an attack against a group of at least 50 individuals would not succeed in most cases. The IAEA D-Value should instead be considered the smallest quantity of radioactive material needed to cause deterministic health effects in one or two individuals. The IAEA D-Values for the Radioisotopes of Concern and High Risk

\[\text{\textsuperscript{110} Ibid.}\]
sources range primarily between 0.5 and 5 curies. Therefore, the first category of Small radiological weapon should be based on the D-Value quantities and should refer to a targeted weapon used against one or two individuals for murder. Because the scale of this attack type is too small to be considered an RDD, it is included here as a Targeted Murder Event. Anything smaller than the lowest D-Value is considered insignificant and is excluded from consideration here.

After a Targeted Murder Event, additional categorization is needed since there still remains a significant difference between a 5 curie weapon and a 100 curie weapon. Although a QoC would not cause devastating radiological effects, this amount of material would result in a use of radiation sizeable enough to concern federal officials. For the “high risk” radioisotopes of concern, the quantities of concern range primarily between 5.4 and 27 curies. Taking into account diminishing rates of radiation due to explosive dispersal, a weapon employing a QoC will probably not result in a dispersal of this magnitude. Therefore, although a Small RDD containing between roughly 5 to 30 curies of radioactive material is not insignificant, its effects would probably be limited. A weapon of this magnitude should be defined as a Small RDD of Limited Effect.

Last but not least, a Small RDD containing 30-100 curies of radioactive material would likely cause enough radiation exposure to pose a concern to government officials.

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111 The full range of D-Values for NRC Radioisotopes of Concern is 0.5 to 1081 curies, and the full range of D-Values for the “High Risk” list, defined by Ferguson et al, ranges from 0.5 to 27 curies. Because the range for NRC Radioisotopes of Concern is too broad to apply to the majority of isotopes considered within the Small RDD weapon range, the “High Risk” range is used here. With the exception of Sr-90 (Yttrium(Y)-90), which has a D-Value of 27 curies, all other isotopes on the high risk list have D-Values ranging from 0.5 to 2.7 curies. This more restrictive range is used here, as this is the range that would most consistently result in a malicious use event perpetrated against one or two individuals.

112 This is true for all seven “high risk” radioisotopes except for Sr-90 (Y-90), which has a QoC of 270 Ci. This quantity is outside the range of a Small RDD device type, and is thus excluded from consideration here.
Although the physics of dispersal make it likely that actual exposure rates resulting from the blast would not reach a full QoC for any given radioisotope, this category of a small device poses the highest level of concern and would probably represent a significant event with primarily disruptive effects. Because more than a QoC of radioactive material would be needed for this scale of weapon, a more-advanced technical skill-set would be required on the part of the perpetrator. For all of these reasons, a Small RDD with 30-100 curies of radioactive material should be considered a Small Device of Concern.

<table>
<thead>
<tr>
<th>Small Radiological Device – Scales of Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Murder Event</strong></td>
</tr>
<tr>
<td><strong>Limited Small Device</strong></td>
</tr>
<tr>
<td><strong>Small Device of Concern</strong></td>
</tr>
</tbody>
</table>

*Figure 8: The sub-categories for Small RDD Weapons presented here gives additional detail on the different groupings of a Small Weapon type and the likely magnitude of attack associated with each device*

Using these more refined categories of a Small RDD weapon, the analysis presented here shows that a moderately capable terrorist intent on perpetrating a ‘dirty bomb’ attack is most likely to successfully construct a Limited Device by collecting commercially available Cat 3 “high risk” radioisotopes adding up to one NRC-defined QoC. While this magnitude of attack would not be insignificant, it would not result in radiation exposure rates high enough to pose an immediate risk to human health. Therefore, the most likely scale of radiological attack against the US would *not* pose a significant threat to national security due to adverse health effects.
Note that this analysis excludes consideration of the economic and psychological threats posed by a dirty bomb of any magnitude.\textsuperscript{113} The disruptive effects of even a minute radiological emission could be significant, and effective communication with the public on the real health risks associated with a given scale of attack is imperative for preventing undue panic. As such, the scales for a Small Radiological Device outlined above are recommended as a guide for effective public outreach and emergency response.

\textbf{VI. CONCLUSION AND RECOMMENDATIONS}

In the ten years since the threat of a terrorist ‘dirty bomb’ attack was first introduced to the American public as a national security concern, the likelihood of a radiological attack has been deemed inevitable by security specialists – yet an attack of this type has not yet occurred. A review of past terrorist RDD attempts shows that the most extensive research into radioactive materials and dirty bomb designs – that of terrorist Dhiren Barot in the UK – was misguided and outlined tactics that would not result in a radioactive dispersal meriting concern. However, the possibility of a moderately competent terrorist actor correcting past mistakes and carrying out a successful radiological attack cannot be overlooked. The widespread availability and use of radiation sources in the world’s industrialized nations, including in the United States, makes it probable that a malicious actor could successfully acquire these materials inside the US and use them to construct a weapon.

\textsuperscript{113} For additional information on the social and psychological impact of a radiological attack, see Igor Khripunov, “The Social and Psychological Impact of Radiological Terrorism,” \textit{The Nonproliferation Review}, 13:2, pp 275-316.
Past academic research on radiological terrorism outlined six steps that a terrorist would need to take to successfully carry out an RDD attack. However, an in-depth review shows that some of these steps have been taken already and at least one is unnecessary based on real-world considerations. Instead, a modern terrorist actor would likely need to take only three steps to develop a radiological weapon. These three steps include acquiring radioactive materials, building an RDD, and detonating the weapon. As assessed by Ferguson and Potter, the most difficult step would be acquiring radioactive material in sufficient quantities to pose public concern.

Using openly available NRC event reports as a guide, it is possible to estimate the quantity of radioactive material currently missing in the United States. According to the NRC data, a total of 70 radiation sources of concern went missing in 2010 alone. To the average analyst, this number of missing sources appears significant.

However, as shown by Dhiren Barot and his faulty technical analysis, it is not the number of radiation sources but the quantity of radioactive material that matters most. A close review of the quantities of material involved in each theft or loss reported in 2010 shows that all 70 missing sources together would not amount to a single QoC for any given radioisotope. Furthermore, the types and amounts of radiation sources reported missing indicates current US regulatory requirements are highly effective for the most dangerous Category 1 and 2 sources, moderately to highly effective for less dangerous Category 3 sources, and less effective for minimal amounts of radiation contained in Category 4 and 5 sources.

\[114\] Ibid.
The analysis presented here asserts that the most likely radiological attack terrorists could probably accomplish with success will incorporate moderately dangerous Cat 3 sources contained in industrial devices used for various commercial applications across the US. In order to consider the likely magnitude of attack that would result from applying these sources in a radiological weapon, it is necessary to review the current academic categorizations of RDD weapon types and scales. Three categories of radiological devices have been defined already – and include definitions of a Small RDD, a Large RDD and a Super RDD. This study concludes that the most likely successful terrorist ‘dirty bomb’ attack will be on the magnitude of a Small RDD – defined as a device containing 1 to 100 curies of a gamma-emitting radioisotope. However, considering the range of risks associated with a 1 curie source of radiation compared to a 100 curie source, it is clear that this range is too broad to maintain meaning.

To correct this problem, this analysis recommends three sub-categories of a Small RDD, including a Targeted Murder Event containing 0.5-5 curies of radioactive material, a Limited Small Device containing 5-30 curies of radioactive material, and a Small Device of Concern containing 30-100 curies of radioactive material. Of these three categories, only a Device of Concern is likely to cause a dispersal of radiation nearing a quantity of concern. Based on a comparison of past terrorist tactics and currently missing materials, the most likely future terrorist attack will use Cat 3 sources to construct a Small RDD falling into the Limited Small Device range – which would cause only limited health effects to the public.

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Following the conclusions summarized above, three specific recommendations should be strongly considered:

- **Better Communication: Quantity Matters.** The NRC does an excellent job of ensuring strict regulation of all radiation sources, providing timely reporting of security breeches when they occur, and embracing a policy of transparency. The United States is a unique global actor in that US regulatory requirements for radiation sources are the most stringent and the most transparent in the world. However, an analyst considering the number of lost and stolen radiation sources in the US might mistakenly focus on the number of missing sources without taking into account the actual quantity of radiological material involved. To ensure accurate analysis and clear understanding by anyone using the NRC event reports or similar data to conduct analysis, the NRC should include a statement on their event reports defining what percentage of a quantity of concern that individual loss represents. By specifying only a percentage point, the NRC could ensure that the significance of the amount of radiation is made clear to the reader without identifying how many additional devices would be needed to reach a quantity of concern. Although one could rather easily figure this out, it may not be readily apparent due to inconsistencies in radioactive decay.

- **More Stringent US Security Requirements for Cat 3 Sources.** The less stringent regulation of Cat 3 sources, along with the portability of some devices holding these sources and their widespread use in industrial
applications, all point to Cat 3 sources as the most likely and easiest terrorist target. Although a single Cat 3 source does not reach a QoC, accumulating three or four of these sources from different locations and combining them together could quickly add up to a QoC. Considering this, it is recommended here that the NRC change current US regulations so that security for Cat 3 sources is required to meet the same level as for Cat 1 and Cat 2 sources. Although this heightened level of regulation goes beyond the international standards outlined in the IAEA Code of Conduct on the Safety and Security of Radioactive Sources, a more stringent level of security is appropriate for the United States – which is one of world’s top targets for radiological terrorism. By embracing a higher regulatory standard, the NRC could serve as the premier global leader in ensuring effective security standards for radiation sources that could quickly accumulate to a quantity of concern.

- **Further defining magnitudes of concern for Small RDD Weapons.** To more effectively portray the different scales of a Small RDD attack and the level of likely concern associated with each, three sub-categories of Small RDD are recommended. These sub-categories are defined, above, as a Targeted Murder Event, a Limited Small Device and a Small Device of Concern. Adopting these sub-categories of small radiological weapons will ensure that policymakers and emergency response planners are better equipped to understand the effects of an RDD attack of the magnitude most likely to occur.
Radiation Primer

Note: The information in this section was taken directly from the US Nuclear Regulatory Commission. None of the definitions contained herein represent original work by the author of this study.

What is radiation?

According to the US Nuclear Regulatory Commission: “Radiation is energy given off by matter in the form of rays or high-speed particles… [Forces within an atom] work toward a strong, stable balance by getting rid of excess atomic energy (radioactivity). In that process, unstable nuclei may emit a quantity of energy, and this spontaneous emission is what we call radiation.”116

What are the different types of ionizing radiation?

Alpha particles: Alpha particles are charged particles emitted from naturally occurring materials and man-made elements. “In general, alpha particles have a very limited ability to penetrate other materials… [and] can be blocked by a sheet of paper, skin, or even a few inches of air…. Materials that emit alpha particles are potentially dangerous if they are inhaled or swallowed, but external exposure generally does not pose a danger.”117

Beta particles: Beta particles are similar to electrons and are emitted from naturally occurring materials. “In general, beta particles are lighter than alpha particles, and they generally have a greater ability to penetrate other materials. As a result, these particles can travel a few feet in the air, and can penetrate skin. A thin sheet of metal or plastic or a block of wood can stop beta particles.”118

Gamma Rays and Ex-Rays: “Gamma rays and x-rays consist of high-energy waves that can travel great distances at the speed of light and generally have a great ability to penetrate other materials… Several feet of concrete or a few inches of dense material (such as lead) are able to block these types of radiation.”119

Neutrons: “Neutrons are high-speed nuclear particles that have an exceptional ability to penetrate other materials. Of the five types of ionizing radiation discussed here, neutrons are the only one that can make objects radioactive… Because of their exceptional ability to penetrate other materials, neutrons can travel great distances in air and require very thick hydrogen-containing materials (such as concrete or water) to block them.”120

What is a curie?

A curie is “one of three units used to measure the intensity of radioactivity in a sample of material. This value refers to the amount of ionizing radiation released when an element (such as uranium) spontaneously emits energy as a result of the radioactive decay (or disintegration) of an unstable atom… A curie is also a quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second (1 gram of radium, for example). The curie is named for Marie and Pierre Curie, who discovered radium in 1898.”121

117 Ibid.
118 Ibid.
119 Ibid.
120 Ibid.
## APPENDIX B

Note: The information in this section was adapted from the “Chart: Al-Qa’ida’s WMD Activities,” produced by the James Martin Center for Nonproliferation Studies Weapons of Mass Destruction Terrorism Research Program, Updated 13 May 2005. None of the data contained herein represent original work by the author of this study.  

<table>
<thead>
<tr>
<th>Approx. date</th>
<th>Incident</th>
<th>Citations</th>
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<tbody>
<tr>
<td>Unspecified</td>
<td>An al-Qa’ida insider has alleged that Usama Bin Ladin was pressured by network affiliates to purchase radiological material through contacts in Chechnya. The insider has been named as Abu Walid al-Misri. Misri is reportedly planning to publish a book detailing his relationship with Usama Bin Ladin and al-Qa’ida leadership.</td>
<td>Nick Fielding, &quot;Bin Laden’s Dirty Bomb Quest Exposed,&quot; London Times Online, 19 December 2004.</td>
</tr>
<tr>
<td>4/2002</td>
<td>Abu Zubayda claims al-Qa’ida has the interest and know-how to produce a radiological weapon, and the group may already have one in the United States.</td>
<td>Jamie McIntyre, &quot;Zubaydah: al Qaeda Had ‘Dirty Bomb’ Know-How,&quot; CNN, 22 April 2002; &quot;Al-Qaeda Claims ‘Dirty Bomb’ Know-How,&quot; BBC, 23 April 2002</td>
</tr>
<tr>
<td>2004</td>
<td>Reports indicate that an al-Qa’ida affiliate named Midhat Mursi, aka “Abu Khabab,” may have been constructing a ‘dirty bomb’ in early 2004. Mursi is reportedly in contact with Ayman al-Zawahiri and was suspected of managing al-Qa’ida chemical labs in Afghanistan.</td>
<td>Muhammad Wajdi Qandyl, &quot;Searching for Weapons of Mass Destruction and Al-Qa’ida,” Al-Ahbar (Cairo), 18 January 2004.</td>
</tr>
<tr>
<td>6/1/2004</td>
<td>Eight men were arrested in Britain and charged with conspiracy to murder after discovered with information on chemicals, explosives, and radiological materials. Also in their possession were plans to attack economic buildings in New York, Washington and New Jersey. The men were identified as Dhiren Barot, Omar Abdur Rehman, Zia ul Haq, Abdul Aziz Jalil, Nadeem Tarmohammed, Moammed Naveed Bhatti, Quaisar Shaffi, and Junade Feroze.</td>
<td>Ben English, &quot;Britain Charges Eight Over US ‘Terror Campaign,’” The Advertiser, 18 August 2004.</td>
</tr>
</tbody>
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Definitions of IAEA Radiation Source Categories 1-5

Note: The information in this section was taken directly from the IAEA “Categorization of Radioactive Sources.” None of the definitions contained herein represent original work by the author of this study.

**Category 1 Source:** “Extremely dangerous to the person: This source, if not safely managed or securely protected, would be likely to cause permanent injury to a person who handled it or who was otherwise in contact with it for more than a few minutes. It would probably be fatal to be close to the amount of unshielded radioactive material for a period in the range of a few minutes to an hour. This amount of radioactive material, if dispersed, could possibly – although it would be unlikely – permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a few hundred meters away, but contaminated areas would need to be cleaned up in accordance with international standards. For large sources the area to be cleaned up could be a square kilometer or more.”

**Category 2 Source:** “Very dangerous to the person: This source, if not safely managed or securely protected, could cause permanent injury to a person who handled it or who was otherwise in contact with it for a short time (minutes to hours). It could possibly be fatal to be close to this amount of unshielded radioactive material for a period of hours to days. This amount of radioactive material, if dispersed, could possibly – although it would be very unlikely – permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a hundred meters or so away, but contaminated areas would need to be cleaned up in accordance with international standards. This area to be cleaned up would probably not exceed a square kilometer.”

**Category 3 Source:** “Dangerous to the person: This source, if not safely managed or security protected, could cause permanent injury to a person who handled it or who was otherwise in contact with it for some hours. It could possibly – although it would be unlikely – be fatal to be close to this amount of unshielded radioactive material for a period of days to weeks. This amount of radioactive material, if dispersed, could possibly – although it would be extremely unlikely – permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a few meters away, but contaminated areas would need to be cleaned up in accordance with international standards. The area to be cleaned up would probably not exceed a small fraction of a square kilometer.”

**Category 4 Source:** “Unlikely to be dangerous to the person: It is very unlikely that anyone would be permanently injured by this source. However, this amount of unshielded radioactive material, if not safely managed or security protected, could possibly – although it would be unlikely – temporarily injure someone who handled it or who was otherwise in contact with it for many hours, or who was close to it for a period of many weeks. This amount, if dispersed, could not permanently injure persons.”

**Category 5 Source:** “Most unlikely to be dangerous to the person: No one could be permanently injured by this source. This amount of radioactive material, if dispersed, could not permanently injure anyone.”

* The size of the area to be cleaned up would depend on many factors (including the activity, the radionuclide, how it was dispersed and the weather.

** Possible delayed health effects are not taken into account in this statement.

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124 Ibid.
125 Ibid.
126 Ibid, p 33.
127 Ibid, p 33
BIBLIOGRAPHY


“Reports of theft or loss of licensed material,” Code of Federal Regulations, Title 10, Section 20.2201.


United States Code, Title 22, Ch 38, S 2656f, (d) Definitions, (2) “terrorism,” <http://www.law.cornell.edu/uscode/22/usc_sec_22_00002656----f000-.html> last accessed on 13 March 2011.