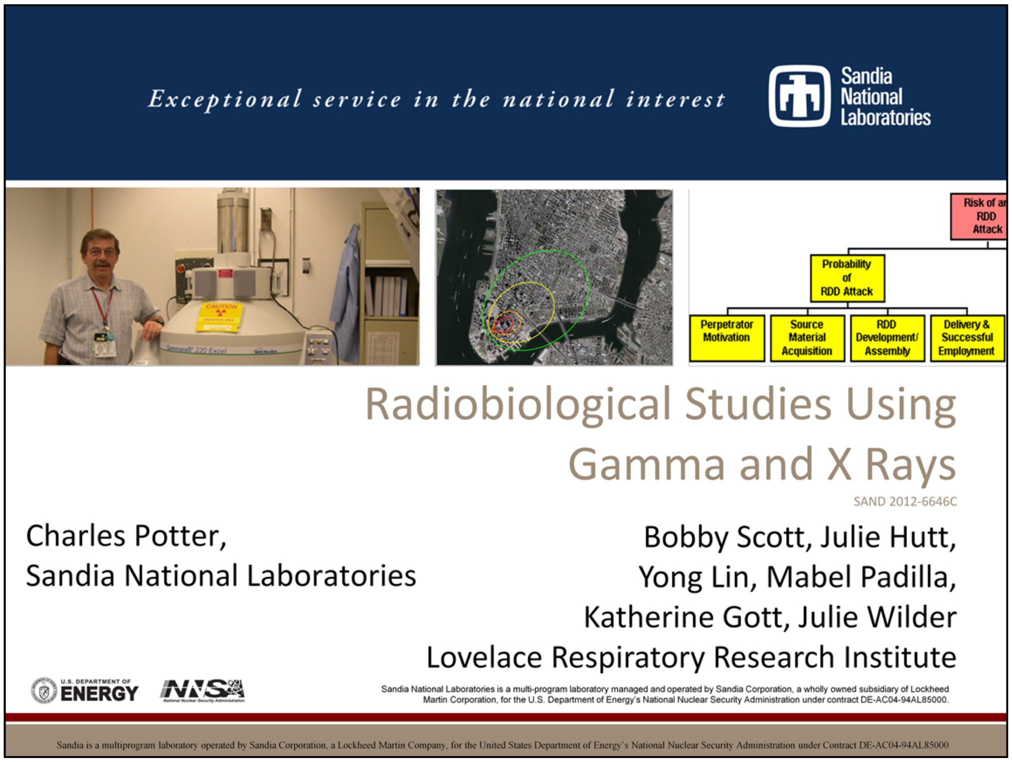
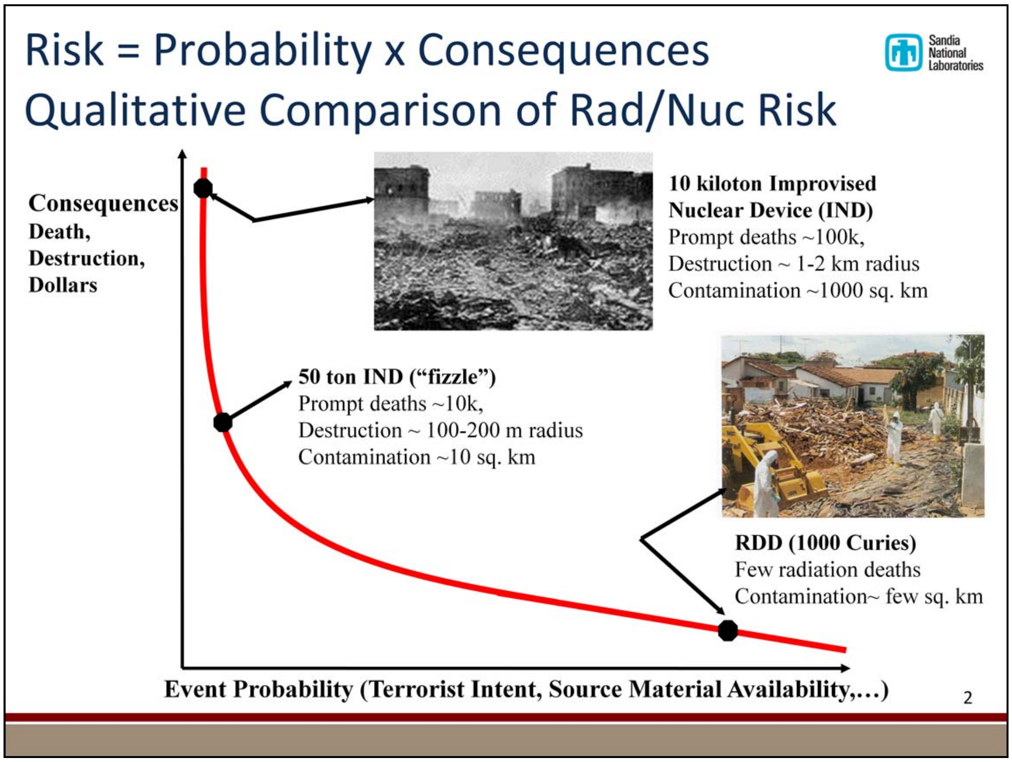


Thank you.

Sandia National Laboratories and the Lovelace Respiratory Research Institute are undertaking this study, Radiobiological Studies Using Gamma and X Rays. This research is sponsored by the NNSA's Office of Proliferation Detection, NA-221 under their Source Replacement portfolio which, unfortunately, has been discontinued in 2013. The research in this study is still ongoing, and this presentation will focus on the need for an alternative to research irradiators and provide some information on the elements of the study.

The need for a viable replacement option for Cs-137 irradiators has been well documented and broadcast, most significantly by the National Academy of Sciences in their 2008 report, Radiation Source Use and Replacement. This study attempts to evaluate the use of an X-ray irradiator as a suitable replacement by comparing the results of identical experiments on biological samples using both systems.



As a metric, the concept of risk can be defined as the product of probability and consequences. A likely model of comparison of radiological vs. nuclear risk and consequences is shown here. Nuclear devices are more difficult – the material is more difficult to obtain and the devices more difficult to develop – and are therefore less probable. Radiological dispersal devices or RDDs, on the other hand, are built using common explosive technologies while including radiological material in the device. The IND causes significant physical damage including deaths, destruction of structures, and contamination, but fortunately the difficulty in development reduces the risk greatly. RDDs would cause few deaths almost entirely from the explosive blast, but could result in significant costs to clean up the resultant contamination.

Options for Radiological Terrorism

Device Type	Dispersal Form	Economic Effects	Health Effects	Comments
Radiation Exposure Device (RED)	None	Low	Radiation sickness	Could impact thousands; Lethality difficult; No lasting economic impact
Food or Water poisoning	Dissolve or mix	Medium	Serious health effects over large population	**Not unique** Other poisons more readily available
RDD for "Area Denial"	Many	High	Few (if any) prompt health effects; Slight increased cancer risk	**Unique** aspect of radiological material

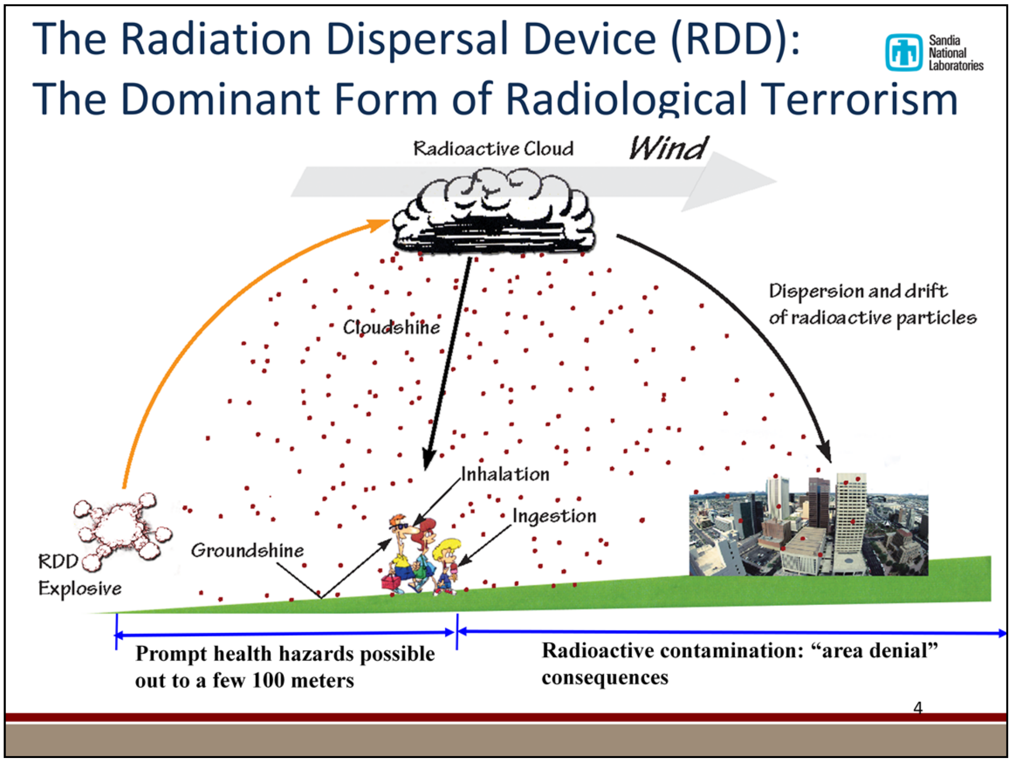
- **An Area Denial RDD has the best likelihood for mass effect**

3

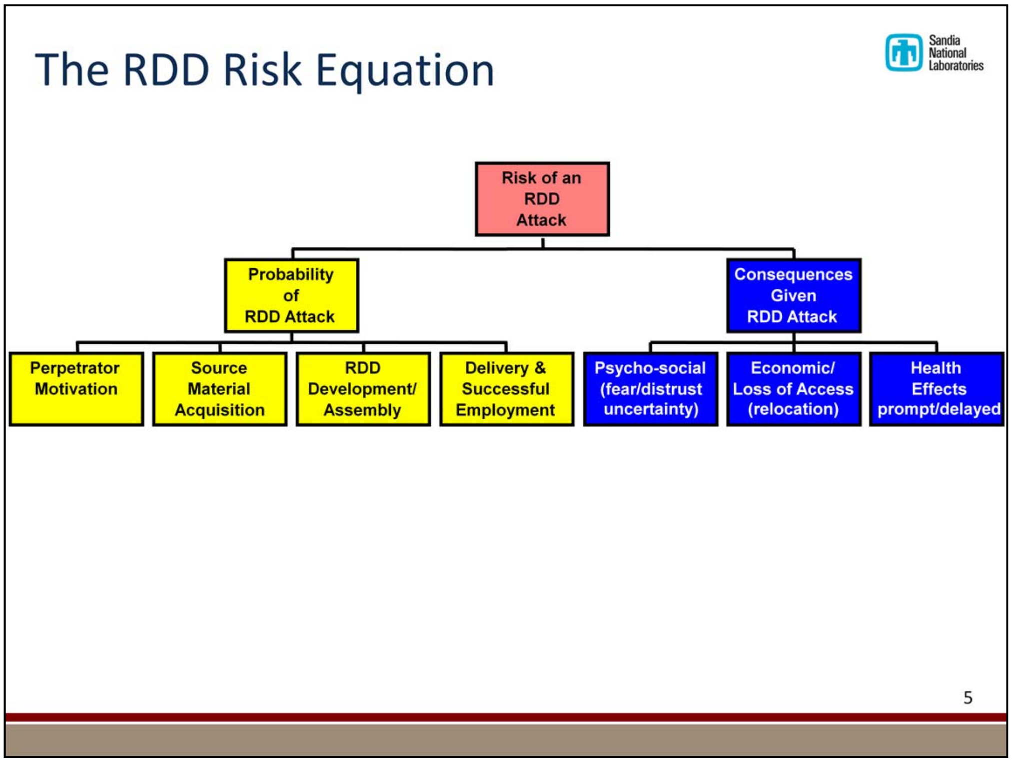
This table shows options available for radiological terrorism. The first, a radiation exposure device, is basically a source left in some area where individuals can walk through the radiation field. Exposure is external only and the duration is dependent on the location and traffic patterns around that location. There is really no mechanism for effects to structures, or vehicles or other economic considerations. However, effects on persons are very possible, their severity dependent on the activity of the source and the time spent in close proximity to the source. If the source is small or located in an area where people are not in the radiation field very long, there may be no possibility of deterministic effects. On the other hand, if the configuration is such where an individual can be in close proximity to a relatively large source for a longer period of time (those of you familiar with the incident involving exposure to strontium irradiators in the country of Georgia can picture) the radiation effects could be considerable.

Using radioactive material for poisoning in either the food chain or water system is extremely challenging. The material must be physically undetectable, meaning that it cannot be seen or tasted. This would indicate a preference for material of higher specific activity, but the shorter half-life of such materials would make that difficult. Also, adding material to the food or water dilutes the material, resulting in either greatly reduced effects or none at all. There are also poisons or other agents that are more effective and easier to obtain than radiological material.

If the goal of the terrorism is an area of denial, this can be accomplished by an RDD. Area that is contaminated by the event will be basically off-limits for an extended period of time during which cleanup of the contamination is performed. This could be economic consequence of large magnitude, especially since no regulations or guidelines exist for cleanup of this type of event.

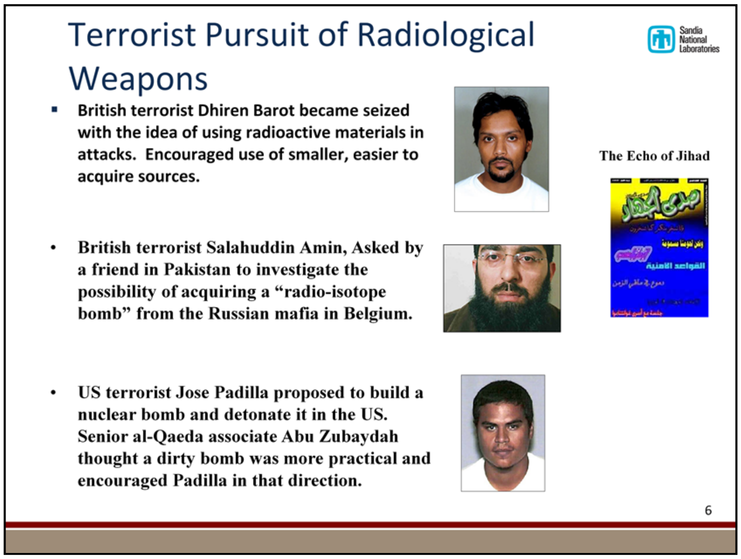


This slide shows the different pathways for exposure following an RDD explosion resulting in considerable contamination. External exposure can come from "groundshine" or "cloudshine" where radiation emitted from particles on the ground or in the air can interact with individuals directly. Internal exposure where radioactive material is taken internally can come from both inhalation and ingestion pathways. Inhalation obviously occurs from material that has become airborne. Ingestion most likely occurs by transferring contamination from the hands to the mouth when touching the face for whatever reason. If the contamination levels were high enough, prompt deterministic effects might happen within a few 100 meters from the detonation. Dispersion, on the other hand, requiring mitigation might extend farther resulting in a large area of denial as previously described.



This slide shows the components of risk for an RDD event. On the left the yellow boxes show components relating to probability. These include motivation of the perpetrator, availability of source material and ability to acquire it, ability to develop and assemble an actual device, and getting the device to the intended target and detonating it.

On the right, the blue boxes show the consequences of a successful operation. These include health effects, whether prompt or delayed, the area of denial concept and resultant economic consequence, and perhaps the worst for an RDD, the psycho-social aspects effecting individuals with a pre-disposed fear of radiation and its potential effects and also the survivors of the event who could be in danger of being stigmatized.



It is known that terrorists have shown interest in the pursuit of radiological materials with which to make weapons. Four instances are shown here.

Dhiren Barot, convicted of plotting simultaneous attacks in the US and UK, actually wrote a book about his early terrorist experiences entitled "The Army of Madinah." He endeavored to engage in feasibility studies of various types of large-scale attacks on Western targets, including the employment of radioactive materials. He proposed the use of radiological materials, recommending sources that were easier to acquire. When arrested, his computer was found to have "recipes for construction" of RDDs.

Salahuddin Amin, convicted of complicity in a planned fertilizer attack in London, was asked to investigate the possibility of acquiring a radiological device from the Russian Mafia in Belgium.

US terrorist Jose Padilla proposed to build a nuclear bomb and detonate it in the US. Senior al-Qaeda associate Abu Zubaydah thought a dirty bomb was more practical and encouraged Padilla in that direction.

Finally, concepts for creation of dirty bombs has also been published in Echo of Jihad.

British Terrorist Dhiren Barot's Research on Radiological Weapons

By Robert Wesley

After returning from his militant adventures in Kashmir, recently sentenced British terrorist Dhiren Barot recounted his experiences in the book The Army of Madinah in Kashmir. Writing under his alias 'Esa al-Hindi, he lashed out against Western powers' interventions in Muslim lands, advising that "in the face of such an adversary, the solution may only be 'flank protection' to be carried out upon the soil of all interfering nations" [1]. Heeding his own advice, Barot subsequently endeavored to engage in feasibility studies of various types of large-scale attacks on Western targets, including the employment of radioactive materials. A detailed examination of his research activities has revealed numerous potential lessons to be learned for those charged with preventing radiological terrorism, three of which are mentioned below.

According to his own writing, Barot initially conceptualized the decision to incorporate radioactive materials into his attack scenarios much in the same way as one would decide between attaching nails or ball bearings to a pipe bomb (i.e. as an after-thought). He quickly discovered, however, that radioactive materials had enough potential to be addressed as a primary weapon rather than simply as a secondary consideration [2]. Barot's surprisingly detailed research unsettlingly reveals just how accessible and instructive the relevant literature is concerning radioactive materials and their potential for malicious use. For example, Barot was able to obtain numerous public documents concerning the potential effects of Radiological Dispersal Devices (RDDs), including employment scenarios. The literature available greatly assisted Barot's investigation of the core obstacles that would need to be overcome for a successful RDD operation.

Another significant consideration is that Barot approached targeting selection and methods of attack for radiological weapons based on, among other things, the simplicity of the plan and availability of resources. This is in line with the traditional practice and advice of al-Qaeda operatives and strategists. Correspondingly, he recommended that acquisition of radioactive sources should be based on ease of access rather than the hazardous effects of the source. The inference was that high activity sources (usually the most harmful) were also the most difficult to secure access to, and thus were to be in most cases avoided in favor of less radioactive, yet more accessible sources.

Barot also addressed access primarily in terms of the potential for operatives to purchase the radioactive materials in question. He stated that, "there are a few large and powerful radioactive devices...however, for the time being we do not have the contacts that would allow us to purchase such items (previously we had one but he has since been arrested)." To date, the prevailing fear of regulatory authorities has been the theft of radioactive sources, not so much the purchase.

In light of these lessons learned from the Barot case, those charged with the prevention and mitigation of attacks involving radioactive materials should clearly reassess protection and regulation standards for all categories of sources regardless of deterministic effects. There is also an immediate need to renew serious discussion of the permissibility of technical and other literature for public release. Ironically, the release of Barot's documents—even though partially sanitized—could potentially be of assistance to those interested in conducting such attacks in the future.

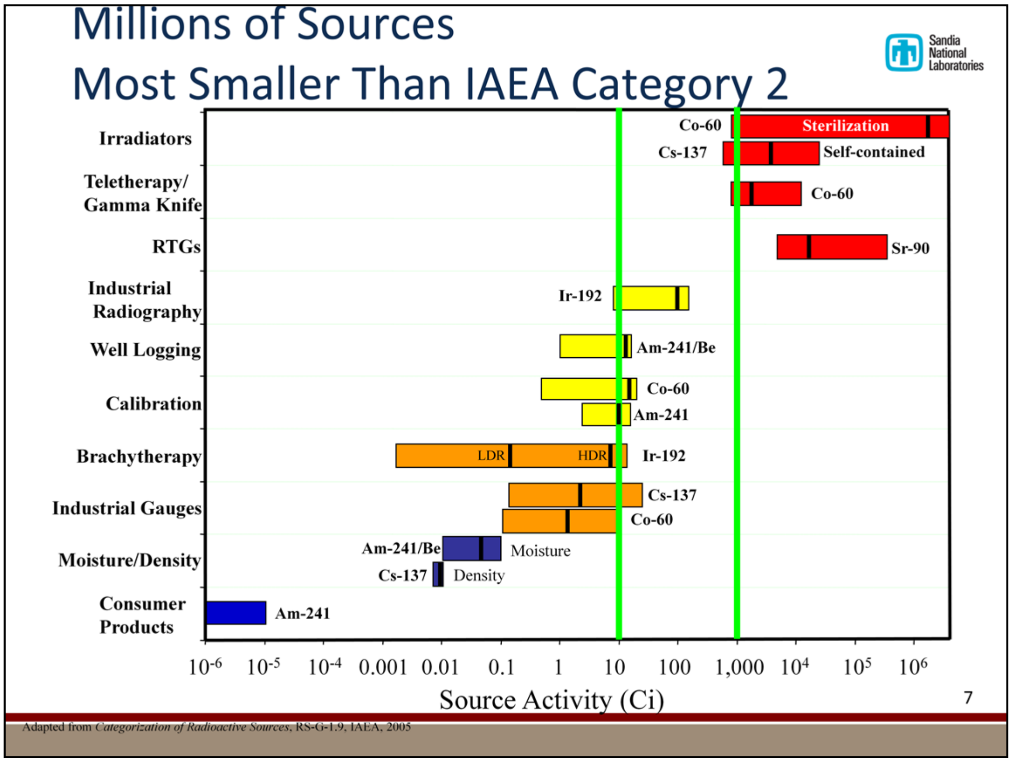
Notes

1. 'Esa al-Hindi, The Army of Madinah in Kashmir, (Makhtaba al-Ansaar Publications, 1999): p. 116.

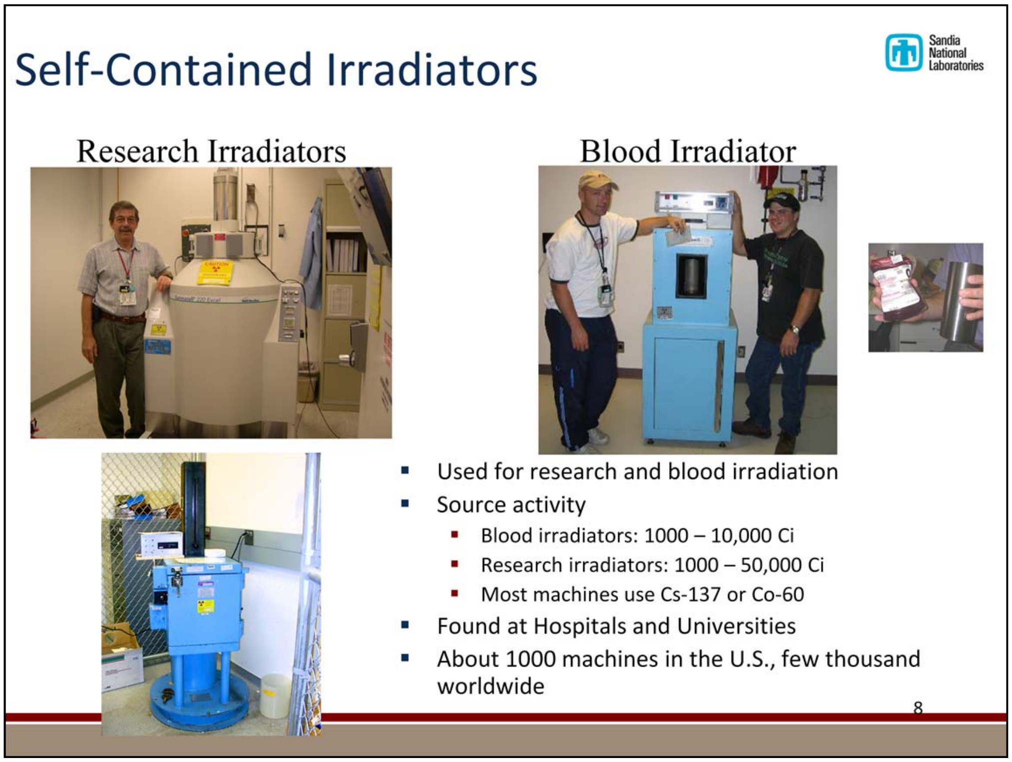
2. All references to Barot's research on radioactive materials in this article come from documents released by the London Metropolitan Police Service entitled "Rough Presentation for Gas Limos Project," "Hazards," and "Final Presentation."

Dhiren Barot is not the first—or the last–to “discover” how easy it is to conduct a radiological attack.

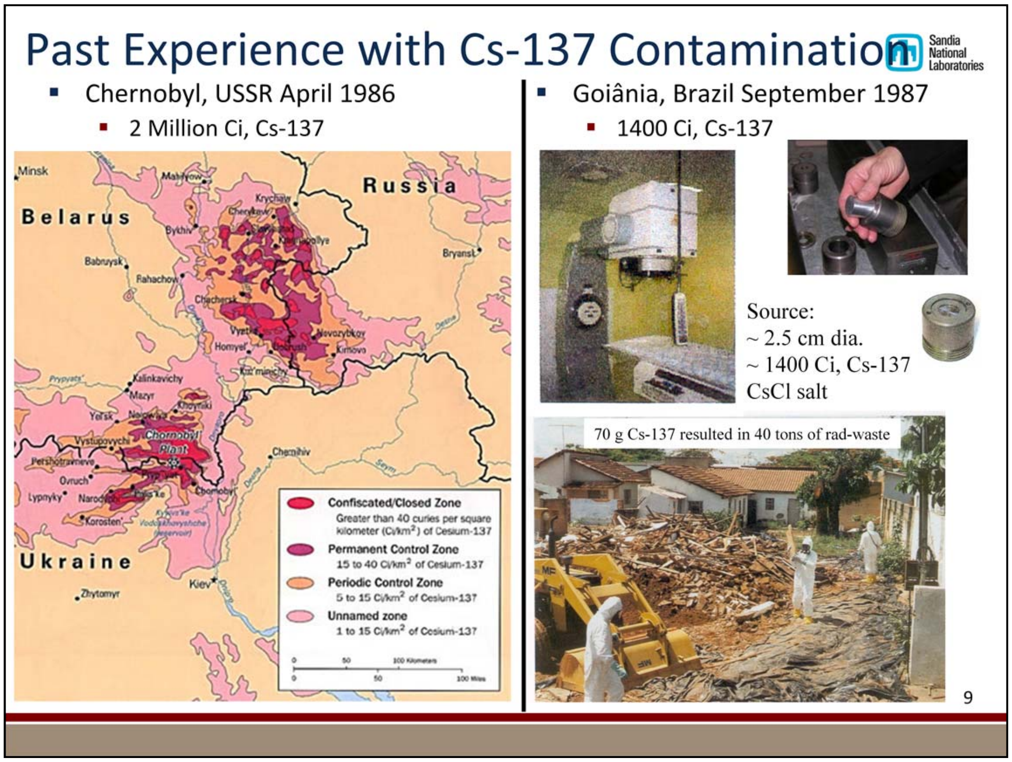
His approach of seeking smaller sources definitely would increase the chances of successfully carrying out a radiological attack, while simultaneously decreasing the radiological impact of such an attack.



This chart shows source sizes in Ci over a large range, six orders of magnitude, from the micro-curie consumer device smoke detector to the mega-curie panoramic sterilization irradiators. The green vertical lines represent threshold quantities for a 10 Ci RDD of concern and a 1000 Ci significant, national level RDD based on area-of-denial and availability of sources of that magnitude. It can be seen that many devices including moisture and density gauges and consumer products such as smoke detectors fall below the 10 Ci threshold. It can also be seen that only three of those nuclides are generally present in greater than 1000 Ci quantities: Co-60 as used in irradiators and teletherapy or gamma knife units, Cs-137 in industrial irradiators, and Sr-90 once in common use in radioisotopic thermal generators. Devices that cross the second threshold of 10 Ci include industrial radiography cameras, brachytherapy devices, industrial gauges, and calibration devices.



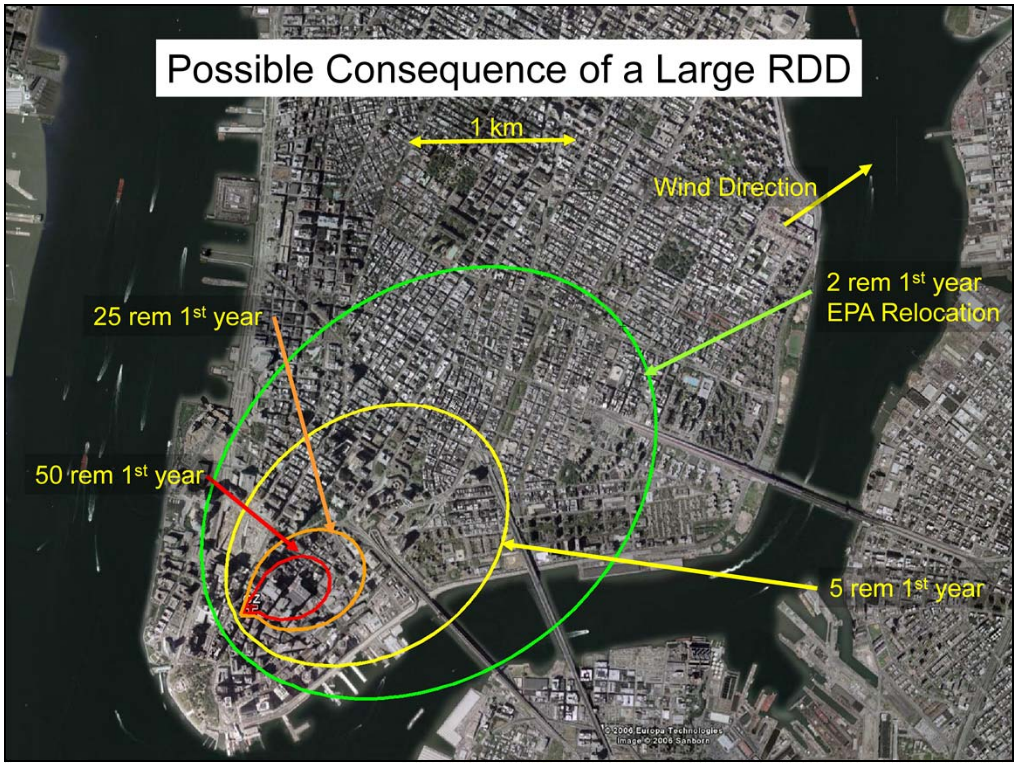
Blood and research irradiators, like those shown here, are widely available. Blood irradiators are commonly used in hospitals to kill donor lymphocytes. This is necessary because those lymphocytes will mount a cellular immune response against the host tissues. Research irradiators are used in many applications, but the one relevant to this research is to understand the response of normal and cancer cells to irradiation, by itself or with administration of some pharmaceutical with which there is hoped to be a synergistic effect. As can be seen on the slide, most of these irradiators use Cs-137 or Co-60 with activities ranging from 1000 Ci to 10,000 Ci for blood irradiators and 50,000 for research irradiators. There are around 1000 in the US with a few thousand more worldwide.



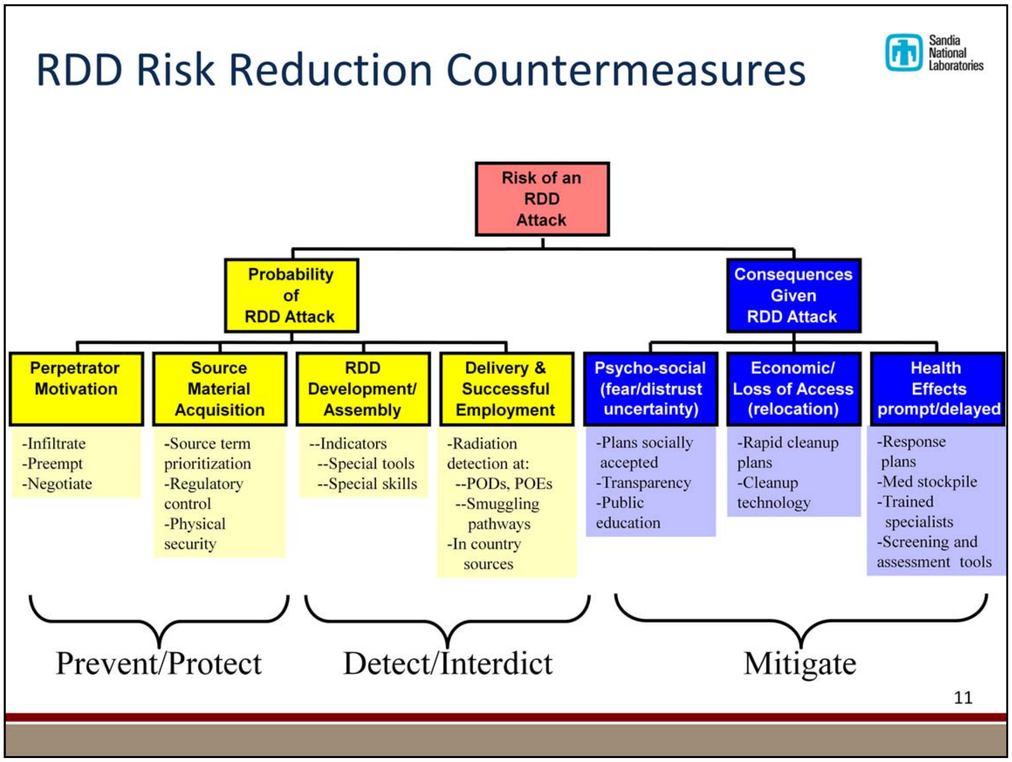
While we have been fortunate not to have experienced an actual RDD attack, there have been some rather famous instances of large-scale contamination events. Lessons learned from these events can be instructive in helping us to understand what a response, particularly by the public, might resemble.

On the left is a map of the Chernobyl contamination spread through the Ukraine, Belarus, and western Russia. The causes and consequences of this disaster are well-known. What is important to remember for this discussion is that 26 years later, much of the contaminated area is still considered uninhabitable, there being no national or international standard for cleanup of radioactive material. In addition, the effected population are considered “victims” as opposed to “survivors” and are reported to engage in risky behavior due to viewing themselves as incurably affected by radiation exposure.

On the right are pictures from the Goiania event. In this event, a Cs teletherapy source was broken open and scattered, resulting in the tragic deaths of four individuals from deterministic effects. Contamination was spread to many different areas of the town and the cleanup effort as shown on the bottom right was considerable. The psychological effect was easily seen in that when the Brazilian government offered screening to anyone who felt the need for it, over 100,000 people showed up at a local soccer field to receive the screening.



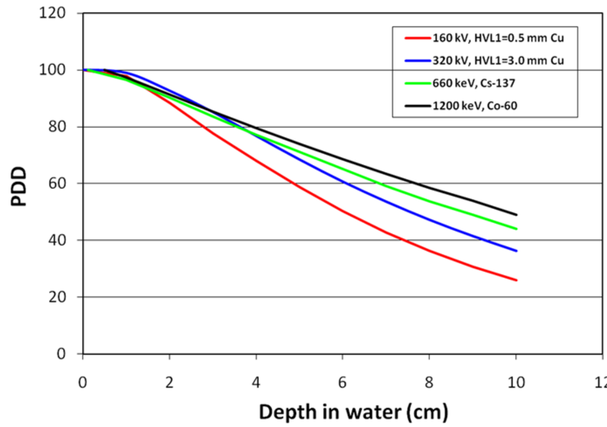
This is an example of what the consequences of a large 1000 Ci RDD could be. The outer circle represents the EPA permissive action guide or PAG for relocation of individuals based on 2 rem in the first year. As can be seen, a sizeable chunk of lower Manhattan could be made uninhabitable both for general living and as a workplace until decontamination was performed. It is clear that the economic consequences would be mind-boggling.



This slide restates the elements of an RDD attack, both risks and consequences with countermeasures. On the risk side, countermeasures include those that would prevent the development of an RDD and protect the source material, and options for detection and interdiction once an RDD has been devised. On the consequence side, options for mitigation are shown.

One obvious way of ensuring that material is not available for use in an RDD is to use the material in the first place. That philosophy drives the desire to replace sources such as Cs irradiators with devices not containing radiological sources like X-ray machines, which is the purpose of the study.

Source Replacement Options Comparison



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This slide shows the percentage depth dose of Cs-137, Co-60, and two X-ray replacement options. Since tissue is primarily water and is known to act as such when impinged by radiation, depth in water is shown as the abscissa. The dose from lower energy X-rays, in this case 160 kVp drop off much more with depth than higher energy. However, the curves for Cs-137 and 320 kVp X-rays are reasonably close to a depth of 4 cm. This would beg the question, can a 320 kVp X-ray irradiator be used instead of Cs-137 with similar characteristics?

SNL/LRRI Joint Project

Sandia National Laboratories

- Project Overview
  - To demonstrate the feasibility of achieving the same success in radiobiological studies with a machine generated 320 kV X-ray spectrum as has been achieved with higher energy gamma rays from ^{137}Cs and ^{60}Co.
- Goals
  - Compare the effects of gamma rays from a ^{137}Cs source and the X-ray spectrum from a 320-kV X-ray irradiator on three types of specimens commonly used for radiobiological studies
    - Normal cells
    - Cancer cells
    - Mice for bone marrow transplantation studies.

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Here is the project overview. The idea was to measure the results of studies replicated in each device – a Cs-137 irradiator and a 320 kVp X-ray machine to determine if the effects were constant between them with dose. Three types of specimens were chosen – normal cells, cancer cells, and mice for bone marrow transplantation studies.

Precision X-Ray X-RAD 320

Sandia National Laboratories

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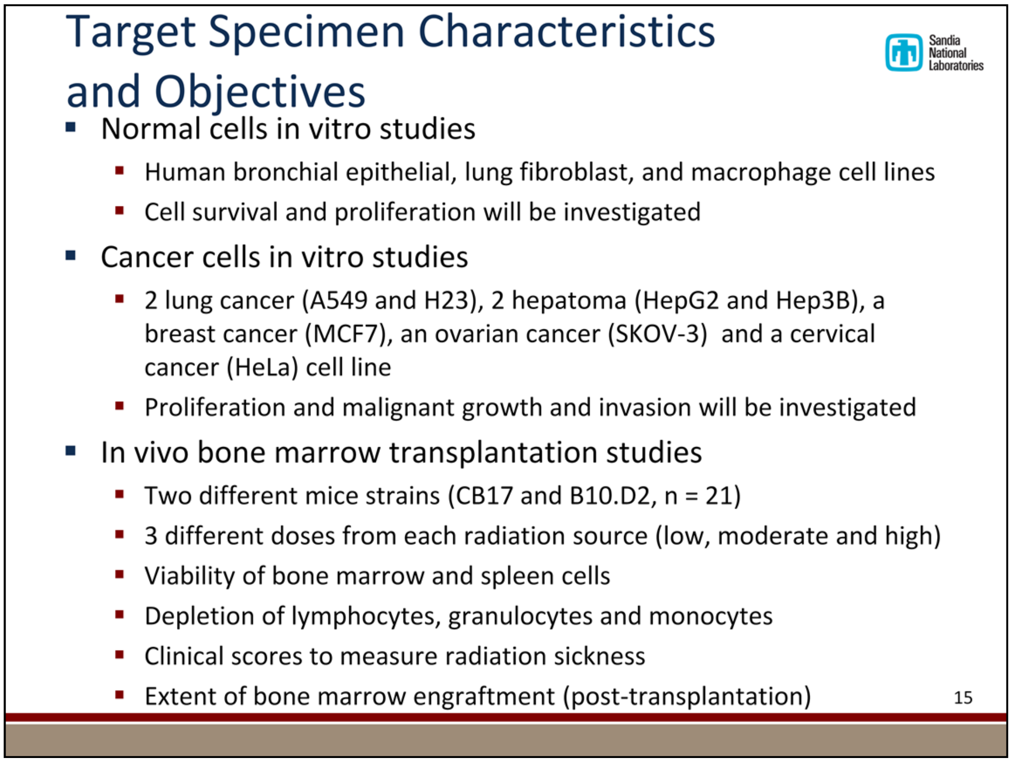
The X-ray machine used for this research is the X-RAD 320 manufactured by Precision X-ray and is a self-contained system for delivering a precise radiation dose to specimens in a biological or small animal research laboratory. The shielded cabinet includes an Adjustable Specimen Shelf, Sample Viewing Window and Beam Hardening Filter Holder. The X-ray tube is designed specifically for radiation therapy having a highly homogenous beam. The unit is capable of providing a dose output of 3 Gy/min with 1 mm Cu hardening, 1 Gy/min with 4 mm Cu harding, and >15 Gy min with no beam hardening.



These are the specifics of the cell types and measurements for each objective.

In the normal cell in vitro study, three cell lines – human bronchial epithelial, lung fibroblast, and macrophage – were used. Cell survival and proliferation were investigated.

In the cancer cell in vitro study multiple cell lines including, two lung cancer, two hepatoma, one breast cancer, one ovarian cancer, and one cervical cancer were used. In this case, proliferation and malignant growth and invasion were measured.

In the in vivo marrow transplantation studies, two different mice strains and three doses from each source were used. Measures as shown here include viability of bone marrow and spleen cells; depletion of lymphocytes, granulocytes, and monocytes; clinical scores to measure radiation sickness; and extent of bone marrow post transplantation engraftment.

Current Status

- Normal and cancer cell work is completed.
  - Work will be published soon in Radiation Protection Dosimetry
  - *Biological Microdosimetry Based on Radiation Cytotoxicity Data*
  - Identified stocasticity issues with microdosimetric measurements on cell populations
- In vivo studies are ongoing
  - Preliminary RBE value is ~1.4 implying longer irradiation times needed for same effect.
  - Specimens are not experiencing adverse skin effects.
  - Results will also be published in open source literature.

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This slide shows the current status of the research. The cell line results have just been published in Radiation Protection Dosimetry. During the initial experiments, it was found that