Dirty Bombs and Liability Exposure in the Petroleum Industry

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Globally, the petroleum industry continues to employ tens of thousands of radioisotopes in activities that range from exploration and production to distribution. The presence of these radioisotope sources, in such vast numbers, represents a statistically significant opportunity for theft and subsequent misuse. Governments worldwide now regard radiological terrorism, through the use of radiological dispersive devices (RDD) - often called "dirty bombs," to be far more likely than use of a nuclear explosive device. In the context of the recent Deepwater Horizon Incident in the Gulf of Mexico, it is incumbent on the petroleum industry to evaluate liability exposure relative to its radioisotope inventory. Whether protecting the customer base or corporate shareholders, technology now exists to largely mitigate the risk associated with previous generation isotope-based technologies.[1]

Radioisotope Threat

Whether for radiography, gauging or compositional analysis, a variety of radioisotopes (see Table 1) have been routinely employed in the petroleum arena for many decades. For example, americium-241\beryllium (^{241}Am\Be), cesium-137 (^{137}Cs) and californium-252 (^{252}Cf) have all been employed for well logging of oil and gas wells, with respective half-lives ($t^{½}$) of 432, 30 and 2.6 years. Radiography devices for x-raying welds on pipelines and petrochemical plants use iridium-192 (^{192}Ir), and cobalt-60 (^{60}Co), with half-lives of 74 days and 5.3 years respectively. Level and density gauges are used throughout petrochemical plants typically employ ^{60}Co, ^{241}Am or ^{137}Cs. Moisture/density devices used in construction contain smaller ^{241}Am/Be neutron sources and/or ^{137}Cs sources. Analytical instrumentation, used for measurements such as positive material identification, may also contain ^{241}Am, or some other less common or less hazardous isotopes.

^{241}Am\Be produces neutrons when the ^{241}Am emits an alpha particle that is absorbed by the beryllium, producing an unstable carbon isotope that decays emitting a neutron. It also emits low energy gamma rays that are not very hazardous. Alpha radiation is very hazardous if inhaled or ingested. Beryllium is also highly toxic if inhaled. The hazard is such that first responders, responding to an RDD event using an alpha emitter, must wear respiratory protection as they can exceed the US Environmental Protection Agency's Protective Actions Guidelines (PAGs) at levels that they cannot measure with the typical radiation meter that they may carry.[2]

The U.S. has been out of the ^{241}Am business for many years and thus has created a shortage. That shortage is now at least partially being filled from Russia. The shortage will become even more critical in the future as many of the sources are over 30 years old and their *special form certificates* which allow them to be shipped inexpensively, are going to expire between now and November 30, 2014. Many of the companies that made the most common ^{241}Am\Be sources are no longer in business, so it is not clear if the certificates can be renewed. It is also not clear if they should be. One of the leading source manufacturers assigns a 15 year life, extendable to 30 years for this type of source and declines to seek a new special form certificate when sources are quite old. In the mean time, ^{252}Cf is being evaluated as an alternative source since it is a very strong neutron emitter. It emits neutrons via prompt fission and, unfortunately, happens to be one of the isotopes with the lowest critical mass for fission in the metallic form, less than Uranium-235 (^{235}U) and Plutonium-239 (^{239}Pu).[3]

The other common well logging isotope is ^{137}Cs, which emits a beta (β) particle and then a high-energy gamma ray (0.662 MeV from a ^{137}Ba decay intermediate). Commonly available as a chloride salt, it is readily soluble in water, making it easy to spread but exceedingly difficult to remediate. Radiography sources, including ^{192}Ir and ^{60}Co, are the most dangerous if used in a Radiological Exposure Device (RED) as they are quite deadly if left unshielded. Both are high-energy gamma ray (γ) emitters: ^{192}Ir principally emits gamma radiation at 0.317 and 0.468 MeV and ^{60}Co at 1.17 and 1.33 MeV. However they are usually not deadly at distances of 10 meters or more, assuming short exposures, and are generally easy to shield and recover if left in a capsule. Both are usually distributed in a solid metal form, but can easily be made usable in a RDD.

The size of the affected area, and the level of destruction caused by an RDD, would depend on the sophistication and size of the conventional bomb, the type of radioactive material used, the quality and quantity of the radioactive material, and the local meteorological conditions. The area affected could be placed off-limits to the public for an extended period during cleanup efforts.[8]

A publicly available software program from The National Atmospheric Release Advisory Center (NARAC), called *HotSpot*, may be used to quickly determine the effects of a theoretical RDD. Using a 16 curie ^{241}Am\Be source as an example, one can easily model the effects. A ground explosion was assumed with the following parameters: one pound (TNT equivalent) charge, wind speed of 4.47 mph, neutral wind stability (Class D), a 1000 meter mixing lid (an atmospheric layer that caps the rise of the plume), and all of the ^{241}Am particles spread by the device were fine enough to be respirable. The resulting radiation exposure area, exceeding 1 REM, extended out 25 km with a maximum width of 3km. This exposure is about four times the average exposure to the public from natural and medical sources of radiation, and it also equates to the EPA PAG for the first years exposure.[9,10]

Table 1: Basic Radiological Properties of 5 Potential Radionuclides for RDDs[4]

Isotope	Half-Life (Years)	Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
				Alpha (α)	Beta (ß)	Gamma (γ)
Americium-241	430	3.5	α	5.5	0.052	0.033
Californium-252	2.6	540	α (SF, EC)	5.9	0.0056	0.0012
Cesium-137	30	88	ß, IT	-	0.19, 0.065	0.662
Cobalt-60	5.3	1,100	ß	-	0.097	1.17, 1.33
Iridium-192	0.2 (74 d)	9,200	ß, EC	-	0.256 - 0.672	0.317, 0.468

SF = spontaneous fission; IT = isomeric transition; EC = electron capture. A hyphen means the decay mode does not produce that type of radiation. The radiation energies for cesium-137 include the contributions of barium-137 metastable (Ba-137m).

Suffice it to say that an abundance of radioactive sources are in the petroleum industry inventory, at activity levels ranging from less than 1 curie (Ci) to more than 150 Ci, which is high enough to be used to effect terror and economic disruption on a large scale. To further put the situation into perspective, as of 2008 in the United States alone, companies have reported losing track of almost 1,700 radioactive sources in the previous decade. Of the very large number of sources in use at any one time, in the United States, an average of 430 sources are lost or stolen each year.[5]

Mass Disruption

A radiological dispersive device combines a conventional explosive device with radioactive material. It is designed to scatter dangerous but typically sub-lethal amounts of radioactive material over a general area. Such RDDs appeal to terrorists because they require limited technical knowledge to build. The primary purpose of terrorist use of an RDD is to cause psychological fear and economic disorder, leading to the popular classification of RDDs as *Weapons of Mass Disruption*.[6] Some devices could cause fatalities from exposure to radioactive materials. Depending on the speed at which the area of the RDD detonation was evacuated, or how successful people were at sheltering-in-place, the number of deaths and injuries from an RDD might not be substantially greater than from a conventional bomb explosion.[7]

Liability Scenarios

While it is believed that immediate human casualties associated with a radiological dispersal event (RDE) would be low, and mostly attributed to the detonation and not radioactivity, such an event is particularly dangerous in that it has the potential to cause major economic disruptions. In a potential RDE scenario in Manhattan, involving the dispersion of the amount of americium-241 used in well-logging equipment, a region two kilometers long and covering sixty city blocks was modeled to be contaminated in excess of EPA safety guidelines. As reported in a 2002 study, the Federation of American Scientists estimated that the decontamination and rebuilding costs for this situation might exceed $50 billion.[11]

A study published by the Center for Risk and Economic Analysis of Terrorism Events (CREATE) in 2005 analyzed the impact of simultaneous small-scale (5 pounds of high explosive each) RDD attacks on the twin ports of Los Angeles and Long Beach. Results of the input-output model indicated that, for the worst case scenario, damage from economic disruption could exceed $34 billion, and cost more than 212,000 jobs (measured in person-years of employment, PYE). The "local" impact of a lower end attack, i.e., job and output losses associated with the cessation of port activities for just 15 days, amounted to $138.5 million of lost output and 1,258 PYEs.[12] An independent follow-up study in 2007, providing further risk and economic analysis of dirty bomb attacks on these ports, determined that the economic consequences from a shutdown of the harbours due to the contamination resulted in significant losses in the tens of billions of dollars, including decontamination costs, as well as business and property losses.[13]

A 2005 planning estimate, prepared by the U.S. Department of Homeland Security (DHS), assessed impact of the detonation of a 3,000 pound truck bomb containing 2,300 curies of ^{137}Cs in the downtown business district of a moderate-to-large city on a school day. As a result of the explosions, 90% of the radioisotope was aerosolized and carried by variable winds of 3-8 mph, with radioactive particles ranging in size from 1 micron to 150 microns. Subsequent fallout contains debris that contaminates surrounding structures. Estimates are that the incident results in 180 fatalities, 270 injuries, extensive environmental contamination, evacuation of thousands of individuals, and 20,000 contaminated individuals in the downwind zone. Decontamination, destruction, disposal, and replacement of lost infrastructure were expected to cost hundreds of millions of dollars. While broader economic impacts were not projected, the entire contaminated area was expected to be economically depressed for years.[14]

Research published in 2009 examined the commercial impact of a RDD attack on a medium sized U.S. city, Dayton, Ohio. In this simulation, 2,300 curies of Cs-137 was detonated downtown, at ground level, using only 100 pounds of high explosive. Through the use of an economic input-output model, the research identified that the economic consequences totaled $1.2 billion, while impacts to labour income were $529.6 million. Overall, 21,374 jobs were affected due to the economic disruptions.[15]

In a study published in 2010, using a large-scale computable general equilibrium (CGE) model of the previously described DHS research, the short-run and long-run regional economic consequences of an attack centered on the downtown Los Angeles area were evaluated. The event-year impacts of this scenario were found to arise almost entirely from business interruption. For a 30 day shut-down of the affected area, the real gross domestic product (GDP) loss, via both direct and indirect routes, was found to be $1.9 billion. At a 5 per cent discount rate, the net present value (NPV) long-term GDP losses were calculated at $12.1 billion.[16]

Alternative Technologies

The only sure way to keep radioactive materials out of the hands of terrorists, and minimise liability to the industry, is to find and implement replacement technologies. There are neutron sources available that can substitute for ^{241}Am\Be or ^{252}Cf. Accelerator tubes are already being used for well logging in a limited capacity. These tubes generally operate by accelerating deuterium gas at high-voltage toward a tritium impregnated target, producing fusion and releasing neutrons in the process. Tritium, while radioactive, is not a very dangerous isotope (useless for making an RDD). Accelerator tubes using only deuterium ,or a mixture of deuterium and tritium, are also under development. The technology to do away with ^{241}Am\Be and ^{252}Cf source is already in place, just underutilized and improvements are possible in the near future Drawbacks to accelerator tubes include a relatively short working life and lack of convenience.

As for the gamma and x-ray sources ^{137}Cs, ^{192}Ir, ^{60}Co, and ^{241}Am, all can be replaced by x-ray tubes. There are also non-radiological alternatives for density and level gauging, moisture/density gauging, and positive material identification. There are some challenges ahead: such as developing a small high voltage source and x-ray tube that can fit in a well logging tool, to replace ^{137}Cs sources, or a field portable high energy accelerator that could replace a ^{60}Co radiography camera. But these are not insurmountable problems. Given a concerted industry-wide effort, it is possible to almost entirely eliminate radioisotope sources.

Conclusions

Assessing the economic impacts of disasters is a very recent systematic field of study, using techniques that include surveys, econometric models, Box-Jenkins time series analyses, input-output models, general equilibrium models, and economic accounting models. While these methods all have predictive limitations, for most natural disasters, losses have been mostly associated with employment income and property damage. Even when other costs are included, short term disasters historically have rarely had a meaningful impact on a national economy. But for some types of disaster – specifically terrorism – an event may precipitate negative long-term effects on macroeconomic performance. For the petroleum industry, the economic shock of occasional environmental incidents, coupled to the RDD impact models reviewed here, are a reminder that cleanup and compensation claims from misuse of unsecured radioisotope sources remain a concern.[17]

Radiological attacks are a matter of serious concern, but not panic. Recommendations for mitigation of risk and unnecessary economic exposure within the petroleum industry generally center on reduction of radioisotope inventories, where it is practical. Sources should be retired and replaced with benign technologies. Non-radioactive technologies, like x-ray and gamma-ray tubes and neutron generators, can be substituted for radioisotopes, reducing the opportunity for loss, theft or misuse.[18]

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[10]First responders will generally need to be wearing respiratory equipment such as SCBAs in this zone. Due to ground deposition the 50 year PAG (5 REM over 50 years) extends 5 km from the blast and about 0.5 km wide. This are will need to be cleaned up before it can ever be occupied again. The area of ground deposition is high enough that food products need to be tested (we assumed 100 picocuries per square meter (pCi/m^2) extend 8 km and is 0.4 km wide. The area with greater than 1 pCi/m^2 extends 320 km and is about 10 km wide. If the assumption is that our terrorist acquires 10 of these sources, the 100 pCi/m^2 zone extends to 45 km, and if 100 sources to 320 km. In both of those cases, measurable amounts of radiation may extend beyond 1000 km. Of course, wind will not likely be that stable for very long so a more random distribution is expected in a more real world example. Depending on the amount of radioactive material, the bomb design and terrain, it is possible for an area covering thousands of square kilometers to be effected; "CPG Sec. 560.750 Radionuclides in Imported Foods - Levels of Concern." U S Food and Drug Administration Home Page. Web. <http://www.fda.gov/ICECI/ComplianceManuals/CompliancePolicyGuidanceManual/UCM074576>.

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