SEALED RADIOACTIVE SOURCES (SRS) AND GREATER THAN CLASS C LOW-LEVEL WASTES (GTCC): POTENTIAL RADIOACTIVE DISPERSAL DEVICES (RDD) RESOURCES

D. V. LeMone
University of Texas at El Paso
El Paso Texas 79968

ABSTRACT

Since the events of September 11, 2001, there has been a major shift in governmental and public thinking with reference to the security of our national infrastructure. The threats are basically fourfold: cyber-, bio-chemical, and nuclear terrorism. The government will have to prioritize these to determine where the available resources are to be expended.

In the nuclear area, the primary concerns have been with the control/proliferation of nuclear weapons of mass destruction and the security of commercial nuclear power plants. Another aspect of the nuclear problem that needs to be examined is the public's risk from radiation dispersal devices (RDDs). These devices can be constructed with either sealed radioactive sources (SRSs) and/or greater than class C low-level (G.T.C.C.) radioactive wastes as source materials. Cradle-to-grave tracking of selected devices and the recovery of lost, disused, spent, and stolen SRSs becomes an immediate high priority.

A solution in the form of the long needed and mandated G.T.C.C. repository would be ideal but, based on prior facility siting experience, probably not feasible in a timely manner. Utilization of the facility at WIPP for not only transuranic (TRU) military waste, but also civilian TRU waste and those SRS devices that qualify radiometrically represent another chioce. The formation of a geographically central, secure, interim storage facility is another reasonable solution. Future utilization of the Yucca Mountain facility is technically excellent but politically speculative. All solutions will require legislative action in order to accomplished.

INTRODUCTION

The events of September 11, 2001, have dramatically shifted governmental and public thinking in reference to the nuclear programs, nationally and internationally. The U.S. Nuclear Regulatory Commission (NRC) has been particularly active since that date. It appears that the country's nuclear power plants under their leadership are in an increasingly more protected system. However, there are problems still remaining, as has been alluded to by a number of organizations such as the Center for Nonproliferation Studies (CNS) and the International Atomic Energy Agency (IAEA).

Among the more important remaining issues are: monitoring of operational and recovery of lost, spent, and disused sealed sources along with the legacy, military, and civilian accumulating masses of Greater Than Class C low-level waste (GTCC). Serious radioactive dispersal devices (RDDs) can be made from both of these sources. These standard and sophisticated detonation RDD devices are utilized as either a political and disruptive weapon or a more serious lethal device with internal or external consequences. The IAEA categorizes 11 radioisotopes of concern from the perspective of safety; they are: Co-60, Cs-137, Ir-192, Sr-90, Am-241, Cf-252, Pu-238, Ra-226, Pd-103, Kr-85, and Tl-204 [1191]. CNS classifies only the first seven radioisotopes of the IAEA list (Co-60, Cs-137, Ir-192, Sr-90, Am-241, Cf-252, Pu-238) to be of concern and identifies them as the reactor-produced radioisotopes that pose the greatest security risks [1]. Some of the most important radioisotopes are typically produced as pellets (Co-60) or powder (Cs-137), either of which can be used effectively in an explosive device. Only a few corporations and governments produce the seven radioisotopes identified by the CNS [1]. The problem is that these radioisotopes have many tens of thousands of end users. A better national tracking system should be initiated for these radioisotopes. All of the spent and abandoned sealed sources need to be sent either to be recycled at a licensed facility or sent to one central, national repository. The solution to the problem does not simplify with the existence of low-level compacts nor with the erection of some possible 50+ separate state and territory sealed source collection points.

GTCC waste and GTCC sealed sources that are no longer in use comprise a sub-category of low-level waste. Low-level radioactive waste is material defined as waste that is not classified as spent fuel, high-level radioactive waste, federal transuranic waste, or certain by-product material (uranium or thorium mill tailings). The external radiation level of low-level radioactive waste may be high enough to require shielding for handling and transport. The U. S. NRC recognizes four low-level radioactive disposal categories in sequential order of more careful disposal specifications: Class A, Class B, Class C, and GTCC. The maximum concentration limits for low-level radioactive waste are established in Title 10, Code of Federal Regulations (CFR) Part 61. To meet disposal requirements, all classes of low-level radioactive waste may not be liquid or packaged in cardboard containers. Normally, they are packed in low-carbon steel drums, boxes, or liners. Class C and GTCC wastes have additional disposal requirements in that they must be protected from inadvertent intrusion by humans and animals. Low-level radioactive waste with concentrations of radionuclides in excess of low-level Class C limitations are not generally acceptable for near surface disposal. Due to the special nature of GTCC, the disposal of GTCC is the responsibility of the U. S. Department of Energy rather than individual states. A disposal facility for government, military, and civilian GTCC is not currently available or even under serious consideration.

Several solutions are feasible. The simplest and most immediate solution is to place the GTCC waste for more secured storage at the U. S. Department of Energy repository at Carlsbad and, eventually, dispose of the waste at either Carlsbad or the Yucca Mountain facility. A more complex and difficult task would be the siting of a new, dedicated GTCC national repository. Prior experience and lessons learned in dealing with radioactive waste disposal in the United States, including the political and legal siting issues and licensing problems, should be remembered. The possibilities for the GTCC sealed sources storage facilities under the control of the federal government are not as difficult. Existing federal facilities can and are being earmarked for GTCC sealed sources storage. These existing facilities could also receive other GTCC waste for more secured storage. Logically, however, it should be in a central geographic location for ease of transport to the facility. It is absolutely essential from a national security aspect that both of these problems be solved as soon as possible to prevent placing the public at risk.

Any solution that may be determined will need to be funded within the dimensions of the current federal dollars available. The congress will have to balance the needs of committing to a solution of this problem versus the future needs of the ongoing, multidimensional War on Terrorism. It is necessary, therefore, to examine the relative risks in the broader spectrum of the nation's security needs. First, what constitutes perceived risks inherent in the different modes of terrorism? Second, can these perceived risks in the different modes of terrorism be ranked as to relative importance? The third question asks is the disposal of GTCC radioactive wastes and categorized sealed sources critical? Lastly, does a financially and timely reasonable solution exist?

NATIONAL SECURITY IN THE TWENTY-FIRST CENTURY

National security terrorism concerns in the post 9/11 world can be broken down into four broad categories: cyber-terrorism, bioterrorism, chemical terrorism, and nuclear terrorism. Any one of these areas may have scenarios with profound negative consequences to any industrialized nation and America, specifically. In any ranking sequence, an argument for any order of importance in ranking these terrorist impacts from most to the least critical would be arguable. Let us examine these four categories and try to evaluate the magnitude of each.

Cyber-Terrorism

Cyber-terrorism may be defined as the execution of an attack to disable, disrupt, or destroy a nation's critical electronic and physical infrastructures. President Clinton's Executive Order 13010 (1996) defines the infrastructures that are critical to the defense and economic security of the United States. Those eight infrastructures would seem as valid today as they were at the time of their designation; they are: electrical power; gas and oil production, storage, and delivery; telecommunications; banking and finance; water supply systems; transportation; emergency services; and governmental operations. All of these infrastructures rely on computers, computer networks, and the internet. [2]

With the now universal development of the internet, the question of information security becomes a paramount concern. Military and governmental security needs would appear to be in process of developing equipment and tight procedures for "sensitive" and "secret" data. However, the commercial sector appears to be lagging significantly behind, but developing. [3] Awareness and response to the negative potential of internet-sensitive nuclear data can be illustrated by the immediate reaction of two agencies. After 9/11, the Nuclear Regulatory Commission (NRC) between October 11 and October 17 removed data from their website in order to prevent inadvertent disclosure of sensitive information (e.g., schematics of nuclear power plants, documents related to scenarios and responses to severe accidents, etc.). The Department of Energy (DOE), in a similar response, removed data concerning locations of all nuclear storage facilities, reactors, surplus plutonium sites, etc. [2]

The world of this century is a globally integrated web of international businesses, corporations, and financial institutions. The internet data transmitted by these entities are vulnerable to such scenarios as threats, attacks (both directly and as Trojan horses), and viruses. Network flooding resulting in "denial of services" by overloading certain targeted internet services; criminal and/or terrorist intrusions into corporate intranets through firewalls erected to protect internal data; and failure to implement safeguards which now have compounded problems with the recognition of internet anonymity are further examples of the problem's dimensions. [3]

In response to this challenge, a whole new area of the security of modern digital communication is evolving. Encryption of messages by several means is an answer. An example would be the one time pad-perfect system. A cipher book of random symbols is held by both the sender and the recipient of the message. An oncoming future in which there will be a complete public key infrastructure (PKI) integrating all the processes now available seems a possibility to some analysts and unnecessary, potentially insecure, and unrealistic to others. [3]

Parallel to secure data transmission problems is the fundamental problem of the identification of an individual not only within the areas vulnerable to cyber-terrorism but also in any potentially sensitive area. In order to solve this relatively universal security problem, it is necessary to implement the technology of the rapidly evolving discipline of biometric security. Chirillo and Blaul [4] state that for today's obligatory verification versus identification for access control, multiple processes must be applied. Examples of such a process would be requiring the individual to know something (password), have a verifiable identification token of some sort (electronic identification card), and be uniquely recognizable (physical and/or behavioral biometrics).

Currently, dependent on definition, physical biometrics consists of seven or more different features; Chirillo and Blaul [4] list: fingerprints (pattern); facial recognition/location (measurements); hand geometry (shape and pattern analysis); iris scan (features of the colored ring of the eye); retinal scan (blood vessel analysis); vascular patterns (vein patterns); and DNA (genetic analysis). Behavioral biometrics include: speaker/voice recognition, signature/handwriting analysis, and keystroke/patterning. As an example, the combination of a hand scan with an electronic card triggering a photo for identification would be a probable low priority system when using a guard as the interface. Unmanned access would require increased biometrics by adding such items as spoken password, iris scan, and signature. Though currently the least reliable of the behavioral methods, keystroke/patterning, like the unique signatures of a Morse Code senders, may develop into a broad, useful security tool of the future. [4]

Bioterrorism

Chaudhuri and others [5] define biological warfare as the utilization of living organisms (plants, fungi, bacteria, etc.) or their toxins to harm, incapacitate, or exterminate an adversary's military forces, civilian population, flora, and/or fauna including livestock. This can be accomplished by utilization of any living organism, including the modern genetically modified ones, and/or bioactive substances. These, consequently, may be delivered either by increasingly proliferating conventional warheads [6] or by less technologically advanced civilian delivery means (e.g., anthrax through the mail system) [7]

Chaudhuri and others [5] conclude that biological weapons are nearly impossible to detect and control as new biotoxins are being discovered every day, They list some 86 wild and cultivated plants that are toxic to animals (man). The capsules and seeds of the castor bean (*Ricinis communis*), for example, are the source of Ricin. The biotoxin Ricin is 6,000 times more poisonous than cyanide and 12,000 times more lethal than rattlesnake venom. Add to this the fact that today, by utilizing genetic technology, we can modify old biotoxins with recombinant DNA manipulation methodology to make them more effective. This technology started in the 1970s and has undergone explosive growth in the field normally referred to as genetic engineering. [7]

In response to the bioterrorism threat, President Bush proposed the formation of a biodefense BioShield program that will be funded for six billion dollars during the next decade. [8] BioShield has been formed to spur the development and procurement of the next generation of medical bio-measures such as vaccines as well as basic research in microbial geonomics. In addition to BioShield there are two other counter-terrorism projects under development. The first, Biowatch, is an interagency effort to produce an early warning system using atmospheric sampling technology for the detection of potentially hazardous bioagents. The second project is Biosense that has been formed to reduce the time lag between the release of a bioagent and the time it takes officials to react. These programs and others were addressed at the second Federal Defense Research Conference held in Washington. The conference (co-sponsored by the American Association for the Advancement of Science [8], Research America, and American Academy of of Pharmaceutical Physicians) reviewed in some detail the responsibilities and programs, developed and planned, by the some 11 federal agencies represented there. It would seem that that those organizations and nation states involved in bioterrorism, as with chemical terrorism, run a considerable risk of leaving a forensic trail [9] inviting an attributable retaliatory response. [10]

Chemical Terrorism

Chemical terrorism has a long list of agents that may be used as weapons of terror and mass murder. These agents kill, maim, debilitate (acutely and also chronically), and have genetic implications that appear in succeeding generations (e.g., the severe birth effects occurring in Iraqi Kurdish children). The Japanese Sarin nerve gas attacks that occurred in Matsumoto (1994) and in Tokyo's subway (1995 with 19 deaths) are recent examples of the random use of chemical warfare agents against the general public. In this incidence the perpetrators were the Aum Shinrikyo, a Doomsday cult. This cult in 1995 was politically active in Japan, had some 10,000 members with offices in 20 Japanese cities as well as in the

United States, Russia, Germany, and Sri Lanka. Yeso Seto [11] details the forensic analysis and identification of the nerve gas agent used and ultimate tracking to its source and the identification of the guilty participants.

Reiders [9] divides chemical weapons into two major categories: "stand-up" chemical weapons and "stealth" chemical weapons. The "stand-up" or sudden bio-impact variety of chemical agent has an immediate adverse effect on the exposed life forms. The "stealth" or delayed bio-impact agents are produced to deliver a delayed toxicity. These agents are activated by the body's metabolic processes (also referred to as toxic bio-transformaters). As stated before, in the discussion on bioterrorism, any organization or nation state involved in chemical terrorism invites an attributable retaliatory response. [10]

Nuclear Terrorism

Radiological weapons utilize radioactive materials in methodologies designed to maim and kill a selected group or the general population of an adversary. In general nuclear weapons may be divided in to a series of categories based on dimensions of the devices, type, technology, and general capability. Major radiological weapons (atomic fission, thermonuclear devices, etc.) are also classifiable as weapons of mass destruction. Such weapons would typically have to be delivered by air or, more likely, by missile. Radiological terror large device capability is pragmatically limited to those nation states with the fiscal commitment to produce such a device and the technological capability to deliver the device by missile.

Missiles are normally classified into a series of five different categories; they are: short range ballistic missiles (SRBM) < 1000 km; medium range ballistic missiles (MRBM) 1001-3000 km; intermediate range ballistic missiles (IRBM) 3001-5000 km; ICBM intercontinental range ballistic missiles (ICBM) > 5000 km; and Submarine Launched ballistic missiles (SLBM) (range not available). [12,1] The development and accessibility to these missiles is increasing, especially in short and medium ranges.

In addition to the well-documented consequences of such delivered devices (e.g., immediate and future loss of life, property destruction, environmental damage, etc.), a secondary feature aligned with cyber-terrorism is the association with an atmospheric nuclear blasts and its resultant generated electromagnetic pulse (EMP). This nanosecond pulse, generated by the atmospheric nuclear blast, develops a power surge that damages and destroys unprotected electronic communication systems, power generators, computers, etc. Weldon [12] also points out another worrisome device that works on the same principle, the radio frequency (RF) weapon which is small, highly portable, and capable of delivering a similar EMP blast to the individual unprotected electronic target.

For control of military governmental nuclear weaponry, the problem of nonproliferation remains as the central international issue. Another major hurdle, awaiting an international solution, is the concept of safeguards and its requisite national acceptances, transparency processes, and unannounced verification inspections. This class of strategic nuclear weaponry must be internationally secure against threats of either theft or sabotage.

The precise definition of what is a "suitcase bomb," as well as its effective level and portability, is unclear. It would seem possible, however, that technical advances in producing smaller yield and sized nuclear devices may make this a future deliverable possibility. It seems highly unlikely that a terrorist plot of the dimensions of the"Superbowl Scenario" enacted within the novel "The Sum of all Fears" [14] could ever take place in a post 9/11 world.

Nuclear power plants, like the nuclear weaponry described, must also be protected from attack, theft, and sabotage. The Nuclear Regulatory Commission, in concert with Homeland Security, over the last 2 years has further increased its ongoing processes of reviewing and upgrading the security of American nuclear power plants. Similar efforts are being made internationally. The American Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR) by their design are reasonably well equipped to withstand most physical events (e.g., airplane crashes, external fires, electromagnetic interference, floods and extreme meteorological conditions, external and internal explosions, etc.). Plant security from hostile groups, such as terrorists, is the responsibility of the nuclear power plant, Homeland Security, and the appropriate associated governmental agencies.

Another area to be examined under the label of nuclear terrorism considers the development of the radiation dispersal device (RDD). RDDs are often popularly referred to as "dirty bombs." Specific radioactive source classes assignable to this area are Greater Than Class C (GTCC) low-level wastes and the ubiquitous medical, industrial, and research sealed radioactive sources (SRS). The classification, transportation, and tracking of operational, lost, spent, and disused sealed radioactive sources are immediate and evident problems. Greater Than Class C low-level waste (GTCC) includes a portion of the sealed sources as well as the accumulated and future masses of operational and decommissioning wastes of military, legacy, and civilian origin. As stated, selected sealed radioactive sources and low-level and Greater Than Class C (GTCC) wastes may have the potentiality of becoming the radioactive resource material for the production of radioactive dispersal devices (RDDs).

RDDS AND THEIR POTENTIAL SRS AND GTCC SOURCES

Radioactive Dispersion Devices (RDDs), approximating the Department of Defense (DoD) definition, refers to any device, weapon, or equipment that is designed utilize radioactive materials by disseminating them in order to cause destruction, damage or injury by decay of such material. [15] RDDs are not devices that detonate by fission and fusion nuclear reactions. The physical and tactical effects of an RDD are dependent on delivery style, target location, effectiveness of conventional detonation, and most critically on type and quantity of radioactive material. Ford [15] evaluates RDD results in three ways: blast and fragmentation effects; immediate and long-term radiation exposures; and instillation of fear and panic in the target population.

RDDs are not normally thought of as weapons of mass destruction. It would probably be preferable to refer to them as either weapons of mass disruption or weapons of mass dislocation. The multiple strategic purposes of RDDs are: to inflict deep psychological damage; to induce panic and disruption in the target population with a resultant chaotic situation at and adjacent to the site of detonation; deliver political impact for either military or domestic purposes; and, lastly, wreak economic damage from the ensuing requisite cleanup. RDDs may use greater-than Class-C low-level wastes (GTCC) and/or selected sealed radioactive sources (SRS) for the device's radionuclide component.

Greater-than-Class-C Low-Level Wastes (GTCCLLW) are those that exceed the Nuclear Regulatory Commission's (NRC) codified Class C of its four low-level classes (A, B, C, GTCC). GTCCLLW waste is not high-level waste (e.g., fuel rods, etc.). The Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) of 1985, Public Law 99-240, makes the states responsible for classes A, B, and C low-level waste. It also requires the federal government (DOE) to be responsible for the disposal of GTCC waste, including SRSs. The DOE classifies Commercial GTCC low-level waste as: (1) nuclear utilities waste (operational and decommissioning PWR and BWR), (2) sealed-sources waste (General and Specific licenses), (3) DOE-held potential GTCC low-level waste, and other generator users. [16] In interim or temporary storage, concentrations of actinides, and I-129 determines the lower activity boundary (0.010 Ci/m^3) with a unit thermal power not to exceed (0.00020 W/m^3). There are no limits on tritium or Co-6 or nuclides with half-lives of less than 5 years. [16]

In May 1989 NRC promulgated a rule that requires that GTCC waste be buried in a deep geological repository. NRC may, on review and approval, allow other sites. DOE was given the responsibility of developing a site for the GTCC. As of 2003, no apparent progress has been made on developing a new repository for the GTCC wastes [17, 18] despite papers and discussions relating to the problem (e.g., [19, 20]). DOE has envisioned completion of a GTCC repository as early as 2007. Given the history of similar repository tries and the requirements necessary for DOE to complete (e.g., NEPA, EIS, etc.) an optimistic date would involve a decade of time. [18]

Available historical data from1993 and projections for 2035 for GTCC were listed in the Integrated Data Base Report of 1997 [16] for an INEEL report. Nuclear utilities wastes constitute the largest volume of waste (± 53%), sealed sources (± 16%), and other sources (31%). Current (1993) data shows nuclear power plant operational and decommisssioning waste (42.28 m^3 – 3,890,000 Ci), sealed sources (38.82 m^3 – 355,119 Ci); and other generator waste (121.1 m^3 – 2,738 Ci). The GTCC inventory as of 1993 was estimated at 202.2 m^3 – 4,247,857 Ci. The 2035 estimate predicts the GTCC waste accumulating to 2446 m^3 – 37,139,076 Ci. [16]

A portion of these wastes could be used for the radionuclide component of the RDD, dependent on the type and activity of the radionuclide employed and its physical and chemical state. The largest GTCC component, operational and decommissioning wastes from nuclear power plants, is reasonably securely monitored. Other generators of wastes include contributions from C-14 users, irradiation laboratories, sealed source manufacturers, university reactors, fuel fabrication facilities, etc. No overall risk evaluation of these GTCC wastes can be made. Sealed radioactive sources (SRS) can be evaluated from the standpoint of security. A radiation source is any source capable of emitting ionizing radiation.

The analysis by Ferguson and others [1] find seven radioisotopes as being of concern in sealed radioactive sources. They divide these seven into two groups of radioisotopes which are primarily either major gamma or beta sources or alpha sources. To these radioisotopes another must be added, the legacy radium from earlier SRSs.

Radium

A sealed radiation source as defined by the IAEA [21] in 1991 is a small entity containing encapsulated radioactive material of high specific activity. Usually it has the appearance of a small harmless piece of metal. The first use of a source for ionizing radiation was in 1901. Pierre Curie gave it to a Paris physician who successfully treated a malignant surface tumor with it. In 1904 the first internal use of radioactivity took place. The delivered cost of the radium has wildly fluctuated from an earlier height of $100,000/gram to $20,000/gram in 1930. Until the late forties no other radionuclide outside of radium was available in sufficient quantities for a sealed source. After World War II the market demand for radium semi-collapsed. This occurred as the result of the development of research reactors and particle accelerators resulting in the increase of some 50 other sources. [21] As these radioisotopes became available radium sources were replaced and sold or given to third world countries where they are still found and present a potential hazard.

Ra-226, with a 1602-year half life, is the result of a natural decay process of U-238 to Pb-206. It is an extremely active alkaline earth nearly always used as a salt (bromide, chloride, sulfate, carbonate). Radium for the first half century as a SRS was typically enclosed in either small needles or tubes composed of either glass or metal. Radium sources, especially in the early days, had a history of leakages and occasional incidents of explosions. In part it is because radium salts are soluble in water. These salts are easily dispersed as a powder if encapsulation is broken. The decay chain from radium to Pb-206 results in yielding five alpha particle helium atoms. If water is introduced or present, the alpha particles decompose it to hydrogen and oxygen furthering the resultant overpressuring. One gram of radium in a free volume of 1 cm^3 will cause an overpressure on the order of 0.2 atmospheres/year. [21]

Radium is a natural product of the earth, and as such, the NRC does not regulate it. The radiotoxic element radium, in the human biological system, reacts like calcite and concentrates in the bone marrow. It is the radium daughter products that make it so radiotoxic. This chain yields alpha energies up to 7.7 MeV, beta energies up to 2.8 MeV, and gamma energies up to 2.4 MeV. Ra-226 (1600 a = years) decays into Rn-222 (3.823 d = days) and its short lived daughters sequence [Po-218 (3.05 m = minutes) — Pb-214 (26.8 m — Bi-214 (19.7 m) — Po 214 ($1.6x10^{-4}$ s = seconds)] to Pb-210. Pb-210 (22 a), in turn, decays into Bi-210 (5.013 d) and Po-210 (138.4 d) to stable Pb-206. [22]

SRS Categorization

The IAEA [23] developed a series of three categories for the general categorization of SRS which were ranked in accordance to the potential harm they may cause. Category 1, most dangerous, included industrial radiography, teletherapy, and irradiators. Category 2 included high and low dose brachytherapy, well logging, and fixed industrial gages involving high activity sources. Category 3 is essentially fixed industrial gages involved with lower activity sources. [23]

The IAEA held an International Conference on the Security of Radioactive Sources which was attended by some 700 delegates representing 127 countries. This conference held in Vienna in March of 2003 introduced a revision of the old categories. The revised categories are still based on the concept of the potential to cause harmful health effects. The categories which in general are an expansion of original proposal are: 1) extremely dangerous sources, 2) sources considered personally dangerous, 3) sources considered to be dangerous if not safely managed and securely protected, 4) sources unlikely to be dangerous and 5) categories not considered to be dangerous [24].

A working group established by the Secretary of Energy and the Chairman of the NRC was directed to determine what radioisotopes presented the greatest risk if used in a conventional RDD. The results of the study are to provide a relative ranking of the degree of risks of each isotope.

Sandia National Laboratory (SNL) workers developed a four factor modeling system that evaluates: potential disposability, number of locations possessing the material, quality of material at each facility, and what protective measures were being applied to secure the material. The weighted combination of these factors yield their "Hazard Index" levels. Specific radioactive materials were ranked high, medium, low, and very low on the bases of their post-incident effectiveness. Psychological and economic considerations were not analyzed. [18]

This study has adopted Ferguson's [1] classification which separates out the seven major radionuclides of concern on the basis of their high-energy emissions; these are: beta and gamma radiation = Cs-137, Co-60, and Ir-192; beta radiation = Sr-90; and alpha radiation = Am-241, Cf-252, and Pu-238. Radium is not classified, as it is a natural decay product of U-238.

BETA/GAMMA RAY EMITTERS

Iridium-192

Iridium-192 (73.8 d) is produced from the neutron irradiation of metallic iridium, which is a noble metal with excellent characteristics. It is neither oxidized in air nor dissolved in water. [21] While its short half life makes it harmless in 5 years, the quantity is important. Iridium yields both high beta and gamma radiation. [1] It is used in portable units (0.1 – 5TBq) primarily with pipeline welds, boilers, and aircraft parts as well as being a leading source of accidents. [25] An example would be the 1979 California construction accident where a worker picked up a 1.6 GBq (28 Ci) device and placed it in his hip pocket. He received a buttock dose of 200 Sv (20,000 rem). [26]

Cesium-137

Cesium-137 (30.2 a) is a fission product of nuclear fuel which must be purified before use. (1145) Cs-137 is a very reactive alkaline metal like sodium and potassium. It decays into the metastable isotope Ba-137m (2.6 m) which is an external hazard. ([21] Specific activity of Cs -137 is 88 Ci/g while Ba-137m is 540 million Ci/g. [1] Cs-137 is undergoing a shift in material form from the former hydroscopic chloride salt powder to source material in ceramic form. [27] Cs-137 is used in sterilization and food preservation (0.1-400 PBq), well-logging (1-100 GBq), belt gauges (0.1-40 GBq), and density gauges (1-20 GBq) in fixed installations. Small portable sources (50-500 MBq) are used to treat cancer patients by brachytherapy. Cs-137 is also used in blood irradiation, as well as measure precise patient dosages, measure pipeline flows, etc.

Cobalt-60

Cobalt-60 (5.3 a) is produced by neutron bombardment of nickel-plated natural cobalt almost free of other radionuclides. [25] It decays with high beta and gamma energies. It is usually in either thin discs or small cylindrical pellets. Cobalt is insoluble, and when introduced into the body is evenly distributed except in the liver. It is used in such fixed industrial installations as level gauges (0.1-10 GBq), sterilization and food preservation (0.1-400 PBq), and research irradiators (1-1000 TBq), (620) It, as Cs-137, is used extensively in medical teletherapy. Portable industrial radiographic units also use Co-60. [21]

Strontium-90

Strontium-90 (28.6 a) is a fission product produced in reactor fuel that must be chemically purified before it is used. [25] It is chemically highly reactive and is normally used as titanate. Sr-90 is used as the radioisotope for thermoelectric generators. These generators were designed to provide power for remote facilities such as lighthouses, radio beacons, and meterological stations. These systems are also utilized by America in Alaska. Activities in these devices range from 40,000 to 150,000 Ci. There are approximately 1000 of these thermoelectric generators in the former Soviet Union that are questionably protected and secured. In the Republic of Georgia six of these devices have been recovered in the past 2 years by a joint national-international group. [24]

Strontium is similar to calcium and is permanently taken up in the human system in the bones and teeth. It can lead to bone cancer. It decays by beta emission to Y-90 (64.1 h) that is a health hazard (550,000 Ci/g) for Y-90 specific activity versus 140 Ci/g for Sr-90. [1] These nuclides are used as beta and bremsstrahlung sources in industry and for medical applications as eye and skin applicators and in high dose brachytherapy.

LPHA EMITTERS

Americium-241

Americium-241 (432.2 a) has chemical characteristics similar to rare earth metals and is commonly used as an oxide. The fine powder oxide is mixed with beryllium and sintered to a ceramic-like product that is stable in air and insoluble in water. It is a high energy alpha emitter with a specific activity of 3.4 Ci/g. It is used in portable moisture detectors (0.1-10 GBq), density gauges (1-10 GBq), and as a bone densitometer (1-10 GBq). It is used with beryllium in well logging. It is used in the ubiquitous smoke detectors (0.2-3 MBq). [25]

Californium-252

Californium-252 (2.7 a) is a high energy alpha emitter with a specific activity of 536 Ci/g. Californium emit neutrons from spontaneous fission and may be classified as potential external hazard as well as an internal hazards from alpha radiation when dispersed in a RDD. It is used for airline luggage inspection, gauging soil moisture in road construction and the building industries. It also measures the moisture of materials stored in silos. [25]

Plutonium-238

Plutonium-238 (87.7 a) has long been used to power heart pacemakers. Today, the power supply for pacemakers is being replaced by nickel-cadmium batteries. Pu-238 since 1972 has been used to power over 20 NASA spacecraft. [25] Small quantities of Pu-238, for export, are listed as radioactive sources of "high security concern," a designation that is neither "specialized nuclear material" nor "special fissionable material." Exports formerly were being made to all countries except Cuba, Iran, Iraq, Libya, North Korea, and the Sudan.

SEALED RADIOACTIVE SOURCE ACCIDENTS

Accidents, up to the present time, represent the best analyses of what the potential impact of a future RDD incident might be. The first accident example is the 16.65 TBq Co-60 (450 Ci with 6000 pellets) non-licensed teletherapy device in Juarez. It was purchased by a Juarez doctor for his clinic. It was subsequently taken from his storeroom in December of 1983. The device either before or during transport in a pickup was broken into with a screwdriver through two stainless steel windows. The process resulted in minor spilling of the pellets into the truck bed and in along the streets in Juarez on the truck's way to the El Fenix Junkyard. Most of the pellets were distributed near the weight scale at the scrapyard. Dispersed pellets were picked up during processing and, later, by a magnetic crane and dispersed in metal shipment going to a Chihuahuan city foundry, Aceros de Chihuahua. The recycled contaminated metal found its way to four other foundries that produced such items as rebar for construction and central pillar table bases. Contaminated rebar was sent to the 17 Mexican states and to the United States. The direct and indirect costs after the accident are conservatively estimated at 34 million dollars. [28]

A second example utilizing another very common isotope, Cs-137, involves a teletherapy device in Goiana, Brazil. [29] The device was left behind (abandoned) when a private radiotherapy clinic moved to a new location. Later, during construction activity in the area, the device was obtained by two individuals looking for scrap. After recovering the device they took it to their home and the device was ruptured. The source capsule was later sold to a scrapyard. This event resulted in 14 individuals seriously injured from radiation exposure; four individuals from this group subsequently died. Some 112,000 individuals were examined and 249 were found to be contaminated either internally or externally. The final volume of waste was 3,500 cubic meters. The cost of the decontamination operation and the construction of two concrete vaults were originally estimated at 15 million dollars. The GAO [18] has upgraded this figure to a more realistic 36 million dollars. These examples clearly reflect the potentiality of the problem economically. This number does not reflect the actual damage done to the infrastructure in the area, the loss of trade and tourism, or psychological damage done to the population.

The problem of inadvertent inclusion of SRS into the U.S. metals recycling industry has been a major factor for consideration long before 9/11. American steel mills have had numerous incidents and find that the average cost per incident is 8 to 10 million dollars. Earlier data from Pennsylvanian studies by Dicus [26] indicate that the majority of the contamination seems to originate from Cs-137 devices followed by Co-90. As a result of the Juarez incident and the continuing problems of recycling metal, today's scrap yards and foundries are for most part equipped with radiation detection devices.

Stakeholder communication in SRS accidents as well as the potential scenario for disruption and dislocation by a RDD are sobering problem to consider. An American Nuclear Society team has produced a paper on the problem of communication with the public.[31] The thrust of this timely paper was to allay the potential psychological, behavioral, and economic consequences of a RDD event. They divide the RDD threat into three broad hazard categories for the 10 radiological materials of concern. The outline of this system represents an excellent starting place for the public and the bureaucracy. [31]

Another continuing and related problem is the final determination of what is the lower limit of radioactivity. To what lower radioactivity level must metals be taken down to in order to be considered no longer radioactive? Something that must be resolved both nationally and internationally in the immediate future.

Spent, disused, lost and Stolen SRSs

As stated earlier, the recovery of spent, disused, lost, and stolen SRSs is of paramount importance to security. SRSs no longer in use, now or in the future, are classified as being spent. spent does not mean that it is no longer a potential radiological hazard. SRSs that may be taken out of service temporarily or indefinitely are referred to as being disused sources. [27] Therefore, any source not in active use and not considered spent, are referred to as disused. Either type, dependent on radiological condition, could be used in a RDD system.

IAEA has developed a technical manual for the handling, conditioning, and storage of Spent sealed radioactive sources. [25] This manual is useful in combination with the IAEA publication on identification and location of spent SRSs. The magnitude of the problem globally was addressed by the IAEA [21] in 1991. The NRC [18] now places the total number of SRS licensees in the U.S. at two million. The European Commission (EC) indicates that 500,000 SRSs have been supplied in the15 nation European Community. The EC estimates the Russian total to be 840,000 SRS; that is far below Russian estimates.

Producing realistic numbers of the uncontrolled abandoned spent SRSs globally or nationally is at best highly speculative. Likewise, the determining of the numbers of abandoned SRSs could well be considered an exercise in futility. At least a portion of that problem in many different localities is tied to the unwillingness of reporting. Such reports may trigger the draconian financial responsibilities that are attached to the abandoned SRS that leads back to the end user. The most reliable of the three estimates is probably the number of recorded orphan SRSs. Losses at 250 SRSs annually has been predicted for the U.S. [29]

The European Union is indicating a preference for the adoption of the French System for SRS control and regulation. First, end users have the device for a period of10 years. Secondly, the company that supplies the device to the end user has to give the cost of disposal in its price. Lastly, all companies in the supply chain contractually agree to take back the source in 10 years. Financial responsibilities are high but handled by an association of source distributors. The reported loss last year was one SRS. Since 1998, 1300 instances of lost, stolen, and abandoned SRSs have been reported in the U.S. Last reporting year, there were 157,000 licenses issued; 135,000 of those authorize radioactive materials in devices (e.g., nuclear measuring devices, etc.). The remaining 22,000 licenses were for specific license users. [18]

CONCLUSIONS

Any evaluation of the four modes of terrorism (cyber, bio-, chemical, and nuclear) is arguable. Ranking them in order of their importance allows prioritization of those areas in which national resources should be allocated. One ranking would argue that cyber-terrorism is the most important in that it threatens the very fabric of the American infrastructure and, consequently, would be the most devastating. Bioterrorism could qualify as second as it is the most ruthless. However, it carries with it the potential of unintended mutational modifications as well as a boomerang effect on the originating group. Furthermore, biotoxins are forensically traceable. Thirdly, chemical terrorism is more direct but less efficient than bioterrorism and is also easily traceable. Any one of these three, properly executed, is a potential disaster.

Nuclear terrorism, probably most controllable, consists of a two level model: state-sponsored weapons of mass destruction and the less lethal state and smaller entity radiation dispersal devices. The Hofferian [30] true believers, the neo-nihilists, and the terrorists of this era should not have either access to or the infrastructure to utilize weapons of mass destruction. Available G.T.C.C. low-level waste and selected SRS (mostly special license types), however, are potential weapons of a mass disruption or mass dislocation. The control of this latent problem would seem to shrink to low priority if a deep geological repository or a secure interim storage facilitates were immediately available.

As for the question of a dedicated repository for SRSs and G.T.C.C. waste, without doubt this is the best solution; but, based on prior experience, time to repository completion would seem to be risky and realistically untenable. Therefore, the development of a new G.T.C.C. disposal facility does not appear to be a reasonable option. As an interim solution, transuranic SRS devices and civilian transuranic wastes need to be disposed of at the WIPP facility outside Carlsbad. This will require congressional action to be effected. The G.T.C.C. nuclear power plant operational and decommissioning wastes and the qualifying, primarily special license SRS waste, could be stored in an interim facility at a centrally located geographic area or disposed of at the deep geological facility at Yucca Mountain.

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