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Cover Page Footnote

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Weaponizing Radioactive Medical Waste – The Looming Threat

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Abstract
Across the globe, the use of radioactive substances for medical treatment by hospitals has resulted in the generation of toxic wastes on a large scale. The disposal of these wastes is being entrusted to waste disposal vendors. Environmental concerns, social pressures, restrictions, and high labor costs compel these vendors to dump these wastes in developing countries, where enforcement and awareness are significantly lower than in developed countries. Unrestricted access to these waste dumps provides an opportunity for terror organizations to extract toxic substances and fabricate dirty bombs to threaten public safety and cause low-level contamination of sensitive areas. It is therefore imperative to create an international organization to monitor, regulate, and supervise the safe disposal of toxic radioactive wastes.

Key Words: *Radioactive medical waste; radioisotopes; nuclear medicine; radiological terror; radiological dispersal devices; dirty bomb*

I. Introduction

Hospitals across the world use radioactive substances for purposes ranging from diagnosis to treatment. Hospitals have therefore become a major source of nuclear waste in the developed and developing world. Most hospital radioactive wastes are generated in the hospitals' departments of nuclear medicine. These wastes are in liquid, solid, and gaseous states **[*1*]**. Disposal of these wastes is proving to be a vexatious problem, and many in developed countries connive with unscrupulous waste vendors to either dump wastes into oceans or in developing countries. These sites of unguarded, toxic, radioactive wastes can be accessed easily by terror organizations to fabricate crude radioactive dispersal devices. For example, Chechen rebels have attempted twice to detonate crude dirty bombs which were manufactured from "orphaned" sources obtained from unguarded nuclear waste sites, but timely intervention by the

authorities averted major tragedies. The continuous global trade in radiological waste along shipping routes makes it vulnerable to attacks by terror groups, pirates, and separatist organizations. This article reviews two major topics: the role of hospitals as a proliferating source of radioactive substances, and the ease with which terrorists can procure, fabricate, and detonate a dirty bomb, thereby causing panic, fear, and low-level contamination in sensitive areas. This possibility necessitates the inclusion of radioactive medical wastes under the purview of Export Trade Controls and also the creation of an autonomous international organization to monitor and regulate safe disposal of toxic wastes in the interest of promoting human welfare and preventing environmental degradation.

A. Methodology

A review of English language articles with the following key words was conducted: "Radioactive medical waste"; "radioisotopes"; "nuclear medicine"; "radiological terror"; "radiological dispersal devices"; "dirty bomb". The most relevant of these articles were selected and analyzed. The lists of references in these selected articles were also reviewed and analyzed.

B. Background

The advent of "nuclear medicine" to diagnose, treat, and prevent diseases began approximately 50 years ago. Today, in modern hospitals, about one-third of all medical procedures involve radiation or radioactivity. These procedures include various medical specialties such as cardiology, psychiatry, and pediatrics **[*2*]**. Medical treatment involves use of both nuclear medicine and radiology. In nuclear medicine, radioisotopes are introduced into the body internally, whereas in radiology, x-rays penetrate the body from the outside **[*2*]**. X-rays, Magnetic Resonance Imaging (MRI) Scanners, Computerized Axial Tomography (CAT) Scanners, and Ultrasound all use nuclear science to examine different parts of the body and diagnose conditions. Nuclear imaging procedures include Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), and cardiovascular imaging. All these procedures involve the administration of radioisotopes which enable detection from the radiation they emit. Administration is by injection, by inhalation, or by mouth. For example: a gamma camera captures an image from isotopes in the body that emit gamma radiation. Then computers enhance the image, thereby revealing the presence of tumors **[*2*]**. This process is different from a diagnostic x-ray, where external radiation is passed through the body to form an image **[*3*]**. Nuclear medicine also enables imaging of the whole body; examples include whole body PET scans, CT scans, Gallium scans, Iridium white blood cell scans, and octreotide scans **[*4, 5*]**.

The medical profession relies heavily on radioactive isotopes for identifying and treating diseases. Radioactive substances used in medicine are of two types—radionuclides and radioactive isotopes. A radionuclide is any type of radioactive substance including elements and the isotopes of elements. An isotope is a particular atomic version of it. Isotopes are atoms of the same element with different atomic mass (i.e., they have the same number of protons but a different number of neutrons) **[*6*]**.

Most radioactive substances are produced commercially in nuclear reactors or cyclotrons, also called particle accelerators. A cyclotron uses electric currents to accelerate atomic particles, which strike the non-radioactive target material, thereby turning it into a radioactive isotope. For example, when the non-radioactive "target" element cobalt is struck by neutrons in a reactor, it is transformed into cobalt-60, which is used to treat cancer **[*6*]**.

At present, there are around 200 radioisotopes which are used on a regular basis, and most are produced artificially. It is estimated that over 10,000 hospitals worldwide use radioisotopes for diagnosis. The most common unsealed radioisotope used in diagnosis is technetium-99, with over 30 million procedures per year **[*7*]**. Other common unsealed radioisotopes include iodine-131, phosphorus-32, and yttrium-90. Common sealed sources include radium, cobalt-60, iridium-192, and tantalum-182. Sealed sources are used to externally irradiate the human body, e.g., radiotherapeutic treatment. Unsealed sources are used to

internally irradiate the human body **[*8*]**. Commonly used radioisotopes in the medical field, along with their half-lives, are given in Table 1.

Table 1

1. Molybdenum-99 (66 hours)	13. Iron-59 (46 days)	25. Ytterbium-177 (1.9 hours)
2. Technetium-99m (6 hours)	14. Lutetium-177 (6.7 days)	26. Ytterbium-169 (32 days)
3. Bismuth-213 (46 minutes)	15. Palladium-103 (17 days)	27. Cobalt-57 (272 days)
4. Chromium-51 (28 days)	16. Phosphorous-32 (14 days)	28. Gallium-67 (78 hours)
5. Cobalt-60 (10.5 months)	17. Potassium-42 (12 hours)	29. Iridium-111 (2.8 days)
6. Copper-64 (13 hours)	18. Rhenium-186 (3.8 days)	30. Iodine-123 (13 hours)
7. Dysprosium-165 (2 hours)	19. Rhenium-188 (17 hours)	31. Krypton-81 m (13 seconds)
8. Erbium-169 (9.4 days)	20. Samarium-153 (47 hours)	32. Rubidium-82 (65 hours)
9. Holmium-166 (26 hours)	21. Selenium-175 (120 days)	33. Strontium-92 (25 days)
10. Iodine-125 (60 days)	22. Sodium-24 (15 hours)	34. Thallium-201 (73 hours)
11. Iodine-131 (8 days)	23. Strontium-89 (50 days)	
12. Iridium-192 (94 days)	24. Xenon-133 (5 days)	

- Radioisotopes of cesium, gold, and ruthenium are used in brachytherapy.
- Cyclotron radioisotopes—carbon-11, nitrogen-13, oxygen-15, and fluorine-18—are used in Positron Emission Tomography (PET) **[*9*]**.

The radioactive wastes emerging from the use of the above materials remain active for varying periods of time. Hence, they are classified in the following manner:

<u>According to level of radioactivity</u>:

a) High-level waste
b) Medium-level waste
c) Low-level waste

<u>According to state</u>:

a) Solid waste
b) Liquid waste
c) Gaseous waste

<u>According to duration</u>:

a) Long half-life waste (half-life of more than a month)
b) Short half-life waste (half-life of less than a month)

Radioactive waste from hospitals is mostly composed of low-level waste, and occasional medium-level waste, with a short half-life.

II. Radioactive Waste Disposal

The disposal of these radioactive wastes is a significant dilemma for all countries. The main objective in radioactive waste management is to ensure that the radiation exposure for both individuals and the

environment is kept within prescribed limits. The radiological impact on hospital personnel, members of the public, and the environment must be within the specified safe limits.

Safe management of radioactive wastes is practiced in most countries. Low-level and medium-level wastes are disposed of in near-surface repositories. High-level waste is stored in interim storage facilities. High-level waste is currently increasing by about 12,000 metric tons every year worldwide and is disposed of by a multi-barrier approach combining containment and geological disposal in remote areas far from human habitation **[*10*]**. The International Atomic Energy Agency (IAEA) has identified medical radioactive sources as a potential threat from terrorists, stating that it could be used for constructing dirty bombs **[*10*]**.

A. Loopholes in Radioactive Waste Disposal

The mounting costs for radioactive waste disposal, environmental concerns, and legal restrictions and prohibitions have resulted in the emergence of waste vendors, who secretly dispose of radioactive waste in the oceans and in developing countries, where awareness is low and corrupt politicians permit dumping. The problem is exacerbated by the fact that medical radioactive waste is combined with various sorts of other toxic wastes from industries and civic areas, and this mix of accumulated waste is then dumped in oceans and exported to developing countries: "third world countries began accepting hazardous waste precisely because of the terrible financial situations that confront them. They are heavily indebted to the developed countries and would like to repay the loans. They see the opportunity of earning the foreign exchange necessary for repayment of the loans and for beginning or completing development projects"**[*11*]**.

B. Radiological Dispersal Devices, Radiological Exposure Devices, and Terrorism

Radiological dispersal devices (RDD), according to the Department of Defense (DOD) of the United States, is defined as "any device, including any weapon or equipment, other than a nuclear explosive device, specifically designed to employ radioactive material by disseminating it to cause destruction, damage, or injury by means of the radiation produced by the decay of such material" **[*12*]**. Relatively low-level radioactive materials from the medical field can be utilized to produce RDDs **[*12*]**. Highly enriched uranium or plutonium, though they can be used to produce an RDD, are not necessarily essential components. RDDs can be used to disperse radioactive debris over a large area by active (e.g., spray) or passive (no mechanically powered device required) means, contaminating the surrounding areas and causing radiation sickness. An RDD can also be utilized to create a conventional explosion (dirty bomb) and can cause fear and panic in public areas. US intelligence services have concluded that it was possible for countries like Iraq to develop a functioning RDD which might not be militarily significant but could cause psychological damage. Terrorists can procure radioactive materials such as x-ray machines from dental treatment facilities and irradiated materials from hospitals, medical laboratories, research laboratories, waste disposal points, and cancer treatment centers.

It is also possible that terrorists could create a radiological exposure device (RED). REDs emit radiation without spreading radioactive materials. For example, terrorists could hide the radioactive sources in populated locations like railway stations, concert halls, or sports stadiums **[*12, 13*]**.

Radiological terrorism, though capable of causing only low-level destruction, can adversely impact the economy of the region due to the costs incurred by the evacuation, relocation, and decontamination of the radiologically contaminated area. In addition to causing distress and panic, there are both short-term and long-term adverse health effects for people located in that area. Also, this mode of nuclear terrorism is the easiest one to be carried out by terrorist organizations, due to the universal presence of the radiological materials and the less technically demanding procedures involved **[*13*]**.

III. Environmental Impact of Disposing Radioactive and Nuclear Wastes into Oceans

A. From 1946 through 1993, thirteen countries used ocean disposal or ocean dumping as a method to dispose of nuclear and radioactive waste. Since 1993, ocean disposal has been banned by the London Convention of 1972, the Basel Convention, and the MARPOL 73/78 Convention[1] **[*14*]**. The countries listed in descending order of total contributions are: USSR, U.K., Switzerland, USA, Belgium, France, Netherlands, Japan, Sweden, Russia, New Zealand, Germany, Italy, and South Korea (USSR and Russia are treated separately). Together, these countries dumped a total of 85,100 TBq of radioactive waste at over 100 different ocean sites. According to the United Nations, companies continue to dump radioactive wastes in the oceans **[*15*]**.

B. In his essay, "Disposal of Radioactive Nuclear Waste," Air Marshal (Rtd) Ayaz Ahmed Khan reveals how nuclear wastes are disposed of in the US. He mentions that barges on the West Coast carry radioactive waste, passing under the Golden Gate Bridge on their way to dump them into the Gulf of Farallones. Here, the bottoms of the barges are opened to release containers of radioactive waste into the sea. Radioactive carcasses of dead animals used in nuclear experiments at the Naval Radiological Defense Laboratories, Hunters Point, near San-Francisco, constituted much of the cargo on some barges. Nuclear waste from applied nuclear research at the University of California's Lawrence Laboratories is sent out in 55-gallon drums that are loaded on to the barges for dumping into the sea. Many of the US Navy's radioactive waste containers were breached, and waste barrels were punctured to facilitate sinking, spreading radioactivity in the sea in the Farallon Islands Nuclear Waste Site. The Farallon Waste Site encompasses most of the Gulf of Farallones National Marine Sanctuary, a refuge of marine and other wildlife. The site includes some of the most fertile commercial fishing waters in the Pacific. Astonishingly, this area was used as America's largest sea dump of nuclear waste until some years back. US officials have long acknowledged that this nuclear dump site contains some 47,500 barrels of low-level radiation waste. The Farallon Islands Nuclear Waste Site is officially termed a 'low level' nuclear waste repository, but, according to SF Weekly, the US Navy's unclassified documents reveal "significant amounts of plutonium which has a half-life of 24,000 years, and similarly long lived 'mixed fission' products were used at the US Navy's laboratory at Hunters Point." The US Navy has acknowledged that all nuclear materials used at the Naval Radiological Defense Laboratories were disposed of at the Farallon Nuclear Waste Site. An entire radioactive ship, the 10,000-ton aircraft carrier Independence, used as a target in the Bikini Atoll's largest US atomic bomb tests, is believed to have been intentionally sunk near this waste site in order to be disposed of. Increasing incidence of cancer and other radiation-linked diseases are reported to afflict seamen working on nuclear waste-carrying barges and tugs and from eating radioactive fish and sea food. Officials and contractors of the US Environmental Protection Agency have said that radioactive material from this dumping site could be entering the food chain and could even be spreading to beaches and into San Francisco Bay. Despite environmental outcry, for fifty years radioactive waste was dumped at the Farallon Islands Nuclear Waste Site **[*16*]**.

Though ocean disposal of radiological wastes makes it hard for terrorists to steal these materials, it may cause environmental harm due to gradual buildup of wastes **[*17*]**. This type of harm bears a resemblance to one of the aims of terrorists, which is to cause harm to the target nations. If every country dumps its radioactive wastes in oceans, this could cause significant buildup of wastes over time and cause harm to the living beings which are present inside the ocean waters. The humans who consume this sea food will also be susceptible to cancer and radiation sickness. This, in turn, has adverse economic and health implications for the countries involved.

[1] MARPOL 73/78 is the International Convention for the Prevention of Pollution from ships from 1973, then modified by the Protocol of 1978. MARPOL is short for Marine Pollution and 73/78 short for the years 1973 and 1978

IV. Terrorists and Radioactive Wastes

The Italian NGO Legambiente has found that since 1994 at least 40 ships have disappeared in Mediterranean waters. The vessels sank in fair weather, had suspicious cargo, sent no Mayday, and the crew vanished. The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy's state research agency, is suspected to have paid the 'Ndrangheta—a criminal organization from Calabria, Italy—to get rid of over 600 drums of toxic radioactive waste from Italy, Switzerland, France, Germany, and the US. The 'Ndrangheta clan blew up shiploads of waste, including radioactive hospital waste, and sent them to the sea bed off the Calabria Coast **[*18*]**. A former member of the 'Ndrangheta, Francesco Fonti, has said that the group sank at least thirty ships loaded with toxic radioactive wastes. Both Fonti and Legambiente claim that ships containing radioactive wastes were received by local rebels in Somalia in exchange for weapons.

India is getting hazardous, toxic waste from smaller countries like Comoros, an island nation in the Indian Ocean. India received toxic consignments by ships from Bermuda, Panama, and even land-locked Mongolia. The less economically developed countries come in handy for countries like Germany and Greece to circumvent international laws; while international laws prevent "the rich" from shipping their hazardous waste directly to India, the "poorer" countries are not barred from dealing in this lucrative international scrap trade with other "poor countries" **[*19*]**.

Now, alarming reports are coming of Illegal, Unreported, and Unregulated (IUU) fleets from around the world dumping and poaching toxic wastes in Somalian waters **[*20*]**. Nick Nuttall, a United Nations Environment Program (UNEP) spokesman, told Al Jazeera that in the tsunami of 2004, rusting containers of toxic waste washed up on the shores of Punt land, Northern Somalia. The containers exposed a "frightening activity" that had been going on for more than a decade. "Somalia had been used as a dumping ground for hazardous waste starting early 1990's. The waste is of many different kinds. There is uranium radioactive waste, lead, and heavy metals like cadmium and mercury. There is also industrial waste, and there are hospital wastes, chemical wastes – you name it" **[*21*]**. What is most alarming is that nuclear waste is being dumped, potentially killing Somalis and completely destroying the ocean **[*22*]**. Moreover, it is believed that the Italian mafia disposed of some of Europe's extremely hazardous wastes. Locals also suspect that Danish and German shipping companies are involved in this illegal trade.

What are the consequences of such irresponsible dumping? It is possible for terror groups like Al Shabaab, Boko Haram, and ISIS to procure radioactive waste from the Somali coast and spread havoc. In the past, Al Shabaab—which has a stronghold in East Africa—has stolen cargo from ships off the Somalian coast and trafficked that cargo through the rest of Africa. This group takes full advantage of its position on the Somalian coast by trafficking arms, ammunition, goods and other items from this strategic location, and they could potentially engage in nuclear trafficking or nuclear terrorism in the future **[*23*]**. The Somali coastline of nearly 650 kilometers has become a dumping ground for toxic radioactive materials. The then-Executive Director of United Nations Environmental Program (UNEP), Dr.Mostafa Tolba, confirmed that European companies had been taking advantage of the on-going political chaos and civil war in Somalia in order to dump hazardous toxic wastes illegally onto the country's long coast **[*24*]**.

A frightening scenario that may be visualized is that of the terror group Al Shabaab, which operates in Somalia, laying its hands on the radioactive waste and fabricating a dirty bomb. Another terror group, Boko Haram, operates in nearby Nigeria, and the terror organization ISIS operates in close proximity, in Iraq and Syria. These extremely violent terror groups can procure these wastes from less developed countries through black market dealings by making use of a network of criminals, smugglers, and middlemen, all without violating any international law, rule, or treaty. The Somali coastline does not have coast guards and is not patrolled, and there are no health officials and facilities to detect the contents of the waste containers **[*25*]**. They will be within their legal rights in making use of the radioactive waste

dumped on the coastline, for which there are no claimants. These wastes have been dropped on the Somali coastline clandestinely, from unknown sources, by unidentified ships and vessels. Since there is no functioning government in Somalia, that country has not been able to file a formal complaint before any international organization like the United Nations or the International Atomic Energy Association. There remains the possibility that these terror groups could collaborate to exploit this nebulous state of affairs to appropriate the toxic radioactive wastes lying on the Somali coastline, fabricate several dirty bombs, and spread havoc throughout West Asia. In other words, if Al Shabaab, Boko Haram, and ISIS collaborate **[*26, 27*]**, the easiest, most profitable and most reasonable target could be West Asia because of the political instability. For example, oil fields in Iraq could be an attractive target. Suicide bombers could volunteer to attack crucial oilfields, refineries, or any institution, office, or civilian or military establishment that could help them to dramatically alter the global military equation. These terror organizations could also foment a miniature dirty bomb war, which would be a horrendous threat. Already, a United Arab Emirates foreign minister has suggested that, "What really scares us now is what we see from Daesh, and are we going to see in the future any sort of collaboration between different terrorist groups like Daesh and Al Shabaab? I think we should start to ask ourselves, how ready we are as countries, companies and international organizations in facing these big threats" **[*28*]**. Conniving nations, unscrupulous waste vendors, greedy transporters, and inefficient, corrupt, and lax administrations are proving to be an ideal cocktail for terror groups.

V. Terrorists Have Demonstrated Their Interest in Acquiring Radioactive Materials for Terror-Related Activities

Terrorists have shown interest in the past in acquiring radioactive and nuclear materials for carrying out their terror attacks. The investigations after the September 11, 2001 attack in the US has revealed that al-Qaeda planned to acquire materials for constructing a radioactive dispersal device. In 2004, a British national was arrested for conspiring to use radioactive materials for creating a public nuisance. Also, in 2004, another British national was arrested for attempting to procure a "radioisotope bomb" from the Russian mafia. These cases clearly demonstrate the interests of terrorists in acquiring and using radioactive materials for their terror activities **[*29*]**.

On April 15, 2013, two people identified as ethnic Chechens were arrested as prime suspects in the Boston Marathon bombings, which killed three people and injured 100 **[*30*]**. In 1991, Chechnya had several facilities with radiological sources. Among them was "the Groznyy Radon," a radiological waste repository, which was the primary source that contained radiological materials. The Radon was used for disposing radioactive wastes by Chechens during 1993-1994, and 1997-1999. Also, there were many facilities including high schools, universities, and hospitals which contained radioactive wastes. In 1998, Chechen law enforcement authorities filed cases pertaining to theft of radioactive sources, and the director of Groznyy radon reported the theft of several containers from the facility **[*31*]**.

In the past, Chechen terror groups have repeatedly, though so far always unsuccessfully, tried to detonate crude dirty bombs. On October 21, 1995, Shamil Salmanovich Basayev, a Chechen militant, said he possessed enough radioactive materials to create several "mini Chernobyl[s]" and "turn Moscow into a desert". On November 23, 1995, Chechen separatists buried a 30-pound container of cesium-137 wrapped in explosives at the Izmaylovsky Park in Moscow. The container emitted radiation 30-700 times the normal level **[*12, 32*]**. Again, in December 1998, a container filled with radioactive materials attached to an explosive mine was hidden near a railway line in Argun, ten miles east of the Chechen capital of Grozny **[*33*]**. In both of the above incidents, timely interventions by the authorities averted the disaster. But, with abundant toxic radioactive wastes like those piled on the Somali coastline, terror groups would have an unending supply.

In 2013, in Mexico City, a truck carrying cobalt-60 used for cancer treatment was hijacked, demonstrating the hidden potential of terrorist organizations using this method to procure radioactive materials to create weapons of mass destruction **[*13*]**.

In December 27, 2017, ten people were injured by an explosion at a supermarket in St. Petersburg. The investigating agency reported that a device rigged with shrapnel and explosives equivalent to 200g of TNT was used for the attack **[*34*]**. Investigators said that the explosion was caused by a homemade bomb packed with pieces of metal **[*35*]**. The Islamic State (IS) militant group claimed that it was behind this bombing **[*36*]**.

In Japan, a drone was employed to carry cesium and land on the roof of the Japanese Prime Minister's office **[*37, 38*]**. Deploying unmanned aerial devices to deliver radioactive material to high profile targets is opening a new vista in terror tactics. The possibility of containers filled with radioactive material being guided and directed to hit targets in West Asia, especially oil refineries, could cause a global disruption of oil supplies, thereby causing a global recession. The radioactive waste on the Somali coastline could be put to endless uses by innovative terrorists, unless the global community acts fast to sequester this toxic dump in a secure and guarded location.

Terrorists may use the radioactive materials to expose targets through means of "inhalation, ingestion, or immersion" **[*13*]**. The first provable example of this mode of radiological terrorism was the murder of former Russian spy Alexander Litvinenko in 2006 by polonium-210 ingestion.

In September 1987, in Goiania, Brazil, scavengers lifted a metal canister containing 1,375 curies of cesium-137 from a radiotherapy machine in an abandoned cancer clinic and eventually gave it to a junkyard. The junk dealer opened the canister, causing the dispersal of radioactive material through runoff and wind, resulting in the contamination of 200 people, the death of 4 people, and radiation injury to 28 people, which shows how hazardous radioactive waste from medical sources can be **[*13*]**.

Georgia is called a "nuclear highway" by atomic energy experts, as it is a smuggling route to ISIS in Syria and Iraq. In 2016, in the ex-Soviet Republic of Georgia, a flea-market trader was caught by two undercover police officers who posed as strangers and acted as if that they wanted an item from the black-market which cost more than gold. To their surprise, the trader showed them a lead box containing a few pounds of radioactive uranium-235, which, if mixed with conventional explosives such as dynamite, could be turned into a dirty bomb. According to interrogation records and other court documents obtained by TIME in Georgia, a box containing radioactive materials was found inside a sack of scrap iron **[*39*]**. According to police investigations, it was found that associates in the attempted uranium sale included construction workers and scrap-metal traders **[*39*]**. What baffled the investigators most was that a potential terrorist could acquire these radioactive substances and other ingredients with such ease. In 2016, Georgian police raided three separate groups of smugglers for attempting to traffic nuclear materials. That January, they spoiled an attempt to smuggle cesium-137 across the border to Turkey. On April 17, 2016, they also caught a group of Georgian and Armenian traffickers selling $200 million worth of uranium-238. A dirty bomb could be as strong as a regular bomb, but in addition to this it could cause radiation poisoning to people who come to aid those affected by these bombings. Additionally, the winds could amplify the damage by spreading the radioactive substances. This route is very attractive to terrorist organizations because it would drive away tourists and customers from the place, have economic implications for clean-up and recovery, and create panic and lasting fear in the state **[*39*]**.

In the investigations after the ISIS-linked Brussels bombings that killed 32 people in March of 2016, Belgian authorities found that a suspected terrorist had surveillance footage of a Belgian nuclear official who had access to radioactive materials. ISIS was looking to procure radioactive materials from a nuclear

center by kidnapping the official or his family members **[*39–41*]**. In 2014, when the Iraqi city of Mosul was controlled by a group of ISIS fighters, they were reported to have seized 40 kg of uranium from a university **[*39, 42*]**.

Ten grams of iridium-192 was stolen from a contractor working for an oil service company in Basra Province in November 2015. The missing Ir-192 was in a shielding container. Iraqi security officials fear that if it falls into the hands of ISIS, they will use it to construct a dirty bomb **[*43, 44*]**.

Reports have circulated of hospitals that treat cancer patients dumping radioactive wastes into public sewage and garbage in Bangalore, India **[*45*]**. It is possible that terrorists could acquire these radioactive wastes from waste vendors at low costs.

In April 2010, radioactive Cobalt-60 contained in a metal pipe was found in West Delhi's Mayapuri scrap market, resulting in a radiation leak the killed one person and affected several people. Subsequently, it was discovered that the Cobalt-60 was in a "Gamma irradiator" which was unused since 1985 in the chemistry department of Delhi University and was sold to scrap dealers of Mayapuri through an auction in February 2010. The radiation leak occurred because the scrap dealers dismantled the equipment resulting in peeling of protective lead covering **[*46–48*]**.

The lack of export controls on medical waste and other radioactive waste has led to this critical situation. Attempting to simply brush off this waste is proving to be a fatal mistake. Cash-strapped governments, hospitals, and research institutions realized that disposal of radioactive waste was a difficult problem and decided to leave it in the hands of waste vendors. Unfortunately, many of these waste vendors turned out to be profiteers, ready to exploit their situation to make money. They had no qualms in dumping radioactive waste, whether in the oceans, in developing countries, or mixing it with other kinds of wastes so as to conceal it and throw it in places where security was lax. The straw which has broken the proverbial camel's back has been the dumping of radioactive toxic waste on the beaches of Somalia. The lack of a proper government and the rogue groups of pirates ruling the beaches has made it possible for bribes to make way for uncontrolled dumping. Radiation injuries among the unsuspecting populace and dwindling marine life have confirmed the worst fears of locals and concerned environmental groups—that a radiation hazard is running riot on the beaches of Somalia **[*25*]**. With terror groups scouting for radioactive material to fabricate a dirty bomb, a radioactive waste bonanza is taking place on the Somali coastline. Totally unguarded and legal, terrorists could ferret for radioactive material, either decayed or decaying, and fabricate dirty bombs, to threaten the security, both military and economic, of people all over the globe. To borrow a biblical phrase, nations have sown the wind and can expect to reap the whirlwind.

VI. Deploying Low-Enriched Uranium for Civilian Use May Minimize Build-Up of Radioactive Wastes

In many countries, there is lack of both regulatory and physical security of radiological sources, leading to thousands of missing or stolen radiological sources. Even in the US, a country with strict regulations, one radioactive source is abandoned outside of an institution's accounting system every day **[*13*]**. In other words, unneeded (no longer required) radioactive sources are relinquished or deserted by institutions and/or officials because of a lack of awareness of the consequences of their misuse. These abandoned radioactive sources can ultimately be misplaced, lost or stolen. Thieves may then store these radioactive sources in public spaces which pose a threat to public health because of the radiological hazard.

Highly enriched uranium (HEU) sufficient to produce a Hiroshima bomb is employed as a neutron target in the production of 99Mo, which decays to the widely used medical radioisotope 99mTc **[*49*]**. Other medical isotopes like iodine-131 and xenon-133 are by-products of 99Mo **[*49*]**. Eighty-five kg of HEU

were used by Canada, South Africa, and Europe for this purpose. During the production of 99Mo from an HEU target, less than 5% of the 235U is consumed. The rest is not recycled and is accumulated as wastes. The theft of these wastes would be of significant concern to all these countries. Due to terrorism related to the civilian use of HEU, both the US and Soviet governments in 1970 created programs to substitute HEU with low-enriched uranium (LEU). LEU contains less than 20% 235U. The US supplies HEU to Canada, which has the world's majority of 99Mo-producing reactors, under the condition that the receiving state converts it to LEU targets. However, the Canadian party said that the costs involved in the conversion procedures are more than HEU. In an article by Hippel and Kahn, the authors demonstrate that the costs of 99Mo production through the LEU method increases by only a few percent in Europe and more than 10% in Canada. However, the costs involved in obtaining the final product 99mTc would be increased by less than 1% when compared to HEU. This method has the additional advantage of eliminating the presence of HEU at production and radioactive waste sites, thereby effectively reducing the security-related costs **[*50*]**.

Radioactive sources used in medicine are susceptible to being abandoned or unprotected once they fall out of use. The IAEA provides safety standards to control disused sources and store, condition, or recover them **[*51*]**. Though the IAEA has guidance on the management of disused radioactive sources and has developed a radioactive waste management registry to effectively track and control radioactive wastes, hospitals, laboratories, and universities rarely implement it **[*52*]**.

VII. Conclusion

Safe disposal of radioactive wastes, including hospital wastes, has been neglected by nations on the premise that it was just waste and would not constitute a problem. However, large quantities of radioactive wastes emerging out of hospitals and research institutions, coupled with toxic industrial effluents, has turned waste management into a critical sector. The concerns of environmental groups, alert citizens, vigilant media, and cognizant judiciaries have forced governments to recognize the issue and seek the aid of waste vendors. Unscrupulousness has led to waste vendors dumping radioactive wastes of all kinds into the oceans. Since 1971, more than 20,000 shipments of over 50,000 tons of high-level wastes and highly radioactive used fuel have been transported over 30 million kilometers; the World Nuclear Association, The Basel Convention, the Bamako Convention, and the Stockholm Convention have all made it difficult for this trans-border movement of such hazardous radioactive waste **[*53*–*55*]**. But the emergence of states like Somalia, with a weakened central government, proved to be a blessing in disguise for waste vendors worldwide. Bargains with pirates cleared the way for bulk toxic wastes to be dumped on the coastline by unidentified shipping vessels. By the time the pirates realized that lethal cargo had been dumped on their doorsteps, the damage had been done and the perpetrators had vanished. In yet another unfortunate development, terror groups worldwide are contemplating the procurement of radioactive waste for fabrication of dirty bombs. It would not require nuclear physicists or sophisticated criminal networks to convert raw radioactive materials into deadly weapons **[*40*]**. Medical radioisotopes can cause radiation poisoning and sickness, and they could serve as a potential target for terrorists aiming to build dirty bombs to contaminate cities, causing panic and huge financial losses **[*40*]**. Instances of the use of radioactive hospital waste for terror attacks in Russia and Japan, though unsuccessful, have opened a new dimension in the ongoing battles against terror being staged in different parts of the world. For anyone looking to procure radioactive materials, there is a treasure-trove lying unclaimed on the Somali coastline. Soon, terror organizations like Al Shabaab, Boko Haram, and ISIS could reach out to Somalia, where they could find a cache of material for dirty bombs.

VIII. Recommendations

1) All radioactive wastes including hospital wastes and toxic industrial wastes should be brought under the domain of export trade controls to ensure that such waste does not get into the hands of terror organizations.

2) IAEA does not have concrete mechanisms to implement the regulation of export and import of radiological medical wastes **[*56*]**. Additionally, the IAEA does not establish or enforce physical protection standards regarding radiological medical wastes **[*8*]**. It is recommended that the government of each state endeavors to thoroughly implement mechanisms and regulations to locally control the exports and imports of hospital radiological wastes. Also, the IAEA should endeavor to create means to establish and enforce physical protection standards pertaining to radiological wastes, perhaps by creating an exclusive international organization for this purpose.

3) The IAEA should direct all the countries, especially Canada, Europe, and South Africa, to exclusively use LEU instead of HEU in the production of medical radioisotopes.

4) Exporting states should notify the importing country prior to exporting the wastes. The contents, weight, quantity, and purpose of exporting/importing the waste should be clearly mentioned on the consignment. The exporting agency should verify whether the importing agency is authorized to collect the export prior to exporting it. It should also review the safety measures undertaken to secure the consignment during its delivery so that it does not fall into the hands of unauthorized people. Exporting and importing countries both should establish a regulatory body locally to oversee these procedures. Any suspicious activities should be reported to the IAEA.

5) The mixing of radioactive wastes and hospital wastes with other wastes should not be permitted, whether for export or internal disposal. Solid radioactive wastes should be collected in foot-operated waste collection bins with disposable polythene linings. Polythene carboys should be used for liquid waste. Separate waste collection bags and bins should be used for different isotopes with different half-lives. The bin or bag should include a label containing information about the name of the radioisotope, its level of activity, and its date of monitoring.

6) Waste vendors who export or import radioactive wastes need to be registered, licensed, and compelled to file quarterly returns of wastes received and disposed. The location of disposal should be identified and periodically inspected. This licensing authority should come under the purview of the IAEA.

7) Safe radioactive waste disposal training programs need to be established for hospital staff, waste vendors, and those connected to the nuclear trade industry.

8) Safe radioactive waste disposal, including of hospital waste, should be made into a distinct subject of study in universities, in order to build up a cadre of waste disposal experts.

9) Ocean-going vessels carrying radioactive wastes, including hospital wastes, should be separately identified—along with the institution of pre-clearance and post-clearance checks—to ensure safe disposal practices.

10) Radioactive wastes, including hospital wastes, should be loaded, shipped, and unloaded only at specially designated ports in each country in the interest of safety and environmental concerns.

11) Radioactive wastes, including hospital wastes, should be disposed of in specially- designated dumping zones, which are monitored and protected by a trained special security force. All hospitals handling radioactive materials should employ a radiation safety officer who observes, monitors, and controls radioactive waste disposal procedures. The government of the state should inform all the hospitals, medical laboratories, and universities handling radioactive wastes to use and maintain the radioactive waste management registry (RWMR) software to record information on radioactive waste management activities, to track licenses, and to track the radioactive waste inventory.

12) Ocean dumping of radioactive wastes, though banned by many international treaties and conventions, is still flourishing clandestinely. Nations should unite to set up a joint task force to patrol ocean dumps. These sites also need to be periodically inspected to determine and assess the level of disintegration of the containers containing radioactive wastes, due to decades of exposure to saltwater and underground water pressure.

13) Customs administrations across the world through the World Customs Council should compulsorily require radiation portals and portable radiation detectors to ensure that no trafficking in radioactive wastes take place in the course of normal trade. If any trafficking is detected, it should be reported to the IAEA.

14) An international task force to secure and seal the Somali coastline should be constituted immediately, and it should draw up an action plan to safely transfer the radioactive wastes to a secure location.

15) The United Nations is requested to designate a day as “Radioactive Waste & Hospital Waste Disposal Day” in order to create global awareness for the need of safe disposal practices.

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