



THE HENRY L.
STIMSON CENTER

**PREVENTING NUCLEAR TERRORISM IN
PAKISTAN:
Sabotage of a Spent Fuel Cask or a Commercial
Irradiation Source in Transport**

**ABDUL MANNAN
PAKISTAN NUCLEAR REGULATORY AUTHORITY**

THE HENRY L. STIMSON CENTER
APRIL 2007

Copyright © 2007
The Henry L. Stimson Center
1111 19th Street, NW
12th Floor
Washington, DC 20036

Telephone: 202-223-5956
Fax: 202-238-9604

www.stimson.org
email: info@stimson.org

ABOUT AUTHOR

Abdul Mannan

Director, Transport and Waste Safety, Pakistan Nuclear Regulatory Authority (PNRA)

Mr. Mannan was a Visiting Fellow at The Henry L. Stimson Center from November 2006-February 2007. At the PNRA, his responsibilities include establishing and maintaining regulatory frameworks for the physical protection of civilian nuclear facilities and transport links including import and export. He holds masters degrees in Physical Chemistry from Karachi University and Nuclear Engineering from the Centre for Nuclear Studies in Pakistan. He has authored or co-authored over 25 scientific papers on various research topics related to radiation and safety.

DISCLAIMER

While pursuing research studies and preparing this manuscript, the author was attached with The Henry L. Stimson Center, USA. The views expressed in this paper do not necessarily reflect those of the Pakistan Nuclear Regulatory Authority, the Government of Pakistan, or any organization under whose auspices this manuscript was prepared.

TABLE OF CONTENTS

Summary	4
Introduction.....	5
Nuclear Terrorism and Pakistan’s Vulnerability	6
Availability of Nuclear Material and Radioactive Sources	8
Spent Nuclear Fuel (SNF) and Radioactive Sources	10
Shipping Container Design.....	12
Concern over Spent Fuel Transportation.....	13
Inventory of Radionuclides in Spent Fuel	16
Dispersion Model.....	17
Hypothetical Case Studies	19
Scenario I (SNF at Karachi).....	19
Scenario II (High Activity Radioactive Source at Lahore).....	25
Addressing Pakistan’s Vulnerability	29
Recommendations.....	30
Conclusion	33

Summary

Although an act of nuclear terrorism is of very remote probability in Pakistan, nevertheless, an attempt has been made to review the pre and post 9/11 threat of nuclear terrorism and its impact on Pakistan. A hypothetical case study has been made of a sabotage on radioactive consignments during transportation within the city of Karachi and Lahore and possible consequences were assessed using Hazard Prediction and Assessment Capability (HPAC) computer code. Pakistan's response to nuclear terrorism and the further need of improvements has been discussed. The controls around various nuclear installations and radiation facilities in Pakistan are enough to deter and delay a terrorist attack and any modified diversion would be detected in early stages. Therefore, fabrication of a Radiological Dispersion Device (RDD) and WMD is not very attractive to a terrorist group in general and specifically within the context of Pakistan.

Introduction

The human desire to attain a better standard of living in terms of comfort of life has led to a concurrent demand for more energy. With conventional sources of energy fast depleting, several countries embarked upon nuclear energy programs, constructing nuclear power plants (NPPs). As of December 2005, 443 NPPs with generating capacities of 370 GWe are operating in 31 countries. In addition, 27 NPPs with total generating capacities of 22 GWe are under construction in 11 countries.¹ The reactors discharge irradiated fuel no longer able to economically sustain a chain reaction. The spent fuel contains fission products generating huge activities and producing heat energy initially after discharge. Except for possible reprocessing, this fuel must eventually be removed from its temporary storage location at the reactor site and be placed in a permanent repository. In addition to NPPs, many more have research reactors (of which there are approximately 550 in the world) and a very large number use other nuclear technologies, in particular, sealed radiation sources.

The nuclear and radioactive sources, the facilities housing such materials including spent fuel storage and fuel cycle facilities have become an urgent source of global concern from the nuclear and radiological terrorism perspective since the tragedy of September 11, 2001. These concerns vary on the basis of risk of nuclear terror acts. According to *The Four Faces of Terrorism* a risk reduction strategy must consider the consequence and probability factors of nuclear terrorism. This stems from two assumptions in nuclear terrorism. First, modes of attack with the gravest consequences are the most difficult to execute because of robust physical protection measures (e.g. NPPs and associated facilities) and thus less likely to occur. Second, attacks with the least consequences are the most likely to occur because of less stringent security measures compared to nuclear installations (e.g. industrial radiography sources in transportation). An Improvised Nuclear Device (IND) while clearly more effective in terms of destruction than a Radiological Dispersion Device (RDD), is more complex and therefore a less likely approach. However, most of the nuclear facilities around the world, including in the US, would not be able to provide a reliable defense against attacks as large as terrorists have already proved that they can mount.² According to the Lugar Survey, the possibility of a WMD attack against a city or other target somewhere in the world is real and increasing over time. The median estimate of the probability of a radiological attack over ten years was twice (40%) as high as the estimate for a nuclear or biological attack during the same period.³ Thus a strategy should reduce the consequences of those nuclear attacks that are the most likely and limit the probability of attacks with the highest consequences.⁴

Given the above considerations, the present paper briefly reviews Pakistan's vulnerability to nuclear terrorism and the consequences during movement of radioactive materials through two possible hypothetical case studies. The first is a successful terrorist attack on Spent Nuclear Fuel (SNF) during transportation and shipment. This scenario is less probably because of expected physical protection measures and SNF shipments are not anticipated in the near future in Pakistan. The second is the more likely of the two, a terrorist attack on high activity radioactive sources being transported within Pakistan.

¹ IAEA Nuclear Power Reactors in the World, Reference Data Series No.2, April 2006, (http://www-pub.iaea.org/MTCD/publications/PDF/RDS2-26_web.pdf)

² Matthew Bunn and Anthony Wier, *Securing the Bomb*, John F. Kennedy school of Government Harvard University, July 2006, (<http://www.nti.org/securingthebomb>)

³ Richard G. Lugar, *The Lugar Survey On Proliferation: Threats and Responses*, June 2005, (<http://lugar.senate.gov/reports/NPSurvey.pdf>)

⁴ Charles Ferguson and William Potter, *Four Faces of Nuclear Terrorism*, (Center for Nonproliferation Studies: Monterey, CA, 2004), p5

Nuclear Terrorism and Pakistan's Vulnerability

The threat of terrorism and possible use of Nuclear, Biological, and Chemical (NBC) Weapons by terrorists was not ignored by many experts. On March 20, 1995, the unimaginable Tokyo subway attack made the threat real. Five coordinated attacks released sarin gas on several lines of the Tokyo subway, killing twelve people and injuring nearly one thousand others.* The attack caused massive disruption and widespread fear in a society that was previously perceived to be virtually free of crime. Considering such risk, the security levels of nuclear power plants and facilities housing nuclear and other radioactive materials were augmented. Still, Americans found the idea of large scale terrorist attacks inconceivable prior to September 11th.⁵

Richard Falkenrath, in his book *America's Achilles' Heel*, recognized the vulnerability of the US to Nuclear, Biological, and Chemical (NBC) terrorism. He elaborated the consequences of an NBC attack as: massive casualties, contamination, panic, degraded response capabilities, economic damage, loss of strategic position and social-psychological damage and political change.⁶ A recent report prepared by Nuclear Consultants of Large & Associates cited a October 16, 2005 news report entitled "Nuke Bomb Plot" revealing that a group of terrorists acquired detailed plans of Britain's most sensitive nuclear sites and were planning a terror attack on a major nuclear target in the UK.⁷ In another event on March 22, 2006, BBC News reported "List of Terror targets Revealed" where a suspected terrorist was allegedly involved in a plot to buy a "radio-isotope bomb". The Sunday Morning Herald on January 6, 2007 reported, "Stolen Australian Army rocket launchers are in the hands of a home-grown terrorist group which planned to use them to attack Sydney's Lucas Heights nuclear reactor, police allege." (See Figure 2.1)

Dr. Charles D. Ferguson commented, "The good news is that the rockets would not have done much, if any, significant damage to the reactor. The bad news is that the emerging details of the case point to the harm that insiders can perpetrate. If Australia moves forward with ambitious plans - as proposed in the controversial Switkowski report - to build 25 nuclear power reactors by 2050, it should take adequate precautions to guard against external and internal security threats."⁸ He further argued that the Australian Defense Forces have dozens of shoulder-fired Javelin "fire-and-forget" missiles that have lock-on targeting and infra-red (night-time) guidance and such a long-range and highly penetrating missile fired more than a kilometer away could have penetrated the relatively thin shell of the shipping casks.

* Sarin, also known by its NATO designation of GB (O-Isopropyl methylphosphonofluoridate), is an extremely toxic substance whose sole application is as a nerve agent. As a chemical weapon, it is classified as a weapon of mass destruction by the United Nations according to UN Resolution 687, and its production and stockpiling was outlawed by the Chemical Weapons Convention of 1993.

⁵ Graham Allison, *Bulletin of Atomic Scientists* September/October 2006, (<http://www.thebulletin.org>)

⁶ Richard A. Falkenrath, Robert D. Newman, and Bradley A. Thayer, *America's Achilles' Heel: Nuclear, Biological, and Chemical Terrorism and Covert Attack*, (MIT Press: Boston, 1998)

⁷ Large Associates "Risks and hazards of transportation of spent fuel in the UK," (London, 27 March 2006)

⁸ Interview, Dr. Charles Ferguson, Washington, DC, January 8, 2007



Figure 2.1: Lucas Heights Nuclear Reactor, Source: Sunday Morning Herald⁹

Getting hold of a nuclear weapon or successful acquisition of nuclear material and detonation of an IND by terrorists could turn a modern civilization into a smoking ruin.¹⁰ Dr. Charles Ferguson outlines nuclear terrorism in four approaches:

- Theft and detonation of an intact nuclear weapon (NW).
- Theft or purchase of fissile material leading to the fabrication and detonation of a crude NW- an improvised nuclear device (IND).
- Attacks against and sabotage of nuclear facilities, in particular NPPs, causing the release of large amounts of radioactivity.
- Unauthorized acquisition of radioactive materials contributing to the fabrication and detonation of a Radiological Dispersion Device (RDD)—a “dirty bomb”—or radiation emission device (RED).¹¹

Any successful attack based on the above possibilities would have catastrophic and far reaching consequences. The damage that can be done by a large release of fission products was demonstrated by the April 1986 Chernobyl accident. More than 100,000 residents from 187 settlements were permanently evacuated because of contamination by Cs-137. Strict radiation-dose control measures were imposed in areas contaminated to levels greater than 15 Ci/km² (555 kBq/m²) of Cs-137. The total area of this radiation-control zone was huge: 10,000 km², equal to half the area of the State of New Jersey. During the following decade, the population of this area declined by almost half because of migration to areas of lower contamination.¹² Beyond contamination, Graham Allison cited in his article that researchers at RAND, a US government funded think tank, estimate that a nuclear explosion at the port of Long Beach in California would cause immediate indirect costs worldwide of more than \$3 trillion and that shutting down all US ports would cut world trade by 10%.¹³

⁹ Les Kennedy and Craig Skehan, “Nuclear plant target for stolen rocket launchers, police allege,” *Sunday Morning Herald*, 6 January 2007, (<http://www.smh.com.au/news/national/nuclear-plant-target-for-stolen-rocket-launchers-police-allege/2007/01/05/1167777281891.html>)

¹⁰ Graham T. Allison, *Nuclear Terrorism*, (2004) and Peter R. Beckman et al, *Nuclear Weapons, Nuclear States and Terrorism 4th Ed*, 2007.

¹¹ Charles D. Ferguson et. Al, *The Four Faces of Nuclear Terrorism*, (Washington, DC, The Center for Nonproliferation Studies, 2004)

¹² Zhang, Hui. "Radiological Terrorism: Sabotage of Spent Fuel Pools." *INESAP: International Network of Engineers and Scientists against Proliferation* no. 22 (Dec. 2003), pp75-78. (http://www.inesap.org/pdf/INESAP_Bulletin22.pdf)

¹³ Graham Allison, *Bulletin of Atomic Scientists*, September/October 2006, (<http://www.thebulletin.org>)

The UN Secretary General Kofi Annan said:

Perhaps the thing that it is most vital to deny terrorists access to nuclear materials. Nuclear terrorism is still often treated as science fiction. I wish it were. But, unfortunately, we live in a world of excess hazardous materials and abundant technological know-how, in which some terrorists clearly state their intention to inflict catastrophic casualties. Were such an attack to occur, it would not only cause widespread death and destruction, but would stagger the world economy and thrust tens of millions of people into dire poverty. Given what we know of the relationship between poverty and infant mortality, any nuclear terrorist attack would have a second death toll throughout the developing world.¹⁴

Nuclear terrorism can be a real threat to Pakistan. Pakistan has dealt with terrorism for some time, with much of the root cause from the Soviet invasion of Afghanistan in 1979. The Soviet Union's departure in 1989 promoted further unrest as it left behind an enormous arsenal of heavy weapons and an internal conflict in Afghanistan that followed. Pakistan's renewed alliance with the US after 9/11 has increased the threat of terrorism. General Pervez Musharraf, President of Pakistan, in his recent book, describes the current situation starkly:

A deadly al Qaeda terrorist network entrenched itself in our major cities and the mountains of tribal agencies on our western border with Afghanistan. A culture of targeted killing, explosives, car bombs, and suicide attacks took root.¹⁵

Major attacks continue in Pakistan, including the recent suicide bomber who killed at least 42 soldiers in Dargai.¹⁶ However, Pakistan had previously experienced such incidents of terrorism but these were very target specific and mostly in retaliation to some action taken domestically or outside our country. None of the terrorist action was designed to kill populations en-masse or to cause panic on a large scale. No such terrorist action was ever directed towards any nuclear installation, radiation facility or other hazardous industry. However, a change in strategy of terrorists cannot be totally ignored.

As the threat of global terrorism has grown so too has the Government of Pakistan's nuclear power program. Today it envisages an expansion in its nuclear power program from its current production capacity of 437MWe to 8,800 MWe by 2030.¹⁷ Besides NPPs, two research reactors, one commercial irradiation plant (PARAS) at Lahore, and numerous high activity radioactive sources are being used for R&D, commercial industrial, and medical purposes. The vulnerability of these facilities to nuclear terrorism cannot be ignored, especially in the current context of Pakistan's active participation with US and Western Allies in the War on Terror.

Availability of Nuclear Material and Radioactive Sources

Today, there are hundreds of tons of nuclear material, not just in the former Soviet Union but in dozen of countries around the world, that remain dangerously vulnerable to theft. As a part of Nunn-Lugar and other initiatives, the US has secured 54% of the buildings housing such materials, leaving still substantial work needed to be completed before the target completion year 2008.¹⁸ Stocks of

¹⁴ Secretary-General Kofi Annan, Keynote address, International Summit on Democracy, Terrorism and Security, Madrid, Spain October 3, 2005, UN Press release SG/SM/9757 (<http://www.un.org/News/Press/docs/2005/sgsm9757.doc.htm>)

¹⁵ General Pervez Musharraf, *In the Line of Fire: A Memoir by President of Pakistan*, (Simon & Schuster, London, 2006)

¹⁶ Pakistani Newspaper Dawn dated November 9, 2006: (<http://www.dawn.com.pk>)

¹⁷ PNRA Report 2001 – 2005, (<http://www.pnra.org>)

¹⁸ Matthew Bunn and Anthony Wier, *Securing the Bomb*, Executive summary p i

fissile material in the US, in spite of higher security measures compared to other states, may be vulnerable to attack because of flaws in protective measures.¹⁹ In a subcommittee hearing on April 27, 2004, an official of the National Nuclear Security Agency (NNSA) of the US Department of Energy (DOE) admitted that Y-12, where the US manufactures and maintains the world's largest repository of 400 MT of HEU, has "some of the most difficult security problems in the complex. Its facilities were built in the early days of the cold war with no thought of the kind of threat we have now."²⁰ Richard Levernier, a security specialist with the DOE, in an interview in 2003 said "in more than 50% of our tests at the Los Alamos facility, we got in, captured the plutonium, got out again, and in some cases didn't fire a shot because we didn't encounter any guards."²¹

Several incidents of theft involving radioactive materials have been reported. One of the most dangerous occurred in 2003 with the theft of three of the world's most potent radioactive sources-Russian "nuclear batteries"- each with the radioactive potential to make an urban area the size of the District of Columbia uninhabitable. Fortunately, thieves discarded the radioactive materials, retaining their pure metal container housing, which they planned to sell as scrap.²² Nineteen individuals were arrested in August 2003 in Ontario, Canada on charges of conspiring to destroy a NPP on the shore of Lake Ontario. This reflects the interest of terrorist organizations in exploiting nuclear facilities to cause grievous harm to the US and its friends.²³

According to the International Atomic Energy Agency (IAEA) database on Illicit Trafficking, there have been 827 confirmed incidents of illicit trafficking incidents through December 31, 2005.²⁴ Of the 827 confirmed incidents, 224 incidents involved nuclear materials, 516 incidents involved other radioactive materials, mainly radioactive sources, 26 incidents involved both nuclear and other radioactive materials, 50 incidents involved radioactively contaminated materials, and 11 incidents involved other materials. Of 224 incidents, sixteen confirmed incidents involved trafficking in HEU and Pu. A few of these incidents involved seizures of kilogram quantities of weapons usable nuclear material but the majority involved very small quantities.

The nuclear proliferation by A.Q. Khan was the most serious case in recent years. President Musharraf wrote:

I can say with confidence that neither the Pakistan Army nor any of the past governments of Pakistan was ever involved or had any knowledge of A.Q.'s proliferation activities." He further wrote: "There is little doubt that A.Q. was the central figure in the proliferation network, but he was assisted over the years by a number of money-seeking freelancers from other countries, mostly in Europe, in manufacturing, procuring and distributing, to countries like Iran and Libya materials and components related to centrifuge technology."²⁵

Radioactive sources are widely used in almost every country in various applications (industrial, commercial, medical, research and development, etc).²⁶ The facilities housing radioactive materials

¹⁹ Jacquelyn S. Porth, "US Goal: Keep Weapons of Mass Destructions Out of Hands of Terrorists", *2002 United States Special Weapons Nuclear & Missile Proliferation News*, March 13, 2002 (<http://www.fas.org/news/usa/2002/index.html>)

²⁰ Reported by the Bulletin of Atomic Scientists, November/December 2006

²¹ Graydon Carter, "Homeland Insecurity," *Vanity Fair*, (New York: November 2003, 519), p64

²² Ferguson, *Four Faces*,

²³ Ibid

²⁴ IAEA, *Fact sheet 2005: Illicit Trafficking and Other Unauthorized Activities involving Nuclear and Radioactive Materials*, (http://www.iaea.org/NewsCenter/Features/RadSources/PDF/fact_figures2005.pdf)

²⁵ Musharaff, p293

²⁶ Ferguson, *Four Faces*,

have lighter physical protection measures as compared to nuclear facilities and therefore the probability of terrorist hauling away with such sources cannot be ignored. Besides half-life, the activity content of a source and its relative dispersability determine relative security risk. High activity sources which have been classified as high risks include radioisotope thermoelectric generators (RTGs), commercial irradiators, medical radiotherapy sources, and industrial radiography sources.²⁷

Spent Nuclear Fuel (SNF) and Radioactive Sources

Among these various options and given the tight security around nuclear power plants, terrorists can target spent nuclear fuel and high activity radioactive sources in transit as it can be a rich and easy radiological dispersion device (RDD). Consequences of such an attack could be disastrous. The 400 power reactors located worldwide produced around 255,000 tons of spent fuel by 2003, which will increase to about 340,000 tons by 2010 and to about 457,000 by 2020. The bulk of SNF (in tons) has been generated by the US (42,710), United Kingdom (41,430), Canada (27,860) France (30,480), Russia (17,860), Japan (17,450), and Germany (9,660). Pakistan has generated around 240 tons through 2000. This figure will swell with the operation of two nuclear power plants to 1,180 tons by 2020.²⁸ Spent fuel from a nuclear reactor is the most radioactive type of material and constitutes most of the high level waste type produced by a reactor. It is very hazardous, highly radioactive, and hot from the energy released by radioactive decay.

Of the millions of radioactive sources used worldwide in various applications, perhaps only several tens of thousands of these sources are classified as high risk sources because of their high activity, portability and dispersibility.²⁹ Among various radioisotopes, Co-60, Cs-137, Ir-192, Sr-90, Am-241, Cf-252, Pu-238 and Ra-226 are sources of greatest security concern.³⁰ Besides NPPs and two research reactors, numerous high activity radioactive sources are being used for R&D, commercial industrial and medical purposes in Pakistan. Appropriate steps have been taken for the last 20 years to ensure proper tracking of all radioactive sources imported into Pakistan (Fig 4.1). Less than 6% of these sources fall within the radioactive sources classifications of category 1 and 2 of IAEA (Fig 4.2). The sources imported into Pakistan have found applications in cancer treatments, R&D, industrial applications etc (Fig 4.3). All the radioactive sources are under strict regulatory control right from import until their disposal.

²⁷ IAEA Safety Standards: *Categorization of Radioactive Sources for protecting people and the environment*, No. RS-G-1.9, Safety Guide

²⁸ Charles McCombie and Bengt Tveiten, *Nuclear Waste Management Organization*, June 2004. Table 2.1, (<http://www.nwmo.ca/Default.aspx?DN=397,211,199,20,1,Documents>)

²⁹ Charles D. Ferguson, Tehseen Kazi and Judith Perra, *Commercial Radioactive Source: Surveying the Security Risks*, (Centre for Nonproliferation Studies: Washington, DC, 2003)

³⁰ Ibid

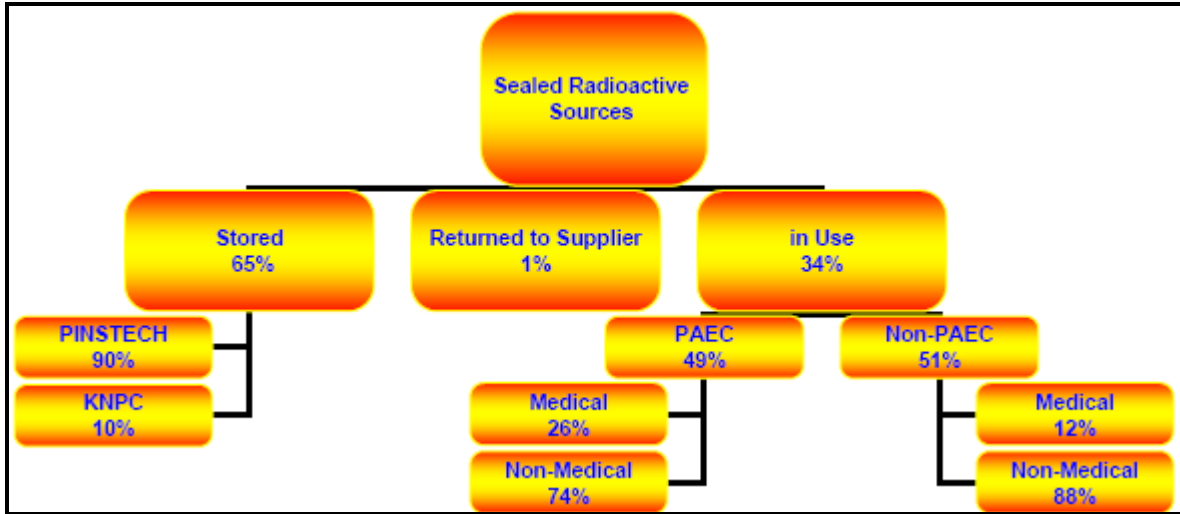
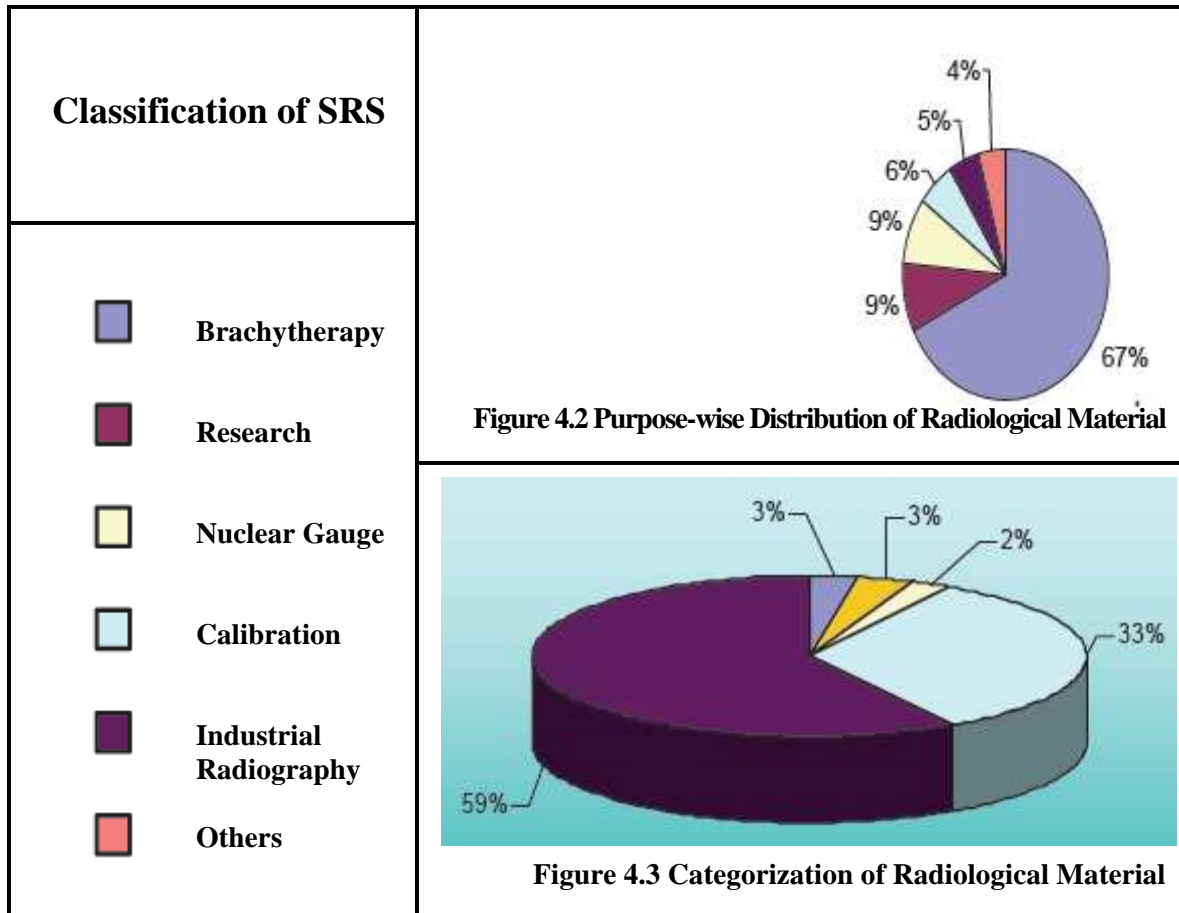


Figure 4.1 Volume of Sources in Pakistan, (Up to 2005)



Pakistan Nuclear Regulatory Authority (PNRA) has been applying stringent measures for administrative and engineering controls over such radioactive sources from cradle to grave by the licensees. The security of radioactive sources is ensured through periodic physical verifications and regulatory inspections.

Shipping Container Design

IAEA transport regulations require that spent fuel transportation casks be evaluated for a series of hypothetical accident conditions.³¹ These include a 30 ft (9 m) drop test, a 40 in (1 m) pin puncture drop test, and a fully engulfing fire with an average flame temperature of 1475°F (800°C) for a period of 30 minutes. In addition, the undamaged containment system of a cask must be designed to withstand an external water pressure of 290 psi (2 MPa) for a period of no less than one hour without collapse. Casks must maintain shielding and criticality control functions throughout the sequence of hypothetical accident conditions.³² In the US the NRC-approved spent fuel transportation cask includes the HOLTEC HI-STAR 100 and the TransNuclear TN-68 rail transportation cask.³³ In Canada, transportation casks have been designed for truck and rail transport. These include two designs for transporting Canadian used fuel, the DSC and the Irradiated Fuel Transportation Container (IFTC) (Fig5.1). The IFTC is a rectangular cask made of stainless steel with dimensions of 1566 mm x 1881 mm x 1697 mm. The wall thickness is 267mm and can hold 2 modules (196 fuel bundles) for road transportation.³⁴ IFTC has been designed for transportation of 2 modules (192 fuel bundles) for road transportation and each bundle contains 19kg of U.³⁵

British Nuclear Fuels (BNFL) designed, licensed, and currently owns and operates a fleet of Excellox casks. BNFL ships SNF for the United Kingdom, continental Europe and Japan for reprocessing.³⁶

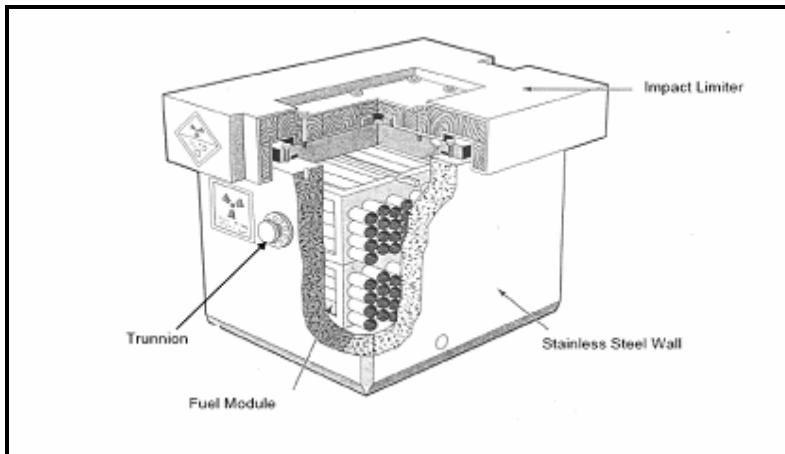


Figure 5.1 Ontario Power Generation's Irradiated Fuel Transportation Container

Courtesy NWMO August 2003 by Amair Hussain & Kwansik Choi

Design features such as cask materials, its thickness, cavity and overall diameter are especially important for assessing the vulnerability of SNF and HLW shipments to terrorist attacks. Different

³¹ IAEA, *Safety Standards Series: Regulations for the Safe Transport of Radioactive Material* (1996 Edition), As Amended 2003, Safety Requirements, No. TS-R-1

³² See Figure 5.1: Typical design of a SNF Cask

³³ Christopher S. Bajwa, Harold E. Adkins, and Judith M. Cuta, *Spent Fuel Transportation Cask Response to a Tunnel Fire Scenario*, (U.S. Nuclear Regulatory Commission, Washington, D.C. and Pacific Northwest National Laboratory, Richland, Washington,) (http://www.nei.org/documents/NRC_Baltimore_Tunnel_Fire_Study.pdf)

³⁴ Amair Husain & Kwansik Choi, Kinectrics Inc, *Status of storage, disposal and transportation containers for the management of used nuclear fuel*, August 2003. (<http://www.nwmo.ca/default.aspx?DN=244,237,199,20,1>)

³⁵ Ibid, and Chemical Technical Division, *ORNL/TM-13502*, Oct 20 1997

³⁶ BNFL, *MOX Fuel Voyage Briefing Note*, 2002, (http://www.bnfl.com/UserFiles/File/151_1.pdf)

shipping container designs could perform very differently in response to an attack.³⁷ Russia is working to develop a next-generation SNF storage, transport, and disposal cask system that meets modern-day requirements. Their requirements for the casks are nearly identical. The leading candidate material is DUO2-steel cermets. Bench-scale laboratory studies of this new radiation shielding material are nearing completion, and the fabrication and testing of ¼-scale demonstration casks is planned. This new material in the cask offers increased protection against rocket and missile attack. Thus, these new casks have the potential for superior resistance to terrorist assault compared with conventional SNF pool storage.³⁸

Concern over Spent Fuel Transportation

Materials like spent nuclear fuel and high activity sources under movement are much more difficult to defend from adversaries than materials in fixed locations. Terrorist attacks against the transportation of radioactive material can occur almost anywhere in any industrialized country. Transporting thousands of shipments of nuclear waste across a country would provide thousands of targets for terrorists, putting millions of people at risk along the transportation routes. Spent fuel is highly vulnerable and there are several tactics terrorists can use with a higher-than-anticipated probability of breaching a shipping cask.³⁹

Many are confident that the casks offer sufficient protection. Gail Marcus, former president of the American Nuclear Society, testified that the same features that render casks highly resistant to highway and rail accidents tend to make them difficult targets for an attack.⁴⁰ The National Research Council also assessed the vulnerability of spent fuel in transit and concluded that “spent fuel transport containers are very robust and appear to offer similar protection against terrorist attack. Studies on the vulnerability of spent fuel transport containers to sabotage suggest that relatively little or no radioactivity would be released in the event of a terrorist attack.”⁴¹ United States General Accounting Office also made an assessment:

The likelihood of widespread harm from a terrorist attack or a severe accident involving commercial spent nuclear fuel is low, according to studies conducted by DOE and NRC. Largely because spent fuel is hard to disperse and is stored in protective containers, these studies found that most terrorist or accident scenarios would cause little or no release of spent fuel, with little harm to human health. Some assessments found widespread harm is possible under certain severe but extremely unlikely conditions involving spent fuel stored in storage pools. As part of its ongoing research program and to respond to increased security concerns, NRC has ongoing and planned studies of the safety and security of spent fuel, including the potential effects of more extreme attack scenarios, including deliberate aircraft crashes.⁴²

³⁷ *Terrorism Considerations in the Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste*, (http://www.ciaonet.org/cbr/cbr00/video/cbr_ctd/cbr_ctd_09.html)

³⁸ M. Jonathan Haire and Charles W. Forsberg, *Characteristics of Next-Generation Spent Nuclear Fuel (SNF) Transport and Storage Casks*, (Oak Ridge National Laboratory, Oakridge, TN , 2001), (<http://www.ornl.gov/~webworks/cppr/y2001/pres/121356.pdf>)

³⁹ *Terrorism Considerations in the Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste*, (http://www.ciaonet.org/cbr/cbr00/video/cbr_ctd/cbr_ctd_09.html) and Large & Associates

⁴⁰ Dr. Gail H. Marcus, Written testimony on nuclear transportation submitted to the Senate Committee on Energy and Natural Resources, May 22, 2002, (<http://www.ans.org/pi/news/d-1022187916>)

⁴¹ Committee on Science and Technology for Countering Terrorism, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (National Research Council , 2002) p48

⁴² United States General Accounting Office, *GAO-03-426: Spent Nuclear Fuel: Options Exist to Further Enhance Security*, July 2003

Such a scenario involving Castor V/19 (PWR) and V/52 (BWR) were theoretically studied. The study was based on a scenario in which a large commercial airliner crashed into a storage facility housing 135 SNF casks containing 170 MCi of Cs-137. A fire ensued and burned for three to five hours at 1000 OC. It was estimated that about 0.04 MCi of Cs-137 would be released.⁴³ A still larger release could occur if a cask were attacked in such a way as to initiate and sustain combustion of the zirconium cladding of the fuel.⁴⁴

Since the 1970s, DOE and NRC have conducted several studies of the effect of an attack during the transportation of SNF. These studies found that a successful attack would have a limited effect on human health.⁴⁵ A study published by the DOE's Sandia National Laboratory in 1999 confirmed earlier studies that, under certain worst-case scenarios, NRC-certified transportation containers could be penetrated by armor-piercing weapons and release small quantities of radioactive materials.⁴⁶ NRC and DOE sponsored studies of the 1970s and 1980s were criticized by the Nevada State Nuclear Waste Project Office (NWPO). They observed that the previous analyses were inadequate as the full-scale test conducted by the DOE did not use weaponry equivalent to the currently best available armor-piercing weapons and that the NRC underestimated the health and economic impact resulting from a terrorist attack.⁴⁷ Guerilla armies around the world are known to be equipped with older anti-armor missiles such as the Soviet RPG-7 and American M72. Such weapons have the ability to penetrate up to 10-14 inches of armor plate and pose a considerable threat to a nuclear waste shipping cask.⁴⁸

Milan Missile

- Armor penetration capability : >1000 mm;
- Man-portability: total system weight is about 33 kg; Long range capability: maximum effective range of 2,000 meters (travel time 12.5 seconds);
- Relative ease of use: sight-on-target, semi-automatic, wire guidance;
- Relative availability: several tens of thousands have been produced and are used by a number of European, Middle Eastern, and Asian armies.



Figure 6.1

Terrorists could conceivably obtain one of the dozen or more anti-tank weapons currently capable of penetrating 12 - 30 inches of tank armor. More advanced missiles like the MILAN (Fig 6.1) and Javelin could be an effective weapon to penetrate or even perforate a large transport cask containing SNF. Conceivably, the Ontario Power Generation shipping container (ITFC) with wall thickness of

⁴³ Robert Alvarez, *Reducing the Hazards of Stored Spent Fuel*, (Science and Global Security, 2003), p20

⁴⁴ *Ibid*, p.19

⁴⁵ U.S. Nuclear Regulatory Commission, *Transporting Spent Fuel: Protection Provided Against Severe Highway and Railroad Accidents*, March 1987

⁴⁶, *Projected Source Terms for Potential Sabotage Events Related to Spent Fuel Shipments, SAND99-0963* (Sandia National Laboratories: Albuquerque, New Mexico, 1999)

⁴⁷ *Terrorism Considerations in the Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste*, (http://www.ciaonet.org/cbr/cbr00/video/cbr_ctd/cbr_ctd_09.html)

⁴⁸ *Terrorism Consideration in the Transportation of SNF and High level Waste Fact sheet*, Nuclear Waste Project Office, State of Nevada, CIAO Date 11/01].

26.7 cm or the HOLTEC HI-STAR 100 and the TransNuclear TN-68 rail transportation cask cannot provide any extraordinary defense against these anti-tank missiles with armor penetration capabilities exceeding 100 cm. It therefore represents the type of weapon that needs to be evaluated in a terrorism risk assessment for spent nuclear fuel and high-level radioactive waste transportation. See the table below for current portable anti-tank weapons. (Table 6.1)

Table 6.1: Current Portable Anti-tank Weapons

Weapon	Country	Weight	Range	Warhead Ø/Kg	Armor Penetration
Milan Anti-Tank Missile	France	32 kg	2000 m	133 mm/3.12 kg	>1000 mm
Eryx Anti-Tank Missile	France	21 kg	600 m	160 mm/ 3.8 kg	900 mm
Panzerfaust 3 Anti-Tank Launcher	Germany	13 kg	300 m	110 mm/NA	>700 mm
Folgore Anti-Tank System	Italy	21 kg	4500 m	80 mm/3 kg	>450 mm
Apilas	South Africa	9 kg	330 m	112 mm/NA	>720 mm
RPG-7 Anti-Tank Launcher	Soviet Union	11 kg	300 m	85 mm/NA	330 mm
C-90-C Weapon System	Spain	5 kg	200 m	90 mm/NA	500 mm
AT-4 Anti-Tank Launcher	Sweden	7 kg	300 m	84 mm/NA	>400 mm
Carl Gustav M2 Recoilless Gun	Sweden	15 kg	700 m	84 mm/NA	>400 mm
LAW 80 Anti-tank Launcher	U.K.	9 kg	500 m	94 mm/NA	700 mm
M72 66mm Anti-tank Launcher	USA	4 kg	220 m	66 mm/NA	350 mm
SMAW	USA	14 kg	500 m	83 mm/NA	>600 mm
AT-8 Bunker Buster	USA	8 kg	250 m	84 mm/NA	NA
Superdragon Anti-tank Missile	USA	17 kg	1500 m	140 mm/10.07 kg	>500 mm
TOW 2 Anti-tank Missile	USA	116 kg	3750 m	127 mm/28 kg	>700 mm
Javelin AAWS/M	USA	16 kg	2000 m	127 mm/NA	>400 mm

Source: Large and Associates

Testifying for NWPO, Robert J. Halstead stated:

An attack on the GA-4/9 truck cask would likely cause complete perforation and release more than one percent of cask contents, resulting in a release about 8,000 curies, with fission products such as Sr-90, Cs-134, and Cs-137 constituting over one third of the total curies, and Pu-241 twenty percent or more. The consequences could be much greater if the attack involved more than one missile or explosive device, or if the attack included use of an incendiary device, or if the attack were accompanied by a fire from combustion of the vehicle fuel supply or another fuel source. Such exacerbating factors could result in: (1) a potentially larger percentage release of cask contents, possibly as great as 10 percent; (2) a potentially higher percentage of respirable particulates and/or vaporized radionuclides; and (3) potentially more widespread dispersal and deposition.⁴⁹

⁴⁹ "Statement of Robert J. Halstead on behalf of the State of Nevada agency for nuclear projects regarding U.S. DOE's draft environmental impact statement for a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nevada, Public Hearing, Washington, DC October 26, 1999

In another testimony on April 25, 2002 it was stated that the transportation effort, as it was proposed, would ensure a target rich environment wherein a terrorist could plan, pick and chose the time and place for an attack. He argued that:

If the transportation vehicle were to be captured, placed in an immobile state by any number of means, or once acquired it was able to be moved at will by the terrorists, it would be susceptible to the application of explosives and/or a human engineered breach. Thus, the cargo could become a radiological dispersion device if the attackers where to breach cargo shielding and release the radioactive contents into the environment.⁵⁰

In the aftermath of a July 2001 incident in the Howard Street Tunnel in Baltimore, Radioactive Waste Management Associates prepared a study that concluded that, had SNF casks been part of the train involved in that accident, the fire in the tunnel would have resulted in a release of contaminating radiation throughout a section of the city.⁵¹ In March 2003, the NRC released a similar report on the Baltimore tunnel incident and the hypothetical consequences if a SNF cask had been involved.⁵² It concluded that an SNF transportation cask, approved under NRC rules for packaging and transportation of radioactive materials (10 CFR 71), subjected to the conditions encountered in the Howard Street tunnel fire would not release radioactive materials. In addition, the health and safety of the public would have been maintained.⁵³

Inventory of Radionuclides in Spent-Fuel

Although a number of isotopes are of concern, we focus here on the fission products namely Kr-85, Sr-90, Pu-241, Cs-134 and Cs-137 which constitute around 90% of activity in 10 year SNF. Of these, Cs-137 has a 30-year half-life, is relatively volatile, and along with its short-lived decay product, Ba-37 (2.55 minute half-life), accounts for about half of the fission-product activity in 10-year-old spent fuel.⁵⁴ The activities of Kr-85, Sr-90, Pu-241, Cs-134 and Cs-137 contained per cask of PWR spent fuel after 10 years from the discharge from the core with average burnup have been estimated from the reported values of activities per ton of spent fuel (Table 6.2).⁵⁵ Similarly, the activities of the above radionuclides contained in PHWR Cask have been estimated and presented in Table 6.3. Cs-137 content has been estimated per ITFC Cask as 7.09E+4 Ci which is lower by a factor of more than 2.5 as compared to PWR Truck Cask activity of 1.89E+5 Ci, owing to lower burnup and enrichment factors.⁵⁶

⁵⁰ "Testimony of James David Ballard, Ph.D, Consultant, on behalf of the Sate of Nevada on transportation of Spent Fuel Rods to the proposed Yucca Mountain Storage Facility" Subcommittees on Transportation and Infrastructure, US House of Representatives, April 2002

⁵¹ Matthew Lamb and Marvin Resnikoff, *Radiological Consequences of Severe Rail Accident Involving Spent Nuclear Fuel Shipments To Yucca Mountain: Hypothetical Baltimore Rail Tunnel Fire Involving SNF* (Radioactive Waste Management Associates: New York, September 2001), (http://www.nd.edu/~kshrader/interest/Baltrpt9_18.doc0)

⁵² NUREG/CR-6799, *Analysis of Rail car Components Exposed to a Tunnel fire Environment*, March 2003

⁵³ United States General Accounting Office, *GAO-03435 Rail Safety and Security: Some Actions Already Taken to Enhance Rail Security, but Risk-based Plan Needed*, April 2003, pp58-58 (<http://www.gao.gov/new.items/d03435.pdf>)

⁵⁴ Alvarez

⁵⁵ Chemical Technical Division, *ORNL/TM-13502 Radionuclide Content For a Range of Irradiated Fuels*, Oct 20 1997, NIREX: United Kingdom Nirex Limited (Nirex), (<http://www.nwmo.ca/default.aspx?DN=244,237,199,20,1>)

⁵⁶ Chemical Technical Division, *ORNL/TM-13502*, Oct 20 1997, Irradiated Fuel Transportation Container, IFTC; Report Aamir Husain & Kwansik, *NWMO*, Choi Kinectrics Inc August 2003 and Lih-Jenn Shyr et al, *SAND099-2138C: Projected Consequence for Potential Sabotage Events Related to Spent Fuel Shipments*, SNL, August 1999, Table-2

Table 6.2 Estimated Inventory, by major radionuclide, of reference PWR Spent Fuel Medium Burnup, 10 years cooling period

Radionuclides	Activity after 10 Years	
	Ci/tU	Per Truck Cask (Ci) (1.604 tU/cask)
Kr-85	6.76E+03	1.08E+4
Sr-90	8.11E+04	1.30E+5
Cs-134	1.01E+04	1.62E+4
Cs-137	1.18E+05	1.89E+5
Pu-241	9.89E+04	1.60E+5
Total	3.51E+05	5.62E+5

Table 6.3 Estimated Inventory, by major radionuclide, of reference PHWR Spent Fuel Medium Burnup, 10 years cooling period

Radionuclides	Activity after 10 Years	
	Ci/tU	Per Truck Cask (Ci) (3.648 tU/cask)
Kr-85	1.15E+03	4.20E+03
Sr-90	1.30E+04	4.73E+04
Cs-134	6.95E+02	2.53E+03
Cs-137	1.94E+04	7.09E+04
Pu-241	1.35E+04	4.92E+04
Total	5.46E+04	1.99E+05

Source: Electrowatt-Ekono (UK) Ltd.

Dispersion Model

Several computer codes have been used to model the dispersion of radionuclides into the atmosphere. For the simple scenarios as modeled in this paper, the most commonly used is the HOTSPOT computer code developed by US Lawrence Livermore Laboratory and first released in 1985. It provides emergency response personnel and emergency planners with a fast and instantaneous set of results for evaluating incidents involving radioactive material. The HOTSPOT user documentation suggests that if D is the calculated radiation, then 50% of the time the true dose should lie between $D/3$ and $3D$.⁵⁷ Later on (Mid 1990s), the HPAC was employed to predict the effects of hazardous material released into the atmosphere and its impact on civilian and military.⁵⁸ HPAC has the capability to include terrain, land-cover and detailed meteorological data for increased accuracy, but can also be used without any of the above, making it quite flexible in operational use. Despite the major differences in the transport and diffusion models used in HPAC and HOTSPOT, the results of very simple scenarios are similar.⁵⁹ A reasonable agreement between the two models was also observed in our studies using the source terms of SNF. The two dose curves are quite close together at the site of incident, however, large differences of an order of magnitude between the two were observed up to 10 kilometers downwind (as much as a factor of $D/3$ and $3D$). Given the greatest

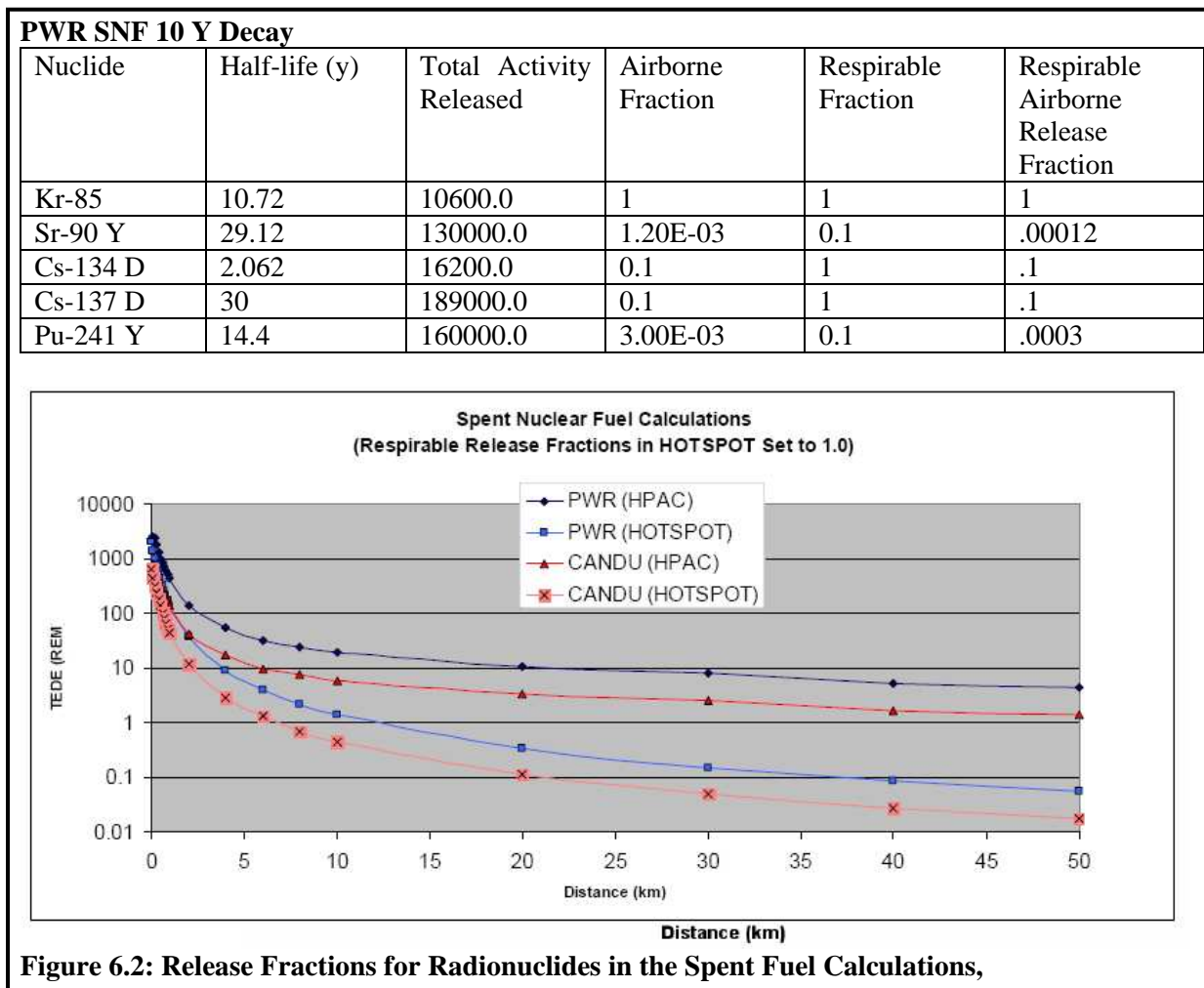
⁵⁷ User Documentation: Introduction to Hotspot Health Physics Codes, (<http://www.llnl.gov/nai/technologies/hotspot/>)

* The computer model assumes that a continuously emitted plume or instantaneous cloud of pollutants can be simulated by the release of a series of puffs that will be carried in a time- and space-varying wind field. The puffs are assumed to have Gaussian or bell-shaped concentration profiles in their vertical and horizontal planes

⁵⁸ Defense and Threat Reduction Agency, November 2006 (<https://acecenter.cntr.dtra.mil/>)

⁵⁹ Alexander Hill, DSTO-CR-029: *Using the Hazard Prediction and Assessment Capability (HPAC) Hazard Assessment Program for Radiological Scenarios Relevant to the Australian Defence Force*, CBRN Defence Centre, Platforms Sciences Laboratory, Australia March 2003

relative variability in the Gaussian plume model with increasing distance, further disagreement in the results beyond 10 kilometers distance were observed (Fig 6.2)



Given the ability to interface with online information on geographical locations of the incident, metrological conditions, and population data and apply these to reliably predict the deposition of radioactive material to the surface and estimate any residual hazard, HPAC was used to analyze radiological scenarios involving both the scenarios of RDDs.

Since the HPAC built-in option is restricted to predict dispersion of PWR spent fuel, the necessary correction factor was applied to the PWR SNF source terms to model dispersion of PHWR SNF as discussed previously (Table 6.2 and Table 6.3). The population dose was calculated by superimposing acute-dose isopleths onto a map of Karachi and Lahore.

Hypothetical Case Studies

In order to illustrate trends of how radioactivity could be released from a damaged flask and possible consequences during transportation within Pakistan, we consider two hypothetical scenarios. The first scenario is the sabotage of a truck containing a cask of SNF within a populous city like Karachi. The second is the sabotage of a truck containing 200,000 Ci Co-60 source near Lahore.

Scenario and Source Term

Scenario-I (SNF at Karachi)

While RDD attacks can be carried out with any source of radioactivity, SNF constitutes a potential source of concern all over the world including in Pakistan. Transporting SNF to a central storage or repository must have serious security considerations from a sabotage point of view.

As described earlier, while a Type B SNF Flask is designed to keep its integrity under fire at 800°C for 30 minutes, it may eventually fail in a fire involving higher temperatures and a longer duration.⁶⁰ I assume that a terrorist carries out “hybrid sabotage” on the radioactive consignment transported in a truck as compared to the study by Luna et al.⁶¹

The study estimated a maximum of 0.01% release by taking into consideration the blowing down effects in damaged fuel resulting from the attack. Furthermore, the release levels have been criticized by several independent experts as the study was too narrow in the sense that only a single limited attack is considered using a single High Energy Density Device (HEDD) missile (Fig 7.1). A case of multiple missile fire involving weapons with much higher penetration power coupled with an additional truck bomb collision may have catastrophic effects. Similarly, the consequences would be greater if the attack included an incendiary device or accompanied by a fire from igniting the vehicle’s fuel supply or another nearby fuel source.⁶²

These additional factors could result in:

1. A potentially larger percentage release of cask contents, possibly as great as 10 percent
2. A potentially higher percentage of respirable particulates and/or vaporized radionuclides
3. A potentially more widespread dispersal and deposition



Figure 7.1 Shape Charge, Courtesy of Journal of National Defense

⁶⁰ Large & Associates

⁶¹ SAND99-0963: *Projected Source Terms for Potential Sabotage Events Related to spent Fuel Shipments*, SANDIA Report, June 1999

⁶² Robert J. Halstead

A less sophisticated but effective approach to increasing radionuclide release from a breached SNF cask would be to inject fuel into the cavity and ignite it. This



would cause ignition of the zircaloy cladding, and at a minimum would greatly enhance the release of cesium and other semi-volatile elements that remain in the fuel pellets. The BNL spent fuel pool study assumed that 100% of the fuel Cs inventory would be released. Recent results from France indicate that heating at 1500°C of high-burnup spent fuel for one hour caused the release of 26% of the Cs inventory.⁶³

Based on the above hypothesis, a scenario is set where terrorists with the convenience of an insider are able to get information on an SNF movement. The terrorists carry out multiple missile firings on the truck cask (Fig 7.2) while the truck was stationed for the repair of one of its tires at a petrol pump (Fig 7.3) located in a congested location in Karachi (fig 7.4). The cask has a breach of containment followed by an engulfing fire for several hours. The explosive attack followed by a fire leads to an increased radioactive release.⁶⁴

Figure 7.2 A typical small SNF shipping cask being mounted on a truck
Courtesy of Nuclear Energy Institute

Scenario I: Spent Nuclear Fuel (SNF)

- Terrorist get information on the movement of SNF from an insider
- Terrorists carry out a “hybrid attack” on the transport truck while it was stationed for the repair of one of the tires of the vehicle at a petrol pump in a congested location in Karachi
 - Multiple missiles are fired on the truck cask which results in a breach in containment
 - This is followed by a fire that engulfs the cask for several hours



Figure 7.3

⁶³ Edwin S. Lyman Presentation: *A Critique of Physical Protection Standards For Transport of Irradiated Materials*, Nuclear Control Institute, 40th Annual Meeting of the Institute of Nuclear Materials Management, Phoenix, AZ, July 1999

⁶⁴ Large & Associates



Figure 7.4 Karachi, Courtesy of Google Earth

Firing missiles at the consignment will trigger explosions and fires at the station. A country like Pakistan is not well equipped to deal with fire involving a consignment containing mega curries of radioactive source. On November 7, 2005, in Karachi, cotton bales, toys and tires worth thousands of rupees were gutted when fires broke out separately in three warehouses in SITE, Lee Market and New Chali. Meanwhile, another office burned in a separate fire incident. Seven to ten firefighters were rushed to the sites and controlled the fires in 5 to 10 hours or longer.⁶⁵

In this case, it could pose serious difficulties due to the radioactive nature of the hazards encountered. Its therefore assumed control of the blaze would take six hours. Based on foregoing discussions, this would lead to a release of 10% of Cs inventory as a conservative estimate. A respirable release fraction of 3 E-4 for Pu-241 and 1 E-4 for Sr-90 is used, recommended as an upper limit for use in safety assessment studies involving chunks of plutonium exposed to hydrocarbon fuel fires.⁶⁶

⁶⁵ “Goods worth thousands gutted in fire incidents,” *Daily News*, 8 November 2005, (<http://www.jang.com.pk/thenews/nov2005-daily/08-11-2005/metro/k3.htm>)

⁶⁶ Robert E. Luna, *SAND93-2528: A New Analysis of the Vixen A Trials*, (Sandia National Laboratories: Albuquerque, February 1994) and Lih-Jenn Shyr, *SAND99-2138C: Projected Consequence for Potential Sabotage Events Related to Spent Fuel Shipment*, (Sandia National Laboratories, Albuquerque, August 1999), Table 2

Dispersion and Consequences

In the first scenario, we consider the sabotage involving a truck cask containing PHWR fuel assemblies leading to release of radionuclides in the heart of the city of Karachi at daytime at 12:00 hr on June 15 (Fig 7.5a). The debris cloud is lifted 562 m high (using HOTSPOT Code) which is expected to be further elevated by fire. The contaminated region includes hundreds of industries, residential row houses, crowded shopping areas, school, colleges and several mosques. Within an area of 0.304 km², maximum total effective dose equivalent TEDE (100 Rem)* is predicted by the model due to release of radionuclides from the breached flask containment only, which is far below the level to cause acute radiation syndrome. However, exposure in the immediate vicinity of the blast to a high radiation field of around 250 Gy/h at one meter distance due to the remaining 90% Cs-137 still contained in the breached SNF Flask, cannot be ignored, thereby creating a difficult situation for the first responders.[†] Whole body exposure to 2000 rem without any post exposure treatment may damage central nervous system within minutes and death in hours to days.⁶⁷

Any attempt to approach the damaged flask without any protection measures would result in acute exposure within few minutes. The wind blowing (WSW) at an average speed of 6.7 m/s disperses the radioactive aerosols to 36 kilometers from the blast location contaminating externally as well as internally the population to a dose contour down to 1 Rem in approximately 167 km² area in around four and half hours time (Fig 7.5b). Consequences of radiation effects due to single exposure to population groups has been estimated on the basis of the BIER VII lifetime risk model which predicts that approximately one individual in 100 persons would be expected to develop cancer from a dose of 10 rem [0.1 Sv] while approximately 41 individuals would be expected to develop solid cancer or leukemia from other causes.⁶⁸ In general, the magnitude of estimated risks for cancer fatalities is not different from the International Commission on Radiological Protection (ICRP) estimates of 5% probability of occurrence of cancer per sievert for whole-body irradiation.⁶⁹ Based on single exposure, cancer morbidity and fatality were estimated for various population groups exposed to radiation levels of 100 Rem down to 1 Rem using BIER VII lifetime risk model and presented in Table 7.1. The HPAC Model predicts about 41 persons receive high exposure of 100 Rem within a dose contour area of 0.4 km². The number of exposed persons increases to 56134, 505436, 643356, 657665 and 659100 to radiation levels of 10, 1, 0.1, 0.01 and 0.001 Rem respectively living in dose contour areas of 4.6, 167, .800, .900 and >900 km² areas. Cumulative excess cancer fatality has been

* Total Effective Dose Equivalent (TEDE): The radioactive material producing the dose equivalent may be external to the body (ex: when material is on the ground or is in the air surrounding the individual), or internal (as when the individual has ingested or inhaled, and retained the material). The Total Effective Dose Equivalent (TEDE) is the sum of the EDE (caused by the external material) and the CEDE (caused by the internal material). The TEDE is the most complete expression of the combined dose from all applicable delivery pathways. TEDE = CEDE (inhalation) + EDE (submersion) + EDE (ground shine), See *User Documentation of Hotspot: Introduction to Hotspot Health Physics Codes* (<http://www.llnl.gov/nai/technologies/hotspot>)

[†] For gamma energies between 60 keV and 1.5 MeV the dose rate from a source A MBq and total energetic gamma emission per disintegration of E MeV = 0.14 AE microGy/h at 1 m. *Rules of Thumb and Practical Hints, The Society for Radiological protection*, (<http://www.srp-uk.org/servthumb.html>)

⁶⁷ US Environmental Protection Agency, "Understanding Radiation: Health Effects," (December 3, 2002), (http://www.epa.gov/radiation/understand/health_effects.htm)

⁶⁸ National Research Council's Committee on the Biological Effect of Ionizing Radiation (BEIR), *Health Effects from Exposure to Low Levels of Ionizing Radiation: BEIR VII –Phase 2*, (<http://books.nap.edu/catalog/11340.html>); The committee concludes that the current scientific evidence is consistent with the hypothesis that there is a linear, no-threshold dose-response relationship between exposure to ionizing radiation and the development of cancers in humans.

⁶⁹ US EPA: *Understanding Radiation*, In other words, a group of 10,000 people exposed to 1 rem of ionizing radiation, in small doses over a life time, we would expect 5 or 6 more people to die of cancer than would not otherwise. In this group of 10,000 people, we can expect about 2,000 to die of cancer from all non-radiation causes. The accumulated exposure to 1 rem of radiation would increase that number to about 2005 or 2006.

estimated to be 649 out of 2,521,732 exposed population. In other words, there would be an increase of 0.13% in cancer fatality due to the incident as compared to deaths due to other circumstances.

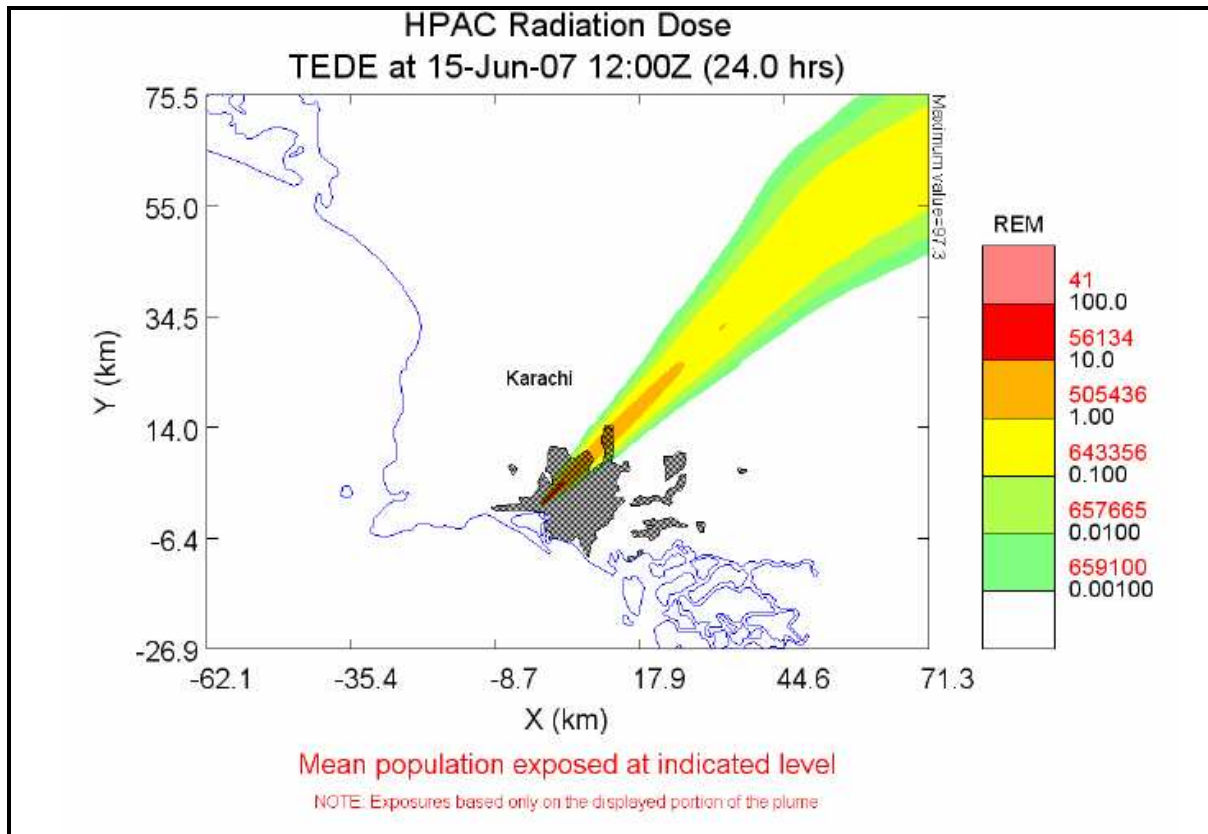


Figure 7.5a Karachi Spent Nuclear Fuel Scenario: 10% of Truck Cask of CANDU-SNF; Historical Weather Data; Actual Population

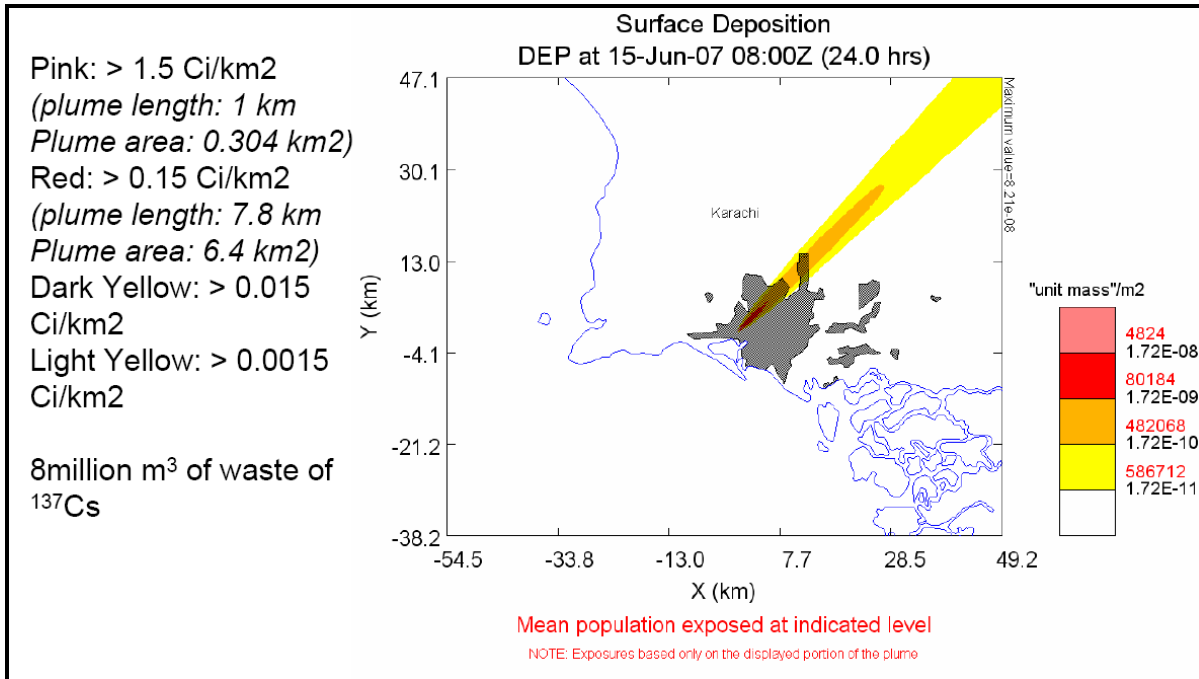


Figure 7.5b Karachi Spent Nuclear Fuel Scenario: 10% of Truck Cask of CANDU SNF; Historical Weather Data; Actual Population

Facts

Karachi, Pakistan
 1,000 lbs. TNT
 160 kg PWR SNF (64 kg CANDU SNF)
 June Historical Weather Data
 Actual Population Figures

REM	Persons	Excess Cancers	Excess Cancers Fatalities	Dose Length (km)	Dose Contour Area (km ²)
100	41	17	8	<0.1	0.4
10	56,134	637	320	5.7	4.6
1	505,436	574	288	36	167
.1	643,356	73	37	>50	>800
.01	657,665	7	4	>50	>900
.001	659,100	1	0	>50	>900
Totals		1,292	649		

7.1 Radiation Effects

The extent of contamination will be a major challenge because Cs-137 is highly water-soluble and is chemically reactive with a wide range of materials, including common building materials such as concrete and stone. The contamination will settle on streets, sidewalks, and building surfaces and

personal property—including vehicles and items inside buildings. In such a situation, the recovery/remediation/restoration measures have been documented in a Homeland Security draft document.⁷⁰ The document suggests measures for surface, interior, and roof decontamination of most buildings, major thoroughfares and sidewalks, and the water treatment plants as quickly as possible, re-pavement of streets, removal of surface soil and vegetation for disposal and replacement with fresh material. Moreover, secondary events may lead to a release of hazardous chemicals and fires on ruptured gas lines may complicate the situation requiring immediate remedial actions. In such an event, the city transportation system is severely affected and would require continuous monitoring to restrict further spread of the contamination. Hospitals, already at maximum capacity with injuries from the blasts, are inundated with “worried well,” most of whom were not in the blast or plume zone but are concerned about health issues. The sewage treatment plant is quickly contaminated as a result of people showering and decontaminating personal effects.”

Currently, Cs-137 level in most parts of Pakistan including Karachi is not well defined. However, areas in former Soviet Union contaminated by the Chernobyl accident have been defined with reference to the background level of Cs-137 deposition caused by atmospheric weapons tests, which when corrected for radioactive decay to 1986, is about 2 to 4 kBq m² (0.05 to 0.1 Ci km²). Considering variations about this level, it is usual to specify the level of 37 kBq m² (1 Ci km²) as the area affected by the Chernobyl accident. Approximately 3% of the European part of the former USSR was contaminated with Cs-137 deposition densities greater than 37 kBq/m².⁷¹

In terms of deposited contamination (Fig 7.5b) the contamination level above 1Ci/km² would require decontamination action out to 1 km and further as foot and vehicular traffic transfer contamination for hours afterward until the entire scene has been effectively controlled and cordoned, contributing to contamination spread beyond the deposition zone. Waste produced as result of decontamination following an hypothetical spent fuel accident is likely to fall into the lowest of the U.S. NRC’s categories of low level radioactive waste, Class A, in which Cs-137 has a concentration less than one Ci/m³.⁷² Based on the estimation of 90 m³ per person, a population of 4,824 living in an area of around 0.304 km² (Fig 7.5b) are likely to generate waste around 0.4 million m³ of Cs-137.

Scenario-2 (High Activity Radioactive Source at Lahore)

Terrorists carry out multiple missile firings on a truck cask carrying 200,000 Ci of Co-60 near Lahore (Fig 7.7) followed by further immediate attack with a fully laden road petroleum tanker, hijacked and brought to the incident site to fuel a fire (Fig 7.6). This could lead into a situation even worse than the December 12, 2006 incident when terrorist detonated a truck loaded with 440 pounds of explosive in Baghdad killing 71 laborers and wounding 220 others.⁷³

⁷⁰ *National Planning Scenarios*, Version 20.1 Draft, April 2005, (<http://media.washingtonpost.com/wp-srv/nation/nationalsecurity/earlywarning/NationalPlanningScenariosApril2005.pdf>)

⁷¹ “Exposures and effects of the Chernobyl accident,” Sources and Effects of Ionizing Radiation, Vol.II, Effects, ANNEX J, (UN 2000), para 107, (<http://www.unscear.org/docs/reports/annexj.pdf>)

⁷² Waste Classification, NRC Regulations, 10 CFR, Part 61.55, (<http://www.nrc.gov/reading-rm/doc-collections/cfr/part061/>) A waste needing disposal following a spent fuel accident is likely to be of the order of 100-million m³ for a 3.5 MCi release (one million affected persons times 90 m³ per person). Jan Beyea, Ed Lyman, Frank von Hippel, “Damages from a Major Release of 137Cs into the Atmosphere of the United States”, *Science and Global Security*, 12:125–136, 2004

⁷³ News report posted at 6:16 p.m. EST, December 12, 2006, (<http://www.cnn.com/2006/WORLD/meast/12/12/iraq.main/index.html>)

Scenario II: High Activity Radioactive Source

- Similarly, terrorists gain information on a consignment of 200,000 Ci of Co-60 being moved.
- Terrorists carry out multiple missile firings on the truck cask near Lahore.
- Immediately after the initial attack, a hijacked petroleum tanker truck is brought to the incident site to fuel a fire.



Figure 7.6, Picture Courtesy of MDS Nordion

Consequences of dispersion of 200,000 Ci of Co-60 with an explosive power equivalent to that of 440 pounds of TNT were analyzed by HOTSPOT and HPAC. HOTSPOT code using Sandia National Laboratories Blast Model reveals a safe distance of 678 meters for unmitigated blast damage. Although, a 200,000 Ci Co-60 source without a shielding would give rise to a dose of around $1.3E+3$ Gy/h at a distance of one meter but due to dispersion effect maximum dose contour of 10 rem was estimated by HPAC encompassing an area of 0.087 km^2 up to a distance of 0.5 km from the blast site (Fig 7.8a).⁷⁴ Within this dose contour of 10 rem, a person is neither expected to die nor to suffer from acute health effect, however, casualties comparable to that of Baghdad incident could be expected due to the blast effect.⁷⁵ Survivors from within the highest dose area could carry radioactive contamination back to their homes and contaminate their neighbors and families (Fig 7.8b). Panic and disinformation may lead to a massive exodus of people from Lahore city into neighboring towns and cities. Additionally, the cobalt plume would contaminate a vast area to levels requiring cleanup and destruction of residential, commercial as well as agricultural lands. Cleanup efforts and destruction of property and land would generate huge amount of waste. Assuming 90 m^3 /person of waste generation for Co-60 as well, the total waste expected to be around 12.6 million metric tons.⁷⁶ Application of BEIR VII cancer risk estimates for single exposure reveals excess cancers of 17 out of 1468 exposed population, 202 out of 177925 exposed population, 86 out of 759304 exposed population, 11 out of 1008145 exposed population due to dose contours of 10 rem, 1 rem, 0.1 rem, and 0.01 rem out to distances of 0.5 km, 5.3 km, 25 km, and 155 km respectively. Off these, cancer fatalities of around 160 (almost fifty percent suffering from excess cancer) are expected (Table 7.2).⁷⁷

⁷⁴ For gamma energies between 60 keV and 1.5 MeV the dose rate from a source A MBq and total energetic gamma emission per disintegration of E MeV $\Rightarrow 0.14 \text{ AE microGy/h at } 1 \text{ m}$: *Rules of Thumb and Practical Hints, The Society for Radiological protection*, (<http://www.srp-uk.org/servthumb.html>)

⁷⁵ 71 deaths: News report posted at 6:16 p.m. EST, Dec. 12 2006, (<http://www.cnn.com/2006/WORLD/meast/12/12/iraq.main/index.html>)

⁷⁶ A waste needing disposal following a spent fuel accident is likely to be of the order of 100-million m^3 for a 3.5 MCi release (one million affected persons times 90 m^3 per person). Jan Beyea, Ed Lyman, Frank von Hippel, "Damages from a Major Release of ^{137}Cs into the Atmosphere of the United States", *Science and Global Security*, 12:125–136, 2004

⁷⁷ BEIR VII – Phase 2 (Free Executive Summary) (<http://www.nap.edu/catalog/11340.html>)



Figure 7.7 Lahore High Activity Radioactive Source Scenario, Courtesy of Google Earth

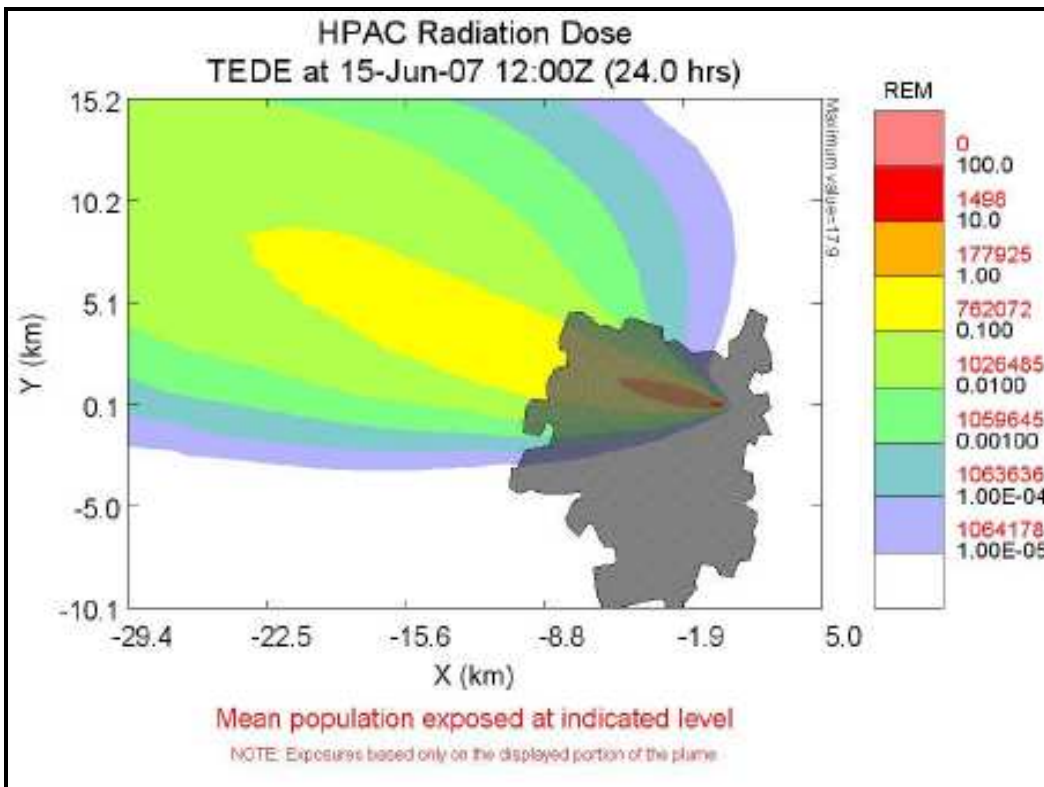


Figure 7.8a Lahore High Activity Radioactive Source Historical Weather Data; Actual Population

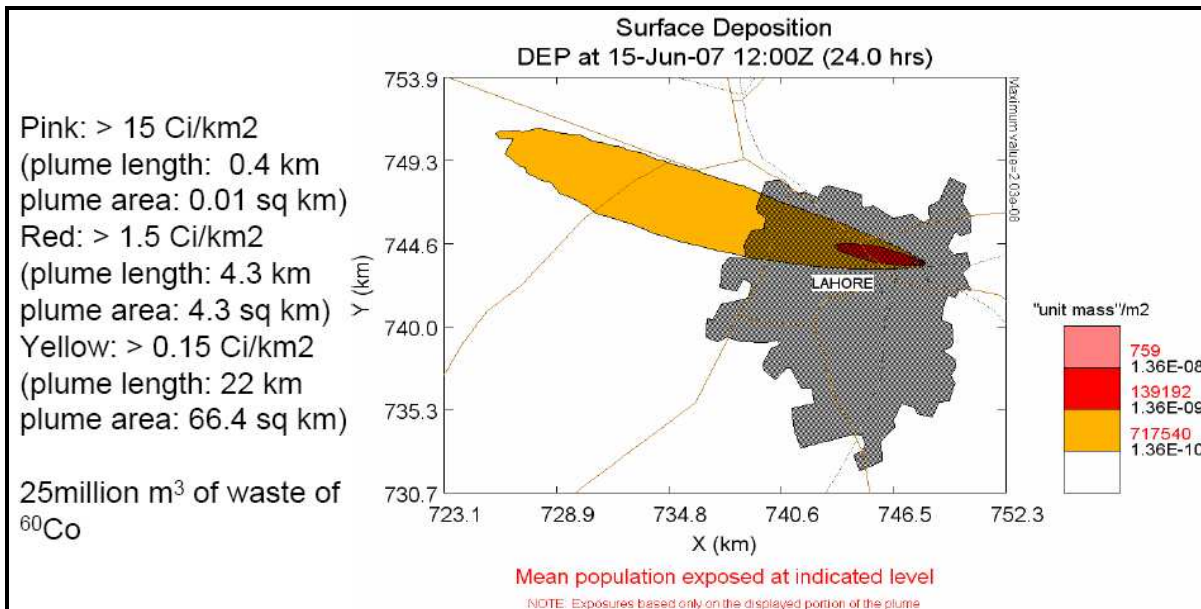


Figure 7.8b Lahore High Activity Radioactive Source; Historical Weather Data; Actual Population

Facts

Lahore, Pakistan
440 lbs. TNT
200,000 Ci Co-60
June Historical Weather Data
Actual Population Figures

REM	Persons	Excess Cancers	Excess Cancers Fatalities	Dose Length (km)	Dose Contour Area (km ²)
10	1498	17	9	.5	.087
1	17792	202	101	5.3	3.9
.1	75930	86	43	24.9	77.17
.01	10081	11	6	155	3028.43
.0001	10395	1	1	300	33026.2
Totals		317	160		

7.2 Radiation Effects

Addressing Pakistan's Vulnerability

The Federal Government has tasked the Pakistan Nuclear Regulatory Authority (PNRA) with the physical protection of nuclear and other radioactive material. The PNRA has initiated towards the last quarter of 2006, a five year National Nuclear Safety and Security Action Plan (NSAP) to establish a more robust nuclear security regime. It seeks capacity building in Pakistan's ability to plan for, respond to, and recover from terrorist incidents in collaboration with relevant governmental agencies. The salient features of the plan cover five areas.

Secure Radioactive Sources of Greatest Concern

Of the approximately 140 firms that handle radioactive sources in government and the private sectors, a third interact with "Greatest Concern Sources." Periodic inspections of these facilities revealed a need to upgrade security. Inspections must be more frequent, carried out at least quarterly to bi-annually depending on the category and vulnerability. A follow up mechanism would ensure issues are addressed promptly.

It is necessary to add Inspectorates to the already existing PNRA Regional Directorates located at Islamabad, Chashma and Karachi. Additional Inspectorates at Peshawar, Multan and Quetta are proposed within the Regional Nuclear Safety Directorates I, II and III. There will be an addition of eighteen inspectors over the next five years, with increases to support staff.

Inspectors will require radiation survey, communication and secretarial equipment in addition to suitable vehicles. Personnel would be trained to required competencies in radiation protection, use of radiation survey equipment, identification of sources, and regulatory requirements. Beyond inspectors, an education program for the licensees and their staff is needed to propagate a security culture.

Establish a PNRA Nuclear Safety and Security Training Centre

The PNRA would be the focal point of training in nuclear safety and security. This Centre will require laboratories with appropriate state-of-the-art equipment and at least six officers and supporting staff.

To start, a few select senior PNRA staff would be trained in appropriate institutions and centers in collaboration with the IAEA. They would then be responsible for developing the training modules for the Centre and establishing its needed infrastructure. They would then educate trainers, having a "multiplier" effect.

New junior officers would be trained in review, assessment and inspection techniques. Externally, first responders expected to deal with radiological emergencies would be trained in the identification and handling of radioactive sources as well as emergency management skills. The Centre would continuously facilitate this training throughout Pakistan due to the significant rotation and redeployment of first responders. Additionally, the Centre would provide consolation and evaluation to licensees. Further, the Centre would have a research role in techniques and technologies in nuclear safety and security.

Establish National Nuclear Security Emergency Co-ordination Centre

A National Nuclear Security Emergency Co-ordination Centre (NuSECC) would assess, respond and co-ordinate in case of a nuclear security emergency at the national level. It would track all movements of large radioactive sources in Pakistan. The centre will be manned 24 hours a day with at

least six officers and support staff. It will also establish six mobile monitoring laboratories, distributed and located at each of the regional Directorates and Inspectorates.

Locate and Secure Orphan Radioactive Sources

An “orphaned source” is material that poses a sufficient radiological hazard to warrant regulatory control but never was because it was: abandoned, misplaced, stolen or otherwise transferred without proper authorization. It is unknown how many orphaned sources there are in Pakistan. Sources and/or their containers can be attractive as valuable metals and may not display a radiation warning label. Unsuspecting victims tamper with these sources causing injury or even death.

The risk to the public and the risk of their possible malicious use will be addressed. The strategy would involve launching a public campaign seeking information on orphan sources, non-physical/physical searches, and finally, eventual recovery, secure storage, and disposal.

Deploy radiation detection equipment widely

All major points of entry in Pakistan do not have radiation detection devices. We remain unaware of any radioactive/nuclear material moving in or out. It is proposed to provide these systems, perhaps in a phased program. Initially one radiation monitoring instrument at each point of entry supplemented later by vehicle/pedestrian portal monitoring equipment where needed. Fixed detectors may be installed at airports. Random inspection of personnel luggage may also be carried out.

In addition, law enforcement and local government need to be equipped with this equipment as well. They would be the first to survey incidents to determine if they were nuclear or radiological. Such equipment would be needed at the District level for a swift response. The PNRA would be responsible for preparing the equipment and training. The installation, operation and maintenance would be the responsibility of other agencies.

Recommendations

Population Protection

In an event of a successful RDD, the following measures may be taken to protect the population⁷⁸:

- Recommend all persons who were outside during the attack to shower and change clothes
- Temporary limits on time spent outside
- Temporary stays in a basement or shelter; staying inside a house offers a safety factor approximately ten
- Limits on the consumption of certain agricultural products
- Ban on harvesting, putting livestock out to pasture, hunting, and fishing
- Temporary evacuation
- Definitive relocation of the affected population

Strengthening Transportation Security

Based on our current studies, the following recommendations are presented to improve security measures to cover range of activities involving transportation of high risk sources:

- **Prevention**

PNRA has taken stringent measures for the physical protection nuclear facilities and radioactive sources. A cradle to grave concept is applied for preventing any radioactive

⁷⁸ Chritoph Wirz and Emmanuel Egger, “Use of nuclear and radiological weapons by terrorists,” *International Review of the Red Cross*, Volume 87 Number 859, September 2005

source getting out of regulatory control. Besides these considerations, preplanning, and intelligence gathering are very important through well developed and coordinated efforts of various agencies to deter, detect and thwart a possible sabotage attempt.⁷⁹ The agencies should keep track of terrorist groups, their financial resources, linkages with outside world, and assess their potential to engage in nuclear terrorism. Information sharing specially with neighboring states on activities of groups likely to engage in nuclear terrorism will be useful. Moreover, prevention efforts should also include measures to prevent illicit trafficking by monitoring at border cross points.

- **Transportation**

Nuclear materials and high risk sources requiring shipment from one place to another should employ dedicated governmental vehicles driven by official drivers with proven trustworthiness. Authorization for simultaneous shipment of high risk sources within a city should be avoided to evade multiple sabotage events leading to dilution of an effective emergency response system. This measure would allow authorities to focus only single post radiological event and pool up their resources to effectively implement and mitigate the consequences.

- **Control Over Missiles**

Any successful sabotage event and consequences would primarily depend on three factors, namely, RDD material, missile, and fuel for fire. Therefore, effective control measures are needed against theft or illicit trafficking of portable anti-tank weapons.

- **Emergency Operations Center and Emergency Plans**

PNRA's NRECC—an emergency operations center—is manned around the clock to receive national as well as international information regarding events related to nuclear or radiological incidents and assist in national emergency response activities. However, the center has to develop capabilities for evaluating potential consequences of various threats to radioactive consignment during movement as well as transit and subsequent radiological impact. Based on threat assessment, the centre has to perform emergency exercises to counter terrorism. Such exercises may include scenarios like dirty bombs, stolen radioactive material, and sabotage of nuclear and radiation facilities and sabotage during movement and transit of nuclear and high risk radioactive materials. It should also emulate from national (eg. earthquake of October 8, 2005 in Azad Kashmir and North West Frontier of Pakistan) and international experiences (US Katrina havoc of 2004) of handling natural disasters in order to enhance its response capabilities in coordination with relevant national agencies in case of nuclear terrorism. PNRA should continue to interact with appropriate stakeholders to continually improve emergency preparedness capabilities at all levels. The Centre, in coordination with national agencies, should have capabilities for emergency assessment and diagnosis of the sabotage event, for management, response, hazard mitigation, victim care, and for guiding advice on evacuation or shelter options.

⁷⁹ DOE, *Spent Nuclear Fuel Transportation: Lessons Learned from Security Planning and Execution*, August 2006, Final

- **Emergency Operations Center and Emergency Plans**

Decision makers need to know what steps are automatically taken and nuclear regulatory authority needs to be present at table with the decision makers, local leaders need to be in direct contact with national leaders, and the most important lesson is that all the systems must be exercised regularly.
- **Emergency Exercises at the Top Level**

Top governmental level exercises of credible nuclear terrorism scenarios are often overlooked.
- **Sheltering and Evacuation**

In an incident in an urban area like Karachi or Lahore, the estimated numbers of citizens affected by the release and dispersion of radioactivity and requiring shelter or even evacuation would depend on the prevailing weather conditions. Based on assumption that during the event, 90% of the public are indoors and thus are already sheltering at a 50% reduction in dose uptake, so the additional benefit of implementing the organized sheltering countermeasure only applies to 10% of the potentially exposed population.⁸⁰ However, advice from the authorities to shelter and evacuation on the basis of national emergency reference levels might lead to a panic situation prompting a mass self-evacuation. If the public undertakes self-action, particularly self-evacuation, many more are likely to be on the streets without much protection and/or in poorly shielded vehicles and, indeed, some may unknowingly move into contaminated areas becoming trapped for hours in the jams and traffic chaos that are almost certain to arise. In such circumstances, the public may receive a greater radiation exposure than if, generally, they remained indoors sheltering. Therefore, unless adequate infrastructure is in place, sheltering or evacuation directive may have counter productive effects.
- **Robust e-Communication**

Robust and direct electronic communication is needed between PNRA to share information amongst federal/provincial/local officials.
- **Credible Information**

A designated, credible spokesman is needed, that can deliver a statement shortly after an incident and can exchange credible real time information with all concerned agencies.
- **Crisis Management**

A crisis management team is needed to handle the current situation as well as to preplan and organize to possibly deter another event at an unknown location.
- **Public Education**

In order to minimize confusion and chaos, it is necessary to create public awareness about the potential effects of nuclear terrorism. This involves integrating the official and unofficial media to disseminate information and encourage public confidence without

⁸⁰ Large & Associates

causing unnecessary panic. The use of the civil defense warning sirens and loud speakers at mosques may be used to alert people and to advise them to check the radio or television for further information.

- **Personnel Reliability Program**

A personnel reliability program has to be an integral part of any nuclear security infrastructure. The elements of PRP have been described as “several lines of inquiry to develop a comprehensive picture of the individual in question. A background check is conducted to verify identity, credit history, criminal history, reputation and character. Psychological and medical screening are used to evaluate the mental health and stability of the individual; depression, schizophrenia, epilepsy, high/low blood pressure and other disorders are all taken into consideration. Additionally, a detailed interview to verify background information and elucidate other potential concerns is conducted at the time of employment or when a sensitive task is being assigned. Periodic reviews of job performance and coworker interaction are a standard means of ensuring that an employee’s reliability remains high over time, and an individual’s after work activities may also be monitored. The following occurrences may result in decertification for nuclear duty: alcohol abuse/dependency, drug abuse, conviction of or involvement in a serious incident, an adverse medical—physical and mental—condition or serious progressive illness, lack of motivation, suicide attempt or threat.”⁸¹ The efficacy of any transport security system specially dealing with nuclear materials and high risk sources would depend on the training, reliability and integrity of the individuals, without which the system would remain vulnerable.

- **Non-nuclear Terrorism**

Even during a case of a catastrophic non-nuclear sabotage event, radioactive consignment under shipment should be reassessed and until such time, all movement should be halted and shipments secured in a safe place.

Conclusion

The advancement in the knowledge of science and technology and their accessibility to terrorists has made the threat of nuclear terrorism no longer a fiction but real with their intention to inflict catastrophic damages to man, environment, and property. Though Pakistan is not considering reprocessing and therefore there may be no need for transportation, however, the case study, based on several low probabilities of sabotage events of spent fuel and high activity sources, has revealed that an explosion and subsequent fire would cause hundred of deaths and severe damage to surrounding buildings. Whereas in an explosion alone only a few casualties could be expected due to radiation sickness in the area of 200m². Amid the failure of SNF containment, aerosol containing mostly volatile Kr-85 and semi-volatile Cs-137, would be lifted into the air leading to extensive environmental contamination and potential exposure of thousands of individuals in the downwind zone. The number of people expected to get exposure to unsafe levels of radiation causing late effects leading to cancerous deaths would not only depend on the strength of the radioactive materials but would also depend on the timing and location of the attack. Any evacuation/sheltering of

⁸¹ Ryan Crow , *Personnel Reliability Programs*, (Project Performance Corporation: McLean, Virginia) (<http://www.ppc.com/modules/knowledgecenter/prp.pdf>) and references therein

communities based on a 360° potential-hazard zone may be adopted instead of a cone shaped zone predicted by the code to eliminate the many associated uncertainties and changing wind directions in real situations. Difficulties are likely to arise in informing members of the public in an urban area where it may not be practicable to evacuate such large numbers, or in a rural situation where individuals may be unaware of the incident and who, scattered about the countryside, may be difficult to locate and advise in time. All exposed individuals will need to be monitored for health outcomes over their lifetimes, especially those that suffer internal contamination. Massive decontamination efforts would be needed for recovery and if decontamination remains unsatisfactory, institutional controls would become essential. To dilute the consequences of any successful sabotage event, preplanning is very important through well developed and coordinated efforts of various agencies. Periodic integrated table-top and field exercises based on credible scenarios developed on the basis of intelligence information gathering should remain the focus at all levels.

The controls around various nuclear installations and radiation facilities in Pakistan are enough to deter and delay a terrorist attack and any malicious diversion would be detected in early stages. The paper is an attempt to calculate the consequences of terrorist acts of very remote probability bordering near impossibility. Therefore, it can be concluded that the fabrication of a RDD and WMD is not very attractive to a terrorist group in general and specially within the context of Pakistan.

ACKNOWLEDGMENTS

The author would like to thank Mr. Michael Krepon, Co-founder of The Henry L. Stimson Center of Washington, DC for providing an opportunity under the VF Program to pursue research studies. I would also like to thank his continuous support and valuable comments at various stages of the research studies as well as for arranging meetings with relevant government officials and think tanks. Further, I would like to thank Dr. Matthew McKinzie for his significant contribution to my work. The author gratefully acknowledges: Ms. Sherri Goodman (Senior Fellow at the Center for Naval Analyses), Ms. Anne Witkowsky (CSIS), Jack Edlow (Edlow International), Dr. Charles Ferguson (Council on Foreign Relations), Ed Lyman (UCS), Thomas B. Cochran (Director of NRDC's Nuclear Program), and NNSA and DOE officials for sharing their experiences on this topic. The author would also like to thank Mr. Lee Dunbar, Intern with the Stimson Center for literature search and editing this paper.
