Paper

SAFETY AND SECURITY OF RADIATION SOURCES IN THE AFTERMATH OF 11 SEPTEMBER 2001

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Abstract—**The attack on the United States on 11 September 2001 resulted in an increased awareness of the need for safety and security measures to protect against terrorism. The potential use of radiation sources in terrorism, in particular radioactive sources, was recognized prior to 11 September 2001, but has taken on new significance since. The planning of security measures for radioactive sources must take greater account of the potential for deliberate acts to attack or use radioactive sources to expose people and cause contamination. The potential consequences of an act of terrorism using radioactive sources can be gauged from the consequences of serious accidents that have occurred involving radioactive sources. These include fatal and injurious radiation exposures, contamination of the environment, and serious economic and psychosocial costs the total effect of which is mass disruption. Steps are being taken to improve security for radioactive sources but strategic approaches that can minimize the threat of radiological terrorism should be considered. When justifying a practice that uses radioactive sources, the potential for diversion or use in terrorism should be considered to be a detriment. In this regard, the consideration and development of alternatives to radioactive sources, such as radiation producing machines, have been recommended by terrorism experts as measures to reduce the threat of radiological terrorism. If a practice using radioactive sources is determined to be justified, the need for special security measures to protect against terrorism should then become part of the safety assessment.**

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INTRODUCTION

THE ATTACK on the United States on 11 September 2001 will have many consequences, not the least of which is heightened awareness of the need for safety and security measures to protect against radiological terrorism.

In radiation protection, "safety" and "security" are terms used to denote an assembly of administrative, technical, and managerial features (González 1999). In at least three languages, English, French, and Russian, they can have somewhat different, yet similar, meanings; in others, a common word is used for both which leads to confusion. Radiation protection programs for radiation sources are directed at providing radiation safety during use and when accidents occur. "Accidents" are unplanned events not having criminal origins. In this context, "safety" is used to cover features that diminish the likelihood of something going wrong with a radiation source and "security" is used to cover features that prevent unauthorized access to or possession of radiation sources and the consequences. An example of security in this context is measures taken to prevent loss of control of radioactive material that could lead to harmful exposures to people.

Unplanned events having criminal origins, such as terrorism, are different from accidents. Their consequences can be qualitatively and quantitatively different from accidents. In this context, security has a different intent, namely to protect against criminal acts intentionally directed at (targeting) radiation sources. This type of security is usually limited to radioactive materials, in particular, fissionable materials (González 1999) and associated facilities and equipment. Since 11 September 2001, security against criminal acts for all radioactive materials has become a greater concern.

THE POTENTIAL FOR ACCIDENTS

The International Atomic Energy Agency (IAEA) reported 136 major radiation accidents occurred worldwide from 1945 to 1999 (González 1999).‡ Of these, 21 involved reactors and criticality accidents. The majority, however, 89, involved radioactive sources. Of the remainder, 23 involved radiation-producing machines, and in 3 the source was not identified. Overexposures of

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‡ The list is by no means complete. For example, the writers are aware of accidents involving analytical x-ray equipment not included in the list. See, for example, Lubenau JO, Davis JS, McDonald DJ, Gerusky TM. Analytical x-ray hazards: A continuing problem. Health Phys 16:739–746; 1969.

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patients in medical settings have also occurred but these constitute a small fraction of the IAEA list.

"Orphan sources," radioactive sources that have escaped institutional controls, have been involved in 60 severe radiological accidents causing overexposure of 266 persons and 39 fatalities (Yusko 2001). In the U.S., each year an average of 375 radioactive sources or devices are reported to the U.S. Nuclear Regulatory Commission (U.S. NRC) as lost or stolen or about one per day (Meserve 2001). Since 1986, 60% of lost and stolen sources has not been recovered (Dolan 2001).

A distinguishing feature of orphan source accidents is that overexposed persons are not radiation workers but members of the public. For example, an orphan source accident beginning on 5 May 2000, in Egypt resulted in two fatalities to members of the public, and bone marrow depression and skin burns in survivors (El-Naggar et al. 2002).

Another type of accident, unique to radioactive sources and a major consequence of sources becoming orphans, is accidental melting in metal manufacturing mills of radioactive sources that became mixed with metal scrap (Lubenau and Yusko 1995, 1998). In the U.S. there have been 21 such incidents at steel mills, the most recent occurring in July 2001.[§] Another 12 incidents have involved mills producing aluminum (7), gold (2), and lead, copper, and zinc (1 each). To date, the harm resulting from such meltings has been limited to financial losses, but these losses have been severe, averaging US$ 12 million** for U.S. steel mills and US$ 23 million in one case (Lubenau and Yusko 1998). In 1998, a Spanish steel mill accidentally melted a multi-GBq ^{137}Cs source resulting in a US$ 26 million loss (Lubenau 1998, 2000). These events occurred at smaller "mini mills." An incident at a large integrated steel mill would likely result in costs of US$ 100 million.[††]. What is striking about these costs is their relatively large size even though existing pollution control systems confine the contamination to specific pathways and end points, thus limiting dispersion of the radioactive material.

The costs incurred by steel mills following a contamination event are consistent with U.S. NRC estimates for decommissioning of facilities having used radioactive materials (U.S. NRC 1981) and cleanup following contamination incidents (U.S. NRC 1987). Estimates of decontamination costs for selected ("reference") radioactive materials facilities having inventories ranging from 74 MBq to 33 TBq (0.002 to 880 Ci) ranged from US$ 37,000 to 8,000,000. These cost estimates are in 1978 dollars. In addition to inflationary increases in wages, etc., that have occurred since 1978, these costs are unadjusted for the sharply increased cost for disposal of radioactive waste. The U.S. NRC study was based upon a disposal cost of US$ 4.75 per cubic foot compared to a cost of US$ 375 per cubic foot in 2000 (Ryan and Newcomb 2000). Also not included are the costs of lost production and wages following an incident. For U.S. steel "mini-mills," which produce over half of the steel made in the U.S., lost production and wage losses from unplanned shutdowns typically cost US$ 0.5 million per day.[‡‡]

All U.S. steel mills have installed radiation detectors to scan incoming metal scrap for radioactive material but these cannot provide 100% protection. Even so, over 500 radioactive sources have been found in U.S. metal scrap since 1983, more than half since 1995 (Lubenau and Yusko 2000).

The quantities of radioactive materials involved in orphan sources are often large. For example, the first reported accidental melting of a radioactive source in a U.S. steel mill (occurring in 1983) involved a 925 GBq (25 Ci) ^{60}Co source (Bradley et al. 1986). In 1983, in Mexico, an unused teletherapy unit containing a 14.8 TBq (400 Ci) ^{60}Co source was removed from storage and sold for scrap (Burson and Lushbaugh 1990; Marshall 1984). The source containment was breached resulting in contamination of other metal scrap that was sold to Mexican foundries and steel mills. In Taiwan in 1983 multiple ^{60}Co sources, the largest of which being 740 GBq (20 Ci), were melted in steel mills (Lubenau and Yusko 1998). Rebar made from the contaminated steel was used in the construction of 200 buildings in Taipei (Hwang et al. 2001). Many of the buildings were later closed following the discovery of radiation from the rebar. In 1987, in Brazil an abandoned teletherapy unit containing a 51 TBq (1,375 Ci) ^{137}Cs source was disassembled and sold for scrap (IAEA 1988). Four persons died soon after that accident, dozens required extended medical care, cleanup costs were very significant, and significant volumes of radioactive waste were generated.

Such accidents also result in litigation. For example, in Taiwan, a civil action was filed that asked for US$ 3.4 million for compensation (Hwang et al. 2001).

[§] U.S. NRC Preliminary Notice of Event or Unusual Occurrence PNO-II-01–022 (16 July 2001), "Melted cesium source." PNOs were available to the public until September 2001 and were then withdrawn. The reader should contact the U.S. NRC Office of Public Affairs to determine their availability.

** From the 2000 U.S. NRC "Regulatory Analysis of Requirements for the Possession of Industrial Devices Containing Byproduct Material." The requirements were published in the Federal Register at 65 FR 69172 (December 18, 2000).

[††] See American Iron and Steel Institute, Public policy, Recommendations for Improving USNRC's Control over Specifically Licensed Devices at http://www.steel/org/policy2/others/st_980121.asp.

[‡‡] Personal communication from Ray Turner, The David J. Joseph Co., Cincinnati, OH.

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In the U.S., during in the period 1992 to 1999, 13 unshielded radioactive sources were found in the public domain (Dicus 1999). Nine were found in facilities that use scrap metal, and one each were found in a conventional waste disposal site, an incinerator, a construction site, and embedded in a public highway. The largest of these sources, 1.5 TBq (40 Ci) of ^{192}Ir, came from a radiography camera that had been stolen and caused overexposures of members of the public including law enforcement officers (Texas Bureau of Radiation Control 1996).

Even a relatively small radioactive source can be a problem. In 1997, a 3.7 GBq (0.1 Ci) ^{241}Am fill level gauge was accidentally discarded by a Pennsylvania brewery as scrap and sent with other metal scrap to a scrap metal processor (Lubenau 2001b). There, a metal shredder separated the source from the source holder and breached the source containment contaminating the shredder. Fortunately, the shredder was fitted with a wet dust control system—not a common practice—that confined the contamination and prevented a release to the environment. The source capsule was recovered. Subsequent examination of it revealed a serial number that enabled tracing the source to the brewery. In such cases, liability for payment of cleanup costs becomes an issue.

The accident in Goiânia, Brazil, demonstrated the psychosocial disruption caused by an accident involving radioactive material can be severe (IAEA 1998c). For example, more than 8,000 residents of Goiânia requested monitoring for contamination in order to obtain certificates stating that they were not contaminated. These were needed because operators of commercial airplanes and buses refused to allow them to board and hotels refused to register them (Binns 1998).

It is evident from this review of orphan source accidents involving radioactive sources that they can be quite disruptive because of the potential for injurious or life threatening radiation exposure to members of the public, severe financial and psychosocial costs, and litigation.

In contrast to radioactive sources, most machine-produced radiation sources when shut down and disconnected from a power source are not radiation sources. Thus, orphan source accidents that cause radiation exposure to workers or the public are impossible for machine-produced radiation sources.

Radiation accidents involving the use or maintenance of radioactive sources and radiation producing machines can be prevented by proper equipment design, training of operators, and adherence to safety procedures for operation and maintenance of equipment.

THE POTENTIAL FOR CRIMINAL ACTS

Criminal acts involving radioactive sources can be divided into two categories:

1. Those in which the nuclear or radiation properties are not known to the criminals or are deliberately ignored, and
2. Those in which there is knowledge of and intent to use the nuclear or radiation emitting properties for criminal purposes.

The most frequently occurring example of the first category of criminal acts is thefts or other illegal removals of radioactive source holders to sell as scrap metal. Scrap metal is bought and sold primarily on the basis of weight. The mass of the lead or depleted uranium used for shielding makes source holders attractive for this purpose. In many cases, the perpetrators, unaware that the holder contains a radioactive source (because warning labels are unreadable, not understood, or obliterated) disassemble the device including the shielding, exposing themselves and others to the source. Accidents of this type, which have resulted in injuries and deaths, occurred in Mexico (Marshall 1984), Brazil (IAEA 1988), Turkey (IAEA 1996, 2000a), and Thailand[§§] (Associated Press 2000; Reuters 2000; Jinaratana 2002; IAEA 2002). In some cases, notably in Mexico in 1983 and in Brazil in 1987, the sources themselves were damaged releasing the radioactive material causing contamination of persons exposed to the source and the environment. In the 1996 incident in Texas, thieves deliberately ignored radiation warnings signs and labels to steal industrial radiography cameras to sell as scrap metal. One camera was damaged during handling exposing a 1.33 TBq (36 Ci) ^{60}Co source (Texas Bureau of Radiation Control 1996).

Portable moisture density gauges are frequent targets for theft, usually from construction sites and commercial vehicles. In 2000, 37 gauges of this type were reported to the U.S. NRC as stolen.*** Of these, 19 (51%) containing a total of 30 GBq (0.8 Ci) ^{241}Am and 6 GBq (0.16 Ci) ^{137}Cs, have not been recovered.

With respect to the second category of criminal acts, namely when there is knowledge of and intent to use the radiation, such acts, while not unknown, are uncommon. A radiation-producing machine was used to induce an abortion.[†††] Radioactive materials were used in an attempted castration of a boy in Texas (Collins and

[§§] An extensive archive is available at http://www.bangkokpost.net by searching for "cobalt-60" or "radioactive cobalt."

*** Data derived from the U.S. NRC Nuclear Materials Event Database (NMED).

[†††] This occurred in Pennsylvania, personal recollection of J.O. Lubenau.

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Gaulden 1980) and in a plan to deliberately contaminate homes, cars, and food of public officials.[‡‡‡]

THE POTENTIAL FOR RADIOLOGICAL TERRORISM

Criminal acts include terrorism. Terrorism has been defined in a U.S. government report as "violence, or the threat of violence, calculated to create an atmosphere of fear and alarm. All terrorist acts are crimes. Terrorist acts are intended to produce effects beyond the immediate physical damage that they cause" (Advisory Panel to Assess Domestic Response Capabilities for Terrorism Involving Weapons of Mass Destruction 1999). In the past, concerns over radiological terrorism focused on nuclear materials, i.e., fissile or weapons materials.

The possible use of radioactive materials for terrorism has been recognized by experts, e.g., emplacing radiation sources in public places or embedding radioactive materials in conventional explosive devices, e.g., "dirty bombs" (Advisory Panel to Assess Domestic Response Capabilities for Terrorism Involving Weapons of Mass Destruction 1999; Lesser et al. 1999; National Commission on Terrorism 2000; NCRP 2001). An example of the former is the 1995 act involving the planting of a radioactive source in a Moscow park (Advisory Panel to Assess Domestic Response Capabilities for Terrorism Involving Weapons of Mass Destruction 1999; National Commission on Terrorism 2000). And, in 1998, officials in Chechnya defused a booby-trapped explosive attached to a container of radioactive material, according to Russian press reports (Kaplan and Pasternak 2001).

The NCRP notes that a terrorist act that disperses radioactive material is qualitatively different from conventional terrorist acts using explosives (NCRP 2001). Such acts are not expected to cause massive numbers of deaths or injuries from exposure to radiation. Rather, their effect is to complicate rescue efforts and recovery work, rendering the latter more expensive because of the presence of radiation hazards (Lesser et al. 1999; NCRP 2001). Most importantly, such acts prey upon public apprehensions about radiation and its hazards. The psychosocial impacts may be the most difficult aspect of consequence management following a terrorist act that dispersed radioactive material (NCRP 2001). The potential disruption that could be caused by a "dirty bomb" has been described in a Rand Corporation report as "fundamentally disquieting" (Lesser et al. 1999). In recent testimony before the Senate Foreign Relations Committee, Steven E. Koonin of the California Institute of Technology, described dirty bombs as "weapons of mass disruption," a phrase formerly limited to cyberterrorist attacks.[§§§]

In 1998, nineteen ^{137}Cs brachytherapy sources totaling 22 GBq (0.6 Ci) were stolen from a North Carolina hospital.**** Brachytherapy sources are relatively fragile and dimensionally small; the NC sources measured 3 mm in diameter and 19 mm in length and the radioactive material contained therein is in a readily dispersible form. Federal assets that were deployed to assist the state included U.S. Department of Energy aerial and ground surveys to locate the sources and coordination with the Federal Bureau of Investigation on the criminal investigation. Despite these efforts, the sources still have not been recovered (Kaplan and Pasternak 2001). The purpose of the theft remains unknown.

Illicit trafficking of radioactive materials is a problem challenging national and international authorities (González 1999; Duftschmid 1999; Stone 2001). The World Customs Organization reported 234 seizures of radioactive materials from 1993 to 1998. Of these, 53 (23%) were cesium sources. Based upon IAEA reports, international incidents involving illicit trafficking of non-fissile radioactive materials exceed by a ratio of 9:1 those involving types of materials that can be used for nuclear weapons. Sources containing ^{137}Cs and ^{60}Co accounted for half of the radioactive material incidents (González 1999). The frequency of such incidents is an indirect measure of the effectiveness of programs to control and provide for security of radioactive materials.

POTENTIAL FOR CONTAMINATION AND RADIATION EXPOSURE

As noted, both types of radiation sources—machines and radioactive materials—have the potential to cause overexposures to workers and/or to members of the public.

Overexposures of workers typically occur primarily because of failures by workers to follow safety procedures (Strom and Watson 1999). Worker injuries and fatalities have occurred from both radioactive sources and from x-ray machines and accelerators.

‡‡‡ U.S. NRC Preliminary Notice of Event or Unusual Occurrence PNO-I-96–043 (14 June 1996), "Two individuals charged with conspiracy to commit murder involving radioactive materials." PNOs were available to the public until September 2001 and were then withdrawn. The reader should contact the U.S. NRC Office of Public Affairs to determine their availability.

§§§ Koonin SE. Weapons of 'Mass Disruption.' http://abcnews.go.com/sections/wnt/DailyNews/WNT_dirtybombs_020306.html ABC News, 6 March 2002.

**** U.S. NRC Preliminary Notice of Event or Unusual Occurrence PNO-II-98–010 (5 March 1998), "Missing brachytherapy sources." PNOs were available to the public until September 2001 and were then withdrawn. The reader should contact the U.S. NRC Office of Public Affairs to determine their availability.

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Overexposures of the public that result in acute injuries or deaths from radiation machines are virtually unknown,[††††] but overexposures to the public have occurred repeatedly from radioactive sources that have escaped from institutional control.

Except for very high energy accelerators,[‡‡‡‡] radioactive contamination is not a concern for machine-produced radiation. Residual radioactive material that may be produced is typically short-lived and confined to the machine and nearby shielding and structures. Radioactive contamination from radionuclide sources that have been breached has happened repeatedly, and has increased in frequency as more sources have come into use.

ISSUES RELATED TO THE DISPOSAL OF DISUSED SOURCES

When no longer needed, or when radioactive decay has made it too weak, disposition of the used radioactive source must be managed. Options include storage, transfer to another user, or disposal as scrap or waste.

Radioactive sources, if no longer needed, must continue to be treated as radiation sources and as a potential radiation hazard. Disposition options, such as transfer to another user or disposal as radioactive waste, are usually restricted by regulatory radiation safety requirements; for example, recipients must be licensed to receive and possess the source. Disposal options may be constrained by lack of availability of or access to radioactive waste disposal sites and by the costs (Lubenau 2002). Former users, faced with the constraints on and costs of disposal, often place unwanted radioactive sources in extended storage where they become vulnerable to theft or abandonment and become orphan sources. The recent orphan source accident in Thailand is a case in point (Associated Press 2000; Reuters 2000; Jinaratana 2002; IAEA 2002).

Government ownership or control of radioactive sources does not preclude their becoming orphan sources. Radioactive sources, some unmarked and unshielded, were abandoned at a military base in the Republic of Georgia by departing Russians resulting in radiation injuries of Georgian border guards (IAEA 2000b; Carsin et al. 2002). In Estonia in 1994, a radioactive source that was discovered in metal scrap was recovered and transferred to a hazardous waste disposal site managed by a municipal enterprise and supervised by the national government. The source was later stolen by local residents (IAEA 1998b). One person died and others were hospitalized.

Orphan sources are easier to divert than regulated sources and, thus, as noted by the IAEA, are more prone to fall within malevolent hands (González 2002). The president of the Federation of American Scientists, in testimony before the U.S. Senate Committee on Foreign Relations hearing on nuclear terrorism in March 2002, stressed to need to recover and securely store unneeded radioactive materials as a first step to improve security against radiological terrorism.[§§§§] The Health Physics Society (HPS) advocates restructuring the U.S. system for retention, transfer, and disposal of unwanted radioactive sources to encourage prompt transfer, storage and disposal.*****

In contrast to radioactive sources, all conventional x-ray machines and most accelerators are not radiation sources when not powered. Since there is no radioactive source, disposal as radioactive waste is not required. If not reused or stored, x-ray machines and most accelerators can be scrapped without concern for radiation hazards. When transferred to another party, the recipient of a radiation producing machine is usually subject to requirements to register the unit with the government regulatory authority and to comply with operating safety requirements.

Except for those using short-lived radioisotopes, radioactive sources eventually become disused radioactive sources.

JUSTIFICATION AND SECURITY

At the global level, the needs to address more effectively illicit trafficking of nuclear and radioactive materials, strengthen national regulatory programs, and address the orphan source problem were recognized in 1998 when the first international conference on safety and security of radiation sources was held. The conference, held in Dijon, France, was co-sponsored by the IAEA, European Commission, World Customs Organization and the International Criminal Police Organization (INTERPOL) (IAEA 1998a). The IAEA has mounted a major effort to strengthen national radiation safety oversight programs for radiation sources as well as other

[††††] In medical settings, patients are not considered to be "members of the public," hence medical overexposures of patients are not included.

[‡‡‡‡] High energy accelerators can produce radioactivity in components and nearby shielding and structures. Such radioactivity is usually short-lived and is relatively less of a radiation hazard than curie quantities of strong gamma emitters. See NCRP Report No. 51, Radiation Protection Guidelines for 0.1–100 MeV Particle Accelerator Facilities (NCRP 1977).

[§§§§] Testimony of Henry Kelly, President. Federation of American Scientists before the Senate Committee on Foreign Relations on 6 March 2002. Kelly's testimony is available on the web http://www.fas.org/ssp/docs/030602-kellytestimony.htm.

***** A position statement on orphan sources was preliminarily approved by the HPS Science and Public Issues Committee in February 2002 subject to final editing. After final approval it will be posted on the HPS web site at http://www.hps.org.

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initiatives to address the problem (González 1999; Yusko 2001). The EC has taken steps to assess and address the problems (Ciani 1999). In the U.S., the U.S. NRC significantly amended its licensing and related programs to improve oversight of radioactive material licensees (U.S. NRC 2000). These actions address for the most part the need to ensure that registered and licensed users of radiation sources comply with requirements for use, storage, and disposal.

More recently, questions are being raised about whether all uses of radiation are justified (Lubenau 2000, 2001a). Justification is a process to assess whether a practice using radiation results in benefits that outweigh the detriments, a fundamental concept in radiation protection. Detriments include potential for radiation exposure, accidents and radioactive waste management.

Justification in the context of radiation protection is not a new concept but has been an integral part of international and national systems for radiation protection for a quarter of a century (ICRP 1977, 1985, 1991, 1997; NCRP 1993). It is the first of the three cornerstone principles that underpin international and national recommendations for radiation safety, the others being optimization and complying with dose limits (ICRP 1991; NCRP 1993). The HPS recommends that U.S. and state licensing policies implement the principles of justification.[†††††]

As noted earlier, radioactive material security is usually part of a radiation protection program covering the use of the radioactive material including accidents. Even in this context, the IAEA has noted that security requirements in its Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources (IAEA 1996) "are minimal" (González 1999). The increased sensitivity to the potential use of radioactive material for terrorism means that security in the other context, namely to protect against deliberate criminal acts, also must be considered. Specifically, the potential for criminal or terrorist use of radioactive material should be treated as a detriment within the ICRP and NCRP frameworks of radiation safety when justifying the practice.

Finding alternatives to radioactive materials such as machine produced radiation sources, even if more expensive, is a step to improve national security against radiological terrorism recommended by U.S. experts on radiological terrorism.[‡‡‡‡]

When a practice that uses a radiation source is determined to be justified, the need for security against criminal or terrorist acts ought to be evaluated either as an expanded part of the radiological safety assessment or as a separate assessment of the threat of criminal acts and their consequences. Significant issues associated with security are:

1. The potential for criminal use, diversion, or damage of sources;
2. Responsibility for providing and financing storage that is radiologically safe and protects against accidents and criminal acts;
3. The potential for overexposures and contamination when breaches of security occur;
4. Responsibility for providing and paying for radioactive waste disposal of sources at end-of-life or when no longer needed; and
5. Liability for reimbursement of damages resulting from accidents and criminal acts.

These security issues are far more significant for systems using radioactive sources as the source of radiation than for those using machine produced radiation.

INTERNATIONAL ASPECTS

In 2001, the IAEA finalized a Code of Conduct on the safety and security of Radioactive Materials (IAEA 2001). The IAEA Board of Governors requested the Director General to circulate it to all countries and international organizations. Unlike a convention, the code is not a binding document, but it represents a consensus of international technical and legal experts on standards that countries should follow to "achieve and maintain a high level of safety and security of radioactive sources." Development of the code was part of an IAEA action plan to improve safety and security of radioactive sources.

Three sections of the code are particularly relevant:

1. Section 8(c) states that radioactive sources shall not be stored for extended periods of time in facilities not designed for the purpose of such storage;
2. Section 17(b) states that each country shall ensure that before receipt of a radioactive source is authorized arrangements have been made for its safe management once it has become a disused source and financial provision has been made for this purpose; and
3. Section 19 states a country should allow for re-entry of a radioactive source if it is disused and if it is accepted that it can be returned to a manufacturer.

To date, the U.S. government has not committed itself to follow the code and implement its provisions.

[†††††] See footnote *****.

[‡‡‡‡] See footnote §§§§. Similar testimony was presented to the committee by Steven E. Koonin, Provost, California Institute of Technology, see footnote §§§.

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SUMMARY

The results of this survey of the issues associated with the choice between radioactive sources and machine sources of radiation are summarized in Table 1.

A CASE STUDY

On 17 January 2002, U.S. Customs Service Commissioner Bonner addressed the Center for Strategic and International Studies in Washington, D.C. §§§§§ He noted that more than 50,000 cargo containers are imported into the U.S. each day. These containers could contain materials or devices deliberately emplaced for terrorism purposes. The Customs service presently inspects only 2% of these. Cargo container selection for searches is not random but the result of a targeting process. In view of the increased security concerns, Commissioner Bonner proposed a Container Security Initiative (CSI) that would include the inspection and sealing of cargo containers at points of embarkation from 10 ports that send the most goods to the U.S. The program would include transfer of radiography technology used for inspecting cargo containers.

Cargo containers are typically made of steel, 2.4 m (8 ft) high, 2.4 m (8 ft) wide, and 6.1, 12.2, or 14.6 m (20, 40, or 48 ft) long. Half height containers are also used. Radiography of cargo containers requires a source of radiation that can penetrate the container walls and its contents. To create an image, either the source and detector or the container are moved while a pencil beam or fan beam traverses the container.

Radiation sources for cargo container inspections include machine-produced radiation and radioactive sources. Machines typically include conventional x ray up to 450 keV and linear accelerators (linacs). Radioactive sources include ^{137}Cs and ^{60}Co whose activity ranges up to 74 GBq (2 Ci). Currently, there are conventional transmission type radiography devices, such as the Vehicle and Cargo Inspection System (VACIS II)****** and x-ray systems that produce conventional transmission type images (Fig. 1) as well as backscatter systems such as the Z Backscatter X-Ray Technology.†††††† Imaging data is collected and processed electronically. The more sophisticated radiation systems, namely those using backscatter technology, can detect low-density materials that are not detectable through conventional contrast radiography such as hidden caches of drugs and plastic explosives.

Commissioner Bonner's proposal to transfer the technology for radiographing cargo containers provides an instructive case study for applying the ICRP principle of justification and the IAEA Code of Conduct on the Safety and Security of Radioactive Sources. The proposal is intended to enhance homeland security. But, will the "transfer of technology" involve exporting U.S. origin equipment for this purpose? If the transfer of technology involves systems using radioactive sources, will such technology be justified given such sources

§§§§§ U.S. Customs Service Commissioner Robert C. Bonner, speech before the Center for Strategic and International Studies, Washington, DC, 17 January 2002. The speech and related information are available on the web at http://www.customs.gov/top/sitemap/htm.

****** SAIC, 10260 Campus Point Drive, San Diego, CA 92121; http://www.saic.com/products/security/vacisii/vacisii.html.

††††† American Science and Engineering, 829 Middlesex Turnpike, Billerica, MA 01821; http://www.as-e.com/technology/technology.html.

Table 1. Comparison of risks and liabilities for radionuclide and machine sources.

Consequence	Radionuclide source	Machine source
radiological accident potential: occupational	have occurred, causing severe injuries and deaths, but minimized by engineered controls. **Can** occur when device is "off"	have occurred, causing severe injuries and deaths, but minimized by engineered controls. **Cannot** occur when device is "off"
radiological accident potential: public	have occurred, including fatalities and severe injuries	low potential
radiological accident potential: orphan source	have occurred, causing severe injuries and deaths	none
radiological accident potential: source melting	have occurred, very expensive cleanup (multimillion dollars)	none
criminal acts	potential is significant, several historical examples	much less potential
radioactive contamination	can happen if source is breached; very expensive consequences	none
radiation exposure when power is off	possible	none
source disposal	must be managed; costs and liabilities can be significant	no radiological concerns
evolving concerns	justification of using radioactive source v. machine source	less of a problem

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Fig. 1. Backscatter x-ray image (above), and transmission x-ray scan of a cargo container (below). Photograph courtesy of American Science and Engineering, Inc., Billerica, Massachusetts.

carry a security detriment and obligations for their disposal when they are no longer needed? Will the export of such systems be in accord with the IAEA Code of Conduct for the Safety and Security of Radioactive Sources provisions calling for prior arrangements for safe management of the sources when no longer needed and possible return to the U.S.? If returned to the U.S., will there be provisions available for their safe secure storage or disposal? Homeland security could be enhanced by the cargo container security initiative, but the selection of the technology that is transferred for this purpose should take into account these considerations.

Consideration of the foregoing does not rule out the use of cargo inspection systems using radioactive sources but should result in limiting their use to situations where they clearly are the system of choice after their unique detriments and the availability of alternatives have been fully evaluated.

CONCLUSIONS

It is clear that there are significant radiological risks and liabilities associated with radioactive sources that do not exist when conventional x-ray or accelerator sources

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are chosen. These risks were known prior to 11 September 2001 but have taken on a new significance since then.

The need to provide security for radioactive sources against terrorist use is a detriment that should be considered in the justification of a practice. If security is an issue, consideration should be given to alternatives to radioactive sources that are technically and economically feasible. When the practice is determined to be justified, the radiological assessment of the practice should include consideration of the security needs. Arrangements to provide for the prompt transfer to safe secure storage or disposal should be in place prior to obtaining radioactive sources. International transactions involving radioactive sources should be conducted in accordance with the IAEA Code of Conduct for the Safety and Security of Radioactive Sources.

Lastly, licensing and regulatory policies in the U.S. should be revised so that they conform to internationally accepted standards for radiation safety and security. U.S. government actions to use and transfer technologies using radiation sources to enhance homeland security should conform to these same standards.

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