Treatment, Not Terror:
Strategies to Enhance External Beam Cancer Therapy in Developing Countries While Permanently Reducing the Risk of Radiological Terrorism

By Miles A. Pomper,
Ferenc Dalnoki-Veress,
and George M. Moore

February 2016

The Stanley Foundation

CNS

Treatment, Not Terror:
Strategies to Enhance External Beam Cancer Therapy in Developing Countries While Permanently Reducing the Risk of Radiological Terrorism

James Martin Center for Nonproliferation Studies
Middlebury Institute of International Studies at Monterey
and The Stanley Foundation

By Miles A. Pomper, Ferenc Dalnoki-Veress,
and George M. Moore

Contents

Executive Summary

In the wake of the 9/11 terrorist attacks, governments across the globe, particularly in developed countries such as the United States, have shown increased concern that terrorists could gain access to high-activity radiological sources that could be used in a dirty bomb or other devices intended to spread radiation and terrorize a population. Hundreds of millions of dollars have been spent on increasing the security of these devices and detecting smuggling of such materials. But given that these materials are in widespread use for commercial applications around the world, fully securing them appears to be a Sisyphean task as well as one requiring endless budget expenditures. As a result, proposals to permanently reduce the risk by replacing the use of such materials with nonisotopic sources have been gaining traction in the international community. A particular focus have been a handful of high-risk sources that are in widespread commercial use and produce high levels of radiation: cesium-137, cobalt-60, iridium-192, americium-241, and combined americium-241/beryllium sources.[1]

The ability to substitute nonisotopic technologies for these high-risk sources varies by the technical readiness of suitable alternatives and the cost that end users have to pay for them. One of the more challenging efforts at replacement is that of substituting linear accelerators (LINACs) for cobalt-60 (also known as Co-60 or ^{60}Co) devices in external cancer radiation treatment.[2] In some respects, the bar of technical readiness has already been overcome: most medical practitioners would prefer to use LINACs for teletherapy, and indeed, in richer countries (higher-middle-income countries and above), LINACs have largely replaced cobalt-60 machines for such treatment. But cobalt-60 machines have historically been less expensive and easier to operate in the lower income regions of the world. This gap had recently been closing, but as a result of past price differences, cobalt-60 machines predominate in low-income countries and run roughly even with LINACs in low-to-middle-income countries.[3]

In addition, cancer treatment in these poorer countries is already grossly inadequate, and cancer rates are rising, making phasing out the use of such machines or preventing new purchases of somewhat cheaper devices problematic.[4] The need for cancer care in low- and middle-income countries (LMICs) is huge: they have 5 percent of the resources but 80 percent of the global cancer burden.[5] Estimates are that there is a current shortfall of 5,000 radiotherapy machines globally, with a large proportion of the need in Africa. One recent expert commentary noted: "In many parts of Africa, there is only one teletherapy unit per 10 million people!"[6] Simply removing cobalt teletherapy machines or preventing new purchases of somewhat cheaper devices runs the risk of preventing patients from getting needed care.

At the same time, there has been a significant increase in terrorist incidents in Africa. According to the Global Terrorism Database operated by the University of Maryland, the last four years had the same number of incidents as the entire previous decade.

Although no specific threats have been made by terrorist groups like Boko Haram to use radiological materials for nefarious purposes, this could change. It is prudent to consider the risk of terrorist groups acquiring radiological materials as credible, and all efforts must be made to decrease this risk.

Policymakers therefore face the challenge of using limited resources to accomplish two potentially contradictory goals: trying to reduce the threat that terrorists could obtain materials for radiological weapons and trying to tackle cancer care in Africa and other developing regions. With the support of the US National Nuclear Security Administration (NNSA) and the United Kingdom Department of Energy & Climate Change, as well as the guidance of the US National Cancer Institute and the University of the Witwatersrand, South Africa, the James Martin Center for Nonproliferation Studies (CNS) and the Stanley Foundation held a workshop in Johannesburg, South Africa, on September 1–2, 2015, to seek ways that the radiological-security and public-health communities might help meet this challenge. The meeting brought together experts from the security, nuclear, public health, and international development sectors. Attendees included representatives from governments, international organizations, private industry, nongovernmental organizations, and medical institutions.[7]

The workshop and additional research yielded the following recommendations:

- A group of donor states, perhaps the Global Partnership Against the Spread of Weapons and Materials of Mass Destruction (or the nuclear powers plus, for example Canada, Germany, Norway, and other states that generally donate to nuclear security or nuclear safety issues), should guarantee to the International Atomic Energy Agency (IAEA) the establishment of a separate fund to be used only to support the removal/repatriation of abandoned radioactive sources when all other (i.e., commercial) remedies have been exhausted.

- The IAEA should publish guidance on long-term disposal of sources and should encourage countries to adopt it into national regulations and should also encourage radiological source suppliers to pledge to adhere to the guidance.

- The international community should employ several measures to make LINACs more accessible to developing countries.

    - Develop LINACs specifically designed for developing countries and bring in new partners to the effort, such as the US National Aeronautics and Space Administration (NASA) and technology firms. Support countries such as India that have already produced such LINACs to promote their distribution. Initiate an XPRIZE-like award to spur development.

    - Facilitate the use of suitable refurbished LINACs through a process that certifies their quality and/or the publication of IAEA guidelines by which states can gauge the suitability of such machines. Run a pilot study to test patient outcomes on such refurbished machines versus new models.

    - Encourage bulk purchases by states, regional bodies, and public-private partnerships.

  - Encourage vendors to lease rather than sell the equipment as a means of assuring functionality and ultimate disposal.

  - Provide LINACs as part of a package of cancer support including diagnostics and health system improvements that would increase the proportion of patients in LMICs who can use such treatment at early stages of cancer, to have greater efficacy and equity of treatment and socioeconomic impact.

- The United States, the IAEA, and other members of the international community should partner with other government agencies and nongovernment actors to provide education, training, and sustainable support necessary for the safe and proper use of LINACs for cancer care.

The Radiological Terrorist Threat and the Case of Cobalt-60

Terrorists in particular could utilize radioactive sources to cause harm in several ways. Highly radioactive sources such as cobalt-60 could be placed in unknown locations and expose the public over a prolonged period of time (this is known as a radiological exposure device, or RED). The sources could be used to poison food and water supplies, thereby denying access to vital human needs. Finally, the source material could be dispersed through fire, explosives, or other means and used to deny access to large areas or property collectively. Such a weapon is referred to as a radiological dispersal device (RDD). Unlike weapons of mass destruction, weaponized high-risk radiological materials are not expected to cause mass fatalities nor would they likely cause deterministic health effects.[8] However, their use could generate substantial economic, social, and psychological upheavals, including widespread fear and anxiety. Even though stochastic effects would likely affect only a small segment of the population,[9] "worries about stochastic effects could add to the psychological burden as people are witnessing, for example, in the aftermath of the radioactive contamination from the accident at the Fukushima Daiichi Nuclear Power Plant."[10]

Although no RDD attack has yet occurred, there is ample evidence that if such an event were to occur, the effect would be devastating. In 1987, a cesium-137 teletherapy device was left in an abandoned hospital in the city of Goiânia in Brazil. Scavengers took the device, ruptured the iridium window causing gamma rays to be emitted, and sold it to a junkyard owner. The blue glow of the small cylinder of cesium chloride that was inside the device made it appear valuable, and it was thus broken into pieces and used for decorative purposes, including rubbing on the skin.

The incident led to four deaths and 28 people being hospitalized with serious radiation burns. Two hundred fifty people were exposed to cesium, with as many as 150 of them suffering from internal radiation exposure because they inhaled or ingested the cesium powder. Over 85 residences were "significantly contaminated," and 41 were either "totally or partially destroyed" after the event. Buses and paper were contaminated, as was money, which had to be screened at local banks. The government lost public trust since it was not able to account for 30 percent of the radioactive material, leading to protests in which people attacked the hearse that carried two of the victims. People whose homes had been destroyed in the cleanup were expelled from hotels, and the people from the city of more than a million residents were ostracized. Furthermore, the incident crippled the health care system as more than one-tenth of the population sought medical attention even though they were not even in the vicinity of the incident.

To be sure, terrorist exploitation of a cobalt-60 source is more likely to be in the form of an RED rather than an RDD.[11] That's because the cesium-137 in Goiânia was in the form of a chloride that has essentially the same properties as table salt and is thus highly dispersible. In contrast, cobalt-60 devices use cobalt in a metal form (typically a wire or foil), and thus the radioactive element is harder to disperse—and easier to decontaminate—unless its physical state is intentionally altered to enhance its dispersibility.[12]

Nonetheless, the consequences of terrorist use of such materials could still be significant in today's LMIC cities given the very high activity level of such sources and the fear of radioactivity.[13]

Cobalt-60 Sources and Terrorism Risks in Africa

The IAEA maintains an online, voluntary database of radiotherapy devices and the sources they house, known as the DIRAC database.[14] According to this database, there are at least 86 cobalt-60 medical devices in Africa, with 75 percent of them in seven countries: South Africa, Egypt, Morocco, Tunisia, Algeria, Sudan, and Nigeria. The sources in these machines are classified as Category 1 sources, the highest risk classification level of the IAEA.[15] Twenty percent of the machines are in seven other countries, and seven more have 5 percent of the cobalt machines (see Table 1). Other African countries have either replaced the machines with linear accelerators or largely do without the treatment. The concern is that some of these radioactive sources exist in countries that suffer from frequent terrorist activity and could be stolen and used for malicious purposes. Specific terrorist groups of concern are Boko Haram in the northern part of Nigeria, Cameroon, Chad, and the Niger Republic; Al-Shabaab in Kenya; Al Qaeda; and Islamic State and its affiliates in Tunisia, Egypt, and other parts of North Africa.

	LINAC	Teletherapy Cobalt-60	Brachytherapy Equipment					TOTAL
			Cobalt-60	Cs-137	Ir-192	I-125	Sr-90	
South Africa	70	10	5	0	13	4	1	103
Egypt	43	21	0	5	7	0	0	76
Morocco	30	2	4	0	2	0	0	38
Algeria	9	10	0	7	0	0	0	26
Tunisia	7	10	0	4	1	0	0	22
Nigeria	8	5	1	4	1	0	0	19
Sudan	2	6	2	1	0	0	0	11
Kenya	6	2	0	0	3	0	0	11
Ghana	1	3	0	3	0	0	0	7
Libya	1	4	0	1	0	0	0	6
Zimbabwe	4	0	0	1	0	0	1	6
Tanzania	0	2	2	0	0	0	0	4
Namibia	0	2	0	1	1	0	0	4
Mauritius	1	2	0	1	0	0	0	4
Uganda	0	1	2	0	0	0	1	4
Madagascar	2	1	0	1	0	0	0	4
Angola	4	0	0	0	0	0	0	4
Cameroon	0	1	0	2	0	0	0	3
Ethiopia	0	2	0	0	0	0	0	2
Mauritania	1	0	0	0	1	0	0	2
Zambia	1	1	0	0	0	0	0	2
Senegal	0	1	0	0	1	0	0	2
Botswana	1	0	0	0	1	0	0	2
Mali	1	0	0	0	0	0	0	1
TOTAL	192	86	16	31	31	4	3	363

Table 1. Use of radiotherapy isotopic sources for different countries in Africa as obtained from the DIRAC database (accessed December 11, 2015). In this publication, our focus is on the teletherapy sources that are highly radioactive Category 1 sources. Brachytherapy sources are more portable but are much less radioactive Category 2 or 3 sources.[16] The DIRAC database does not have information on 18 additional countries that are presumed not to have any radiotherapy centers. Source: http://www-naweb.iaea.org/nahu/dirac/informationupdate.asp.

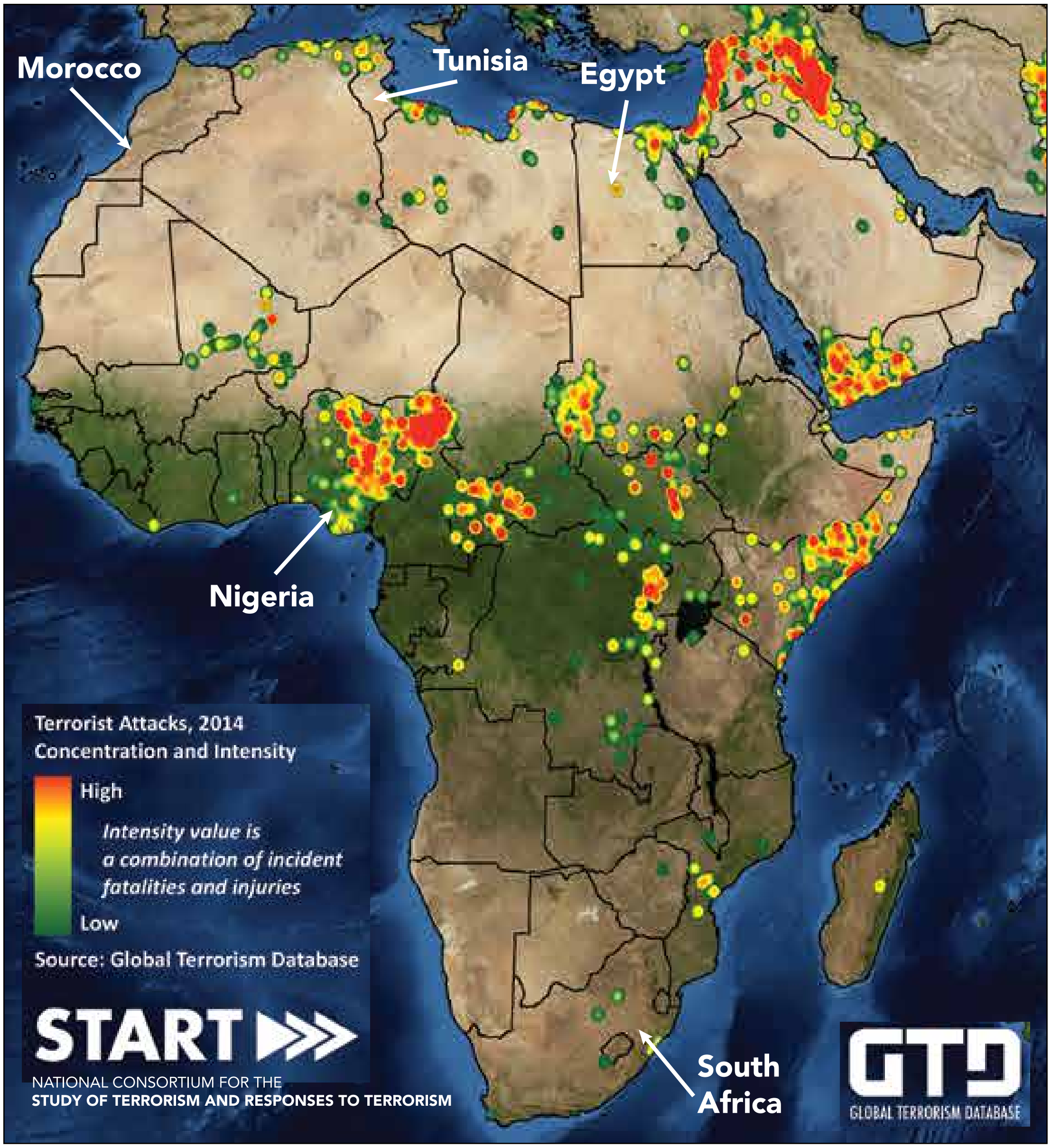

Figure 1. Density map of terrorist activity in Africa in 2014 as registered by the Global Terrorism Database, a summary of incidents maintained by the University of Maryland. Also indicated are the six countries that possess 80 percent of all medical isotopic devices in Africa. Source: National Consortium for the Study of Terrorism and Responses to Terrorism, University of Maryland, Global Terrorism Database 2014, *http://www.start.umd.edu/gtd/images/START_GlobalTerrorismDatabase_2014TerroristAttacksConcentrationIntensityMap.jp.*

A pertinent example of a country that suffers from the threat of terrorism and from the spread of terrorism to neighboring nations is Nigeria. Nigeria is threatened from within by the rapid growth of the militant terrorist organization Boko Haram and the splinter group Ansuri.[17] Boko Haram has grown from a regional terrorist group in northern Nigeria to one that has spread to neighboring Cameroon, Chad, and Niger, and has even committed crimes in Lagos, a city of 21 million far to the south. It has grown from a small group dissatisfied with the economic disparity between the north and the oil-rich south in Nigeria to an organized terrorist group allied with Al Qaeda in the Islamic Maghrab as well as Al-Shabaab, and most recently it declared a religious caliphate.[18] The group is apparently gaining experience and bomb-making expertise, and it has stolen explosives from a raided construction site. In 2013 in neighboring Niger, suicide bombers from Al Qaeda in the Islamic Maghrab attacked a uranium mine owned by the nuclear company Areva, "killing 26 people and injuring 30."[19] There is evidence that Boko Haram is interested in targeting the oil industry in the south, since there is a perception that the north has not benefited much from the industry despite enormous oil wealth in the south.[20] General Carter Ham, former commander of the US Africa Command, has compared the present status of Boko Haram to "that of Al Qaeda in the 1990s," stating, "Boko Haram's leadership aspires to broader activities across the region, certainly to Europe, and I think, again, as their name implies, anything that is Western is a legitimate target in their eyes."[21]

Boko Haram has made no statement regarding specific interest in practicing radiological or nuclear terrorism, but the group has raised concerns given its similarity to Al Qaeda and its alliance with groups that have expressed interest in using weapons of mass destruction. Figure 2 shows the number of attacks that Boko Haram has perpetrated and the major Nigerian nuclear facilities (until 2013).[22] It is prudent to prepare now for the possibility of further radicalization of Boko Haram and the possibility it may use radiological weapons in the future.

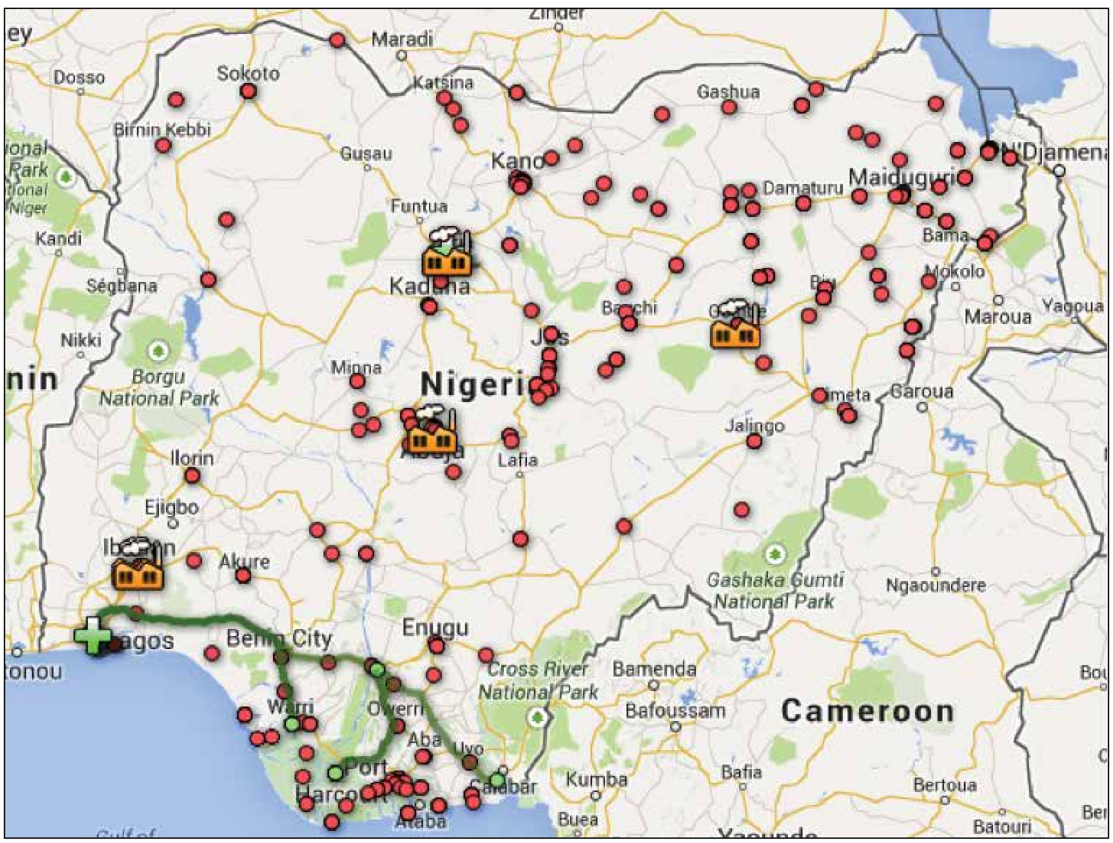

Figure 2. The red dots indicate where Boko Haram attacks have occurred. Since Boko Haram emerged as a violent terrorist organization in 2010, as many as 10,000 people have been killed. Also shown are major nuclear facilities (see orange icons), such as the Nigerian research reactor, hospitals, and irradiation facilities. In addition to the nuclear facilities, many americium-beryllium neutron sources are used in southern Nigeria, where the majority of oil production is located. Source: Ibrahim Abdulmajeed, *Minimizing the Risk of Proliferation and Nuclear/Radiological Terrorism in Nigeria*, CNS report, 2014.

Denying access to radioactive sources is a key way to decrease the risk of a radiological terrorism act. Unfortunately, in Africa, some radioactive materials are poorly secured and vulnerable to theft, and in at least one country, the risk of theft of radioactive sources for clandestine purposes is not considered a credible threat.[23] Some facilities housing nuclear material do not have armed guards on site but instead plan to rely on local and private security forces in the event of an attack that could be easily overcome. In most countries, armed personnel are also not required to protect the transport of even the most dangerous radioactive sources. A further challenge is that most African countries do not consider credible the notion that employees at facilities with radiological sources or materials may willingly participate in the theft of radioactive sources or even be coerced to do so. Finally, some African states do not have the technical capability or adequate resources to respond to nuclear and radiological terrorism if it were to occur.

Cobalt-60 (and LINAC) Use in Cancer Treatment

External beam therapy has been a critical component of global cancer care for decades.[24] Shortly after the discovery of radium in the nineteenth century, scientists realized that rapidly dividing cancer cells can be killed with ionizing radiation. The radiation damages the cancer cells' DNA (among other targets), which can cause tumor shrinkage and even cure the illness. High-energy photons (such as gamma rays from nuclear decay in cobalt-60 machines or highly energetic photons produced from LINACs) tend to be the most common form of radiation used in cancer therapy. Using careful treatment planning and delivery, such high-energy photons can penetrate deeply and destroy tumors embedded in the body. As the multiple beam treatment penetrates the body, it focuses a dose at the site of the tumor, but it will destroy normal cells at higher depths as well. Radiation oncologists plan the dose profile in three dimensions so the dose incurred to the tumor is maximized while damage to the surrounding tissue is minimized.[25]

All else being equal, medical practitioners prefer to use LINACs because they can produce higher energy photons that can penetrate much deeper, access deeper tumors, and have a sharper edged beam. More recent advances in the technology have also allowed high customization of the radiation treatment for the patient. As a result, LINACs can deliver a greater radiation dose to the tumor or target area with less damage to surrounding skin in a shorter time. This vastly increases the quality of treatment, and the shorter time exposure means more patients can be treated with a LINAC than with a cobalt-60 unit. In addition, the LINAC provides a dose rate throughout its lifetime that can be relatively uniform, while the cobalt-60 units provide a dose rate that decays over the five-year half-life of the source. At the five-year mark, therefore, a patient would need twice as long for treatment as when the source was installed.[26] The generally higher dose rate capability of a LINAC also allows for the possibility that radiation treatment with a LINAC can be curative as opposed to palliative, thereby potentially curing cancers without the need to resort to alternative treatments or combined treatments such as chemotherapy.[27] (See Appendix for details of the performance differences between the technologies.)

LINACs also are not as risky from a security point of view as cobalt-60 machines. After two to three half-lives (10 to 15 years), the cobalt-60 source may not be useful from a medical point of view, given the long treatment times required, but it is still a highly dangerous source from a security point of view if it is removed from a functioning cobalt machine for either replacement of the source or disposal of the device. A rule of thumb is that it takes 20 half-lives for a source to decay by a factor of one millionth of its original value; in the case of cobalt-60, this would be 112 years of decay.

From a nuclear security viewpoint, the chief concern is the potential abandonment of sources once their useful life has expired. This was the situation in Goiânia in 1987 and has been a factor in several other fatal incidents involving radioactive sources used in medical or experimental devices. A typical Category 1 teletherapy unit, such as the one that was carjacked in Mexico in December 2013 on its way to a disposal facility, may contain an 8,000 to 13,500 (300 TBq-500 TBq) curie cobalt-60 source, depending on the size of the source.[28]

The requirement to replace sources has also led, in some instances, to logistical supply problems for the device user, who may find at the time that replacement is necessary that the supplier/manufacturer is no longer doing business, prices have increased for replacing it, or some combination thereof. For example, there are approximately 85 cobalt-60 teletherapy units in Ukraine, and because of current tensions between Ukraine and Russia, Ukraine cannot obtain replacement cobalt-60 from the Russian Federation.

In high-income countries, strong security or regulation and alternative vendors can minimize these supply risks. However, because cobalt-60 sources must also be disposed of in a safe and secure manner, high disposal costs and security requirements and a lack of ready alternatives are a challenge for health care providers in Africa and other regions with LMICs. They are pressured to provide the security equivalent of facilities in high-income countries without having the financial and cultural incentives to do so.

These disadvantages of cobalt-60 units have led high-income countries to largely phase out the use of such devices for radiotherapy treatment. However, they still remain in wide use in lower-income countries, particularly the poorest ones, because of their simple technology, easier installation, lower capital and maintenance costs, and ability to function in relatively austere environments without stable electrical systems and other infrastructure. In addition, even in those places that have recently begun purchasing LINACs, many old cobalt-60 machines remain in place to treat growing patient loads. For newer machines, this remaining advantage of cobalt-60 machines is less pronounced in the post-9/11 environment as the cost of using the cobalt-60 machines in particular is increasing because of increasing complexity and higher security, transportation, and disposal costs, but new cobalt machines still tend to be priced less than new LINACs, especially when only sticker prices are compared.[29]

Cancer Treatment in Resource-Constrained Environments: The Case of Africa

To understand how low-income countries decide whether to use LINACs or cobalt-60 cancer-treatment machines, it is useful to take a closer look at one region: Africa. As noted above, cancer treatment in LMICs, such as many countries in Africa, is woefully inadequate. African countries have only 20 percent of the number of radiotherapy units that medical experts consider adequate; some countries lack a single machine. This problem is only becoming more challenging.

Moreover, as discussed above, there is a growing need for cancer-therapy resources in Africa. Population growth, longer life spans, and health and environmental factors have all led to that need. There are also large differences in availability of care for those affected, and treatment is often delayed because of an absence of early screening for cancers and a lack of awareness of the symptoms of cancers. Furthermore, there is often a stigma associated with cancers such as cervical cancers since these are caused by sexually transmitted diseases. All of these factors dramatically affect the five-year cancer-survival rates in Africa. For example, the five-year survival rate for breast cancer in the United States is 90 percent, but it is only 50 percent in Gambia, Uganda, and Algeria. The types of cancers in Africa also vary from high-income areas such as North America. For example, in Africa, cancers "related to infectious agents (cervix, liver, Kaposi sarcoma, urinary bladder)" tend to be the most common, whereas in North America, cancers related to unhealthy behavior and lifestyles are more common. However, cancers such as lung, colorectal, and prostate cancer are becoming more common as Africa adopts "unhealthy behaviors and lifestyles associated with economic development, such as smoking, physical inactivity, and consumption of calorie-dense food."[30] One estimate suggests that at least 700 new machines are necessary to fulfill the need in Africa, out of the 5,000 machines that are estimated to be needed worldwide.[31]

As an example, Uganda has one radiotherapy unit to treat the country's 27,100 yearly cancer cases. Because this machine, located in the country's capital of Kampala, can handle only a maximum of 1,000 cases per year, 95 percent of the people are underserved and are either not treated or must travel outside the country for treatment.

Zambia established a cancer center in its capital of Lusaka with the help of the IAEA in 2006. However, that provides little comfort to many patients living too far from the capital to receive treatment. The cost of treatment also makes it unattainable for many patients whose incomes are comparatively low in LMICs, even though the patients can physically get to the cancer center. In LMICs, people with no or limited insurance coverage must pay for the treatment themselves. This defeats the very purpose of providing adequate health care since it is not affordable. Therefore, an additional challenge is that radiotherapy must be accessible to the population rather than just available.[32]

A further complication is that African patients from LMICs are often diagnosed late—in part because of the lack of local screening facilities—and tend to have advanced-stage cancers, so there is a higher need for radiotherapy.[33] Over 50 percent of breast cancer patients present at an advanced stage at diagnosis compared to 15 percent in high-income countries.[34] Likewise in India, 70 percent of cervical cancer patients present with Stage III (cancer has spread beyond the organ in which it was found) disease compared to 15 percent in high-income countries.[35] Furthermore, the distribution of cancers is different in LMICs, with prevalent cervical, head, and neck cancers, which require radiotherapy as the primary treatment. The most common cancers in the United States are breast, lung, and prostate.

In addition to the funds required to establish a radiotherapy center, a large challenge is hiring and maintaining qualified staff with sufficient radiotherapy experience. Medical physicists and skilled technologists are critical to treatment planning, delivery, and machine maintenance.

Yet there has been a trend of medical professionals from resource-poor countries relocating to resource-rich locations, causing a brain drain in LMICs. Experience shows that once they have received the training that is in demand in developed countries, many people go where they perceive the opportunities are better. In addition to the training of medical professionals, developing countries need to build maintenance and technical support capacity, which is also a challenge from the financial and human-capital perspectives and also creates brain-drain issues. A 2014 publication by Niloy Datta et al. estimated the deficit in the number of radiation oncologists, radiotherapy technologists, and medical physicists in LMICs. They used the IAEA and European Society for Radiotherapy & Oncology (ESTRO) recommendations for the Quantification of Radiotherapy Infrastructure and Staffing Needs (ESTRO-QUARTS) to estimate the present deficit of medical professionals. Twenty-two African countries are represented in the estimate, demonstrating that there is a deficit of more than 3,100 radiotherapy professionals (radiation oncologists, radiotherapy technologists, and medical physicists). In addition to the current deficit, an additional 4,300 radiotherapy professionals will be needed by 2020 in the 22 African countries.[36]

Similarly, cancer pathologists are in high demand in Africa. While in the United States there is one pathologist per 20,000 people, in sub-Saharan Africa the ratio is closer to one pathologist per one million people, which means that many cases of cancer go undiagnosed or are diagnosed too late for effective care.[37]

In addition to the deficit of trained staff and the lack of training there are also challenges in the delivery, operation, and maintenance of radiotherapy equipment. For example, certain regions of Africa lack reliable supplies of water or electricity for the equipment to function properly. Also, machines that break down may not be fixed for weeks or months until a foreign expert arrives; countries often lack trained maintenance engineers or local manufacturer representatives. Finally, countries that own these machines may not have adequate warranties or after-sale service contracts, making them vulnerable to interruptions in treatment should the machines break down.

Moreover, health care providers in low-income countries are financially constrained and often must rely on equipment donations from high-income countries, which often removes some of the decision-making power from the donation recipients and can lead to the acquisition of inappropriate equipment. Such equipment can be faulty or come with strings attached or without needed capabilities such as trained professionals or funding to operate or maintain it. Moreover, such equipment may not function adequately without appropriate and often missing health-system and physical infrastructure. Donors are often willing to give equipment but may be much less likely to help finance training and maintenance costs, particularly when these costs may equal a sizable fraction of, or perhaps more than, the initial cost of the equipment. Similarly, issues such as a lack of local support for maintenance or training may have a large impact on the supplier/manufacturer's ability to provide refurbished or reconditioned equipment to low-income countries.

In considering the options for use of LINACs in Africa, it should be noted that most of the cancer-treatment resources in Africa are concentrated in only a few African states (and often only a few sites within such states), and there is a tremendous need for either kind of cancer-treatment equipment. Those states with cobalt-60 facilities will face the issue of whether to retire such potentially useful units.

A typical example is Nigeria, which had five cobalt-60 units, two of which have been decommissioned. It also has five LINACs, and four more will be added in the next two years. However, like other African states, its three functioning cobalt-60 units are providing much-needed treatment, and whether they will be decommissioned is an open issue. Influencing the decommissioning decision are Nigeria-specific circumstances, such as terrorism in the northern part of the country, which may also affect the willingness of donors to provide alternative LINACs. Like Nigeria, other African states are phasing out cobalt-60 machines and replacing them with LINACs.

However, the decisions about cobalt-60 teletherapy units are not limited to whether to continue operating them along with LINACs. Each state also faces the question of whether its limited financial resources might better allow it to increase overall treatment capacity by adding new cobalt-60 units absent additional incentives to purchase LINACs instead.

Challenges from the perspective of industries that supply LINACs and teletherapy units. Working in Africa and LMICs in general can provide major challenges for manufacturers of LINACs and teletherapy units. In addition to having to deal with governmental entities, diverse regulations (or lack of regulations), and financial uncertainties, the industry faces additional challenges.[38] As noted above, these include weak infrastructure and shortages of trained medical and technical personnel.

As a result, manufacturers may need to ensure that there are additional arrangements and/or contracts either with them or other suppliers that will ensure that any equipment sold is maintained in an operable and safe condition. At the same time, various issues, including political instability, may make the provision of services difficult. In addition, they may need to provide more training for doctors and medical support personnel than they would provide in high-income countries.

Recommendations

Cobalt-60 Source Disposition and Repatriation Issues

One apparent easy fix to the problem of disposing of disused radiological sources would be to hold suppliers and manufacturers responsible for disposal at the end of the sources' useful life. In fact, most manufacturers, such as Best Theatronics (formerly part of MDS Nordion), agree to take sources back as a matter of contract. However, they do not agree to pay the shipping costs, which are considerable and are what typically prevent the proper disposal of cobalt-60 sources, leading to source abandonment. The position of the supplier/manufacturer is that this is a known factor at the time of device purchase, and the purchaser should price the services in a manner that allows a set-aside fund to cover source return. However, given the economic challenges faced by many facilities in LMICs, such funds are not available at the time the source has reached the end of its useful life.

Source disposal and potential abandonment are significant issues. Some states have required equipment/source purchasers to provide a bond to ensure there are adequate funds available for source repatriation. Although this is a common practice in some developed countries, it is far more problematic in Africa and developing countries. Countries in which the source suppliers/manufacturers reside might implement controls requiring the suppliers/manufacturers to pay the cost of repatriation, but to date that has not been a practice, and until such regulation is uniform internationally, most states that host suppliers/manufacturers would likely be reluctant to essentially handicap native corporations.

International organizations such as the IAEA and donor states can play a role in the prevention of source abandonment. In 2009, the IAEA established the Advisory Group on increasing access to Radiotherapy Technology in low- and middle-income countries (AGaRT) under its Programme of Action for Cancer Therapy (PACT), with the technical support of the IAEA's Division of Human Health and Division of Radiation, Transport and Waste Safety. AGaRT acts as a neutral facilitator to bring together radiotherapy equipment suppliers and radiotherapy users in developing countries to encourage that the radiotherapy service requirements of LMICs are met by the technology available.[39] However, AGaRT does not provide for source repatriation. The IAEA does, from time to time, provide for the repatriation of sources, but there is limited funding, and this is an exceptional practice by the IAEA. In 2006, the IAEA recovered two sources in Georgia, and in 2008, it recovered a source from Nigeria.[40]

Although the problem with repatriation of cobalt-60 and other high-intensity radiation sources is well recognized, there has been no international agreement on the issue, there are no regulations in most states regarding the issue, and the response of the international community has been on what is arguably an unsustainable ad hoc basis. The IAEA's Code of Conduct on the Safety and Security of Radioactive Sources, guidance supported by most states, calls on countries to "attach clear and unambiguous conditions to the authorizations issued by it, including conditions relating to . . . the safe and secure management of disused sources, including, where applicable, agreements regarding the return of disused sources to the supplier." And the IAEA is in the process of drafting supplementary guidance on the long-term management of disused sources, including organizing the return to suppliers and related financial arrangements. The IAEA should publish this guidance and encourage countries to adopt it into national regulations and also encourage radiological source suppliers to pledge to adhere to the guidance.

However, these are only voluntary, nonbinding measures, leaving the responsibility for carrying out such agreements on the recipient states. This is an issue of some concern to developed states and of less concern to developing nations now, but the time may be ripe for better funding of an international response to the issue.

Enhancing IAEA Involvement in Radioactive Source Removal

The IAEA is the logical international body to engage with states on the removal/repatriation of abandoned sources when all other (i.e., commercial) remedies have failed. Unilateral activities by the United States might not be well received by many states in which these problems could potentially arise.

As mentioned above, the IAEA has a limited program for securing and removing radioactive sources. The program is run through internal cooperation between the IAEA's Division of Nuclear Security and the agency's Radioactive Waste Management Program. Personnel involved in the program come from the waste management program, and most of the financing comes from the Nuclear Security Fund, which receives voluntary contributions from IAEA member states to support nuclear security efforts. Efforts are sometimes triggered by a request by a member state to the IAEA's Incident and Emergency Center, as was the case in a 2013 incident in Sierra Leone.[41]

Although the IAEA's efforts have significantly enhanced nuclear safety and security worldwide, the ad hoc nature and uncertain funding of the agency's program is problematic. The program needs to be put on a stable financial footing and adequate resources from the regular agency budget provided. The hazard is that if such removal becomes a routine method of dealing with disused or abandoned sources, it would be a disincentive for prudent management of sources in a cradle-to-grave management system that the agency promotes.

Therefore, the IAEA should have a well-funded emergency source-recovery program that would also attempt to recover fees from the state and/or source user.

Such an outlay would likely require a directive from the Board of Governors endorsed by the General Conference, a challenging task given budget pressures. An alternative approach would be for the United States to organize a group of potential donor states (perhaps the Global Partnership) and provide to the agency a separate fund to be used only to support pressing source-removal/repatriation activities. Such an approach could have a potentially significant impact on global nuclear security and safety for a relatively small cost.

Thus far the fatalities and damage resulting from disused and/or abandoned radioactive sources have been manageable, albeit tragic. The rise of substate actors potentially intent on misuse of radioactive sources, coupled with the need for expansion of the use of radioactive sources in many developing states, makes the establishment of an improved system for source recovery a priority that should be addressed as soon as possible.

Need for New LINACs Specifically Designed for LMICs

As stated in a recent report by a distinguished group of experts published in *The Lancet Oncology* and numerous other publications, there is an urgent need to improve current radiotherapy machines to be able to function despite "regular interruptions to the power supply, lack of air temperature control in buildings, and weak health systems." An example cited the development of an "environmentally friendly radiotherapy accelerator that consumes little power on standby and has reduced heat production, low instantaneous power demand, and local power storage."[42] Other desirable features of such LINACs are for the machine to be highly modular, so that parts can be easily exchanged, and to be self-diagnosing if the machine becomes nonfunctional. Some possible paths include working with NASA, which has similar requirements for its spacecraft (in terms of modularity, resilience, and easy replacement of parts); with Silicon Valley on innovative solutions to these problems; and with India, which has produced lower-cost LINACs and which has stepped up its foreign aid to Africa.[43] Nelly Enwerem-Bromson, the director of PACT, has floated the idea, modeled on the XPRIZE, of a global competition with a prize of $1 million or more for designing a LINAC that is best suited for operating in LMIC environments, such as single-energy mode (less capability), low cost, low power consumption, and robustness against physical damage.[44]

Appropriately refurbishing LINACs for resource-constrained countries. In recent years, some private groups and developed countries have generously donated used LINACs to health care facilities in developing countries. However, these donations have sometimes not been accompanied by suitable maintenance contracts, training, etc., nor at times have they been sufficiently examined by experts to see if they are suitable for further use. To ensure that health care providers in developing countries receive appropriate machines, it would make sense for the IAEA, with the support of the US Department of Energy national laboratories and relevant manufacturers, to develop guidelines and processes for certifying such machines as functional, much as car dealers resell used cars as "certified, pre-owned vehicles." While some older LINACs may lack some of the features of the latest models, the sophistication of the newer models may be counterproductive in settings where medical practitioners have less sophisticated medical training and experience. The lower cost of the older LINACs and an effective parts-and-services program could help increase the reach and availability of cancer treatment beyond the wealthiest urban centers.

An IAEA PACT advisory group some years ago developed some recommendations on guidelines countries might use to determine whether donated LINACs were suitable, but the guidelines were never published. They should be and could form the kernel of ultimate certification standards that might be used in PACT and other procurement decisions, as well as in bulk purchases or leases (see below). To increase clinician confidence in such certified machines, once the IAEA and or NNSA agree on the standards for such machines, it would be valuable to run a pilot study in a developing country comparing patient outcomes on new versus refurbished machines. Similarly, the use of single-energy LINACs could significantly reduce the cost of LINACs for developing countries while not running the security risk of cobalt-60.[45] Any comparison of used versus new LINAC would need to account for the cost and availability of parts and services, and lifespan. A developing-world LINAC with modular enhancements as capability increases could be an option for LINAC companies to consider. Costs could be phased in by starting with a basic unit, and options could be provided for new technology and a long-term maintenance contract with the vendor.

While the use of refurbished LINACs and single-energy LINACs could significantly lower the cost to developing countries of using such technology, current financial resources and models will be inadequate to meet the vast unmet demand for cancer treatment in the LMICs, no matter which generation of technology is employed. To meet this demand, new funding sources will need to be identified. In addition, new financing models that stretch out payments over time, lower per-unit costs, and/or modular design could have benefits for developing countries' ability to afford and operate such machines.

Bulk Purchases

PACT or other donors or recipients might also consider using bulk purchases of equipment to drive down costs. The members of the Global Task Force on Radiotherapy for Cancer Control of the Union of International Cancer Control have estimated such bulk purchases alone could drive down purchase costs by 16 to 23 percent.[46] Such capital costs of equipment are by far the largest cost component in developing countries (salaries dominate in high-income countries).[47] For instance, a regional group of countries might join together to purchase many machines for a lower cost and cooperate with manufacturers to support training of health and service personnel. Or donors could examine the feasibility of supporting private sector efforts along these lines. For example, the Swedish manufacturer Elekta has struck an innovative deal with Equra Health, a chain of 24 private cancer-care facilities in South Africa: Equra has agreed to purchase at least 15 LINACs over a 10-year period.[48]

In an annual report, Elekta notes, "The partnership will also address the potential lack of skills in the newer technology readily available today amongst doctors, physicists, therapy radiographers and service engineers through a joint training center in South Africa, which will be available to the entire continent."[49]

Similarly, Brazil has pledged to invest 500 million reals ($130 million) in radiotherapy equipment and infrastructure to develop 41 new facilities with 80 LINACs. In return, the international vendor that will install the radiotherapy facilities and equipment will establish a manufacturing plant in Brazil and will source 40 percent of the parts, accessories, and software related to the radiotherapy facilities from Brazil.[50]

Leasing and Other Means of Assuring Functionality and Disposal

Under current arrangements, developing countries typically purchase a LINAC and not only have to pay an upfront cost but can encounter maintenance challenges—either because of inadequate service by vendors or an insufficient maintenance contract—and ultimate disposal questions.

One solution that might address both the financial and operational challenges would be for the vendors to lease rather than sell the equipment. With NNSA support, PACT could encourage the use of such arrangements in its next Model Demonstration Sites (see "New Funding Sources" below) as pilot projects.

Otherwise, purchasers of such equipment should be required to provide assurance that they have the funds for disposal of cobalt units or maintenance for LINACs through financial instruments such as bonds or escrow arrangements, or other mechanisms. At the same time, vendors should be required to provide service for the lifetime of the machine and in a timely manner, rather than taking weeks or months to make a repair. And they should be prepared to take back disused equipment if the user or a government pays the shipping cost.

New Funding Sources

PACT has been one of the champions in the international arena for cancer treatment in developing countries. Since 2006, PACT has established eight Model Demonstration Sites around the world—in Albania, Ghana, Mongolia, Nicaragua, Sri Lanka, Tanzania, Vietnam, and Yemen—where it has collaborated with the World Health Organization (WHO) and the International Agency for Research on Cancer on cancer control, including radiation treatment.[51] These sites, as experts have noted, have provided a "proof of principle" of the value of radiation treatment in developing countries and shown the "challenges and commitments" in related health-system and cancer-care investments needed to make such efforts successful.[52]

PACT has received support from some bilateral donors, such as the United States, France, and South Korea, as well as the OPEC Fund for International Development.[53] However, PACT, which is only a small part of an agency primarily focused on other issues, simply does not have the scale or the resources to tackle the enormous challenge of cancer treatment in developing countries. For example, it has spent $18 million since 2006; this year, the international community has established a set of Sustainable Development Goals that call for reducing premature mortality from noncommunicable diseases, such as cancer, by one-third by 2030.[54] In the case of cancer, that achievement would likely require hundreds of billions of dollars in investment, although the economic benefits to developing-country economies through increased productivity would ultimately substantially outweigh the costs.[55]

The Lancet Oncology Commission 2015 report "Expanding Global Access to Radiotherapy" called for a broad range of public and private stakeholders to fill the gap—from governments to international development banks to private foundations, financiers, and nongovernmental organizations. It agues that a particularly necessary step is for WHO, which has focused on prevention, to use its leadership role in public health to also tackle treatment in order to prevent cancer deaths. The report also suggests a number of innovative financing mechanisms that have been used in other health and non-health sectors for other public goods, such as airline taxes, debt forgiveness, long-term purchase commitments by governments for vaccines, diaspora and social-impact banks, and development-bank guarantees.[56]

Study Improvement in Training and Education

Significant problems in training and education include lack of continuous quality control, maintaining an informed and trained staff, and having evidence-based clinical guidelines that are customized for low-income countries. Currently, most clinical guidelines are developed with resource-rich countries in mind. However, according to Surbhi Grover et al, "the differing equipment, limited number of radiation treatment units available, large number of patients and great distances travelled for care all influence the way treatment needs to be delivered locally," and these difference are not reflected in the guidelines.[57] In addition, the "types of treatments are not as complex as in resource-rich countries." Grover et al. state that, "It would be good to have guidelines that coincide with their patient loads equipment and resources available and the complexity of the treatments given. Gathering data and evaluating the clinical experiences from centers in Africa, Latin America and Asia would be a good starting point."[58] As an example, the University of Pennsylvania and Botswana have launched a partnership whereby medical doctors from the university live and work in Botswana.[59] However, Botswana is concerned about brain drain occurring when local medical professionals are sent to the University of Pennsylvania for training. Other disadvantages include "the expense of re-locating to the West, as well as the differences in the environment and the training and educational culture."[60]

Therefore, it makes sense to establish regional cancer centers of excellence that focus on training oncologists and other cancer and related health workers locally. Also, encouraged is South-South cooperation rather than that between LMICs and richer countries.[61] Furthermore, local issues that prevent people from presenting themselves at the clinics (preference for traditional medicine, lack of trust in Western medicine, health providers being outsiders and culturally disconnected, fear of prognosis, and cultural taboos against breast and gynecological malignancies) take time to systematically study and mitigate so that establishing a permanent presence with local people and gaining trust and confidence is critical.[62] A new US National Cancer Institute Center for Global Health to establish regional centers of research excellence for noncommunicable diseases, including cancer, in LMICs is a step in this direction. The centers will seek to combine the expertise of global-health academic researchers in high-income countries with regional investigators in LMICs to explore better ways to control noncommunicable diseases. The research priorities will be defined by assessing local needs through active engagement of local experts.[63]

The IAEA through PACT could facilitate many of these cooperative projects. For example, PACT has established the Virtual University for Cancer Control Network for Africa with current participation of six African countries. This could be expanded to include more countries, especially ones that do not have established education programs.[64]

In addition, according to Rifat Atun et al., "core clinical knowledge of cancer and radiation oncology practice needs to be shared more effectively. Training should leverage advances in communications, including distance learning and e-learning, for undergraduate and postgraduate training of health professionals who could benefit from massive open online courses and variants such as small private online courses."[65] Distance learning and e-learning should be used by companies that manufacture radiotherapy machines to communicate with radiotherapy professionals in case the units break down (spare parts would be required in the field if this was to work). Communication technology could transfer images and support "video conferencing, teleconsultations, teaching and training" with the help of local centers of excellence.[66] There are already successful models whereby radiation oncology and other cancer-related topics are taught through telecommunication.[67]

The International Cancer Expert Corps (ICEC) "empower low-income nations to develop and sustain better cancer care by establishing a network of oncology professionals to mentor and work with local and regional groups." The ICEC aims to "establish a mentoring network of cancer professionals who will work with local and regional in-country groups and, along with required local investment, establish ICEC centers to develop and sustain expertise for cancer care."[68] Coordinated approaches such as the ICEC and others "are powerful in helping to bring new radiotherapy services online, commission equipment, and train local staff" and should be expanded.[69]

Finally, to fill the void of a lack of doctors and trained surgeons in LMICs, specially chosen health workers have been trained to perform specific surgeries (a process known as task shifting). Almost half of sub-Saharan countries have workers perform minor surgical procedures.[70] Nigel Crisp, in his book (and an article) *Turning the World Upside Down,* reports on such a successful surgery program in Mozambique, where the health workers are known as *tecnicos de cirurgia*.[71] Studies have shown that there are "no clinically significant differences in the outcomes between surgeries undertaken by *tecnicos* and by physicians." Furthermore, an important benefit is that the *tecnicos* "are more likely to understand the local customs and language, and to remain in their home country because their training is not internationally recognized. It is also less expensive to train [them] than physicians."[72] Therefore, one recommendation is to train more people on specific tasks related to cancer care the same way that clinical officers or *technicos* are trained for surgery or other tasks. Training individuals to repair radiotherapy equipment might also be useful as long as spare parts are readily available in the countries themselves. It is also more costly to train physicians than these midlevel professionals, so focusing on the latter's education would allow more individuals to be trained.

Need for a Report Aimed at IAEA Director General

The magnitude of the global disparity in cancer care has not received the attention it deserves. Therefore, we recommend having a set of senior African statesmen from LMICs draft a letter with specific recommendations to address the disparity in their countries. The letter can build on the recommendations in the 2015 Lancet Oncology Commission report as well as suggest that WHO increase the prioritization of treatment rather than focus almost entirely on cancer prevention.[73]

The letter should be broadly published so that it draws attention from influential philanthropists who may not realize the consequences cancer will have on Africa in the future. The letter should also address factors that influence cancer care, which, while not unique to LMICs, are significantly worse in African countries, such as lack of "political commitment, public awareness, education about the benefits of radiotherapy, reduction of the stigma associated with cancer and radiotherapy, transportation options for patients, and the affordability" of cancer therapy services.[74]

The IAEA is involved in multiple technical cooperation programs with respect to cancer care, such as the Human Health program and PACT, that work with member states to obtain radioactive sources for radiotherapy. At the same time, the agency's nuclear security division seeks to remove such sources when they have sufficiently decayed. Therefore, another suggestion is for the statesmen to work through the Board of Governors to have that body call for drafting a detailed expert group report that would facilitate a more holistic approach to all IAEA activities related to improving cancer care and enhancing communication between different technical programs in order to fully take advantage of the pool of talent at the IAEA. Reports such as these have been enormously successful. For example, a report on multilateralization of the fuel cycle has led to the recent establishment of a uranium fuel bank in Kazakhstan.[75]

Use Better Screening to Make Radiotherapy Treatment More Effective and Efficient in Africa

A Kampala-based population registry measured the survival rates for different cancers in Uganda and compared them to African-American patients during the same time period. The five-year survival rate was one-third of the rate for African-American patients in the United States. The principal reason for this disparity is late presentation of the disease in African countries.[76]

Cervical cancer is the most common cancer among women in LMICs and is much more common in Africa than in other parts of the world.[77] It is more common because it is known to be one of the cancers connected to women living with HIV and is associated with certain strains of the human papillomavirus. Screening for cervical cancer in Africa is not nearly as common as in other countries, and there is a cultural stigma associated with HPV testing and the Papanicolaou (Pap) smear.[78]

Improved screening, pathology, and other health-system improvements would reduce the need for radiation treatment (and devices) for cervical and other cancers and make the treatment given more effective at curing the disease (rather than merely easing symptoms). It would also make it more likely that those outside of capital city elites could receive treatment in sufficient time to make a difference.

Innovative approaches can improve screening rates in LMICs. A simple test for cervical cancer screening (known as VIA) is a visual inspection of the cervix after 4 percent acetic acid is applied to the cervix. The Botswana-University of Pennsylvania partnership used a novel but simple approach to take cell-phone pictures of the cervix, which are remotely analyzed by a gynecologist.[79] The advantage of this approach is that the gynecologist can virtually inspect many women without physically being present. The other advantage is that the sociocultural barriers to screening may be lessened: many women currently do not get screened because of their fear of the Pap smear.[80]

Such innovative, cost-effective solutions would be a step forward. It might even be possible to make use of new research in machine learning and big-data analysis techniques to remove the remote gynecologist from the analysis completely, because visual pattern matching is one of the strengths of new data techniques. With a well-written cell-phone app, the analysis can be done using the computing capability of the cell phone itself. Thus, cancer screening and analysis could be done instantly without requiring expert knowledge.[81]

Recently, the American Society for Clinical Pathology (ASCP); the Institute for Health Metrics and Evaluation; Omnyx LLC, a joint venture between GE Healthcare and UPMC; Pfizer Inc.; Partners in Health; Roche Diagnostics; and Sakura Finetek announced plans to establish pilot projects to improve pathology services in five African countries—Botswana, Rwanda, Swaziland, Lesotho, and Liberia—as well as Haiti. Members of the ASCP will use telepathology to diagnose cancers remotely, interpreting cloud-based images of specimens prepared with modern automated equipment installed locally. The program will start in Botswana, with plans to expand to sites in the other countries. Thus, professionals based in the United States will be able to contribute to patient care and medical education in these six countries.[82]

However, if patients are screened and are found to be positive, there will be further challenges to get them proper treatment, such as obtaining access to radiotherapy, which may be too far to travel to or be too expensive. Therefore, mobile clinics (radiology on wheels, similar to Orbis for eye surgery) might be invented that have the capability to perform cancer therapy, including radiotherapy.[83] In addition to assuring proper equipment function and critical alignment needed for therapy (which are not issues with diagnosis), a big challenge will be obtaining sufficient electricity to power a LINAC or cobalt-60 machine for 12 hours a day. This would require powerful batteries that could recharge in the next 12 hours, requiring a battery that must be able to store at least 0.6 MWh for the LINAC alone and be small enough to be mobile.[84] It would be useful to research the applicability of improvements in energy storage coupled with alternative energy sources such as wind or solar energy in order to provide sufficient power. The goal of a mobile unit is to provide care to people who have been identified as having cancer and catch the disease early enough so treatment is curative rather than palliative.

Many of these problems are not exclusive to cancer care and can have technological solutions as long as they are commensurate with a sociocultural understanding of the communities they serve. The enormous technical know-how and social entrepreneurship in Silicon Valley and in urban centers in Africa should be taken advantage of. An example of this approach is the partnership between the Social Entrepreneurship Accelerator at Duke and Innovations in Healthcare, which held their first ever Health Hack-a-thon in Nairobi, Kenya, in September 2015. The Health Hack-a-thon included "programmers, healthcare enterprises, established multinational corporations, and funders." Hack-a-thons and Maker Fairs are powerful venues where ideas are generated and even accelerated because of friendly competition toward a specific goal.[85]

Role of the NNSA and other US Government Agencies

Tackling the cancer challenge in developing countries is a massive task that will require support from a wealth of stakeholders. Aside from the United States, other governments, international organizations, international coalitions such as the Global Partnership Against the Spread of Weapons and Materials of Mass Destruction, public health foundations, medical practitioners, businesses, and recipient countries all have roles to play. Further studies suggesting how such a campaign might be organized would be valuable.

The United States, as the leading national donor, can play an important role in this task. The National Cancer Institute, which focuses on research, should continue its leadership in the area and seek to initiate a broader whole-of-government approach as part of a US commitment to tackle noncommunicable diseases in LMICs. The Office of Global Affairs and the Office of the Assistant Secretary for Preparedness and Response of the US Department of Health and Human Services have expertise that might address both cancer care and risk from radiation sources. In the security arena, the Pentagon's Defense Threat Reduction Agency, which has been casting about for a new mission since its work in Russia ended, could be a valuable partner, along with regional commands such as the African Command. The military and the Defense Threat Reduction Agency's experience with logistics could prove valuable in areas such as quickly removing current or disused sources, stockpiling spare parts for LINACs, or transporting technicians. Such cooperation on cancer treatment would protect US troops from potential radiological terrorism and buy goodwill for US forces in areas where they operate. The October 2015 $26.5 initiative by the White House Office of Science and Technology Policy addressing innovative combinations of technology and pathology is a welcome step.

The NNSA can also play an important role. Its primary mission will continue to be to reduce the risk and related security expenses posed by high-risk radiological sources such as cobalt-60 by encouraging the use of nonisotopic technologies such as LINACs.[86] Nevertheless, given the superior medical treatment LINACs can provide, the NNSA can prioritize its work to achieve its threat-reduction objective without impairing, and while even improving, cancer treatment.

As outlined in a previous, broader CNS report, NNSA efforts to replace high-risk radiological sources should be prioritized according to several criteria: the radioactive risk of the material, its perceived necessity to meet the given application, and its location.[87] When it comes to cobalt-60 teletherapy machines, the NNSA's first consideration should be location and relevant security concerns. Urgent efforts should be made to swap LINACs for cobalt-60 machines in countries wracked by civil war or terrorism. These should include active cobalt-60 units and disused sources. More broadly, a second priority should be ensuring that disused sources have safe disposal pathways and providing such pathways if they do not exist.

A third priority should be seeking to leverage other initiatives to make best use of any LINACs given to developing countries. The NNSA should seek to work with the new ASCP coalition to deploy LINACs in tandem with the new pathology tools. It should also work with the National Cancer Institute's planned regional centers for noncommunicable diseases to carry out some of the pilot studies related to LINACs discussed above.

Similarly, expanding PACT's Model Demonstration Sites program would leverage contributions from additional donors and expand cooperation with WHO in this area. This program should particularly focus on providing at least one radiation treatment facility in countries without them with the ultimate goal, as urged by the Lancet Oncology Commission, to have one cancer-treatment center in every LMIC by 2020, along with regular related training.

The scale-up of the PACT program should be accompanied by innovation in areas such as pilot projects in leasing and utilizing certified refurbished LINACs. PACT should also explore bulk purchases of new LINACs.

While PACT uses any additional NNSA funds to add focus on low-income countries, efforts should be made to have development banks and innovative funding mechanisms provide funds for cancer treatment in middle-income countries, particularly lower-middle income countries. The Lancet Oncology Commission report clearly demonstrates that the key barrier to developing-country use of LINACs rather than cobalt-60 machines are financial resources; as countries get wealthier, they overwhelmingly opt for LINACs. For these countries, the NNSA's direct role can be largely advisory: to offer advice and perhaps some small incentives to choose LINACs over cobalt-60 units, especially when the latter reach the end of their useful life.

For these countries, the NNSA's primary contribution could come from training and education on LINACs and using the national laboratories and working with private enterprise to certify refurbished machines and help develop equipment more appropriate to developing countries. The NNSA could also support ongoing education and training of physicists, engineers, and technicians in-country, as without this expertise, LINACs cannot be used properly. Helping overcome the personnel shortage could be a major incentive for LMICs to move to LINACs.

Appendix

Cobalt-60 Machines and Linear Accelerator Technology for Teletherapy

The goal of this section is to survey the capabilities of LINACs and cobalt-60 teletherapy devices. The goal of both technologies is to provide a precise, well-defined dose of radiation to the tumor while minimizing the dose to the surrounding healthy tissue. Dose distribution and magnitude depend on the energy and type of radiation particle, the distance from the beam source to the patient, the beam profile, and the type of tissue to which the dose is applied.[88] The particles most often used in LINACs are electrons and X-rays; the only particle the cobalt-60 source emits are gamma rays with an average energy of 1.25 MeV (an MeV is one million electron volts), whereas LINAC X-ray photon energies can vary from 4 to 30 MeV. In a LINAC, photons are produced by bombarding accelerated electrons onto heavy metal (tungsten or copper-tungsten laminate) targets, producing characteristic X-ray lines corresponding to the target superimposed on a forward peaked bremsstrahlung spectrum.[89] The other particles used in radiotherapy are protons, neutrons, and heavy ions (ions of helium, carbon, nitrogen, argon, neon). These alternate technologies have certain advantages but have not been used as widely as LINACs and cobalt-60 machines because the machines that use these particles are "considerably more expensive than standard radiotherapy."[90]

For the remainder of this appendix, we will consider only high-energy photons and electrons and discuss the parameters that affect the clinical utility of both machines. We will conclude with tables of parameters allowing us to recognize differences between both modalities. The specific parameters we will discuss describe the quality of the beam in terms of producing a well-defined uniform dose across the beam ("Penumbra" and "Isodose Contours" below); producing appropriate strength and depth of the dose ("Particle Depth Dose" and "Source Skin Distance" below); and minimizing damage to the skin ("Skin Dose" below).

Particle Depth Dose

The depth penetrated by a particle beam is expressed in terms of the parameter PDD (percentage depth dose), which is the dose at various depths normalized to the peak dose that occurs at a certain depth Zmax (known as depth of dose maximum). The shape of the PDD curve as a function of depth can be described as a steep curve as it reaches the peak (100 percent) at Zmax (known as buildup) and then has a long tail to high depths indicating that finite doses are administered even at high depths (see Figure 3). For a cobalt-60 beam, Zmax occurs at 0.5 cm depth for a water phantom, whereas for a 6 MeV LINAC, a maximum dose is reached at a depth of 1.5 cm and increases with higher energy beams. The PDD curve has a long tail past the peak dose at Zmax so that one-half of the maximum dose (PDD=50 percent) occurs at a depth as high as 11 cm for a cobalt-60 machine. For a 6 MeV photon beam, PDD=50 percent is reached at 20 cm, considerably farther than a cobalt-60 beam, which can be important for destroying tumors located deep beneath the skin. It is important to realize that the PDD will also vary with the dimensions of the beam and the distance from the source to the patient's skin surface, or SSD, so it is necessary to specify both when comparing PDD for different beam energies.

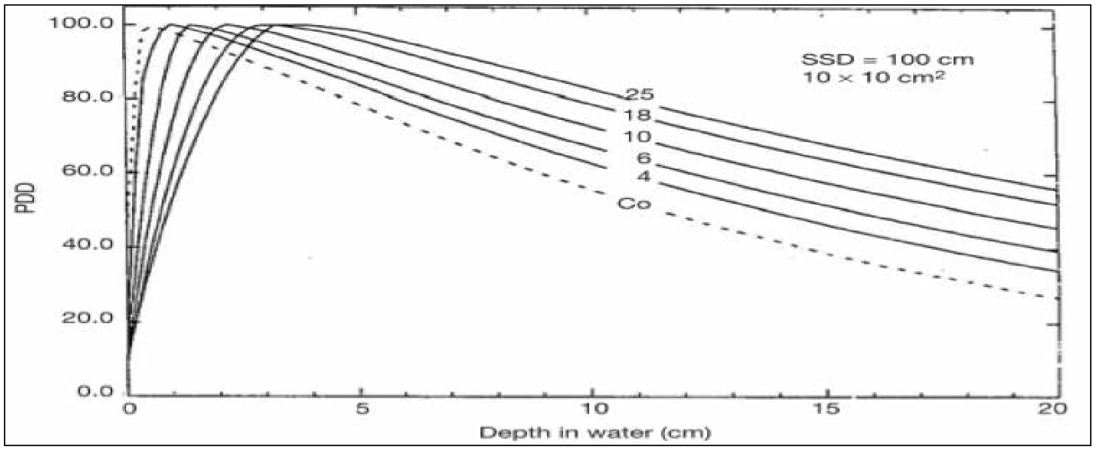

Figure 3. PDD curves in water for a 10 × 10 cm 2 field at an SSD of 100 cm for various megavoltage photon beams ranging from cobalt-60 gamma rays to 25 MeV X-rays. The depth at which the maximum dose is applied corresponds to the Zmax (known as depth of dose maximum). Source: Ervin B. Podgorsak, *Radiation Oncology Physics: A Handbook for Teachers and Students* (Vienna: International Atomic Energy Agency, 2005), p. 182.

Source Skin Distance

The source skin distance (SSD) is the distance from the source of the beam to the surface of the skin. The intensity of the beam will vary as a function of distance according to the inverse square law.[91] Therefore, the dose is higher as the SSD is decreased because the same number of particles contributes to the dose over a smaller area.

Penumbra

The beam profile (intensity as a function of lateral distance across the beam) transverse to the beam is not perfectly square but has a slope (see Figure 4). The distance from

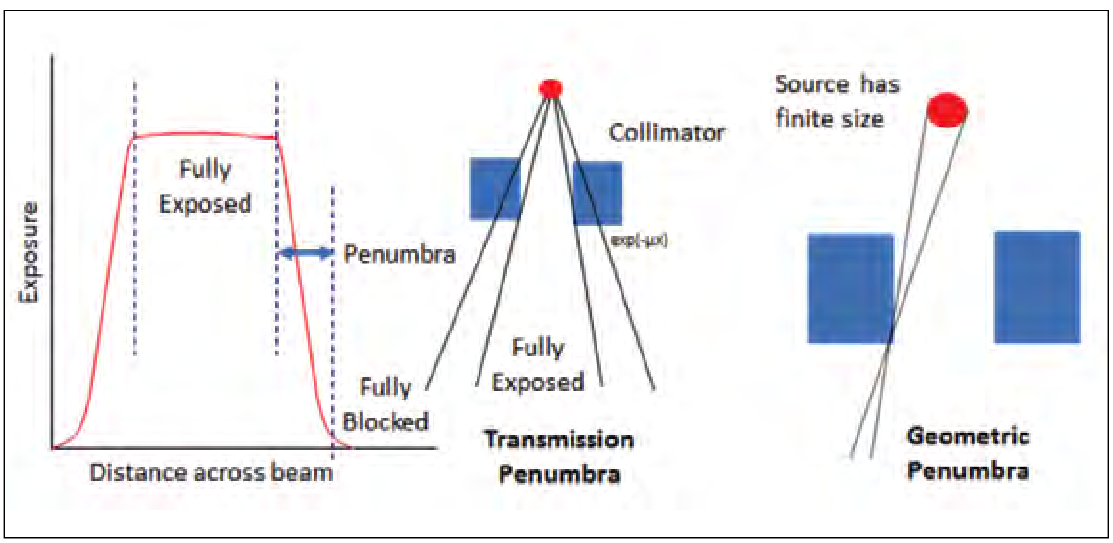

Figure 4. The exposure of the patient to the beam varies across the beam because of the finite penumbra (the slope from "Fully Exposed" to "Fully Blocked" is not vertical). The penumbra is caused by two effects: the transmission penumbra is due to photons that are attenuated as they travel different distances through the collimator, and the geometric penumbra is due to the finite source dimensions. Furthermore, the dose in the "Fully Exposed" region is also not necessarily flat, so that special absorbers are placed in front of the beam to further shape the beam. Source: Ferenc Dalnoki-Veress, Middlebury Institute of International Studies at Monterey.

the maximum intensity of the beam to where it falls to zero is finite and is known as the penumbra region. The beam profile does not fall off as a square step-function. This is significant because it means that part of the tissue is exposed to the beam with a varying dose across the beam. The penumbra consists of an effect due to the size of the collimator used (known as transmission penumbra) to define the beam, and due to the finite size of the source (known as geometric penumbra). In the case of the cobalt-60 source, the source dimensions are a 1.5 cm diameter cylinder with a height of 2.5 cm. Increasing the SSD will decrease the geometric penumbra, but it will also decrease the dose to the patient. Unfortunately, the cobalt-60 source dimensions can't be made smaller because this would decrease the physical dose to the patient. Setting the SSD is optimizing the required dose to the tumor while not increasing the penumbra.

Skin Dose

The dose applied to the skin varies with the energy and type of beam. Cobalt-60 machines apply 50 percent of the peak dose to the skin, which can cause damage to the skin. LINACs penetrate deeper and administer considerably less dose to the skin, ranging from 25 percent for a 6 MeV LINAC to 15 percent for an 18 MeV LINAC.

Isodose Contours

The dose across the beam produced by cobalt-60 machines and LINACs can vary and could have the undesirable effect of exposing tissue to varying doses laterally across the beam just like the penumbra would (see "Fully Exposed" section in Figure 4). In a LINAC, the beam is flattened by placing conical objects, which preferentially absorb photons, on the central axis, making a flattened profile. The isodose contours in cobalt-60 are more rounded.

These aspects of the beam are summarized in Table 2 for cobalt-60 and LINACs.

Aspect	Cobalt-60	LINAC
Buildup (Zmax)	0.5 cm	1.5 (6 MeV), 35 cm (18 MeV)
Skin Dose	50%	25% (6 MeV), 15%-25% (18 MeV)
Penetration @ 10 cm	54%	67% (6 MeV), 77% (18 MeV)
Penumbra	90%-10% is 1.5 cm	Sharp beam field
Isodose Contours	Rounded	Flattened by filter
Energy	Low (1.25 MeV)	High (>6 MeV)

Table 2. Comparison of cobalt-60 teletherapy to LINACs for different factors affecting the quality of the treatment. Source: Adapted from R. Ravichandran, "Has the Time Come for Doing Away With Cobalt-60 Teletherapy for Cancer Treatments," *Journal of Medical Physics,* Vol. 34, No. 2, 2009, p. 63.

Practical Differences Between Machines

Other practical factors in consideration of cobalt-60 machines compared to LINAC machines are maintenance, safety, security, staffing, and cost. These aspects of the two technologies are compared in Table 3.

Aspect	Cobalt-60	LINAC
Maintenance	Source needs to be replaced every five years	Frequent quality assurance necessary
Safety	Leakage radiation when beam is off is significant = 0.01 mSv/hr; exposure varies as the source is rotated into place and needs to be taken into account	Labor intensive quality assurance procedures
Security	Sources need to be transported to be disposed of; constant security risk requiring around-the-clock security; terrorism risk	No radioactive source used; no terrorism risk; however, will need to be guarded
Staffing	Easier to perform quality assurance and to operate the machine	Requires more training
Cost	Cobalt-60 without IMRT (intensity-modulated radiation therapy is an advanced mode of high-precision radiotherapy that uses computer-controlled linear accelerators to deliver precise radiation doses to a malignant tumor or specific areas within the tumor), much less expensive than LINACs; however, cobalt-60 IMRT are priced similarly to LINACs	Ongoing maintenance is expensive

Table 3. Comparison of cobalt-60 teletherapy to LINACs for different practical considerations. Source: Adapted from R. Ravichandran, "Has the Time Come for Doing Away With Cobalt-60 Teletherapy for Cancer Treatments," *Journal of Medical Physics,* Vol. 34, No. 2, 2009, Table 1.[92]

Treatment Planning and Delivery

Treatment plans are based on the location of the tumor, surrounding normal tissue, and normal tissue tolerance. These require three-dimensional imaging and medical dosimetrists who work with the physician and medical physicist. Multiple field arrangements are used that eliminate some of the problems of depth dose using cobalt-60 versus LINAC machines. The much sharper beam edges and beam shaping now possible with LINACs provide newer approaches to minimizing dose to normal tissue, such as IMRT, image guided radiation therapy, and hypofractionated radiation, which uses very short courses of radiation. The latter may provide an additional advantage for a LINAC in high-volume settings such as LMICs. These treatments require on-site physics expertise.

Endnotes

1 George M. Moore and Miles A. Pomper, *Permanent Risk Reduction: A Roadmap for Replacing High-Risk Radioactive Sources and Materials*, Occasional Paper No. 23, James Martin Center for Nonproliferation Studies, July 2015, p. 17, http://www.nonproliferation.org/wp-content/uploads/2015/07/permanent_risk_reduction.pdf. This list is narrower than those that include materials not in widespread commercial use. The US government has labeled a dozen radiological materials a security concern due to their high levels of ionizing radiation (specific activity) and significant half-lives. See Table 1: Radioisotopes of Security Concern, and Table 3: High-Risk Radioactive Sources in Charles Ferguson, *Ensuring the Security of Radioactive Sources: National and Global Responsibilities*, US-Korea Institute at SAIS, 2012, pp. 6 and 10, http://fas.org/_docs/201203-EnsuringSecurityofRadioactiveSources-Ferguson.pdf; Charles Ferguson, Tahseen Kazi, and Judith Perera, *Commercial Radioactive Sources: Surveying the Security Risks*, James Martin Center for Nonproliferation Studies, Occasional Paper 10, January 2003, p. 16; DOE/NRC Interagency Working Group on Radiological Dispersal Devices, *Report to the Nuclear Regulatory Commission and the Secretary of Energy—Radiological Dispersal Devices: An Initial Study to Identify Radioactive Material of Greatest Concern and Approaches to Their Tracking, Tagging, and Disposition*, May 2003. A federal task force classified 16 radionuclides as those of principal concern when considering the problems they could cause if used in a radiological dispersal device: US Nuclear Regulatory Commission, *The 2010 Radiation Source Protection and Security Task Force Report*, US Nuclear Regulatory Commission, August 11, 2010. See in particular Table II, which lists the lower limit for these radionuclides to be Category 2 IAEA RS-G-1.9 sources, p. 11, www.nrc.gov/security/byproduct/2010-task-force-report.pdf.

2 In this report, we have chosen to focus on external beam teletherapy, not internal radiation treatment or radiosurgery. Replacement of high-risk sources for these applications will require different strategies, as detailed in Moore and Pomper, *Permanent Risk Reduction*, pp. 5–8. Please see the appendix to this paper for an explanation of how cobalt-60 units and LINACs work.

3 Rifat Atun, David A. Jaffray, Michael B. Barton, Freddie Bray, Michael Baumann, Bhadrasain Vikram, Timothy P. Hanna, et al., "Expanding Global Access to Radiotherapy," *Lancet Oncology,* Vol. 16, No. 10, September, 2015, p. 1167, Table 4.

4 It is clear that the solution will not come from expanding the use of cobalt-60 machines, since their "production cost is increasing and there are heightened security concerns." Eeva K. Salminen, Krystyna Kiel, Geoffrey S. Ibbott, Salminen, Eeva K., Krystyna Kiel, Geoffrey S. Ibbott, Michael C. Joiner, Eduardo Rosenblatt, Eduardo Zubizarreta, Jan Wondergem, and Ahmed Meghzifene, "International Conference on Advances in Radiation Oncology (ICARO): Outcomes of an IAEA Meeting," *Radiation Oncology,* Vol. 6, No. 11 (2011), p. 1. As well, the costs of modern cobalt-60 machines are becoming commensurate with LINACs when comparing the initial and operations costs.

5 Paul Farmer, Julio Frenk, Felicia M. Knaul, Lawrence N. Shulman, George Alleyne, Lance Armstrong, Rifat Atun, et al., "Expansion of Cancer Care and Control in Countries of Low and Middle Income: A Call to Action," *Lancet,* Vol. 376, No. 9747, 2010, p. 1186.

6 Daniel Grant Petereit and C. Norman Coleman, "Editorial: Global Challenges in Radiation Oncology," *Frontiers in Oncology*, Vol. 5, 2015, p. 2.

7 The workshop was conducted under rules of nonattribution, so individual participants' views will not be identified in this report.

8 Deterministic health effects are the manifestation of tissue damage due to ionizing radiation with a dose threshold below which the effect does not appear (0.1 Gy). Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), *Health Effects of Security Scanners for Passenger Screening* (Based on X-Ray Technology), European Commission, April 26, 2012, p. 27.

9 Stochastic effects of ionizing radiation are chance events, with the probability of the effect increasing with dose, but the severity of the effect is independent of the dose received. Stochastic effects are assumed to have no threshold. Primarily cancer risk, but also hereditary disorders, are stochastic effects with a combined detriment of ~5%/Sv. Ibid., p. 28.

10 Ferguson, *Ensuring the Security*, p. 7.

11 Cobalt is rarely found in an easily dispersed format unless damaged or deliberately produced. Rather it is usually found in metallic form. See John Peterson, Margaret MacDonell, Lynne Haroun, Fred Monette, R. Douglas Hildebrand, and Anibal Taboas, *Radiological and Chemical fact Sheets to Support Health Risk Analyses for Contaminated Areas*, Argonne National Laboratory Environmental Science Division (2007).

12 Cobalt metal can be easily dissolved in hydrochloric acid, precipitated into cobalt chloride salt, and this resulting salt is half as soluble as cesium chloride in water. Therefore, cobalt-60 still poses a serious risk as an RDD as well as an RED.

13 F. P. Stone, *The Worried Well Response to CBRN Events: Analysis and Solutions*, The Counterproliferation Papers Future Warfare Series #40, US Air Force Counterproliferation Center.

14 DIRAC stands for Directory of Radiotherapy Centres. The database is at http://www-naweb.iaea.org/nahu/dirac/.

15 Radioactive sources are organized in terms of five categories according to the risk they pose. Category 1 (higher risk) and 2 (lower risk) sources are considered to pose a high risk to human health if not managed safely and securely, as well as if the material is dispersed. A Category 3 source is considered to be much less dangerous and unlikely to be fatal if a person is exposed to it over a prolonged time or the material is dispersed. Detailed descriptions can be found in International Atomic Energy Agency (IAEA), Categorization of Radioactive Sources, IAEA-TECDOC-1344, 2003.

16 Ferguson, *Ensuring the Security*, p. 8.

17 The complete name of the organization is Jama'atul Alhul Sunnah Lidda'wati wal Jihad, or, "people committed to the propagation of the Prophet's teachings and jihad." The term *Boko Haram* is translated as "Western Education is forbidden."

18 Majority Staff of the Committee on Homeland Security, "Boko Haram: Growing Threat to the U.S. Homeland", U.S. House Homeland Security Committee Report, September 2013, p. 16, https://homeland.house.gov/boko-haram-growing-threat-us-homeland.

19 John Daly, "Nigeria Planning Country's First Nuclear Power Plant,"Oilprice.com, http://oilprice.com/Alternative-Energy/Nuclear-Power/Nigeria-Planning-Countrys-First-Nuclear-Power-Plant.html.

20 In May 2013, the group held the Nigerian minister of petroleum for ransom for several days.

21 Majority Staff of the Committee on Homeland Security, "Boko Haram: Growing Threat to the U.S. Homeland, US House Committee on Homeland Security, September 13, 2013, p. 10, https://homeland.house.gov/boko-haram-growing-threat-us-homeland/.

22 Ibrahim Abdulmajeed, *Minimizing the Risk of Proliferation and Nuclear/Radiological Terrorism in Nigeria*, CNS report, 2014.

23 Independent survey of medical physicists in Africa conducted by person attending the workshop.

24 In this section, the use of LINACs for general cancer treatment will be considered, and it will be compared and contrasted to the use of cobalt-60 teletherapy units. The same arguments generally apply to a comparison of the use of LINACs in cancer surgery applications with the use of cobalt-60 surgical equipment such as the Gamma Knife.

25 One way to accomplish this is through stereotactic surgery (using Gamma Knife or Cyber Knife), in which photon beams penetrate a tumor from many directions so that by utilizing the superposition principle, the tumor receives the required dose.

26 A resulting effect is that the time required to deliver a specific dose increases so the patient may need to be in the machine longer to receive the necessary exposure for the prescribed treatment.

27 However, it should be noted that quality assurance may be considerably more complicated for LINACs. See Brandi R. Page, Alana D. Hudson, Derek W. Brown, Adam C. Shulman, May Abdel-Wahab, Brandon J. Fisher, and Shilpen Patel, "Cobalt, Linac, or Other: What Is the Best Solution for

Radiation Therapy in Developing Countries?, *International Journal of Radiation Oncology, Biology, Physics,* Vol. 89, No. 3, 2014, pp. 476–480.

28 See Chapter 12, "Cobalt Machines," in Philip Mayles, Alan Nahum, and Jean-Claude Rosenwald, eds., *Handbook of Radiotherapy Physics: Theory and Practice* (New York: CRC Press, 2007). Category 1 is the highest hazard rating in the IAEA's RS-G-1.9 categorization scheme.

29 After 9/11, the cost of replacing cobalt-60 sources (replacing the source as well as disposing of the old source) is estimated to cost as much as $400,000 to $500,000; Massoud Samiei, "Challenges of Making Radiotherapy Accessible in Developing Countries," Cancer Control, Vol. 85, 2013, p. 85.

30 American Cancer Society, *Cancer in Africa*, p. 3. https://www.cancer.org/acs/groups/content/@epidemiologysurveilance/documents/document/acspc-031574.pdf.

31 Samiei, "Challenges," p. 85.

32 Ibid., p. 88.

33 T. Peter Kingham, Olusegun I. Alatise, Verna Vanderpuye, Corey Casper, Francis A. Abantanga, Thaim B. Kamara, Olufunmilayo I. Olopade, Muhammad Habeebu, Fatimah B. Abdulkareem, and Lynette Denny, "Treatment of Cancer in Sub-Saharan Africa, *Lancet Oncology,* Vol. 14, No. 4, 2013, p. 158.

34 Michael B. Barton, Michael Frommer, and Jesmin Shafiq, "Role of Radiotherapy in Cancer Control in Low-Income and Middle-Income Countries," Lancet Oncology, Vol. 7, No. 7, 2006, p. 585.

35 Surbhi Grover, Nayha Dixit, and James M. Metz, "Radiation Therapy in the Developing World," in *Global Perspectives on Cancer: Incidence, Care, and Experience*, ed. by Kenneth D. Miller and Miklos Simon (Santa Barbara, CA: Praeger, 2015), p. 205.

36 Niloy R. Datta, Massoud Samiei, and Stephan Bodis, "Radiation Therapy Infrastructure and Human Resources in Low- and Middle-Income Countries: Present Status and Projections for 2020," *International Journal of Radiation Oncology, Biology, Physics*, Vol. 89, No. 3, 2014, p. 453.

37 Jo Handelsman and Robbie Barbero, "Cancer Diagnostics in the Developing World," White House Office of Science and Technology, October 26, 2015, https://www.whitehouse.gov/blog/2015/10/26/cancer-diagnostics-developing-world.

38 Panel on "Radiological Security and the Threat of Nuclear Terrorism," Workshop on Minimizing the Threat of Radiological Terrorism in Developing Countries While Expanding Access to Public Health and Cancer Treatment, Johannesburg, South Africa, Sept. 1–2, 2015.

39 *See IAEA, Programme of Action for Cancer Therapy (PACT),* http://cancer.iaea.org/agart.asp.

40 See "Radioactive Sources Recovered in Georgia," IAEA News Centre, July 27, 2006, https://www.iaea.org/newscenter/news/radioactive-sources-recovered-georgia; also see "IAEA Helps Recover Stray Radioactive Sources in Nigeria," IAEA News Centre, February 14, 2008, https://www.iaea.org/newscenter/news/iaea-helps-recover-stray-radioactive-sources-nigeria. In addition, the IAEA has published a number of technical documents on the problems and issues with spent radiation sources. See Nuclear Fuel Cycle & Waste Technology, Waste Technology Section, Source Recovery Publications, IAEA, https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/WTS/sealedsources-references.html.

41 See "Managing Disused Radioactive Sources: IAEA Trains Operators in Egypt, Recovers Source in Sierra Leone," IAEA News Centre, October 24, 2013, https://www.iaea.org/OurWork/ST/NE/NEFW/News/2013/repository/2013-10-24-NL-ManagingRadioActiveSources.html.

42 Atun et al., "Expanding Global Access," p. 1174.

43 Ibid., p. 1175; Nirmala George, "India Woos Africa With Aid, Technology As China Looms Large," *World Politics Review*, October 27, 2015, http://www.worldpoliticsreview.com/articles/17056/india-woos-africa-with-aid-technology-as-china-looms-large.

44 According to the XPRIZE Web site, "An XPRIZE is a highly leveraged, incentivized prize competition

that pushes the limits of what's possible to change the world for the better. It captures the world's imagination and inspires others to reach for similar goals, spurring innovation and accelerating the rate of positive change." *http://www.xprize.org/about/what-is-an-xprize*.

45 However, Atun et al., pointing to the example of Ethiopia, notes the resistance some developing countries have to buying such "perceived second-class equipment" as single-energy LINACs, despite the fact that they may be most suitable financially for those countries. "Expanding Global Access," p. 1160.

46 Ibid., p. 1166, Table 3.

47 Ibid., pp. 1165–1166, including Figure 8. In low-income countries, equipment is said to constitute 81 percent of the cost of operating such a facility.

48 Elekta annual report for 2012/2013, p. 21, *https://www.elekta.com/investors/reports/downloads/Elekta-Annual-Report-2012-13.pdf*.

49 Ibid.

50 Atun et al., "Expanding Global Access," p. 1175.

51 *PACT, "PACT Model Demonstration Sites (PMDS)," IAEA, http://cancer.iaea.org/pmds.asp*.

52 Atun et al., "Expanding Global Access," p. 1177.

53 PACT, "Partnership," IAEA, *http://cancer.iaea.org/partners.asp*.

54 "Goal 3: Ensure healthy lives and promote well-being for all at all ages", UN Sustainable Development Homepage *http://www.un.org/sustainabledevelopment/health/*; Nelly Enwerem-Bromson and May Abdel-Wahab, "Expanding Global Access to Radiotherapy: The IAEA Perspective," *Lancet Oncology*, Vol. 16, No. 10, September 2015, p. 1151.

55 Atun et al., "Expanding Global Access," p. 1161. This Lancet Oncology Commission report estimates a cost for scaling up radiotherapy to levels adequate to ensure optimal radiotherapy treatment for the 12 million people worldwide who would need radiotherapy treatment by 2035. Given the current lack of treatment in the LMICs, many of these saved lives would be in developing countries, particularly middle-income countries. The expenditure for such an effort would be less than $200 billion across all LMICs while the net benefits could reach as much $365 billion.

56 Ibid., p. 1176.

57 Grover, "Radiation Therapy." p. 217.

58 Ibid., p. 205.

59 Jennifer Cohn and Harvey M. Friedman, "Sustainable International Partnership Building for Academic Medical Centers: Experiences With the Botswana-Upenn Partnership," *Virtual Mentor,* Vol. 12, No. 3, 2010, p. 179.

60 Mahmoud M. El-Gantiry, comments at "Cancer in Developing Countries: Facing the Challenge," IAEA 54th General Conference, September 20–24, 2010, Vienna, *https://www.iaea.org/About/Policy/GC/GC54/ScientificForum/iaearole.html*.

61 Datta et al., "Radiation Therapy Infrastructure."

62 From slides of Dr. Surbhi Grover at Johannesburg Workshop, September 1, 2015.

63 Handelsman and Barbero, "Cancer Diagnostics."

64 Datta et al., "Radiation Therapy Infrastructure"; see Crisp, *Turning the World*, pp. 106–126 and pp. 204–209, for broader concepts about training LMIC health workers.

65 Atun, "Expanding Global Access," p. 1173.

66 Datta et al., "Radiation Therapy Infrastructure," p. 455.

67 See, for example, Sushma Agrawal, Anil Kumar Maurya, Kirti Shrivastava, Shaleen Kumar, M. C. Pant, and Saroj Kant Mishra, "Training the Trainees in Radiation Oncology With Telemedicine As a Tool in a Developing Country: A Two-Year Audit," *International Journal of Telemedicine and Applications,* ol. 2011, 2011, p. 1.

68 C. Norman Coleman, "Bringing Cancer Care to the Underserved Globally: A Challenging Problem for Which Radiation Oncology Can Pioneer Novel Solutions," *International Journal of Radiation Oncology, Biology, Physics,* Vol. 89, No. 3, 2014, pp. 443–445.

69 Atun et al., "Expanding Global Access," p. 1174.

70 Margaret E. Kruk, Andreas Wladis , Naboth Mbembati, S. Khady Ndao-Brumblay , Renee Y. Hsia , Moses Galukande, Sam Luboga, Alphonsus Matovu, Helder de Miranda, Doruk Ozgediz, et al., "Human Resources and Funding Constraints for Essential Surgery in District Hospitals in Africa: A Retrospective Cross-Sectional Survey," PLoS Medicine, Vol. 7, No. 3, March 2010, p. 7, *http://www.plosmedicine.org/article/fetchObject.action?uri=info:doi/10.1371/journal.pmed.1000242&representation=PDF*.

71 Crisp, *Turning the World*, p. 117–119.

72 *Unite for Sight, "Module 5: Task Shifting," http://www.uniteforsight.org/global-health-surgery/module5#_ftn6.*

73 Given the importance of a preventative approach to cancer, there has been a trend to question a curative approach versus preventative measures. See Viviana Balanescu, "Prevention Is Better Than Cure, Say Romanian Doctors," Bulletin of the World Health Organization, Vol. 89, 2011, p. 248, *http://www.who.int/bulletin/volumes/89/4/11-030411/en/*.

74 Enwerem-Bromson and Abdel-Wahab, "Expanding Global Access," pp. 1151–1152.

75 *Multilateral Approaches to the Nuclear Fuel Cycle*, Expert Group Report to the Director General of the IAEA, INFCIRC/640, *https://www.iaea.org/INPRO/2nd_Dialogue_Forum/mna-2005_web.pdf*.

76 Adam Gondos, Eric Chokunonga, Hermann Brenner, Donald Maxwell Parkin, Risto Sankila, Margaret Z. Borok, Z. Michael Chirenje, Anna M. Nyakabau, and Mary Travis Bassett, "Cancer Survival in a Southern African Urban Population," *International Journal of Cancer,* Vol. 112, No. 5, 2004, p. 863.

77 H. S. Cronje, "Screening for Cervical Cancer in Developing Countries," *International Journal of Gynecology & Obstetrics, Vol.* 84, No. 2, 2004, p. 101.

78 A. Goodman, and N. Nour, "Cervical Cancer Screening: The Complex Interplay of Medical Infrastructure, Society, and Culture," *Oncologist*, Vol. 19, No. 4, 2014, p. 316, *http://theoncologist.alphamedpress.org/content/19/4/315*.

79 Kelly E. Quinley, Rachel H. Gormley, Sarah J. Ratcliffe, Ting Shih, Zsofia Szep, Ann Steiner, Doreen Ramogola-Masire, and Carrie L. Kovarik, "Use of Mobile Telemedicine for Cervical Cancer Screening," *Journal of Telemedicine and Telecare,* Vol. 17, No. 4, 2011, pp. 203–209.

80 Maghboeba Mosavel, Christian Simon, Catherine Oakar, and Salome Meyer, "Cervical Cancer Attitudes and Beliefs—A Cape Town Community Responds on World Cancer Day," *Journal of Cancer Education,* Vol. 24, No. 2, 2009, p. 118.

81 This is an area where there has been a great deal of development and there is also a lot of promise. For example, the IAEA recently released a new app on determining the cancer stage that a patient is in. "IAEA Launches New Smartphone App for Cancer Staging," Dunya News Network, October 28, 2015, *http://dunyanews.tv/en/Technology/305925-IAEA-launches-new-smartphone-app-for-cancer-stagin*.

82 Handelsman and Barbero, "Cancer Diagnostics."

83 Orbis, "Flying Eye Hospital," *http://www.orbis.org/feh/*.

84 This assumes 250V/150A "three-phase" power as stated in *Radiotherapy Facilities: Master Planning and Concept Design Considerations*, IAEA Human Health Reports No. 10, 2014, *http://www-pub.*

iaea.org/books/IAEABooks/10561/Radiotherapy-Facilities-Master-Planning-and-Concept-Design-Considerations. P=51.9 kW so that for 12 hours, this is equivalent to requiring 622.8 kWh of energy.

85 "SEAD to host 'Health Hackathon' in Nairobi," iHub, August 30, 2015,http://www.ihub.co.ke/blogs/25511.

86 "Considering the volume of high priority sites globally, the most sustainable and resource-efficient means of addressing material vulnerabilities is to encourage reliable and efficient non-isotopic alternatives for the highest activity sources, and develop incentives for users (licensees) to replace high-activity devices with safe alternatives." National Nuclear Security Administration, *Prevent, Counter, and Respond—A Strategic Plan to Reduce Global Nuclear Threats (FY 2016–FY 2020)*, report to Congress, March 2015, pp. 2-16, http://nnsa.energy.gov/sites/default/files/NPCR%20Report_FINAL_%28with%20signatures%29_3-18-15.pdf.

87 Moore and Pomper, *Permanent Risk Reduction*, p. 17.

88 "Beam profile" refers to how the beam varies in the plane perpendicular to the beam itself.

89 Mayles, Nahum, and Rosenwald, *Handbook of Radiotherapy Physics*, p. 49. Bremsstrahlung (breaking radiation) is the process by which the X-rays are produced.

90 Ervin B. Podgorsak, *Radiation Oncology Physics: A Handbook for Teachers and Students* (Vienna: IAEA, 2005), p. 154.

91 The inverse square law states that the intensity of a beam decreases with the square of the distance from the source.

92 For additional information on comparisons of LINACs and cobalt-60 machines see: Page et al., "Cobalt, Linac, or Other?," pp. 476–480.

About the Authors

Miles A. Pomper is a senior research associate in the Washington, DC, office of CNS and the co-chair of the Fissile Materials Working Group, aimed at combatting nuclear terrorism. His work focuses on nuclear energy, nuclear nonproliferation, nuclear security, and nuclear arms control and he has authored several papers on replacing high-risk radioactive sources with non-isotopic alternatives. He is also a member of the advisory board of the International Cancer Expert Corps. Pomper is the former editor-in-chief of Arms Control Today, a former congressional foreign policy reporter with CQ Weekly and Legi-Slate News Service, and served as a foreign service officer with the U.S. Information Agency. He holds a master's degree in international affairs from Columbia University and a master's degree in journalism from Northwestern University.

Ferenc Dalnoki-Veress is Scientist-in-Residence at the Center for Nonproliferation Studies (CNS). He holds an MSc and PhD in high energy physics from Carleton University, Canada, and specializes in ultra-low radioactivity background detectors. He also has professional experience in the field of astroparticle physics - primarily neutrino physics. Dr. Dalnoki-Veress joined CNS in 2009 after a rewarding career as an experimental physicist, and has been focusing on the proliferation of fissile materials, nuclear spent fuel management, nuclear reactor safety, emergency preparedness and verification of nuclear disarmament.

George M. Moore is a scientist-in-residence and adjunct professor at the James Martin Center for Nonproliferation Studies (CNS) at the Middlebury Institute for International Studies at Monterey. A former naval officer, he previously worked at the Lawrence Livermore National Laboratory and the International Atomic Energy Agency. Dr. Moore received his bachelor's degree from the US Naval Academy, a master's and PhD in nuclear engineering from the University of California, Berkeley, and a juris doctor degree from the University of California's Boalt Hall (Berkeley) School of Law. He is the co-author with Miles A. Pomper of Permanent Risk Reduction: A Roadmap for Replacing High Risk Radioactive Sources and Materials (CNS, 2015)

Acknowledgments

The authors would like to acknowledge the support of the US National Nuclear Security Administration and the United Kingdom's Department of Energy & Climate Change; the contributions and insights gained from the workshop we co-convened with the Stanley Foundation in Johannesburg, South Africa, on September 1–2, 2015; and the help of the US National Cancer Institute and the University of the Witwatersrand, South Africa, in conducting this study. We would particularly like to thank C. Norman Coleman, MD, of the National Cancer Institute for his constructive comments and guidance on the manuscript.

James Martin Center for Nonproliferation Studies

The James Martin Center for Nonproliferation Studies (CNS) strives to combat the spread of weapons of mass destruction by training the next generation of nonproliferation specialists and disseminating timely information and analysis. CNS at the Monterey Institute of International Studies is the largest nongovernmental organization in the United States devoted exclusively to research and training on nonproliferation issues. More information is available at nonproliferation.org.

Middlebury Institute of International Studies at Monterey

The Middlebury Institute of International Studies at Monterey provides international professional education in areas of critical importance to a rapidly changing global community, including international policy and management, translation and interpretation, language teaching, sustainable development, and nonproliferation. We prepare students from all over the world to make a meaningful impact in their chosen fields through degree programs characterized by immersive and collaborative learning, and opportunities to acquire and apply practical professional skills. Our students are emerging leaders capable of bridging cultural, organizational, and language divides to produce sustainable, equitable solutions to a variety of global challenges. More information is available at www.miis.edu.

The Stanley Foundation

The Stanley Foundation advances multilateral action to create fair, just, and lasting solutions to critical issues of peace and security. The foundation's work is built on a belief that greater international cooperation will improve global governance and enhance global citizenship. The organization values its Midwestern roots and family heritage as well as its role as a nonpartisan, private operating foundation. The Stanley Foundation does not make grants. Online at www.stanleyfoundation.org.