

TREATMENT NOT TERROR: Africa, Progress and Lessons

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Abstract

Addressing the large gap in cancer care in low- and middle-income countries requires innovation in technology, education, training and economic models involving sustained mentorship and security policy to mitigate potential health, economic and terrorism risks of cobalt-60 radiological sources. Nowhere is this task more challenging than in Africa, given the enormous shortfall in external beam radiation treatment machines, the lack of expertise in their use, and challenging environments. Nonetheless, concerted efforts have been undertaken between the 2016 and the 2020 IAEA International Conferences on Nuclear Security to both provide greater access to treatment and to improve radiological security, mainly through the greater use of linear accelerators (LINACs). The paper draws on extensive qualitative research conducted around a series of expert meetings organized within and outside of Africa between 2017 and 2019. It identifies a number of lessons learned from the transition to LINACs in countries where the infrastructure is marginal and the workforce is lacking. It offers practical recommendations that have the potential to enhance teletherapy treatment and reduce radiological security risk in Africa, showing that contrary to popular mythology, taking on the cancer crisis in developing countries is not “too hard.”

1. INTRODUCTION

The World Health Organization (WHO) estimates that there were 18.1 million new cancer diagnoses and 9.6 million cancer-related deaths worldwide in 2018. Further, WHO estimates that the number of new cancer cases likely will increase to 24 million by 2035. About 65% of all cancer deaths globally in 2012 occurred in

LMICs [1]. The proportion is projected to increase to 75% by 2030, even though the UN Sustainable Development Goals call for cutting premature mortality from non-communicable diseases, such as cancer, by one-third by the same year [2].

Efforts to prevent cancer, including vaccinations to prevent HPV virus, thereby reducing cervical cancer and hepatitis vaccine to reduce liver cancer, may slow the growth in new cases in future years. However, even if such preventive efforts are successful, they will still leave millions of people with cancer requiring treatment for decades. Radiation therapy is recommended as a curative or palliative treatment for about 60% of cancer patients, when used by itself and as part of regimens with surgery and systemic treatments [3]. Moreover, economic studies have indicated that providing additional radiotherapy is especially cost-effective for developing countries, reaping greater economic benefits than the investments required [4]. Despite a lower incidence of cancer in LMICs compared to high-income countries (HICs), relative cancer mortality is significantly higher, particularly among people of working age, leading to a greater economic impact through loss of productive work years [5]. For instance, in Africa's most populous country, Nigeria, about 115,000 new cases of cancer occur every year, with a high case fatality of about 70,000 annually [6].

Unfortunately, only 10% of patients in low-income and 40% in middle-income countries who need radiotherapy have access to the necessary treatment equipment and expertise [7]. In its comprehensive 2015 Lancet Oncology Commission report, the Global Task Force on Radiotherapy for Cancer Control (GTFRCC) of the Union for International Cancer Control estimated that to meet the radiotherapy demands in LMICs by 2035, as many as 12,600 additional megavoltage external beam radiation treatment machines will be needed worldwide [8]. As documented in this report, a significant fraction of that shortfall of RT equipment is in Africa, where cancer has been recognized as a growing public health threat.

Patients with cancer in these countries suffer not only from a lack of access to technology but also a lack of related expertise to treat patients using advanced technologies. Such shortages are both qualitative and quantitative. In Nigeria, for example, there are an estimated 85 radiation and clinical oncologists and only a couple of trained linear accelerator maintenance engineers for a country of nearly 200 million people [9]. The Lancet Oncology Commission report noted above estimated using the current staffing model, that to meet the radiotherapy demands in LMICs by 2035, there will be a need for an additional 30,000 radiation oncologists, more than 22,000 medical physicists and almost 80,000 radiation technologists.

Furthermore, today's appropriate cancer care requires the knowledge to utilize and maintain complex technology. Linear accelerator technology is readily useable with appropriate education and training with a need to continue education and mentorship to help assure confidence as local and regional centres expand their capabilities. Manufacturer-based training is limited to a few weeks, following the sale and installation of the machines, and few opportunities offer systematic hands-on training for radiation technicians, clinical oncologists and ancillary staff to treat patients using advanced technology with professional guidance and oversight. Currently, there are too few programs and resources addressing this critical need, including a novel program of sustained education, training and mentoring through twinning programs driven by the International Cancer Expert Corps (ICEC) [10], Medical Physicists for World Benefit (MPWB) [11], the International Atomic Energy Agency's (IAEA) Programme of Action for Cancer Therapy (PACT) [12] and others. However, there remains an urgent need for more training resources.

The IAEA has long recognized that the lack of in-country expertise to build and sustain cancer programs in LMICs is a critical gap in providing quality cancer management. To establish sustainable in-country expertise for the curative and palliative treatment of patients with cancer and to support related health programs, the International Atomic Energy Agency (IAEA) is investing in radiation therapy education, training and facilities.

The lack of radiotherapy is particularly acute in Africa, especially Sub-Saharan Africa. According to GLOBOCAN, an estimated 847,000 new cases of cancer occurred in Africa in 2012 and 635,400 deaths occurred there in 2015. Their forecast, if current trends persist, is that there will be 1.4 million new cases of cancer in Africa with one million deaths in 2030. Yet, there is a severe shortfall in radiation treatment capacity in Africa. Fig. 1 below indicates the number of people per functioning machine in relevant countries. For example, Ethiopia had a single functioning machine to cover its population of nearly 110 million in 2018 [13].

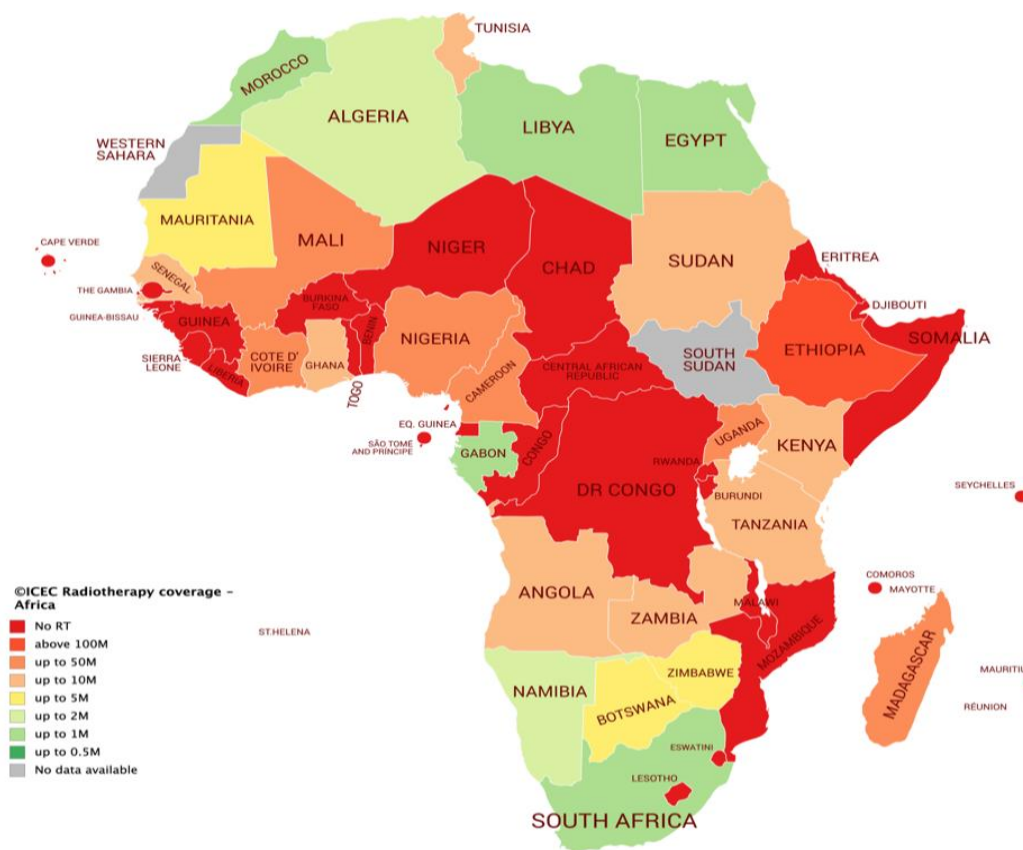


FIG. 1. Map showing the number of people per functioning machine in countries in Africa

In 1959, the International Atomic Energy Agency (IAEA) initiated DIRAC, the DIrectory of RAdiotherapy Centres. This database collects information on radiotherapy sites producing the most comprehensive database on radiotherapy resources. Though far-reaching, the information provided by institutions, radiotherapy centres, research laboratories and other organizations is voluntary and therefore is not a complete listing. However, the database is updated, reviewed and authenticated on a continuous basis, in an effort to provide the most comprehensive record publicly available. In addition, recent changes in early 2019 have restricted information publicly available on the DIRAC site, including eliminating the option to download raw data and to locate the precise reference location of radioactive sources.

According to the IAEA's Directory of Radiotherapy Centre (DIRAC) database, half (27) of the countries in Africa do not provide any radiotherapy services [14]. Throughout Africa, there are 217 radiotherapy centres that are equipped with a total of 385 treatment machines. Moreover, about 66% of the machines are in just three countries: South Africa, Egypt and Morocco (See chart below). Only one of those states, South Africa, is among the 46 that the UN Development Program lists as lying in sub-Saharan Africa. In Middle and Southern Africa combined, there are currently 6.2 million people per megavolt radiotherapy machine [15]. The IAEA recommends one megavolt machine per 250,000-500,000 people, a number far from current availability [16]. The statistics for countries with the number of radiotherapy machines as of October 2019 are presented in Fig. 2.

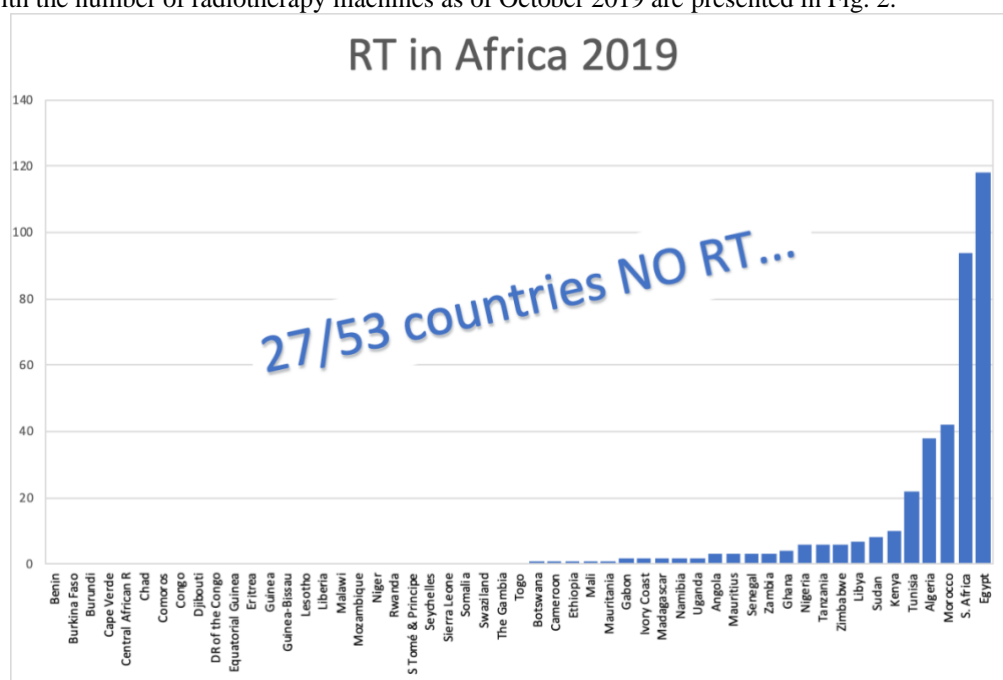


FIG. 2. Chart showing the number of people per functioning machine in countries in Africa

Moreover, not only are skilled medical personnel in short supply in Africa but also there remains a shortage of engineers to install and maintain the treatment machines. These shortages are compounded by often unstable infrastructure that fortunately, is becoming somewhat less of a problem with time. Efforts to establish regional training centres for radiotherapy personnel are also underway.

2. CURRENT LINAC VS COBALT-60 TECHNOLOGY

In trying to fill this gap, African medical providers, like their counterparts elsewhere, have two general choices for conventional external beam radiotherapy (excluding proton and carbon-ion therapy), cobalt-60 machines or linear accelerators (LINACs).

The cobalt-60 radioisotope used in cobalt-60 machines constantly emits gamma rays that are used to treat patients with cancer. These machines are relatively inexpensive and straightforward compared to LINACs, but they require close attention due to the treatment implications of ongoing radioactive source decay and due to the safety and security issues related to the radioactive material. A problem that has emerged in recent years is the large expense associated with the return of used, but still highly radioactive sources, to their manufacturer, which should occur about every six years. This is often not detailed in the initial purchase price. Moreover, many countries have legacy sources they cannot repatriate. They lack adequate disposal facilities, or they simply cannot afford to return disused sources, leaving them vulnerable to theft or loss.

In contrast, a LINAC is not radioactive but produces a high energy x-ray beam on demand to deliver external beam radiation treatments to cancer patients. As a result, there are no security risks with LINACs, but it requires a reliable and more stable electricity supply, including air conditioning, to operate [17]. The x-ray beam from a LINAC can be programmed to deliver high radiation doses that conform more closely to the specific size, shape and location of a tumor in a patient's body than is possible with cobalt-60 machines. The LINAC's specification thereby minimizes the exposure of normal surrounding tissues and organs at risk to high, and potentially injurious, radiation doses. The large penumbra of the photon beam from cobalt-60 radiation therapy machines (due to the physical size of the cobalt source) is the reason for less well-defined radiation dose distributions from those machines to tumors. In addition, the low energies of the photons from cobalt-60 (1.17 and 1.33 MV) produce the maximum radiation dose at a depth of 0.5 cm in tissues compared to 1.5 cm for 6 MV photons from a linear accelerator. This shallow maximum dose can cause skin damage and severe radiation fibrosis if a moderate radiation dose is given from a single direction, whereas there would be no skin damage nor radiation fibrosis from 6MV photons with a comparable radiation dose.

Moreover, cobalt-60 sources have a five-year half-life meaning that the dose rate decreases by one-half every five years, which results in longer treatment times to deliver the prescribed radiation dose to a patient's cancer (at the end of a 5-year half-life the same treatment takes twice as long). These increasing treatment times result in fewer patients being treated in a typical clinic workday with a cobalt-60 machine, in contrast to the patient treatment capacity of linear accelerators which should not decrease with time.

In summary, under circumstances that permit regularly scheduled operation, linear accelerators offer considerably higher-quality treatment for patients with cancer than cobalt-60 machines and are capable of treating larger numbers of patients in a workday with a single treatment unit. As a result, few cobalt-60 machines are used for teletherapy treatment in high- and upper-middle-income countries, and physicians in LMICs chafe at using treatment machines that would not be used in UMIC or UICs. As pointed out by Fisher for Ebola virus disease, which is surely applicable going forward for cancer care, "It should no longer be acceptable to have two standards of care — one for patients in resource-constrained settings and another for those in countries where resources are more readily available [18]."

However, because of cost and operational considerations, they are still being used for treatment in some poorer countries. Linear accelerators generally have greater infrastructure demands, as the advanced technology requires a stable power grid to support the highly sophisticated componentry that delivers optimized treatment. Many countries in sub-Saharan Africa do not have access to a stable power supply nor access to clean water, both necessary resources to effectively and efficiently run and operate a linear accelerator. Interventions including battery backups, solar arrays and diesel generators have been implemented to mitigate brownouts. They also have higher operational costs due to increased training and education and more staff positions to run and operate the machines. Necessary service and maintenance contracts are costly. In their absence, treatment machines can have significant downtimes, especially if enough spare parts are not on hand, and their delivery and shortage of trained technicians can also slow or halt patient treatment for weeks to months at a time.

Moreover, the new linear accelerators cost two to four times the cost of the new cobalt-60 machine. On the other hand, Cobalt-60 radiotherapy units are less complex than LINACs, making them more reliable in challenging environments. Presumably, that advantage will disappear should new robust and affordable medical linear accelerators become available [19] and as the infrastructure in LMICs improves over the next several years. For

now, as the number of cancer cases and deaths in Africa continues to rise and African states race to get ahead of this wave by acquiring additional radiotherapy machines, they will need to decide on whether to use LINACs or Co-60 machines. This decision will be based on their individual needs and capabilities and the status of current and future infrastructure, personnel, and financial, service, and maintenance resources.

3. TRENDS IN AFRICA EXTERNAL BEAM RADIOTHERAPY: RESEARCH RESULTS

To better understand the challenges involved and lessons learned in the adoption and use of linear accelerators in Africa, the authors employed a mixed-method approach, incorporating quantitative and qualitative research and analysis.

The results of the research are clear: when presented with a choice, better-off African countries, such as South Africa and Nigeria, have moved almost entirely to LINAC-based treatment. Other countries are following in almost direct proportion to their wealth. This shift can be attributed not only to the superior performance of these machines but also to rising terrorist attacks and threats in Africa, enhancing radiological security concerns. For example, Nigeria (see chart below) has transitioned mainly from cobalt-60 machines to LINACS. It has also increased the total number of machines. Nevertheless, that growth has just kept up with the country's population growth over that period from 120 million to nearly 200 million people. Today, as in 2001, there is roughly one external radiation treatment machine for every 20 million people.

Table 1 and Table 2 below summarize the state of radiotherapy in Nigeria in 2001 [20] and 2019 [21].

TABLE 1. RADIOTHERAPY CENTRES IN NIGERIA IN 2001

Radiotherapy Centre	Cobalt-60 Machine	LINAC Machine	LDR Brachytherapy	TPS/Imaging Machine
LUTH, Lagos	2		2	
Eko Hospital, Lagos	1			
UCH, Ibadan	1		1	
ABUTH, Zaria	1		1	
NHA, Abuja		1	1	1 Simulator
TOTAL	5	1	5	1

TABLE 2. RADIOTHERAPY CENTRES IN NIGERIA IN 2019

Radiotherapy Centre	Cobalt-60 Machine	LINAC Machine	Status	LDR Brachytherapy	HDR Brachytherapy	TPS/Imaging
LUTH, Lagos	Phased Out	2	PPP	Phased Out	2 About to commence treatment	TPS/CT Simulator
UCH, Ibadan	Phased Out		Public		Phased Out	
ABUTH, Zaria	1		Public	Phased Out		
NHA, Abuja		2	Public	Phased Out		TPS/CT Simulator
Eko Hospital, Lagos	1		Private			
UNTH, Enugu		1	PPP			CT Simulator
UDUTH, Sokoto		1	Public			CT Simulator
UBTH, Edi		Not functional	Public			CT Simulator
FMC – Gombe			Public		1 HDR	
Total	2	6		5	1	5

LUTH - Lagos University Teaching Hospital, UCH – University College Hospital, ABUTH - Ahmadu Bello University Teaching Hospital, NHA -National Hospital Abuja, LDR – Low Dose Rate, HDR – High Dose Rate.

Nonetheless, costs (both purchase and operating costs) and operational challenges continue to remain obstacles to a complete Cobalt-LINAC transition in sub-Saharan Africa and to the acquisition of a sufficient number of radiotherapy machines. More than 18 African countries still have co-60 machines, while some among the 27 generally poorer African countries that lack a single teletherapy machine, may consider purchasing additional co-60 machines. The continent houses 88 cobalt-60 machines (half of which are more than 20 years old), along with 189 linear accelerators, which represents a higher proportion of cobalt-60 machines than in other continents.

4. SECURITY CONCERNS

A particular African concern is a growing and diverse array of violent militant Islamist groups active within different geographic concentrations in Africa, a trend that is likely to continue into the foreseeable future. Recent studies have been concerned with the rising number of groups, their spread and violent activities. Specifically, the African Centre for Strategic Studies, an academic institution within the U.S. Department of Defense established and funded by Congress for the study of security issues relating to Africa, published a review of violent events involving militant Islamist groups in Africa in 2018 [22]. According to its data, militant Islamist group activity in Africa existed in all the five subregions, the number of groups active in these subregions has been growing, and reported fatalities related to their activity rose more than two-thirds: from 366 in 2017 to 611 in 2018. The figure illustrates the existence of a credible threat of a terrorist attack involving radioactive material.

Security vulnerabilities in Africa like conflicts have made high activity radioactive sources easy prey for smugglers or insiders seeking profit through illegal trade. Several major studies have confirmed an increase in the number of civil wars and an increase in countries with conflicts in their territory in Africa during the past five years. In a June 2019 study, PRIO reported an increase in civil wars from 18 in 2017 to 21 in 2018 in Africa [23]. In a September 2019 International Crisis Group report, 29 of the more than 80 conflicts globally were in Africa [24]. In the same report, seven of 13 countries with deteriorating conflict situations were in Africa. For many countries with conflicts, security measures for cobalt sources, where they exist, are inadequate. In other countries, including where terrorists operate, governance is patchy and regulation is weak.

Poorly secured facilities housing cobalt-60 machines are vulnerable to theft, black market, and misuse. Governments and hospitals also have difficulty disposing of disused sources, which may no longer be adequate for treating patients but retain sufficient radiation to harm people if misused. Cobalt-60 sources have average radioactivity of 2000 Curies, and therefore represent significant risk due to their potential use in radiological dispersal devices (dirty bombs) or radiological exposure devices. Although there has not been an event in Africa involving intentional malicious use of high-activity radioactive sources, given a rise in terrorism on the continent, African governments are considering nuclear security best practices and initiatives that can be taken to minimize the significant risk posed by radioactive cobalt-60 sources.

5. LESSONS LEARNED

5.1. Operational Challenges Beyond Treatment Delivery Hamper Progress

Beyond the complex obstacles to delivering radiation therapy treatment, many operational challenges exist that impede the ability to offer access to radiotherapy. Cancer registries collect and provide information regarding the incidence, prevalence and mortality related to cancer in a given country or region and are instrumental in the development of National Cancer Control Programmes [25]. Data collected through registries allow for governments and ministries of health to assess the cancer burden and help allocate how resources are to be distributed. Resources not only include equipment purchase but also required investment in infrastructure including bunkers, access to electricity, clean water, workforce, education, and training. Data from the Global Initiative for Cancer Registry Development (GICR) indicates that only one in five LMICs collect the necessary data to effectively develop a policy for the formulation of cancer control plans, which include equipment acquisition, infrastructure investment and workforce building [26].

Other obstacles include the prohibitive cost of the equipment and the necessary service plans needed to keep machines operational. This emphasizes the need for a robust, well-trained workforce spanning the spectrum of abilities as well as the need for training from commissioning the equipment to regular service and maintenance, through operations including actual beam delivery and patient treatment. Linear accelerators require more staff to

run than Co-60 machines, and countries and regions must consider training programs to operate the highly technical equipment, especially as countries strategize to address the growing cancer burden.

In 2011-2012, Zimbabwe made a public commitment to decommission its last cobalt-60 teletherapy unit and initiate the acquisition of linear accelerators. This shift to LINACs was influenced by the training of healthcare professionals who had experienced the use of both teletherapy modalities and understood the shortcomings of cobalt-60 teletherapy as related to increased treatment risks. Source security, replacement, decommissioning and disposal protocols and other costs were also considered when making the decision to invest in new technology. Growing public and private commitment to increase education and training programs, including the expansion of a formal postgraduate level physics program, was paramount to support the shift to linear accelerators and to ensure that Zimbabwe was no longer reliant on contractual externally clinical oncologists. Challenges remain regarding the ongoing service and maintenance of the linear accelerators, ensuring the availability of a stable power supply, and the guarantee of health financing. However, government support, a strong regulatory framework, and a dedicated healthcare workforce all provide the basis for a sustainable and expanding radiotherapy program [27].

5.2. LINAC manufacturers need to be more transparent about what medical providers need to make effective use of their equipment.

Manufacturers should ensure that purchasers fully understand the implications of what the system in its entirety requires in order to deliver quality cancer care, which includes, safe, effective, patient-centred, timely, efficient and equitable treatment [28]. Transparency would require manufacturers to be candid on costs and other efficiencies (access to spare parts and highly skilled accelerator engineers and service technicians) related to operations, service and maintenance, as well as providing a full range of educational and ongoing training resources to guarantee purchasers are capable of utilizing the new equipment efficiently. An example of this is ongoing in the National Hospital Abuja where new LINACs have been purchased, but the staff have not been afforded access to the additional training needed to adopt advanced treatment techniques, including IMRT, VMAT and IGRT. This is a common experience where vendors sell products without stressing the importance of working to support technology transfer, to insure full integration and utilization of the equipment. This is not unique to Nigeria, as multiple other countries in the region are experiencing the same dilemma. There is an absolute need to collaborate with IAEA, vendors, and governments on the need to streamline training in order to fully utilize the advanced treatments the machines are designed to deliver. Without this additional support, the end-users are only able to deliver 3-Dimensional Conformal Radiotherapy (3DCRT), thus denying safer, more effective treatment to thousands of patients.

5.3. States have ambitious radiotherapy expansion plans involving LINACs

In most of the African countries considered in the project, there were ambitious plans for the expansion of radiotherapy services. As of December 2016, for example, Nigeria had two functional radiotherapy machines (one LINAC and one cobalt-60 unit) [29] for a population of about 186 million, Ghana had three functional radiotherapy machines (one LINAC and two cobalt-60 units) for a population of 28 million and Senegal had one cobalt-60 machine for a population of 15 million. As of October 2019, three years later, Nigeria had six functional radiotherapy machines (four LINACs and two cobalt-60 units) for a population of 196 million, Ghana had five teletherapy machines (three LINACs and two cobalt-60 units) for a population of 30 million, and Senegal had three functional LINACs for a population of 16 million.

5.4. A more effective transition to LINACs requires good assessment, clearly defined management and excellent coordination.

The African participants keenly highlighted the need to plan, manage and coordinate the process of transitioning to LINACs to ensure that both organizational and service expectations are clearly articulated, and that affected employees have “buy-in” to the transition to LINACs. The process for planning LINAC transition and use in Africa is perhaps best captured in a recent state-of-the-art LINAC transition “Planning Guide” by Lawrence Livermore National Laboratory for the US NNSA Office of Radiological Security. The guide identifies the major stakeholders in the management of the transition process: government, policy, administrative, management, clinical, physics, regulatory, diagnostics, IT, financial, nursing, and pathology.

The guide identifies five major planning areas including assessment of needs, facility, technology, implementation as well as ongoing procedures. Under each area, the Guide lists appropriate stakeholders and lists relevant materials for further consultation. The needs assessment is important because it helps the hospital or clinic determine the gaps in knowledge, practices, or skills that are preventing it from reaching its desired

radiotherapy service goals. In the planning Guide, the needs assessment appraises the cancer plan, radiation therapy plan, infrastructure, funding and clinical needs.

The facility assessment phase helps to identify gaps in the staffing needs, other support services, radiation protection planning compliance, removal of exiting radioactive systems, construction and utility needs. Participants identified two useful resources to maximize the facility assessment phase: Radiotherapy Facilities: Master Planning and Concept Design Considerations [30] and Considerations for the Adoption of Alternative Technologies to Replace Radioactive Sources [31].

Technology assessment focuses on the valuation of diagnostic imaging, radiation treatment, other support services, treatment planning, quality assurance, patient immobilization and treatment verification. Implementation assessment considers staffing and training, equipment removal, equipment specifications, construction and utility works, procurement processes and radiation protection. It also appraises equipment installation and quality assurance procedures. Finally, assessment of ongoing procedures determines needs for clinical practice, education, staffing, quality assurance, radiation protection and equipment maintenance.

Due to poor LINAC transition planning and coordination in two countries, the installation of three LINACs was delayed for more than five years after purchase and delivery. The machines were recently installed and commissioned.

5.5. A stable and reliable power supply is a requirement for the efficient functioning of current LINAC technology.

While power stability and reliability are related, their impacts on a LINAC are different. Poor power stability is caused by several factors including bad connections, interference, wiring issues and natural causes. Indeed, electrical power supply instability that causes alternating current voltage fluctuations change the amount of power available to highly digital LINACs. This can result in damage to electronic equipment, significantly affect magnetron lifetime and can damage computers, therefore impacting the treatment planning and control systems.

Many African hospitals and clinics that submitted responses to the study questionnaire have outdated and problematic power grid systems that cause frequent, lengthy and widespread power outages. In addition, the power station capacity for many countries is insufficient to supply the demand from all the customers. To that end, load shedding is implemented as a measure of last resort to prevent the collapse of the power system countrywide. The impact of such power outages on the sensitive electronic components of LINACs and computers resulted in significant operational delays, equipment instability and component failure. It resulted in the loss of profit, produced higher running costs due to inefficient use of power, and engendered patient dissatisfaction in the hospital service. Power cuts can cause components to operate outside normal rated values, leading to overheating and operational issues such as data error or loss, equipment malfunction and component failure.

The adoption of measures to tolerate the above challenges in the use of LINACs in resource-constrained hospitals and countries in Africa has minimized their impact. Dedicated standby automatic electrical generators are used to provide power to radiotherapy units and hospitals when there are mains electricity interruptions. This has minimized machine downtime, ensured continued treatment service and improved patient confidence in service delivery.

Another measure is the use of uninterruptible power supply (UPS) to provide protection for LINACs, desktop computers, workstations and other electronic devices in the radiotherapy facility by maintaining a steady voltage during brownouts and blackouts. UPS also offers surge protection against overvoltage spikes or other disturbances in the AC power supply which can damage or degrade electronic equipment. Unfortunately, a power surge caused a UPS to fail in one hospital in 2016 during the commissioning of a new LINAC. The cost of replacing the UPS delayed the commissioning of the LINAC for close to a year.

Voltage stabilizers are a third measure used to manage power fluctuations in challenged LINAC environments in Africa. A voltage stabilizer feeds a constant voltage current to LINACs, computers and other sensitive electronic equipment to protect them from damage due to voltage surges, swells, and sags. In sum, although the power management measures contribute to ensuring the continuous operation of LINACs and radiotherapy facilities, these measures increase the running cost of LINAC-based radiotherapy clinics and hospitals.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the above discussion, the following conclusions and recommendations are made:

- 6.1 The IAEA has provided support to national health authorities to review and assess the needs and gaps, to help them develop and implement national cancer control strategies and to develop self-reliance in human

capacity-building for cancer management. To enhance this effort, the IAEA could 1) support governmental and hospital efforts in the establishment and strengthening of radiotherapy and nuclear medicine centres in Africa, 2) build capacity through the long-term training of radiation oncologists, nuclear medicine physicians, medical physicists, engineers and related professionals and 3) assist in the procurement of equipment and expert services. Other organizations, like the ICEC, have complemented the work of the IAEA in capacity development.

- 6.2 Nonprofit organizations should conduct more capacity building activities to increase the understanding of the necessity of nuclear security and peaceful use of nuclear materials in achieving the United Nations Sustainable Development Goals in Africa.
- 6.3 The Secretariat of the Economic Community of West African States should work with LINAC suppliers to establish a technical centre in a member state that will be stocked with spare parts and manned by LINAC-certified biomedical engineers to promote wide adoption and sustainable use of current LINAC technology on the continent.
- 6.4 LINAC suppliers should offer their client hospitals and clinics a comprehensive program, as part of the purchase contract, to help medical physicists, biomedical engineers, and radiation oncologists to fully attain the highly technical knowledge and skills that are needed to operate and use LINAC technology, effectively and efficiently.
- 6.5 Additional research should study the environmental and workforce challenges associated with current LINAC technology that currently is costly and unsustainable in Africa, in order to determine the priority of design improvements or needed modifications of the current LINAC technology. In addition, other problem areas should be examined to learn what further innovations of the current LINAC technology could increase system tolerance, machine robustness and lower the purchase and operational costs.

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