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Review Paper

IAEA-led Advances in Nuclear Technology Applications: A Comprehensive Review of 2019-2022

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Abstract

The idea that prosperity is linked to health is supported by a prolonged usage of nuclear technology in the medical industry. Between 2019 and 2022, a detailed evaluation of the global and African trends in nuclear application in the health sector was conducted. The most important advancement in the treatment of gynecological cancer is the introduction of intra-operative instruments like the portable gamma-camera. The IAEA has recently provided Namibia, a new machine to tackle the rise in cancer incidences, particularly skin cancer. To accomplish SDG 3: Promote well-being, the Peaceful Uses Initiative (PUI) has funded 16 programs that aim to combat cancer on a worldwide scale. It's a great idea to include the electron beam in the IAEA's external audit service. Brazil, Cuba, Germany, Greece, Indonesia, Italy, Malaysia, Mauritius, Mexico, Spain, and the United States of America are among the countries that are advancing the use of SIT for mosquito control. The participation of Africans in IAEA programs is highly recommended for development.

Keywords: Nuclear; Health; cancer; radiological; mosquito.

Introduction

This research looks into the most recent developments in nuclear technology and their uses in medicine, specifically in Africa but also globally, from 2019 to 2022. These applications include radiation and quality assurance, cancer, infectious illnesses, diagnostics, and nutrition. examining the nuclear industry's growth trends and recommending the essential actions for African development. Africa has been involved with nuclear technology for sixty years, starting with the initial criticality of the TRICO I research reactor at the University of Kinshasa in the Democratic Republic of the Congo. Following closely behind were Egypt and South Africa, demonstrating the continent's dedication to granting academics access to cutting-edge nuclear analytical methods and irradiation capabilities. On the continent, eight nations that are all members of the International Atomic Energy Agency have built a total of twelve research reactors thus far [1] . While it may be claimed that the nuclear power sector is currently experiencing a new pause in some regions of the world, nations like China and Russia are aggressively increasing their nuclear footprint to address the problems posed by global climate change and a shortage of resources. Building new nuclear power plants are the United Arab Emirates, Argentina, and Vietnam. To reduce their continued reliance on fossil fuels, many additional countries, including Indonesia, Turkey, Belarus, and Poland, are interested in developing new nuclear technology. Nuclear power plant construction is underway or being considered in more developed countries like Finland, Sweden, and India. Across the board, more than 45 countries are actively considering including nuclear power facilities in their energy mix.

Using five important criteria, this study contrasts the

many advanced nuclear technologies being developed by the US and other countries to give decision-makers a better knowledge of the options available to achieve desired goals.

1. Security hazards
2. Cost
3. Issues with waste
4. Regulation
5. Possibility of advancing nuclear weapons technology.

Radiation and Quality Assurance

A quality assurance procedure is necessary to verify that radiation is applied clinically in a high-quality, safe, and efficient manner over the long term when using nuclear technology to diagnose and treat disease. This lessens the possibility of accidents and mistakes and helps with an effective diagnosis and course of action. Education and training are essential to achieving and maintaining a high level of quality and efficacy in radiation therapy and diagnostic imaging. The professionals in charge of implementing quality assurance procedures in the clinical environment are radiological medical practitioners and medical physicists with clinical training. Through coordinated research projects, scientists from different nations can work together to develop and test novel quality assurance techniques. Assuring that the research findings are openly accessible to all Member States, the IAEA promotes such projects. Figure 1 showcases the implementation of new quality assurance protocols during a Task Force meeting, aiming to enhance nuclear medicine services' quality. The head phantom, a tool simulating the human head, is precisely aligned in the gantry of a Computed Tomography machine, ensuring accurate and reliable diagnostic information. The scene exemplifies the dedication of healthcare professionals and organizations to continuously improve and ensure patient safety through quality assurance measures.

In March 2020, it was originally suggested that Africa adopt more unified quality control. An effort was made to develop and write QC protocols after a task force was formed in recognition of the continent's expanding usage of nuclear technology for imaging services and the accompanying requirement to ensure their quality and safety. By standardizing both data collection and analysis, the harmonized QC advice, which was peer-reviewed by medical physics specialists from Africa and Europe under the coordination of the IAEA Technical Officers, will allow hospitals in Africa to closely coordinate their quality assurance programs. This will make it possible for medical institutions to compare and validate their findings.The new QC guidelines can also be adopted by certain nations who have not yet set up their own national quality control programs, which will help improve effective diagnosis throughout the African continent [2]. The IAEA acts as a focal point for the global harmonization and uniformity of radiation therapy dosimetry. In 135 nations, 2300 radiation centers have received our support, according to Abdel-Wahab. Over 80% of the IAEA's 653 dosimetry audits last year were related to linacs [3].

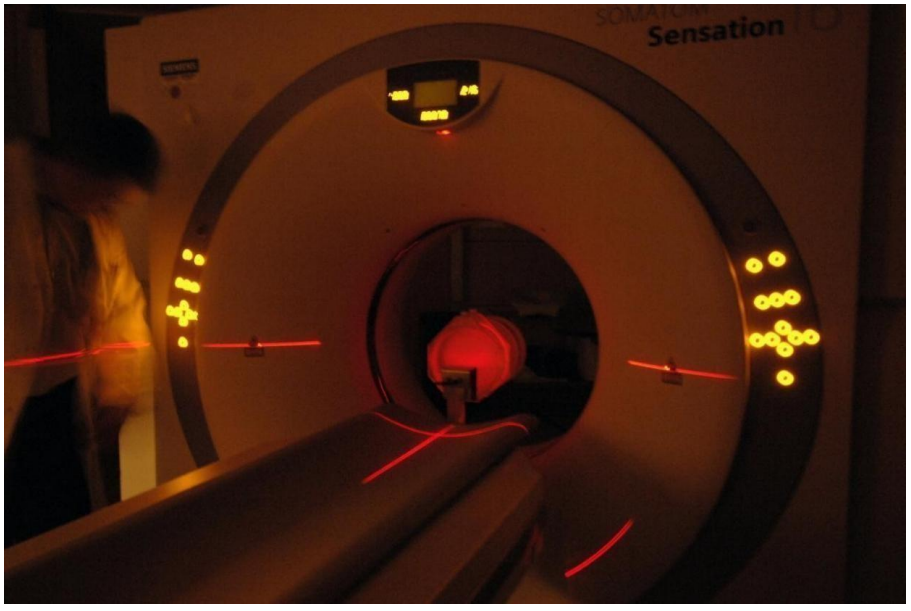

Figure 1. During the Task Force meeting, new quality assurance protocols were elaborated to improve the quality of nuclear medicine services. Here, a head phantom is being aligned in the gantry of a Computed Tomography machine at the Allgemeines Krankenhaus in Vienna, Austria. (Photo: D. Calma/IAEA) [13].

Figure 2. Gamma probe used in SLN detection pre operatively with corresponding high count on the screen.

Cancer

Globally, there will be about 10 million cancer-related deaths and more than 19 million new instances of cancer in 2020 [4]. On a global scale, cancer is a factor in about one out of every six fatalities [5]

The emergence of intra-operative tools like the portable gamma-camera is the most significant development in the treatment of gynecological cancer [6]. The intraoperative image provided by this gadget helps locate SLNs prior to excision. Once the surgical field has been eliminated, a second imaging will show no activity, which will indicate a successful resection. In comparison to a full surgery operation, the technique only lasts between 5 and 15 minutes for cancers of the vulvar, cervical, and endometrium. Figure 2 depicts the use of a gamma probe in pre-operative settings for the detection of the sentinel lymph node (SLN) with a high count displayed on the screen. SLN detection is critical in cancer diagnosis and treatment, and the gamma probe, a cutting-edge medical device, detects gamma radiation emitted by a radioactive tracer. This innovative technology enables precise identification of the SLN, leading to improved diagnostic accuracy and better patient outcomes. The image exemplifies the power of advanced medical technology in enhancing medical practices and improving patient care.

According to NCCN recommendations [7], the SLNB has emerged as the gold standard of therapy for early-stage breast cancer in axillas that are clinically and radiologically negative as the primary detector of nodal metastases. A portable intraoperative gamma camera has been created recently that provides a quick intraoperative real-time view of the SLN and can take the place of preoperative traditional gamma camera images [8].

To address a significant global gap in access to cancer care, six countries have donated more than €9 million in support of the new International Atomic Energy Agency (IAEA) program Rays of Hope, which was launched earlier 2022. The funds pledged by France, Japan, Monaco, the Republic of Korea, Sweden, and the United States will be used to buy life- saving equipment, improve staff abilities, and transfer knowledge necessary to prevent cancer deaths, which account for 70% of deaths worldwide but only 5% of deaths in low- and middle-income nations. Beforehand, Rays of Hope received support from the United State and Japan..Namibia's Windhoek Central Hospital received a new orthovoltage radiotherapy system from the IAEA in late 2021. This device uses radiation to kill cancer cells. As a result, nearly 600skin cancer sufferers can now obtain treatment for their condition each year.Figure 3 provides a visual representation of the potential harm caused by using higher voltage machines in treating superficial cancers. Such machines can penetrate deeper layers of the skin, causing damage to healthy cells and unnecessary resource use. The graphic underscores the significance of appropriate medical technology, effective decision-making, and patient- centered care in delivering optimal health outcomes. By highlighting the importance of utilizing suitable medical equipment and prioritizing patient well-being, the image demonstrates the power of informed medical practices in promoting quality care and enhancing patient satisfaction.

Benin, a nation in West Africa, is one of the nations receiving help under the Rays of Hope initiative that has been specially adapted for it. Seventy percent of all cancer patients in Benin died in 2018 due to insufficient funding and delayed diagnosis. Several patients were forced to travel abroad for their care. Nuclear medicine tools and other resources will now be provided across the nation through Rays of Hope to improve patient diagnosis and care. The IAEA's aid will be a valuable addition to ongoing national initiatives to raise money for the establishment of a new cancer hospital, which is

anticipated to open in 2023. In terms of the significance of nuclear applications in cancer therapy to this review, it is important to note that the use of nuclear medicine techniques is becoming increasingly important in the fight against cancer, particularly in low- and middle-income nations where access to other forms of cancer treatment may be limited. The donation of life-saving equipment, such as the orthovoltage radiotherapy system provided to Namibia's Windhoek Central Hospital, can have a significant impact on cancer patients in these regions, providing them with access to potentially life-saving treatment options.While it is unclear what percentage of the Rays of Hope program is focused on nuclear applications in cancer therapy, it is likely that this component of the program will play an important role in addressing the global gap in access to cancer care.

Through imPACT Reviews, resource mobilization, and by assisting in the creation of strategic documents like Comprehensive National Cancer Control Plans and bankable documents for fundraising, Programme of Action for Cancer Therapy (PACT) offers support in the domain of cancer.

Additionally, it aids IAEA initiatives pertaining to cancer that are carried out through technological cooperation, human health, and other initiatives (IAEA, 2022). By establishing cancer centers, effective diagnostic and therapeutic services, such as medical, surgical, radiotherapy, and palliative care, could be scaled up. This would have significant positive effects on society, the economy, and health, as well as help reduce the access to cancer care services gap globally. A US dollar invested in cancer treatment yields a $2.30 return on direct productivity and a $9.50 return on investment based on both direct productivity and social benefits [9].

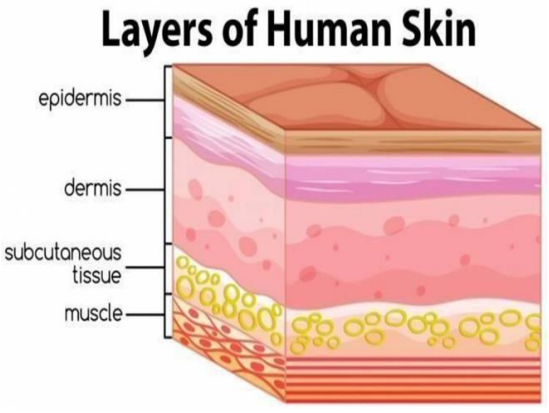

Figure 3. Higher voltage machines often treat deeper layers of skin when treating superficial cancers, leading to an unnecessary use of resources and the damage of healthy skin cells (Graphic: Vecteezy) [12].

Infectious Illness

Some of the most serious illnesses in the world, like Malaria, Ebola, and Zika, can be found, contained, and stopped from spreading with the aid of nuclear- derived technology. To aid our Member States in the fight against infectious diseases, we advocate the adoption of various nuclear-derived techniques that are effective, affordable, ecologically friendly, and residue- free.

Extrabudgetary contributions made through PUI have been utilized to assist a wide range of IAEA initiatives targeted at advancing general development goals in Member States. Enhancing food security, zoonotic disease prevention programs, giving marginalized areas access to drinkable water, and other PUI projects are some of those that could help the world's most pressing problems (the Sustainable Development Goals, or SDGs) be solved. infrastructure for nuclear energy should be developed and strengthened. interventions centered on combating climate change and making adaptations, to protect and sustainably utilize marine resources for sustainable development, Protect, restore, and encourage sustainable use of terrestrial ecosystems. Manage forests sustainably. Fight desertification. Halt and reverse land degradation. Stop the loss of biodiversity. In order to contribute to the achievement of the SDGs, the IAEA will carry on the PUI's work to increase the advantages of the peaceful applications of nuclear science and technology. Diagnostic testing is essential for limiting illness outbreaks like COVID-19. A nuclear-derived technology known as real-time reverse transcription-polymerase chain reaction is one of the quickest and most precise ways for COVID-19 virus detection (real time RT–PCR). Senegal has been a member of the IAEA since 1960 and is working closely with the IAEA on issues ranging from healthcare to energy development to agriculture. Since May 2020, the IAEA has provided Senegal with training and testing equipment using real-time reverse transcription-polymerase chain reaction (real-time RT-PCR) to support the fight against the pandemic of COVID19.

Like in most tropical nations, dengue is a growing health concern in Cuba. High fever, pain in the muscles and joints, skin rashes, and, in the most severe cases, death are all symptoms of this virus transmitted by mosquitoes. Over the past 20 years, the number of dengue cases reported to the World Health Organization has multiplied eight-fold on a global scale. Therefore, the Cuban government is developing nuclear technology that can lower the number of mosquitoes to tackle the pandemic of dengue fever. Figure 4 depicts the campaign to eradicate dengue fever in Havana, Cuba, using sterile insects. Female mosquitoes of the Aedes aegypti species spread dengue, a virus that infects millions of people worldwide. To limit the number of wild female

mosquitoes and eliminate their ability to reproduce, the campaign utilizes sterile male insects. When sterile males are released into the environment, they can mate with wild females, which effectively stops dengue from spreading. The graphic highlights the crucial role played by scientific research in thwarting threats to world health and shows the effectiveness of creative and long-lasting solutions in solving public health issues.

Figure 4. Females of the mosquito species Aedes aegypti are carriers of dengue. Sterile insect technique campaigns, like that being carried out in Havana, Cuba, rely on sterilizing males that attempt to breed with and neutralize the reproductive potential of wild females. (Photo: R. Gato Armas/Pedro Kourí Tropical Medicine Institute) [11].

One of the most environmentally friendly pest control strategies ever created is SIT. Mass-breeding insects are sterilized with irradiation, such as gamma rays and X-rays, to preserve sexual competition but prevent reproduction. In the past five years, Gato Armas has closely collaborated with IAEA and FAO experts to gather fundamental data and design the SIT pilot test as an alternative to decreasing and environmentally harmful mosquito control measures. Gato Armas predicted that the project's research area will expand by the end of 2022, but that this would necessitate equipment updates, such as automatic gender classifiers, to cut down on labor-intensive work and boost efficiency. According to Cardoso Pereira, "the IAEA and FAO will continue to support Cuba and other nations in the region in the field through SIT. "The IAEA and FAO will continue to provide Cuba and other nations in the region with help in the field of pest management through SIT."

Diagnostics

Numerous non-communicable or chronic diseases are treated utilizing diagnostic imaging techniques, which produce visible images of the inside of the body using radiography, ultrasonography, fluoroscopy, or nuclear medicine. Cardiovascular illnesses, cancer, chronic respiratory disorders, and diabetes are the four main categories of these. The radioisotope technetium- 99m is the one that is most frequently employed in nuclear diagnostics. To treat chronic conditions including cancer and cardiovascular disease, it is used in over 10,000 hospitals globally. Figure 5 showcases the operational status of the SAFARI-1 research reactor, a prominent nuclear facility in South Africa. The reactor serves various purposes, including scientific research, medical isotope production, and nuclear technology development. The photograph underscores the importance of nuclear technology in driving progress, promoting innovation, and advancing medical practices. By highlighting the significance of advanced technology in addressing global challenges, the image exemplifies the potential of nuclear facilities to transform human lives and facilitate solutions to complex problems.

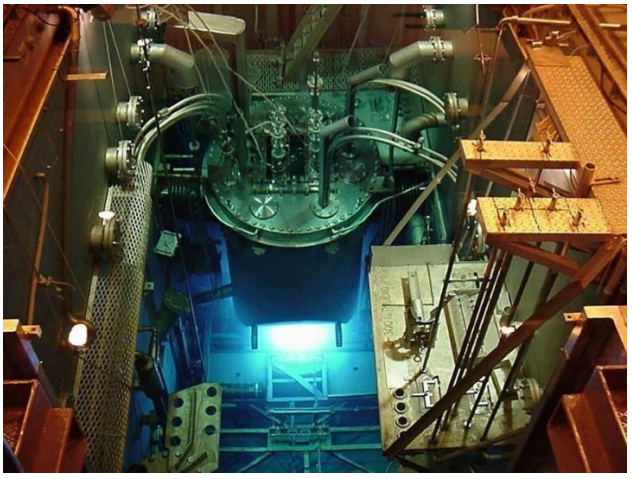

Figure 5. The SAFARI-1 research reactor in operation (Photo: Necsa) [14].

Pharmaceutical medications manufactured mostly in research reactors enable more than 80% of the annual medical imaging needed to diagnosis illnesses like cancer. These radiopharmaceuticals contain the radioisotope technetium- 99m (99mTc), which is derived from the radioisotope molybdenum-99 (99Mo), which is primarily created in research reactors. Implementing management systems, maintenance programs, employee training, and strategic planning in a well-structured and regulated manner has been the key to becoming a global player in the radiochemical and radiopharmaceutical sector.

Nutrition

To support technical cooperation projects and other unfunded IAEA projects in the fields of peaceful application of nuclear technology, the Peaceful Uses Initiative (PUI), which was established in 2010, has played a crucial role in mobilizing extrabudgetary

contributions that supplement the Technical Cooperation Fund.

Over the past ten years, the Peaceful Uses Initiative (PUI) has provided Indonesia with a large amount of assistance. Through programs funded by the PUI, the IAEA's Regular Budget and Technical Cooperation Fund, as well as other sources, it has accomplished significant milestones like the creation of new rice and soybean types. Indonesia was one of the first developing nations to assist the PUI a few years ago, providing both financial and human resources in the form of its professionals, who were willing to offer guidance and training to other nations [10].

Conclusions

Through the dedicated Radiation Protection of Patients website, the IAEA has created useful instruments for information and knowledge exchange. It has also created resources to enhance healthcare professionals' education and training. This project aims to support Member States in increasing justification and optimization implementation and enhancing medical radiation incident and accident prevention. Future plans are specifically intended to accommodate the unique requirements of professionals who use high dose imaging procedures but who are still in the training phase. It is anticipated that the project will lead to the creation and application of useful strategies and powerful instruments to aid Member States in their efforts to increase the justification, optimization, and application of radiation protection and safety in medical uses of ionizing radiation. The anticipated overall budget is 438700 Euros for the two-year period., 7% PSC is included in the budget (in euros).

Year 1 is 236 470 and Year 2 is 202 230. The aim of this review is to provide decision-makers with a better understanding of the options available to them in achieving their desired goals.

The first criterion to consider is security hazards. Nuclear technology can pose significant security risks if not properly managed. The study found that advanced nuclear technologies, such as accelerator-driven systems and small modular reactors, have made significant progress in reducing security risks. For example, some small modular reactors are designed to be inherently safe, with features that prevent overheating and fuel damage. Additionally, new technologies such as fusion reactors have the potential to reduce security risks even further, as they do not produce nuclear waste.

The second criterion to consider is cost. Nuclear technology is often viewed as an expensive option, but advances in technology are helping to reduce costs. For example, small modular reactors are designed to be more cost-effective than traditional nuclear reactors, and research is ongoing to find ways to further reduce costs. Additionally, new technologies such as fusion reactors have the potential to be more cost-effective in the long run, as they produce more energy and do not require costly fuel.

The third criterion to consider is issues with waste. Nuclear waste is a significant issue associated with nuclear technology. However, the study found that advances in nuclear technology are helping to address this issue. For example, new technologies such as molten salt reactors and accelerator-driven systems can consume nuclear waste as fuel. Additionally, research is ongoing to find ways to safely store nuclear waste and reduce the amount of waste produced.

The fourth criterion to consider is regulation. Nuclear technology is heavily regulated to ensure safety and security. The study found that advances in nuclear technology have led to new regulatory challenges, but also new opportunities for innovation. For example, small modular reactors are designed to be easier to license and deploy than traditional nuclear reactors, which could help to accelerate their adoption.

The fifth and final criterion to consider is the possibility of advancing nuclear weapons technology. Nuclear technology can be used for peaceful purposes, such as medical isotopes and energy production, but it can also be used to develop nuclear weapons. The study found that advanced nuclear technologies, such as fusion reactors and accelerator-driven systems, have a lower proliferation risk than traditional nuclear reactors. Additionally, advances in nonproliferation technologies are helping to reduce the risk of nuclear weapons proliferation.

The study highlights the many advances being made in nuclear technology and its applications in medicine. By using the criteria of security hazards, cost, issues with waste, regulation, and the possibility of advancing nuclear weapons technology, decision-makers can better understand the options available to them and make informed decisions. These advances will continue to drive innovation and improve the safety and effectiveness of nuclear technology in medicine.

Abbreviations

IAEA: International Atomic Energy Agency; SDG: Sustainable Development Goals; PUI: Peaceful Uses Initiative; SIT: Sterile Insect Technique; TRICO: TRiga Mark I Congo; QC: Quality Control; SLNs: Sentinel Lymph Nodes; NCCN: National Comprehensive Cancer Network; PACT: Programme of Action for Cancer Therapy; PSC: Percentage of the Contract Sum; FAO:

Food and Agriculture Organization; SLNB: Sentinel Lymph Node Biopsy; SAFARI: Nuclear research reactor located at the South African Nuclear Energy Corporation.

Author Contributions

All authors contributed to this study. All authors gave their final approval.

Competing Interests

We declare no competing interests.

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