

Roundtable B

How are we meeting radiation protection challenges in design and implementation of new technologies?

SHIELDING CHALLENGES FOR A DUAL-ROOM SLIDING GANTRY CT CONCEPT IN AN EMERGENCY DEPARTMENT

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Abstract

Many publications provide guidance detailing shielding solutions for rooms/areas in which X-ray equipment is used. The practice of identifying these solutions is considered a routine task for professionals who undertake this work on a regular basis. It is only in the event that regulatory and construction requirements are revised or when new technologies are purchased that this task can be challenging. The procurement of a sliding gantry CT scanner which can be operated in either a dedicated CT Room or in an adjacent Resuscitation Room within the Emergency Department in an Irish Hospital proved to be a challenging task from a shielding perspective. The final shielding recommendations for this project are summarised in the paper. In addition, the difficulties encountered while identifying the solutions are also presented.

1. INTRODUCTION

University Hospital, Limerick (UHL) provides major surgery, cancer treatment and care, emergency department services, as well as a range of other medical, diagnostic and therapy services for the Mid-West Region in Ireland. It is one of the busiest Emergency Departments in the country providing a 24/7/365 service to over 64,000 patients annually [1]. The Hospital officially opened it's new Emergency Department (ED) in June 2017.

The Royal College of Radiologists publication "Standards of practice and guidance for trauma radiology in severely injured patients" recommends that a multi-detector CT (MDCT) scanner be located adjacent to, or in, the emergency room [2]. In keeping with these recommendations, a decision was made by the Project Team which was tasked with designing and equipping the new ED to install a dual-room sliding gantry CT concept. The team consisted of representatives from clinical, technical, medical physics, procurement, radiography staff and architects. This innovative design, which allows the CT scanner move between the CT Room and a dedicated Resuscitation (Resus) Room, is the first of its kind in Ireland and the UK. The challenges encountered by the Project Team when determining the shielding solution for this concept are described in this paper. In addition, the final shielding recommendations are specified.

2. EQUIPMENT SELECTION

The CT equipment, a Siemens Somatom Definition AS 128 slice CT system was selected in accordance with the requirements outlined in the National procurement policy. As part of the tender evaluation process, relevant members of the Project Team visited a European reference site to observe the equipment in clinical use.

One of the main benefits for installing a dual-room sliding gantry CT system is that it reduces the number of bed transfers critically unstable patients are required to undergo when CT imaging is requested by ED doctors. In addition, it substantially diminishes delays resulting from transferring these patients from the ED to the Radiology Department [3,4].

3. ROOM DESIGN/LAYOUT

The architects and the Radiation Protection Adviser (RPA) agreed a plan of the CT Room and adjoining Resus Bay/Room as part of the building project. Following several meetings with medical physicists, radiographers, clinical staff and equipment suppliers, the location of the scanner and other medical devices required in the rooms was identified. Siemens Healthcare Sector subsequently provided detailed drawings of the CT installation which were incorporated into the architect's plans. The RPA assessed and approved the final plan (Fig. 1) from a radiation protection perspective.

The CT scanner will primarily be operated in the CT room. However as required, the equipment will be moved to the Resus Room. In this event, a sliding wall which separates the two rooms will be retracted and the CT scanner will move into the Resus Room. The scanner will be operated in the Resus Room with the sliding wall in the open position to minimise delays in treating patients. Both the CT and Resus Rooms become the Controlled Area when the CT equipment is in operation in the Resus Room.

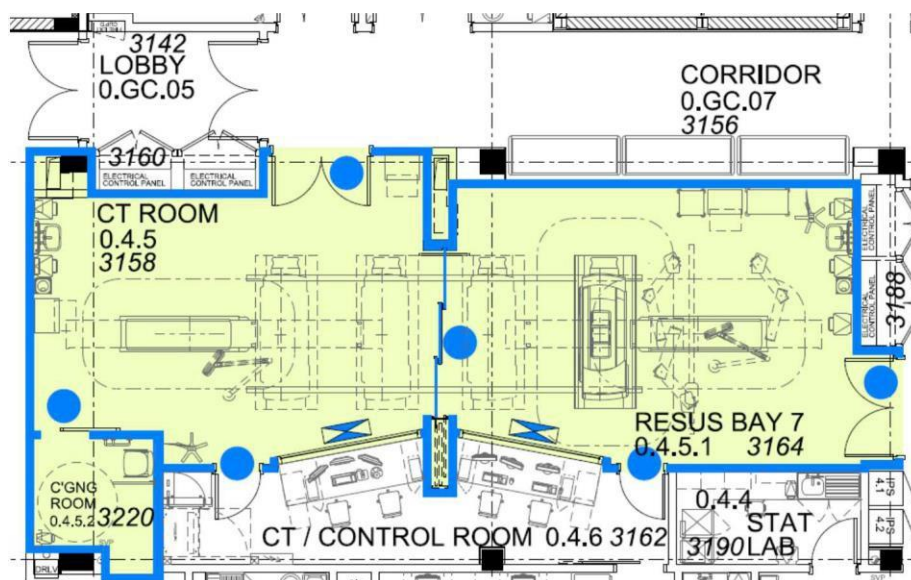


FIG. 1. Architect's drawing of the CT Room & Resus Room/Bay.

3.1. Room Shielding

Shielding calculations were performed in accordance with recommended guidelines to meet national legal requirements [5, 6]. Patient workloads, projected by radiography, radiology & ED staff were adjusted to take into account the likely increased future patient throughput in the Department.

The RPA advised that a consistent level of protection be installed in all boundaries in both rooms. This was dictated by the boundary that required the most shielding. This cautious approach is taken as standard practice for all building projects as experience has proven that specifying different levels of shielding for various boundaries in rooms has resulted in errors which are more costly to rectify. A minimum shielding of Code 7 (3.15mm) lead equivalent material was recommended for all boundaries. All walls were required to be shielded from floor to ceiling slab. As the floor and ceiling were constructed with a minimum of 300mm reinforced concrete slabs, no additional shielding was required in these boundaries.

3.2. Specific shielding challenges

Identifying the shielding solutions for the sliding wall between the two rooms (Fig. 2) and the Siemens ceiling cassette which guides the scanner as it moves between the adjoining rooms proved to be the most challenging task. Several iterations of the drawings were produced following meetings with all relevant parties

in order to identify a shielding solution for these features. The process is discussed in detailed in Sections 3.2.1 and 3.2.2. A 3-D model incorporating these features was constructed by the RPA to assist with the interpretation of the plans.



FIG. 2. Sliding wall between the CT Room & Resus Room (view from Resus Room).

3.2.1 Sliding Wall

The sliding wall travels automatically across a clear opening of 3.1m wide and 2.9m high (Fig. 2) which was sized to allow the CT scanner pass between the rooms. The automated boundary acts as a folding shielded wall and slides back into a recessed housing when open. The wall operation is controlled from the CT Control Room. A safety feature is in place to ensure that the automated wall cannot be activated inadvertently.

A number of challenges were identified during the shielding design phase. These included the overall weight of the wall and the fact that the CT scanner was installed in close proximity to a shielded wall with a gap at floor level. The gap is required to allow the wall open and close. Identifying a shielding solution for the supports which carry the sliding wall above the false ceiling was a challenge. Finally, it had to be ensured that the sliding wall did not come in contact with the magnetic CT scanner tracks/rails on the floor (Fig. 2).

3.2.2. CT Ceiling Assembly (Cassette)

The fixed overhead ceiling assembly unit/ cassette guides the scanner as it moves between the adjoining rooms. It also houses many of the CT scanner electronics and cables. This cassette (1000mm wide x 280mm high) penetrates the concrete wall and thus the shielding between the two rooms (Fig. 3).



FIG.3. Ceiling cassette assembly which penetrates the concrete wall.

It was not possible to incorporate shielding into the ceiling cassette as this would have invalidated the CE marking on the system. This presented a challenge for the architects and the RPA. The front of the ceiling assembly which faces into the clinical areas must remain free of obstructions while the CT scanner travels between the rooms (Fig. 3). Hence the cassette could only be shielded with a lead shroud on three sides. An additional shielding solution was required for the front of the cassette. A separate Code 7 lead shield was identified as the most practical solution and this was incorporated into the first sliding wall leaf at cassette height level (Fig. 4). This shield moves into place to cover front of the cassette when the sliding wall is closed.

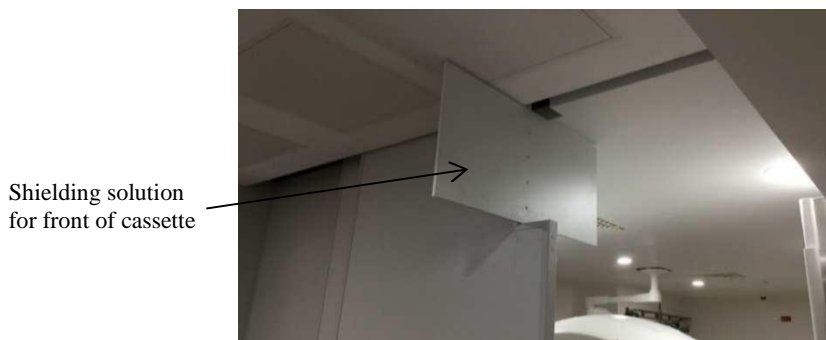


FIG.4. Shielding solution for front of ceiling cassette

3.3. Assessment of the shielding

The RPA and medical physicists performed routine site visits during the construction phase of both rooms to assess installation of the shielding and to ensure that it fulfilled the design criteria. Spot checks on the integrity of the shielding were performed using a ^{99m}Tc radiation source and a calibrated contamination monitor [5,6]. These tests were undertaken during the construction phase and a final assessment was made during commissioning of the CT scanner. Regular meetings took place between the RPA, architects and building contractors to address issues identified during these assessments.

Scatter radiation measurements were also performed in the rooms during commissioning of the CT scanner. Tissue equivalent phantoms were scanned using clinically relevant imaging protocols to generate the scatter radiation. Measurements confirmed that the shielding solution for the CT ceiling cassette was successful in ensuring design requirements were met.

Scatter measurements were also performed in the Resus Room while the scanner was in operation in the CT Room. These results exceeded acceptable levels, even though the gap between the sliding wall and the floor was designed to be within recommended limits [6]. Following an adjustment to the sliding wall guides at ceiling level, the wall was dropped several millimeters. The maximum gap between the floor and the sliding wall was reduced to approximately 7mm. Subsequent scatter measurements confirmed that the issue had been resolved. This finding highlights the importance of performing scatter measurements during the commissioning phase to validate the shielding works.

4. CONCLUSIONS

The Project Team was tasked with identifying a shielding solution for a dual room sliding gantry CT scanner concept in a busy ED. Although faced with a number of design restrictions from the onset of the project, the team identified a satisfactory solution.

5. REFERENCES

- [1] Health Service Executive (HSE), "UL Hospitals Group Operational Plan 2017".
- [2] The Royal College of Radiologists, Standards of practice and guidance for trauma radiology in severely injured patients, 2nd Edition, 2015.
- [3] Wada, D., Yasushi N., Yamakawa, K., et al. First clinical experience with IVR-CT system in the emergency room: positive impact on trauma workflow, *Scand J trauma Resusc Emerg Med.* (2012) 20:52.
- [4] Frellesen C., Boettcher, M., Wichmann, JL., et al. Evaluation of a dual-room sliding gantry CT concept for workflow optimisation in polytrauma and regular in-and outpatient management. *Eur J Radiol.* (2015) 117-122.
- [5] Sutton, DG., Martin, CJ., Williams, JR., Peet, DJ., Radiation shielding for diagnostic radiology, 2nd Edition, The British Institute of radiology, 2012.
- [6] The Radiological Protection Institute of Ireland, The design of diagnostic medical facilities where ionising radiation is used. A code of practice issued by the Radiological Protection Institute of Ireland, 2009.

THE ART OF REMOTE SENSING FOR NUCLEAR MEDICINE

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Abstract

Remote sensing can play crucial role in the evolving nuclear medicine sector in Egypt. As the number of national medical centers that use Positron Emission Tomography (PET)/ Computed Tomography (CT) scans and radioactive isotopes for diagnostics and therapeutic services of cancer patients, is increasing. Remote sensing also copes with the worldwide efforts of having specific cyclotron together with radio pharmacy and clinic on-site. The paper presents an integrated remote sensing solution for nuclear medicine facilities, to detect radiation exposure, and contamination in the production, diagnostic and therapeutic areas. The system allows economic and reliable autonomous monitoring, it helps reducing the cost, enhancing production quality, increasing number of treated patients, improving the patient remedy, assuring the staff safety, and complying with regulatory requirements. Four communication technologies ZigBee, Bluetooth, Wi-Fi, and Z-Wave, have been investigated, and compared in context of network parameters (data rate, coverage, power constrains and bandwidth) and success factors (cost, reliability, ease of deployment and security). The ZigBee technology seems to be the best candidate for the proposed system. Results demonstrate the feasibility of using remote sensing for nuclear medicine and promise the efficient performance of the national facilities.

1. INTRODUCTION

Radionuclides are unstable isotopes produced in a cyclotron and attached to biological tracer, they have excess neutrons or protons that cause radioactively decay, in the form of emission of gamma rays or subatomic particles. The cyclotron accelerates particles to very high speeds and focusing them on a target substance where a reaction takes place to produces the desired short-lived radionuclide for industrial and medical purposes. Once produced in the cyclotron, the radioactive material is transferred to a shielded "hot cell" where it is run through sophisticated chemistry process to produce active tracers. These tracers can be used in medical imaging to more accurately diagnose, treat and prevent diseases. The most commonly used cyclotron-produced radionuclides in radio pharmacy are ^{11}C , ^{13}N , ^{15}O , Tc-99m and ^{18}F , their respective half-lives are 20.38, 9.96, 2.03, 360 and 109.7 min [1], the most commonly used tracer cancer diagnosis is the FDG based on F-18.

The PET scanner allows the study of physiological, biochemical and pharmacological functions on the molecular level. Illnesses such as cancer, cardiovascular diseases and even neurological disorders can be detected long before symptoms appear. The produced FDG has to be tested against TQM tools to assure that is highly reliable, and fully compliant with Good Manufacturing Practice (GMP) [2]. At the diagnostic & therapeutic side, before the PET scan take place, a small amount of FDG is injected into the patient by a qualified nurse, and because cancer grows at a faster rate than healthy tissue, cancer cells absorb more of the FDG that is concentrated in the tissue of interest.

Radiopharmaceuticals have special characteristics and require unique quality assurances described in numerous pharmacopoeias. The quality control includes testing for both chemical and radiochemical purity before the radiotracer is administered to the patient, there is a constant drive to reduce the time spent on quality control. From the point of view of protecting environment and public, a significant issue is the control of activity of volatile radionuclides released during irradiation or chemical synthesis of PET radiopharmaceuticals inside hot cells, or in case of target breaks or failure [1]. Therefore, effective radiation protection program in shall include fixed area and air monitoring in the controlled areas to evaluate dosage inside facility and activity estimation of radioactive gaseous species released through the stack to limit releases into the atmosphere. In addition, both workers and patients shall be monitored and it is necessary to reduce the risk within a reasonably achievable range for the patients receiving radiopharmaceutical. Generally, the patient may receive around $70 \mu\text{Sv/h}$ in 1ml FDG (350 MBq) during the treatment, and his vital signs be monitored [3].

2. PROPOSED NUCLEAR MEDICAL FACILITY

To meet the radiation protection program requirements, the facility shall have sophisticated radiation monitoring system with variety of radiation monitors, displaying and alarm units to offer effective control, data acquisition and information systems. Wireless Sensor Network (WSN) will ensure autonomous radiation monitoring and prevent personnel over-exposures of workers and patients. The cyclotron area designed with specific maze-style to hold any radioactive gases until they are decayed to non-radioactive elements. The walls, ceiling, and door of the cyclotron vault have thick concrete walls according to the shield calculations. Although in case of event, cyclotron cannot produce radioactivity without electrical power, gamma and positron detectors are installed and inside the stack duct to increase sensitivity.

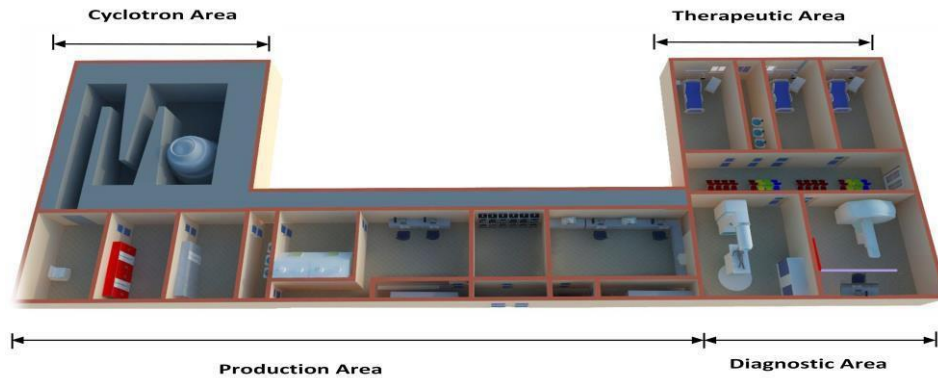


FIG. 1 Layout of proposed nuclear medicine facility

The production area designed with radiochemistry laboratories that contains adequately shielded hot cells for the manipulation and dispense of radiopharmaceuticals, cleaning rooms, quality assurance laboratories, delivery rooms and central monitoring room in the middle as shown in Fig. 1. Diagnostic area where the PET/CT scanners are installed while therapeutic areas where patients are prepared or receive treatments. Both areas are controlled areas with high exposure risks and require specific site planning and monitoring objectives.

3. INTEGRATED REMOTE SENSING SOLUTION

The Integrated Remote Sensing Solution (IRSS) is optimized to the specific needs of the proposed facility as shown in Fig. 1, with variety of radiation detectors for area, airborne, process and effluent monitoring that installed at fixed points to cover the different areas. All worker personal dosimeters connected to the system wirelessly and have visual and audible alarms that are generated as soon as a predefined threshold is exceeded on doses or dose rate. At the same time, it enables the collection, and sharing of multi variables of the patient condition including the dose received for oncology QA purposes, [3] and his vital signs for health care. IRSS managed by integrated software for sensing, processing, sending/receiving, storing, reporting, controlling alarms & interlocks, and supported by user friendly graphic interface. The data stored in the database can be accessed through software installed on any workstation in the network, it can be analysed shown in tables and graphs to facility the decisions taken by the workers or the nuclear medicine staff. It can also offer actuating audible, visual, and remote alarm notifications, by setting area monitors to conservative alarms levels and notify workers of increased area dose rates in real time.

3.1. System configuration

The system consists of number of sensing nodes, centralized computer, and communication network. Wireless Sensor Network (WSN) is covering the production, diagnostic, and therapeutic areas, while due to the concrete shielding wired star topology network is installed with an access point at the vault exit door and connected to the WSN via a gateway. Radiation sensor nodes measure radiation levels in the surrounding environment and communicates the information gathered via the communication network, as shown in Fig.2. The WSN consist of sensor node, router, and server or base station. Each node has specific sensing unit and is equipped with wireless module to communicate the sensed data to the base station through routers that work as repeaters. Base station is connected to central PC in the central monitoring room via serial link.

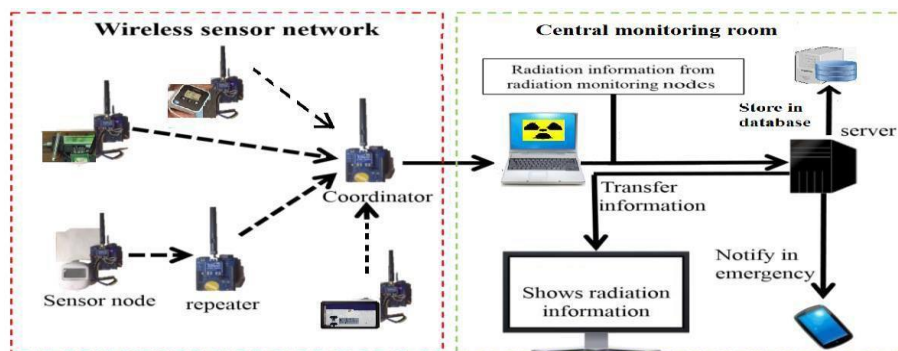


FIG. 2 The architecture of integrated remote sensing solution showing different sensor nodes

Three different sensing units with certain specifications, as described in Table, is to be installed in:

1- **The radiation detection unit**, which is a multi-tasking unit, used for;

- Production monitor unit for the cyclotron area.
- Contamination monitor unit for radiochemistry & quality control laboratories, diagnostic and therapeutic areas.
- Air monitors unit to detect radioactive particulates in the air vented from the exhaust ducts to the atmosphere after passing through a HEPA and carbon filter.

2- **The dosimeter unit**, which is used for the radiation monitoring of the dose collected by cyclotron workers or the medical staff in the diagnostic and therapeutic area.

3- **The health care unit**, which is used in monitoring the dose rate for QA purposes and the vital signs of the patients during radioactive isotopes injection and scanning.

TABLE 1. SPECIFICATION OF DIFFERENT SENSING UNITS

	Detector type	Measurement Range	Min. units
Production-monitoring	gamma detector (GM, NaI(Tl) scintillation) and neutron detectors	0.1mSv/h ~ 50mSv/h	3
Area monitoring	gamma detectors (GM counters)	Fast & thermal neutron ~12Mev	1
Air monitoring	gamma detectors (GM)	0.1mSv/h ~ 50mSv/h	12
Dosimeter unit	electronic personal dosimeters	1 μSv/h ~10 m Sv/h	1 (No. of ducts)
Health care unit	biomedical sensor measure heart rate (HR), electrocardiogram (ECG), oxygen saturation (SpO2), and body temperature (T°) and QA oncology detector (Dual-Diode Dosimeter)	0.1mR/h - 100R/h	20 (No. of workers) 3 (No. of patients)

4. NETWORK EVALUATION

Four communication technologies ZigBee, Bluetooth, Wi-Fi, and Z-Wave, have been investigated, results shown in Table 2. All the four technologies use the 2.4 GHz except for the Z-wave which reduce the possibilities of potential interference issues. Z-wave available data rates include 9600 bits/s and 40 kbits/s, which may limit the indoor transmission reliability for the complex environment as the medical centre. Wifi has the highest data rate (54Mb/s), while Zigbee is ideal for low data rate (250 kb/s), that suites the monitoring and control applications. Bluetooth and Wifi protocol is far more complex, resulting in longer development times, while Z-Wave uses simpler protocol which make it user friendly. Zigbee, Wifi and Z-wave security based on AES encryption key with date protection of Cyclic Redundancy Check (CRC). Z-Wave is slightly more expensive than Zigbee as it is single company owned standard that manufacture the chipsets, while there are tons of WiFi, Bluetooth and Zigbee chipsets in the market from comparatives companies. The most significant factor in determining the network lifetime is radio power consumption per each node, Zigbee, Bluetooth and Z-wave radios consume milliamps compared to Wifi radios, and this very low-power operation can only be achieved by combining both low-power hardware components and low duty-cycle operation techniques. It was reported frequently that Zigbee had a total average sleep current of 6.5 μA (at 3.0V), it consumes approximately 23 mA during transfer and, small package takes around 10 ms to transfer [4].

TABLE 2. ZIGBEE, BLUETOOTH, WI-FI AND Z-WAVE CHARACTERISTICS

	Zigbee	Bluetooth	Wi-Fi	Z-Wave
IEEE Specifications	IEEE 802.15.4	IEEE 802.15.4	IEEE 802.11a,b,g,n	IEEE 802.15.4
Frequency	2.4 GHz	2.4 GHz	2.4 GHz, 5 GHz	9.6MHz
Date Rate	250 kb/s	1Mb/s	54Mb/s	9.6- 40 Kb/s
RF coverage	30-100 m	100m	>300 m	30-100 m
Power Consumption	Ultralow	low	Medium	low
Security	AES-128 encryption.	ED Stream cipher	AES block cipher	AES-128 encryption
Cost	Not expensive	More expensive	More expansive	Slightly expensive
Ease of deployment	Easy	Complex	Complex	User friendly
Applications	Monitoring & Control	Cable replacement	Web, email, video	Smart homes
Scalability	Up to 65000 node	8 nodes	30 node	232 node

Bluetooth does not have the ability to mesh, like Z-Wave & Zigbee, therefore limiting its overall range that is around 100 m outdoor. Wifi is high-bandwidth network with non-line-transmission ability with RF range more than 300, it is primarily used for media streaming, browsing the web, and other data-heavy activity. Comparing WiFi and ZigBee both have their positive qualities, but they obviously come with negatives. What you gain in bandwidth with WiFi is lost in battery power and range and vice versa. Zigbee and Z-wave can extend its range use hop techniques, it has the ability to hop further than Z-Wave (30 hops as compared to 4). However, more hops means higher coverage range, it means more latency or delay in network. A single Zigbee based network can have a network size of up to 6500 nodes whereas Z-Wave network can have up to 232 nodes. Both Bluetooth or Wifi has very limited ability to add paired clients if compared to Zigbee; 8 and 30 nodes as shown in Table 2. Scalability is a key issue for monitoring applications; it means that no performance degradation is resulted when adding more sensor nodes to the network. With varying network size, as increasing numbers of workers and patients; Zigbee network could provide reliable performance with no degradation [5]. Zigbee-based Wireless Sensor Network (WSN) has the features of high bandwidth and typical data rate for monitoring application, with low cost, low power consumption, reasonable indoor coverage and ability of accommodating large number of nodes seems to be the best candidate for the proposed system. Planned deployment with practical site survey enhances the proper placement of the nodes and set the amount of infrastructure required to meet the network demands to overcome shielded wall of the production buildings.

CONCLUSION

The system allows economic and reliable autonomous monitoring, it helps reducing cost, enhancing production quality, increasing number of treated patients, improving the patient remedy, assuring staff safety, and complying with regulatory requirements. Results demonstrate the feasibility of using remote sensing for nuclear medicine and promise the efficient performance of the national facilities. IRSS provide real-time, remote dose rate monitoring which support effective radiation protection program. Zigbee technology with low power, defined rate of 250 kbit/s, low cost and high ability to scale best suited the proposed system.

REFERENCES

- [1] INTERNATIONAL ATOMIC ENERGY AGENCY, Cyclotron Produced Radionuclides: Production and Quality Control of FDG, Technical Reports Series No. 11, IAEA, Vienna, 2010.
- [2] Mukherjee, B. A real-time positron monitor for the estimation of stack effluent releases from PET medical cyclotron facilities. *Applied Radiation Isotopes*, pp. 899–905, 2002.
- [3] Ko, J., Lu, C., Srivastava, M. B., Stankovic, J. A., Terzis, A. and Welsh, M., “Wireless sensor networks for healthcare,” *Proceedings of the IEEE*, vol. 98, no. 11, pp. 1947-1960, 2010.
- [4] A. E. Kouche, A. M. Rashwan, and H. Hassanein, “Energy consumption measurements and reduction of zigbee based wireless sensor networks,” *IEEE GLOBECOM*, pp. 557–562, Dec 2013.
- [5] J. Granjal, E. Monteiro, and J. S. Silva, “Security for the internet of things: A survey of existing protocols and open research issues,” *IEEE Communications Surveys Tutorials*, vol. 17, pp. 1294–1312, 2015.

Epoxy/ Magnetite Composite for Radiation Attenuation and Restoration Mortar for Cracks in Biological Shields

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Abstract: A trial was made to create epoxy/ magnetite/ boron carbide (Ep/Mag/B₄C) composite for radiation shielding and repair mortar for the developed cracks in biological shields. Mechanical properties; flexural, compressive and impact strengths, as well as, physical properties; water absorption, porosity and dry bulk density have been carried out to study the composite integrity for practical application. Also, attenuation properties have been performed using a collimated beam emitted from spontaneous fission ²⁵²Cf (100 µg) neutron source and neutron gamma spectrometer with stilbene scintillator. The pulse shape discrimination (PSD) technique based on the zero cross over method was used to measure the fast neutron and gamma ray spectra. Thermal neutron fluxes have been measured using the thermal neutron detection system and the BF₃ detector. The attenuation parameters, namely macroscopic effective removal crosssections Σ_R (cm⁻¹), macroscopic crosssections Σ (cm⁻¹) and total attenuation coefficients μ (cm⁻¹) of fast and thermal neutrons and gamma rays respectively were evaluated using the attenuation relations. Also, MERCSEF-N and WinXom programs have been used to calculate the macroscopic effective removal crosssections Σ_R (cm⁻¹) and total mass attenuation coefficients μ/ρ (cm².g⁻¹) respectively for the concerned composites. Measured and calculated results were compared and a reasonable agreement was found. The studied parameters are important and needed to be determined prior to using a material clinically in radiation treatment and protection.

Keywords: *Composite, Mechanical and Physical Properties, Radiation shielding Parameters, Spectra, Removal cross section, Mass Attenuation Coefficient.*

1. Introduction

Any concrete structure may develop structural or non-structural cracks either by aging or any other cause. Cracks in reinforced concrete greater than approximately 1–2 mm require sealing/injection to prevent ingress of moisture, oxygen and other materials or for other reasons that could deteriorate the structure (Allen and Edwards, 1987). Also, the nuclear facilities biological shield concrete structures deteriorate by the impact of increasing temperature and exposure to radiation. In addition, irradiation of concrete to nuclear radiation, lead to increase the temperature which affects on the mechanical, physical and radiation shielding properties of the concrete. Cracks, chips and broken or flaking in concrete are not only unsightly, they can lead to further deterioration of the surface (Acevedo and Serrato, 2010; Granata and Montagnini, 1972).

When repairing the concrete, it's important to select the right repair product for the job and not all products are suited for overlaying large areas. A product ideally suited for general patching may not work well on small cracks and fractures. The rapid growth of the polymer consumption encourage the growth of the incorporated fillers dispersed in the polymeric matrix to minimize the cost, mass besides to increasing strength and the stiffness of the composite. Where, the composites characteristic grow from matrix-filler interaction each constituent participate in the rendering of the composite material (Xanthos, 2010; Niu, 1992). Structural bonding is obtained by means of low viscosity and high viscosity epoxy injection resins. Epoxy resin provides for permanent bonding even of smallest cracks and crack ramifications in concrete and masonry thanks to its high adhesive tensile strength and inherent strength (Kim, 1995). The main

advantage of epoxies is their amazing compressive strength, which at 12,000 psi or greater exceeds that of most concrete. However, epoxies cure very slowly, generally taking hours to harden. This can be an advantage because it allows time for the epoxy to flow into even the smallest crevices (Concrete crack repair, Info@webac.do.).

With polymeric materials providing good neutron attenuation, it has been suggested that these might also be made suitable as shields for gamma and X-rays by adding a heavy mineral or metals (Milewski, 1987). Magnetite (Fe_3O_4) having a high density (4.9- 5.2 g/cm³) is an effective shielding material for neutrons and γ -rays (Bashter et al., 1997; El-Sayed Abdo and Megahed, 2001). In addition, to high-density aggregates, additives containing boron are sometimes used to improve shielding properties. Where, the boron has been induced as a neutron absorber in various materials in addition to concrete. For instance, borated graphite, a mixture of elemental boron and graphite, has been used in fast reactor shields. Boron has also been added to steel for shield structures to reduce secondary gamma ray production. Boral, consisting of boron carbide, aluminum and epoxy resins has been used for local shielding purposes (Sesonske and Glasstone, 1986).

To restore concrete structures to their original strength, cured epoxy resin (Ep) filled with crushed magnetite (Mag) in addition to boron carbide (B_4C), is suggested a composite (Ep/Mag/ B_4C) shielding material, as well as, a repair mortar for developed cracks in the biological shields. This mortar will be satisfying the requirements of improved plastics such as high mechanical strength, adhesiveness and reasonable physical properties beside its main role in radiation shielding for this application.

Recently, many researchers have been studied the effect of the dispersed fillers in variety polymers which satisfied the requirements for the radiation shielding (El-Sarraf et al., 2013; El-Sarraf and El-Sayed Abdo, 2013). The prepared concerned composite (Ep/Mag/ B_4C) can be utilized in radiation attenuation with different applications as, shipping and storage of radionuclide materials, many mobile and stationary sources. Also, can be used a portable radiation shielding in medical as lining for the walls of diagnostic and radiotherapy rooms. In addition, might foresee applications for detector shields, neutron guides controlled zones doors, valves and pipes (El-Sayed Abdo et al., 2003; 2003).

The present study has the primary aim of using epoxy, magnetite and boron carbide to prepare (Ep) and (Ep/Mag/ B_4C) composites for the construction of radiation attenuation shields used for variety of applications, as well, a mortar for the developed cracks in biological concrete shields. Measurements have been carried out to investigate the mechanical, physical and radiation attenuation properties. Also, theoretical calculations have been achieved using MERCSEF-N and WinXom programs.

2 Experimental and calculation procedures

2.1 Materials and sample preparation

The concerned composite epoxy/ magnetite/ boron carbide (Ep/Mag/ B_4C) was prepared with definite weights of constituents to provide a suitable; mechanical, physical and attenuation properties. The standard Bisphenol-A based Epoxy resin (Ep) of commercial name (DGEBA DER331 product of DOW Chemical Company-USA, with technical purity 95% and epoxide weight 182-192) hardened by polyoxypropylenediamine (Cetepox 1465 H product of Chemical & Technologies for Polymers Co.-Egypt) was used a composite base. Magnetite obtained from (Atomic Materials Authority, El Kattameya - Egypt) in the form of ore crushed to mesh size -500 μm and boron carbide (B_4C) chemical form (Sigma-Aldrich Ltd, England) were used a composite fillers. Definite weight of the fillers were scattered in the epoxy blank (Ep = 15 %, Mag = 75 % and B_4C = 10 %) to create the (Ep/Mag/ B_4C) composite. First, the molds were glued to the planchettes. The formula ingredients (resin – curing agent – filler) are weighted with an electronic balance and were then mixed together (according to the specified ratios) and stirred to obtain a homogenous mixture. Then the mixture was degassed in order to allow the entrapped air bubbles to be released. Finally, it was poured with courtesy in the specimen's molds. After curing, the samples were extruded from molds and left for more than one week to allow the cross linking process to complete. Cylindrical molds (10 cm diameter and \approx 5 cm thickness) for radiation attenuation measurements and molds of ASTM dimensions for the required mechanical

and physical tests were used. After 24 hours the samples were released and leaved 7 days for extremecross linking before they were shaped with steel adaptation frames tothe final dimensions.

2.2 Mechanical and physical tests

The mechanical tests; compressive, bending and charpy impact strengths have been carried out at room temperature in the National Institute for Standards (NIS) of Egypt. The 400KN ZWICK Universal Testing Machine (No 15376), Zwick Testing Machine Z010 with calibrated cell and charpy impact hammer according to the ASTM (D-695, 1991); ASTM (D-790, 1990) and ASTM (D-256, 1990) designations were used to achieve the mechanical tests. Water absorption, total porosity and dry bulk density, were measured according to the ASTM designation (D-570-81, 1981) and ASTM designation (C948-81, 1981) re-approved 2001.

2.3 Fast neutron and gamma ray measurements

Fast neutron and total gamma ray (primary+ secondary) spectra have been measured behind cylindrical epoxy blank (Ep) and epoxy/ magnetite/ boron carbide (Ep/Mag/B₄C) composite samples with 10 cm diameter and different thicknesses. Measured spectra have been carried out using a collimated beam emitted from the spontaneous fission ²⁵²Cf (100 µg) neutron source and neutron gamma spectrometer with cylindrical stilbene scintillator (Ø= 4cm and thickness=4 cm). The pulse shape discrimination technique (PSD) based on the zero-crossover method were used to measure the pulse amplitude distribution and to reject undesired pulses resulting from recoil protons and electrons due to neutrons and gamma rays respectively. The collimated beam was provided by the narrow beam experimental facility, which consisted of radioactive source, collimator and samples shoulder and detector collimator. Arrangement layout is shown elsewhere (El-Sarraf et al. 2013). The purpose of the beam-detector collimation is to provide the beam of specific intensity and protecting the detector against the side scattered radiations that would enhance the discrimination capability. The spectrometer set up, pulse amplitude distribution and discrimination technique have been explained in detail elsewhere (Miller, 1968; McBeth et al., 1971). Spectrometer discrimination, linearity and energy scaling were checked before taking measurements by accumulating spectra of ²²Na, ¹³⁷Cs, ⁶⁰Co and Pu- α-Be sources. A diagram of the spectrometer components was shown elsewhere (Bashter et al., 1996). Measured pulse amplitude distributions of the recoil protons or electrons were converted into energy spectra of fast neutrons and gamma rays using two unfolding codes (NSPEC and GSPEC) based on the double differentiation and matrix correction methods respectively (Toms, 1971; Kolevatov et al., 1969).

2.4 Slow neutron measurements

Slow neutron fluxes have been measured behind the concerned epoxy blank (Ep) and (Ep/Mag/B₄C) composites with different thicknesses using the thermal neutron detection system with the BF₃ (LND-20354) detector. The same experimental layout in section 2.3 was used where, BF₃ tube was introduced into the detector collimator with an operating voltage of 1600 V. Output pulses of the BF₃ were fed to the preamplifier, then to the amplifier type ORTEC 572A. The amplified pulses were fed to the PC incorporating a TRUMP 8K/2K data acquisition card. The diagram of the measuring system components was shown elsewhere (El- Sayed Abdo et al., 2003). The slow neutron (0–1000 eV) fluxes were measured by integrating the net area under the peaks 2.31 and 2.7 MeV (Knoll, 1989).

2.5 Theoretical calculations

1-Macroscopic effective removal cross section of fast neutrons

The macroscopic effective removal cross sections of fast neutrons Σ_R (cm⁻¹) through (Ep) and (Ep/Mag/B₄C) composites have been calculated using the MERC SF-N computer program. The program had been constructed, verified and applied for calculating the macroscopic effective removal cross-section Σ_R (cm⁻¹) of fast neutrons through homogeneous mixtures, compounds, concretes and composites. To achieve the calculations, atomic masses and mass removal cross sections $\Sigma_{R/\rho}$ (cm².g⁻¹) of all elements and its fraction (constituent elements or compounds of

composite) by weight were fed to the program as input physical data. MERCFS-N program; description and confirmation, in details was given elsewhere (El-Khayatt and El-Sayed Abdo, 2009). The program output is the macroscopic effective removal cross-section Σ_R (cm^{-1}) of fast neutrons through the concerned target. The applications of the program are given in many publications, for instance; (El-Sarraf and El-Sayed Abdo, 2013; El-Sarraf and El-Sayed Abdo, 2013). The program was used to calculate the macroscopic effective removal cross-section Σ_R (cm^{-1}) of fast neutrons through the concerned composites and the results are illustrated in Table 3.

2-Total mass attenuation coefficients of gamma rays

The XCOM program and database cross-section of elements from $Z = 1$ to $Z = 100$, recently prepared to calculate the total/partial mass attenuation coefficients μ / ρ ($\text{cm}^2 \cdot \text{g}^{-1}$) for elements, compounds and mixtures at energies from 1 keV to 100 GeV (Berger and Hubbell 1987). Calculation of the total mass attenuation coefficients μ/ρ ($\text{cm}^2 \cdot \text{g}^{-1}$) at higher energies, are useful for the shielding design of particle accelerators, power reactors and other applications. The program inputs are the constituent elements or compounds and its fraction by weight and it is output gives the total/partial mass attenuation coefficients μ/ρ ($\text{cm}^2 \cdot \text{g}^{-1}$) at standard or choose energies or both selected by the user. Gerward et al., have been updated the Xcom program to a modern version named **WinXcom** runs under the windows operating system which has ability of the conversion of the interaction parameters to excel form which could be easily analyzed and graphed. Details of the WinXcom program are given at (Gerward et al., 2000). WinXcom has been used to calculate the total mass attenuation coefficients μ/ρ ($\text{cm}^2 \cdot \text{g}^{-1}$) for the regarded (Ep) and (Ep/Mag/B₄C) composites, and the obtained results are graphed in Fig.7.

5- Results and discussion

5.1 Mechanical properties

The epoxy blank (Ep) mechanical strengths are presented elsewhere (El-Sayed Abdo, et al., 2003) and for the epoxy/ magnetite/ boron carbide (Ep/Mag/B₄C) are shown in table 1. The decrease in the mechanical properties for the (Ep/Mag/B₄C) is due to the fillers loading fraction. The fillers loading lead to particle agglomeration which affects the composite adhesion and consequently low filler-resin matrix bonding. In other words, particle loading transcends the critical level, called mechanical percolation.

5.2 Physical properties

Water absorption, porosity and dry bulk density for the concerned epoxy blank (Ep) and epoxy/ magnetite/ boron carbide (Ep/Mag/B₄C) composites are presented in table 2. It's noticed that, (Ep/Mag/B₄C) composite has higher values than those for epoxy blank (Ep), and this may be attributed to the fact that, filler incorporation affects composite cross-linking, since it introduces pores to the matrix. By comparison with the published data (El-Sarraf, et al., 2013; El-Sarraf and El-Sayed Abdo, 2013) obtained results are reasonable in terms of practical applications.

5.4 Attenuation results

The measured pulse amplitude distributions of recoil protons and electrons were converted to energy distributions (spectra) of neutrons and gamma rays respectively. The observed spectra of fast neutrons exiting epoxy blank (Ep) ($\rho = 1.00 \text{ g/cm}^3$) and epoxy/magnetite boron carbide (Ep/Mag/B₄C) ($\rho = 2.995 \text{ g/cm}^3$) composites for thicknesses; bare (0), 4.36, 8.50, and 19.02 cm and 4.30, 8, and 20.56 cm are displayed in Figs. 1 and 2. The general trend for the intensity of the neutron spectra is of a decrease with increase in energy and shield thickness, and displayed spectra almost have the same shape and profile for both composites. It is clear that, the spectra does not show build up of neutrons at low energies, and this may be attributed to, the removal of fast neutrons by inelastic scattering is not so effective, where the neutrons of energy above the threshold of inelastic scattering are low at the incident beam. It is apparent that, the spectra depend on the sample thicknesses, for neutrons of energies within 1 to 7 MeV. However, at energies larger than 7 MeV the spectra have the same profile in both Figs. In Fig.2, the magnetite effect on the neutron attenuation is being clear for all thicknesses and at all energies. It

is noticed that, spectra are nearly close with increasing the thicknesses (in both Figs.) and also at all energies, and this may be attributed to the reduction of the neutron yield, consequently the extension of the composite thickness has insignificant effect.

Total gamma ray (primary + secondary) spectra behind the concerned composites and with the same thicknesses are displayed in Figs. 3 and 4. The displayed spectra show the similarity in shape and profiles for all measured thicknesses. The spectra have closely similar profiles, decreasing in intensity with increasing the photon energy and composite thicknesses. The maxima of the gamma ray energy at about 2.225 MeV (in both curves) refers to the contribution of the captured gamma rays due to the absorption of slow neutrons by hydrogen atoms. It is apparent that, epoxy blank (Ep) spectra are closely larger than those for (Ep/ Mag/ B₄C) composite, and this may be attributed to the magnetite and boron carbide effects, consequently the composite density.

Measured fluxes have been integrated over the observed energy range (0.8 to 9 MeV) and (0.4 to 6 MeV) for fast neutrons and gamma rays respectively, while for slow neutrons fluxes have been integrated under the peaks located at 2.31 and 2.7 MeV. The integrated values are plotted against the thicknesses of the concerned composites, and are shown in Figs. 5 and 6. The attenuation curves (Fig. 5) show, fast neutrons and gamma rays flux intensity to decrease exponentially with increase in composite thickness. The fall off is the least for gamma rays and the greatest for fast neutrons and for both composites. And this may be attributed to; the loss of gamma rays is compensated by fast and slow neutrons interaction, resulting in the lowest attenuation of gamma rays. The usual attenuation relations were used to obtain the macroscopic effective removal cross sections Σ_R (cm⁻¹) and total attenuation coefficients μ (cm⁻¹). Figure 6 presents the attenuation relations of slow neutrons where the flux intensity to decrease exponentially with increase in composite thickness. It is clear the absorption effect of slow neutrons by B₄C in case of (Ep/ Mag/ B₄C) composite. The macroscopic cross-sections Σ (cm⁻¹) has been evaluated using the attenuation relations. The obtained attenuation shielding parameters; macroscopic effective removal cross sections Σ_R (cm⁻¹), macroscopic cross-sections Σ (cm⁻¹) and total attenuation coefficients μ (cm⁻¹) of fast and slow neutrons and total gamma rays respectively are shown in Table 3.

The total mass attenuation coefficients μ / ρ (cm².g⁻¹) for the concerned composites have been calculated using the WinXcom program at energies from 10 keV to 100 MeV and are displayed in Fig. 7. The presented curves may be divided to three regions according to the change of mass attenuation coefficients with the photon energy. Region (1) from 10 keV to about 0.1 MeV, region (2) from 0.1 MeV to about 9 MeV and region (3) from 9 MeV to 100 MeV.

At energy range from 10 keV to about 0.1 MeV, the total mass attenuation coefficients (μ/ρ) sharply decrease with increasing the photon energy for both composites. At this range of energy, the predominant photon interactions are the absorbed photons by photoelectric effect and the Compton scattering, where for an absorber with atomic number 20, the dominant interaction at energy from 0.01 to 0.1 MeV is photoelectric effect and from 0.1 to 100 MeV is the Compton scattering (Kaplan, 1989). Accordingly, the photoelectric effect may be considered the main interaction (attenuation effect) in this region. It is obvious, the (μ/ρ) attenuation is larger for (Ep/ Mag/ B₄C) than (Ep) and this may be attributed to the higher atomic numbers of (Ep/ Mag/ B₄C) constituents, especially, magnetite component.

The energy range from 0.1 MeV to about 9 MeV, (μ/ρ) slightly decrease with increasing the photon energy for both composites. The decrease of (μ/ρ) with increasing the photon energy may be attributed to the fact that, the Compton scattering and the pair production are the predominant reactions in this region. The Compton scattering is predominant for gamma photons with energies from 1- 10 MeV for elements of low and intermediate atomic numbers and pair production is predominant at photon energies from 0.5 to 5 MeV for atomic number 60 (Kaplan, 1989). Therefore, the Compton scattering cross section may be considered as a main interaction in this region.

The energy range from 9 MeV to 100 MeV, (μ/ρ) coefficients revert slightly to increase with increase of the photon energies for both composites. This may be return to the successive collisions due to several Compton scattering. So, the photon energy being reduced to the level where photons are absorbed by the photoelectric and the pair production processes, in addition to the Compton scattering. Therefore, in this region, the three main interactions of gamma rays are included, consequently, inconsiderable increase of the total mass crosssections. It is evident also that, the (μ/ρ) is larger for (Ep/ Mag/ B₄C) than (Ep) and this attributed to the higher atomic numbers of (Ep/ Mag/ B₄C) constituents, consequently to the higher density of the composite (El- Sayed Abdo, 2002).

Conclusion

From the measured and calculated results for Ep and Ep/Mag/B₄C composites, it can be concluded that;

1- The measured mechanical properties for (Ep/Mag/B₄C) are less than (Ep), while the physical properties (Ep/Mag/B₄C) have higher values than (Ep), however the measured obtained results for the mechanical and physics properties are reasonable in terms of practical applications.

2- Fast neutron and gamma ray fluxes decrease with increasing of the energy and composite thicknesses, and the attenuation relations for fast and slow neutrons and gamma rays show the fluxes exponentially decrease with increasing the composite thicknesses.

3- The measured (Σ_{R-Meas}) and calculated ($\Sigma_{R-MERCF}$) results for (Ep) and (Ep/Mag/B₄C) are in reasonable agreement, which confirms the measurement and calculation methods.

4- The total mass attenuation coefficients μ / ρ for both composites, sharply decrease by the main, photoelectric effect at energy range from 10 keV to about 0.1 MeV, and slight decrease where, the predominant reaction is the Compton scattering at energy range from 0.1 MeV to about 9 MeV. It is revert slowly to increase where, the three interactions included at energy range from 9 MeV to 100 MeV.

5- Obtained results indicate the Ep/Mag/B₄C composite offers a good mechanical, physical and attenuation properties for many shielding applications, and besides, applicable to be injected mortar for cracks in biological shields.

References

- Acevedo, C. E. and Serrato, M. G., 2010. Determining the effects of radiation on aging concrete structures of nuclear reactors- 10243.WM 2010 Conference, March 7- 11, Phoenix, AZ.
- Allen, R.T.L. and Edwards, S.C., 1987. The Repair of Concrete Structure. Blackie, Glasgow.
- ASTM D-695, 1991. Standard Test Method for Compressive Properties of Rigid Plastics. ASTM materials standards.
- ASTM D-790, 1990. Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. ASTM materials standards.
- ASTM D-256, 1990. Standard Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials. ASTM materials standards.
- ASTM D-570-81, 1981. Standard Test Method for Water Absorption of Plastics. ASTM materials standards.
- ASTM C-948-81, 1981. Standard Test Methods for Dry and Wet Bulk Density, Water and Apparent Porosity of Thin Section of Glass-Fiber Reinforced Concrete. ASTM materials standards.
- Bashter, I.I., Makarious, A.S., El-Sayed Abdo, A., 1996. Investigation of hematite-Serpentine and ilmenite-limonite concretes for reactor radiation shielding. *Annals of Nuclear Energy*, Vol. 23, PP. 65–71.
- Bashter, I. I., El-Sayed Abdo, A. and Samir Abdel-Azim, M., 1997. Magnetite Ores with Steel or Basalt for Concrete Radiation Shielding. *Japn. J. Appl. Phys.*, Volume 36, Part 1, Number 6A, PP. 3692-3696.
- Berger M. J and Hubbell J. H (1987) N B S I R 87-3597, XCOM: Photon Cross

Sections on A Personal Computer, National Institute of Standards Gaithersburg, M D 20899, U. S. A.

Concrete Crack Repair, Epoxy Injection Resin, Info@webac.do.

El-Khayat, A. M. and El-Sayed Abdo., A, 2009. MERCSEF-N: A program for the calculation of fast neutron removal cross-section in composite shields. *Annals of Nuclear Energy*, 36, 832–836.

El-Sarraf, M. A., El-Sayed Abdo, A. and Abdul-Wahab, M. A., 2013. Usability of epoxy/ilmenite composite material as an attenuator for radiation and a restoration mortar for cracks. *Annals of Nuclear Energy*, Vol. 60, PP. 362–367.

El-Sarraf, M. A. and El-Sayed Abdo, A., 2013. Insulating epoxy/barite and polyester/barite composites for radiation attenuation. *Applied Radiation and Isotopes*, 79:18–24.

El-Sayed Abdo, A. and Megahed, R. M., 2001. Homogeneous and Multilayered Shields for Neutrons and Gamma Rays. *Jpn. Appl. Phys.* V.40, Part 1, No. A4, PP. 2460-2404.

El-Sayed Abdo, A., 2002. Calculation of the cross-section for fast neutrons and gamma-rays in concrete shields. *Annals of Nuclear Energy*, Vol. 29, PP.1977-1988.

El-Sayed Abdo, A., Ali, M. A. M. and Ismail M. R., 2003. Influence of magnetite and boron carbide on radiation attenuation of cement-fiber composite. *Annals of Nuclear Energy*, 30, PP.391-403.

El-Sayed Abdo, A., Ali, M. A. M. and Ismail M. R., 2003. Natural fiber High density polyethylene and lead oxide composites for radiation shielding. *Radiation Physics and Chemistry*, 66(3), PP.185-195.

El-Sayed Abdo, A., El-Sarraf, M. A. and Gaber, F. A., 2003. Utilization of ilmenite/epoxy for neutrons and gamma rays attenuation. *Annals of Nuclear Energy*, 30, PP.175-187.

Granta, S. and Montagnini, A., 1972. Studies on behavior of concretes under irradiation. American Concrete Institute (ACI). *Concrete for nuclear reactors* (Special Publication (SP – 34), Vol. II, p. 1163 – 1172.

Gerward, L., Jensen, K. B., Levring, H., and Guilbert, N., 2000. X-Ray absorption in matter. Special Course CS 110, Department of Physics, the Technical University of Denmark.

Kaplan M. F., 1989. *Concrete Radiation Shielding*. John Wiley & Sons, Inc., New York.

Kim, D. H., 1995. *Composite Structures for Civil and Architectural Engineering*. E & FN Spon, London, Glasgow, New York, Tokyo.

Knoll, G.F., 2010. *Radiation detection and measurement*. 3rd ed., John Wiley & Sons.

Kolevatov, Yu. I., Kukhtevich, V.I. and Goryachev, I.V., 1969. Scintillation gamma spectrometry with stilbene crystal. *Voprosy Dozimetrii Zashchity ot Izlucheniya*, Moscow, 10:131–137.

McBeth, G. W., Lutkin, J. E. and Winyard, R. A., 1971. Pulse shape discrimination with organic scintillators. Koch-Light Laboratories Ltd., Colnbrook, Bucks, London.

Milewski, J. V., 1987. "Handbook of Fillers for Plastics", Van Nostrand, Reinhold, USA.

Miller, T.G., 1968. Measurement of pulse shape discrimination parameters for several scintillators. *Nuclear Instruments and Methods* 63, PP. 121–122.

Niu, M. C. Y., 1992. *Composite airframe structures: practical design information and data*. Conmilit Press.

Sesonske, A. and Glasstone, S., 1986. *Nuclear Reactor Engineering* 3rd ed. New York, USA: Springer.

Toms, M.E., 1971. A computer analysis to obtain neutron spectra from an organic scintillator. *Nuclear Instruments and Methods*, 92(1), PP. 61 – 70.

Xanthos, M., 2010. *Functional fillers for plastics*. John Wiley & Sons.

Figure Captions

Figure 1: Measured fast neutron spectra behind (Ep) composite

Figure 2: Measured fast neutron spectra behind (Ep/Mag/B₄C) composite

Figure 3: Measured total gamma ray spectra behind (Ep) composite

Figure 4: Measured total gamma ray spectra behind (Ep/Mag/B₄C) composite

Figure 5: Measured fast neutron and total gamma ray fluxes behind (Ep) and (Ep/Mag/B₄C) composites

Figure 6: Measured slow neutron fluxes behind (Ep) and Ep/Mag/B₄C) composites

Figure 7: Total mass attenuation coefficients of gamma ray for (Ep) and (Ep/Mag/B₄C) Composites

Table 1: Measured mechanical Properties for (Ep/Mag/B₄C) Composite.

Mechanical Tests Composite	Bending		Compression		Impact
	Flexural Strength MPa	Modulus of Elasticity MPa	Compressive Strength MPa	Modulus of Elasticity MPa	Impact Strength (J/m)
Ep/Mag/B ₄ C	31.03	9363.96	62.82	2454	142.97

Table2: Measured physical propertiesfor (Ep) and (Ep/Mag/B₄C) composites.

Physical properties Composite	Water absorption %	Porosity %	Drybulk density (g.cm ⁻³)
Ep	0.0106	0.0124	1.16
(Ep/Mag/B ₄ C)	0.0389	0.066	2.63

Table 3: Measured and calculated attenuation parameters for (Ep) and (Ep/Mag/B₄C) composites.

Composite Parameter	Ep	Ep/Mag/B ₄ C
$\Sigma_{R-Meas}(cm^{-1})$	0.09531 ± 0.00373	0.11295 ± 0.00196
$\Sigma_{R-MERCF}(cm^{-1})$	0.103347	0.12060
$\mu_{Meas}(cm^{-1})$	0.06353 ± 0.00108	0.09457 ± 0.00185
$\Sigma_{Meas}(cm^{-1})$	0.04345 ± 0.00393	0.05832 ± 0.00722

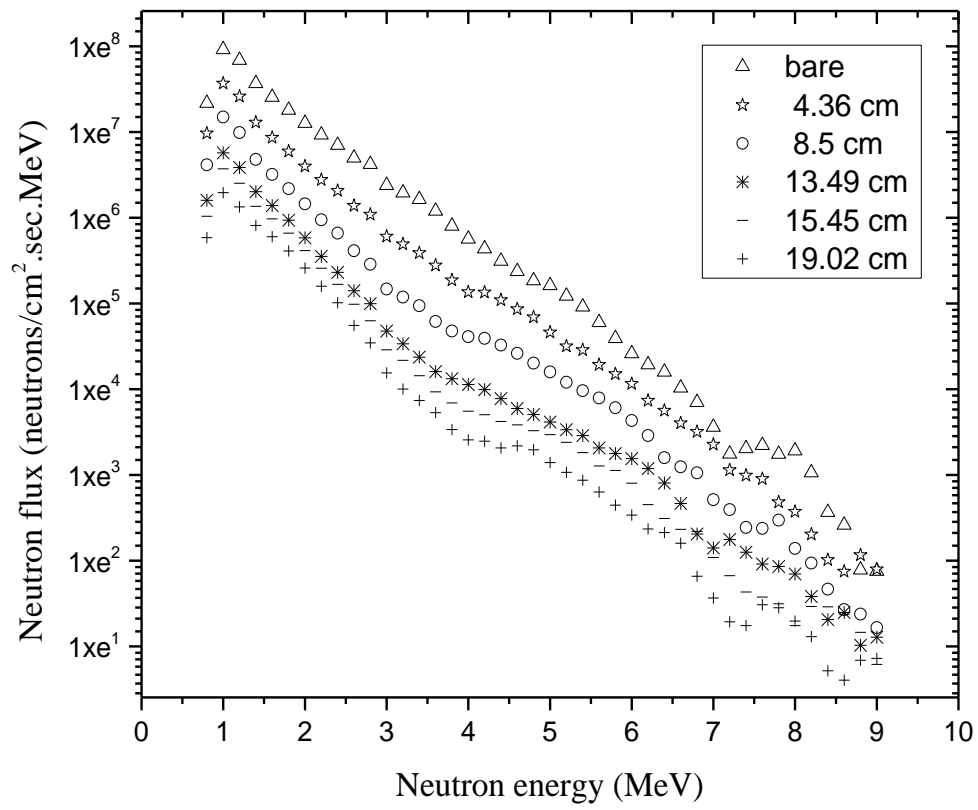


Fig. 1:

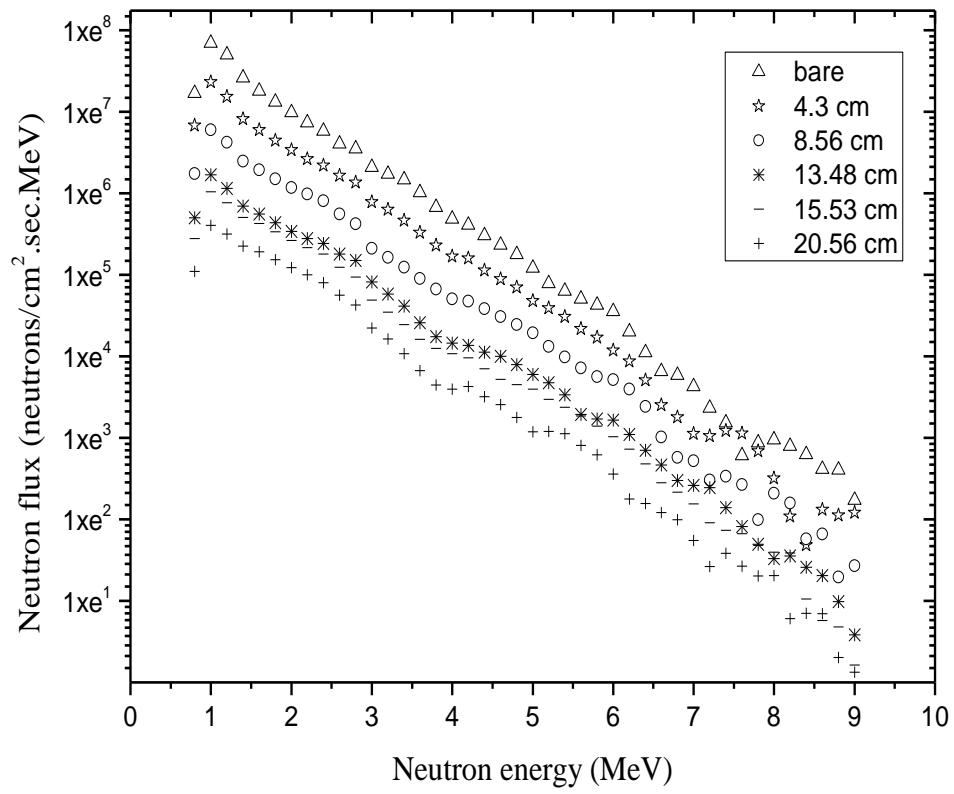


Fig. 2:

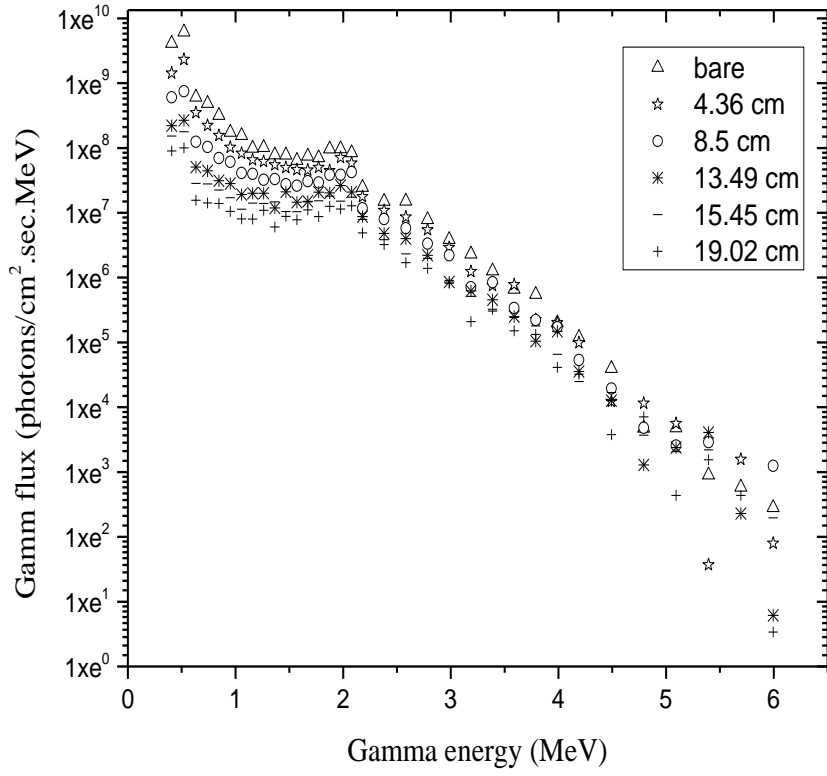


Fig.3:

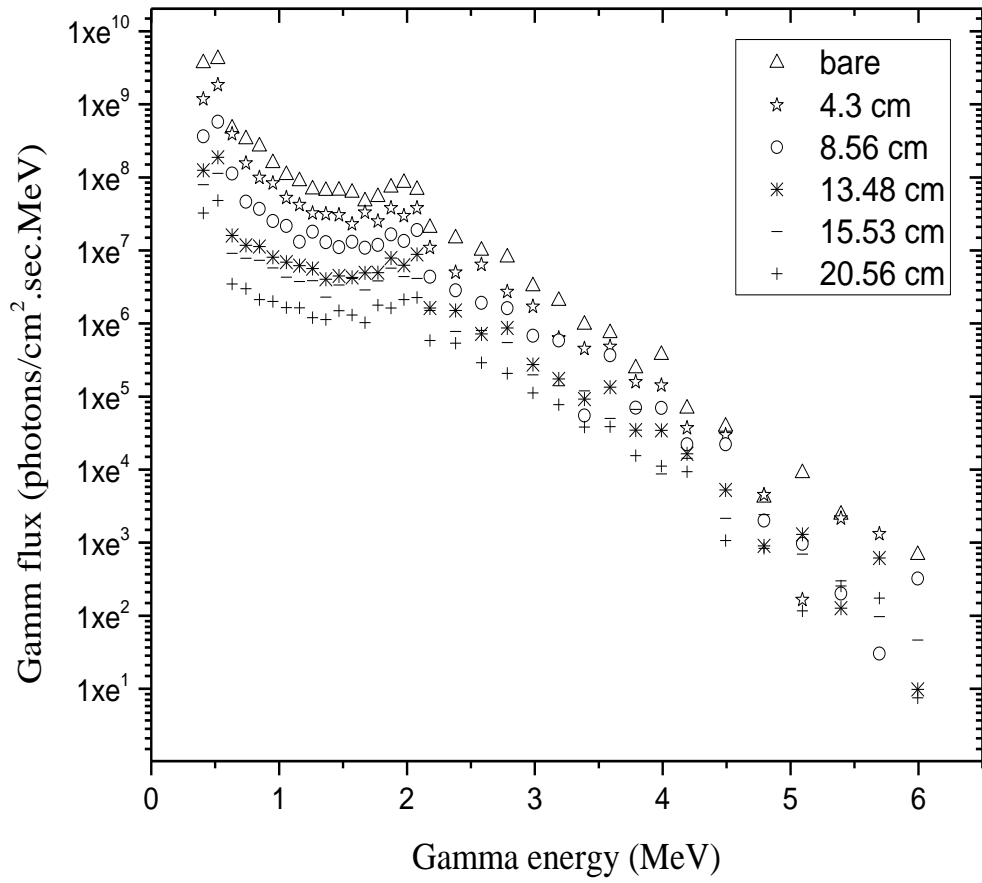


Fig. 4:

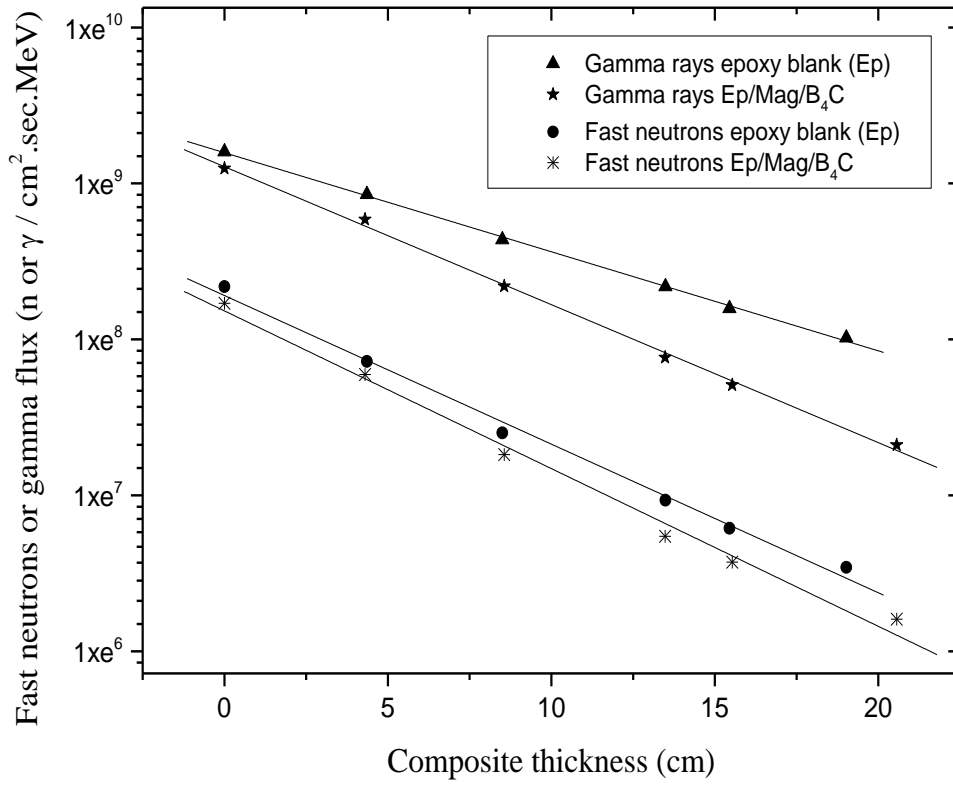


Fig.5:

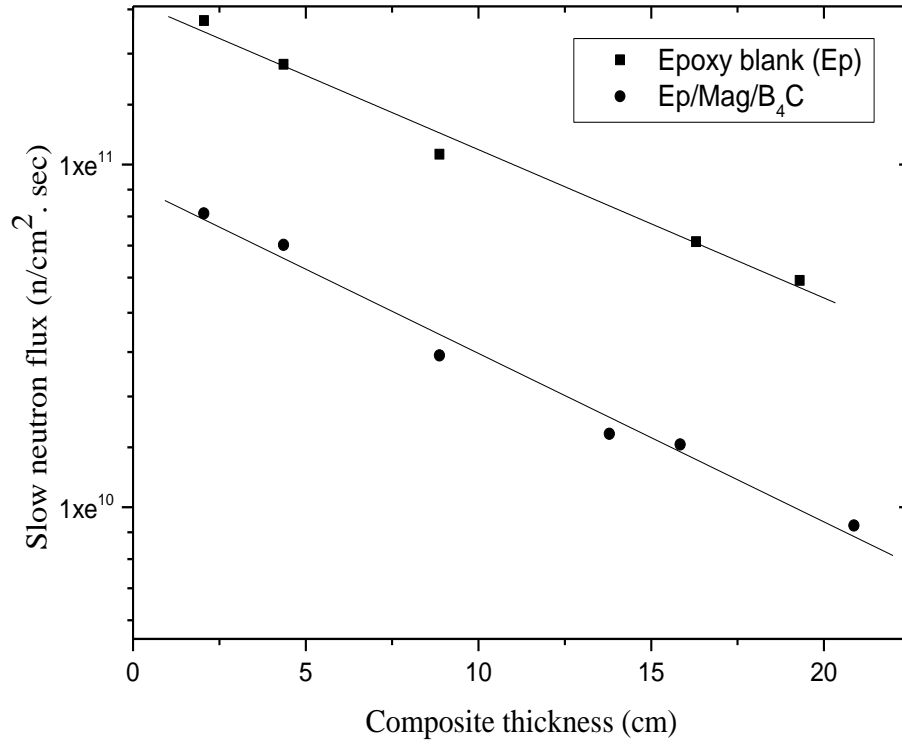


Fig.6:

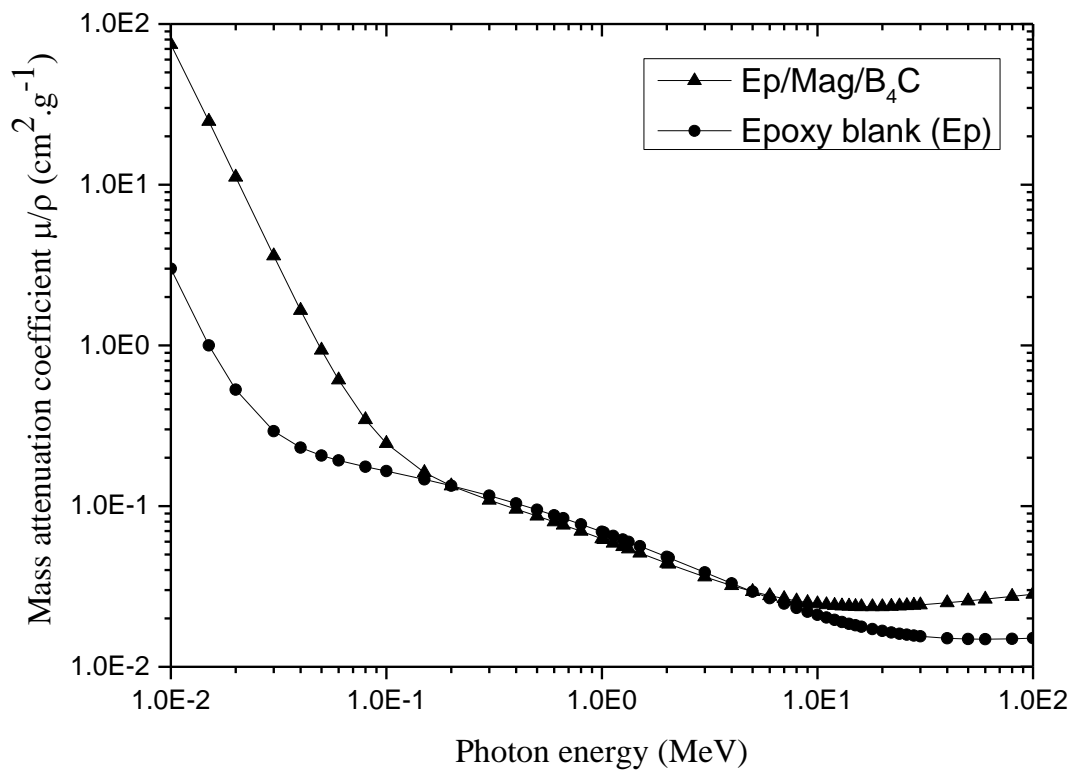


Fig. 7

CUBAN EXPERIENCES IN THE IMPLEMENTATION OF NEW MEDICAL TECHNOLOGIES: ACTIONS AND CHALLENGES.

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Abstract

Current technological progress in medicine has led to an extraordinary change in both diagnostic and therapeutic radiological procedures. The new technologies are a substantial and indispensable part of contemporary medical practice, so better and more efficient methods of diagnosis and therapy have been developed, which are becoming more sophisticated and require a greater specialization of all technical and medical staff. These technologies generate a very complex universe and evolves vertiginously. In the last decade there has been a planned and notable introduction of new medical technologies in Cuba, so, the Regulatory Authority (RA) and the Ministry of Public Health (MINSAP), have had to develop strategies and undertake actions for the proper regulation of them, which has as main objectives: to ensure the safety use and at the same time to promote of a safety culture to encourage a questioning and learning attitude by the staff of the medical institutions and discourage complacency. The paper reflects essentially the actions taken by the Cuban RA to face, from the regulatory point of view, the introduction of new technologies as well as their conscious, safe and sustainable implementation, ensuring that regulatory compliance corresponds to the new era of medical technologies.

1. INTRODUCTION

The new technologies are a substantial and indispensable part of contemporary medical practice. As a result, better and more efficient methods of diagnosis and therapy have been developed, which are becoming more sophisticated and require a greater specialization of all technical and medical staff. These technologies generate a very complex universe that among other peculiarities evolves vertiginously. In the last decade there has been a planned and notable increase of new technologies in medical practice in Cuba, for this reason, the National Centre for Nuclear Safety (RA), has had to develop strategies and undertake actions for the proper regulation of them. Among the main objectives of these actions, updating regulations and promotion of a safety culture to encourage a questioning and learning attitude by the staff of the medical institutions and discourage complacent attitude, can be mentioned.

2. ACTIONS DEVELOPED IN THE IMPLEMENTATION OF NEW MEDICAL TECHNOLOGIES

The following actions have been undertaken:

1. Conduction of a joint safety assessment project, together with medical institutions, to different radiotherapy services, applying Risk Matrix tools. Through this project, a safety assessment was conducted on the current status of the different services in Radiotherapy, including the different modalities (Tele-cobalt Therapy, HDR Brachytherapy, Teletherapy with Linear Accelerators) and also new technologies introduced. Currently, this project is being applied to the services of Nuclear Medicine.
2. Conduction of Annual Regulatory Conferences, oriented to managerial staff and radiation protection officers, for discussion and debate on radiological safety issues, regulations, and safety requirements of new technologies, among other topics.
3. Definition of the frequency of inspections commensurate with the risk of the practices and the peculiarities of the new equipment. This frequency is increased if the result of previous inspections and the general situation of the installation so indicate, also if there were some safety problems during the commissioning of the new equipment.
4. Establishment of the Rules for Staffing, Training and Authorization of Personnel involved with the use of ionizing radiations. These rules clearly establish the qualification, experience and training requirements, for the workers occupationally exposed and define the personnel subject to the process of individual authorizations. On the other hand, one of the requirement imposed by the RA to obtain the Institutional Operating License is the demonstration that there is sufficient staff and they have required training.
5. Systematic training and qualification of the Regulatory Authority's personnel in the new technologies that are introduced in the country. This training may include internships at medical institutions and courses funded by the IAEA.
6. Establishment of contractual agreements with companies supplying the new technologies for qualification, training and certification of personnel, both nationally and internationally.
7. Proactive attitude of the Regulatory Authority in the development of radiological protection courses, as well as of advanced training courses and master degree courses in Medical Physics.
8. A technical judgment of acceptance is required for the clinical use of the equipment involved in the medical applications; issued by the Center for State Control of Drugs and Medical Equipment and Devices (CECMED); competent authority for the quality assurance of the medical equipment.
9. Conducting national workshops with the participation of specialists from different hospitals who have acquired the same new equipment with the aim of exchanging experiences about their operation and safety measures.
10. A project has been prepared by the Ministry of Public Health of Cuba (MINSAP), in collaboration with three institutions of the National Health System (NHS) and institutions of other sectors, specialized in the early diagnosis of cancer, evaluation of response to treatment and therapy with ionizing radiation.

11. Within the above mentioned project, multidisciplinary working groups were created, integrated by specialists of different profiles as required: doctors, medical physicists, technologists, radiochemists, producers of radiopharmaceuticals, engineers, regulators, among others, with the following general objectives:
 - To identify the need of equipment, both the main hardware and all auxiliary supporting elements, among them, the instruments for quality assurance and radiological protection.
 - To identify areas of training for personnel.
 - To evaluate the offers presented by suppliers that submitted the tender of the equipment.
 - Acceptance and commissioning of the equipment.
12. Development of periodic technical meetings to evaluate the compliance with the construction schedule and related technical standards to prevent risks during the construction process, installation of equipment and acceptance of the technology.

3. DISCUSSION

An important aspect to follow in the implementation of the new medical technologies, is the dynamics of the technical and technological advances, which happen at a vertiginous speed, and poses a significant challenge, not only for the personnel directly involved in the practice, but also for the personnel of the Regulatory Authority. Therefore, for an effective and efficient performance of the Regulatory Authority in this process, it is required that:

- its personnel is properly qualified, trained and knowledgeable of the latest advances in the medical technology that uses ionizing radiations,
- the staff is enough and proportional to the scale of the national development in the radiological medical practices being introduced.

Other aspects to consider are the wide spectrum of sources associated to the different radiological medical practices, the significant variation in their technical and technological complexity, as well as the range of associated doses; which condition a need for establishment of risk based requirements, that would help the Regulatory Authority to focus efforts and optimize financial and human resources.

For operators who own new technology equipment it is very important the initial training and certification of the staff, as well as the maintenance of their competences through a continuous and conscious training program, to guarantee an optimal and safe exploitation of all installed capacities. Other issues to take into consideration are: adequate design and construction of the premises where the new equipment will be installed, compliance with the regulatory requirements and recommendations of international organizations, which contributes positively to the process of obtaining the corresponding Operation License.

4. CONCLUSIONS

1. The Regulatory Authority should maintain a proactive role in the implementation of the

- new medical technologies without losing its independence of judgement.
2. The work in teams of the different actors involved in the process of assimilation of these new technologies promotes an enhancement in the safety culture at the Regulatory Authority and at the medical institutions as well.
 3. It is very important to ensure an adequate safety performance in medical practices by assuring that the staff are appropriately trained for their duties, that the equipment used meet relevant international specifications for radiation safety and that safety culture is embedded in the routine activities in all departments.
 4. Staff training cannot be underestimated, considering the risks involved and the complexity of the technology.
 5. The organizational methodology presented in this paper has made possible to implement the introduction, step-by-step of new technology in medical practices, bearing in mind that the fundamental purpose is the improvement of safety in diagnosis and treatment of cancer.
 6. The work in teams composed by administrative, specialized and regulatory staff to share knowledge and tasks, as well as creating a working schedule for the process introduction of new technology in the field of cancer diagnosis and treatment has demonstrated its effectiveness.
 7. It has been very effective that the RA has trained its staff before medical institutions introduce new technologies for cancer diagnosis and treatment.

References

- [1] Ministry of Science Technology and Environment, CITMA; Ministry of Public Health, MINSAP: Rules Basic Radiation Safety Standards, in force by Joint Resolution CITMA - MINSAP, Havana, Cuba, 2002, available only in Spanish)
- [2] Ministry of Science Technology and Environment, CITMA; Ministry of Public Health, MINSAP: Rules for Staffing, Training and Authorization of Personnel involved with the use of ionizing radiations, in force by Joint Resolution CITMA - MINSAP, Havana, Cuba, 2004, available only in Spanish)
- [3] Safety Guide for Nuclear Medicine, in force by Resolution No. 40/2011, Havana, Cuba, 2011, available only in Spanish)
- [4] National Center for Nuclear Safety, CNSN: Safety Guide for Safety Assessment of practices and activities involving the use of ionizing radiations, in force by Resolution No. 17/2012, Havana, Cuba, 2012, available only in Spanish)
- [5] National Center for Nuclear Safety, CNSN: Safety Guide for Radiotherapy, in force by Resolution No. 41/2011, Havana, Cuba, 2011, available only in Spanish)
- [6] Guerrero Cancio M., Romero Pérez Teresa de la Caridad, Introducción de tecnologías para el diagnóstico y el tratamiento del cáncer en Cuba. Revista Nucleus No.60, La Habana, 2016, 8-12

Radiation exposure in Cryoballoon ablation compared to catheter ablation with 3D-electroanatomic mapping in AF patients

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Abstract

Aim: to compare radiation exposure to patients during cryoballoon ablation compared to 3D-electro-anatomic mapping catheter ablation in AF patients to compare their effectiveness in reducing radiation exposure to patients.

Patients and Methods: The study conducted on 30 patients referred to AF ablation from electrophysiology clinic in the Cardiology department at Ain-Shams University Hospitals. All patients subjected to full history, 12-lead electrogram, echocardiogram, electrophysiological study after a written informed consent then ablation of the pulmonary vein potentials either by 3D mapping system or cryoballoon. Procedure duration and fluoroscopy time were collected and analysed. Radiation exposure to the patients were measured by placing thermoluminescent dosimeter (TLD) along edges of the cardiac silhouette and cover the entire region facing the fluoroscopy source.

Result: there was statistically significant higher procedure time with 3D mapping ablation group compared to cryoballoon ablation group, but showed no statistically significant between the two group regarding fluoro-time. Also, our results showed statistically significant higher patients' peak skin doses at right scapular area and cryoballoon ablation group compared to 3D mapping ablation group.

Furthermore, our findings showed that there was no statistically significant correlation between peak skin doses and fluoro-time, but there was statistically significant correlation between peak skin dose and usage of high frame rate and also with high DAP (dose area product).

Introduction

More than 15 years ago, the basis for the development of catheter ablation of AF was established when foci of ectopic beats originating from the pulmonary veins were observed to be capable to trigger AF [1, 2].

AF ablation, when performed in experienced centers by adequately trained teams, is more effective than antiarrhythmic drug therapy in maintaining sinus rhythm, and the complication rate, though not negligible, is similar to the complication rate for antiarrhythmic drugs [3, 4].

Today, two different electro-anatomic mapping systems are widely used in clinical practice. The CARTO mapping system (CARTO-3), which relies both on a magnet-based visualization of ablation catheter and an impedance-based system that allows for both tip and catheter curve visualization and simultaneous visualization of multiple electrodes. The second electro-anatomic mapping system is guided by electrical impedance mapping (NavX, St. Jude medical, St. Paul MN) using voltage and impedance for localization. Both of them have demonstrated reduction in fluoroscopy duration [5].

Focal point-by-point RFCA of AF to isolate PV electrically has shown considerable success in treating paroxysmal AF. However, the procedure is complex, time-consuming, and highly dependent on operator competency [6].

Recent meta-analysis showed Cryo-Balloon has comparable clinical efficacy and safety in comparison to Radio-Frequency ablation; with a trend towards reduction of procedure time [7].

Following the dramatic rise in the number of percutaneous interventional procedures, cases of patients with deep skin ulceration and necrosis were reported in the 1990s [8].

In 1994 the U.S. Food and Drug Administration issued an advisory regarding skin injury from fluoroscopically guided procedures [9]. The ICRP and WHO reiterated the importance of preventing skin injuries from interventional fluoroscopy procedures [10].

PATIENTS AND METHODS

PATIENT SELECTION:

This study enrolled 30 patients presenting with paroxysmal/persistent atrial fibrillation and referred for AF ablation either by 3D anatomic mapping or Cryoballoon in Ain Shams university hospitals throughout one year.

Definitions of AF types were decided according to AF definitions stated in ESC guidelines 2016 [11], as follows:

- **Paroxysmal AF:** Self-terminating, in most cases within 48 hours. Some AF paroxysms may continue for up to 7 days. AF episodes that are cardioverted within 7 days should be considered paroxysmal.
- **Persistent AF:** AF that lasts longer than 7 days, including episodes that are terminated by cardioversion, either with drugs or by direct current cardioversion, after 7 days or more.

Inclusion criteria:

Patients who have paroxysmal/persistent atrial fibrillation which were Drug refractory (had failed treatment with class I or III antiarrhythmic drugs) and Documented by 12 lead ECG or Holter monitoring.

Exclusion criteria:

Patients who have one or more of the following were excluded from the study: Hugely dilated left atrium, Patients with rheumatic valvular heart disease, Left atrial thrombi discovered by transesophageal echocardiography, Manifest accessory pathway detected by standard surface ECG or Ventricular tachycardia.

Method:

The selected patients were subjected to **history taking, Baseline 12-lead electrogram:** (done before & after the procedure) to assess rate, rhythm, baseline intervals, any conduction disturbances and **Echocardiogram** for baseline measurements of LA, LV dimensions, systolic & diastolic LV functions, valvular functions. Transesophageal echocardiography will be done on the day of ablation to exclude LA thrombi.

All patients were given written informed consent for electrophysiological study and radiofrequency ablation. Full explanation will be done about the procedure in details.

The following data were collected:

I. **Radiation exposure to the patients:** skin dose will be measured at patients' back (at both scapular regions and vertebral region) and peak skin dose by using Thermoluminescent dosimeter (TLD) along edges of the cardiac silhouette and cover the entire region facing the fluoroscopy source.

II. Procedure data :

- Fluoroscopy time: total duration of fluoroscopy during procedure (minutes).
- FPS (Frame Per Second) and DAP (Dose Area Product) readings were collected from Fluoroscopy machine.
- Total Procedure duration: time from entering to leaving the catheterization laboratory (minutes).

Results

Procedure Data

30 patients were categorized to two groups, 15 (50%) patients categorized to 3D mapping ablation group, and the other 15 (50%) categorized to cryoballoon ablation group. There was an additional atrial flutter ablation case within each group, which represent (6.7%) of total case numbers.

Mean procedure time (mins) was (168.70 ± 44.33), ranged within (105.00 - 290.00). Mean Fluoro-time (mins) was (68.99 ± 26.42), ranged within (31.00 - 137.00). The mean value of DAP (Dose Area Product) recorded after the procedures was (382707.03 ± 217920.8) (mGy/cm^2), ranged within (72907.00 - 948005.00) (mGy/cm^2).

Patient Skin Dose:

It was measured at patients' back (at both scapular regions and vertebral region) and peak skin dose. The mean value of measured patient skin dose at right scapular area was (902.681 ± 546.631) (mGy) ranged within (269.563 – 2247.64).

The mean value of measured patient skin dose at vertebral area was (962.532 ± 1475.166) (mGy) ranged within (114.54 – 8640.86) (mGy). The mean value of measured patient skin dose at left scapular area was (35.6718 ± 33.669) (mGy) ranged within (8.798 - 193547) (mGy). The mean value of measured patient peak skin dose was (1065.8499 ± 470.5785) (mGy) ranged within (269.563 – 2247.64) (mGy).

Table (1): shows comparison between 3D mapping ablation group and cryoballoon ablation group regarding **procedure time (mins)**, **fluoro-time (mins)**, **frame per second (FPS)** used and **dose area product (DAP)**

		3D mapping ablation	Cryoballoon ablation	Independent t-test	
				t	p-value
Procedure time	Mean±SD	190.67 ± 41.01	146.73 ± 36.80	3.088	0.005
	Range	120 – 290	105 – 200		
Fluoro-time (mins)	Mean±SD	76.85 ± 23.47	61.13 ± 27.61	1.680	0.104
	Range	43.3 – 137	31 – 118		
FPS	Mean±SD	7.75 ± 5.39	11.50 ± 5.20	-1.939	0.063
	Range	3.75 – 15	3.75 – 15		
DAP (mGy/cm ²)	Mean±SD	368465.00 ± 209267.11	396949.07 ± 232687.98	0.353	0.727
	Range	179883 – 901506	72907 – 948005		

The previous table shows that there was statistically significant difference between 3D mapping ablation group and cryoballoon ablation group regarding procedure time, as there was statistically significant longer procedure time with 3D mapping ablation group (p-value = 0.005).

Interestingly, there was no statistically significant difference between 3D mapping ablation group and cryoballoon ablation group regarding fluoro-time (p-value = 0.104), although lesser fluoro-time was noticed in cryoballoon group.

Although there was higher usages of high frame per second (FPS) with cryoballoon ablation group (mean value 11.50 ± 5.20 vs 7.75 ± 5.39 mins), there was no statistically significant difference (p-value = 0.063).

Also, there was no statistically significant difference between 3D mapping ablation group and cryoballoon ablation group regarding dose area product (DAP).

Table (2): Comparison between 3D mapping ablation group and cryoballoon ablation group regarding **patient skin dose** at Patients' back (at both scapular regions and vertebral region), also a comparison between their peaks

		3D mapping ablation	Cryoballoon ablation	Independent t-test	
				t	p-value
Right scapular area	Mean±SD	574.875 ± 105.220	1230.486 ± 614.508	-4.073	0.000
	Range	358.663 – 686.551	269.563 – 2247.64		
Vertebral area	Mean±SD	887.879 ± 131.599	1037.185 ± 2116.225	-0.273	0.787
	Range	782.568 – 1322.737	114.54 – 8640.86		
Left scapular area	Mean±SD	31.71 ± 10.836	39.633 ± 46.873	-0.638	0.529
	Range	13.536 – 56.848	8.798 – 193.547		
Peak skin dose (mGy)	Mean±SD	887.879 ± 131.599	1243.82 ± 611.159	2.205	0.036
	Range	782.568 – 1322.737	269.563 – 2247.640		

Interestingly, there was statistically significant association between skin doses at right scapular area and cryoballoon ablation group, but there were no statistically significant differences between 3D mapping ablation group and cryoballoon ablation group regarding either left scapular area or spinal area.

Also, that there was statistically significant association between peak skin doses and Cryoballoon ablation group.

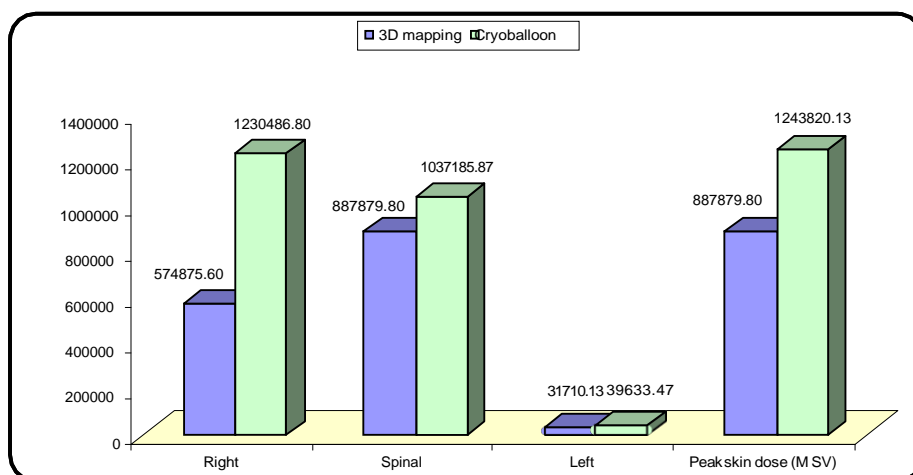


Figure (1): Shows there was statistically significant association between skin doses at right scapular area and Cryoballoon ablation group, but there were no statistically significant differences between 3D mapping ablation group and Cryoballoon ablation group regarding either left scapular area or spinal area. Also, there was statistically significant association between peak skin doses and Cryoballoon ablation group.

Table (3): shows correlation of **peak skin dose** with **fluoro-time**, **FPS** and **DAP**

	Peak skin dose (MSV)	
	r	p-value
Fluoro-time(mins)	0.231	0.219
FPS	0.581**	0.001
DAP (mGy/cm2)	0.782**	0.000

The previous table shows that there was no statistically significant correlation between peak skin doses and fluoro-time, but there was statistically significant correlation between peak skin dose and usage of high FPS and also with high DAP.

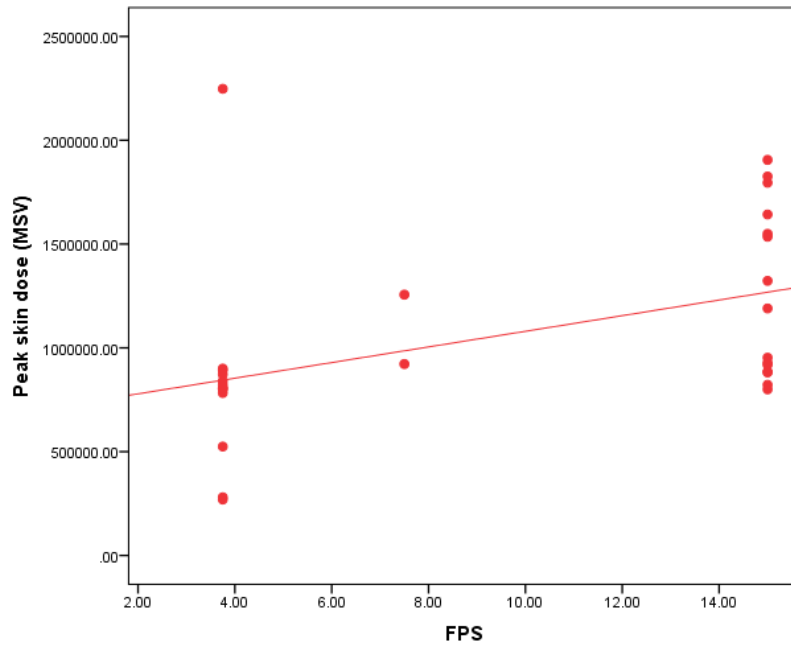


Figure (2): Correlation between peak skin dose and FPS.

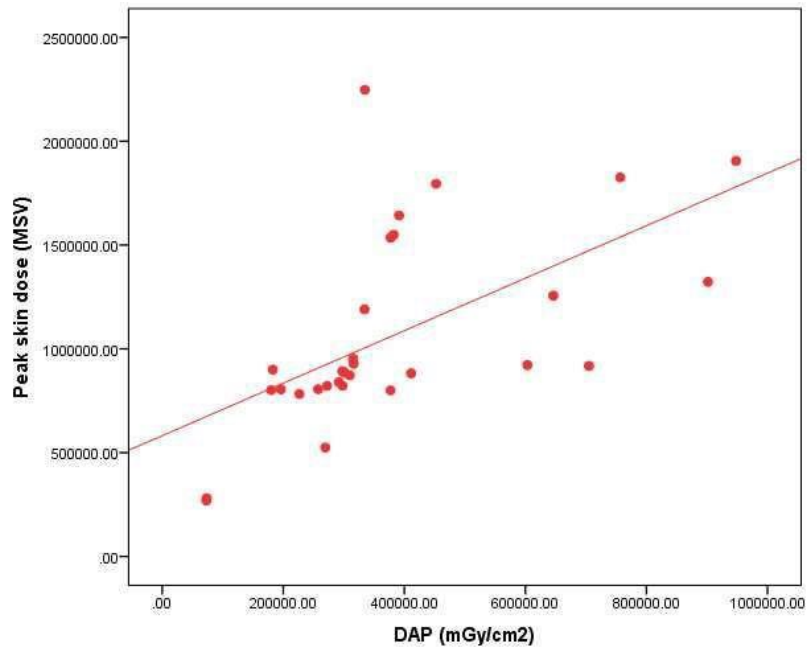


Figure (3): Correlation between peak skin dose and DAP.

Discussion

Procedure time

Our results showed there was statistically significant higher procedure time with 3D mapping ablation group (mean time 190 vs 146 mins) (range 120 – 290 min vs 105 – 200 mins) compared to cryoballoon ablation with (p-value = 0.005).

These findings were compatible with findings of recent meta-analysis [7] which concluded that cryoballoon has comparable clinical safety in comparison to RF ablation, and shows that use of second generation cryoballoon ablation is associated with reduction of procedure time ablation (range 112–215 min vs. 111–284 min; WMD [95% CI] $\frac{1}{4}$ 214.44 [232.91 to 4.02], P $\frac{1}{4}$ 0.13), although there was a high heterogeneity for this risk estimate.

Our finding also agree with 4 trials [12, 13, 14, 15] comparing RF and cryoballoon PVI in AF patients and reported that mean procedure and fluoroscopy times were lower in cryoballoon compared to RF ablation.

Our findings were compatible with a previous meta-analysis comparing two techniques, [16] which showed cryoballoon was comparable with RF ablation in terms of efficacy, with significantly shorter procedure duration and similar fluoroscopy time. However, mixed patient samples of paroxysmal and persistent AF were included in this study, and there were significantly more patients with paroxysmal AF referred to cryoballoon ablation than to RF ablation. Both meta-analyses included only studies using the first-generation cryoballoon catheters.

Similarly, previous meta-analysis Xu et al. [17] which found cryoballoon is associated with significantly shorter fluoro-time and procedure duration and similar efficacy and safety compared with radio-frequency ablation. However, there was strong evidence of heterogeneity and studies included in this meta-analysis considered mixed populations of paroxysmal and persistent AF.

Study of *Metzner et al.* [18] suggested that the shorter procedure duration with the second-generation cryoballoon catheters is likely due to a larger surface area of coolant distribution, which allows a more extended and simultaneous circumferential ablation and with the potential reduction of bonus freeze cycle(s) and/or additional touch-up applications compared with first-generation devices.

Fluoro-time

Our findings showed a fluoro-time (range 43.3 – 137) (mean 76.85 ± 23.47) in 3D-mapping group vs fluoro-time (range 31 – 118) (mean 61.13 ± 27.61) in cryoballoon group which showed no statistically significant between the two group regarding fluoro-time.

These findings agree with *Buiatti et al.* [7] meta-analysis which displayed a comparable fluoroscopy duration in cryoballoon vs. radio-frequency (range 17–61 min vs. 18–73 min; WMD [95% CI] $\frac{1}{4}$ 1.05 [22.89 to 4.99], P $\frac{1}{4}$ 0.60).

Our findings are also compatible with the study by *Macle et al.* [19] which showed that even in very experienced hands, catheter ablation of atrial fibrillation is associated with a fluoroscopy time of approximately 60 min and, consequently, with a relatively high radiation exposure.

Our findings are also compatible with a retrospective analysis *Khaykin et al.*, [20] which showed that non-fluoroscopic 3D mapping system was associated with the average fluoro-time still close to one hour (mean 52 ± 21 min).

Our findings shows no statistical significance difference of additional (extended) atrial flutter ablation regarding procedure time and fluoro-time over AF procedure (not extended). These findings were not compatible with study of *Kuck et al.* [21] which showed that extended ablation procedures (beyond PVI) consistently require longer procedures, more fluoro-time and ionizing radiation, potentially creating risk for patients. Our findings were limited by low patient number, and considered for further studies.

Study of *Verma et al.* [22] showed that Left atrial macro re-entrant tachycardia is relatively uncommon after PVI ($\approx 5\%$), which may occur in up to 25% of patients after left atrial substrate modification ablation, often due to incomplete ablation lines. Thus, for patients with persistent AF, ablation of complex fractionated electrograms, ablation of rotors, or routine deployment of linear lesions or other additional ablations does not seem justified in the first procedure.

Interestingly, study of *Rolf et al.* [23] showed a technology with ECG-synchronized fluoroscopy cine loops (e.g. in left oblique and right oblique view), with a latency of 80 ms, that achieved a reduction of 50% fluoroscopy time for AF ablation, from 31 min to 16 min.

Frame Rate

Our results showed mean value frame rate (9.63 ± 5.54) used during the procedures, ranged within (3.75 - 15.00), these finding refer to usage of medium and high frame rate in majority of procedures.

Although there was higher usages of high Frame rate with cryoballoon ablation group (mean value 11.50 ± 5.20 vs 7.75 ± 5.39), our study found there was no statistically significant

difference (p-value = 0.063) and this modifiable factor may contribute to higher patients skin dose especially in long procedure, as Study of *Chambers et al.* [24] concluded.

Study of *Chambers et al.* [24] shows that a reduction of the fluoroscopic pulse rate from 15 frames/sec to 7.5 frames/sec with a fluoroscopic mode to low dose reduces the radiation exposure by 67% and recommends to use 7.5 frames/sec fluoroscopy setting or lower on long cases.

Patient skin doses

Our results showed a mean value of measured patient peak skin dose was (1065.849 ± 470.5785) mGy ranged within (269.563 - 2247640.00) mGy among our cases.

Our findings agree with *Miller* [25] which stated that knowledge of the patient's skin dose distribution could help to avoid the risk of skin injuries, but measurement of skin dose distribution is not an easy task in fluoroscopically guided procedures, especially in cardiology, where very different C-arm angulations are used during the procedures and the regions of the irradiated skin can also be very different. However, using different C-arm angulations can help reduce peak skin dose, especially when collimation is also used.

As patient radiation dose increases, the operator should consider the radiation dose already delivered to the patient and the additional radiation necessary to complete the procedure. It may be possible to reduce further radiation usage and control skin dose by limiting the number and length of cine series, decreasing the dose rate for cine or fluoroscopy, using collimation or changing the gantry angle slightly.

DAP (Dose Area Product) or KAP (Kerma Air Product)

Our findings showed a mean value of DAP or KAP was (382.707 ± 217.92) (Gy/cm²), ranged within (72.907 – 948.005) (Gy/cm²). Also, there was no statistically significant difference between 3D mapping ablation group and Cryoballoon ablation group regarding Dose Area Product (DAP), but there were higher values among Cryoballoon ablation group.

Noteworthy that, a KAP between 150 and 250 Gy/cm² in cardiology procedures is more appropriate, depending on the radiation field size and the specific protocols. These values could indicate peak skin doses greater than 2 Gy in a single procedure. These values are intended to trigger follow-up for a radiation dose that might produce a clinically relevant injury in an average patient [26].

Our findings showed benefits of displaying DAP (or KAP): First, if the trigger level has been exceeded, the patient's personal physician should be informed about the patient's radiation dose and the possibility of ionizing radiation effects. Appropriate clinical follow up should be arranged. If the dose estimate after the procedure is close to the threshold for deterministic effects then the patient should be informed of possible symptoms or observable skin effects by the interventionist or his/her staff. Information about what the patient should do in case these effects appear should be provided.

These observations are compatible with study by *Miller* [25] which concluded that knowledge skin dose distribution and KAP and peak skin dose (PSD), are sometimes more important, particularly when repeated procedures are performed on the same patient.

Second, during the procedure, the cardiologist should be aware of the fluoroscopy time, the number of cine series and cine frames, and the total patient dose, either as KAP or DAP. Modern fluoroscopy systems that are compliant with the international standard for interventional fluoroscopy systems display radiation data to the operator during the procedure [27].

Interestingly, our study found statistically significant association between skin doses at right scapular area and cryoballoon ablation group, which reflects higher usage of LAO angulation among this group. As a fact, this angulation directs X-ray tube toward patient's

right scapular area (shoulder) and near to the operators. Furthermore, our study shows there was statistically significant association between patients' peak skin doses and Cryoballoon ablation group, which may be explained from higher usage of high frame rate, higher usage of LAO view.

In linear regression analysis, our findings showed that there was no statistically significant correlation between peak skin doses and fluoro-time, but there was statistically significant correlation between peak skin dose and usage of high FPS and also with high DAP. But, there was highly statistically significant positive correlation between peak skin dose with fluoro-time and DAP at different FPS = 3.75, FPS = 7.5 and also at FPS = 15.

These findings are compatible with studies by *Chida* [28], *Fletcher* [29] which concluded that Fluoro-time does not include the effect of fluoroscopy dose rate and does not indicate the radiation dose from cine. It is not a useful descriptor of patient radiation dose.

Also, agree with study by *Chambers* [24] which showed that Fluoro-time should not be the only dose measurement recorded or audited.

Overall, our study results deserve several considerations. First, the wide dose ranges observed in our study and previous studies are most likely due to both the wide variation in procedure complexity and the inconsistent use of shields and personal protective devices. Second, cryoballoon ablation was introduced as a new tool in AF ablation in 2005. As in the majority of participating centers the method was introduced only in 2007–2008, and introduced in our hospital very recently, longer procedure and fluoroscopy times might be related to the impact of a learning curve in the early stage. In the majority of the centers, RF ablation has been introduced earlier than cryoablation. This might in part explain our procedural findings. Third, Modest operator dose reductions are expected over time in ablation procedures, due to continuous technological, strategic improvements and enhancement of radiation protection measures.

Conclusion

- We concluded that Cryoballoon ablation technology simply can shorten the demanding procedure duration of PVI compared to 3D mapping ablation technology but not superior to 3D mapping ablation technology in reducing fluoroscopy time which is found compatible with most recent studies comparing both techniques.
- Cryoballoon ablation may be associated with higher peak skin radiation doses to patient skin due to dependence on fluoroscopy image and LAO angulation during the procedure, which require patient dose optimal management of fluoroscopic dose rates.
- Our results concluded that knowledge of DAP and peak skin dose is more important as there was statistically significant positive correlation between peak skin dose and usage of high FPS and high DAP but not always with fluoroscopy time.

Recommendation

- During the procedure, the cardiologist should be aware of the fluoroscopy time, the number of cine series and cine frames, and the total patient dose, DAP.
- In cardiology procedures, a DAP between 150 and 250 Gy/cm² may be more appropriate, depending on the radiation field size and the specific protocols.

- Skin dose distribution, and KAP and peak skin dose (PSD), are sometimes more important, particularly when repeated procedures are performed on the same patient.
- Optimal management of patient dose requires knowledge and control of the typical fluoroscopic dose rates and values of dose per cine frame for the most common operational modes.

REFERENCES

- [1] Haissaguerre M, Jais P, Shah DC, Takahashi A, Hocini M, Quiniou G, Garrigue S, Le Mouroux A, Le Metayer P and Clementy J. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. *N Engl J Med* 1998; 339: 659–666.
- [2] Arentz T, Haegeli L, Sanders P, Weber R, Neumann FJ, Kalusche D and Haissaguerre M. High-density mapping of spontaneous pulmonary vein activity initiating atrial fibrillation in humans. *J Cardiovasc Electrophysiol*, 2007; 18: 31–38.
- [3] Cosedis Nielsen J, Johannessen A, Raatikainen P, Hindricks G, Walfridsson H, Kongstad O, Pehrson S, Englund A, Hartikainen J, Mortensen LS and Hansen PS. Radiofrequency ablation as initial therapy in paroxysmal atrial fibrillation. *N Engl J Med* 2012; 367: 1587–1595.
- [4] Mont L, Bisbal F, Hernández-Madrid A, Pérez-Castellano N, Viñolas X, Arenal A and Matía R. Catheter ablation vs. antiarrhythmic drug treatment of persistent atrial fibrillation: a multicentre, randomized, controlled trial (SARA study). *European heart journal*; 35(8): 501-507.
- [5] Scaglione M, Biasco L, Caponi D, Anselmino M, Negro A, Di Donna P, Corleto A, Montefusco A and Gaita F. Visualization of multiple catheters with electroanatomical mapping reduces x-ray exposure during atrial fibrillation ablation. *Europace*. 2011; 13: 955-962.
- [6] Calkins H, Reynolds MR, Spector P, Sondhi M, Xu Y, Martin A, Williams CJ and Sledge I. Treatment of atrial fibrillation with antiarrhythmic drugs or radiofrequency ablation: two systematic literature reviews and meta-analyses. *Circ Arrhythm Electrophysiol* 2009; 2: 349–361.
- [7] Buiatti A, von Olshausen G, Barthel P, Schneider S, Luik A, Kaess B and Hoppmann P. Cryoballoon vs. radiofrequency ablation for paroxysmal atrial fibrillation: an updated meta-analysis of randomized and observational studies. *Europace*, euw262, 2016.
- [8] Shope TB. Radiation-induced skin injuries from fluoroscopy. *Radiographics* 1996; 16: 1195-1199.
- [9] FDA, 1994. Avoidance of serious x-ray-induced skin injuries to patients during fluoroscopically-guided procedures. Statement 9 Sept. 1994, Food and Drug Administration, Rockville, MD, USA.
- [10] ICRP. Radiological protection in medicine. ICRP Publication 105. *Ann ICRP*, 2007b; 37: 1-63.

- [11] ESC (2016): European Society of Cardiology, Atrial fibrillation. Long term rhythm control.
- [12] Linhart M, Bellmann B, Mittmann-Braun E, Schrickel JE, Bitzen A, Andrie R, Yang A, Nickenig G, Lickfett L and Lewalter T. Comparison of cryoballoon and radiofrequency ablation of pulmonary veins in 40 patients with paroxysmal atrial fibrillation: A case control study. *J Cardiovasc Electrophysiol* 2009; 20: 1343-1348.
- [13] Kuhne M, Suter Y, Altmann D, Ammann P, Schaer B, Osswald S and Sticherling C. Cryoballoon versus radiofrequency catheter ablation of paroxysmal atrial fibrillation: Biomarkers of myocardial injury, recurrence rates and pulmonary vein reconnection pattern. *Heart Rhythm* 2010; 7: 1770-1776.
- [14] Kojodjojo P, O'Neill MD, Lim PB, Malcolm-Lawes L, Whinnett ZI, Salukhe TV, Linton NE, Lefroy D, Mason A, Wright I, Peters NS, Kanagaratnam P and Davies DW. Pulmonary venous isolation by antral ablation with a large cryoballoon for treatment of paroxysmal and persistent atrial fibrillation: Medium-term outcomes and non-randomised comparison with pulmonary venous isolation by radiofrequency ablation. *Heart* 2010; 96: 1379-1384.
- [15] Sorgente A, Chierchia GB, Capulzini L, Yazaki Y, Muller-Burri A, Bayrak F, Sarkozy A, de Asmundis C, Paparella G and Brugada P. Atrial fibrillation ablation: A single center comparison between remote magnetic navigation, cryoballoon and conventional manual pulmonary vein isolation. *Ind Pacing Electro* 2010; 10: 486-495.
- [16] Cheng X, Hu Q, Zhou C, Liu LQ, Chen T, Liu Z et al. The long-term efficacy of cryoballoon vs irrigated radiofrequency ablation for the treatment of atrial fibrillation: a meta-analysis. *Int J Cardiol* 2015;181:297-302.
- [17] Xu J, Huang Y, Cai H, Qi Y, Jia N, Shen W et al. Is cryoballoon ablation preferable to radiofrequency ablation for treatment of atrial fibrillation by pulmonary vein isolation? A meta-analysis. *PLoS One* 2014;9:e90323
- [18] Metzner A, Wissner E, Ouyang F, Kuck KH. Second-generation cryoballoon ablation for paroxysmal atrial fibrillation: a step forward? *Europace* 2014;16:621-2.
- [19] Macle L, Weerasooriya R, Jais P, Scavee C, Raybaud F, CHOI KJ and Haissaguerre M. Radiation exposure during radiofrequency catheter ablation for atrial fibrillation. *Pacing and clinical electrophysiology*, 2003; 26(1p2): 288-291.
- [20] Khaykin Y, Oosthuizen R, Zarnett L, Wulffhart ZA, Whaley B, Hill C, Giewercer D and Verma A. Carto-guided vs. Navx-guided pulmonary vein antrum isolation and pulmonary vein antrum isolation performed without 3-d mapping: Effect of the 3-d mapping system on procedure duration and fluoroscopy time. *J Interv Card Electrophysiol*. 2011; 30: 233-240
- [21] Kuck KH, Brugada J, Furnkranz A, Metzner A, Ouyang F, Chun KR, Elvan A, Arentz T, Bestehorn K, Pocock SJ, Albenque JP and Tondo C. Fire and Ice Investigators. Cryoballoon or Radiofrequency Ablation for Paroxysmal Atrial Fibrillation. *N Engl J Med* 2016; 374: 2235-2245.

- [22] Verma A, Jiang CY, Betts TR, Chen J, Deisenhofer I, Mantovan R, Macle L, Morillo CA, Haverkamp W, Weerasooriya R, Albenque JP, Nardi S, Menardi E, Novak P, Sanders P and STAR AF. Investigators. Approaches to catheter ablation for persistent atrial fibrillation. *N Engl J Med* 2015; 372: 1812–1822.
- [23] Rolf S, Sommer P, Gaspar T, John S, Arya A, Hindricks G and Piorkowski C. Ablation of atrial fibrillation using novel 4D catheter tracking within auto-registered LA angiograms. *Circulation: Arrhythmia and electrophysiology*. 2012; 1:CIRCEP-112.
- [24] Chambers CE, Fetterly KA, Holzer R, Paul Lin PJ, Blankenship JC, Balter S, Laskey WK. Radiation safety program for the cardiac catheterization laboratory. *Catheterization and Cardiovascular Interventions*. 2011; 77(4): 546-56.
- [25] Miller DL, Balter S, Noonan PT and Georgia JD. Minimizing radiation-induced skin injury in interventional radiology procedures. *Radiology* 2002; 225: 329-36.
- [26] NCI. National Cancer Institute, 2005. Interventional fluoroscopy: reducing radiation risks for patients and staff. NIH Publication No. 05-5286. National Cancer Institute, Bethesda, MD. Accessed December 31, 2010.
- [27] IEC. Report 60601 Medical electrical equipment - Part 2-43: Particular requirements for the safety of X-ray equipment for interventional procedures. 2nd ed. Geneva, Switzerland: International Electrotechnical Commission; 2010. ICRP, 1990. The 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. *Ann ICRP* 1991; 21(1-3):1-201.
- [28] Chida K, Saito H, Otani H, Kohzuki M, Takahashi S, Yamada S, Shirato K and Zuguchi M. Relationship between fluoroscopic time, dose-area product, body weight, and maximum radiation skin dose in cardiac interventional procedures. *Am J Roentgenol*. 2006; 186: 774-8.
- [29] Fletcher DW, Miller DL, Balter S and Taylor MA. Comparison of four techniques to estimate radiation dose to skin during angiographic and interventional radiology procedures. *J Vasc Interv Radiol* 2002; 13: 391-97.

TOTAL WORKLOAD FOR RADIOACTIVE FACILITIES WITH VOLUMETRIC MODULATED ARC TREATMENT.

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Abstract

In shielding projects for leakage radiation, generally the value used for Intensity Modulated Radiotherapy (IMRT) factor is 5. This work will show that this value is overestimated and it has direct impact on the calculation of the thickness of leakage radiation. It was performed a retrospective analysis of absorbed dose and monitor unit of 970 patients treated in two years with VMAT radiotherapy technique. A new workload and VMAT factor was obtained. The new value of VMAT factor will be compared with standard value used in Brazilian installations, 5. The average workload for 40 treated per month was 700 Gy/week. The new VMAT factor was found 1,94, 61,2% lower than reference IMRT factor, 5; the leakage barriers were recalculated using both factors: 5 and 1,94 and the difference between two total thickness was 0,41 TVL. The paper showed that the value 5 for IMRT factor is overestimated to leakage shielding, therefore the leakage radiation projects need to be revised to adapt to this new reality.

1. INTRODUCTION

In recent years, there have been drastic changes in the modalities of cancer treatment, particularly with regard to shielding calculation; the change from of 3D conformal radiation therapy (3D-CRT) to intensity modulated radiation therapy (IMRT) has resulted in the increase of monitor units. Rodgers [1] reports that the IMRT factor – which is a comparison between the monitor units (MU) of a conventional treatment with the MU in IMRT treatment having the same dose – has values that can vary from 2 to 10 [1, 2]. Increasing this factor would result in an additional tenth-value layer (TVL) in the shielding of radioactive facilities.

The theory of dose delivery through volumetric arcs was proposed by Yu [3] as intensity modulated arc therapy (IMAT), however, it was only possible to implement the proposed technology, volumetric modulated arc therapy (VMAT), through the development of optimization algorithms geared toward this practice [4, 5]. Oliver et al. [6] reported a shorter beam-on time, with a sharp drop in MU numbers when comparing both techniques.

2. METHODS

The total workload is a quantity of the utmost importance in radiological protection. It is defined as the total dose released by the linear accelerator in Gy/week or Gy/year at a well-defined point, usually at one meter from the source at the isocenter of the linear accelerator. It is quantified by adding the clinical workloads (patient treatment) and the physical workload (quality control, acceptance, commissioning, preventive, and research irradiations).

To quantify this clinical workload over two years (2012 to 2014), the following were extracted from the AriaTM data management system (Varian Medical Systems, Inc.): data on total dose, number of arcs, number of monitor units (MUs), sites, treatment stages, and numbers of hypofractionated treatments.

The institution did not perform treatments of total body irradiation (TBI), total skin irradiation (TSI), or intraoperative radiation therapy (IORT).

In the physical workload, the MUs referring to commissioning, acceptance, prevention, quality control (daily, monthly, quarterly, semi-annual and annual) were quantified. For total workload, some standardizations were made: 1 month (4 weeks) and 1 year (52 weeks).

For the clinical workload [7, 8], using the 953 patients, conventional dose treatments were considered with fractionation ranging from 25 to 39 sessions at a dose below 3Gy/day, with a total of 852 treatments (89.4%); for the case of hypofractionation, the maximum number of sessions considered was 15, with doses ranging from 3 to 20 Gy. The total number of institutional hypofractionated treatments is 101 (11.8% of all treatments).

The physical workload encompasses any radiation that is not patient related, for example: commissioning [8, 9], acceptance, and all quality controls of the linear accelerator. In the latter, the recommendations of TG-142 were followed [10], and the MU values were considered, following the equivalence of 100 MU = 1Gy.

2.1. VMAT Factor

Modern radiation therapy techniques increase the MUs when compared to some conventional treatments, particularly those that use no filter. This increase in MU does not significantly affect the thickness of the primary or secondary barrier [1, 12]; however, for leakage radiation, the MUs can increase up to tenfold at institutions that use IMRT [13], and may significantly affect the leakage workload.

NCRP 151 recommends that for obtaining the factor, firstly, one must obtain MU_{IMRT} , was calculated as shown in equation 1.

By setting the same dose value, the MU value is obtained, with the following configuration in the linear accelerator: source–surface distance = 100 cm; field = 10 x 10 cm², and depth = 10 cm, MU_{conv} is obtained; with the value of this magnitude, the value of the IMRT factor, C_1 can be obtained, making the following equation 2:

Oliver et al., 2009 [6], the number of MUs for modulated volumetric arcs is lower than for the IMRT Step-and-Shoot and Sliding Window treatment modalities.

3. RESULTS

The total dose for all treatments carried out in the two years of conventional treatment with dose limit up to 300 cGy was 34153 Gy, considering one year, 52 weeks, therefore two years is 124 weeks, so the clinical workload in Gy/week will be:

Similarly, for hypofractionated treatments, we have:

The physical workload can be listed according to the institutional dosimetric protocols of all of the quality controls. Total doses of these controls for photon energies of 6, 6SRS, 10 MV and electrons energies of 6, 9, 12, 15, 18 MeV are listed:

TABLE 1. Values for physical workload for radioactive installation that realize VMAT.

Workload (Gy/sem)	
Acceptance + Comissioning	70
Daily Quality Control	83
Monthly Absolute Dosimetry	28
Annual Quality Control	13
Pacient Specific Quality Control	25
Total Wf	219

The total workload for 40 patients is will be:

$$W_T = W_C + W_F; W_T = 328 + 33 + 219 = \mathbf{580 \text{ Gy/sem}}$$

Compared to the Step-and-Shoot and Sliding Window IMRT techniques, use of the VMAT technique requires fewer fields (arcs) for a better conformation of the dose at the target volume, with lower dose values in adjacent radiosensitive organs. The IMRT techniques use from 5 to 9 fields; in this study, the average number of arcs was 1.8.

The VMAT factor is obtained first by calculating the MU_{VMAT} , which is obtained using equation 1, then calculation the ratio MU_{IMRT} / MU_{conv} , was obtained the VMAT factor with average value of 1.94.

The leakage shielding (TVL) was calculated using two values of IMRT factors, 5 is the value of Comissão Nacional de Energia Nuclear (CNEN) recommendation and 1.94 is the value was obtained in the paper. This diference between two values of IMRT factors resulted in a reduction of 0.41 TVL in the leakage barrier thickness.

4. DISCUSSION

The evolution of linear accelerator technology and optimization algorithms resulted in reduction of MU's to perform different radiotherapy treatments, but the value IMRT factor in the leakage barrier has not changed to suit to this new reality. Os results showed that the reduction of IMRT factor would result in a decrease in the leakage barrier.

The IMRT factor results demonstrate that there is no significant difference between the average value calculated for all treatments, 1.94. Therefore, the authors recommend that facilities performing exclusively VMAT treatments use the overestimated value of 2.5 to calculate leakage barrier thickness. The IMRT factor founded in the paper is 50% of standard value used by CNEN in the calculations mentioned above.

5. CONCLUSION

Radiation therapy services are migrating to high technology with arc treatments, and it was shown that important values in the calculation of shielding – such as physical workload, clinical workload, MU_{IMRT} and VMAT factor – need to be updated.

ACKNOWLEDGEMENTS

The authors thank to Clínicas Oncológicas Integradas and the Universidade Federal do Rio de Janeiro.

REFERENCES

- [1] RODGERS, J. E. Radiation therapy vault shielding calculational methods when IMRT and TBI procedures contribute. *J. Appl. Clin. Med. Phys.* 2(3), 157-164 (2001).
- [2] FOLLOWILL, D., GEIS, P., and BOYER, A. Estimates of whole-body dose equivalent produced by beam intensity modulated conformal therapy. *Int. J. Radiat. Oncol., Biol., Phys.* 38, 667–672 (1997).
- [3] YU, C. X. Intensity-modulated arc therapy with dynamic multileaf collimation: An alternative to tomotherapy. *Phys. Med. Biol.* 40, 1435–1449 (1995).
- [4] CROOKS, S. M., WU, X., TAKITA, C., WATZICH, M., and XING, L., Aperture modulated arc therapy. *Phys. Med. Biol.* 48, 1333–1344 (2003).
- [5] BRATENGEIER, K., 2-Step IMAT and 2-Step IMRT in three dimensions *Med. Phys.* 32, 3849–3861 (2005).
- [6] OLIVER, M., ANSBACHER, W., BECKHAM, W. A. Comparing planning time, delivery time and plan quality for IMRT, Rapidarc and tomotherapy. *J. Appl. Clin. Med. Phys.* 10, 117-131 (2009).
- [7] INTERNATIONAL ATOMIC ENERGY AGENCY. Radiation Protection in the Design of Radiotherapy Facilities. Safety Report Series, IAEA, Vienna (2006).
- [8] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS. Structural Shielding Design and Evaluation for Megavoltage X and Gama-Ray Radiotherapy Facilities. NCRP Report No. 151 Bethesda, MD: NCRP) (2005).
- [9] DAS, I. ET AL. Accelerator beam data commissioning equipment and procedures: Report of the TG-106 of the Therapy Physics Committee of the AAPM. *Med. Phys.* 35, 4186– 4215 (2008).
- [10] KLEIN, E. E. ET AL. Quality assurance of medical accelerators: Report of the TG-142 of the Therapy Physics Committee of the AAPM. *Med. Phys.* 36, 4197– 4212 (2009).
- [11] INTERNATIONAL ATOMIC ENERGY AGENCY. Absorbed Dose Determination in External Beam Radiotherapy. IAEA, Technical Reports Series No. 398, Vienna, (2000).
- [12] MUTIC, S. AND LOW, D.A. Whole-Body dose from tomotherapy delivery *Int. J. Radiat. Oncol. Biol. Phys.* 42(1), 229-232 (1998).
- [13] PURDY, J.A. ET AL. Intensity Modulated Therapy: Current status issues of interest. *Int. J. Radiat. Oncol. Biol. Phys.* 51(4), 880-914 (2001).

Topical Issue: 12. How are we meeting radiation protection challenges in design and implementation of new medical technologies?

IAEA-CN-255/28: CHALLENGES IN REGULATING RADIOTHERAPY FACILITIES AND ACTIVITIES TO RESPECT RADIATION PROTECTION REQUIREMENTS

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Abstract

Importation and setting up of radiotherapy facilities and activities with respect to radiation protection standards is a big challenge with regulatory bodies in developing countries like Cameroon due to second hand donated equipment. The coming of new technologies in the treatment of cancer using ionizing radiation is also another challenge with scarcity in Energy. Cameroon presently has two radiotherapy facilities with more to be constructed in the coming years. How to regulate this will be an issue. The use of radiation in medicine has led to major improvements in the diagnosis and treatment of human diseases. Recognition that safety is the first step in the acquisition of nuclear capacity, Cameroon like most Sub-Saharan countries faced enormous challenges in getting radiotherapy sources and associated equipment from overseas installed. These among others are Political acceptance that safety is as important as security and safeguards to respect International Atomic Energy Agency (IAEA) standards and Competent Authorities or Heads of State do not meet to discuss nuclear safety.

National Radiation Protection Agency (NRPA), as a regulatory, body is leading the implementation of national legislative and regulatory framework in radiation protection with respect to IAEA and other related standards.

1. INTRODUCTION

Radiation sources are widely used in medical facilities and are commonly available in nuclear facilities. Control and accountability of these sources are conducted mainly from a safety and health perspective, not from the security perspective that is common practice in the control and accountability of special nuclear material. Importation with respect to international and national standards is a big challenge with regulatory bodies in developing countries, like Cameroon, due to second hand donated equipment. The coming of new technologies in the treatment of cancer using ionizing radiation is also another challenge.

The use of radiation in medicine has led to major improvements in the diagnosis and treatment of human diseases. As the benefits for patients gain recognition, the use of radiation in medicine increases. For Africa, especially Cameroon, radiation protection is an emerging but important health challenge. Some causes of inappropriate imaging are peculiar to Africa whereas others are similar to those in other continents. Recognition that safety and security is the first step in the acquisition of nuclear capacity, Cameroon like most Sub-Saharan countries faced enormous challenges in getting radiotherapy sources and associated equipment from overseas controlled and installed. These among others are:

- Political acceptance that safety is as important as security and safeguards to respect International Atomic Energy Agency (IAEA) standards. Competent Authorities or Heads of State do not meet to discuss nuclear safety;
- Heads of State have the perception that the IAEA is the International watchdog for safety;
- Cases of non-compliance in the area of safeguards can be reported by the Board of Governors to the UN Security Council while instances of security non-compliance follow the path of UNSCR 1540;
- Currently no formal mechanism to address nuclear safety deficiencies at the international level until an accident occurs. [1]

Table 1. Use of radiotherapy Category 1, 2 or 3 isotopic sources for different countries in Africa as obtained from the DIRAC database (accessed December 11, 2015).

	LINAC	Teletherapy Cobalt-60	Brachytherapy Equipment					TOTAL
			Cobalt60	Cs-137	Ir-192	I-125	Sr-90	
TOTAL	192	86	16	31	31	4	3	363

The IAEA maintains an online, voluntary database of radiotherapy devices and the sources they house, known as the DIRAC database. 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 [2]. The sources in these machines are classified as Category 1 sources, the highest risk classification level of the IAEA. 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 [1].

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 non-isotopic sources have been gaining traction in the international community. A particular focus has 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.

National Radiation Protection Agency (NRPA) of Cameroon regulatory activities started in 2009 under Decree number 250/2002. Existing laws that are sufficient to provide basis for respecting the current IAEA standards, faces a major public-health challenge from non-communicable diseases. NRPA as a regulatory body that is leading the implementation of national legislative and regulatory framework in radiation protection in medicine with respect to IAEA and other related national standards [7]. Authorizations and Inspections systems with enforcement have been put in place to check compliance with the setting up and operations of Radiotherapy facilities and activities. NRPA is also a member and chair of Forum for Nuclear Regulatory Bodies in Africa (FNRBA) and intend to create collaboration under the Radiotherapy Working Group with various partners in order to implement the priority Action plan for 2016 - 2021 in Africa region. Cameroon presently has two radiotherapy facilities with more to be constructed in the coming years.

2. METHODS

The ability to substitute non-isotopic technologies for 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. 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. Most of these have been shipped to as donations to low income countries. 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. 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: [6] Simply removing cobalt teletherapy machines or preventing new purchases of somewhat cheaper devices runs the risk of preventing patients from getting needed care.

2.1. Challenges from the perspective of industries that supply LINACs and teletherapy units and regulatory controls

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. These include weak infrastructure and shortages of trained medical and technical personnel [4].

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.

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

Cancer treatment in LMICs, like Cameroon 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.

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.

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.

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.

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 cobalt60 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 hypo fractionated 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.

NRPA regulatory team has been trying to implement IAEA and other standards for respect of compliances. [8,9]. A lot of challenges have been faced with regards to donated machines and new technologies.

3. RESULTS

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. Regulatory

bodies like NRPA has difficulties in executing regulatory functions adequately to respect compliance. Regulators require adequate and sustainable training in the variance equipment in order to execute their duties well. Most of these machines that are second-handed do not have adequate warranties or after-sale service contracts, making them vulnerable to interruptions in treatment should the machines break down.

4. DISCUSSIONS

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.

International organizations such as the IAEA and donor states can play a role in the prevention of donated sources that are obsolete. 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. IAEA Supported Cameroon in 2016 to repatriate 02 disused radiotherapy sources with NRPA as main coordinator.

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 [1].

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 (IAEA Catalogue sources). To increase clinician confidence in such certified machines, once the IAEA and or United States of America based National Nuclear Security Administration (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 [1].

Under current arrangements, developing countries typically purchase a LINAC and not only have to pay an upfront cost but can encounter maintenance and regulatory 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 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.

5. CONCLUSIONS

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 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. This will facilitate regulatory work for beneficiary countries.

ACKNOWLEDGEMENTS

Our sincere appreciations go to IAEA for continuous support to member states to face the challenges of advanced technologies through Technical cooperation projects.

REFERENCES

- [1] Miles A. Pomper et al; Treatment, Not Terror: Strategies to Enhance External Beam Cancer Therapy in Developing Countries While Permanently Reducing the Risk of Radiological Terrorism, Center for Nonproliferation Studies publication (2016).
- [2] IAEA DIRAC stands for Directory of Radiotherapy Centres. The database is at <http://www-naweb.iaea.org/nahu/dirac/> (Accessed December 2015).
- [3] Rifat Atun, David A. Jaffray, Michael B. Barton, Freddie Bray, Michael Baumann, Bhadransain Vikram, Timothy P. Hanna, et al., “Expanding Global Access to Radiotherapy,” *Lancet Oncology*, Vol. 16, No. 10, September, 2015, p. 1167, Table 4.
- [4] 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.
- [5] IAEA Human Health Reports No. 10: Radiotherapy Facilities: Master Planning and Concept Design Considerations (2014).
- [6] IAEA/CODEOC/IMO-EXP/2012 : AIEA Guide pour l’Importation et l’Exportation de Sources Radioactives, (Révision 2012).
- [7] 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 Meghziene, “International Conference on Advances in Radiation Oncology (ICARO): Outcomes of an IAEA Meeting,” *Radiation Oncology*, Vol. 6, No. 11 (2011), p. 1.
- [8] IAEA STI/PUB/1296: Setting up a radiotherapy programme: clinical, medical physics, radiation protection and safety aspects. — Vienna: International Atomic Energy Agency, (2008).
- [9] NCRP Report No 151: Structural Shielding Design and Evaluation for Megavoltage X – and Gamma – Ray Radiotherapy Facilities, National Council on Radiation Protection and Measurements (2005).
- [10] Chapter1, Article 4, paragraph 2 of Decree 2002-250 of 31 October 2002 for creation, organisation and functioning of National Radiation Protection Agency (NRPA) (2002).

New Trends in the Internal Design for Radiation Protection in Radiological Medical Facilities

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ABSTRACT

The incidence of cancer throughout the world is increasing with the prolonged life expectancy that has resulted from improvements in standards of living. About half of all cancer patients receive radiotherapy, either as part of their primary treatment or in connection with recurrences or palliation. For that The Safety Report 2015, was initiated result of increase in the construction of radiotherapy facilities, and in response to Member States that have requested practical guidance regarding the design and shielding of such facilities.

The objective of this paper is to elaborate the requirements for the interior design and shielding of radiological facilities prescribed in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation, Safety Series No. 115. This report gives guidance on the design of diagnostic and radiotherapy facilities and describes how the required location of shielding should be determined, as well as shielding for brachytherapy units. The Design is used necessary for location shielding, for all types of radiotherapy facilities.

So that, this paper explains achieve the global trends in interior design for radiological facilities, and the extent to apply which the local situation.

Introduction

The Internal design of radiological facilities has evolved dramatically in the past two decades. Through design new trends according to design professionals. Safety interior design is use in the first class by environmental engineering, and in the remodeling of existing facilities. Sections of the report will also be of interest to architects, civil engineers, hospital administrators and others who are concerned with the design of radiotherapy facilities. In addition, the guidance in this report will be useful to regulatory personnel responsible for the licensing and inspection of these facilities.

Environmental engineering and internal designing are considered basic to the modern international requirements so as to establish functionality for institutions. The importance of its application increases especially for radiological facilities. The study of using shielding walls and directions and colors as well as lighting, are very important for changing the psychology for those living there. They also help in responding to treatment, help in protecting Man and environment, and help in enhancing the safety competence for workers and patients. They do not affect the internal elements. It needs specialized study.

Elements of the interior design:

- 1- Shielding walls.
- 2- Direction.
- 3- Lighting.
- 4- Colors.
- 5- Natural ventilation.
- 6- Distribution.
- 7- Flexibility of design and the ability of extension.
- 8- Circulation paths.

Definition of the Interior Design

Interior Design is the art and craft of creating beautiful and functional environments. It is about finding harmony in a space. This harmony comes from the fusion of all the senses. Interior Design has become a crucial element in many fields. Interior Design enables

us to create an environment to reflect a specific character. It has a long and rich history. Once understood, the rules can either be followed or broken with awareness.

Interior Design Considerations

The methods that can be used to enhance the interiors of Radiological facilities are endless! This introductory section can only offer a few basics to consider when design. A good piece of advice is to work closely with your designer. They will have the creativity, experience, and knowledge to help you choose from the countless materials that are available in today's design marketplace.

The Elements of Interior Design:

- Space.
- Line.
- Shape.
- Light.
- Ventilation
- Color.
- Pattern.
- Texture.

The Principles of Interior Design:

- Function
- Balance.
- Rhythm and Repetition.
- Emphasis.
- Proportion and Scale.
- Harmony.

Interior Design Considerations

Lighting

Indirect lighting to produce softer, subtler environments and the use of increased indoor lighting have been the revolutionary changes in terms of lighting in the radiological building, say design experts. Designers are also becoming more creative with lighting to produce relaxing, stress-free atmospheres by using intricate illumination designs.

Windows allowing natural light to provide a psychological boost and a connection to nature is another way of reducing stress. Natural light can also be a source for cheap, high quality light if controlled properly. Today, it's easier than ever to get creative with natural light. Decorative windows, available in colored contemporary and natural outdoors scenes, are just as efficient as conventional windows.

Generally, for the treatment room, ambient lighting should be evenly distributed, shadow free, have good color rendering and be concentrated at the patient's head. The doctor should use lamps with a high Color Rendering Index (CRI) (a CRI number of 100 shows the "truer" colors) to perform tasks such as tissue inspections, shade readings for colored restorations, and aesthetic evaluations.

Doctor can reduce the amount of eyestrain during the day if the ambient lighting of the treatment room is high enough to prevent a large difference when moving the eye from internal task lighting to regular room lighting. Generally, overhead treatment room lighting from two banks of 2' x 4' four tube fixtures will be adequate room illumination.

Flooring

There is a myriad of flooring choices for the radiological units. Keep in mind that flooring choices are subject to applicable laws. Floors are available in vinyl composition tile (VCT), sheet vinyl, ceramic tile, slate, a combination of all of these, or others. With the variety of hard surface flooring and available today, they can be incorporated as way finding techniques and patterns to reinforce larger themes.

Walls

Interior designers can assist you in planning your wall preparations. Painted walls are usually inexpensive and easy to clean. New technologies are producing wall coverings or wallpaper with sharper and more sophisticated designs. Wallpaper is available in a wide variety of color combinations, designs, and textures — including natural grass cloths. In addition, these new products are meeting fire code requirements.

One trend that is evolving with wallpaper is that more commercial spaces are using “residential” colors and patterns. Radiological buildings use the residential theme to help patients relax and feel more comfortable. Wallpaper also is a great way to “cover” imperfections in walls, which can be common in older buildings. Consider a combination of paint and wallpaper in certain areas to enhance the wall look.

Alternating ceiling heights or placing a border along the ceiling can give an impression of more space or enhance the design. Along Inside the ceiling can be a good way to trap sound and reduce the noise level in the office. In addition, ceiling art such as painted murals, mobiles, even artifacts embedded in the ceiling, can provide positive distractions for patients.

Corridors

Use wide, spacious corridors and hallways – a minimum of five feet for two people to pass each other comfortably. This will also help your supplier with any equipment installation and servicing. Frequently, the doctors subtract space in the hallways to acquire space for another treatment room. This is usually a bad idea. Cramped quarters will increase the stress levels in your office. In regards to accessibility, corridors should be free of clutter and loose doormats. Doorways should be at least 32 inches wide, with thresholds no more than one half inch high. Ramps should be equipped with handrails that extend beyond the end of the incline. Elevators should be large enough for wheelchairs and the buttons should be accessible from a seated height.

Interior Materials and Finishes

Partitions

Interior partitions should be primarily painted gypsum wallboard on metal studs. Partitions enclosing physician offices, exam rooms, and treatment rooms should be provided with sound attenuation batts between the studs in accordance with H-18-03, VA construction standard CD 34-1, Noise Transmission Control.

Partitions, windows and doors enclosing Nuclear Medicine rooms that require radiation shielding must have the shielding engineered by an appropriately certified Health Physicist. Refer to H-18-03 VA Construction Standard 64-1, X-Ray Radiation shielding and Special Control Room Requirements. Construction documents will require written certification by a registered Health Physicist.

Floors

Floors in offices, conference rooms and waiting areas should be carpet with a 4-inch-high resilient base. Floors in toilet rooms should be ceramic tile with a ceramic tile base. Floors in Imaging Units, Radiobioassay Units, and Radiopharmacy should have welded seam sheet flooring with an integral base. Floors in exam rooms and most other spaces should be vinyl composition tile with a 4-inch high resilient base. Treatment rooms and other spaces where higher doses of radiation or longer lived isotopes will be administered should be of welded seam sheet construction.

Floor assemblies enclosing Nuclear Medicine rooms that require radiation shielding must have the shielding engineered by an appropriately certified Health Physicist.

Ceilings

Ceilings should be primarily lay-in acoustic ceiling tile. Certain areas, such as procedure rooms and treatment rooms, should have lay-in acoustic ceiling tile with a washable sprayed plastic finish. Coordinate the ceiling height requirements with the equipment manufacturer.

Pathways above ceilings for cable assemblies should be provided for specific equipment types. Ceiling assemblies enclosing Nuclear Medicine rooms that require radiation shielding must have the shielding engineered by an appropriately certified Health Physicist. Refer to H-18- 03 VA Construction Standard 64-1, X-Ray Radiation shielding and Special Control Room Requirements. Construction documents will require written certification by a registered Health Physicist.

Wall Protection

Wall and corner guards should be used in corridors and all other areas where damage from cart and stretcher traffic is anticipated.

*Hospital Regulation Page 20 of 96 Ref. No. HRD/HRS/FRU001

- Wall finishes shall be washable, moisture-resistant and smooth, wall finish treatments shall not create ledges or crevices that can harbour dust and dirt.
- Joints for floor openings for pipes and ducts shall be tightly sealed.
- Floor drains shall not be installed in delivery rooms. If floor drain is installed in Cystoscopy, it shall contain a non-splash, horizontal-flow flushing bowl beneath the drain plate.
- Wired glass; or plastic, break-resistant material that creates no dangerous cutting edges when broken shall be used in certain areas such as glass doors and sidelights
- Highly polished flooring, walls or finishes that create glare shall be avoided.
- All doors between corridors, rooms, or spaces subject to occupancy shall be of the swing type or shall be sliding doors.
- Patient's room door swings should be oriented to provide patient privacy.
- Curtains used throughout the hospital shall be washable/cleanable, fireproof and maintained clean at all times.
- Each patient shall have access to a toilet room without having to enter a corridor.

Interior Doors

Interior doors should be 1 ¾ inch thick solid core flush panel wood doors or hollow metal

doors in hollow metal frames. Doorjamb, except in rooms with radiation shielding, should

have hospital type sanitary stops that stop 8 inches from the floor to facilitate mopping. Doors in wall assemblies that require shielding must be rated to provide the same

shielding

level as that in adjacent partitions. Hollow metal doors should be used where high impact is a concern and where fire rated doors are required. Kick / mop plates should generally be

applied to both sides of the doors. Handicapped accessible hardware should be used throughout. Refer to VA Handbook PG-18-14, Room Finishes, Door and Hardware Schedule, for additional information.

Doors leading to radionuclide receiving and storage area and radiopharmacy are required to be steel security doors that may in some areas need to have proper lead shielding. Refer to VA Handbook PG-18-14, Room Finishes, Door and Hardware Schedule, for additional information.

Definition of Radiological Facilities

That Facilities which include Radiation facilities, irradiation facilities, mining and milling facilities, waste management facilities and any other place where radioactive materials are produced, processed, used, handled, stored or disposed of – or where generators are installed – on such a scale that consideration of protection and safety is required.

Activities include the production, use, import and export of radiation sources for industrial, research and medical purposes, the transport of radioactive material, the mining and processing of radioactive ores and closeout of associated facilities, cleanup of sites affected by residues from past activities and radioactive waste management activities such as discharge of effluents.

What is Radiology?

Radiology or radiography is a photographic process used to image anatomic structures. Instead of visible light, radiography utilizes X-ray energies which penetrate the body. These energies are absorbed at different rates by different tissue densities and are particularly effective for imaging bone and dense tissues. By varying the frequency and intensity of the X ray energies different tissue structures can be imaged.

Many different applications of X-ray imaging technology have been developed over the years. In addition to the direct imaging technologies originally developed to print images on film, new computerized detectors have largely replaced film to produce electronic versions of the radiographic image. By using X-ray images of a volume acquired from different angles, three-dimensional reconstructions of the object can be created. This is the technology used for Computed Tomography (CT) scanners which can create acutely detailed volumetric models of anatomy. X-ray energies are a form of ionizing radiation that does have known health risks. However, the level of exposure from diagnostic imaging examinations, when appropriately proscribed, does not present significant health risks. The VA Radiology service also includes ultrasound which uses non-ionizing sound waves instead of X-rays to produce images for diagnosis or to guide treatment. Design guidance for Magnetic Resonance Imaging (MRI), often co-located with radiology services, is addressed in a separate VA Design Guide.

Radiological Facilities types:

- Hospitals
- Laboratories
- Factories
- Research Centers

Classification of Radiological Facilities

The design of the facility should take into consideration the type of work and the radionuclide and their activities intended to be used. The concept of ‘categorization of hazard’ should be used in order to determine the special needs concerning ventilation, plumbing, materials used in walls, floors and work benches.

Registrants and licensees shall ensure that a multilevel (defence in depth) system of sequential, independent provisions for protection and safety that is commensurate with the likelihood and the magnitude of the potential exposures is applied to sources for which the registrants and licensees are authorized. Registrants and licensees shall ensure that if one level of protection were to fail, the subsequent independent level of protection would be available. Such defence in depth shall be applied for the purposes of:

- (a) Preventing accidents;
- (b) Mitigating the consequences of any accidents that do occur;
- (c) Restoring the sources to safe conditions after any such

accidents. Defense in Depth nuclear medicine:

- Source
- Shielded container
- Work area
- Laboratory
- Department
- Hospital

Categorization of Hazard Based on calculation of a weighted activity using weighting factors according to radionuclide used and the type of operation performed.

High hazard

Room for preparation and dispensing radiopharmaceuticals, temporary storage of waste.
Room for administration of radiopharmaceuticals Examination room Isolation ward.

Medium hazard

Room for storage of radionuclide.
Waiting room Patient toilet.

Low hazard

- Room for measuring samples Radiochemical work (RIA) Offices.
- Premises frequented by patients.

*PLANNING A CLINICAL PET CENTRE INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA, 2010, IAEA HUMAN HEALTH SERIES No. 11

Design of the Radiological Facilities

The design of the facility has to suit the functional program, which defines the activities of the facility and will be reflected in the layout. It is crucial for the success of the facility to organize a design team that can work in a coordinated way. That includes the facility director, physicians, architects, engineers, radiation protection experts, and equipment vendors. The next step is to develop a floor plan taking into



account how the rooms and the space will be distributed according to functions to be performed in each area the flows and radiation protection measures. A suggested layout is described below.

According to the risk and level of radiation exposure, in the following, different functions will be allocated to areas with either a low risk (Section 6.3.1) of significant radiation exposure (so called ‘cold’ or ‘uncontrolled areas’), or with high risk (Section 6.3.2) of radiation exposure (so called ‘hot’ or ‘controlled areas’). Activities listed under Section 6.3.1 could be shared with other facilities (e.g. if the PET centre is set up in an already existing nuclear medicine and/or diagnostic imaging department).

Stages in Safety in Design

There are essentially stages in the design process that may be affected by the principles of SiD as follows:

Functional Design this may include preliminary design. At each stage of the design process risk identification should take place to eliminate risk or where this is not possible reduce risk as low as reasonably practicable through the implementation of control measures.

TABLE 7.1. SPACE REQUIREMENTS FOR A TYPE 1 FACILITY

Function	Classification	Area (m ²)	No. of air changes (h ⁻¹)	Room pressure (Pa)
Entrance for personnel	Uncontrolled area	4	—	—
Offices for staff	Uncontrolled area	50	—	—
Quarantine storage room	Uncontrolled area	5	—	—
Material entrance	Uncontrolled area	3	—	—
Corridor	Uncontrolled area	24	—	—
Janitorial room	Uncontrolled area	2	—	—
Kitchen	Uncontrolled area	9	—	—
Data centre (archive)	Uncontrolled area	7	—	—
Toilets	Uncontrolled area	12	—	—
Storage room for released raw materials	Uncontrolled area	12	—	—
Storage room for technical gases	Uncontrolled area	2	—	—
Personnel airlock for entering the controlled area	Controlled area	9	5–10	-5
Corridor	Controlled area	34	5–10	-10
Preparatory laboratory	Controlled area	7	5–10	-10
Radiopharmaceutical handling	Controlled area, GMP class ‘C’	16	10–20	+20
Storage for radioactive waste, recalled products and retention samples	Controlled area	3	5–10	-25
Janitorial room	Controlled area	2	5–10	-10
QC laboratory	Controlled area	25	5–10	-10
Material airlock/emergency exit	Controlled area	4	5–10	-5

*Radiation Protection Dosimetry (2013), Vol. 155, No. 3, pp. 351–363 doi:10.1093/rpd/nct005, Advance Access publication 20 March 2013

Low risk areas

Reception. As patients arrive they are received and logged in by the administrative staff. Brochures and leaflets with general information about the PET/CT technique and any specific recommendations that apply to their particular scan should be provided and available to read while waiting. Typically, the reception is located at the front of the facility, normally with the *secretarial room* to its rear. Both areas need between 10–20 square meters, depending on the workload.

Waiting room. The appointment schedule should allow for a waiting time of no more than 30 minutes and if any delay is likely patients should be informed. It should be taken into account that oncological outpatients frequently come with an accompanying person, and so the waiting room should be constructed accordingly. An area of no less

than 16 square meters is advised for a department with a single scanner. A location close to the reception is recommended.

Consulting room. In this room the request and clinical records are analyzed and the patient is interviewed and physically examined, if necessary. The patient is informed about the nature of the specific examination he/she is undergoing. This room should be close to the waiting room and adequately equipped. A supply of oxygen gas for medical use and vacuum for aspiration and all other services as per local regulations should be provided. An area of not less than 12 square meters is necessary.

Cleaning utilities room and store. A small room or cabinet should be available for the storage of QC phantoms, supplies and other materials. There should also be a dedicated space allocated to the cleaning utilities. Those can be located at one end of the facility and 5 square metres each would be sufficient.

Offices. In addition to the reporting room, a certain number of rooms should be available for clinical, scientific and technical staff, and for meetings and teaching activities, the number depending on the size and aims of the unit.

High risk areas

Small hot lab. Normally, PET radiopharmaceuticals can be delivered to the injecting room in two ways: either in a mono dose syringe or in a vial. When it is in a vial, the radioactivity may be very high, depending on the number of patients, and each dose has to be dispensed from the vial; in this case, a small room, designed as a basic hot lab with shielding for positron emitters and near the injecting room, is needed. The IAEA's Operational Guidance on Hospital Radiopharmacy: A Safe and Effective Approach [6.3] should be consulted for proper guidance on setting up this laboratory.

The most favorable situation applies when the PET imaging facility is part of a PET/CT center with its own production unit (cyclotron and radiochemistry lab). This allows for mono-dose syringes to be delivered to each injecting room in lead containers.

Preparation, injection and uptake room. When procedures start, patients are asked to lie on a bed or to sit on a reclining chair. They might be medicated or otherwise treated according to the protocols followed in the unit before being injected with the FDG dose. If there is no specific changing room, a locker or small wardrobe should be provided in the preparation room for safekeeping of patient belongings. Position and size are crucial for smooth operations in a busy PET center. These rooms should be located close to the scanners room; an adequate work place/station should be available for the nursing personnel. Injection/preparation rooms should be available to host three to four patients (not less than roughly 12–16 square meters) for each PET/CT scanner installed. Patients after injection are a relatively intense source of radiation (of the order of 30–50 $\mu\text{Sv/h}$ per patient at 100 cm just after the administration). The assembly of several patients in the uptake room areas is a radiation protection problem that should not be overlooked; proper positioning and shielding of the uptake rooms need particular attention [6.4].

Toilet. After injection and an uptake period dependent on the protocol, before starting the actual PET scan procedure, patients are asked to void their bladder. The toilet must be located adjacent to the preparation rooms so that it can be easily accessed from any one of them. Within the facility, the toilet and preparation rooms are like an independent block that accomplishes specific functional and radiation protection requirements. About 30 square meters is sufficient for the entire block.

Control and scanning room. This is the core of the facility. The scanning room must be easily reached from the preparation rooms and the toilet. The door is normally just in front of the preparation block.

Although the area needed for proper installation of a PET/CT scanner can be as small as 7 m x 5 m, some extra space will ease diagnostic as well as maintenance operations. Vendors' prerequisites and installation guidelines should be considered in the planning phase. Also, careful consideration should be given to the fact that PET/CT scanners are somewhat demanding in terms of site prerequisites: the gantry of a multi-modality scanner could weigh in excess of 3000 kg.

The corridors and angles should allow the biggest single package to be moved until its final position. Most parts of the scanners are air cooled; since the power consumption can reach 30 kW/h, proper air conditioning is mandatory. For scanners that are water cooled, some extra space may be necessary for the water chiller. *Post-examination waiting room.* Patients should wait in the post-scan waiting room while their scans are checked. They will also need to change clothes if they are wearing a hospital gown. This allows faster patient throughput. Patients are released from the post-scan waiting room and leave the facility.

Reporting room. When the scan is finished the examination is checked and the images transferred for reporting. There should be space for at least one processing and fusion workstation, one for visualization, a desktop, and the typical furniture for diagnostic imaging. The area should be not less than 10 square meters and it should be located in the same area as the offices. Since studies could be transferred through the PACS system, this room does not necessarily need to be in the 'controlled area'.

Waste disposal room. The materials used for the dispensing of the FDG and anything which could be contaminated (clothes, linen, etc.) should be stored in a dedicated area to let the radioactivity decay before being disposed. The whole space required for a facility adhering to the above description is about 170–200 square meters, of which about half will be 'controlled/restricted' areas, including the PET/CT block and the tracer administration block, while the other half will host activities which do not imply the use of any radioactivity, such as offices and the reception block. Therefore, should the facility be located in a nuclear medicine department, about 40% of the space required could be considered as being for common use, which would account for a considerable saving in the budget allocated for construction. The bare minimum will be a space to process, and a separate space with the facilities to do QA on the final product before injection.

* Legal and Ethical Issues in Medical Practice, Including HIPAA

*RADIATION PROTECTION IN THE DESIGN OF RADIOTHERAPY FACILITIES INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2006, SAFETY REPORTS SERIES No. 47

General Considerations for Interior Design FEATURES

General Regulations

General work area laws restrict eating, drinking, smoking, applying cosmetics or lip balm, and handling contact lenses in the work area. These laws also forbid storing food or drinks in refrigerators that are used to store blood or other potentially infectious material. Refrigerators must have working thermometers to ensure proper cooling temperature (see Figure 3-4).

There are also required procedures for various specific on-the-job injuries. For instance, for eye injuries such as burns and chemical splashes, OSHA requires flushing the eye(s) for 15 minutes with a constant water flow.

LOCATION

Several factors should be considered when determining the location of Radiology Services within a facility. This service should be strategically located to

maximize efficiency in usage. As technology is constantly changing and new methods of Imaging Services are being developed, consideration should also be given to the high probability that the area will require renovation, expansion and / or equipment replacement in the future. It is frequently more cost effective to expand an existing Imaging Service than to relocate the service completely.

Thus, it is desirable to locate the service on the perimeter of a facility and where future expansion is possible. This location also provides for ease of service of existing equipment and equipment replacement as new technologies are developed. Soft space such as administrative offices and support space should be located adjacent to the high technology / diagnostic equipment areas to facilitate ease of expansion for the equipment areas.

Radiotherapy departments are usually located on the periphery of the hospital complex to avoid radiation protection problems arising from therapy rooms being adjacent to high occupancy areas. As pointed out in NCRP 49 [2], operational efficiency, initial cost, as well as provision for future expansion and/ or increased workload, should be considered when locating a therapy installation. Proximity to adjunct facilities, ready access for in-patients and outpatients, and consolidation of all therapeutic radiological services, however, may be more important than construction cost. For rooms below ground level, the reduction in shielding costs for floors and outside walls should be weighed against the expense of excavation, watertight sealing and of providing access. For rooms on or above ground level, the outside walls always require shielding; and additional structural support may be required for heavy equipment and for the additional weight of the shielding barriers.

The amount of shielding required in each of the barriers of the treatment bunker will depend to some extent on the use of the surrounding areas. Areas with high occupancy levels will require greater shielding. Wherever possible the treatment bunker should be surrounded with rooms that have low or controlled occupancy. For example locks or signs prohibiting unauthorized entry could control access to the roof space above a bunker.

ACCESS

The main Radiology Service should be readily accessible to both inpatients and outpatients, and in proximity to the central vertical transportation system serving other areas of the medical facility. It should be located near Ambulatory Care, Nuclear Medicine, Outpatient Services, and the Emergency Department.

Access to the room for the delivery and replacement of the treatment unit and subsequently by patients must be considered. Patients may arrive in wheelchairs or on trolleys or beds. Entrance to the room may be through a shielded door or via a maze. It is necessary to include in the room design an open access conduit for dosimetry equipment cables.

This dosimetry duct should always be through a secondary barrier so that the primary beam can never strike it. Ideally it should run at an angle through the barrier to the treatment control area. Also, for security purposes, radiotherapy facilities using radioactive sources should be located in areas where access by members of the public to the rooms where sources are used and stored can be restricted. Further, the proximity of source storage facilities to personnel that may respond in the event of a security breach should also be considered.

ROOM SIZE

The machine manufacturer's pre-installation manual should provide the minimum room dimensions (length, width and height). The room should be large enough to allow full extension of the couch in any direction, with room for an operator to walk around it. The desirable size depends upon the type of treatments; for example, a total body irradiation (TBI) procedure will require a larger treatment distance to one wall. For intra-operative procedures (IORT) that require extensive support staff and equipment, the room may need to be larger. The accessory equipment such as electron applicators, breast positioning boards, etc., are usually stored within the room, and should be located to minimize the walking distance for each patient set-up.

MAZES

In order to reduce the radiation dose near the entrance, a restricted access passageway leading to the room may be incorporated in the design. This passageway is termed the maze. Ideally this should be as long and with as small a cross-section as possible. The minimum width may be determined by the dimensions of the treatment unit to be delivered by this route or by access for a hospital bed. A maze ensures that photon radiation can only exit the room after scattering has attenuated it. A maze reduces the need for a heavy shielding door. If the length of the maze is sufficient, or if there are enough bends, there may be no need for a radiation protection door at the maze entrance. However, it is recommended that a physical barrier such as a normal door(s) or gate be installed to discourage entry to the maze during patient treatment if a shielded door is not required. Linear accelerators normally only require a gate to prohibit entry during treatment times and/or motion detectors to detect unauthorized entry if a shielded door is not required to reduce dose rates. Another advantage of a maze is a route for ventilation ducts and electrical conduits without compromising the shielding.

TREATMENT CONTROL AREA

The treatment control area is where the operators control the machine. This area should be close to the entrance to the treatment bunker so that the operators can view the entrance area. The control area should be sufficiently large to accommodate the treatment unit control console and associated equipment. There may be computer terminals for record and verification, electronic portal imaging, hospital information system and dosimetry equipment, as well as closed circuit TV monitors.

PATIENT OBSERVATION AND COMMUNICATION

The operator should be able to visually monitor the patient during treatment with closed circuit TV. Two cameras are recommended. These should be situated 1- 1.5 m off and above the gantry rotation axis for optimum observation of the patient on the treatment couch. The cameras should be located far away from the radiation source, consistent with tele-zoom capabilities, to minimize degradation of the image receptor by scatter radiation. There should also be provision for two way audio communication between the treatment control area and the room. A patient activated alarm may be required for patients unable to give an audible call.

PENETRATION OF DUCTS

Ducts and conduits between the treatment room and the outside must be adequately shielded. This includes ducts for cables necessary to control the treatment unit, heating and ventilation ducts, ducts for physics equipment and other service ducts. It is recommended that ducts should only penetrate the treatment room through

secondary barriers. No duct with a diameter greater than 30 mm should penetrate the primary shielding.

The ducts should be placed in such a way that radiation passing through them will require the least amount of compensation for the barrier material it displaces. No duct should run orthogonally through a radiation barrier. It could either run at an angle through the barrier or have one or more bends in it so that the total length of the duct is greater than the thickness of the radiation barrier.

If required, lead or steel plates are suitable materials to compensate for the displaced shielding. To shield the scattered radiation that passes along the duct, it is better to place the additional shielding outside the treatment room, where the radiation has a lower average energy and therefore, less shielding material is needed.

Treatment machine cables are usually run below the floor level under the primary or secondary barriers, before bending up to reach the treatment control area. Provided there are no rooms below, additional shielding is not usually required unless the treatment control area is directly behind a primary barrier, and the cable passes beneath the same primary barrier.

Water pipes and narrow electrical conduits are usually placed in groups inside a larger duct. It is recommended that they also should not penetrate through barriers, but follow the maze to exit the treatment room as described above or follow a route beneath the shielding barrier.

Heating and ventilation ducts should not penetrate through primary barriers because of their large cross-sectional area, which makes it costly to compensate for the shielding material they displace. If the ducts must pass through a secondary barrier, the cross-section of the duct should have a high aspect ratio to decrease the radiation passing through the duct as a result of multiple scattering interactions with the duct/shielding walls. The axis of the duct and the longer side of the duct cross-section should be as orthogonal as possible to the direction of the leakage radiation from the target towards the duct.

Ceilings

The recommended placement of these ducts is above a false ceiling along the path of the maze, to exit the maze at or near the external maze door where the photon and/or neutron fluence are lowest. For accelerators of energies up to 10 MV, usually no additional shielding around the duct is required, for higher energies. If it is necessary for the ducts to pass through the secondary barrier, they should be placed as high as possible to minimize the scattered radiation to personnel outside the room.

Conduits are required for dosimetry cables, beam data acquisition system control cables, quality assurance (QA) equipment cables, and in vivo dosimetry equipment cables. The conduits are usually PVC pipes of 80–100 mm diameter included in the concrete formwork. They should be inclined at an angle (in the vertical and horizontal planes), and penetrate through the secondary barrier but not through the primary barrier. If the openings are at least 300 mm above floor level they are more convenient to use. Ideally, the opening in the treatment control area should be at the counter top level and the opening in the treatment room side should be at a different level but within easy reach.

International trends in interior designing of radiological facilities.

- 1- The importance of the interior design in distribution, direction, and identify the shielding, that is Leads to a doubling the efficiency.
- 2- A detailed study of internal elements such as: doors, windows, floors, ceilings, walls, finishing material and warning signs.
- 3- Establishment of modern management systems for different units' functionality and usage, with the ability of extension and usage flexibility.
- 4- Programs and codes to analyze study and improve interior blanks and it is considered one of the most important, and recent instrument internationally in the field of environmental engineering and internal design facilities, such as:
 - Monte Carlo.
 - -Daylight design.
 - 3D Max - AutoCAD.
 - Thermal analysis.
 - Radiation analysis.
 - Ventilation flow.
 - Faluk.
- 5- A detailed study for water and ventilation circulation mechanisms to create a safe and healthy environment
- 6- Earthquake protection mechanism.
- 7- Making use of some international programs (geographic information system GIS) to study the environmental design to direct the building and thus study the lighting and internal natural ventilation and the aesthetic appearance and the psychology of colors to increase healing capacity.

Recommendation:

Our recommendation is the: Establishment of a relationship between an entire modeling design with thermal analysis and protection design, in addition to the enhancement systems for radiological facilities by environmental internal design.

- The merger between international trends of internal design elements and the requirements of radiological facilities building.
- Using the most recent technologies for studies and analysis, along with enhanced building and finishing material for radiation protection (protection barriers) in order to achieve international trends milestones:
 - Enhancing treatment efficiency.
 - Better radiation protection for employees, patients and surrounding environment.
 - Expenses minimization.

Conclusion:

The international trends and standards pertaining to environmental internal design in Egypt have been applied after studying the extent of its adaptation and appropriate implementation to domestic field for new radiological facilities; The following have been implemented:

- The most recent international designs for protection barriers.
- Implementation of good module management systems that leads to the enhancement of efficiency, design flexibility and extension capacity.
- The implementation of the most recent systems for motion paths in order to reduce exposure to radiation between the hospital units (floor color planning to facilitate movement and guarantee protection).
- Environmental design to study natural orientation and lighting.
- The use of the latest finishing material.
- Implementation of the latest international trends in children injection units and waiting rooms.
- The latest doors' systems, alarm systems and children-friendly warning signs.

Addressing the current case for best results and least costs:

- Change of module generation design by changing the units' orientation, redistributing the motion paths for better isolation and reducing the need for protection barriers and reducing its costs.
- Using local lead sheets (equivalent to international production) or types of lead bricks or Gibson board, and the choice must be based on the easiness of construction and replacement optimizing protection and cost.

REFERENCES

1. PLANNING A CLINICAL PET CENTRE INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA, 2010, IAEA HUMAN HEALTH SERIES No. 11
2. Radiation Protection Dosimetry (2013), Vol. 155, No. 3, pp. 351–363 doi:10.1093/rpd/nct005, Advance Access publication 20 March 2013
3. Legal and Ethical Issues in Medical Practice, Including HIPAA
4. RADIATION PROTECTION IN THE DESIGN OF RADIOTHERAPY FACILITIES INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2006, SAFETY REPORTS SERIES No.47
5. NBS Handbook 92 IAEA, Safe Handling of Radionuclides Guide for the Preparation of Applications for Medical Programs (RH 2010 4/90) CDC-NIH Biosafety in Microbiological and Biomedical Laboratories (BSL 2, D.3) Guidelines for Research Involving Recombinant DNA Molecules (NIH Guidelines) App. G-II-B-4-b
6. Colour and lighting in hospital design, Hilary Dalke, Hilary Dalke, Jenny Little, Elga Niemann, Nilgun Camgoza, Guillaume Steadman, Sarah Hilla, Laura Stott, Colour Design Research Centre, London South Bank University, Borough Road, London SE1 0AA, UK, Colour Design Research Centre, Kingston University, Knights Park, Kingston KT1 2QJ, UK Available online 19 October 200
7. WALL COLOR OF PATIENT'S ROOM: EFFECTS ON RECOVERY By KORTNEY JO EDGE. A THESIS PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT, OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF INTERIOR DESIGN, UNIVERSITY OF FLORIDA 2003.
8. CCR, Title 24, Part 2, Table 16A-OC. Title 8, 3241
9. Performance evaluation of natural ventilation strategies for hospital wards e A case study of Great Ormond Street Hospital, Z.A. Adamu*, A.D.F. Price, M.J. Cook, School of Civil and Building Engineering, Loughborough University, Loughborough, LE11 3TU, United Kingdom
10. INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Assurance for PET and, PET/CT systems. IAEA Human Health Series No. 1, IAEA, Vienna(2009).
11. BEYER, T., et al., Combined PET/CT Scanner for Clinical Oncology, J. Nucl. Med. **41**,(2000)1369–1379.
12. INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Guidance on Hospital, Radiopharmacy: A Safe and Effective Approach, IAEA, Vienna(2008).
13. INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection in Newer, Medical Imaging Techniques: PET/CT, Safety Reports Series No. 58, IAEA, Vienna(2009).
14. RADIATION PROTECTION AND SAFETY OF RADIATION SOURCES: INTERNATIONAL BASIC SAFETY STANDARDS, IAEA SAFETY STANDARDS SERIES No. GSR Part 3 (Interim) "Safe Handling of Radioactive Materials", National Council on Radiation Protection (NBS Handbook 92)
15. "Safe Handling of Radionuclides", International Atomic Energy Agency, Safety Series No. 1, (1973 ed. is still current as of 1999) (IAEA)
16. CDC-NIH Biosafety in Microbiological and Biomedical Laboratories, 3rd Edition Guidelines for Research Involving Recombinant DNA Molecules (NIH Guidelines), January 1997.
17. Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide, Federal Emergency Management Agency: FEMA-74, 1994 EH&S Design Guide General Requirements for Stanford Laboratories, Version 2.0/ 13-02 Section 1 Page 3, Optimization of protection and safety, IAEA Basic safety standard (BSS).

18. Safety of Radiation Sources: International Basic Safety Standards, General Safety Requirements Part3 No.GSR Part 3.

19. IAEA Safety Guidance on Occupational Radiation Protection (RS-G-1.1 &RS-G-1.3).

20. IAEA TECDOC SERIES-17, The Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR): Industrial Radiography.

ج ا ن ن س:

ودئ طبنت الاجه اومات اولم عابري دلاولبة المعقولة لبا، مصيم دلاايلاخ لالبية ني نه حص دع به رساة دمي كة، يبياه ونيز، يها الم سينا اجمل لل لمايلاح ني نا لما ربق البش لاععية دج نا يد؛
وهناك لالحات ازمية ج هري عاهج لال اوائل ا لمولة سمتم بام ني نه ذلك ولكن لا يقص نه على مائة مثل 57357
سم لاتفريات غ لاج ساراطن. ودئ تم نينيد ام يه؛
- ادحت لبا مصاميم ل ودلهاة لوجازج الحماية.
- نينيد يمظيح يد د لاجرة الدحات لنالمية و ندي إلى زغ نيز لفا انة مورونة لبا مصيم وار دن اة داش ر لابة.
- نينيد دحاث ل أنظمة راس مات الحكرة من جال لجا د من لغارص البش لاععية بين دحات لماس ترفني (خ نطيط و ان ل أرض
لمص يل رح لالكة ضوم ان الحماية).
- التمص يم لبا يني س ارهة و لاجه الطبيع عاض لا او) ر لالغ الفازج ع ااض لابة ني ص مر(.
- ساهت ل دحاث اومد لبا شطيط.
- نينيد دحاث الاجه اومات لدلولة ني دحات قح ن الا طل وغرف ل انظرا.
- ادحت أنظمة و ل لابة اوزنظمة ل انذار و ع لومات ل انرا اذ المص يه فظال ال.

ج لاعمة اللجاة اراينة لوصول على أفضل لباتاج أوئل لبالفايف :-
غ نيدر مص يم دحات ل فيه الاطة عن رطبقة غ نيدر اج ناه لداحات، إعودا زو نيع راس مات الكرحة لبس ح بن لغ لزة و تله بل
لح احة لبل لجا جاوز البعولة ح لبا ينفخ وض ذلك يانها . -
سيما م دح قراوا لوا اص ص ل ح م اية)أي ام يعدل ل زبغ الادي لو (وأ أن ع او الطوب الاصر ص أو لوحة ج بوبوس ن، ويحجب أن
س ينيد خ لالتر اهي لل سهلولة لبا ناء اواس لبال اما لبل ح لابة ل و لالفاة.

ص ب ت :

"نص و ب ناي ه: اقامة علولة بين مص يم لنا جظمة بأكماله مع اللح بل رح لاري و تمص يم ح لامة، اض لرا نة لبل مظناة زغ نيز
لما ربق البش لاععية حسب لبا مصيم ي ل خ ادلا لبا يني.
- الان ج امد بين الاجه اومات لدلولة ل عنر صا لبا مصيم خ اد اويل جولطبات بباء لما ربق البش لاععية.
جرب مع زغ نيز بباء اومو لبا شطيط ح لامة من البش لاععية (الوجازج
ح لامة) من أجل قح بق مع لال الان ج اومات ل ودلهاة:
• ج لاع لابة انك ز يزع نه.
• ح م اية أفضل لعا ل للمفظ بن ص لاو بير ل و بية ح م لاطة.
• تله بل المورص نات.
- دس لة دمي لبالفايف ني نه نطيط ل انعا اومات لدلولة نيطنا و ع ل ادلاي.
- سدلة ل ح بول لل الحاة الجازحة.
- شكف جولجاة الح لال ل الانفاة.

