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Radiotherapy Facilities: Master Planning and Concept Design Considerations

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RADIOTHERAPY FACILITIES: MASTER PLANNING AND CONCEPT DESIGN CONSIDERATIONS

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FOREWORD

According to the International Agency for Research on Cancer and the World Health Organization, the number of new cancer cases detected each year worldwide is expected to increase, especially in low and middle income countries. More than half of all cancer patients will require radiotherapy as part of their disease management. Radiotherapy is a multidisciplinary field that uses complex technologies utilizing radiation sources for the imaging and treatment of cancer patients. Thus, radiotherapy facilities require specialized shielded rooms, careful planning and specialized design to ensure that they not only provide radiation protection, but also optimize workflow.

There is a significant gap in the number of national cancer control programmes, including radiotherapy services, available to cancer patients in low and middle income countries. The IAEA has produced general guidelines for planning national radiotherapy services and for setting up a radiotherapy programme, including clinical, medical physics, radiation protection and safety aspects. Several international reports detail the methodologies that are used to perform the shielding calculations for radiotherapy equipment.

The IAEA, through its technical cooperation programme, is however often requested to provide guidance to Member States on the master planning and concept design process for establishing radiotherapy services. In this context, master planning refers to the development of an evolutionary document, which provides a framework of the intended plan of action leading to the detailed design of the radiotherapy facility. This document informs the development of a feasibility study and guides the overall project planning in terms of the key outputs and the timely allocation and mobilization of resources. Similar guidance may be needed when it is desirable to upgrade or expand existing facilities.

To address this need, the IAEA convened a consultants meeting to prepare a publication providing the basis for preparing a master plan and concept design for a radiotherapy facility. This publication is intended to provide an overview of the process based on lessons learned and guidance on the mobilization of the appropriate team and resources to ensure a sustainable project. As such, it is aimed at professionals and administrators involved in infrastructure development, planning and facility management, as well as engineers, building contractors and radiotherapy professionals.

The contribution of F. Lange (South Africa) to the present publication is gratefully acknowledged. The IAEA officers responsible for this publication were D. van der Merwe and E.H. Zubizarreta of the Division of Human Health.

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1. INTRODUCTION

A practical tool which can be used in planing national radiotherapy services was published by the IAEA in 2011 [1]. The publication comprehensively summarizes the need for services within the global context of cancer management. It is further enhanced and complemented by the IAEA publication on Setting Up a Radiotherapy Programme: Clinical, Medical Physics, Radiation Protection and Safety Aspects [2], which provides a framework for the development, implementation and management of a radiotherapy programme. A large number of Member States, however, have no access to radiotherapy services or are grossly under-resourced, especially in the African region [3].

The location and siting of a radiotherapy facility within the hospital environment requires careful consideration because of the role of radiation oncology in multidisciplinary cancer management, including the requirement for diagnosis, coordinated referral and long term follow-up of patients. The construction of specialized bunkers (shielded rooms) for housing the treatment equipment is technically an engineering challenge and needs professional oversight to ensure long term structural integrity. A generic design is important to cater for future requires and advances in technology.

This publication provides information on the environmental, legal, technical and professional aspects related to developing a master plan for the construction of a radiotherapy facility. Use of this guidance does not obviate the responsibility of the engineering consultants to develop a complete and accurate detailed design that meets the user's needs and complies with national regulations and requirements. The principal output of the strategic master planning process is a comprehensive feasibility document that states the needs. It includes the results of all surveys and investigations for future reference, i.e. copies of the title deeds, zoning diagrams, commitments and time frames for services to be in place and all negotiated easements. The document could describe several different options for siting, as well as short, medium and long term plans to meet the need for comprehensive national cancer control, including radiotherapy services. The commitment and measures in mitigation of all high risk items should also be given.[1] The master plan document can also inform key elements of a bankable document to secure financial support.

A sample checklist is provided to serve as a guideline for project management and to indicate the critical stages in the process where technical expert assistance may be needed (see Appendix II).

Since the process of radiotherapy is closely related to key staff functions [2], the detail of the internal design of the facility is important to achieving sound workplace ergonomics and to facilitating workflow. An overall concept design should therefore consist of the five key functional areas which expedite radiotherapy workflow. These functional areas in radiotherapy are the reception and clinical consulting areas, the imaging and treatment planning area, and the two treatment suites (teletherapy and brachytherapy). The relative placement of these areas should be adapted to the proposed site and preferred local practice. However, it should expedite broader staff and patient movement, consultation and communication. The position of the major equipment at the various duty stations within each functional area is provided for in the detailed layouts provided in Section 5. Expansion route possibilities are also indicated.

Clinically qualified medical physicists are responsible for ensuring that the shielding calculations are based on acceptable estimates of the projected local workload, use and occupancy factors, and that the design accommodates the desired clinical workflow. In addition, the future implementation of new techniques and technologies should also be considered. The national radiation safety regulator is mandated to approve the final design prior to construction and to license the facility prior to the commencement of patient treatment.

2. INITIAL CONSIDERATIONS

Once the decision to establish a radiotherapy facility has been taken, careful coordination and monitoring of the planning and timelines are key to a successful project. The professional team required to design, construct and commission a radiotherapy facility needs to be multidisciplinary, because the project not only involves the

[1] Guidance provided here in the form of 'should' statements, or simply in the present tense indicative, describing good practices, represents expert opinion but does not constitute international consensus recommendations.

construction of specialized bunkers to house the radiotherapy imaging and treatment equipment, but it also needs to take into account the clinical workflow as well as anticipate non-disruptive expansion in the future.

An established radiation safety regulatory infrastructure is necessary to plan, develop and initiate a radiotherapy programme. In order to identify the best possible site, a broader situational analysis needs to be performed based on the following questions:

(i) Is there a national cancer control plan? (See Ref. [1].)
(ii) Are there existing facilities and how old are they? Are they operational and sustainable?
(iii) Where are the national tertiary or central hospitals in the country? Which of these are university teaching hospitals?
(iv) Are there national resources to support the establishment or expansion of radiation oncology?

The answers to these questions should result in a key decision as to whether this project should result in a new facility or an upgrade to an existing facility. If there is no existing modern functional facility, then a programme initiation plan or a master plan is required. The details of this process and the expertise required are given in Sections 3 and 4, respectively. If a facility already exists and experienced expertise is available, then the reader is referred directly to the risks and timelines given in Appendices I and II. The generic layouts that inform a detailed design for a radiotherapy facility based on the typical workflow are given in Section 5.

The demographics of the country are of primary importance to the siting of a radiotherapy facility, as optimal siting provides the most equitable access. The facilitation of evidence based medical practice, multidisciplinary teams for comprehensive cancer management and a structured treatment approach are highly recommended. The associated health sector infrastructure, especially radiology and pathology services, neighbouring the radiotherapy facility is key to efficient referral, for instance.

A government project team consisting of at least one representative each from the health, finance and public works (infrastructure or facility management) sectors needs to be constituted to give the go-ahead for the project and commit to providing the required coordinated oversight for the project duration.

3. STRATEGIC MASTER PLANNING PROCESS

3.1. LEGAL DUE DILIGENCE (CONFIRMED PREREQUISITES)

Assuming that the site has been identified, the prerequisite to developing a feasibility study for radiotherapy is that legal due diligence has been confirmed, i.e. a formal investigation is undertaken to ensure that all legal aspects are met. These include the right to the site and that the regulatory infrastructure to support the safe and effective installation of radiotherapy treatment units is in place [4].

Ownership of the land is the first consideration, followed by the ability to use the land for a health sector project with high energy radiotherapy equipment. The process of zoning ensures that the land is, or can be, designated for this specific project. In some Member States, the land has to be zoned for health, and in others, for business as opposed to private or domestic use. Confirmation is needed that the future plans of adjacent property owners are investigated, for example, plans to build high rise buildings on adjacent land may affect the actual placement and orientation of the radiation bunkers within the facility. The size of the land needs to be adequate; not only should the area of land that will be developed accommodate the current plan but consideration should also be given to future expansion needs. The minimum site area required for a basic radiotherapy department is 3500 m^2 excluding access roads and parking areas and assuming 50% coverage.

The support and advice of the regulatory authority in the country is also of key importance to establishing radiotherapy services, particularly with respect to licensing of the facility; the management of radioactive sources; occupational, public and medical exposure concerns; and the radiation protection of the patients. There are IAEA publications dealing with safety standards, the radiation protection aspects and the specialized shielding calculations pertaining to radiotherapy [2, 5, 6].

3.2. GEOTECHNICAL CONSIDERATIONS

Geotechnical surveys confirm flood lines, earthquake zones and ground conditions, i.e. high water tables and soil characteristics. The purpose of the geotechnical investigation is to evaluate the subsoil stratigraphy and determine its character and physical properties in order to design the foundations of the building. The investigation should provide sufficient data for the geotechnical engineer to recommend the most appropriate and efficient design, and sufficient information for the contractor to bid appropriately and reduce change orders and claims. The type of structure to be built and the anticipated geological and field conditions have a significant bearing on the type of investigation to be conducted. Therefore, the investigation should be planned with knowledge of the intended project size and anticipated building loads as well as knowledge of the geological history of the area. A geotechnical investigation usually includes surface and subsurface exploration of the site. A complete foundation investigation and analysis should include in situ tests, field sampling, laboratory testing, and engineering analysis and evaluation, with the results and recommendations presented in a report form. The investigation and analysis should be performed in compliance with international standards and generally accepted principles of sound engineering practice.

3.3. ELECTRICAL SERVICES

The availability of reliable three-phase power needs to be confirmed, for example, a linear accelerator requires a 250 V/150 A power supply, a chiller requires 480 V/60 A, an air-conditioning plant requires 480 V/30 A and a conventional simulator requires 480 V/60 A. A linear accelerator treatment room, for instance, requires an exhaust system to the outside capable of handling 2–10 exchanges of room volume per hour. If power is not readily available, costs may be incurred to ensure a reliable and permanent connection to the grid. This may imply consideration of a different site or the use of diesel generators, transformers, power conditioners or uninterrupted power supplies (UPSs), which will affect the level of technology that can be installed.

In addition to the description of the particular electrical installation requirements for a radiotherapy facility described above and in Section 5, general recommendations are presented here for electrical services to help the designer and the end user understand the specific project needs and assist them in establishing the specifications, planning and design of the electrical power distribution, lighting, signal, telecommunications and related systems. The electrical services design of a radiotherapy facility should be carried out by accredited electrical and communications engineers and installed by qualified and experienced contractors to ensure a safe environment for both staff and patients.

The electrical engineer should prepare load calculations that justify the size of each branch circuit and feeder, overcurrent protection devices, transformers and equipment buss (panel board, switchboard, switchgear, automatic transfer switch, etc.). A power and signal plan showing the complete design for general use receptacles, communication and signal outlets, and the main circuit servicing the equipment should be prepared along with a lighting plan. These plans, including that of the lighting, need to be in conformity with the radiotherapy equipment suppliers' power requirements.

The electrical capacity of the substation should be carefully calculated to have sufficient power supply for the whole radiotherapy facility's needs and for future expansion of services. It is recommended that an emergency backup system be provided to supply power to the essential illumination and high priority equipment, noting the stringent requirements for power conditioning on sophisticated devices. In addition, strategically placed UPSs, as autonomous power sources, can be installed to support critical servers, workstations, light points, the fire alarm system, etc. The UPS will need a suitable rating with voltage regulation and spike protection to provide for 60 minutes' backup. This can be reduced to at least 15 minutes if the UPS is powered by the emergency system and caters only for the switchover period or a programmed shutdown.

3.4. FIRE PROTECTION

It is most important that the project implementation team includes a fire protection engineer to ensure effective detection, containment, control and extinguishing of fire events at the earliest possible stage. A written

fire prevention plan should be coordinated with the facility management. The design aspects should include escape doors, signage, fire alarm systems with smoke/heat detectors, indicator panels, call boxes, electronic sirens and wiring and escape facilities for disabled persons, provision of fire hydrants, fixed firefighting installations, portable firefighting equipment, etc. Special consideration needs to be given to the specification of smoke/heat detectors in radiation treatment and simulator rooms, as they should not be sensitive to radiation (i.e. photoelectric). In some countries, lightning protection also needs to be provided.

3.5. RADIOTHERAPY STAFFING

The core professional team in radiotherapy consists of radiation oncologists, radiation therapists and medical physicists who have received post-graduate specialized academic education and training. Staffing levels are described elsewhere [2], as are the respective staff roles and responsibilities [7]. The core team is usually supported by nursing, administration, medical officers, etc. Suitably qualified staff need to be identified for the centre in advance since all training is long term, e.g. a radiation oncology residency is typically four years' duration. At the least, local expertise in medical physics and radiation oncology should be available for input when the facility is under construction so that staff can contribute to the equipment selection, clinical commissioning, final fit-out and finishes, as well as the development of local protocols and standard operating procedures, which are required in advance of the first patient treatment. Preferably, at least a medical physicist would be available to contribute to the design phase.

Consideration also needs to be given to sustainability in human resource capacity; therefore, early investment in national education and training programmes is highly recommended. Expansion of services and implementation of advanced radiotherapy technologies will require additional staffing levels.

3.6. PROJECT RISK ASSESSMENT

A risk (or value) assessment determines the affordability and sustainability of the project, and concerns not only the buildings but also the maintenance, running costs, consumable supply, staffing and access. There should be commitment, for instance, to appointing staff immediately after long term training and to including budgeting for post-warranty equipment maintenance. Appendix I shows an example of a project risk register. A spreadsheet of this nature immediately provides the team with alerts to potential challenges in the project and their origin, e.g. regulatory, financial, design, equipment, staffing.

3.7. TYPICAL TIME FRAME FOR ALL PRELIMINARY WORK

Appendix II shows a typical project checklist with time frames for completing the master planning process. This can be used as a project planning and monitoring tool. It includes timelines for the training of human resources, recruitment of external expert services and initiation of clinical activities that precede the first patient treatment. Some activities can be carried out in parallel (e.g. training of human resources), and there can be significant lead times; for example, equipment specification and procurement procedures can commence prior to completion of the construction.

4. CORE IMPLEMENTATION TEAM AND EXPERTISE

Once the project to commission a radiotherapy facility has been approved at a ministerial level, a professional team needs to be constituted to manage the project. In the event that expertise is not available locally, external experts with the relevant experience should be consulted. At a minimum, the team should consist of the following:

— A qualified architect, preferably experienced in the design and construction of radiation oncology facilities.
— A structural or civil engineer with experience in large concrete structures, e.g. dams or other large concrete structures. Expertise in casting large volumes of concrete is a requirement.
— A mechanical engineer with experience in hospital design, including cooling, heating and ventilation systems.
— An electrical engineer experienced in the calculation and design of reticulation and standby electrical systems for hospitals. The ability to design the information technology (IT) and communication reticulation is highly recommended.
— A cost consultant or quantity surveyor or equivalent.
— A clinically qualified radiotherapy medical physicist with competency in the planning of new departments in similar environments. It is important that the medical physicist can participate fully in the specification and commissioning of appropriate equipment in order to provide the maximum possible access to radiotherapy, taking into consideration the prevailing infrastructure and resource constraints.
— A qualified radiation oncologist experienced in setting up and coordinating a radiation oncology facility within a system of similar resources is highly recommended.

In all cases where the expertise is not locally available and an external expert is recruited to assist, a local consultant should be designated for shadowing purposes.

5. RADIOTHERAPY WORKFLOW AND CONCEPT DESIGN

Cancer treatment is becoming more integrated with other clinical disciplines and typically includes any or all of the following in any combination:

— Surgery.
— Chemotherapy (medical oncology).
— Radiotherapy.
— Paediatric oncology.
— Nuclear medicine.
— Diagnostic services (radiology and pathology).
— Allied medicine: physiotherapy, oncology social work, counselling, dietetics, palliative supportive care, emergency care, etc.

It is therefore preferable if new facilities, or additions, are planned to expedite a multidisciplinary solution, if at all possible, and to make sure that all other diagnostic and treatment options are at least in the closest proximity possible, if not at the same institution. The possibility of future changes to the facilities should also be considered at the planning and design phases, as should options for the expansion of the facility.

Patient, visitor and staff circulation should be considered when planning and designing, and, if possible, the routes should be separated whenever possible. Crossing of patients and public should be avoided. Staff only entrance and exit options should preferably be provided so that staff can enter and exit without passing by waiting patients and visitors. These discreet routes of entry and exit can also be used for stretcher and non-ambulatory patients and this should be incorporated into the design. The provision of disabled access and disabled-friendly washroom facilities, etc., should also receive high priority.

A typical facility should consist of, or comprise a combination of, the following five main functional areas:

— Reception, administration and waiting areas;
— Clinical consulting areas;
— External beam radiotherapy (EBRT);
— Brachytherapy;
— Imaging and treatment planning.

5.1. RECEPTION, ADMINISTRATION AND WAITING AREAS

The reception and main waiting areas should be located at the main entrance to the department and act as distribution point for all the different sections in the department (Fig. 1). Colour coded lines on the floor can be considered to direct patients to a specific area in the department, e.g. imaging and planning, brachytherapy, EBRT, etc. The reception station staff should be sufficient to service the number of oncologists and medical officers for new and follow-up patients; a typical ratio would be one per team of two clinicians.

Administration consists of separate offices for financial matters, for instance, which are generally more private and where matters can be discussed confidentially.

The requirements for long term storage of patient records differ between countries. As a general guideline, every paediatric record is kept until the child is 21 years of age, or for at least ten years after the last contact, whichever is the longer. The ten year rule can also be considered for adults. Sufficient space needs to be allocated to accommodate the anticipated number of records, and the arrangement could be partly on- and off-site. Files could be kept separate from images as a double safety measure. A separate secure server room for the backup of electronic patient files, billing information and medical records should be provided. This should be fireproof and waterproof to ensure external hard drive safety. The server room needs to be big enough to allow maintenance access from all sides.

Sufficient parking should be made available for ambulances, staff and patients. Ideally, patients should be allocated the parking closest to the department, and it is important to take into account the fact that, although there would be a limited number of patients being actively attended to in the centre at any given point in time, patients nevertheless spend many hours inside the department when undergoing imaging or planning, consulting with doctors or receiving brachytherapy.

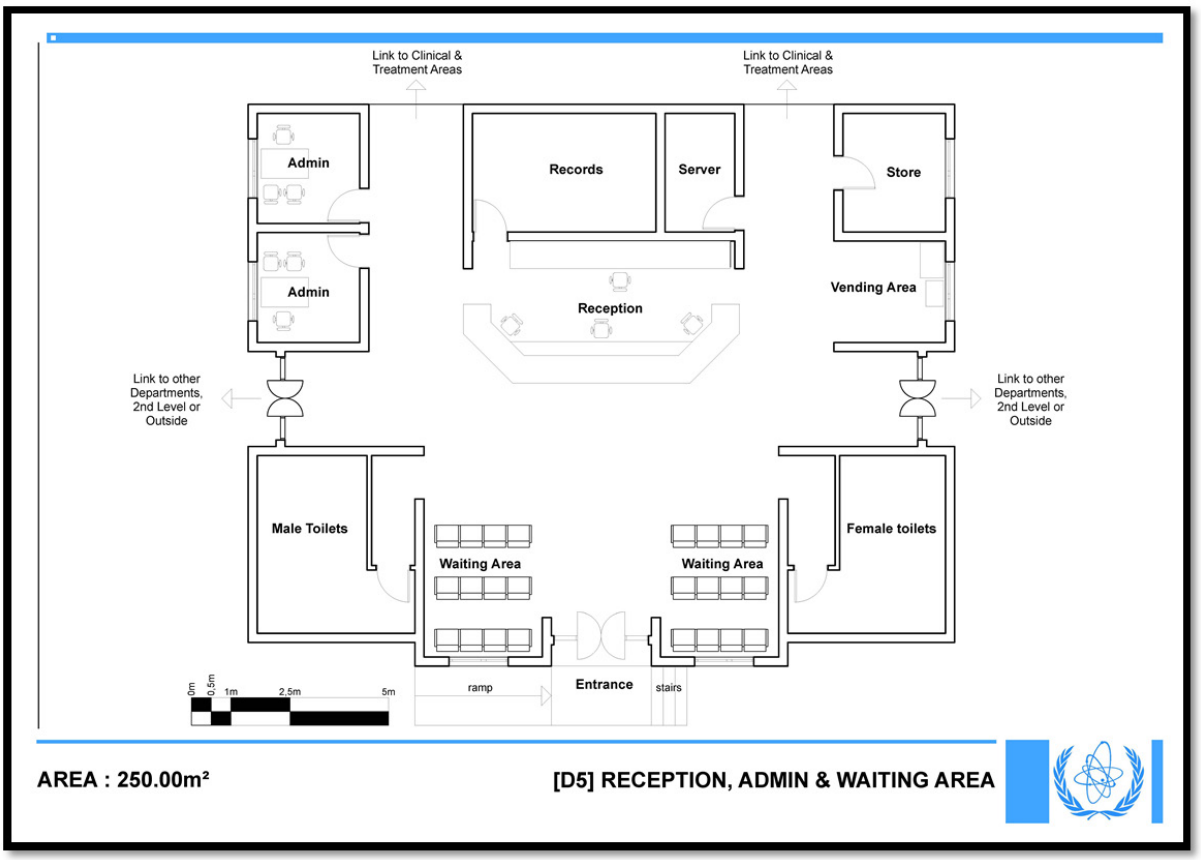


FIG. 1. Typical layout of the main reception area.

Waiting areas, where appropriate, may be designed with separate enclosures to meet cultural requirements, for instance. The size of the main waiting area in reception does not need to cater for all patients attending the facility daily, because sub-waiting rooms should be provided in all the functional areas, i.e. in the clinical consultation area, and in the imaging and treatment planning, brachytherapy and EBRT areas. Provision needs to be made for stretcher bays, ideally using a separate side or rear entrance, near the treatment facilities. Consideration may be given to separate waiting areas for paediatric cases. Strategically placed public television sets can enhance privacy by creating a distraction. Ideally, there needs to be easy access to the outside (the use of atriums is encouraged) to make use of natural light and to allow patients and accompanying persons to move about. When considering the size of waiting areas, it is important to take into account whether patients would be spending an extended period of time in the centre or whether they would be accommodated elsewhere on-site. In many centres, most patients (often accompanied by a relative) spend the whole day at the centre throughout their course of radiotherapy.

Retail outlets, vending machines and drinking fountains can be dispersed throughout the department in the various waiting areas. There should be sufficient washroom facilities strategically placed throughout the facility for male, female and disabled persons, including separate facilities for visitors and staff. The requirements for clean and dirty areas should be respected throughout the facility.

5.2. CLINICAL CONSULTING AREA

Sub-waiting areas at the various clinics for consultations need to be provided with their own reception or nurses' station. A typical design is shown in Fig. 2.

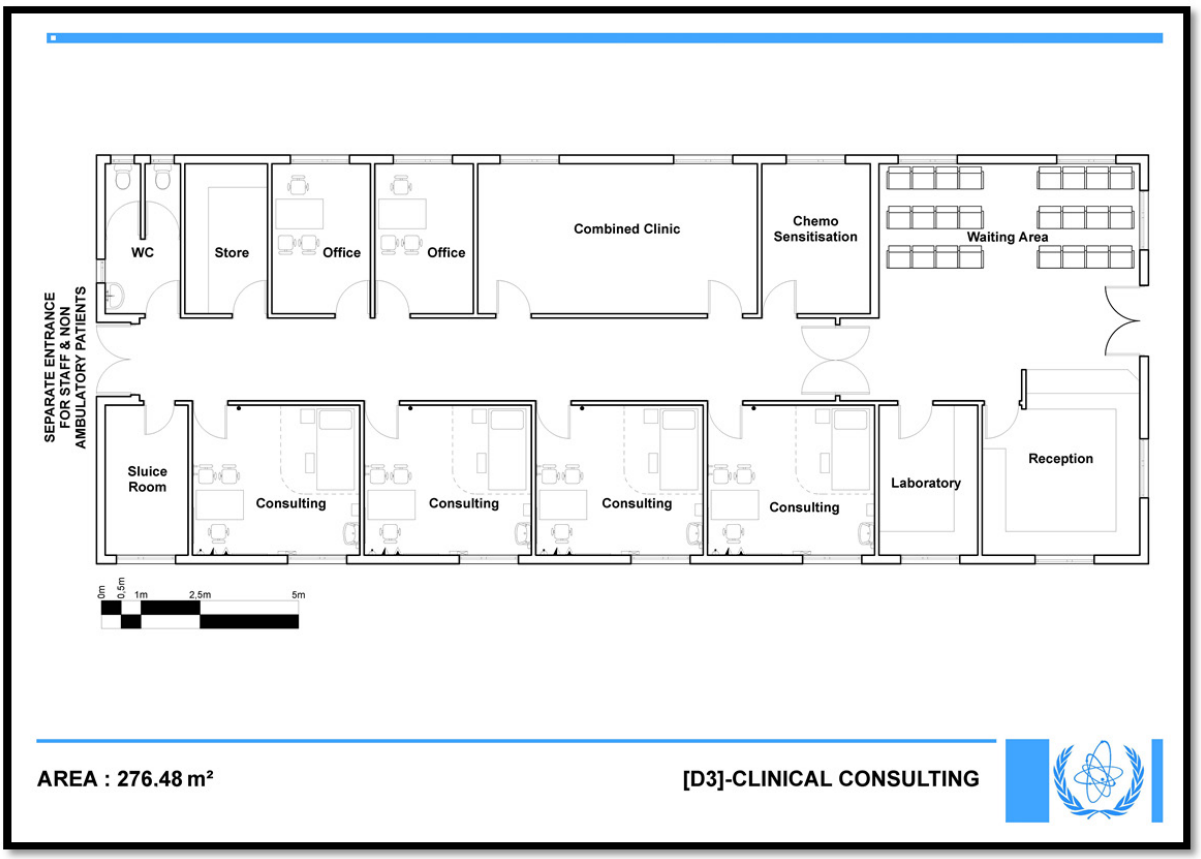


FIG. 2. Typical layout of a radiotherapy clinical consulting area.

The size of the clinical consultation rooms should be adequate to house a desk and two to three visitor chairs and include a screened or separate examination area with a wash hand basin (WHB). The total number of consultation rooms would be related to the number of radiation oncologists, medical officers and trainees in the department. Future expansion possibilities should be considered upfront in order to preserve the workflow and logistics in the overall design.

Pre-consultation (procedure or laboratory) rooms for nurses (physician extenders or nurse practitioners), including a small desk, chair, examination couch, WHB, scale, drugs, dressings and equipment for minor procedures, e.g. blood pressure monitoring, can also be considered. These rooms could also be used to prepare patients for clinical assessment by the relevant physician if suitably trained nursing staff are employed and appropriate standard operating procedures are developed.

Social workers, dieticians and other allied health workers may also need to be provided with consultation rooms or offices within the facility. Depending on the overall design, similar offices could also be provided for the weekly review of the patients on treatment and placed in the vicinity of the treatment area.

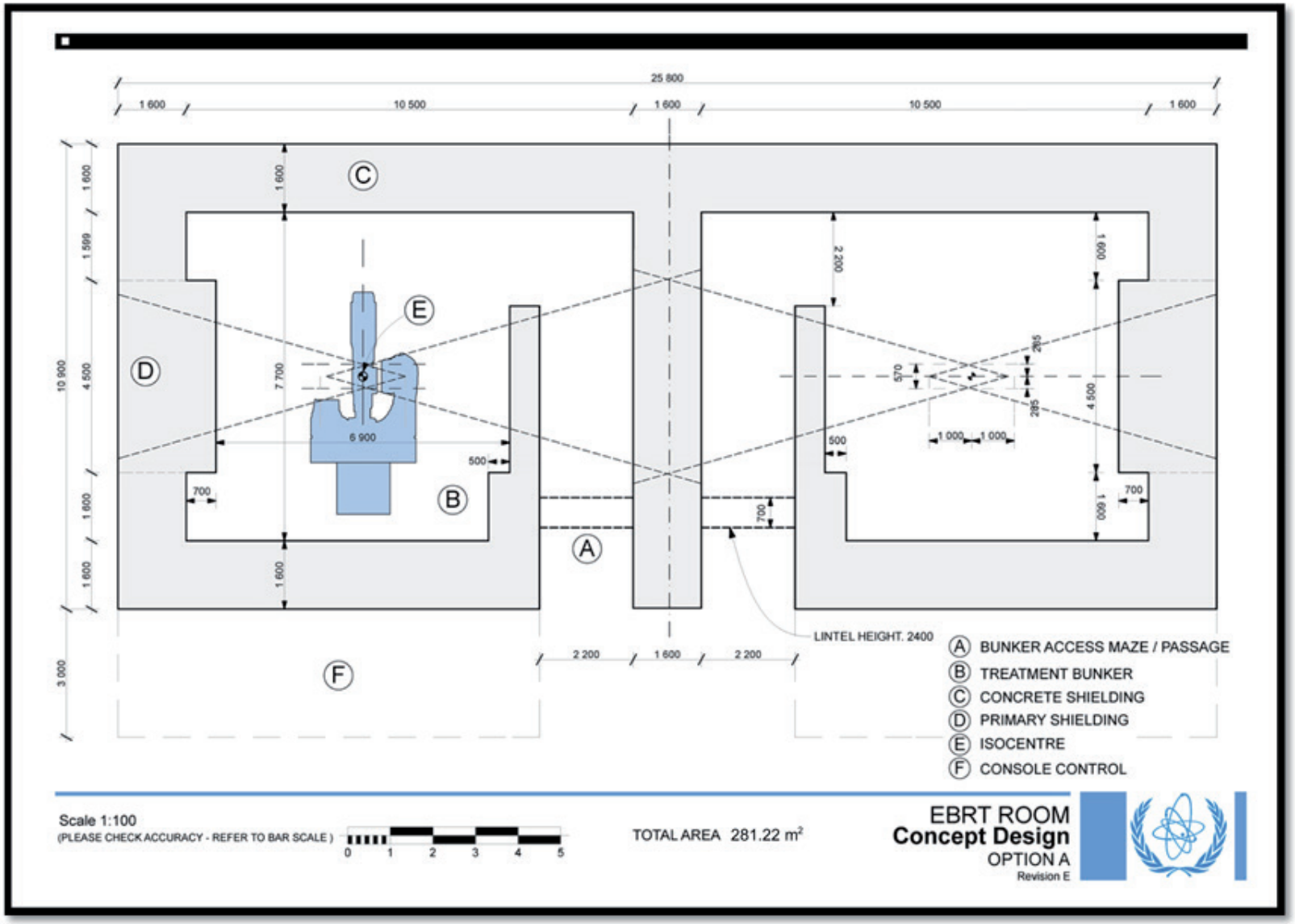
5.3. EXTERNAL BEAM RADIOTHERAPY

It is advisable to place bunkers above ground, together with the rest of the facility. When infrastructure, power and financial resources are constrained, use of natural lighting and ventilation can be maximized. In addition, in tropical or high rainfall regions, waterproofing and drainage of an excavated site could be an additional challenge. The construction of fully shielded underground bunkers (as opposed to retaining structures only) may also be required if future plans for adjacent underground facilities are not known.

Facilities are ideally designed with adjacent bunkers to reduce costs by sharing the primary shielding structures and, in so doing, minimize the footprint and the total volume of shielding material needed. Two alternative layouts (options A and B) for maximum energy 10 MV linear accelerators (LINACs) are shown in Fig. 3. Sizes are given in millimetres and all thicknesses are given for 2.35 g/cm^3 concrete. The workload used assumes 1000 Gy/week delivered at the isocentre. A main advantage of a maximum energy of 10 MV is that neutron shielding is not required. Nevertheless, safety and security assessments may require that a door be installed at the end of the maze. However, it should be noted that, in these instances, the door would be for restricting access by providing a physical barrier only and not for shielding against radiation. Access during radiation can be prevented with a combination of light sensors and/or push gates or barriers that are interlocked to the control panel. It should be noted that single energy units of less than 10 MV (e.g. ^{60}Co teletherapy, a 6 MV single energy LINAC), can also be accommodated in this bunker design. Modern megavoltage photon teletherapy units have a gantry with a maximum source–axis distance of 100 cm. The gantry and the patient treatment table are engineered to rotate around an isocentre. The minimum recommended inside room dimensions are 7 m × 7 m with the isocentre positioned approximately in the centre of the room. These room dimensions provide space for the structure of the teletherapy unit and for the maximum longitudinal extension of a typical patient treatment table. Similarly, the width will enable comfortable access around the gantry and the patient for all angles of rotation. The minimum structural room height should be 4 m, including along the maze. This height is necessary for ease of access when equipment is delivered, to provide for the air conditioning, heating, exhaust and ventilation system design, and for installing additional electrical supply cabling. A false ceiling can be added later. A maze width of 2.0–2.2 m will also ensure an adequate turning circle for equipment delivery. A lintel restricting the height to 2.4 m should be installed along the maze at some point, as reducing the cross-section provides additional shielding against neutrons if the use of higher energies in the future is considered.

When establishing services for the first time, provision for the base-frame is highly recommended; measuring from the centre of the back of the unit, a 6 m × 2 m × 0.3 m deep excavation in the floor will suffice. Finishing of the floors, ceiling and walls should be completed by the supplier so that the final levelling and ergonomic design is customized to the treatment unit.

A bunker does not need a shielded roof if the primary beam can never be directed towards adjacent structures; this can be confirmed using geometrical projections of the radiation field external to the facility based on the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1 000
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4 500
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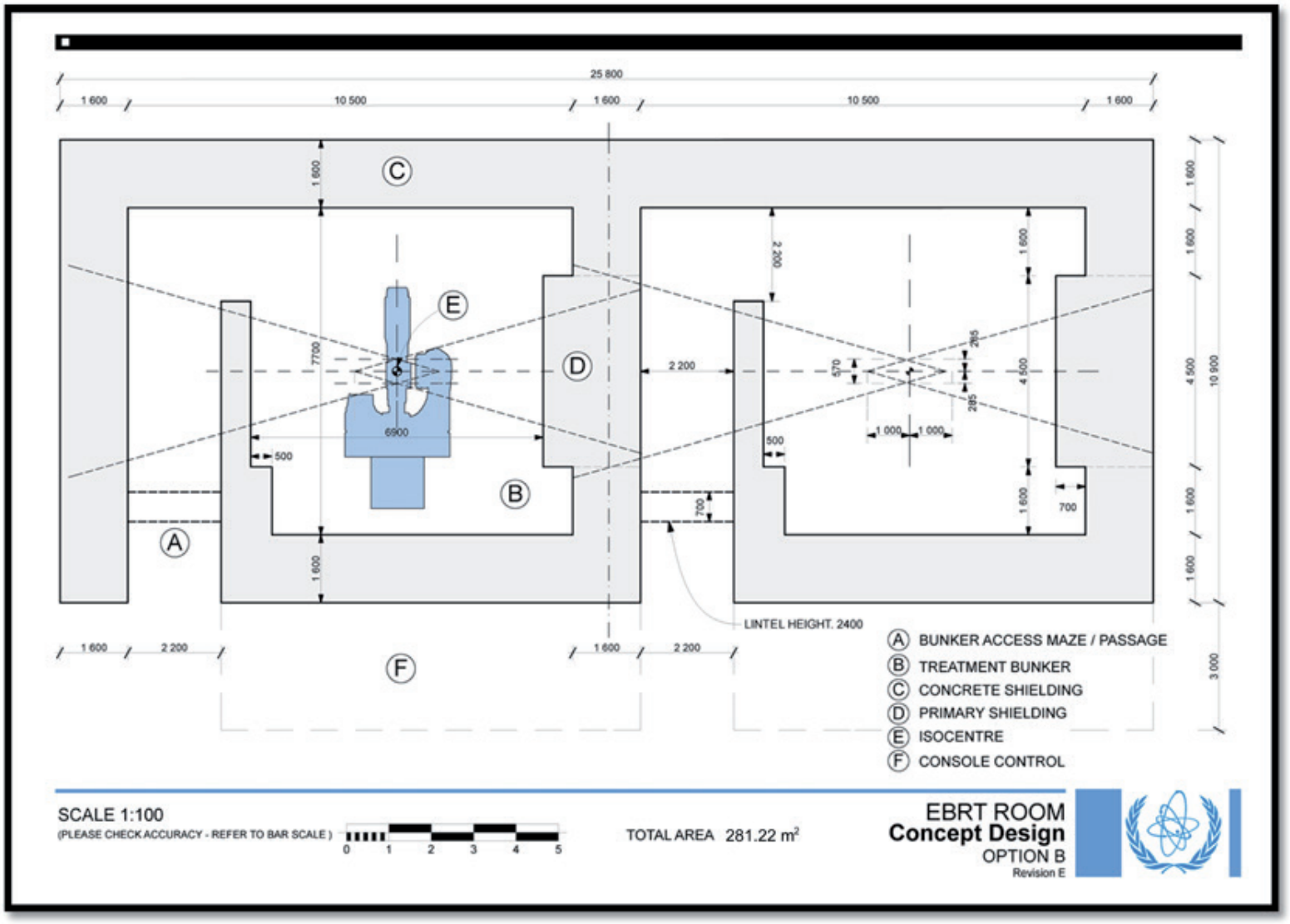
700
700
LINTEL HEIGHT. 2400
A BUNKER ACCESS MAZE / PASSAGE
B TREATMENT BUNKER
C CONCRETE SHIELDING
D PRIMARY SHIELDING
E ISOCENTRE
F CONSOLE CONTROL
Scale 1:100
(PLEASE CHECK ACCURACY - REFER TO BAR SCALE)
0 1 2 3 4 5
TOTAL AREA 281.22 m²
EBRT ROOM
Concept Design
OPTION A
Revision E

OPTION A



OPTION B

FIG. 3. Two possible layouts (options A and B) for the external beam radiotherapy equipment showing 'mirrored' and 'parallel' designs, respectively. The main difference relates to the proximity of the entrances to the maze for each bunker. Sizes are given in millimetres.

infrastructure, ownership and zoning of the surrounding properties (see Section 3.1). Access to the roof itself should be restricted and cordoned off, with a security entrance, interlocked to the treatment machine. It is possible to place the water chiller and the air-conditioning plants on the roof, for instance, as both require controlled access. It is highly recommended that the plane of gantry rotation is parallel to the treatment control panel area. The overall orientation of the bunkers should take into account all high occupancy areas.

Additional secondary shielding has been added to the layout in order to provide for higher workloads, which may be important when a transition is made to intensity modulated radiotherapy or dose escalation techniques, for instance. In addition, a unit with maximum photon energy of higher than 10 MV could be installed in these bunkers if workloads are significantly less than 1000 Gy/week at the highest energy and appropriate calculations are performed to justify the occupational and public effective dose rates. The workload, the use and occupancy factors, and the local legislation will then also determine the need for a door to shield against neutrons. All final layouts require that detailed shielding calculations are performed, which should be signed-off by a local, clinically qualified, medical physicist and have approval of the national radiation safety regulatory authority.

The bunker may include plumbing for a WHB and should have adequate storage space for all positioning and immobilization devices and accessories. Provisions for joints, ducting and sleeves should not follow the divergence of the primary beam, and this is easily achieved by placing these in the secondary shielding and using a curved path. Some thought should be given to mechanical, electrical and safety considerations, for example, the ability to dim the room lights, emergency switches and the provision of standby lighting, which could be achieved by placing rechargeable torches in the treatment room, for instance. Ducting is required for connection between the gantry structure and the treatment control panel. In addition, isolated ducts should be provided for dosimetry cables (minimum 150 mm diameter) and connectivity to the chiller system.

Two separate control areas should be provided, one for each bunker. All radiotherapy treatment control areas are provided with a patient intercommunication device and at least two closed circuit television monitors. Privacy and confidentiality in the use of these devices is mandatory. The worktop should be of adequate length for all patient information sheets and images to be immediately available to the staff member, who should also have a direct view of the control panel and the closed circuit television monitors. Power skirting therefore needs to be provided along the length of the worktop and allow for multiple devices to be powered, including additional emergency switches. An X ray viewing box or equivalent is recommended and the ambient lighting should provide adequate viewing conditions. Figure 4 shows a possible design and cross-section of a worktop, which could equivalently be used for any duty station.

In most low and middle income countries, the lack of adequate transportation infrastructure does not allow for small waiting areas for outpatients. Cultural aspects need to be considered, such as gender separation and the fact that many family members sometimes accompany each patient. Chairs can be immovable so that access pathways and wheelchair and stretcher bays are not obstructed. At least one stretcher bay needs to be provided per treatment unit and be large enough to allow clinical assessment of the patient. Clear signposting using international signage and/or all local languages is recommended for all waiting areas. A clear access route starting at the main entrance for patients who are only receiving daily treatment needs to be available. Local practice sometimes prefers changing rooms outside of the treatment rooms to improve patient flow, but this decreases the time that the radiation therapists have to communicate with patients on an individual basis. Changing rooms can however only be included if patient privacy is maintained and enough security can be provided for their belongings. In many departments, the radiation therapists prefer to assist patients to undress in the treatment room.

In order to optimize workflow in the vicinity of any external beam treatment machine, double (separate) circulation passages for patients and staff are highly recommended. This can be achieved using partitioning. In addition, an access route with adequate floor loading should be available for all future equipment deliveries. Provision should be made near the treatment area for a networked imager or printer, or a small plumbed darkroom for processing X ray films. This can be shared with brachytherapy or imaging but the amount of time the radiation therapists need to spend away from the treatment control area should be minimized. A small store room of at least 3 m × 3 m for the major dosimetry equipment near the treatment units is needed for the medical physics services.

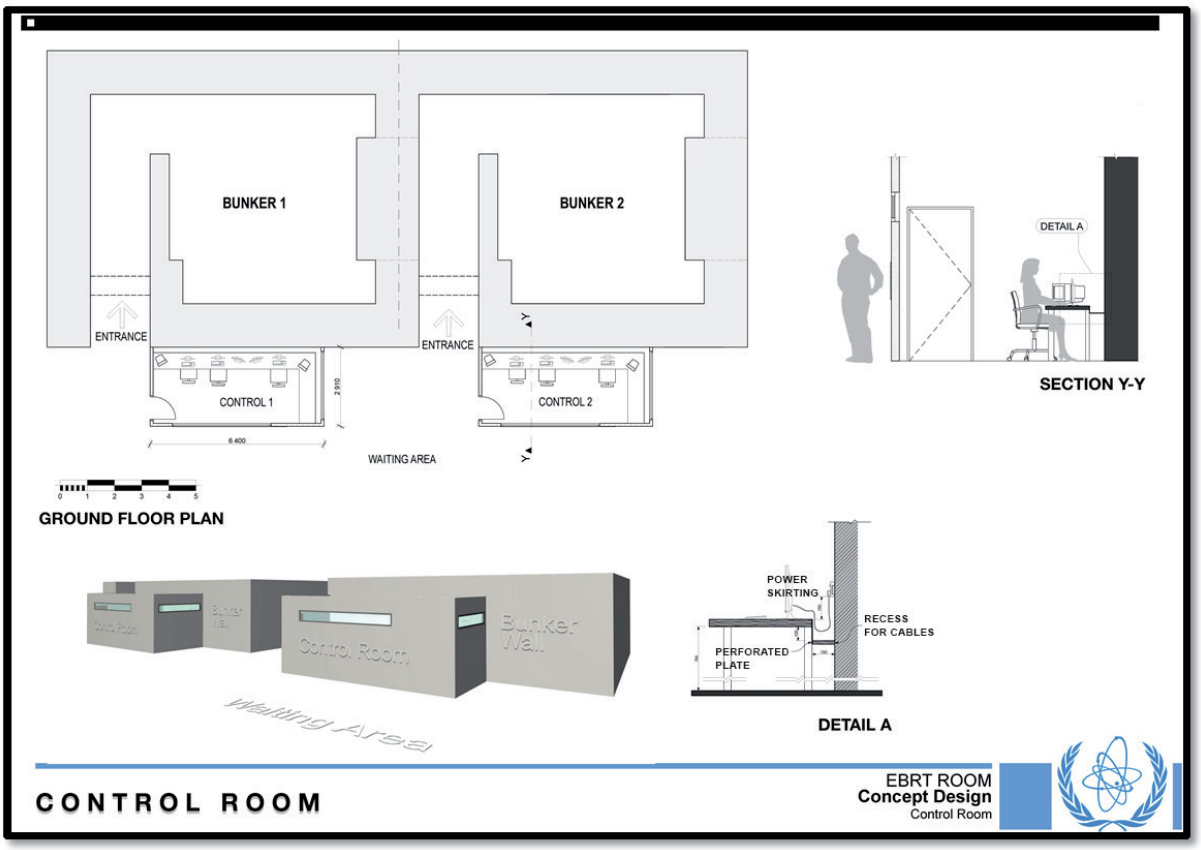


FIG. 4. An example of the configuration of the control console area for the operators of the EBRT equipment. Detail A shows how the equipment cabling can be hidden from view using a simple under-table skirting.

5.4. BRACHYTHERAPY

A brachytherapy suite should include the shielded treatment room, a control area, a procedure/preparation room, a recovery area, a sluice room and an imager or film processing area (Fig. 5). This suite should be positioned behind a red line. Some centres prepare the patient in the treatment room whereas others prefer to do this in a separate procedure room. If patients are prepared in a separate room, then movable, interchangeable patient tables are generally supplied so that the patient is not moved unnecessarily between applicator insertion and treatment delivery. A C-arm is generally required for applicator placement and therefore will need to be installed in the appropriate room, either the procedure room or the treatment room depending on the local practice. When there is a high workload of gynaecological applications using 3-D techniques, then a computerized tomography (CT) or magnetic resonance imaging scanner and control console could be installed in the procedure room. The CT will have the same shielding requirements as the X ray bunkers described in Section 5.5. The other option is to share the resources and locate the brachytherapy service in the vicinity of the CT scanner required for the imaging and treatment planning area (Section 5.5).

The brachytherapy bunker shown provides adequate shielding for a ^{60}Co high dose rate remote afterloading unit, currently the highest energy brachytherapy source available. The shielding assumes operation at maximum source activity for 1 hour per shift. It has a maze design with wall and ceiling thicknesses of at least 100 cm (primary and secondary shielding concepts are irrelevant for isotropic radiation applications). The maze shown is 1.8 m wide to allow for easy access in the event of an emergency and the design shown has no door. Access control can be achieved using light beams to trigger an interlock. This also improves the sterility of the environment. Since there is generally no public access to this functional area, staff vigilance at the control area is less likely to be disturbed and physical barriers can therefore be avoided during operation. The inside dimensions of the room are a minimum of 4 m × 4 m × 3.6 m height (ceiling height of 3 m) in order for there to be enough space around the unit to manoeuvre a C-arm and a procedure trolley, if the patient is prepared in the treatment room. Because the source

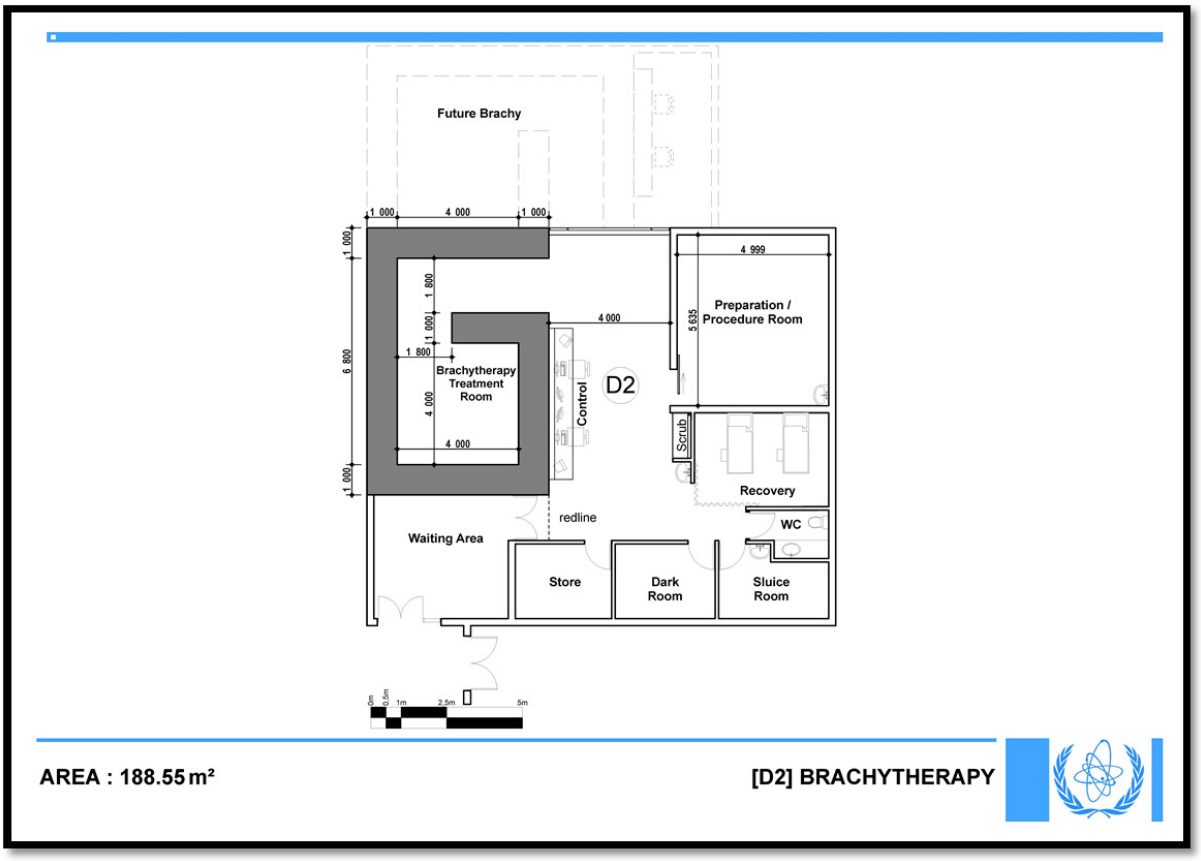


FIG. 5. Typical layout for a brachytherapy suite.

emits radiation isotropically, a shielded roof is required. Plumbing should be available for the procedure as well as for sterilization. An easily accessible applicator storage cupboard can be provided with enough clearly marked hanging space for all catheters and transfer tubes to minimize contamination.

The treatment control area has the same requirements for the operators as the megavoltage units (see Section 5.3) but should include space for an on-line treatment planning system. Alternatively, a separate space can be allocated for a treatment planning workstation, e.g. modification of the store shown in the layout. If 3-D techniques are used, the radiation oncology and medical physics teams need to spend more time in this area to perform the actual treatment planning. This workstation should be networked to the CT or magnetic resonance imaging scanner.

A sub-waiting area may be necessary for brachytherapy, but this depends on the location of the suite from other waiting areas, e.g. those used for EBRT.

5.5. IMAGING AND TREATMENT PLANNING

The IAEA guidelines describing the buildings for the essential equipment of a basic radiotherapy clinic recommend an imaging area (required for treatment planning) consisting of a simulator room [2]. Two X ray bunkers, each with an associated control room, to house a fluoroscopic simulator and a CT scanner or CT simulator (Fig. 6) are suggested here. Shielding requirements are met with walls of thickness equivalent to 230 mm of solid brick or concrete, and lead-lined sliding entrance doors, which is standard for diagnostic X ray facilities. Viewing windows for the operators should be lead glass and embedded into the wall structure. The inner room dimensions should be the same as for the EBRT bunkers (structurally 7 m × 7 m × 4 m high) because manoeuvrability of a simulator and the storage space needed are the same as for a teletherapy system. A common imaging or film processing room is recommended. If all equipment includes digital imaging, this room could be used as secure storage space for a portable computed radiography reader, printer and/or laser imager to manage images from all

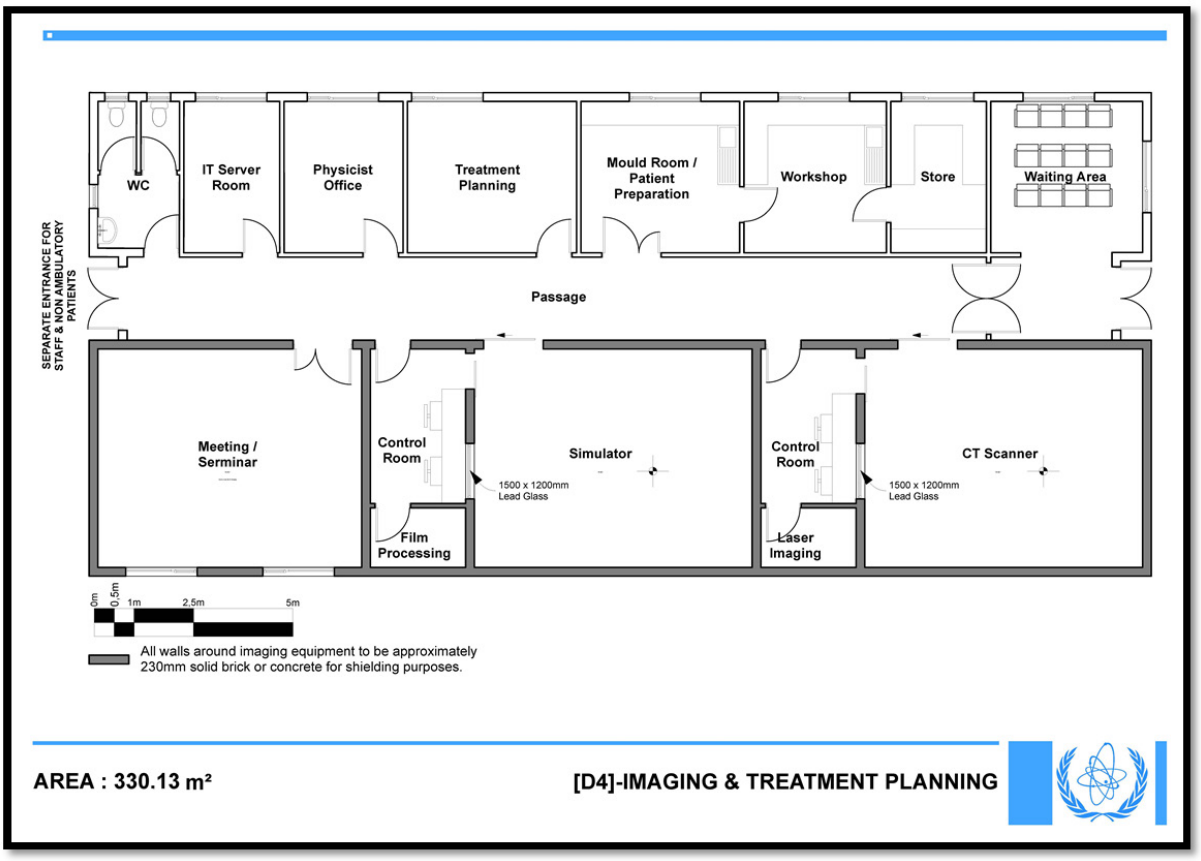


FIG. 6. Typical layout of an imaging and treatment planning area for radiotherapy.

treatment and imaging workstations. An adjacent meeting room is shown in this design, which could be used as an additional imaging bunker should future expansion of the service so demand.

Provision for the system management of the IT equipment is critical. A separate secure room for the treatment planning system backup, imaging archives, and the record and verify system server and gateway systems should be provided. The size of the server room needs to be large enough so that easy service access to the equipment is possible from all sides. This room should also be provided with controlled access at all times and should be fireproof and waterproof. Air-conditioning to keep equipment running temperatures at acceptable levels is strongly recommended. Backup natural lighting will be essential in areas where electricity supply is unreliable. A UPS to all IT equipment is recommended, and if a separate UPS battery room is provided, it should conform to national fire and ventilation regulations.

A patient preparation area is required for manufacturing customized patient immobilization devices. This should include a workshop for the manufacture of devices and other accessories. Manual block cutting and chemical procedures require adequate air extraction. A storage area is necessary for mould room consumables.

The room designated for treatment planning needs to be big enough to house an adequate number of computer workstations, with generous worktops and viewing boxes. The internal layout can be an open-plan design. Two-dimensional radiotherapy workspace requires an area with under-table lighting. Virtual simulation workstations are additional to the planning workstations and space for an oncology workstation for film review is also desirable. X ray viewing boxes (or equivalent) need to be installed at each workstation. An adjoining office for the medical physicists is recommended.

A sub-waiting area is needed for patients. However, the overall design needs to respect patient privacy and confidentiality in view of the various procedures and discussions taking place in this area.

5.6. OTHER RELATED AREAS

It is recommended that other related areas are also incorporated into the concept design as necessary. A few examples are given:

— Academic area: This area can include private offices and teaching facilities, if applicable. The sizes of meeting rooms are related to the number of staff. Ideally, at least one big meeting room should be provided that can accommodate the clinical team (including the allied health staff) and all the other staff in the department. Projection facilities are important in venues that will be used for peer review meetings. A smaller meeting room can also be designated for private meetings, scientific visits, auditors, etc. The area could be placed on a level (floor) above the reception and administration or clinical consulting rooms, for instance.
— Chemotherapy: If there is an existing medical oncology department at the greater facility, its role in concurrent chemoradiation protocols should be determined. Should the radiation oncologists be responsible for concurrent chemotherapy administration, a subdepartment should be designed that has a treatment area with separate, easily accessible toilet facilities for chemotherapy patients and a dedicated area for safe storage (under required storage conditions), mixing, preparation and waste disposal of the toxic pharmaceuticals used for the therapy. Ideally, the treatment area would have external views or access to an outside area. Typical staffing levels are a dedicated pharmacist and one oncology nurse per 3–5 patients per session, depending on the complexity of the regimens used.
— Diagnostic services:
  • Depending on the resources and the size of the treatment facility, it would be ideal if the facility had its own CT scanner for simulation and radiotherapy treatment planning. A minimum requirement would be access to an existing radiology CT scanner.
  • If possible, a small laboratory should ideally be provided in the facility with the ability to provide full blood count and other required results within acceptable time limits. Alternatively, easy access to existing laboratory facilities or their delivery services is necessary.
— In-patient wards: Some dedicated radiation oncology in-patient wards are generally provided. These may need to be split into male, female and paediatric wards where applicable. If wards are allocated to cancer patients, the location relative to the treatment facility should be as close as possible so that daily transfer of the patient to the facility for treatment is expedited.
— Transit facilities: In countries where many patients come from remote areas and where the transport infrastructure is underdeveloped, consideration needs to be given to the provision of overnight or transit facilities (sometimes referred to as hotel services or interim homes), which can accommodate a patient and a relative. These facilities will typically be self-serviced and not be staffed full time with nursing professionals. This lessens the demand on ward beds, reduces hospitalization costs and ensures that medical beds are not occupied for purely social reasons. The role of non-profit and non-governmental organizations could be investigated to help with establishing and overseeing these facilities.
— Palliative care facilities may be considered in conjunction with the master plan, noting that the privacy of terminal patients should be respected.
— Other facilities: There are other areas which could be considered depending on the specific needs of the planned facility. These could include counselling areas, lounges, paediatric play therapy rooms, gardens, quiet areas, etc.

5.7. EXPANSION OF SERVICES

It is very common for departments to grow over time and it is just as common for departments to be constructed in accordance with available funding, which often means that the first phase is constructed according to the available budget. This may mean that the facility is small and lacking in some areas. If the master plan or original concept design does not allow for future expansion, it could lead to major problems later when the service needs to be expanded.

The need to plan for change and/or expansion cannot be overstated. This needs to be an integral part of a master planning process, but even where a master plan (for whatever reason) is not prepared, the project owners should make sure that there is adjacent land available and that all services (electrical, water, sewage) can be upgraded to accommodate any future possibilities.

Figure 7 shows an overall layout of an entire radiation oncology centre, including all the main functional areas discussed above. The buildings occupy approximately 50% of the total site. The layout shows a central open atrium, which can be used in mild climates to enhance lighting and ventilation. Skylights can also be used throughout the facility. The dotted lines represent expansion to the brachytherapy and external beam treatment areas which will not result in disruption of services. The arrows indicate how the radiotherapy unit could connect to the rest of the hospital.

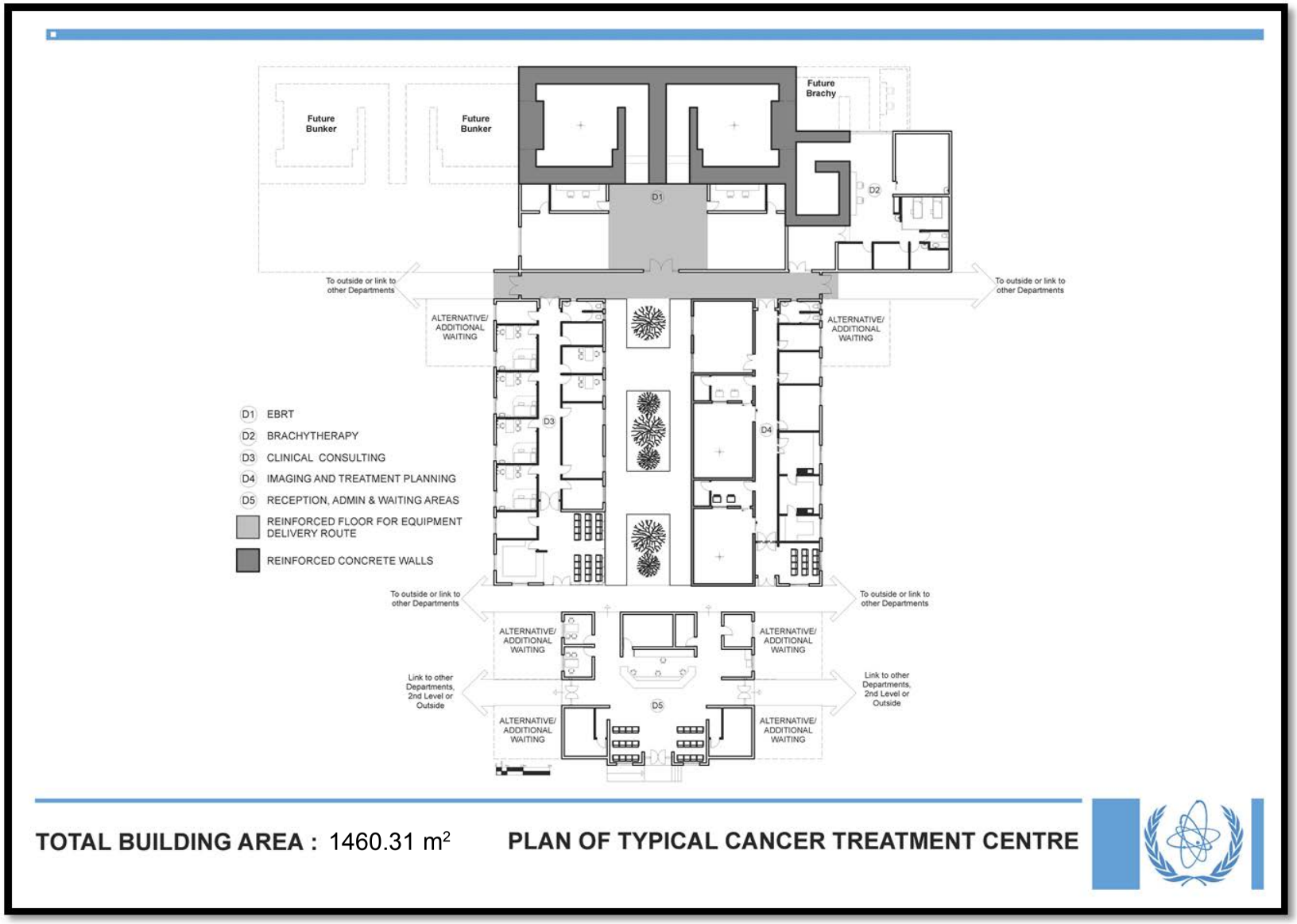


FIG. 7. Overall layout of a radiotherapy facility including all workstations. Alternative access routes which link the facility to other departments are shown. The dotted lines represent future expansion possibilities which will not disrupt services.

Appendix I

EXAMPLE OF A RADIOTHERAPY PROJECT RISK REGISTER (based on the joint Australian and New Zealand standard [8])

Risk section	Identified risk	Probability/ likelihood	Consequence/ impact	Risk rating	Proposed risk mitigation measures
Regulatory	Possible political instability	Possible	Major	Very high	Ensure that projects are not unduly delayed, equipment stands unused and loses warranty by rather postponing projects to when the political situation stabilizes.
Regulatory	Ownership of land precludes use for an oncology centre	Unlikely	Major	High	Ensure ability to use land identified for proposed project.
Regulatory	Zoning of parcel of land or easements prohibits use as intended	Unlikely	Major	High	Ensure appropriate zoning or ability to rezone property in timely manner.
Regulatory	Adjacent property development plans	Possible	Moderate	High	Check on proposed use, land ownership and zoning of surrounding properties to ensure proposed facility and long term expansion plans are feasible.
Regulatory	Existence of cancer control plan and associated planning from Ministry of Health perspective	Possible	Moderate	High	Check whether such a plan exists and engage Ministry of Health to ensure support for proposed centre.
Regulatory	Licensing requirements (radiation regulatory office) or lack of such infrastructure	Possible	Moderate	High	Ensure compliance.
Regulatory	Poor quality assurance applied or quality assurance programme lacking in its entirety	Possible	Moderate	High	Ensure internationally accepted quality criteria are applied and all services are frequently measured against such criteria.
Environmental	Site is subject to flood lines, earthquakes, cyclones, fire hazards, etc.	Rare	Major	Medium	Ensure that proposed parcel of land is not subject to any environmental hazards by virtue of its position.
Environmental	Site has problems related to soil conditions and potential road access	Rare	Major	Medium	Ensure that full geotechnical report and environmental impact assessments are done.
Feasibility	Not affiliated with the national tertiary specialist hospitals or teaching hospitals which could later be competing for resources or patients	Possible	Major	Very high	Ensure the oncology centre is aligned with such hospitals and preferably closely associated with or even co-located with such major hospitals.

Risk section	Identified risk	Probability/ likelihood	Consequence/ impact	Risk rating	Proposed risk mitigation measures
Feasibility	Not taking demographics of the country into account to ensure most optimal siting to ensure the most equitable access	Possible	Moderate	High	Ensure the oncology centre is established where the majority of potential patients would have the easiest access to care.
Feasibility	Lack of support from local and/or national Ministry of Health	Possible	Moderate	High	Ensure support from the outset, as the upfront and ongoing costs can be exorbitant, especially if another competing facility is established by the Ministry of Health.
Financial	Check for existing facilities which would compete for support and/or funding from Ministry of Health	Unlikely	Moderate	Medium	If existing facilities exist, consider viability and/or reconsider whether expanding the existing facility is a more viable alternative; ensure ongoing support from the Ministry of Health to fund additional and/or expanded facility.
Financial	Insufficient capital to design, construct and fit out the facility	Unlikely	Major	High	Proactive short and medium term cash flow planning. Obtain appropriate financial support from government.
Financial	Insufficient capital to enable training of staff required to operate such a facility, e.g. radiation oncologists, radiation therapists and medical physicists	Unlikely	Major	High	Identify critical staff early on and seek support from local government for the required training programmes which span 2–4 years for 12–15 individuals.
Financial	Insufficient capital to equip and run the established facility, including general running costs, maintenance costs, consumables and source costs, as appropriate	Unlikely	Major	High	Proactive short and medium term cash flow planning. Obtain appropriate financial support from government for ongoing operational costs.
Financial	Insufficient working capital in future to enable ongoing running of facility, including staffing costs and, ultimately, replacement costs	Unlikely	Major	High	Proactive short and medium term cash flow planning. Obtain appropriate financial support from government.
Financial	Lack of comprehensive survey of clinical needs and patient demographics	Unlikely	Major	High	Apart from own survey, also acquire independent surveys on patient numbers and types of treatment required.
Infrastructure	Check availability of services required for such a facility, e.g. electricity, water, sewerage, telecommunications	Possible	Moderate	High	Ensure adequate power, communications, ventilation and sewerage can be made available.

Risk section	Identified risk	Probability/ likelihood	Consequence/ impact	Risk rating	Proposed risk mitigation measures
Infrastructure	Lack of consistent electricity supply	Unlikely	Moderate	Medium	Put arrangements in place to ensure consistent supply and have arrangements made for backup power.
Infrastructure	The availability and level of IT services as well as local and national telecommunication networking possibilities	Possible	Moderate	High	Ensure adequate telecommunications infrastructure exists or consider wireless solutions.
Infrastructure	No possibility to expand the centre in the future	Possible	Moderate	High	Ensure that there is ample space allocated in the future to expand the centre as number of patients grows.
Infrastructure	The availability of services required for continuous operation of such a facility, e.g. office supplies, printing and computer technical help and supply	Unlikely	Moderate	Medium	Ensure adequate availability of goods and the ongoing maintenance thereof; focus on larger local suppliers with proven track record.
Design	Lack of suitable local expertise to design the facility, either professional, clinical or engineering	Possible	Major	Very high	Appoint consultants with appropriate expertise (e.g. architect with hospital experience, structural or civil engineer with experience of previous mass concrete works, electrical and mechanical engineers) and appoint a cost consultant. Ensure radiotherapy expertise is available to provide input.
Design	Poor design resulting in workflow issues due to lack of experience with regard to the operation of such facilities	Possible	Major	Very high	Appoint experienced consultants.
Construction	Unable to find suitable contractor with appropriate experience	Possible	Major	Very high	Identify possible contractors with proven track record in delivering similar projects in this region and on time.
Construction	Delays in completion of building works, hence delays in equipment installation and commissioning	Possible	Major	Very high	Appoint contractor with proven track record in delivering similar projects in this region and on time. Ensure that project manager is available to independently track progress and keep all parties updated.
Equipment	Insufficient support equipment that impacts on quality of service	Possible	Major	Very high	Check that the proposed equipment package has all components required for the level of service to be rendered, e.g. dosimetry and safety equipment, external beam with simulation and planning capabilities.

Risk section	Identified risk	Probability/ likelihood	Consequence/ impact	Risk rating	Proposed risk mitigation measures
Equipment	Suitable equipment unavailable when ready to install	Rare	Major	Medium	Ensure that equipment is only ordered once the project has started, to ensure timely delivery and the most up to date technology and upgrades are supplied.
Equipment	Redundancy of equipment if supplier leaves the market	Possible	Moderate	High	Ensure supplier has proven track record and has sufficient size and product range to be able to fulfil support services well into the future and over the lifetime of the installed equipment.
Equipment	Equipment from more than one vendor, especially in replacement scenario, not compatible	Possible	Moderate	High	Target compatible equipment as a priority but resolve insurmountable issues by engaging with third party service providers to provide integration solutions.
Equipment	Unscheduled downtime due to poor maintenance	Likely	Major	Very high	Ensure maintenance and service contracts are in place and that all maintenance requirements are adhered to.
Equipment	Unscheduled downtime due to malicious damage to equipment	Unlikely	Major	High	Ensure maintenance and service contracts are in place and that all maintenance requirements are adhered to. Arrange in advance for alternative treatment slots on neighbouring facilities' equipment to cater for events where equipment cannot be repaired within a month.
Equipment	Unavailability of technicians for unscheduled breakdowns	Possible	Catastrophic	Very high	Ensure that service contract and management by supplier is treated as of paramount importance, and that frontline service engineers are identified and/or trained as part of the equipment procurement process.
Equipment	Limited access to international logistics for timely spares in event of breakdowns and routine servicing	Possible	Major	Very high	Obtain a written undertaking from the supplier that the service delivery chain will be integrated with existing local logistics support and infrastructure.
Equipment	Availability of outsourced functions if these are not in-house (radiology, nuclear medicine, etc.)	Possible	Major	Very high	Ensure radiology and other services are available and well established in the area; if not, consider that as part of the development.
Patient	Unavailability of transport	Possible	Moderate	High	Explore the provision of a bus service for transporting patients from more remote locations to the centre.
Patient	Unavailability of parking on-site	Unlikely	Moderate	Medium	Negotiate an arrangement for upgraded parking facilities.

Risk section	Identified risk	Probability/ likelihood	Consequence/ impact	Risk rating	Proposed risk mitigation measures
Patient	Unavailability of low cost accommodation, or on-site ward facilities	Unlikely	Moderate	Medium	Access the community programmes in place to assist patients with this expense; negotiate preferential accommodation and travel packages for patients receiving treatment.
Patient	Lack of communication in culturally diverse areas	Possible	Moderate	High	Review staff's multilingual abilities. Ensure availability of interpreters. Ensure that social workers or counselling services are available to assist in managing the needs of culturally diverse populations.
Patient	Security of patients and staff and their belongings	Possible	Moderate	High	Ensure adequate security of patients, families and staff, as required.
Personnel	Radiation oncologists, radiation therapists or medical physicists not available due to insufficient numbers trained	Possible	Major	Very high	Ensure suitable candidates are identified and sent for training as soon as project is signed off to reduce the reliance on outsourced staff.
Personnel	Sudden loss of key staff members which results in interruption of service	Unlikely	Major	High	Arrange in advance to have all necessary professional registrations and work permits in place for staff from other centres/countries to provide a locum service to address an acute shortage of staff.
Personnel	Availability of appropriate number of key support staff needed in the centre, e.g. oncology nurses, social workers, counsellors, mould-room technicians	Possible	Moderate	High	Proactively manage staff to complement and develop key qualities for continuity of service.
Personnel	Availability of appropriate numbers of other specialities needed to support oncology service, e.g. pathology, radiology, nuclear medicine (non-essential), surgical specialities, medical oncology (unless oncologist is dual qualified)	Possible	Moderate	High	Seek to align with major hospitals where such services are more likely to be available.
Personnel	Poor access to specialist architect, various types of engineer, cost consultant and other specialist oncology design skills needed in the construction process of centre and specifically the bunker(s)	Unlikely	Moderate	Medium	If local skills are not forthcoming, then outsourcing will be required for the duration of the construction period.

Priority	Negligible	Minor	Moderate	Major	Catastrophic
Rare	Low	Low	Low	Medium	High
Unlikely	Low	Medium	Medium	High	Very high
Possible	Low	Medium	High	Very high	Very high
Likely	Medium	High	Very high	Very high	Extreme
Almost certain	Medium	Very high	Very high	Extreme	Extreme

A	Extreme	Extreme/(23–25) Immediate action and involvement required at a senior management level to control the risk
B	Very high	Very high/(16–22) Detailed research and management planning required at a senior management level
C	High	High/(12–15) Management attention needed and management responsibility specified to control the risk
D	Medium	Medium/(6–11) Manage by specific monitoring or response procedures locally
E	Low	Low/(1–5) Manage by routine procedures, unlikely to need specific application of resources

Appendix II

SAMPLE PROJECT CHECKLIST

Process	Duration	Responsibility	Start Date	End Date	% Complete
Develop Radiotherapy Programme (Cycle 1)					
Best estimate of national cancer burden					
Prepare country master plan (e.g. national cancer control plan, non-communicable disease strategy)					
Obtain go-ahead for the project					
Prepare feasibility study					
Prepare bankable document for funding (if applicable)					
Identify clinicians; initiate education as radiation oncologists	36–48 months				
Identify physicists; initiate education as medical physicists	24–30 months				
Identify radiographers; initiate education as radiation therapists	12–18 months				
Facility Planning and Construction (Cycle II)					
Constitute implementation team					
Complete inspection of existing facilities to determine siting options					
Prepare initial project master plan					
Site selection					
Legal due diligence					
Update master plan and sign off					
Technical due diligence					

Process	Duration	Responsibility	Start Date	End Date	% Complete
Prepare accommodation schedule					
Prepare concept design					
Prepare detailed layout					
Confirm shielding and design with medical physicist					
Prepare detailed layouts of all elevations and obtain medical physicist sign-off					
Obtain regulatory approval of the detailed layouts					
Finalize detailed engineering drawings (e.g. mechanical, structural, electrical, IT)					
Prepare cost and quantity estimates based on final plans					
Sign-off by implementation team					
Prepare final documentation for construction					
Tender process, if applicable					
Construction and monitoring	12–18 months				
Commission building					
Equipment and Clinical Commissioning (Cycle III)					
Specification and procurement of equipment	12 months				
Delivery and installation of equipment and final finishes	4–6 months				
Acceptance testing of equipment	1–2 months				
Commissioning of equipment	2–3 months				
Licensing of facility					

Process	Duration	Responsibility	Start Date	End Date	% Complete
Applications training on equipment	1 month				
Prepare clinical protocols and procedures					
Start treatment					
Post-completion evaluation and provide close-out report					

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