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**PLANNING
OF RADIOTHERAPY FACILITIES**

Report of a Joint IAEA/WHO Meeting

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WORLD HEALTH ORGANIZATION

GENEVA

1966

**JOINT IAEA/WHO MEETING
ON PLANNING OF RADIOTHERAPY FACILITIES**

Geneva, 15-19 December 1964

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PLANNING OF RADIOTHERAPY FACILITIES

Report of a Joint IAEA/WHO Meeting

A Joint IAEA/WHO Meeting on Planning of Radiotherapy Facilities was held in Geneva from 15 to 19 December 1964. Dr F. Grundy, Assistant Director-General of the World Health Organization opened the meeting and welcomed the participants on behalf of both organizations. He referred to the two earlier joint IAEA/WHO meetings on radiotherapy and radiation physics that had prepared the way for the present meeting, which had been convened to focus upon the most important practical issues involved in the planning of radiotherapy facilities—the organization and staffing aspects, equipment, and architectural considerations—with particular emphasis on the needs of the developing countries. He pointed out that radiotherapy was an essential element in the treatment of cancer patients, and it was necessary for it to be integrated with and organized as part of general medical care. A number of factors, such as the general health conditions of the country and the existing medical service facilities, the incidence rates of the different forms of cancer, population distribution, transport, availability of trained personnel, etc., needed to be taken into account when planning the establishment and development of radiotherapy facilities.

Dr J. J. Nickson was elected Chairman, Dr P. K. Haldar Vice-Chairman, and Dr H. J. Ham and Mr E. E. Smith Rapporteurs.

1. INTRODUCTION

In many parts of the world, particularly in developing countries, cancer control and treatment programmes have had relatively low priority in the past, because of the pressure of other public health problems such as communicable disease. However, communicable diseases are being brought rapidly under control, and more of the population are reaching the age at which the incidence of malignancy is high. Thus cancer may be expected to become a larger problem and to demand a higher priority in public health planning. The creation of adequate facilities and the training of the necessary personnel to deal with this situation will take time, in many cases 10 to 15 years.

Radiotherapy is at present, and will remain for many years, one of the principal methods of treatment of cancer. It is also used to some extent in the treatment of certain non-malignant conditions, but the indications for such use have tended to diminish with the introduction of other effective

methods of therapy. It is for the treatment of cancer that radiotherapy deserves consideration as an essential service in the organization of medical care of any population.

It has been estimated in some developed countries that there are as many as 2000 to 3000 new cases of cancer per million of population arising each year. Similar figures might be expected to be reached in developing countries as the incidence of malignant disease increases. It has also been estimated that radiotherapy has a proper place in the treatment of at least half of all cancer patients at some time in the course of their disease, either as the sole method of treatment or in combination with surgery, chemotherapy or treatment with hormones. In some countries the incidence of cancer may be greater or less than that mentioned above, and there may be great differences in the incidence of various forms of cancer and in the organs affected. However, malignant disease is ubiquitous, and there is a necessity for radiotherapy in all countries whatever their climatic, dietary and economic conditions. In places where medical, social and educational services are less well developed, there will be a higher proportion of cancer cases with advanced disease when first seen medically, and for them radiotherapy may be the only practical method of treatment that will give any chance of alleviation. While for a given country at a particular time it may be that financial and other priorities must go first to the control of other diseases, nevertheless wherever any real attempt is made to improve the treatment of cancer, radiotherapy services must be developed.

Experience has shown that a high standard of achievement in radiotherapy will be maintained only if it is conducted by specialist radiotherapists working in departments devoted solely to radiotherapy. The subject is such a wide one that it is hardly possible for a physician to combine radiotherapy with the practice of another specialty such as radiodiagnosis. If there is to be reasonable economy in the operation of a radiotherapy department, and if efficient treatment is to be given to the maximum number of patients, the conditions of employment of the radiotherapist must be such that he can spend the whole of his working day in the radiotherapy department. He should be thoroughly trained in both the theoretical and technical aspects of radiotherapy, and his clinical competence and status should be comparable with that of other specialists on the medical staff of the hospital.

The treatment of cancer always demands teamwork, and collaboration on the part of the clinicians involved is imperative. The surgeon, the physician practising hormonal treatment or chemotherapy, and the radiotherapist should not work in isolation but should combine their skills and experience in the day-to-day treatment of a majority of cancer patients. The radiotherapy department should therefore be sited in a hospital or oncological institute where medical and surgical care of good quality is also available.

In addition, the radiotherapy department must include appropriately qualified and experienced radiological physicists and trained radiotherapy and physics technicians. The reports of two earlier meetings convened by the International Atomic Energy Agency and the World Health Organization, in Vienna in 1959¹ and in Montreal in 1962,² have pointed out the necessity for such an organization and have detailed the type of work that the various staffs would carry out.

Adequate records of all patients and of their treatment should be maintained, and if progress and improvement are to be achieved, there must be an effective system of follow-up to determine the results of treatment.

Newly developed radiotherapy departments and services may often be fully occupied with routine treatments, but provision of facilities for research work is nevertheless highly desirable and is important in helping to maintain a high standard of treatment.

Proper attention must be paid to the provision of adequate protection against radiological hazards, both in the construction of departments and in the organization of the daily work. The engineering services necessary for the maintenance of apparatus should also be available.

With the foregoing in mind it is the purpose of this report to discuss essential factors in the planning of radiotherapy facilities, in the hope that it may be useful to those who are considering the establishment of such facilities and to those who are responsible for radiotherapy in the treatment of cancer.

2. ORGANIZATION OF RADIOTHERAPY IN RELATION TO OTHER HOSPITAL SERVICES

The organization of radiotherapy services varies from country to country at present, ranging from the large autonomous radiotherapy institute with its own essential services and staff, operating independently of other hospitals, to the small radiotherapy section of a department of radiology that is primarily diagnostic, where, in some cases, radiologists still cover both radiodiagnosis and radiotherapy in their hospital work.

Radiotherapy, however, is a specialty in its own right, and should be organized as a separate department or centre, with separate staff appointments provided for specialized radiotherapists.

¹ *Use of radioisotopes and supervoltage radiation in radioteletherapy (Report of and background information for a study group convened by the IAEA and WHO)*, Vienna, IAEA, 1960.

² IAEA/WHO (1963) *Report on Meeting on Practical Methods of Assisting Radiotherapy Centers in Less-Developed Areas*, *Acta Radiol. (Stockh.)*, N.S.1, 217.

In the initiation or extension of radiotherapy services in a developing country or part of a country, the national and regional planning authorities should decide the size and geographical distribution of radiotherapy departments and centres, taking into account the magnitude of the problem and the probable patient load, staffing, capital and operating costs. Generally, radiotherapy will be restricted to comparatively few centres, with each serving perhaps a number of hospitals in its region. It is desirable that radiotherapy departments or centres should be attached to large general hospitals, preferably teaching hospitals, where the services of general medicine, surgery, pathology and radiodiagnosis, as well as ward accommodation, already exist. In this way, combined consultative clinics may be more readily organized.

Annex 3 provides a schematic representation of the relationships between a radiotherapy department and other hospital departments and health services.

2.1 Organization of radiotherapy services

Radiotherapy departments should be developed in accordance with the standards of other specialty hospital departments in the country, and the head of the department should be a highly qualified and experienced radiotherapist, equal in status to other specialists. (Staff qualifications are discussed in the next section.)

Every radiotherapy department requires outpatient facilities (further considered under section 6.1) and a complement of beds under the control of the radiotherapy staff should be provided (further considered in section 6.5).

The department should include a separate operating theatre for the application and insertion of sealed radioactive sources (see section 6.6), because radium therapy and the application of other sealed radioactive sources are the responsibility of the radiotherapist.

2.1.1 Service to peripheral hospitals

When the organization of the main centre has been established, consideration should be given to regular visits by radiotherapists from the centre to peripheral hospitals in the regional area to conduct outpatient clinics, arrange for preliminary investigation, and effect the follow-up of patients already treated. This system has a number of important practical advantages :

- (a) more early cases are encountered ;
- (b) personal contact with the patient's doctor and relatives is possible ;
- (c) accommodation in the main centre is saved by the carrying out of preliminary investigations (biopsy, etc.) ;

- (d) great savings in travelling are effected ;
- (e) the patient is seen for follow-up near home and the follow-up records will be more complete ;
- (f) patients who may not be fit or may not be able to afford to travel to the main centre will be seen ;
- (g) the visits have an educative effect on both the profession and the public ;
- (h) such visits help to familiarize the radiotherapy staff with conditions in their own region.

2.1.2 *Association with other specialties*

As teamwork is very important in the treatment of cancer, involving close co-operation between the various specialists concerned—the physician, surgeon, radiotherapist, diagnostic radiologist, pathologist and radiological physicist—combined consultative clinics are of great value, and their value is enhanced when they embrace the review of patients treated earlier. The exercise of joint decision and review is profitable to the patients, to the consultants, and to junior staff and students who attend. Once the line of treatment has been jointly decided, the details of radiotherapy (if this is the treatment of choice) are the responsibility of the radiotherapist.

2.1.3 *Relation to diagnostic radioisotope services*

Radioisotopes are used in a variety of diagnostic and functional tests in many branches of medicine. Because of its special knowledge of radiation problems, the radiotherapy department may be associated with these tests although the main responsibility for them will usually rest elsewhere. Some investigations, such as the detection and localization of tumours and metastases, are of special interest to the radiotherapy department and are frequently (although not invariably) carried out within the radiotherapy department.

It also happens, particularly in small or newly established hospitals, that the radioisotope laboratory of the radiotherapy department is expected to undertake a range of diagnostic tests including some unconnected with tumour localization. It is not recommended, however, that the radiotherapy department should deliberately seek to establish this function where other arrangements for diagnostic radioisotope tests can be made in the hospital, or to retain the function beyond an initial transitional period.

2.1.4 *Relation to radiological physics*

It is again emphasized that every radiotherapy department should have on its staff a full-time, trained radiological physicist. The physicist, in addi-

tion to his regular duties of radiation dosimetry, calibration of equipment, etc., must be associated as a full partner in the radiotherapy team, playing an important part in treatment planning, supervising the physics of radioisotope work, and assisting or organizing the radiation protection measures in the hospital. His responsibilities include participation in the teaching, training and research programmes and are discussed in more detail in the report of the Joint IAEA/WHO Meeting on Practical Methods of Assisting Radiotherapy Centres in Less-Developed Areas.¹

2.1.5 *Relation to teaching and training programmes*

Formal lectures should be given by the radiotherapist to undergraduates during the medical course. There should also be formal attendance of medical students at the radiotherapy department on a number of occasions, when the value of radiotherapy and its hazards should be discussed. The radiotherapist and radiological physicist should also play their part in the education of radiotherapists, physicists and technicians, and in the postgraduate education of other specialists.

2.1.6 *Records*

Accurate records contribute considerably to clinical research in cancer and to the development of new methods of treatment. It is emphasized that it is essential to set up an efficient records system for all patients seen, whether treated or not. This should cover the history, clinical details, results of investigations, accurate details of any radiotherapy, and follow-up. The establishment of a statistical section in association with the records system is necessary.

3. STAFF REQUIREMENTS FOR A RADIOTHERAPY DEPARTMENT

The qualifications that should be required for the medical, scientific and technical personnel are discussed below together with the responsibilities and duties of the various categories of staff.

3.1 **Medical radiotherapist**

(a) A medical radiotherapist should possess a medical qualification acceptable in his own country.

¹ IAEA/WHO (1963) *Acta Radiol. (Stockh.)*, N.S.1, 217.

(b) He should have had a minimum of two years' general clinical experience, including pathology.

(c) Ideally he should have had a minimum of three years' experience in a large radiotherapy centre if he is to assume the senior post in a new department or centre. If he is to join a centre in a subordinate post, two years may be sufficient.

(d) When at all possible, the period of postgraduate training in radiotherapy should lead to an examination to determine the competence of the candidate.

3.1.1 *Responsibilities and duties*

3.1.1.1 *Clinical duties.* The radiotherapist collaborates with his clinical colleagues in diagnosing the disease and in making the fundamental decision as to whether or not it should be treated by radiotherapy. He is responsible for the medical care of the patient undergoing radiotherapy. He is also responsible for ensuring that adequate records of the patient and his treatment are kept.

3.1.1.2 *Treatment planning.* The aim of treatment planning is to irradiate a defined volume of tissue and to deliver to it a dose considered as optimum. The radiotherapist is responsible for this task; he is helped by physicists and technicians but his responsibility remains complete. His minimum duties in treatment planning are the following:

(a) Localization of the tumour; delineation of the target volume; determination of the relation of the target volume to the external contour of the body in the treatment position and to neighbouring structures.

(b) Choice of the type of radiotherapy, e.g., external beam therapy or interstitial therapy.

(c) Deciding the dose; total absorbed dose in the tumour, fractionation, overall time and number of sessions.

In some cases, his work of treatment planning can be limited to these items. Usually, however, in conjunction with the physicist, he also chooses the best way of delivering radiation to the patient.

After estimation by the physicist of the absorbed dose within the body of the patient, the radiotherapist must satisfy himself that none of the radio-sensitive normal tissues receives a dangerous dose.

3.1.1.3 *Conduct of treatment.* (a) Clinical examination of the patient at least twice weekly, in order to judge the effects of the radiation; (b) overall verification of the technician's work, especially as regards the positioning of patients before irradiation and the absence of any change of position during treatment.

3.1.1.4 *Follow-up of the patient after treatment*

3.1.1.5 *Radiation protection.* The senior radiotherapist is responsible for protection of his staff against radiation.

3.1.1.6 *Teaching and research.* As already indicated, an important part of the radiotherapist's work may lie in the fields of teaching and research.

3.2 Radiological physicist

(a) The radiological physicist must possess a basic qualification in physics.

(b) After qualification, he should have preferably a minimum of three years' postgraduate training in radiological physics, including practical experience in radiotherapy (including supervoltage radiotherapy) and instruction in radiation health and safety. In those instances where it may be impossible to allow three years' postgraduate training, every effort should be made to make up the deficiency by attendance at regional symposia, by inviting visiting senior physicists to work in the radiotherapy department, and by attendance at short courses.

(c) It is highly desirable that the course of study lead to an examination to determine the competence of the candidate.

3.2.1 *Responsibilities and duties*

Generally speaking, the responsibilities of the physicist fall into three categories: services related to the treatment of patients, teaching and research. The amount of time he will spend on each of these will depend on the state of development of the radiotherapy department and the hospital with which he is associated.

As minimum duties, the physicist shall be responsible to the radiotherapist for: (a) all aspects of radiation dosimetry; (b) collaboration in treatment planning; (c) all physical aspects of radiation protection; (d) all physical aspects of the use of radioisotopes; (e) design and construction of ancillary apparatus, such as beam-directing devices; (f) overall supervision of maintenance of equipment; (g) advice on the choice of new radiotherapy and radioisotope equipment and building-design problems.

3.3 Radiotherapy technician

It is recommended that the radiotherapy technician should have a recognized secondary school education followed by a course of study in a large, well-equipped department of radiation therapy, during which time

he would obtain clinical experience. Ideally this course of study should lead to an appropriate examination and qualification as a radiotherapy technician.

3.3.1 *Responsibilities and duties*

In general the duties of the radiotherapy technician are to assist the radiotherapist to plan and execute the treatment of the patients, and to record relevant information concerning the treatment. The radiotherapy technician is directly responsible to the radiotherapist for these duties, which may include :

(a) assisting the radiotherapist in the day-to-day treatment of the patient, including positioning of the patient for and during treatment ;

(b) preparing equipment for daily use, for example warming up X-ray machines, calibrating treatment units (under the general direction of the physicist), and recording the value obtained ;

(c) using beam directing aids, including field localizing films ;

(e) assisting the radiotherapist in the preparation and use of positioning aids, such as body cast, moulds, etc. ;

(f) maintaining records of treatment data (statements of exposure dose, treatment time, relevant calculations, etc.) ;

(g) assisting the radiotherapist in the therapeutic use of sealed and unsealed radioisotopes.

3.4 **Physics technicians**

It is unnecessary to specify in detail the qualifications of technicians to assist the radiation physicist. The selection and training of such personnel will be the responsibility of the senior radiological physicist ; the background of such individuals may include practical experience in engineering or a formal qualification in that field. Their duties and responsibilities will be assigned by the senior radiological physicist.

3.5 **Other staff considerations**

The following considerations, which in the past have led to some difficulty in the establishment of new radiotherapy services in the less developed areas, deserve emphasis.

(1) It is self-evident that the usefulness of any medical service to the community depends upon the quality of the persons responsible for its operation. Any department or centre, however lavishly equipped, will

not provide maximum benefit to the community unless the professional and supporting staff are fully qualified and devote their full effort to the care of the patients. Therefore, if at all possible, arrangements should be made so that the remuneration provided to the medical and physical staff is commensurate with that obtained in comparable scientific positions. Since the terms and conditions of such scientific positions vary widely, no attempt is made here to give detailed recommendations. It is essential, however, that those in positions of authority understand that failure to provide for realistic solutions to this problem will diminish or even vitiate the usefulness to the community of the radiotherapeutic department or centre.

(2) Unless a fully-qualified radiotherapist and a radiological physicist will be available for staffing a new department, the wisdom of establishing it should be reviewed.

Since in less developed areas such persons are not likely to be present before the establishment of the department, it is suggested that the first consideration should be the selection of suitable persons for training. Due attention should be given to qualities of leadership as well as to professional competence, as the overall abilities of the radiotherapist and radiological physicist will be important in determining the success of the department.

(3) Ideally, the period of training of the personnel and of construction of the new department should terminate at the same time. If a choice exists it is better for the radiotherapist and physicist to be available to supervise the final stages of construction and of installation of the apparatus. In any event, they should be in frequent consultation with the architects throughout.

(4) The initial number of radiotherapy technicians will be determined largely by the number of patients and by the number of therapy units and sealed sources planned for the new department or centre. One technician will usually be sufficient for the low-voltage X-ray therapy machine and sealed sources, unless it is anticipated that the use of the sealed sources will be very heavy—in excess of 300 applications per year. For supervoltage units more than one technician may be required. In any case, a minimum of three trained technicians should be available when the department opens, or very shortly thereafter.

(5) The availability of fellowships to assist in the initial and subsequent training of the necessary personnel may ease the financial burden of providing suitably qualified people, but in no way changes the recommendation that a department be staffed adequately. Major radiotherapy training centres will accept suitably sponsored candidates with the understanding that positions are available for them upon their return. (Training is also discussed in the reports of the two IAEA/WHO meetings referred to on page 5.)

4. CHOICE OF RADIOTHERAPY EQUIPMENT

4.1 Introduction

In order to provide good radiotherapy for the treatment of cancer arising in various sites, a variety of equipment is necessary. Lesions may be divided into four categories, for each of which different treatment modalities are appropriate. These are :

- I. Deep-seated lesions.
- II. Lesions within a few centimetres of an accessible surface.
- III. Superficial lesions either of the skin or in a body cavity.
- IV. Systemic disease or local disease amenable to attack with unsealed radioisotopes.

For the treatment of lesions in these categories, the following types of radiation sources are currently available from various suppliers :

- I. (a) Cobalt-60 teletherapy units ;
(b) 2-MV resonant transformer machines ;
(c) 2-MV Van de Graaff machines ;
(d) 4- to 8-MV travelling-wave linear accelerators ;
(e) betatrons for X-rays up to 42 MV and electrons greater than 20 MeV.
- II. (a) 200-400-kV X-ray machines ;
(b) medium-distance gamma-ray beam units ;
(c) high-energy electron beam machines (6-20 MeV).
- III. (a) Superficial X-ray therapy machines ;
(b) short-distance gamma-ray beam units ;
(c) sealed gamma-ray sources ;
(d) beta-ray applicators ;
(e) low-energy electron beam sources (up to 6 MeV).
- IV. (a) Phosphorus-32 for haemopoietic disorders or disseminated osseous metastases ;
(b) iodine-131 for thyroid dyscrasias ;
(c) phosphorus-32 and gold-198 for local instillations.

How much of this equipment is needed by the centre will depend on the relative incidence of cancer at various sites, the treatment policies adopted, and the internal administrative arrangements for handling the patient flow. Because multiple irradiation sessions are usually given during treatment by external beams of lesions in categories I and II, more therapy units

are required for treatment in these categories than in category III. Typically, 20 to 40 patients per day may be treated per therapy unit or machine.

It is recommended that basic equipment for a radiotherapy department include one unit for each of the first three categories above, i.e., one large supervoltage therapy unit, one medium-voltage X-ray therapy unit or a medium-distance telecurie therapy unit, one superficial X-ray unit and a range of sealed gamma-ray sources for brachytherapy. In areas where there is a high incidence of superficial skin and eye malignancies, beta-ray applicators are also desirable.

This basic equipment should easily be able to provide 50 treatments per day with the supervoltage and medium-voltage units combined (categories I and II). Thus, a total number of new cases of about 600 per year, including superficial disease (category III), would be a reasonable case-load for which such a department should be instituted.

4.2 Recommendations for specific therapy equipment

4.2.1 *Considerations affecting choice of specific equipment within a given category*

Several physical aspects of competitive devices should be compared, including :

- (a) the ease and uniformity with which a selected tumour dose can be delivered ;
- (b) the reliability and ease of maintenance ;
- (c) the versatility, i.e., ability to provide treatment in more than one of the above categories ;
- (d) the radiation safety ;
- (e) the capital cost ;
- (f) the economy of operation and maintenance.

4.2.2 *Treatment of deep-seated lesions*

The most important single piece of apparatus to be selected for a new radiotherapy department is the supervoltage unit. Multiple-field or rotational treatment plans, using X-rays ranging from 2 MV to 30 MV or gamma rays from cobalt-60, do not differ remarkably. In all cases, adequate doses of sufficient uniformity are deliverable to the volume containing the lesion. In these circumstances, reliability, ease of maintenance and cost become the decisive factors.

4.2.2.1 *Reliability of supervoltage equipment*

Probably the two most reliable types of supervoltage radiation sources are the 2-MV resonant transformer and the cobalt-60 teletherapy units. The

former have been known to run for 10 years without being opened and without replacement of the glass accelerator tube. Tube lives of over 10 000 hours have been recorded. In the same way, modern cobalt-60 units frequently give continuous service for periods of several years between source replacement. Such replacement can usually be effected over a weekend. Vertically mounted cobalt-60 units generally give rise to fewer maintenance problems than rotational units.

It is generally recognized that Van de Graaff machines, linear accelerators and betatrons require the rapid availability of a skilled maintenance engineer or technician. Without such skilled personnel and without preventive maintenance routines, it would hardly be possible to operate these machines and not incur excessive loss of treatment time. Neither the resonant transformers nor the teletherapy units require the immediate availability of specially trained maintenance personnel. It is therefore concluded that reliability dictates the installation of one of these types of equipment in the developing countries.

4.2.2.2 *Economics of supervoltage equipment*

Analyses of the economics of competitive supervoltage equipment have been made during the preparation of this and earlier reports.¹ The assumptions are made that all units are operated under conditions of full use during a treatment day and at the same or comparable source-surface distances. A constant set-up time per patient is assumed.

In Table 1, comparative estimates of operational cost per 200-rad tumour dose at 10 cm depth are presented. These comparisons do not include the costs of personnel, since these are highly variable in different parts of the world. To some extent, personnel costs may be considered constant per treatment given, since a rising patient load ultimately requires more medical and physical staff. On the other hand, small increases in patient load can be handled without increase of staff, and in this circumstance a unit with high output may be more economical because of smaller personnel costs per treatment.

The operational costs are seen to be lowest for the cobalt teletherapy units and the Van de Graaff machine. The major operational cost for cobalt units is the decay of the source. The costs of rotational units are greater than those of vertically mounted units.

It is therefore recommended on grounds of reliability and economy that the supervoltage unit of choice for a developing country is a large cobalt-60 teletherapy unit. A desirable source output is in the range of 3000 to 5000 roentgens per hour at one metre, the lower exposure rate being more

¹ *Use of radioisotopes and supervoltage radiation in radioteletherapy (Report of and background information for a study group convened by IAEA and WHO)*, Vienna, IAEA, 1960.

Maintenance:										
Parts and service	500	500	1 000 ¹⁰	500	500	5 900 ¹¹	4 500 ¹²	4 000 ¹³	7 000 ¹⁴	
Exchange of source ¹⁵	350	350	350	350	280*	0	0	0	0	
Hospital personnel ¹⁶	0	0	0	0	0	1 000	0	1 000	1 000	
	15 370	11 020	17 670	9 525	17 700	26 600	29 420	30 550		
Total	1.89	1.82	1.80	1.24	2.02	2.82	2.71	3.52		
Cost per treatment (\$)										

¹ The four units have the following characteristics:

- A = 5000 Ci 2-cm source with vertical support 100 cm SSD
- B = 3000 Ci 2-cm source with vertical support 100 cm SSD
- C = 5000 Ci 2-cm source with rotational support 80 cm SAD
- D = 3000 Ci 2.5-cm source with vertical support 80 cm SSD

(NOTE: In commercial practice, the output of a teletherapy source is frequently stated in "Rhm", i.e., in R/h at a distance of 1 metre. As a rough approximation, 1 Ci of cobalt-60 is equivalent to 1 "Rhm".)

² For the cobalt sources the mean exposure-rate over a 4-year life is quoted (77.5% of initial rate).

³ Mean exposure-rate at 70 cm SSD (80 cm SAD).

⁴ Mean exposure-rate at 80 cm SSD over a 5-year life (73% of initial rate).

⁵ 1 year is 52 weeks at 40 hours per week.

⁶ Building costs at \$5 per cubic foot of space.

⁷ Includes room for power supplies.

⁸ Amortization over 10 years for equipment, 20 years for building and 4 years for cobalt-60 sources.

⁹ 5-year life in this case.

¹⁰ Inquiries show more maintenance problems with rotational teletherapy units.

¹¹ 60% of tube life at \$6500 per tube + \$2000 for service from manufacturer.

¹² \$4000 for tube pro rata (assuming 2000-h life) plus \$500 for other maintenance.

¹³ 300 hours at \$10 per hour for component life + \$1000 for service from manufacturer.

¹⁴ \$6000 for cost of 1 "doughnut" per year (600 hours life) plus \$1000 for other components and service.

¹⁵ Net cost after credit for old source deducted.

¹⁶ No maintenance personnel is assumed for cobalt-60 and resonant transformer equipment; 10% of the time of a maintenance engineer with \$10 000 per year salary is assumed for other equipment.

economical where there is less than full utilization. A desirable treatment distance is 80 cm source-surface distance (SSD) or source-axis distance (SAD) in the case of rotational units.

4.2.3 Treatment of lesions near the body surface

Lesions in this category are located several centimetres below an accessible treatment surface. Two competitive types of equipment are recommended for the treatment of such lesions: medium-voltage X-ray machines and medium-distance telecurie units. The medium-distance telecurie units operating at 30 to 50 cm SSD have several advantages over the conventional 200- to 400-kV X-ray machines.

(a) There is a considerably higher percentage depth dose for small fields using cesium-137 or cobalt-60 gamma rays (see Table 2).

TABLE 2. PERCENTAGE DEPTH DOSES (FOR 6×6 CM FIELD) WITH VARIOUS THERAPEUTIC X- AND GAMMA-RAY BEAMS

Depth (cm)	X-rays ¹ (SSD = 50 cm)	Cs-137 gamma rays (SSD = 50 cm)	Co-60 gamma rays (SSD = 50 cm)
0	100	100 (0.12 cm)	100 (0.5 cm)
1	96.5	95.4	96.7
2	88.3	88.5	90.1
3	78.8	81.2	83.6
4	69.0	74.0	77.3
5	60.1	67.6	71.3

¹ Half-value layer = 3 mm of copper.

(b) A considerably higher dose per field can be administered using these gamma-ray beams before a given degree of skin reaction is produced. The delivery of adequate tumour doses to some moderately deep lesions without exceeding skin tolerance is readily achieved with the telecurie units while it may be difficult with medium-voltage X-ray machines.

(c) With the higher energy radiation, treatment planning and the design of wedge-filters is simplified, and more uniform dose distributions can usually be achieved.

(d) The maintenance problems with telecurie units are usually small and the radiation source has a useful life of about 4 years for cobalt-60 and about 20 years for cesium-137.

(e) Operation of X-ray units in hot or humid climates intensifies the maintenance problems due to electrical failure of cables, insulating oil and other components.

The principal disadvantages of the medium-distance telecurie units are the higher initial cost of the units and the treatment room, and operational difficulties such as sticking shutters. The latter difficulty can usually be overcome with a simple programme of routine maintenance, which in any case is important.

If the department includes both a long-distance and a medium-distance cobalt-60 unit, it may be possible to re-use in the medium-distance unit a cobalt-60 source that has partially decayed in the long-distance unit. This measure substantially improves the economy of operation of such a department.

It is therefore concluded that a medium-distance telecurie unit is preferable to the installation of a medium-voltage X-ray machine in a new therapy department. Such a unit need initially contain no more than 1200 curies of cobalt-60 or 3500 curies of cesium-137, giving initial exposure rates of about 80 R/min at 50 cm SSD.

If an X-ray machine is installed it should be capable of operation with an exposure rate of at least 50 R/min at 50 cm SSD and with a half-value layer of at least 3 mm of copper. A most important criterion for the selection of such a unit in a developing area is the rapidity and reliability with which maintenance services are available from the manufacturer or his agent. A generous stock of spare parts should be readily available.

The use of high-energy electrons to treat shallow lesions, although technically attractive, is not recommended in developing countries because of the maintenance problems and high cost of the equipment and because specially trained radiotherapeutic and physical staff are necessary for its operation.

4.2.4 *Treatment of superficial lesions*

4.2.4.1 *Superficial X-ray therapy machines*

In the selection of a single machine for superficial X-ray therapy the most important consideration is versatility of use over a wide range of beam qualities and treatment distances. Ideally the quality range should encompass half-value layers from 0.1 to 2 mm of aluminium while the treatment distance should be variable from 5 cm or less to 20 cm. In practice, X-ray machines offering only part of this range are available. Moreover, superficial X-ray machines operated with very short treatment distances and low inherent filtration are difficult to calibrate accurately. The recommended single machine for superficial use should operate in the 40-kV to 120-kV range at up to 10 mA tube current with a beryllium window tube. Applicators within the above range of focus-skin distance (FSD) for a variety of field sizes from 2 cm to 20 cm in diameter should be provided. For intracavitary use applicators permitting direct viewing of the surface under treatment are recommended.

Depending on the types of superficial lesion to be treated, it may be necessary to acquire more than one machine so as to enlarge the range of lesions for which appropriate treatment can be given. Further, it is desirable that a medium-voltage machine used primarily for the treatment of deeper lesions should also be capable of operating in the region of 100 kV at about 20 cm FSD, so as to provide a standby or supplementary source of superficial X-rays.

4.2.4.2 *Gamma-ray sources for brachytherapy*

Radium encapsulated in needles or tubes has long been the principal source of radiation for intracavitary or interstitial therapy. However, radium has three disadvantages. These are the gaseous daughter-product radon, which causes undesirable environmental contamination if the source should leak, the high radiotoxicity of radium-226 which exacerbates the consequences of source rupture, and the large half-value layer of the gamma-rays, which renders radiation protection difficult. Nevertheless, if a stock of suitable sources is available, the use of radium need not be discontinued.

It is recommended that in selecting a supply of brachytherapy sources, serious consideration should be given to acquiring sealed cesium-137 sources which are now available. Because of its relatively short half-life and high-energy gamma-rays, cobalt-60 is considered less desirable than cesium-137 for this purpose.

4.2.4.3 *Beta-ray applicators*

Applicators containing beta-ray emitters of long half-life, usually strontium-90, are readily available. The distribution of depth dose from these applicators is similar to that from superficial X-ray units with a half-value layer of 0.1 mm of aluminium or less. The limited treatment areas of existing commercial designs prevent their wider employment. These devices require no maintenance other than periodic leak tests and are highly suited to use in remote parts of the world. The applicator should be equipped with a hand-shield and the active surface stored in an appropriate shield.

4.2.4.4 *Low-energy electron sources*

Both large-area beta-ray applicators and machines such as the Van de Graaff generators and travelling-wave linear accelerators have been successfully used to treat extensive areas of superficial lesions, such as mycosis fungoides. In view of the experimental nature of this modality and the difficulties of machine maintenance which are discussed later, the installation of such units is not recommended in the developing countries at the present time.

4.2.5 *Treatment with radioisotopes*

While it is not recommended that a small or newly-established radiotherapy department should be equipped with facilities for the full range of radioisotope therapy, such facilities should be provided in larger centres; they must include means for ensuring the safe handling and administration of the radioisotopes used therapeutically, and for their measurement. Some of these requirements are discussed in sections 5 and 7 of this report. A brief description of measuring equipment is included here.

Instrumentation for standardization of beta and gamma emitters in therapeutic amounts is required. In its simplest form this may be an ionization chamber, preferably of the 4π type, in which incoming shipments can be placed and which is connected to an electrometer. In the case of phosphorus-32 the emergent bremsstrahlung is measured.

For the assay of beta or gamma emitters in the sub-microcurie range, an end-window Geiger-Müller counter in a shielded sample-holder connected to a scaler is recommended. For gamma-emitters, a scintillation well-counter is desirable.

If it is decided to set up a diagnostic isotope programme in the radiotherapy department (see section 5) further instrumentation will be necessary. For the measurement of gamma-emitters *in vivo*, probe-type scintillation counters with suitable collimation are highly desirable. A radioisotope scanner is necessary for diagnostic studies concerning thyroid tissue localization and tumour localization, particularly in the brain, liver, kidney and bone. The equipment at present available commercially offers a wide choice.

4.3 **Measuring instruments for radiotherapy**

4.3.1 *Calibration*

An instrument of the ionization chamber type is recommended as a standard for output measurements for all therapy units discussed in this report. Such instruments are available from several commercial companies. They should be calibrated before use and periodically thereafter by a standardizing institutions, e.g., a national standards laboratory. Between calibration, the use of a device to check the constancy of calibration (e.g., a radium source with a fixed geometrical relation to the chamber position), is recommended.

Postal dosimetry services, employing dosimeters of the thermoluminescent or ferrous sulfate type, may develop in the near future. The use of such services might be of assistance to radiotherapy departments in developing countries.

4.3.2 *Dose-distribution studies*

It is recommended that standard central-axis depth dose data and isodose charts prepared for the specific apparatus in use should be utilized.¹ Where such charts are not available, use may be made of the data sheets obtainable from IAEA.²

4.3.3 *In vivo measurements*

For this type of measurement, special microdosimeters (e.g., ionization chambers, glass rods or thermoluminescent powder) together with associated instruments are required. Such dosimeters may be used on the body surface or in body cavities inside protective coverings. Measurements of this type are only of value when high accuracy is achieved.

4.3.4 *Instruments for surveys and monitoring*

Instruments for this purpose are discussed in section 7.6.

5. RADIOISOTOPE SERVICES IN RELATION TO RADIOTHERAPY

5.1 Introduction

The use of radioisotopes in medicine is generally divided into two main categories :

- (a) work with sealed sources ; and
- (b) work with unsealed sources.

This main division is useful from the point of view of the handling procedures and the radiation protection requirements.

Teletherapy, in which sealed sources of very high activity are used, is discussed in section 4, and will not be considered here.

The widespread and rapidly-increasing application of radioisotopes in various medical fields is recognized. With regard to the organization of radioisotope services it is recommended that the radiotherapy department :

- (a) shall be solely responsible for all work with sealed sources ;
- (b) shall be mainly responsible for the therapeutic use of unsealed sources but in association with other relevant hospital departments, e.g., the department of endocrinology ; and

¹ Tsien, K. C. & Cohen, M. (1962) *Isodose charts and depth dose tables for medium energy X rays*, London, Butterworths.

² International Atomic Energy Agency (1964) *Radiation data for medical use. Catalogue No. 1*, Vienna.

(c) may be associated with the diagnostic use of radioisotopes although the responsibility may rest elsewhere.

5.2 Sealed sources

Interstitial, intracavitary and superficial therapy using sealed sources is an important part of radiotherapy. Techniques for temporary or permanent implants were originally developed using radium or radon. This work, therefore, is often classified as "radium therapy" or "brachytherapy" and not considered as a task for the radioisotope service, although the tendency nowadays is to replace the use of radium by other gamma-emitting radioisotopes, currently by cobalt-60, iridium-192 and cesium-137.

For *temporary implants*, a number of radioisotopes are now available which offer important advantages over radium from the point of view of radiation protection and toxic hazards. Therapeutically, these isotopes may be regarded as equivalent to radium. Their half-lives are short compared with that of radium so that allowance has to be made for decay, and periodic replenishment of the stock is necessary. These sources are, however, considerably cheaper than the corresponding radium sources.

The artificial isotope of choice for temporary implants is cesium-137. This has a reasonably long half-life (about 30 years) and its gamma-radiation is of lower energy than that of radium, so that less shielding is required; furthermore a source placed within a body cavity (as in the treatment of gynaecological cancers) may be effectively screened in certain directions with heavy material, thereby reducing the risk of radiation damage to healthy tissues. Cesium-137 needles and tubes are now available with the cesium in insoluble form, and this minimizes the serious consequences that would result from leakage if a source were damaged while in use within the body.

The use of cobalt-60 has economic advantages over radium. However the fairly short half-life (five years) is a disadvantage, particularly in needles and tubes of small activity.

In spite of its short half-life (74 days), iridium-192 is recommended for temporary implants where flexibility of the source is of importance. The gamma-radiation emitted by iridium-192 is of even lower energy than that of cesium-137, so that the remarks made above with respect to internal and external shielding apply to both isotopes.

For *permanent implants*, either gold grains (gold-198) or radon seeds may be used, the preference depending upon the circumstances of supply.

As already indicated, work with sealed sources generally involves radiation protection problems which, at present, can only partly be solved by the use of special devices and by suitable design of the building, as discussed in section 7.4. *After-loading techniques* offer important improvements from the protection point of view, as well as therapeutic advantages.

Such techniques are now being developed for both interstitial and intracavitary therapy and should be considered when establishing new departments.

5.3 Unsealed sources

Radiotherapy with unsealed sources at present comprises, amongst others, the following procedures: the treatment of polycythaemia vera with phosphorus-32; the treatment of thyroid dyscrasias, both malignant and non-malignant, with iodine-131; the treatment of ascites and of pleural effusion of malignant origin by intracavitary instillation of colloidal gold-198 or of phosphorus-32 in the form of chromium phosphate.

Close collaboration between the radiotherapist and other medical specialists is important in some of these therapeutic applications, for example in the treatment of thyroid disorders.

These isotopic preparations have different physical, chemical and metabolic properties. Further, the quantities of active materials used and their radiotoxicities vary within wide limits. With unsealed sources there is a risk of contaminating the staff, their clothing, the instruments and the building itself. The protection requirements are further discussed in section 7.5.

The handling and administration of unsealed radioisotopes in therapy involves the following procedures:

- (a) reception and storage of isotopes;
- (b) dispensing, standardization and administration of radioactive solutions;
- (c) measurement (where necessary) of the isotope distribution within the body, e.g., colloidal gold-198 within the peritoneal cavity;
- (d) handling and treatment of radioactive waste, including excreta (provision should also be made for the safe disposal of cadavers containing significant quantities of radioactivity).

The constructional features of a laboratory intended for a full range of therapy with unsealed sources are essentially those of a Grade B radioisotope laboratory, the design of which has been described elsewhere.¹ Instrumental requirements are discussed in section 4.2.5.

¹ International Atomic Energy Agency (1958) *Safe handling of radioisotopes*, Vienna (IAEA Safety Series No. 1).

6. ACCOMMODATION AND BUILDING LAYOUT FOR A RADIOTHERAPY DEPARTMENT

6.1 Introduction

In planning accommodation and building lay-out for a radiotherapy department account should be taken of the following factors :

- (a) radiotherapy is a rapidly growing medical specialty ;
- (b) the design of the equipment is liable to major changes ;
- (c) a special feature required in hospital design for such a department is that rooms containing teletherapy or high-voltage equipment need thick and heavy shielding for protection of staff against ionizing radiation.

This leads to the following planning principles :

- (a) The treatment areas of the department should be free to expand, and individual rooms should be capable of modification without serious disruption of the work of the department.
- (b) The treatment areas should be planned for a basement or the ground floor.
- (c) It is advantageous for the treatment rooms to be planned as a single-storey structure to avoid the expense of providing protection to floors above.

In the planning and organization of a radiotherapeutic service, it is important to bear in mind that it can seldom achieve full maturity immediately, as limitations are usually imposed by financial considerations, by lack of staff, or by inadequate accommodation. In the following paragraphs, proposals and recommendations are made for :

- (1) A department with the essential minimum provision of accommodation and equipment to provide a viable and economical service. For present purposes this will be called a " basic radiotherapy department ".
- (2) A department with a fuller range of equipment and ancillary accommodation. For present purposes this will be called a " radiotherapy department ", or, on a larger scale, a " radiotherapy centre ".¹

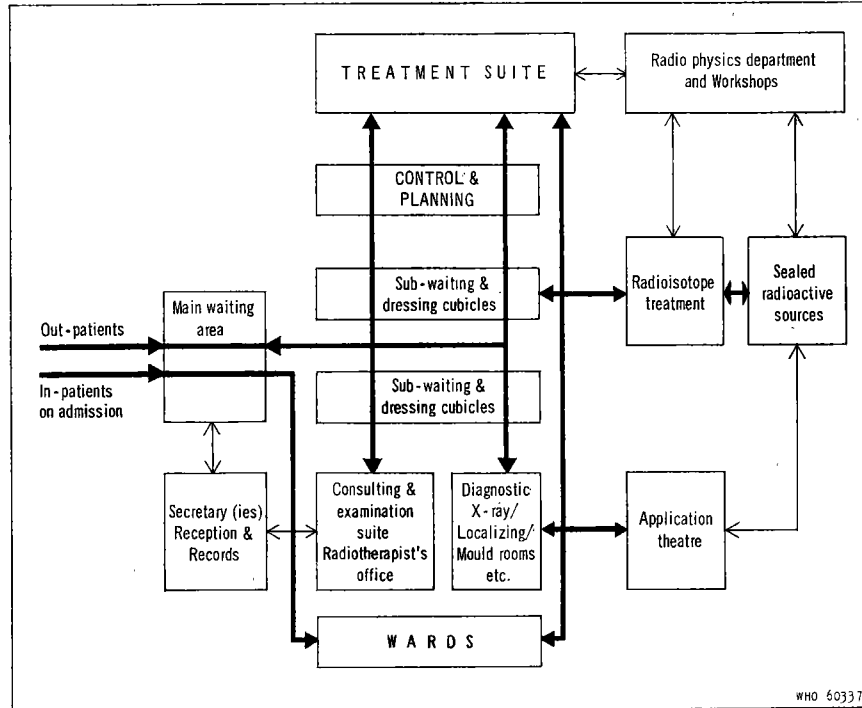
The basic radiotherapy department is designed to provide a radiotherapy service in a developing area or an area of low population density. The radiotherapy department or centre is suitable for establishment in

¹ The term "radiotherapy institute" is sometimes used to indicate a further extension of the facilities and services of a large radiotherapy centre. In Annexes 1 and 2, no separate schedules are given for a radiotherapy institute, but certain supplementary accommodation is shown that might prove useful in planning such an institute.

hospitals where the full range of medical facilities is being planned or already exists.

Although radiotherapy is a separate specialty, the facilities of the diagnostic X-ray department, laboratories and operating theatres of the hospital should be available when required and there should be easy communication between the departments.

FIG. 1. SCHEMATIC DIAGRAM SHOWING CIRCULATION OF PATIENTS IN A RADIOTHERAPY DEPARTMENT OR CENTRE



In general, most of the patients requiring treatment will be out-patients and those referred to the department for follow-up procedures. It is, therefore, of the utmost importance that the planning of the department should be considered in parallel with a well-organized appointments system, for both in-patients and out-patients, as well as with the detailed day-to-day planning of the programmes for treatment. Wherever possible, the organization should be planned and the administrative manual prepared concurrently with the planning of the accommodation, for the guidance of both the architects and the medical staff concerned in the direction of the department.

Fig. 1 is a schematic diagram indicating the circulation of patients in a typical radiotherapy department forming part of a general hospital.

The condition of patients attending radiotherapy departments calls for sustained sympathetic handling. Most patients will be worried by the prospect of their treatment and sometimes incapable of making elementary decisions or of complying with routine administrative requirements without assistance. It is recommended that specially trained social workers or, if local conditions permit, voluntary personnel, should be used to provide such assistance and to act as a means of communication between the medical staff and the patients, particularly to reassure patients and allay their fears and worries. This would relieve administrative and medical staff for other essential duties. The accommodation in the reception areas should be planned in relation to local customs in respect to these questions.

6.2 Accommodation required for a basic radiotherapy department

In section 4, details are given of equipment needed for a radiotherapy department. Accommodation is required in the treatment areas to house the following pieces of equipment :

- (a) one supervoltage X-ray machine or large cobalt-60 unit ;
- (b) one medium-voltage X-ray machine or small teletherapy unit ;
- (c) one superficial X-ray machine ;
- (d) sealed radioactive sources.

The basic categories of accommodation required for the above equipment and to form the department consist of :

- (a) reception and administration ;
- (b) consulting rooms and examination clinics, together with supporting offices and utility rooms ;
- (c) treatment suite ;
- (d) handling and treatment suite for radioisotopes (sealed and unsealed sources ;
- (e) physics laboratory ;
- (f) in-patient accommodation.

A detailed list of the rooms contained in each of these sections is given in Annex 1.

6.3 Accommodation required for a radiotherapy department or centre

The creation of a radiotherapy centre may be considered desirable for services to a population of 1-2 million. It can be assumed that such a centre would treat up to 2000 patients a year. In-patient accommodation attached to the centre will be dependent upon the total bed complement of the centre. A minimum of 25 beds should be allocated for radiotherapy.

If more beds are required to deal with the total patient turn-over, the number should be calculated in relation to the patient load and period of stay in the hospital. In large population centres, there may be justification for up to 50 beds in ward units. It is further suggested that hostel accommodation should be provided for patients requiring treatment but not in need of the full range of nursing procedures.

Details of the equipment for the centre are given in section 4. Accommodation is required in the treatment areas to house the following :

- (a) two to three supervoltage units, including large cobalt-60 units ;
- (b) two medium-distance units, at least one of which should preferably be a cobalt-60 or a cesium-137 teletherapy unit ; the second unit may be a 200-400 kV X-ray machine, if preferred.
- (c) one or two superficial X-ray machines ;
- (d) sealed radioactive sources ;
- (e) radioisotope treatment and preparation area.

The basic categories of accommodation required for the above equipment and to form the centre consist of (see Annex 2) :

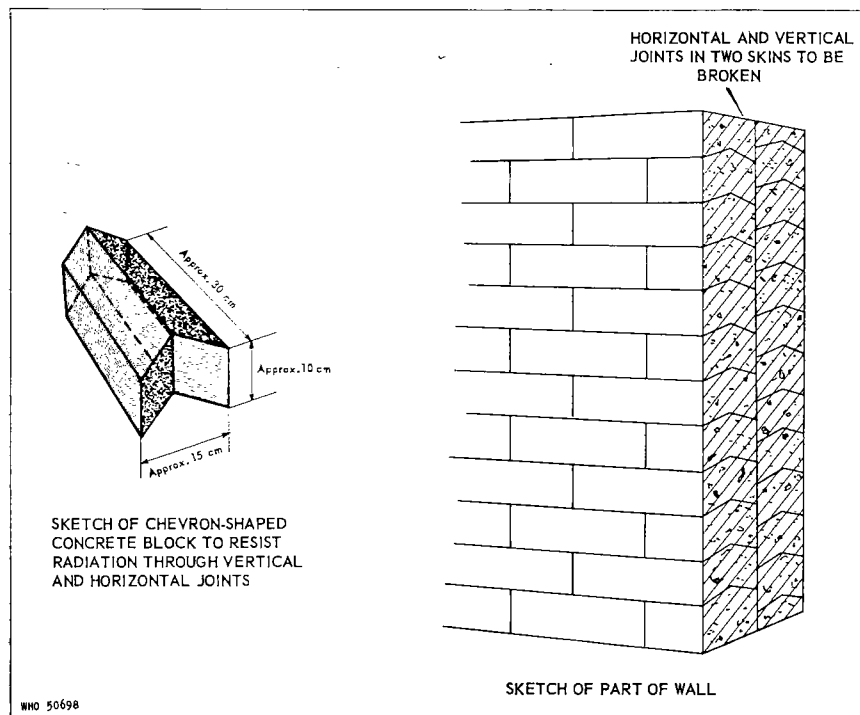
- (a) reception and administration ;
- (b) consulting rooms and examination clinics, together with supporting offices and utility rooms ;
- (c) treatment suite ;
- (d) handling and treatment suite for radioisotopes (sealed and unsealed sources) ;
- (e) physics department, including dosimetric laboratory and workshops ;
- (f) laboratories ;
- (g) additional accommodation :
 - (i) application theatre suite ;
 - (ii) radioactive waste store ;
 - (iii) in-patient accommodation.

6.4 Treatment units—general and special considerations

Adequate shielding of treatment rooms is the overriding consideration. Details of the requisite protective measures are given in section 7. The following are the elementary provisions that should be made.

The construction of thick, poured concrete walls to provide protection should, where possible, be avoided ; protection can equally well be provided by specially designed blocks as shown in Fig. 2. The broken joints will provide protection against direct beams, and the dry construction permits the walls to be altered or demolished without great disruption to the department if changes in equipment necessitate space modifications.

FIG. 2. METHOD OF CONSTRUCTING DEMOUNTABLE PARTITION FOR SHIELDING SUPERVOLTAGE TREATMENT ROOMS



Note. Several proprietary makes of bricks of similar design to the above are already on the market.

An alternative method is to erect two structural skins of reinforced concrete or brickwork to form the walls, and to use a heavy matrix of, say, iron ore for the in-filling. The total thickness of the barrier is determined by the degree of protection required.

It is important to recognize that, in the planning of the treatment rooms, the enclosed space is for the housing of equipment. This equipment may be designed by different manufacturers and is likely to differ widely in size, shape and design. Therefore, in making structural provisions, it is essential to request details of the apparatus selected from the manufacturer and to allow adequate tolerance in dimensions to accommodate any changes in equipment. Some machines of the rotating type, especially cobalt-60 and supervoltage apparatus, require a concrete pit or movable floor to allow for full rotation. If this provision is made in all the treatment rooms, it will frequently avoid later expense and disruption caused by cutting into heavy concrete to accommodate the new equipment.

It is generally better to make over-provision for protection to enable all the supervoltage rooms to be used for any kind or make of equipment. It is for this reason that X-ray rooms planned in series will lead to ultimate economies. Treatment rooms arranged in series should be left free at one end to allow for expansion of the department.

Access to the treatment rooms may be either by way of a labyrinth or through a lead-lined sliding door; the former is more expensive in terms of space, the latter provides mechanical difficulties in the movement of the heavy door. Where a door is used, interlocking electrical safety devices must be provided. For supervoltage units—above 400 kV—it is preferable to provide a labyrinth. Entry into the labyrinth must also be controlled by a door incorporating an interlock.

All treatment rooms should be provided with a window in order that the staff sees the patient at all times. The window must have the equivalent protection of the wall in which it is inserted. The introduction of audio-aids between controller and patient is advisable.

The interior decoration of these rooms is important in order to reduce the psychological effect on ill patients of the large machinery and sometimes ominous-appearing surroundings.

6.5 Requirements for radiotherapy in-patients

The provisions for in-patients can be planned in the following ways:

- (a) hostel accommodation, not necessarily immediately attached to the department;
- (b) ward units where the radiation hazard is sufficiently low for the patients to be nursed without special precautions; and
- (c) ward units where special protective measures are necessary.

The purpose of the hostel accommodation is to relieve the pressure on hospital beds; it is designed for patients who are not critically ill but who live at a considerable distance or lack adequate facilities for home care. The provision of hostel accommodation for these patients ensures the keeping of routine time-tables for treatment and also ensures that the proper rest periods and nutrition are maintained. The hostel may also be used for patients who require extended after-care.

The majority of in-patients can be treated in the normal ward unit adopted in the region. The ward units should be as near as possible to the treatment area and particularly the application theatre, and as far as necessary from areas of the hospital where sensitive radiation counting equipment is located.

A number of specially designed wards with one to four beds are required for patients presenting high radiation hazards (e.g., from radium or other radioactive sources implanted or inserted in the body) in order to provide

adequate protection for other patients and staff. Each of these special wards should be provided with its own utility rooms.

6.6 Special provisions—operating theatres

There are procedures in radiotherapy that require surgical techniques. It is desirable to establish within the radiotherapy department an application-operating theatre, equipped with built-in radiation shielding, where sealed source applications and minor operations can be carried out which do not need the full aseptic discipline of a major operating theatre.

Radiotherapy procedures that involve open surgery and/or require aseptic routines should be carried out by the surgical staff in collaboration with the radiotherapy staff in the regular operating theatres of the surgical department of the hospital. In such cases movable protective screens of suitable design and thickness will need to be provided.

7. PROTECTION

7.1 Introduction

According to the International Commission on Radiological Protection (ICRP)¹ the objectives of radiological protection are to prevent or minimize somatic injuries and to minimize the deterioration of the genetic constitution of the population. In practice, this means the adoption of protective measures to ensure that the various maximum permissible doses recommended by ICRP for hospital staff and other persons are not exceeded. In the case of patients, the objective is to limit the irradiation to the minimum value consistent with the medical requirements.

In the various techniques employed for radiotherapy, the protection methods differ and are discussed in turn below. Attention is given first, however, to some considerations concerning currently recommended maximum permissible doses.

7.2 Maximum permissible doses

In the ICRP recommendations, which have been widely adopted as a basis for codes of practice and have been followed by the International Atomic Energy Agency in formulating its *Basic Safety Standards*,² distinction is made between (a) persons who work in controlled areas and are "occupationally exposed" radiation workers (in this category, women

¹ International Commission on Radiological Protection (1964) *Recommendations of the International Commission on Radiological Protection (as amended 1959 and revised 1962)*, London, Pergamon Press (ICRP Publication 6).

² International Atomic Energy Agency (1962) *Basic safety standards for radiation protection*, Vienna (IAEA Safety Series No. 9).

of reproductive age are regarded as a special class), (b) adult non-radiation workers who work in the vicinity of controlled areas or who enter them occasionally, and (c) individual members of the population at large, who may live in the proximity of a controlled area and some of whom will inevitably be children. ICRP also distinguishes for protection purposes between irradiation that involves the gonads, the blood-forming organs or the whole body and irradiation that involves other organs or the extremities of the four limbs. The result is a complicated series of maximum permissible doses which are summarized in the following table :

TABLE 3. SUMMARY OF ICRP RECOMMENDED MAXIMUM PERMISSIBLE DOSES

Organ or part of body	Radiation workers	Non-radiation workers	Individual members of the population at large
Gonads, blood-forming organs and whole body	3 rem/13 weeks ¹ 5 rem/year (average)	1.5 rem/year	0.5 rem/year
Skin, thyroid and bone	8 rem/13 weeks 30 rem/year	3 rem/year	3 rem/year
Feet & ankles, hands & forearms	20 rem/13 weeks 75 rem/year	7.5 rem/year	7.5 rem/year
Single organs other than those specified above	4 rem/13 weeks 15 rem/year	1.5 rem/year	1.5 rem/year

¹ In the case of women of reproductive age, exposure of the abdomen should not exceed 1.3 rem in a 13-week period. When a pregnancy has been confirmed, the dose to the foetus during the remaining period of the pregnancy should not exceed 1 rem.

The most important figure in the table from the practical point of view is the average of 5 rem/year to the gonads, blood-forming organs and whole body because this is in general the most restrictive recommendation. It is equivalent to an average of 100 mrem/week or to 2.5 mrem/hour (assuming a 40-hour week), and this last dose rate is that normally employed in calculating shielding requirements for radiation workers. For non-radiation workers and for members of the population at large, the corresponding dose rates will be seen to be 0.75 mrem/h and 0.25 mrem/h respectively.

It is immaterial whether the irradiation of the body is from external sources or from radioactive materials within the body. It follows that if simultaneous exposure to both types of source occurs, the total irradiation should not exceed the appropriate permissible level.

In the case of exposure to unsealed radioisotopes, it is the rate of intake that is important, and ICRP^{1,2} has published lists of maximum permissible

¹ International Commission on Radiological Protection (1959) *Report of Committee II on Permissible Dose for Internal Radiation*, London, Pergamon Press (ICRP Publication 2).

² International Commission on Radiological Protection (1964) *Recommendations of the International Commission on Radiological protection (as amended 1959 and revised 1962)*, London, Pergamon Press (ICRP Publication 6).

concentrations (m.p.c.) in both air and water for all the isotopes generally available. Also given are the maximum permissible body burdens for each isotope, these being the quantities that, if maintained in the body, would give rise to the maximum permissible radiation doses to the organs concerned. The values given in the list apply to radiation workers, but they can be adjusted for the other groups of persons by using similar factors to those used in deriving the values given in the table.

The ICRP recommendations provide that radiation workers be kept under medical surveillance and that the doses of external radiation they receive be systematically checked. If exposure to unsealed radioisotopes occurs, additional tests are required with the object of determining the body burden or of ensuring that it is well below the maximum permissible level. It is these general measures of radiological control and supervision that have been taken as the basis for the higher maximum permissible doses that are permitted to radiation workers. Where the other groups of persons are concerned, there is often no control except the overall one of ensuring, by means of periodical site monitoring, that conditions are satisfactory, hence permissible doses have been set at lower levels. Apart from safeguarding the health of the individuals in these other groups by the lower levels of dose, the overall effect is to reduce the total dose received by the whole population and thus keep the genetic dose at a low level. It will be realized from the above that there are advantages in keeping to a minimum the number of persons who need to be classified as radiation workers, as this will result in economies in radiation control measures and in a limitation of the overall dose received by all involved.

7.3 Radiotherapy by means of external beams

External beams used for radiotherapy are usually either X-rays or gamma rays, but electrons, beta rays, neutrons and other particulate radiations are also used in some establishments. Recommendations concerning most of these applications have been made by the ICRP^{1,2} and various national bodies such as the National Committee on Radiological Protection³ of the USA.

In general the treatment is undertaken in a specially protected room from which all persons other than the patient are excluded during the

¹ International Commission on Radiological Protection (1960) *Report of Committee III on Protection against X-rays up to Energies of 3 MeV and Beta- and Gamma-Rays from Sealed Sources*, London, Pergamon Press (ICRP Publication 3).

² International Commission on Radiological Protection (1963) *Report of Committee IV on Protection against Electromagnetic Radiation above 3 MeV and Electrons, Neutrons and Protons*, London, Pergamon Press (ICRP Publication 4).

³ United States Department of Commerce, National Bureau of Standards, Handbooks Nos. 55, 63, 73, 76, 97.

treatment period, the only exception to this being in the case of superficial therapy using X-rays generated at voltages of less than 100 kV. In the latter case protective screens in the room itself are capable of providing sufficient protection, but even so it is preferable for persons other than the patient to remain outside unless there are compelling reasons to the contrary.

In designing the protection associated with a therapy room in which penetrating radiations are to be used, consideration must be given to (a) the type and energy of the radiation, (b) the anticipated amount of use per week (the work load), (c) the directions in which the useful beam will operate (the use factor), (d) the nature of the surrounding areas, that is the group of persons that will occupy them and for how long (occupancy factor) and their distances from the source of radiation, and (e) the possible presence of other sources of radiation that might cause added irradiation of the same areas. If all these factors are known, the required amount of shielding can be derived from absorption data such as are presented in the ICRP and NCRP reports.¹ If the useful beam is prevented from operating in certain directions, some of the walls will need to be protected against scattered and leakage radiation only, and economies will be effected. Data regarding protection against scattered and leakage radiation are also presented in the ICRP and NCRP reports. Further considerable economies will be achieved by siting supervoltage equipment in basements or on ground floors and arranging to absorb the useful beam in the solid earth.

Having provided a protected room it is necessary to ensure that personnel do not enter it while the equipment is in use. This is achieved by means of interlocks on the entrances to the room, which either prevent entry during irradiation or cause the irradiation to cease if a door is opened.

In the case of electron beam generators or large beta-ray emitters the production of secondary electromagnetic radiation (bremsstrahlung) needs to be borne in mind in designing the protection of the installation. In the case of radioactive beta-ray sources, bremsstrahlung also has to be considered in designing the source shutters, so that the dose rates in the treatment room can be reduced to the acceptable level before entry.

With machines operating at 10 MeV or above, the possibility of neutron production must be considered. If this occurs, structural protection against neutrons will have to be considered and it will also be necessary to take precautions against the possibility of induced radioactivity in the treatment room.

¹ International Commission on Radiological Protection (1959) *Report of Committee II on Permissible Dose for Internal Radiation*, London, Pergamon Press (ICRP Publication 2); International Commission on Radiological Protection (1960) *Report of Committee III on Protection against X-rays up to Energies of 3 MeV and Beta- and Gamma-Rays from Sealed Sources*, London, Pergamon Press (ICRP Publication 3). See also: United States Department of Commerce, National Bureau of Standards, Handbooks Nos. 55, 63, 73, 76, 97.

With regard to X-ray and gamma-ray units, the protection requirements for tube or source housings and beam-defining devices should be met. In addition, it is necessary to ensure that the machine outputs are calibrated at regular intervals, that all necessary filters and beam-defining devices are in place, and that the operating voltages and currents are as intended. These precautions are just as essential for superficial therapy as for megavoltage therapy, for in either case the consequences of error may be serious.

Finally, in administering the prescribed treatment to the patient, it is essential to ensure that the irradiation of healthy tissues is kept to the practical minimum.

7.4 Radiotherapy by means of sealed radioactive sources (brachytherapy)

Sealed radioactive sources used for brachytherapy need a proper accountability system and an adequately protected store. The latter should contain a number of protected compartments which can be opened individually, and the protection provided by the store should be such that the exposure involved in operating it amounts to only a small fraction of the weekly permissible dose. Long-handled instruments must be used for manipulating sources, which must never be touched by hand.

When a treatment has been prescribed for a patient it is necessary to withdraw the required sources from the store and to prepare them for use. Once they are out of the store it may not be possible to limit the dose rate to 2.5 mrem/h, as in the case of beam-therapy installations; for example, the dose rate at 50 cm from 100 mCi of radium when unshielded is more than 100 times greater than this value. It is thus necessary to plan the procedures carefully, so that the minimum time is involved. Shielded benches should be provided as well as screens behind which close manipulations, including those in the theatre itself, can be undertaken in comparative safety. Transport containers need to be protected, as do sterilizers, source containers and any other equipment or locations where sources might be lodged temporarily. For example, wards need protected safes for sources that are stored temporarily after removal from patients. The nursing of patients undergoing treatment with sealed radioactive sources requires special consideration and it is preferable to keep the patients in one unit. In this way the staff involved in their care is kept to a minimum and can, in consequence, be highly trained; also it is possible to employ special procedures and protective devices, including mobile screens, that would be more difficult to utilize in a general ward.

Despite all the precautions taken, it may be found that some members of the staff are liable to receive excessive doses, either to their bodies or to their hands. In these circumstances it will be necessary to arrange for a rota of duties, but with modern techniques this should not often arise.

Sources should be periodically inspected for damage and leakage. The avoidance of damage, particularly of beta-ray sources, necessitates very careful handling, not only in therapeutic use but in all other manipulations including sterilization. (The instructions of the suppliers of the sources with regard to sterilization must be complied with.) The possibility of losing a source must be considered, and the necessary equipment should be available to permit a search to proceed without delay. The risk of loss will be minimized if local rules are drawn up which state quite clearly all the procedures to be followed at every stage in the manipulation of the sources.

7.5 Radiotherapy by means of unsealed radioisotopes

In the case of unsealed radioisotopes the hazards of inhalation, ingestion and external bodily contamination are added to those of external radiation. Not only are protected storage areas required, but a special radioisotope laboratory is needed where the necessary manipulations and dispensing can be carried out under satisfactory conditions. As is the case with sealed sources, a proper accountancy system is necessary. Detailed recommendations and requirements are given in such publications as the IAEA report on safe handling of radioactive isotopes¹ and in the British *Code of Practice for the Protection of Persons against Ionizing Radiations arising from Medical and Dental Use*.²

In brief, the facilities needed consist of the following: (a) an isotope dispensary and store, (b) a wash-up room, (c) an excreta and specimen store with measurement facilities and sluice room, (d) an isotope treatment room, (e) a clinical examination room, and (f) a counting laboratory.

If small activities are handled (a) and (b) and also (d) and (e) may be combined. Suitable washing facilities will also be needed, preferably including a shower bath in case general contamination of workers occurs. A fume hood is desirable and it will have to be provided with shielding against the gamma rays emitted by some of the isotopes used. All the surfaces in the laboratory should be capable of easy cleaning and decontamination and, in the case of floors, of easy removal. Bench tops should be covered with disposable covers and, to minimize the risk of spills, drip trays or double containers should always be used.

The discharge of liquid radioactive waste must be regulated so as to conform to the requirements of the authorities concerned with sewage disposal. It is preferable to limit the number of discharge points as much

¹ International Atomic Energy Agency (1958) *Safe handling of radioisotopes*, Vienna (IAEA Safety Series No. 1).

² United Kingdom (1964) *Code of Practice for the Protection of Persons against Ionising Radiations arising from Medical and Dental Use*, London, H. M. Stationery Office.

as possible in order to minimize the spread of contamination and the problems that will arise when the drains need attention.

The manipulation of radioisotopes should be undertaken with the help of suitable aids, such as compression bulbs for the pipetting of solutions or the operation of wash bottles, and with appropriate devices for remote handling. Workers should be clothed in suitable laboratory coats or gowns, gloves, caps, masks and overshoes. The procedures adopted should be designed to minimize the spread of contamination, not only in the interests of the personnel but also to prevent interference with counting procedures. Details of the manipulations should be worked out with non-active solutions, and major changes should be introduced only after approval by those in charge.

Patients undergoing treatment with radioisotopes should be placed in special wards containing only a few beds, as this will simplify the control of radiation hazards and reduce the number of exposed persons. These wards should have special toilet and bathing facilities and there should also be an area where highly radioactive excreta can be stored pending disposal.

In general, the nursing of patients undergoing treatment with radioisotopes is similar to that with sealed radioactive materials, but there is the additional problem of radioactive contamination. It is necessary therefore to draw up local rules that detail the procedures to be followed in both normal and abnormal circumstances. In particular, spills must be catered for and it is desirable to have a special kit always available, preferably on a trolley, for decontamination purposes.

It will be necessary for members of the staff to ensure that they are not contaminated before leaving active areas, and instruments to check contamination levels will therefore be required. If excessive levels are observed, standard decontamination procedures should be instituted, again in accordance with an agreed procedure. If the contamination is persistent, the facts should be reported without delay to those in charge so that decontamination can proceed under medical supervision.

Other matters that will require consideration include :

(a) the conditions under which patients who have been treated with permanent implants or with unsealed radioisotopes can be discharged from hospital to return to their homes ;

(b) the provision of arrangements for the storage and ultimate disposal of solid radioactive waste or of liquid waste that is too active to discharge into the drains.

7.6 Instruments for surveys and monitoring

For surveys around radiotherapy units a portable survey meter of the beta-gamma ionization-chamber type is recommended. The chamber

should have a plastic wall to preserve reasonable energy independence and its maximum sensitivity should be at about 3 mR per hour.

In radioisotope facilities, the ionization-chamber instrument should be supplemented by a portable Geiger-Müller type instrument to facilitate the detection of contamination from unsealed isotopes. Such an instrument will also serve to measure radiation from wipe tests of work surfaces, equipment, housings of teletherapy units, and storage areas for sealed sources. Leakage tests of sealed sources may also be performed with the aid of this instrument.

Personnel monitoring of the radiation workers is normally carried out by means of film badges, supplemented by pocket dosimeters in the case of persons exposed to unusual hazards. These should normally be worn on the trunk of the body. Individuals handling therapeutic amounts of radioactivity should also wear finger or wrist badges.

7.7 Organization for controlling radiation hazards

In order to ensure that the radiation protection measures are adequate and constantly applied it is necessary to establish an organization to this end. Those in control of the hospital should appoint a radiological safety committee which should secure the services of a physicist who is an expert in radiological protection and a medical officer whose responsibilities include the various medical examinations that are required. Depending on the size of the department, a number of radiological safety officers may be needed, sufficient to cover adequately the various areas where protection problems arise, and it may also be necessary to appoint additional persons with particular responsibilities, such as custodians of the stocks of sealed and unsealed radioactive materials. The various sets of local rules should be drawn up by the radiological safety committee, and it will be necessary to ensure that all appropriate members of the staff read and understand them, suitable instruction being given where necessary. The rules should include the names of the safety officers and the other officials referred to above so that speedy reference to them can be made when necessary.

If the safety committee meets regularly, at a frequency that is dictated by experience, and receives reports at its meetings from the heads of departments where ionizing radiations are used and also from the physicist and doctor referred to above, the radiological protection problems will soon be well under control. This will not prevent the occasional untoward occurrence, but the existence of a properly co-ordinated safety organization will do much to minimize its importance.

Annex 1

**PROPOSED SCHEDULE OF ACCOMMODATION FOR A BASIC
RADIOTHERAPY DEPARTMENT**

1. Reception and administration, etc.

Type of room	Individual room size (ft ²)	Number of rooms (or other remarks)
(i) Waiting room	15 ft ² per person	150 ft ² minimum
(ii) Reception office, secretaries, and records	200	1
(iii) Patients' lavatories, male and female		as required
(iv) Staff lavatories, male and female		as required
(v) Bed and trolley waiting space	60	1
(vi) Refreshment bar	50	1
(vii) Cleaners' room	50	1
(viii) General storage	50	1

2. Consulting and examination rooms

(i) Consulting room	150	1
(ii) Examination room	90	2 (to be fitted with dark blinds)
(iii) Radiotherapist's office	150	1
(iv) Clean utility room	170	1
(v) Dirty utility room	110	1

3. Treatment suite (teletherapy)

(i) Patients' sub-waiting, including space for control and planning	450	Space for undressing, say 4 cubicles
(ii) Treatment room — supervoltage	450	1
(iii) Treatment room — medium-voltage	450	1
(iv) Treatment room — superficial	250	1
(v) Radiographers' (radiotherapy technicians') room	150	1

4. Handling and treatment suite for radioisotopes (sealed and unsealed sources)

Type of room	Individual room size (ft ²)	Number of rooms (or other remarks)
(i) Sealed sources preparation room	100	1 (to include a shielded handling bench and provision for storage of sealed sources)
(ii) Mould room, including plaster bay	300	1 (to include a work bench for construction of simple setting-up devices)
(iii) Application theatre	150	1 (with built-in radiation shielding)
(iv) Dispensary and store for unsealed radioisotopes	100	1 (Grade B laboratory)
(v) Isotope treatment room	150	1 (Grade B laboratory)
(vi) Radioisotope waste store	50	1 (shielded)

N. B. (i) and (ii) may be combined as one large room if preferred ; (iv), (v) and (vi) may be omitted if treatment with liquid radioisotopes is not contemplated (see sections 4.2.5 and 7.5). Room (ii) is intended to serve the needs of teletherapy as well as sealed-source therapy, and should be sited accordingly.

5. Physics laboratory

(i) Laboratory	150	1
(ii) Physicist's office	100	1
(iii) Workshop	150	1
(iv) Store	90	1

6. Ward accommodation

Allocation of beds in general hospital and in hostel		Number of beds depends on size of hospital
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Annex 2

**PROPOSED SCHEDULE OF ACCOMMODATION
FOR A RADIOTHERAPY DEPARTMENT
TO TREAT UP TO 2000 PATIENTS PER YEAR**

1. Reception and administration, etc.

As in Annex 1, but separate the records office (300 ft²) from the reception office (150 ft²) and provide additional space for waiting beds and trolleys (200 ft²) and for the refreshment bar (100 ft²).

2. Consulting and examination clinics

The basic accommodation listed in Annex 1 should be increased as follows :

- | | |
|-----------------------|---|
| (i) Consulting room | Up to 4 rooms, but may be somewhat smaller (120 ft ²) |
| (ii) Examination room | Up to 8. |

N. B. Alternatively, up to 8 combined consulting/examination rooms (180 ft²) may be provided.

- | | |
|-------------------------------|----------|
| (iii) Radiotherapist's office | Up to 4. |
|-------------------------------|----------|

Add the following :

- | | |
|--|------------------------------|
| (vi) Secretary/typists' office | 2 (120 ft ² each) |
| (vii) Darkroom annex to consulting suite | 1 (90 ft ²) |
| (viii) Dressing/minor operation theatre | 1 (170 ft ²) |
| (ix) Nursing supervisor's office | 1 (100 ft ²) |
| (x) Linen store | 1 (50 ft ²) |

3. Treatment suite (teletherapy)

The basic accommodation listed in Annex 1 needs to be increased, not only by the addition of more treatment rooms but by providing separate accommodation for treatment planning and additional space for patients and for radiographers. The proposed schedule is as follows :

Type of room	Individual room size (ft ²)	Number of rooms (or other remarks)
(i) Patients' sub-waiting space	120	1
(ii) Patients' dressing cubicles	15	12 (average of 2 per treatment room)
(iii) Treatment room — supervoltage	450	3
(iv) Treatment room — medium voltage	450	2
(v) Treatment room — superficial	250	1
(vi) Treatment planning room	200 to 250	1
(vii) Simulator room	250	1
(viii) Darkroom	65	1
(ix) Control area		One to each major treatment room

Type of room	Individual room size (ft ²)	Number of rooms (or other remarks)
(x) Superintendent radiographer's room	100	1
(xi) Radiographers' common room	220	1
(xii) Patients' rest room	100	1
(xiii) Clean utility room	170	1
(xiv) Dirty utility room	110	1
(xv) Trolley waiting space	100	1

4. Handling and treatment suite for radioisotopes (sealed and unsealed sources)

The accommodation required is not essentially different from that listed in Annex 1, but a somewhat larger preparation room (150 ft²) for sealed sources is required, including a shielded handling bench with provision for at least two working positions. The accommodation should include rooms (iv), (v), and (vi) for unsealed radioisotopes, and, in addition the following two rooms:

- (vii) Radioisotope counting laboratory (Grade B laboratory) 150 ft²
- (viii) Radioisotope scanning room 120 ft²

It is assumed that these two rooms will be concerned with diagnostic tests only for the detection and localization of tumours and that isotope laboratories for other diagnostic and functional tests are located elsewhere in the hospital.

5. Physics laboratory

Type of room	Individual room size (ft ²)	Number of rooms (or other remarks)
(i) Laboratory, including office space for assistant physicist(s)	160 minimum	1, 2 or 3 rooms with a total area of not more than 320 ft ²
(ii) Chief physicist's office	150	1
(iii) General workshop	600	1
(iv) Workshop store	100	1
(v) Electronics laboratory or workshop	200	1
(vi) Secretary's office	100	1
(vii) Room for physics and workshop technicians	120	1
(viii) General storage space	80	1 or more spaces with a total area of 80 ft ²
(ix) Cleaners' room	50	1

6. Radiotherapy ward unit

Type of room	Individual room size (ft ²)	Number of rooms (or other remarks)
(i) Wards : Single-bed wards Multiple-bed wards or bays	120/140 100/110	Up to $\frac{1}{3}$ of beds in single-bed wards. Number of wards to suit local requirements
(ii) Day and dining space	18 ft ² per bed	1 or 2
(iii) Treatment room	170	1
(iv) Utility rooms : Clean utility Dirty utility	100 100	1 1
(v) Bathrooms	—	3 (or 2 baths and 2 showers)
(vi) Ablution facilities	—	1 lavatory basin to 6 patients
(vii) Toilets	—	1 toilet to 6 patients
(viii) Sluice room	100	1
(ix) Test room(s)	20	1 or 2
(x) Nursing supervisor's room	120	1
(xi) Nurses' duty room or station	80/100	1 or 2
(xii) Nurses' lavatory and cloakroom	—	1
(xiii) Ward pantry	120	1
(xiv) Linen bay(s)	—	1 or 2, with total floor area of 50 ft ²
(xv) Store(s)	—	Total floor area of 80 ft ²
(xvi) Cleaners' room	50	1
(xvii) Wheel-chair bay	—	1
(xviii) Flower room(s) or bay(s)	—	1 or 2, total area of 50 ft ²
(xix) Sundry facilities	—	
(xx) Radioactive waste disposal store (if required)	40	

7. Supplementary accommodation

(i) X-ray, diagnostic and special radiological investigations	350	1
(ii) Biochemistry laboratory	350	1
(iii) Haematology laboratory	350	1
(iv) Blood transfusion laboratory	350	1
(v) Pathology laboratory	350	1

Annex 3

TYPICAL ORGANIZATION CHART FOR A RADIOTHERAPY DEPARTMENT OR CENTRE

