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**CODE OF SAFE PRACTICE FOR THE USE OF
IRRADIATING APPARATUS IN MEDICAL
THERAPY**

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1. INTRODUCTION

1.1 This Code of Safe Practice deals with the radiation safety of conventional therapeutic equipment employing an external beam of ionizing radiation. The range of equipment covered comprises kilovoltage x-ray units, Co-60 or Cs-137 teletherapy units, and medical linear accelerators. Whenever it is used, the generic term "high energy" refers to radiation of higher energy than 1 MeV, thus excluding kV x-ray and Cs-137 units.

1.2 Requirements in the Code are taken from the Radiation Protection Act 1965 and the Radiation Protection Regulations 1982. Other requirements and recommendations are taken from source material listed in the section of References and Bibliography, or from advice received from experts in the field. Their assistance is gratefully acknowledged.

1.3 Whenever compliance with this document is required as a condition to a licence under the Radiation Protection Act 1965 for the purpose of Medical Therapy (see Section 2.1), the word "shall" is used. The word "should" indicates a practice that is recommended but not mandatory. Whenever a requirement is not specified explicitly, but uses the terms "suitable" or "suitably qualified", the judgement as to whether these terms are satisfied rests with the National Radiation Laboratory (NRL).

1.4 There are requirements which are intended to protect the patient from medium and long term detriment from radiation. These are not necessary for patients with terminal disease who are being given palliative treatment. They are prefaced with the words "For curative treatments . ." or something similar. In these cases the requirements should be interpreted as recommendations for palliative treatments.

2. RADIATION PROTECTION LEGISLATION

2.1 Licences for Radiotherapy and Medical Physics

2.1.1 The Radiation Protection Act 1965 does not permit any person to use irradiating apparatus for any purpose unless he or she holds a licence under the Act for that purpose, or is acting on the instructions or under the supervision of a person holding such a licence.

2.1.2 Licences issued under the Act may be subject to special conditions. Compliance with a Code of Safe Practice issued by NRL may be required as a special conditions.

2.1.3 An application for a licence for the purpose Medical Therapy is assessed on the basis of the qualifications and experience of the applicant, taking into account the advice of the Radiation Protection Advisory Council when necessary.

2.1.4 A medical physicist may hold a licence for the purpose of Hospital Physics. Such a licence does not confer responsibility for patient care. Responsibility, however, may be taken by the medical physicist for non-clinical aspects of radiation safety. Approval for the issue of a licence for this purpose is given only when relevant expertise can be demonstrated. It is an advantage if the applicant is a Member of the Australasian College of Physical Scientists and Engineers in Medicine, or its overseas equivalent, with specialisation in radiotherapy.

2.2 Legal responsibilities; multiple licences

2.2.1 Whenever more than one licensee is employed in a given area, Regulation 9(3) of the Radiation Protection Regulations 1982, requires that the owner of the irradiating apparatus either appoints one as principal licensee, or clearly defines the respective areas of responsibility of the individual licensees. When there is more than one licensed radiation oncologist, one may be appointed to take overall responsibility, or each may take responsibility for his or her own patients. Responsibility for the safety of irradiating apparatus will need to be designated when this is not covered separately by a hospital physicist.

2.2.2 When there are one or more medical physicists holding licences for hospital physics then their areas of individual responsibility shall be clearly designated.

3. RADIATION PROTECTION AND RADIOTHERAPY

3.1 The basic principles

The New Zealand radiation protection legislation is based on the following 3 principles, most recently set down by the International Commission on Radiological Protection in Publication 60 (ICRP, 1991):

- (a) No practice shall be adopted unless its introduction produces a positive net benefit to the exposed individuals or to society. (The justification of the practice.)
- (b) In relation to a particular practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposure shall be kept as low as reasonably achievable, economic and social factors being taken into account. (The optimisation of protection.)
- (c) The risk either from a dose or potential dose to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission. (Individual dose and risk limits.)

3.2 The justification of a practice

3.2.1 The justification of the use of radiotherapy to treat any particular disorder shall take into account the relative merits of other treatment modalities, and the risks entailed in the administration of radiation.

3.2.2 Once radiotherapy is chosen, the dose prescribed and the treatment plan used shall be justified by considering the optimisation of probability of a successful treatment of the disorder against the possibility of undesirable side effects, and the current international state of knowledge, except in the case of approved clinical trials.

3.3 The optimisation of protection

3.3.1 A radiotherapy practice shall be designed so as to minimise the undesired exposure of individuals from radiation, and to minimise the risk of any failure in equipment or procedure which could result in the undesired exposure of individuals.

3.3.2 When a patient is treated with radiation, the risk of toxicity of exposed healthy tissue, and for curative treatments the risk of stochastic harmful effects shall be minimised by choice of procedure and use of protective equipment.

3.3.3 In order to maintain the effectiveness of protection a suitable quality assurance programme shall be followed covering all aspects of the radiotherapy process.

3.4 Individual dose and risk limits

3.4.1 The individual dose limits are prescribed by the Radiation Protection Regulations 1982. These are:

- (a) 50 mSv per year for persons whose job requires them to work with radiation, except that women of reproductive capacity are restricted to no more than one quarter of this in any 3 month period, or during the period of pregnancy after diagnosis;
- (b) 5 mSv per year for all others.

3.4.2 At the time of going to print, this legislation is under review. Revisions are likely to take account of the recommendations in ICRP 60 (ICRP, 1991) resulting in a change to the above limits to 20 mSv and 1 mSv respectively.

4. TREATMENT EQUIPMENT

4.1 Therapy equipment installations

4.1.1 The plans of any proposed installation of an irradiating apparatus to be used for medical therapy should be referred to NRL for prior approval of the shielding design and other safety features required by the legislation. Any modification of an existing installation or design that could affect radiation safety should be similarly referred.

4.1.2 The radiation shielding should be sufficient to maintain the average radiation dose rate at less than 20 μ Sv per week (including the dose equivalent contribution from neutrons where appropriate) in any area continuously accessible to the public. In areas of low occupancy, the average dose rate may be weighted by the occupancy factor.

4.1.3 The radiation dose rate in areas occupied by staff who are employed to use radiation as part of their work should not exceed 400 μ Sv per week, summed over the period occupied. However, in practice, it is usually feasible to maintain the same dose rates in the areas used by staff as in 4.1.2 and therefore in accordance with 3.3 above, this should be done.

4.1.4 Before any irradiating apparatus is put to use, a survey of the radiation dose rate at accessible locations shall be carried out by a suitably qualified person to confirm that the plans have been followed and that the protection is sufficient. A report of this survey shall be forwarded to NRL.

4.1.5 The design of the facility and operating protocol shall be such that the patient is kept under observation throughout the treatment period.

4.1.6 When the radiation has an energy greater than 150 kV there shall be a suitable warning device in the treatment room and on the outside of the entrance door to the treatment room to indicate that radiation is being produced.

4.1.7 When the radiation produced has an energy greater than 150 kV an interlock is required on the entrance door to the treatment room. Opening the door shall terminate the exposure automatically such that the apparatus can only be restarted at the control panel.

4.2 Performance of Treatment Equipment

4.2.1 General requirements

- (a) No treatment equipment shall be used for treating patients until either:
 - it has been found to comply with all the manufacturer's performance specifications that are relevant to the intended use, or
 - any non-compliance with specifications has been discussed with the manufacturer, and the responsible licensee is satisfied that the non-compliance does not cause any significant radiation hazard.
- (b) The exposure shall be controlled by an automatic device that ends the exposure after a predetermined time or delivered dose.
- (c) A suitable warning device on the control panel of an irradiating apparatus shall indicate clearly whether radiation is being produced.
- (d) Where the radiation exposure is controlled by a timing device, it shall be accurate to within 1% for times greater than 100 seconds, and to within 1 second for shorter times. When there is a difference between the beam-

on time and the set time of more than 1 second this shall be allowed for in the calculation of the time to be set.

4.2.2 X-ray therapy apparatus below 300 kV

- (a) The tube housing shall provide sufficient shielding such that the leakage radiation air kerma rate at 1 metre from the focus does not exceed 10 mGy/h averaged over 100 cm², nor 300 mGy/h averaged over 10 cm² at any position accessible to the patient 5 cm from the tube housing.
- (b) The apparatus shall have interlocks, colour coding, or some other system to prevent unintentional combinations of filter and kV.
- (c) Cones, applicators, or diaphragms shall not transmit more than 2% of the useful beam.

4.2.3 X-ray therapy apparatus not more than 50 kV

- (a) The irradiating apparatus shall comply with section 4.2.2;
- (b) The air kerma rate of leakage radiation shall not exceed 1 mGy/h averaged over 10 cm² at any position 5 cm from the tube.

4.2.4 Megavoltage x-ray and electron apparatus

- (a) The treatment control panel shall clearly and unambiguously indicate the settings of all machine parameters that affect the dose delivered to the patient, including the use of wedges, and filters. It shall have interlocks that prevent the generation of any radiation if there is any disagreement between the settings at the control panel and the machine.
- (b) The apparatus, if manufactured after 1980, shall be equipped with 2 independent dose monitoring systems independently able to terminate irradiation. They should be designed so as to be unlikely to fail simultaneously. If the primary monitor fails, the secondary monitor shall terminate the beam after delivering no more additional radiation to the patient than the equivalent of 0.4 Gy at the normal treatment distance.
- (c) The air kerma rate due to leakage radiation (excluding neutrons) outside the maximum useful beam in a circular plane of radius 2 m perpendicular to the

beam axis at normal treatment distance shall not exceed 0.2% of the air kerma rate on the central axis at the same distance.

- (d) Outside the plane defined in (c) above, the kerma rate of leakage radiation (excluding neutrons) at 1 m from the path of the electrons between their origin and the target or the electron window shall not exceed 0.5% of the air-kerma rate on the central axis of the beam at the normal treatment distance.
- (e) Adjustable beam limiting devices for photons shall attenuate the radiation in the area shielded by them such that the absorbed dose at the normal treatment distance does not exceed 2% of the absorbed dose on the beam axis at the same distance.
- (f) Adjustable or interchangeable beam-limiting devices for electrons shall attenuate the radiation in the area shielded by them such that the absorbed dose at the normal treatment distance does not exceed:
 - 2% of the central axis absorbed dose, averaged over the area bounded by the line 4 cm outside the 50% dose contour and the maximum field size, and
 - 10% of the central axis absorbed dose, at any point in the area bounded by the line 2 cm outside the 50% dose contour and the maximum field size.
- (g) The dose equivalent rate from neutrons within the primary beam shall not exceed 1% of the dose equivalent rate from the therapeutic beam.
- (h) Medical electron accelerators should comply with IEC 601-2-1(1981) and amendments (BS 5724: Section 2.1: 1989). The methods used to test compliance with this IEC standard, and also with the other subclauses of this Section (4.2.4) should be in accordance with IEC 601-2-1: Amendment No. 2: 1990 (British Standards Institution, 1991).

4.2.5 Sealed source teletherapy apparatus

- (a) The apparatus, if manufactured after 1980, shall be equipped with 2 independent timers, each independently able to terminate irradiation. They should be designed so as to be unlikely to fail simultaneously. If the primary timer fails, the secondary timer shall terminate the beam after delivering no more than 0.4 Gy additional radiation to the patient.

- (b) The head leakage air-kerma rate with the beam OFF shall not exceed 20 $\mu\text{Gy/h}$ averaged over an area of 100 cm^2 at any accessible position 1 metre from the source, nor 200 $\mu\text{Gy/h}$ averaged over an area of 10 cm^2 at a distance of 5 cm from the head surface.
- (c) With the beam ON the air kerma rate due to leakage radiation outside the maximum useful beam in a circular plane of radius 2 m perpendicular to the beam axis at normal treatment distance shall not exceed 0.2% of the air kerma rate on the central axis at the same distance.
- (d) Outside the plane defined in (c) above, the kerma rate of leakage radiation at 1 m from the radiation source shall not exceed 0.5% of the air-kerma rate on the central axis of the beam at the normal treatment distance.
- (e) Adjustable beam limiting devices shall attenuate the radiation in the area shielded by them such that the absorbed dose at the normal treatment distance does not exceed 2% of the absorbed dose on the beam axis at the same distance.
- (f) The beam mechanism shall be such that it automatically returns to the OFF position in the event of a failure of the control system or electrical supply. The OFF position shall be maintained until the beam is switched ON again from the control panel.
- (g) When the radioactive source material is in a form such that it may leak from the encapsulation, the source shall be leak tested annually. The presence of more than 2 kBq of activity on any surface indicates the source is leaking and it shall be withdrawn from use immediately.
- (h) Sealed source teletherapy apparatus should comply with the standard IEC 601-2-11: 1987 (British Standards Institution, 1989b).

4.3 Treatment simulators

4.3.1 A treatment simulator installation shall comply with all sections of the Code NRL C5 *Code of Safe Practice for the Use of X-Rays in Diagnosis (Medical)* except when requirements restrict procedures specifically used in treatment simulation.

4.3.2 The design of a treatment simulator should be such that:

- (a) Any geometry of patient position and beam dimensions and orientation which is used in an isocentric treatment can be reproduced on the simulator.
- (b) The couch is of similar design to those used during treatment, and permits the attachment of the same immobilisation devices.
- (c) The laser alignment system is arranged in the same way as in the treatment room.
- (d) It should be possible to mount shadow trays on which the same field-shaping blocks as will be used for treatment can be mounted or represented.
- (e) The specifications for the mechanical accuracy of movement of the gantry, couch, and field definition are at least equivalent to the treatment machine which will be used.

4.4 CT Scanners

4.4.1 If possible a CT scanner should be dedicated to radiotherapy applications.

4.4.2 If a CT scanner is to be used for treatment planning it should have the following qualities:

- (a) Gantry aperture ≥ 70 cm.
- (b) Couch and accessories should have identical properties to those on the treatment machine.
- (c) Couch movement accuracy better than ± 1 mm.
- (d) Scan reproducibility better than ± 1 mm.
- (e) Diagnostic resolution capability.

- (f) Accuracy in electron density determination better than $\pm 2\%$ with a spatial resolution better than ± 2 mm.

5. DOSIMETRY

5.1 Equipment

5.1.1 Local reference dosimeter

- (a) A radiotherapy department shall, for each type of radiation, have at least one dosimeter which serves as the local reference dosimeter. For Co-60, Cs-137, megavoltage beams, and x-rays above 50 kV the ionization chamber shall be a Nuclear Enterprises 2505/3A, 2561, or 2571 graphite cylindrical chamber or the equivalent from another manufacturer. For x-rays less than 50 kV a thin-windowed parallel-plate ionization chamber should be used. A radioactive constancy check source shall be available for each local reference dosimeter.
- (b) The local reference dosimeter shall be calibrated at intervals not exceeding three years, or after any repairs, by NRL or any other calibration laboratory accredited by a body that has a mutual recognition agreement with New Zealand. A constancy check using a radioactive source shall be performed immediately before and after calibration. For megavoltage beams, the calibration shall be in terms of the absorbed dose to air chamber factor, N_D . For kilovoltage x-ray beams the calibration shall be in terms of exposure, N_X , or air kerma, N_K , for each x-ray quality that is used clinically.
- (c) When the reference chamber is for low energy x-rays (less than 50 kV) then it may be mounted at surface level in a solid phantom and a derived calibration in terms of surface dose to water can be given.
- (d) A parallel plate or pancake type ionization chamber may be used for electron beams with mean surface energy less than 10 MeV and shall be used for electrons less than 5 MeV. It must be calibrated by comparison with a secondary standard or local reference cylindrical chamber in accordance with the IAEA Protocol (Worksheet A1 in NRL 1989) using the highest energy electron beam available (rather than a photon beam as recommended in Worksheet A1).

5.1.2 Field dosimeter

- (a) The reference dosimeter may be reserved for the measurement of machine output under reference conditions and for the calibration of field instruments. A field dosimeter of more robust construction may be used for routine output constancy checks and other daily use.
- (b) If the field dosimeter is to be used for absolute calibration of therapy beams then it shall be calibrated by comparison with the reference dosimeter in accordance with the IAEA Protocol (Worksheet A1 in NRL 1989).

5.2 Beam calibration under reference conditions

The radiation dose rate of each beam used for treating patients shall be determined under reference conditions in accordance with the Code of Practice TRS-398 (Andreo 2000). The measurement shall be traceable to a Primary Standards Dosimetry Laboratory.

[Note: For the measurement of kilovoltage x-ray beams, traceability to the NRL primary standard of radiation exposure in accordance with Appendix I.2 of TRS-398 is acceptable.]

Reference:

Andreo P, Burns D T, Hohlfeld K, Huq M S, Kanai T, Laitano F, Smyth V and Vynckier S. IAEA INTERNATIONAL ATOMIC ENERGY AGENCY, “Absorbed Dose Determination in External Beam Radiotherapy. An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water”, Technical Report Series no. 398, Vienna (2000).

Note: may be downloaded from

http://www-pub.iaea.org/MTCD/publications/PDF/TRS398_scr.pdf

Excel spreadsheets are available from

<http://www-naweb.iaea.org/nahu/dmrrp/trs398.zip>

5.3 Clinical beam measurements: Co-60 and MV x-rays and electrons

5.3.1 All radiation dosimetry outside the reference conditions should be done as measurements relative to the reference calibration for the beam being used. Modifications to the beam due to the use of wedges, different field sizes and shapes, tissue compensators, etc should be expressed as factors modifying the reference output.

5.3.2 The location of a dosimeter in air or within a phantom shall be accurate to within ± 1 mm. A radiation field analyser that permits the movement of a dosimeter in 3 dimensions under computer control shall reproduce a specified position within ± 1 mm.

5.3.3 When using a solid or water phantom, the phantom dimensions shall be such that there is always a margin of at least 5 cm outside the beam at the depth of measurement, and in the beam direction.

5.3.4 Comments on the use of an ionization chamber

- (a) When taking depth-dose measurements with high energy photons, relative dose can be taken to be equal to relative ionization. Accurate measurements in the build-up region are difficult. If a pancake chamber is used for this, significant errors may result if the guard between the side wall and the collecting electrode is insufficiently wide (Rubach *et al*, 1986).
- (b) When measuring depth-dose relationships in electron beams, the mean electron energy must be determined and the dosimetry protocol applied to measurements at each depth. Because of uncertainty in the perturbation factors for cylindrical chambers with electrons, a pancake chamber is recommended outside the reference conditions for all electron energies and is required when the mean surface energy is less than 10 MeV.
- (c) When scanning across an electron beam at fixed depth, the average electron energy can be taken as constant and equal to that on the beam axis.

5.3.5 Comments on the use of semiconductor diodes

- (a) Semiconductor diodes may be used for relative measurements, but it is necessary to establish that the response is adequately energy-independent. Diodes are not intrinsically energy-independent but some are designed to compensate for this. Typical depth dose measurements should be made with both the diode and a suitable ionization chamber. If there is a difference then the ionization chamber should be taken as the standard.
- (b) It should also be noted that diodes suffer from response change with age, due to radiation damage. This response change can also affect the energy dependence.

5.4 Clinical beam measurements: kilovoltage x-rays

5.4.1 Because of variation in the effects of scatter from different applicators (eg, see Klevenhagen *et al*, 1991), the beam produced by each clinically used combination of applicator, added filter, and set kV shall be measured. If a lead mask is used against the skin there will be considerable scatter from the edge of the lead, but less back-scatter because of the reduced area of tissue irradiated. This leads to considerable doubt as to the surface dose. Whenever possible the clinical configuration should be measured with a dosimetry system that directly responds to the back-scatter.

5.4.2 Because the scatter from the inside of the applicator is usually of lower energy and more isotropic than the primary beam, it is less penetrating. For superficial treatments this scatter is part of the useful beam, and will be registered by a thin window chamber. It will, however, be very difficult to gauge either the HVL or the variation in dose with depth. A chamber with a calibration factor that is constant within $\pm 2\%$ over the relevant range of HVLs should be used.

5.4.3 In the case of more penetrating x-rays ($\text{HVL} > 2 \text{ mm Al}$), the effective beam should be measured at a depth of a few centimetres in a phantom, preferably water, and the dose maximum at the surface obtained from published or previously-measured depth dose data. A measurement in air or on the surface of a phantom will be influenced by the applicator and mask scatter. In the case of a small aperture in the mask, the radiation field at depth in the

phantom will be more uniform in the volume of the chamber and will be less likely to give erroneous results than a measurement in air at the mask.

5.5 In vivo dosimetry

5.5.1 If possible, calculated doses should be verified by direct measurement on a representative sample of patients, using either surface or intracavitary TLD, ionization chamber, or diode measurements.

5.5.2 Whenever possible, *in vivo* dosimetry should be used to monitor sensitive organs that may receive an unintended clinically significant dose.

5.5.3 Dosemeters used for *in vivo* measurement shall be calibrated against a local reference dosimeter. A field dosimeter may be used to transfer the calibration. In the case of dosemeters used for measuring surface dose, the calibration should be transferred using a suitable pancake chamber on the surface of a phantom.

6. TREATMENT PLANNING

The term "treatment planning" in the context of Section 6 is taken to mean the process of determining treatment times, field sizes, beam types, beam modifications, etc irrespective of what method is used.

6.1 General Requirements

6.1.1 Curative treatments shall be planned such that the target absorbed dose delivered at the dose specification point is within $\pm 5\%$ of the dose prescribed by the radiation oncologist. The uncertainty involved in physical dosimetry is typically $\pm 3.5\%$. Therefore the errors due to treatment dose calculations, patient set-up and dose delivery should sum in quadrature to less than 3.5%.

6.1.2 For curative treatments all reasonable steps should be taken to produce a treatment plan such that, within the target volume, the radiation dose does not fall by more than 5% below the dose prescribed by the radiation oncologist.

6.1.3 In the case of x-rays of less than 100 kV, treatment planning is uncomplicated and is usually based on the clinician's experience. When x-rays of higher energy but less than 300 kV are used, the method given in ICRU 24

(ICRU, 1976) should be followed. The rest of Section 6 deals exclusively with beam energies higher than 300 keV.

6.2 Manual Planning

The ability to perform manual planning of at least a sample of treatment procedures shall be maintained even after the acquisition of a computerised system. This serves the following purposes:

- (a) manual planning is useful for training or educational purposes;
- (b) the computer system may be temporarily unavailable because of a technical breakdown, renovation or system modification;
- (c) someone experienced in manual procedures will more easily detect any errors that may have occurred in the use of a computerised dose planning system;
- (d) in unusual clinical situations, or in the implementation of new treatment techniques, the range of applicability of the computer algorithms may be exceeded.

6.3 Computer-based planning systems

6.3.1 There should be a continuing programme of reviewing the performance of new computer treatment planning systems as they become available. Every effort should be made to take advantage of new versions of presently-used software that permit a genuine improvement in both accuracy and confidence with which a therapeutic dose may be delivered while sparing healthy tissue. It is important that clinical practice should evolve as the capability improves.

6.3.2 Before a treatment planning system is put into use it shall be tested extensively to ensure it reproduces all of the input beams within the tolerances of Sections 6.3.4 and 6.3.5. It shall then be checked against manual plans and previously used plans, and all differences resolved. Table 6.1 is taken from McCullough and Krueger, 1980 and is a suggested protocol for verification of a new treatment planning program for external beam photons. A similarly thorough protocol should be followed for electrons.

6.3.3 There shall be a contingency plan to cover the failure of any part of a computerised treatment planning system. Alternatives such as manual planning or the use of similar computer equipment at another hospital shall be available for all regularly-used treatment techniques.

6.3.4 The inaccuracy on the central axis from the beam reconstruction algorithm should be less than $\pm 1\%$ or ± 1 mm for open and wedged beams and less than $\pm 2\%$ for corrections for individual patient beam modifiers. If the inaccuracy is significantly greater than this in regions of high dose gradient (eg, $> 5\%$ or > 5 mm) then the radiation oncologist shall be made aware of this when choosing margins for the target volume.

6.3.5 For treatments at the normal SSD or SAD (excluding total body irradiation) the calculated dose within a target volume should be accurate within $\pm 3.5\%$ irrespective of the use of wedges, beam compensators, irregularly shaped fields, corrections for tissue inhomogeneities, etc. In the case of adjacent fields where the penumbras are within the target volume, the $\pm 3.5\%$ accuracy should extend out to the 80% isodose contour.

6.3.6 With the greater flexibility permitted by true 3-dimensional programs accepting non-coplanar beams, the treatment planning program should provide a clear method for comparison of alternative plans.

6.4 Building a beam library

6.4.1 Measurements of clinical beams used for input to a treatment planning program shall be performed in accordance with Section 5.3.

6.4.2 Data should be input in a form as near as possible to that in which it is used by the program. If the program bases the calculation on the isocentric geometry then it is better to input measured tissue-phantom ratios. Conversely, if it uses source-surface geometry then use measured percentage depth dose data.

6.4.3 Beam data should be entered for as many combinations of fields and wedges as possible. Check the compliance with 6.3.4. Extreme rectangular fields should be entered as special fields if they do not satisfy this requirement.

6.5 Patient data input

6.5.1 Manual input

- (a) Equipment used for measurement of patient dimensions and contours shall have an accuracy of better than ± 1 mm when checked on a phantom and a repeatability of better than ± 5 mm when used on a patient.
- (b) Whichever method is used to generate a patient's contour, it should be checked by taking antero-postero and left-right lateral measurements using an accurate method such as the alignment lasers, couch height indicator, or callipers.

6.5.2 Use of CT and other data

- (a) Whenever appropriate, patient data should be taken from a radiotherapy planning CT scan.
- (b) When CT data are to be used for treatment planning, the patient should be positioned on a similar couch to that used for treatment.
- (c) Because of the possibility of the movement of internal organs, CT images should be compared with other imaging modalities (eg, simulator images) before placing full reliance on the CT data for treatment planning.
- (d) Whenever necessary other imaging modalities, such as SPECT and MRI should be used to help define the topography of the tumour and sensitive organs.

6.6 Treatment planning procedures

6.6.1 The target volume and target absorbed dose (see Appendix for definitions) should be specified by the radiation oncologist in terms of the patient's anatomy or diagnostic images before any dose distributions are calculated.

6.6.2 The department shall have a clear policy on how the following features of a treatment plan are to be optimised:

- (a) Minimum target absorbed dose;
- (b) Peak dose to organs at risk;
- (c) Dose variance over the target volume;
- (d) Conformation of treatment volume to target volume;
- (e) Simplicity of plan to minimise set-up errors.

6.6.3 Every target volume should be treated as 3-dimensional. Corrections should be made for any significant well-defined inhomogeneities (particularly lung tissue). If the calculation method is 2-dimensional then the treated volume should be partitioned into slices such that within each slice:

- (a) No important variations occur in external contour;
- (b) No important variations occur in the topography of the relevant internal structures such as size, shape and location of the target volume, organs at risk, heterogeneities, etc;
- (c) No important variations are expected in the dose distribution that are relevant to the treatment plan.

6.6.4 The absolute beam output that is used for treatment planning calculations shall be derived from a reference beam measurement in accordance with Section 5.2.

6.6.5 Beam modification factors adjusting for field size, block tray, wedges, etc shall be used explicitly to derive treatment time or number of monitor units for each beam. All the factors used shall be listed on the treatment plan chart for verification, but the calculation should be performed by computer whenever possible.

6.6.6 Each stage of the treatment planning documentation shall be initialled by the individual primarily involved. It shall be checked and counterinitialled by a second staff member of at least equivalent seniority.

6.6.7 For curative treatments, the tumour size and patient contours should be checked regularly. If there is evidence that there has been a change that could have a clinical significance for either the target volume or sensitive tissues, the treatment should be replanned.

TABLE 6.1: A suggested protocol for verification of a treatment planning program for external beam photons
(McCullough and Kreuger, 1980)

- 1. Normal incidence**
 - A. Source-to-skin distance (SSD) beams
 1. Unwedged
 - a. 10 x 10 cm² at 80 cm
 - b. 10 x 10 cm² at 130 cm
 - c. 25 x 25 cm² at 80 cm
 - d. 5 x 30 cm² at 80 cm
 2. Wedged
 - a. 10 x 10 cm² at 80 cm, 30° wedge
 - b. 10 x 10 cm² at 80 cm, 60° wedge
 - B. Source-to-axis distance (SAD) beams
 1. Unwedged
 - a. 10 x 10 cm² at 80 cm (SSD = 70 cm)
 2. Wedged
 - a. 10 x 10 cm² at 80 cm (SSD = 70 cm), 30° wedge
- 2. Oblique incidence**
 - A. SSD beams
 1. 10 x 10 cm² at 80 cm, flat surface, 45° incidence
 2. 7 x 7 cm² at 80 cm, tangential breast
- 3. Bar blocked**
 - A. 15 x 15 cm² at 80 cm, widths = 1 - 4 cm at surface
- 4. Inhomogeneities**
 - A. Lung
 1. Anthropomorphic phantom
 - a. Single field, 15 x 15 cm² at 80 cm SSD
- 5. Irregular fields**
 - A. Unblocked, 35 x 35 cm² at 100 cm
 - B. Mantle, 35 x 35 cm² at 100 cm
- 6. Parallel opposed**
 - A. SSD beams

1. 10 x 10 cm² at 80 cm, patient thickness = 20 cm
 - a. Weightings = 1:1, 1:2, 1:3
- B. SAD beams
 1. 10 x 10 cm² at 80 cm, patient thickness = 20 cm
 - a. Weightings = 1:1, 1:2, 1:3

7. Isocentric (SAD)

- A. Rotation
 1. 360 deg, 8 x 8 cm² at 80 cm SAD
 2. 2 x 180 deg, 8 x 8 cm² at 80 cm SAD
- B. Arc
 1. 180 deg arc, 8 x 8 cm² at 80 cm SAD, isocentre displaced laterally from centre of 20 x 33 cm²
- C. Wedged pair
 1. 8 x 8 cm² at 80 cm SAD, 45° wedge, 90° hinge angle

7. TREATMENT PROCEDURES

7.1 General Procedures

7.1.1 Irrespective of automatic verification and interlocking systems used, a method of human double-checking of all machine parameters should be included as routine practice prior to every radiation exposure.

7.1.2 The operator and all other persons should normally be outside the treatment room when the equipment is about to be, and is being used.

7.1.3 In the case of low energy x-rays (10 kV to 100 kV, HVL < 2 mm Al), it is permissible for the operator and other essential persons to remain in the room during treatment. If there is no other barrier used, protective aprons (and gloves when appropriate) of lead equivalence not less than 0.25 mm shall be worn.

7.1.4 When a gamma source is used, there shall be a protocol to be followed in the event of the source sticking in the exposed position. A daily check should be made of the correct location of any tool required for this procedure. Any radiographers operating the equipment shall be familiar with the protocol.

7.2 Patient Set-up

7.2.1 There is strong evidence that sub-centimetre positioning errors are related to local control rate decreases on the order of 10% to 20% and that field misalignments of about 1 cm can occur up to 20% of the time (Boyer, 1986). Patient-field alignment is one of the areas that can most benefit from continuous quality assurance.

7.2.2 The patient should be set up for treatment in such a way that the target volume is constrained, either voluntarily or by immobilisation devices if necessary, within ± 5 mm of its correct position with respect to the treatment beam.

7.2.3 The positioning of the target volume in a patient on a treatment simulator should be within ± 5 mm of the subsequent positioning on the corresponding treatment machine, relative to the beam geometry.

7.2.4 Whenever possible the patient's position should not be altered during the treatment of one target volume or of abutting target volumes.

7.2.5 It is strongly recommended that an on-line real-time portal imaging system is used on each high energy treatment machine, permitting the constant observation of the treatment field in conjunction with direct viewing of the patient. If any move likely to have a clinical significance for either the target volume or sensitive tissues is observed in the portal image, the beam exposure should be stopped immediately and restarted with the required amount of time or monitor units remaining after the patient has been correctly repositioned.

7.2.6 Every curative high energy field should be checked on a treatment simulator when this is clinically desirable. A film of the field should be taken for comparison with portal verification films.

7.3 Localisation and verification portal films

7.3.1 In a recent survey (Reinstein, 1986, Reinstein *et al*, 1984) have shown that almost half of a sample of portal films were judged to be of "poor" quality. Because of the crucial role these play, as much care should be taken over image quality of portal films as for conventional diagnostic x-ray films. A lead or copper front screen should be used in contact with the film to enhance the image quality.

7.3.2 At the start of each curative course of treatment with high energy radiation, a portal verification film should be taken of each field to verify position relative to simulator check films when these have been taken. (See 7.2.6)

7.3.3 Further films should be taken frequently during a course of curative treatment under the following circumstances:

- (a) An un-cooperative patient;
- (b) Treatment of a critical site where accuracy greater than that specified in 7.2.2 is needed;
- (c) A difficult set up such as an obese patient or one with moveable, unstable skin marks;
- (d) Treatments where matching of field edges is important;
- (e) Paediatric treatment;
- (f) Any changed or reduced field.

7.4 Machine parameter setting verification and recording systems

7.4.1 Every high energy treatment machine that is computer-controlled shall be equipped with a system that automatically compares the machine settings for each field with predetermined settings and records the settings actually used for the exposure.

7.4.2 The overriding of the machine settings in a verification and recording system shall only be permitted under circumstances set out in a protocol agreed to by the radiation oncologist.

8. TREATMENT RECORDING

8.1 The requirements for record keeping

Records of any radiotherapy treatment, sufficient to show what parts of the body were irradiated, the quality of the radiation, the magnitude of the radiation dose, and relevant data on which the estimate of the radiation dose was based shall be retained in a form and location to allow retrieval if necessary for at least 40 years or 10 years after the death of the patient, whichever occurs first.

8.2 Types of records to be kept

8.2.1 All data relevant to the diagnosis and treatment of each individual patient shall be kept in some recoverable form. This includes all simulator films, treatment plans, portal films, and dose delivery charts. Each beam delivered to the patient shall be documented and each treatment initialled by the operator responsible at the time. The terms used for recording the treatment shall conform to the specifications in ICRU Report 29 (ICRU, 1978). Definitions are given in the Appendix.

8.2.2 Data stored by an automatic verification and recording system (Section 7.4) shall be kept in a bulk data storage medium for at least 1 year.

8.2.3 A suitable computerised cancer registry should be maintained that contains data on radiotherapy treatments and outcomes of at least the most common types of cancer. Treatment data should include details of the radiotherapy (target dose, fractionation system, etc) together with other treatment modalities used in combination. Outcome data should include tumour response, morbidity, mortality, and recurrence. The reporting methods should follow WHO Offset Publication 48 (WHO, 1979). Annual summary reports should be reviewed by the Head of Radiation Oncology and compared with other treatment results in order to assess the quality of the treatments being given by the Department.

9. QUALITY ASSURANCE PROGRAMME

9.1 Responsibility for the programme

The principal or each licensee for radiotherapy in a radiotherapy department shall ensure that a suitable programme of quality assurance is instituted and maintained (Clause 3.3.3).

9.2 General requirements for a quality assurance programme

9.2.1 The programme shall contain such routine checks and procedures as are required to give reasonable confidence in the compliance with the rest of this Code of Practice.

9.2.2 There shall be a well-defined responsibility and reporting structure. Each staff member shall routinely review the results of checks for which they are responsible and report summary results to their superior. Any anomalous check results shall be reported immediately. Each staff member shall be responsible for the maintenance of the quality assurance programme by personnel under his or her control.

9.2.3 As far as possible all critical procedures should be designed such that steps that are prone to human error are independently checked by another staff member of at least equivalent seniority. Procedures should be standardised and set down in protocols or local rules whenever possible to avoid errors due to confusion between variants.

9.2.4 All equipment shall be checked at suitable regular intervals to ensure it is performing within suitable tolerances of accuracy and constancy. Recommended schedules are given below. As well as routine tests, any machine or system malfunctions or errors shall be logged and reported to superiors.

9.3 Quality assurance of equipment

(a) The frequency with which a particular parameter is tested should be determined by both the likelihood and the consequences of an error beyond the acceptable tolerance. The schedules given below are given as guidelines. However, the schedules actually used should be based on

local experience and confidence in the equipment. See for example Purdy *et al*, 1986.

- (b) The acceptable tolerance levels given in the tables are based on the international literature. Tolerance levels given in the manufacturer's specifications may be used when they do not vary too widely from the tabulated values.

9.3.1 Equipment for localisation and tissue data acquisition

- (a) All diagnostic imaging equipment used for treatment decisions or measurements shall be tested for performance and image quality in accordance with normal procedures followed by the Medical Imaging Department.
- (b) When data from a CT scanner are used as direct input into a treatment planning program, the aspects of the data that are critical to dose calculations shall be routinely tested. A suggested schedule of tests is given in Table 9.1. The checks in the first 2 sections of the Table are taken from a set of acceptance tests in McCullough and Holmes, 1985.

9.3.2 Treatment planning equipment

- (a) A standard set of beam profiles should be generated by the program and compared with reference data measured in a water phantom. The set should include square, rectangular and irregular fields. Tolerances are given in Table 9.2.
- (b) A set of sample plans which incorporate all regularly used features should be run at least once a month to test for inadvertent modifications of the software or database. The tests should each start from a standard raw data set as would be input for a patient, and include the use of all peripheral hardware through to plotting of treatment charts. A record of the output from each test should be filed for future comparisons. Tolerances are given in Table 9.2.

9.3.3 Equipment for treatment simulation

- (a) X-ray tube performance and image quality shall be tested in accordance with routine quality assurance procedures for diagnostic imaging equipment.
- (b) The mechanical, optical, and radiation alignment shall be tested routinely. A suggested schedule of tests based on McCullough and Earle, 1979 is given in Table 9.3.

9.3.4 Therapy machines

Performance of therapy machines shall be tested routinely. The schedules given in Tables 9.4 and 9.5 are taken from WHO, 1988. For linear accelerators it is strongly recommended that the test methods and schedules in IEC 976 and IEC 977 are followed (British Standards Institution, 1990a and 1990b).

9.3.5 Dosimetry equipment

A quality assurance schedule based on WHO 1988 is given in Table 9.6. Dosimeters that are not used for absolute dosimetry need not be calibrated against the national standard. However the short term stability (standard deviation of a series of repeated measurements) should be tested regularly.

9.4 External quality audits

9.4.1 The hospital radiotherapy department should be visited regularly, usually annually, by NRL field officers to inspect and discuss compliance with this Code.

9.4.2 The calibration of treatment beams under reference conditions should be checked from time to time using independent equipment and personnel from NRL.

9.4.3 From time to time the accuracy of the dose calculation of the treatment planning program should be checked using an instrumented phantom provided by NRL.

TABLE 9.1: Schedule of tests for a CT scanner used for treatment planning (See McCullough and Holmes, 1985)

<u>Every 6 months:</u>	Tolerance
1. Correct dimensioning Compare known dimensions of details on a phantom with a plot of the same image generated by the planning program. Repeat in orthogonal directions.	$\pm 1 \text{ mm}$
2. CT number to tissue property conversion Check calibration of CT number against relative electron density using known tissue-like materials ($Z = 6 - 8$) and bone-like materials ($Z = 11 - 13$)	$\pm 2\%$
3. Mechanical accuracy Table positioning, laser alignment system as for treatment simulator (Table 9.3)	

TABLE 9.2: Schedule of tests for treatment planning programs

<u>Every month:</u>	Tolerance
Standard fields contours	$\pm 1 \text{ mm}$
dose	$\pm 1\%$
Standard plan contours	$\pm 2 \text{ mm}$
dose	$\pm 5\%$

TABLE 9.3: Schedule of tests for a treatment simulator
(McCullough and Earle, 1979)

<u>Weekly tests:</u>	Tolerance
1. Field size indicators (at 2 FADs)	± 1 mm
2. Light/radiation field congruence	± 1.5 mm
3. SSD/SAD indicator accuracy	± 1 mm
4. Other digital readouts	± 1 mm $\pm 0.5^\circ$
5. Laser localization accuracy with respect to the isocentre.	± 1 mm
<u>Monthly tests:</u>	Tolerance
Cross-hair wander with	
(a) Collimator rotation	± 1 mm
(b) SAD variation	± 1 mm
(c) Change in table height	± 1 mm
(d) Movement of table about isocentre	± 1 mm
(e) Gantry rotation.	± 1 mm
<u>Yearly tests:</u>	
1. A full acceptance test to the manufacturer's specifications	
2. Radiographic tests	
(a) Focal spot size	
(b) kVp indicator accuracy	
(c) Timer accuracy	

- (d) mAs linearity
- (e) mA and mAs repeatability
- (f) Air kerma per mAs
- (g) Inherent filtration.

TABLE 9.4: Schedule of tests on mechanical and geometric performance for megavoltage treatment machines (WHO, 1988)

Daily tests:

- Entrance door interlock
- Warning lights and test display lights
- Wedge filters, blocks and blocking tray (visual check)

Weekly tests:

Tolerance

Source distance indicators On a range including points of entry and exit on patients	± 2 mm
Light field indication Compared with radiation field at usual treatment distances	± 2 mm
Patient alignment devices (lasers, etc.)	± 2 mm

Monthly tests:

Tolerance

Yoke rotation Zero position scale	$\pm 0.2^\circ$
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Beam axis indicators		
Cross-hair alignment, etc		± 2 mm
Numerical field indicators		
Compared with radiation field at usual treatment distances		± 2 mm
Treatment couches		
Vertical scales: Height relative to isocentre		± 2 mm
Treatment verification systems		In accordance with manufacturer's specifications
Every parameter controlled by system		
Immobilisation devices		
Check possible patient motion (monthly or before use of individually adapted devices)		± 2 mm
<u>Yearly tests:</u>		Tolerance
Gantry rotation		
Check 4 main positions for vertical and horizontal beams		$\pm 0.5^\circ$
Isocentre		± 2 mm
Collimation system rotation		$\pm 0.5^\circ$
Treatment couches:		
lateral and longitudinal scales		± 2 mm
isocentric axis, (compared with gantry isocentre)		± 2 mm
vertical deflection (with patient load)		± 5 mm

TABLE 9.5: Tests on beam performance and light field accuracy (WHO, 1988)

<u>Daily tests:</u>	Tolerance
Output constancy checks on linear accelerators Dose per M.U.	$\pm 2\%$
 <u>Weekly tests:</u>	 Tolerance
Output constancy checks on kV x-ray units Each quality used	$\pm 2\%$
 <u>Monthly tests:</u>	 Tolerance
Light field indication Visual inspection for the four main gantry positions Density measurements (every 6 months)	$\pm 2 \text{ mm}$
Constancy checks: Co-60 and Cs-137, under treatment conditions	$\pm 2\%$
Timer of Co-60	$\pm .01 \text{ min}$
Linear accelerator beams (twice per month) Flatness Symmetry Beam energy (check of depth dose) Linearity of dose per M.U.	$\pm 3\%$ $\pm 3\%$ $\pm 2 \text{ mm}$ $\pm 2\%$
Co-60 and Cs-137 beams Beam symmetry	$\pm 3\%$
kV x-ray units Beam symmetry Timer error kV - filter identification safety	$\pm 3\%$

<u>Yearly tests:</u>	Tolerance
Central axis dose calibration Each beam under reference conditions	
Linearity of monitor	$\pm 1\%$
Transmission factor	
Wedges and compensators	$\pm 2\%$
Trays	$\pm 2\%$
kV x-ray units	
Check depth dose or HVL	$\pm 0.5 \text{ mm}$

TABLE 9.6: Tests on dosimeters and phantoms

	Tolerance
Calibration:	
Reference dosimeter (Every 3 years or after repairs)	
Field dosimeter (Calibrated against local reference yearly or after repairs)	
Stability checks: (Monthly or before and after each time calibrated)	
Reference dosimeter	$\pm 1\%$
Field instrument	$\pm 2\%$
Checking of dimensions, marks, and reproducibility of detector positioning and beam data acquisition systems: (Yearly)	$\pm 1 \text{ mm.}$

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APPENDIX

ICRU DEFINITIONS OF TERMS USED IN TREATMENT PLANNING AND RECORDING

(ICRU, 1978. Report 29)

Target Volume. The volume to which the clinically effective radiation dose is to be applied. This is specified in terms of the patient's anatomy and topography. Allowance must be made for movements during treatment, changes in size of organs within the target volume (eg, tumour shrinkage, variation in bladder size), and in patient set-up during the course of the treatment.

Treatment volume. The volume enclosed by the isodose surface corresponding to the minimum target absorbed dose.

Irradiated volume. The volume which receives an absorbed dose considered significant in relation to tissue tolerance. This is typically 50% of the specified target absorbed dose.

Target absorbed dose. The nominal absorbed dose that is taken to be representative of the absorbed dose to the target volume. It is defined as the absorbed dose at a nominal specification point at representative location within the target volume. For isocentric treatments this is usually taken as the isocentre.

Maximum target absorbed dose. The highest absorbed dose in the target volume covering an area of more than 2 cm². Hot spots covering less area than this are considered to be clinically insignificant.

Minimum target absorbed dose. The lowest absorbed dose in the target volume. There is no minimum area for this.

Mean (Median, Modal) target absorbed dose. The mean (median, mode) of the dose calculated on regularly spaced lattice points within the target volume.

Hot spot. A volume outside the target volume indicated by an isodose curve enclosing at least 2 cm² area which receives more than 100% of the specified target absorbed dose.