



The Transition from
2-D Brachytherapy to
3-D High Dose
Rate Brachytherapy



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THE TRANSITION FROM
2-D BRACHYTHERAPY TO
3-D HIGH DOSE RATE BRACHYTHERAPY

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FOREWORD

Cancer is one of the leading causes of death globally, and radiotherapy is an essential component in the management of cancer patients, either alone or in combination with surgery or chemotherapy, both for cure or palliation. It is now recognized that safe and effective radiotherapy services need not only substantial capital investment in radiotherapy equipment and specially designed facilities, but also continuous investment in maintenance and upgrading of the equipment in line with technical progress and staff training.

Advances in computer technology and diagnostic imaging have made possible the transition from basic 2-D treatment planning and delivery (2-D radiotherapy) to a more sophisticated individualized approach with 3-D radiotherapy. Whereas 2-D radiotherapy can be applied with simpler equipment and maintenance, the transition to 3-D radiotherapy treatments requires more resources in technology, equipment, staff and training. This is true for both external beam radiotherapy and brachytherapy.

Owing to the increased interest of Member States to implement modern applications of radiotherapy, the IAEA has received a number of requests for guidance from radiotherapy departments that wish to upgrade their facilities to include a 3-D brachytherapy service through the technical cooperation programme. These requests are expected to increase in future. In addition, the Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology has recognized the emerging demand for advanced approaches to brachytherapy through the initiation of the regional project Supporting 3-D Image-Guided Brachytherapy Services. Since these treatment techniques are more complex, there is concern that institutions and States need to be informed of the preparatory conditions and resources involved. Furthermore, the current status of the evidence supporting the use of 3-D brachytherapy in terms of patient outcomes has to be considered when planning an investment in the technology.

To respond to the needs of Member States to establish guidelines for the transition from 2-D brachytherapy to 3-D high dose rate brachytherapy, a consultants meeting was convened to discuss the necessary steps and the milestones for the transition. This publication serves as complementary guidance to *Setting up a Radiotherapy Programme: Clinical, Medical Physics, Radiation Protection and Safety Aspects*, published by the IAEA in 2008. Both publications provide a comprehensive overview of the additional radiotherapy infrastructure and processes.

This publication is addressed to professionals and administrators involved in the development, implementation and management of radiation oncology programmes who seek to supplement or replace the conventional approach with an individualized approach by making a transition from simpler radiation treatment methods to more complex radiotherapy techniques. This publication provides guidelines and highlights the milestones to be achieved by radiotherapy institutions in the transition from 2-D to 3-D brachytherapy treatment, and outlines the efforts being made to provide access to safe and effective treatment for the steadily increasing number of cancer patients in Member States.

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1. INTRODUCTION

This publication covers aspects of the transition to volumetric image based 3-D high dose rate (HDR) brachytherapy, including clinical evidence, resources, milestones, a description of clinical processes, education, training and staffing requirements, and quality assurance guidelines. Appendix I provides a self-evaluation questionnaire to determine the state of readiness of an institution to make the transition to 3-D HDR brachytherapy. Appendix II provides indicative costs of the equipment required, and Appendix III presents an example checklist relevant to treatment planning verification.

This publication is aimed at Member States that are using 2-D afterloading brachytherapy techniques, and it is focused mainly on the transition from 2-D to 3-D HDR brachytherapy for gynaecological cancer. However, it may be applied to other sites such as the breast, head and neck, and to endoluminal tumours. The publication does not apply to permanent implants or ophthalmic plaques. This publication also does not apply to prostate brachytherapy treatment, which is always performed using highly specialized 3-D techniques. This publication does not address treatment schedules or resource sparing fractionation regimes for HDR treatments. In addition, the use of biological optimization based on normal tissue complications and tumour control probabilities in brachytherapy treatment planning is still largely investigational and is not considered further in this publication.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

2. 3-D HDR BRACHYTHERAPY

This publication describes the benefits of 3-D HDR brachytherapy and the technological, logistical and personnel requirements to enable the safe and accurate delivery of brachytherapy, including guidelines on the establishment of treatment facilities. The publication has been written to complement other IAEA publications [1, 2], which includes the recent IAEA publication Radiotherapy Facilities: Master Planning and Concept Design Considerations, which should be consulted in conjunction with this publication, particularly the sections which describe the requirements for establishing a brachytherapy programme. This publication also builds on a previous IAEA publication on HDR brachytherapy implementation [3] and develops more fully the concepts and practice of 3-D brachytherapy based on the latest literature.

Three dimensional HDR brachytherapy describes the design and delivery of radiotherapy treatment plans based on at least one 3-D image dataset. The delivery consists of a HDR radioactive source stopping for short times at various dwell positions in an automated manner to treat only the target tissue. This publication proposes a tiered system to describe the complexity of the brachytherapy treatment process. Levels 1–3 are illustrated in Table 1. The first level of brachytherapy (Level 1) can be carried out in any radiotherapy department with the basic facilities described in Ref. [2]. Level 1 involves the selection of library based treatment plans for fixed applicator configurations and need not involve imaging for treatment planning. Level 2 brachytherapy is partially individualized so that some optimization of the dose delivered is achieved, but the design of the treatment is based on a small number of points determined from 2-D planar images of the patient. Level 3 brachytherapy requires a full 3-D patient dataset, usually of computed tomography (CT) or magnetic resonance (MR) images, in which the tumour volume and organs at risk (OAR) are defined according to the concepts of International Commission on Radiation Units and Measurements (ICRU) Report 50 [4]. Level 3 may include the use of automated optimization tools (inverse planning). Table 1 provides an overall summary of the methodology and tools associated with each level, but not every treatment needs to use all the techniques listed.

TABLE 1. LEVELS OF BRACHYTHERAPY ACCORDING TO THE METHODOLOGY AND TOOLS ASSOCIATED WITH EACH STEP OF THE PROCEDURE

	Level 1 Library based	Level 2 Planar image based 2-D	Level 3 Volumetric image based 3-D
1. Applicator placement			
Applicator type	Radio-opaque	Radio-opaque	CT/MR compatible ^a
Applicator fixation	Required	Required	Required
2. Imaging, and OAR and target definition			
Imaging methodology	Planar images (or none)	Planar images with or without contrast agents	Cross-sectional imaging (CT, MR and US) with or without contrast agents
Purpose of imaging	Record	Applicator reconstruction and definition of points of interest	Applicator reconstruction and volumes of interest definition
OAR definition	n.a. ^b	Point based	Volume based
Target definition	n.a. ^b	Point based or volume based clinically assessed CTV	Volume based GTV, CTV
3. Treatment planning			
Applicator reconstruction	Library	X ray catheter or applicator based; geometry	Indirect applicator visualization using multiplanar reconstruction
Plan optimization	n.a. ^b	Based on point A/target and OAR points	Based on CTVs and OAR volumes
Plan evaluation	n.a. ^b	Isodoses and dose constraints	Isodoses, DVH and dose constraints
Final dose prescription	n.a. ^b	May be adjusted according to dose constraints	May be adjusted according to dose volume constraints
Dose reporting	Library reference	ICRU	ICRU and/or GEC–ESTRO
Plan verification and approval	Selected from the library	Checklist	Checklist
4. Plan transfer to afterloader via network			
	Desirable	Essential	Essential
5. Pre-delivery quality control			
	Normal practice	Normal practice	Normal practice
6. Treatment delivery			
In vivo dose measurements	Desirable	Desirable	Desirable
Dose recording	TRAK and dose–time pattern	ICRU minimum or GEC–ESTRO	ICRU advanced or GEC–ESTRO
7. Removal of applicators (and sources)			
	Normal practice	Normal practice	Normal practice
8. Follow-up evaluation			
	Essential	Essential	Essential

Note: CT — computed tomography; CTV — clinical target volume; DVH — dose volume histogram; GEC–ESTRO — Groupe Européen de Curiethérapie–European Society for Radiotherapy and Oncology; GTV — gross tumour volume; ICRU — International Commission on Radiation Units and Measurements; MR — magnetic resonance; OAR — organs at risk; TRAK — total reference air kerma; US — ultrasound.

^a For CT based planning, CT compatible applicators are desirable but not obligatory.

^b n.a.: not applicable.

The design and delivery of a 3-D HDR brachytherapy programme require a set of procedures, all of which need to be in place if the treatment is to be safe and effective. It is therefore essential that all procedures have been established and tested before embarking on patient treatment. The procedures are:

- (a) Using high quality 3-D medical imaging devices to accurately reconstruct the applicator and to determine gross tumour volume (GTV), clinical target volume (CTV) and OAR volumes;
- (b) Using 3-D treatment planning systems (TPSs) to optimize dwell times and positions;
- (c) Computing 3-D dose in GTV, CTV and OAR volumes;
- (d) Evaluating the dose plan using dose volume histograms (DVHs) and 3-D dose visualization tools;
- (e) Correctly transferring the plan data to the delivery machine;
- (f) Measuring the outcome of the treatment.

Section 4 provides a list of milestones to be achieved in a project to establish a Level 3 volumetric image based 3-D HDR brachytherapy programme.

3. CLINICAL EVIDENCE FOR 3-D HDR BRACHYTHERAPY

The development of 3-D planning for external beam radiotherapy (EBRT) was a major achievement for more individualized patient treatment, better clinical outcomes and reduced toxicity. Brachytherapy, however, is still mostly based on 2-D planning, with the exception of prostate cancer treatment for which 3-D planning is already well established and considered the standard of care. The transition to 3-D planning for the other most common brachytherapy indications, such as gynaecological cancers, is a logical development.

Historically, dosimetry systems such as the Manchester, Paris, Quimby and Stockholm systems were derived from rich clinical experience which was used to deliver a specified dose to the tumour fairly accurately in the absence of computerized TPSs. With the development of new applicators and different radium substitutes, such as ^{137}Cs , ^{60}Co and ^{192}Ir , the potential of other brachytherapy modalities became evident. HDR remote afterloading systems, coupled with advances in TPSs, have ensured that safer delivery and improved methods of brachytherapy dose analysis are possible. However, the imaging modality used in brachytherapy was largely limited to planar radiographs obtained from radiotherapy simulators or C-arm imaging systems. The major limitation of conventional 2-D brachytherapy is that it is applicator and point based and, therefore, there is a lack of spatial information on the tumour volumes and OAR volumes. For gynaecological brachytherapy, point doses are conventionally calculated for the rectum and bladder according to ICRU Report 38 recommendations [5]. These point doses do not always represent the dose received by the entire volume of the organ and as a result, the doses to the OAR volumes are often not accurately known [6, 7]. Hence, there is no significant correlation between the point doses and incidence of toxicities in an organ such as the bladder [8–11]. Furthermore, the inability to visualize the extent of the tumour in 3-D resulted in suboptimal planning of application technique with inadequate dose coverage for large tumours. As a consequence, local control for bulky tumours was compromised [12].

Since 1990, significant technological advances have resulted in the use of imaging modalities for 3-D data acquisition, the introduction of contouring tools for both target and OAR volumes, newer planning algorithms and volume optimized treatment planning for both external beam and brachytherapy applications, along with new applicator and afterloader designs for brachytherapy.

Various 3-D imaging modalities such as ultrasound, CT, MR and positron emission tomography (PET) have been explored. Among all the imaging modalities, CT is the most commonly used, since it is often available in facilities performing 3-D conformal EBRT [13–16].

Volumetric image based 3-D brachytherapy is mainly practised in only a few institutions. However, compared with the robust outcome data from Level 1 and 2 techniques, it is still evolving. The Groupe Européen de Curiothérapie–European Society for Radiotherapy and Oncology (GEC–ESTRO) have published recommendations for the practice and reporting of volumetric image based 3-D brachytherapy in cervical cancer, which provides a unified approach to users [17, 18]. A target concept based on MR imaging was introduced and definitions of GTV, high risk CTV (HR-CTV) and intermediate risk CTV (IR-CTV) were given. The group also

recommends starting with the standard method of dose prescription as described in ICRU Report 38 [5], either using point A or the 60 Gy reference volume, and then adjusting the loading pattern and dwell times to ensure target coverage in regions of underdose. Therefore, parameters traditionally used in 2-D practice are still considered useful for the transition to 3-D practice.

There are no randomized phase III studies comparing 2-D to 3-D brachytherapy in terms of patient outcome. However, one of the largest series published so far is from Pötter et al. [19], who report on the clinical outcome of 156 cervical cancer patients treated with image guided adaptive brachytherapy combined with 3-D conformal EBRT with or without chemotherapy. The 3-D results are promising, with excellent local control rates of 95–100% at three years in patients with tumours less than 5 cm and 85–90% in patients with large tumours (>5 cm) with an acceptable treatment related morbidity rate. Compared with their historical 2-D series, there is a relative reduction in pelvic recurrence by 65–70% and a reduction in major morbidity. Other single institution outcome data endorse these findings [20–25]. This is being tested further in an ongoing multicentre study involving several institutions in Asia, Europe and the United States of America [26].

The potential of ultrasound as an alternate imaging modality for guidance of intracavitary brachytherapy in cervical cancer has also been explored [27–29]. The advantages of the universal availability of ultrasound, its cost effectiveness, advances in 3-D and real time ultrasound imaging, and the small learning curve make it an area for clinical research with the potential to increase the accessibility of volumetric based brachytherapy. Similarly, CT has also been compared with MR in a few small dosimetric studies, but findings need to be validated in larger clinical studies [30–32].

Together with these achievements in gynaecological brachytherapy, several other brachytherapy interstitial procedures are performed nowadays with image guidance and 3-D planning, such as breast or head and neck implants. These procedures require a more complex infrastructure because of the need for anaesthesia and, in many cases, cooperation with surgeons. Basic 2-D principles are usually followed but are technically improved with a better target and normal tissue anatomy definition by the images [33–38].

The potential benefit of implementing 3-D HDR brachytherapy should be balanced with the higher cost and more time consuming nature of the imaging and the 3-D treatment planning process (around four hours is required to treat each fraction for a typical patient with cervical cancer). The required imaging examinations are more expensive, and treatment with 3-D brachytherapy may further burden an already busy radiotherapy department. Access to imaging equipment and other resource constraints in the radiotherapy department need to be considered.

However, the cost of replacing 2-D with 3-D techniques may be counterbalanced by an improvement in treatment outcome [19], resulting in lower overall costs of care.

4. MILESTONES FOR 3-D HDR BRACHYTHERAPY

A Level 3 HDR brachytherapy programme should be built on a firm foundation of expertise in a Level 2 planar image based 2-D brachytherapy programme, and should not be embarked on until certain basic milestones have been met. The questionnaire in Appendix I provides a checklist of the steps in the process. The following is a summary of the milestones in setting up a 3-D HDR brachytherapy programme.

Milestones that need to be achieved before resources are committed to the establishment of volumetric image based 3-D HDR brachytherapy include:

- (a) Facilities are in place for the provision of Level 2 planar image based brachytherapy;
- (b) Facilities are in place for the provision of EBRT, preferably three dimensional conformal radiotherapy (3-D CRT);
- (c) Adequate diagnostic imaging facilities are in place for diagnosis and staging;
- (d) Adequate additional access is available to CT, ultrasound or MR imaging facilities for brachytherapy treatment planning;
- (e) Demonstration by audit that there is compliance with the Level 2 brachytherapy methodologies and tools given in Table 1, in Section 2.

Milestones during the transition process include:

- (a) Appointment of sufficient numbers of staff so that the existing radiotherapy programme will not be compromised;
- (b) Education, including practical training, of the staff that will be responsible for the programme;
- (c) Specification and purchase of all necessary additional equipment and licences;
- (d) Applications training of the staff;
- (e) Commissioning and validation of the 3-D brachytherapy equipment and software;
- (f) Validation of each step in the transition from Level 2 to 3 using a parallel process, as outlined in Section 10.5;
- (g) Extension of the institution's comprehensive quality assurance programme to cover 3-D brachytherapy;
- (h) Establishment of institutional clinical, imaging, dosimetry and treatment guidelines along with quality control procedures and auditing policies for 3-D brachytherapy.

5. RESOURCES TO ESTABLISH 3-D HDR BRACHYTHERAPY

Establishing a 3-D brachytherapy programme requires considerable planning. There are significant differences between Levels 1 and 2 brachytherapy compared with Level 3 brachytherapy in terms of equipment, imaging, treatment planning and dose recording (see Table 1, in Section 2). The logistical steps necessary to establish a 3-D brachytherapy programme at an institution are:

- (a) To define the scope of the programme;
- (b) To identify the necessary space and equipment;
- (c) To define the possible impact on patient throughput;
- (d) To develop a programme budget, prepare space and purchase equipment;
- (e) To develop staffing needs for the programme and hire new staff;
- (f) To allow a reasonable timeline to perform acceptance testing and commissioning;
- (g) To train all personnel to be involved with the programme;
- (h) To develop the necessary guidelines, policies and procedures;
- (i) To develop and implement a comprehensive quality assurance programme for 3-D brachytherapy.

It is important to allow sufficient time for training prior to the arrival of the equipment so that trained medical physicists are in place to carry out the acceptance testing and commissioning. The resources required to establish such a programme are outlined in this section.

5.1. EQUIPMENT

5.1.1. Imaging

Ideally, each institution will have access to a CT scanner. Other imaging modalities that are useful in the delineation of target volume are magnetic resonance imaging (MRI), ultrasound and various functional imaging modalities such as PET, single photon emission computer tomography, functional MRI, MR spectroscopic imaging and molecular imaging. The rationale for using 3-D image information is to define accurately the target volumes to be irradiated and the OAR volumes to be spared. Unlike 3-D CRT, treatment planning is not traditionally dependent on relative electron density information for dose calculation [39].

5.1.2. Applicators

Use of MR compatible applicators and fixation devices (non-ferromagnetic) is essential to ensure safety in magnetic fields when performing MRI. CT/MR compatible applicators are desirable in order to minimize imaging artefacts for CT based planning. Thought should be given to the number of applicator sets required to expedite the workflow so that the choice of applicators available for placement in patients being prepared for treatment is not dependent on the patient being treated. Proper sterilization of the applicators is also essential to avoid damage to the applicators and delay in their return for future patient use.

In addition, for adequate target coverage and maintenance of normal tissue sparing, the need for different types of applicators should be considered (e.g. combined interstitial–intracavitary applicators). Transfer tubes are necessary for each procedure type, and some are coded to ensure attachment of each applicator component to a specific channel number, therefore extra sets may be needed. X ray catheters are necessary for the commissioning process and MR line markers can be useful to visualize the source path in MR.

5.1.3. Treatment planning system

TPS software to support volumetric image based 3-D brachytherapy using the methodologies shown in Table 1, in Section 2, should be available. The TPS will include features pertaining to data acquisition, dose calculation and information display, as well as capabilities for image and plan transfer via a network. Guidance on the particular aspects of brachytherapy treatment planning is provided in Section 6 (see Ref. [40] for more details).

5.1.4. Afterloader

The number of channels required depends on the type of applicators used and the anticipated workload using multichannel techniques.

5.1.5. Networking

Connectivity of the TPS to the imaging devices using the digital communication standard — Digital Imaging and Communications in Medicine (DICOM) — is essential. Therefore, hardware and software licences are required at both ports. The speed and availability of the data should ensure that the brachytherapy workflow is not compromised, especially considering that the planning and treatment procedure usually occurs over less than half a working day. Connectivity of the afterloader and brachytherapy TPS to the record and verify system used to support electronic records in EBRT is desirable for completeness.

5.2. STAFFING AND TRAINING

There is a significant risk of patients receiving suboptimal treatment if members of the treatment team lack the necessary training in the 3-D brachytherapy process. Thus, it is essential that the treatment team is well trained in cross-sectional imaging and its application to the 3-D brachytherapy treatment planning process. In addition, the team needs to have a good understanding of the uncertainties and limitations involved in these techniques. The buildings, equipment and staffing to provide a basic radiotherapy service are described in Table 2. This service can treat around 200 patients per year with brachytherapy (typically 600–800 procedures for a high gynaecological cancer workload) and assumes that a Level 2 practice is in place. The underlying assumption is that at least one full-time equivalent radiation oncologist, medical physicist and oncology nurse are dedicated to running the brachytherapy service. This is the recommended baseline from which additional resources can be anticipated when making the transition to a Level 3 practice (see Section 9).

TABLE 2. ESSENTIAL EQUIPMENT AND STAFFING FOR A BASIC RADIOTHERAPY CLINIC

Buildings	<p>A megavoltage bunker (space for one more is desirable) An X ray bunker for an orthovoltage unit A simulator room A darkroom (for film processing) A dosimetry planning/physicist room (and for equipment storage if necessary) An HDR bunker (or LDR room)^a A mould room Ample clinical space (for examination, consulting, changing and waiting rooms)</p>
External beam therapy equipment	<p>A single photon energy teletherapy unit An orthovoltage unit Beam measurement and QA + RP^b physics equipment A simulator, preferably a CT simulator (otherwise access to a CT is desirable) A computerized TPS Film processing equipment Patient immobilization devices and mould room equipment</p>
Brachytherapy HDR or LDR equipment ^a	<p>A brachytherapy afterloader^a (two or more if LDR) An X ray C-arm A computerized TPS (if LDR, it can be integrated into the external beam TPS) A full range of applicators Quality assurance physics equipment</p>
Personnel	<p>Four or five radiation oncologists^c Three or four medical physics staff^d Seven RTTs Three oncology nurses^c One maintenance technician/engineer</p>

Note: CT — computed tomography; HDR — high dose rate; LDR — low dose rate; TPS — treatment planning system.

Source: Table 1 of Ref. [2].

^a HDR versus LDR. An LDR brachytherapy unit can treat only approximately 100 patients per year. Sites with a larger number of cervical cancer cases require HDR brachytherapy.

^b QA + RP: quality assurance and radiation protection.

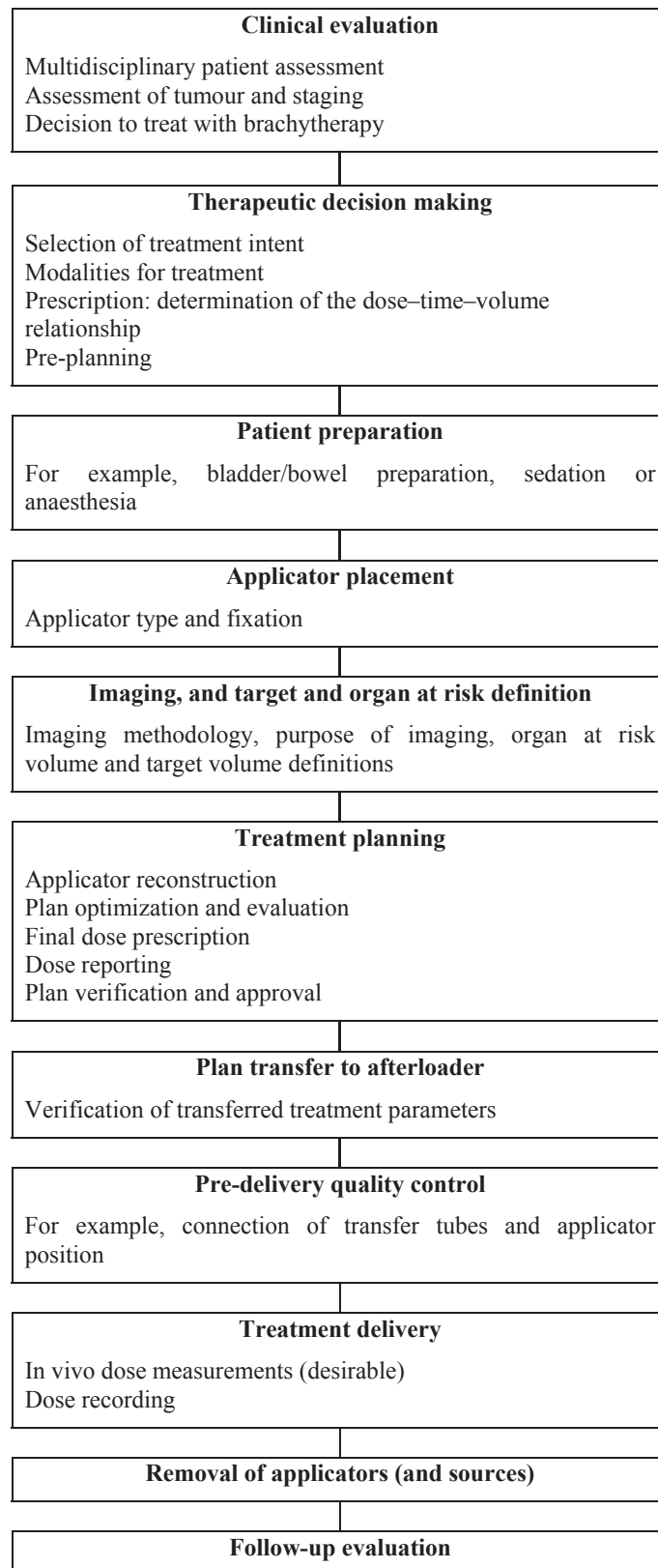
^c An increase of 50% is required if staff are also responsible for chemotherapy. In that case, a chemotherapy suite needs to be available.

^d This requires at least one but preferably two senior clinically qualified radiotherapy medical physicists. Other physics staff required need to be clinically qualified radiotherapy medical physicists, resident physicists or dosimetrists.

6. CLINICAL PROCESSES OF 3-D HDR BRACHYTHERAPY

6.1. CLINICAL PROCESS

The entire clinical process in 3-D brachytherapy is outlined in Fig. 1 and involves ten steps from clinical evaluation to follow-up that are covered in the following subsections.



Note: The professionals involved in each step of the process are likely to be the same as for Level 2 brachytherapy. The overall clinical responsibility, however, lies with the radiation oncologist, whereas the medical physicist is responsible for the physical, technical and dosimetric aspects.

FIG. 1. A typical 3-D brachytherapy process.

6.2. CLINICAL EVALUATION

A multidisciplinary patient assessment is desirable for each treatment. Assessment of the tumour anatomy and proper staging by physical examination, pathology and imaging are required for the decision to treat with 3-D brachytherapy. Since HDR brachytherapy is fractionated and often given in conjunction with EBRT, an assessment of tumour anatomy and response at each application is also required.

6.3. THERAPEUTIC DECISION MAKING

Treatment intent is based mainly on staging and tumour volume which guide the decision making: curative or palliative. The treatment technique with reference to the different types of applicators and accessories is made according to the institution's clinical policies and equipment availability. A planning aim is also defined at this point, including the intended dose prescription to be delivered and the dose constraints for the OAR volumes. Dose–time and dose–volume relationships are also considered, such as the interval between fractions, the possibility of tumour shrinkage during the intervals and patients' tolerance to treatment. Combination treatment with external beam irradiation has also to be considered (timing and dose).

When making the transition to 3-D HDR brachytherapy, the dose prescription for each tumour site has to be modified in order to maintain radiobiological equivalence to low dose rate (LDR) schedules. Therefore, the physical dose per fraction for HDR has to be re-calculated using radiobiological models [41]. Alternatively, the HDR dose schedule could be based on existing clinical evidence.

6.4. PATIENT PREPARATION

Patients should be made aware of the nature and objectives of the 3-D treatment. There are no significant differences in patient preparation between 2-D and 3-D techniques, unless the imaging method or different applicators require it. Sedation or anaesthesia should be considered for patient comfort. In case of interstitial procedures, adequate anaesthesia should be provided.

6.5. APPLICATOR PLACEMENT

Applicator placement is based on 2-D guidelines and in accordance with the institution's current practice. In order to achieve an accurate placement of the applicators, image guidance is useful (e.g. ultrasound guidance for positioning of an intrauterine tandem).

6.6. IMAGING: TARGET AND ORGANS AT RISK VOLUME DEFINITION

Three dimensional brachytherapy implicitly requires the use of cross-sectional imaging modalities. The use of CT, MR or ultrasound is primarily used to define CTV and OAR volumes, together with the applicator geometry. Inhomogeneity corrections are not applied in the American Association of Physicists in Medicine (AAPM) Task Group 43 dose calculation formalism [42]. Therefore, the preferred imaging modality should ideally be based on obtaining the best image contrast for target visualization and applicator reconstruction.

6.6.1. Imaging methodology

Institutional imaging procedures should be developed based on the slice thicknesses (typically 2–5 mm) for each modality, considering the requirements for resolution, the accuracy of the dose–volume calculation and the intrinsic geometric error of half the slice thickness [43]. Consideration should also be given to the patient preparation (e.g. bladder and bowel filling) and the image orientation relative to the applicator or implant so that the most accurate applicator reconstruction can be obtained. Local policies and procedures should be developed

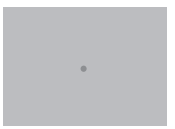




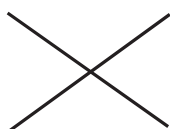
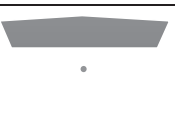


to ensure image scan parameters are optimized for image quality in enabling identification of the tumour/target volumes and OAR.

Other important factors to consider may include:

- (a) How to manage when there is only access to CT [44].
- (b) Working without CT/MR compatible applicators.
- (c) Contraindications in the use of contrast.
- (d) Material properties of all accessories with regard to their compatibility with the imaging technique used (see Fig. 2).
- (e) Comparisons between imaging modalities: For practical reasons, the image modality used for diagnosis, brachytherapy treatment planning and interfraction verification before dose delivery may differ (e.g. MRI for diagnosis, CT for planning and radiographs for applicator positioning verification) [45].
- (f) MR distortion and artefacts can influence the depiction of both the applicator and tumour/organ geometry and their appearance (see Figs 3 and 4) [46, 47].

6.6.2. Organs at risk and target volume definition

The same concepts used in EBRT should be applied with regard to volume definitions and dose–volume constraints. Three dimensional HDR brachytherapy treatment is planned on an image based simulation approach for accurately delineating tumour and OAR volumes for an individual patient. These volumes are drawn on a slice by slice basis on a CT, MR or ultrasound dataset. Tumour and OAR volumes are contoured manually, although modern TPSs can segment various structures automatically. It is incumbent upon the radiation oncologist to ensure that target volumes drawn are accurate. This places a premium demand on the radiation oncologist to specify targets with greater precision and on the medical physicist to develop procedures for accurate imaging, applicator reconstruction and treatment delivery verification. The following provides guidelines for delineation of target volumes and OAR volumes.

Material		Plastic	Titanium	Steel
Characteristic		Flexible	Rigid	Rigid
Image modality	CT			
	MRI			
	US			

Note: Significant artefacts may appear for steel and titanium in all modalities. Steel must not be imaged with MR. CT — computed tomography; MRI — magnetic resonance imaging; US — ultrasound.

FIG. 2. Illustration of the suitability of various materials in 3-D imaging for brachytherapy.

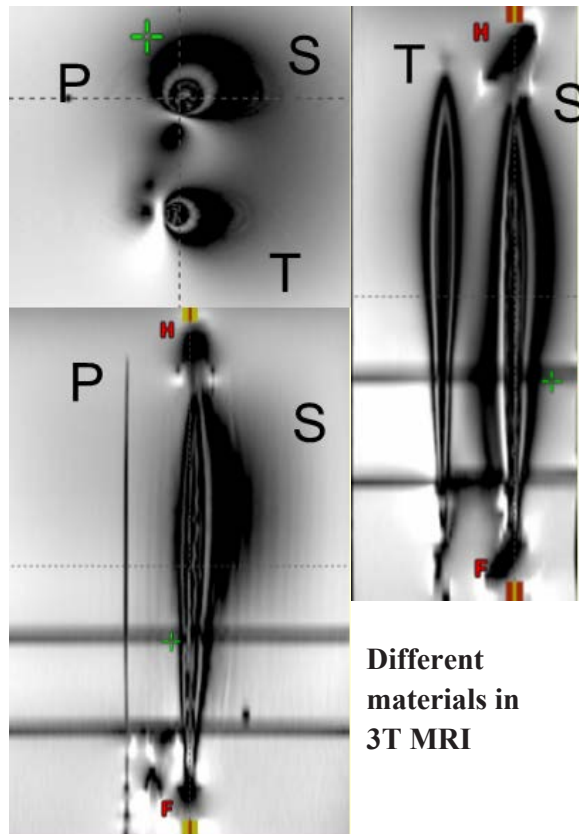
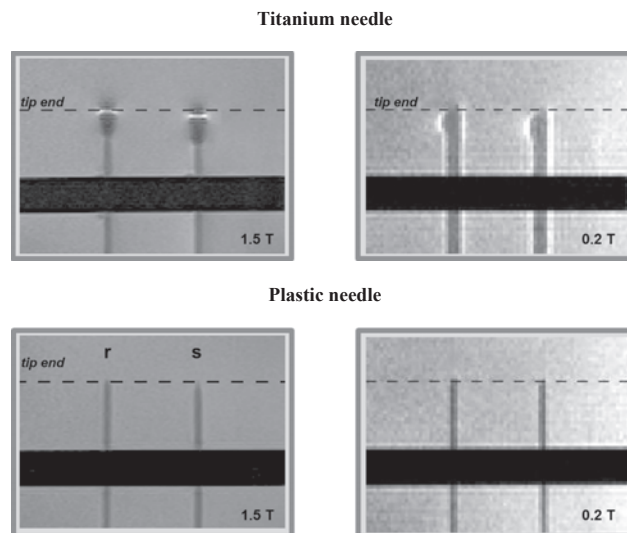


FIG. 3. Example of artefacts in high field (3 T) MR images of plastic (P), steel (S) and titanium (T) applicators (courtesy of K. Tanderup, Aarhus University Hospital, Denmark).



Note: The dotted line indicates the real needle tip end for both the rounded tip end (r) and sharp tip end (s). For titanium needles, the artefacts appearing in the upper images are dependent on the field strength and the MRI scanner type, whereas the plastic needles do not show these artefacts.

FIG. 4. Example of a quality check for needles scanned using low (0.2 T) and standard (1.5 T) field strength MRI scanners (courtesy of S. Menhart, Medical University of Vienna).

Volume definition is a prerequisite for meaningful 3-D brachytherapy treatment planning and for accurate dose reporting. ICRU Report 38 [5] describes the process for point based 2-D gynaecological brachytherapy. An update of the publication will present new guidelines for 3-D brachytherapy (ICRU Report 88 is in preparation). Dose–volume parameters for the practice and reporting with 3-D MR imaging for cervical cancer brachytherapy have been defined in the GEC–ESTRO recommendations [17, 18] and have been widely accepted so that a unified approach is formed among practitioners. Those recommendations are for the delineation of GTV, defined as “macroscopic tumour extension at time of BT [brachytherapy] as detected by clinical examination and as visualised on MRI” [18]; high risk CTV (HR-CTV) with “major risk of local recurrence because of residual macroscopic disease” [18] and intermediate risk CTV (IR-CTV) with:

“[M]ajor risk of local recurrence in areas that correspond to initial macroscopic extent of disease with at most residual microscopic disease at time of BT. ... The delineation process is based on clinical examination at diagnosis and at BT and on a set of sectional images (preferably MR T2 weighted) taken at diagnosis and at BT with applicator in place” [18].

HR-CTV includes GTV (if present), the whole cervix and the presumed extracervical tumour extension at time of brachytherapy.

Very few specific definitions have been developed for target volume delineation in 3-D brachytherapy for other disease sites (e.g. breast and prostate). Thus, it is reasonable to use the same concepts described by the ICRU [4, 48] for external beam irradiation when contouring for brachytherapy:

“Gross tumour volume (GTV): the gross palpable or visible/demonstrable extent of location of malignant growth.” [4]

GTV is usually based on information obtained from physical examination by the oncologist and the results from imaging modalities (such as CT, MR and PET) and other diagnostic modalities (such as pathologic and histopathologic reports).

“The clinical target volume (CTV) is the tissue volume that contains a demonstrable GTV and/or sub-clinical microscopic malignant disease, which has to be eliminated. This volume thus has to be treated adequately in order to achieve the aim of therapy, cure or palliation.” [4]

In order to define CTV, a margin has to be created for subclinical microscopic spread and other areas considered at risk and requiring treatment. Data for this are derived from histopathological specimens removed at operation or studies of local failure patterns for individual tumours. All structures with well defined anatomical limits within the CTV (e.g. muscle fascia and bones) should be excluded.

For 3-D brachytherapy, however, the internal target volume and planning target volume are not defined, since organ or tumour motion and set-up errors are not expected relative to the source and applicator.

Organs at risk are usually contoured as a whole structure (like bladder, sigmoid colon and rectum in cervix cancer) rather than organ wall because when volumes smaller than 5 cm³ are considered, the DVHs computed from external organ contours for the bladder and rectum can be used instead of DVHs computed for the organ walls only [49].

6.7. TREATMENT PLANNING

6.7.1. Applicator reconstruction

Applicator reconstruction is required to define the source pathway in three dimensions for each channel and to determine the tip-end of each channel in order to establish the most distal source position. This is usually performed using multiplanar reconstructions of the imaging data. Direct reconstruction of the source pathway — with X ray dummy source marker wires, as used in Level 2 — is not as simple to apply in 3-D. Even though CT X ray dummy markers and MR line sources can provide a similar approach, there are additional considerations

(e.g. image artefacts and partial volume effects). Owing to the finite slice thickness of cross-sectional images, accurate localization of the distal end of each needle in an interstitial implant with multiple channels may need to be confirmed, using a radiographic image for instance, especially if the needles are not all exactly aligned within a single image plane.

Indirect visualization of the source pathway is often used since sometimes only the outer dimensions of the applicator channel can be resolved, and then additional information is required to identify the actual source pathway. The distance from the physical end of the applicator to the first source position needs to be established during the commissioning process (see Section 10.2).

6.7.2. Plan optimization and evaluation

The experience gained during Level 2 practice should be implemented when making the transition to 3-D techniques. For instance, failure to include HR-CTV and IR-CTV in the optimization process for gynaecological cancer may result in a non-pear-shaped distribution when relying only on the graphical or inverse planning solution [50]. On the other hand, the benefit of volumetric optimization in single channel applications (e.g. endoluminal and vaginal) is limited.

In general, optimization is based on dose constraints assigned to the target and OAR volumes or a set of points in pre-defined volumes (location and depth known from clinical assessment). In Level 2, the points are generally applicator based, or related to bony landmarks, fiducial markers or surrogates, and the available plan evaluation tools are based on the isodose distributions and the dose constraints. In 3-D, dose–volume histograms are additional evaluation tools. Furthermore, the isodoses are superimposed on the radiographic anatomy to better locate and assess the risk–benefit of any hot and cold spots.

6.7.3. Dose prescription and reporting

The dose–time–volume relationship anticipated from the therapeutic decision making process may be modified once the individualized treatment plan is evaluated.

Dose reporting should be performed according to GEC–ESTRO [17, 18] recommendations and ICRU reports [5, 51]. At the time of publication, there are ongoing discussions in an attempt to achieve international consensus in dose reporting for 3-D brachytherapy.

6.7.4. Plan verification and approval

A local checklist should be developed to ensure that the plan is consistent with the prescription and that all data used to generate the treatment plan are valid. The radiation oncologist is responsible for final approval of the treatment plan. Table 4, in Appendix III, provides an example checklist for treatment plan verification.

6.8. PLAN TRANSFER TO AFTERLOADER

Once the treatment plan has been approved by the radiation oncologist, the details need to be transferred from the TPS to the treatment unit. If possible, a direct link between the TPS and the control panel of the treatment unit should exist so that the data transfer is carried out electronically.

6.9. PRE-DELIVERY QUALITY CONTROL

A pre-delivery quality control checklist should include [52]:

- Radiation safety features check;
- Patient identification;
- Transfer tube inspection;
- Patient set-up check;

- Applicator positioning inspection;
- Treatment documentation review (e.g. prescription, fractionation and signatures);
- Treatment parameters in agreement with plan.

The reason for using 3-D brachytherapy is usually to reduce the volume of normal tissue included within the treated volume compared with Levels 1 and 2. It is therefore an essential requirement that careful attention is given to delivery verification. It is important for the staff to be fully aware of issues relating to uncertainties (see Section 7). The primary aim of pre-delivery quality control is to reduce the uncertainties by ensuring that the patient anatomy is the same as it was during imaging (e.g. bladder filling guidelines).

6.10. TREATMENT DELIVERY

Because the complexity of the treatment in 3-D is greater, there is potentially an increased possibility of error. In addition, the prescribed dose is likely to be closer to tolerance, and therefore the effect of a dose error will be greater. Hence, some form of independent dose check or in vivo dosimetry should be conducted during treatment. A recent review of in vivo dosimetry in brachytherapy concludes that detection of gross errors in brachytherapy treatment delivery is possible with in vivo dosimetry [53]. However, the review emphasises that further developments are required to refine detector technology for the level of accuracy to be comparable to that achieved in EBRT in vivo dosimetry.

6.11. REMOVAL OF APPLICATORS AND SOURCES

The removal of applicators and sources is no different from 2-D brachytherapy. The institution's normal practice should be followed.

6.12. FOLLOW-UP EVALUATION

Three dimensional brachytherapy is expected to produce the same, or fewer, side effects than high quality Level 2 treatment. The standard institutional policy should be followed in terms of assessing morbidity, disease control and quality of life. As with any transition process, additional clinical monitoring of patients is advisable to detect patterns of untoward effects.

7. UNCERTAINTIES IN BRACHYTHERAPY

It is beyond the scope of this publication to provide a detailed description of all uncertainties in the brachytherapy process. The IAEA publication Accuracy Requirements and Uncertainties in Radiation Therapy is dedicated to this broad topic in radiotherapy, and brachytherapy uncertainties are quantified in that publication.¹ An AAPM report [54] considers uncertainties in brachytherapy excluding uncertainties during treatment delivery. A combined dosimetric uncertainty less than 5% ($k = 1$) is estimated with the proviso that international consensus brachytherapy dosimetry data are used. A few pertinent points in making the transition to 3-D brachytherapy are:

- (a) The transition from 2-D HDR to 3-D HDR brachytherapy in principle does not change dosimetric uncertainties related to source calibration, TPS algorithms and treatment delivery.

¹ INTERNATIONAL ATOMIC ENERGY AGENCY, Accuracy Requirements and Uncertainties in Radiation Therapy, Human Health Series No. 31, IAEA, Vienna (in preparation).

- (b) There will be an additional uncertainty associated with the use of different imaging modalities and applicator reconstruction from 3-D datasets. These uncertainties will need to be characterized during the commissioning process (see Sections 10.1 and 10.2).
- (c) Three dimensional brachytherapy also introduces uncertainties related to target and OAR volume definition from 3-D patient datasets. Interclinician and intraclinician variations in target volumes have recently been reported in gynaecological brachytherapy [55, 56].

8. EDUCATION AND TRAINING REQUIREMENTS

There are significant differences between competencies to perform 2-D and 3-D brachytherapy imaging and treatment planning. Making a transition from one to the other is a substantial undertaking. Experience gained by carrying out Levels 1 and 2 brachytherapy is essential. However, additional skill sets are necessary to make the transition to Level 3. Sections 6 and 10 give a description of how to implement Level 3 at an institution. It is imperative that each member of the team involved in the planning and delivery of brachytherapy understands his or her role well so that safe and effective use of this technique can be assured. The Level 3 training programme needs to include detailed exposure to each of the steps outlined in Section 6. Appendix I details the competencies required to support a Level 3 brachytherapy programme. The reader is also referred to section 6.1 of Ref. [3] for guidance on the personnel requirements and the training required to establish a HDR brachytherapy programme.

9. STAFFING REQUIREMENTS

Additional human resources are required to provide a 3-D HDR brachytherapy service, owing to the additional complexity in imaging and treatment planning. The IAEA has developed a tool to estimate staffing levels in radiotherapy practice which will soon be published. If 200 patients per year are to be treated with 3-D brachytherapy, then the number of radiation oncologists dedicated to brachytherapy needs to increase by 0.8 full-time equivalent (FTE) compared with a 2-D service managing the same number of patients. Similarly, the number of medical physicists needs to increase by 0.5 FTE and radiation oncology nurses by 0.3 FTE.

10. COMMISSIONING, QUALITY ASSURANCE AND AUDITING IN VOLUMETRIC IMAGE BASED 3-D BRACHYTHERAPY

For the safe practice of Level 3 brachytherapy, it is essential that there is a quality assurance programme covering the whole process from clinical evaluation through to follow-up. This needs to include all staff and activities involved in the process. Members of the team need to be aware of the impact of their contribution. For example, in Section 6.12, the importance of monitoring the clinical outcome as part of the overall quality assurance process is emphasized.

The subject of quality assurance programmes in radiotherapy is covered in detail in Ref. [2]. There are additional quality control procedures that need to be performed for each step of the 3-D brachytherapy process, particularly for imaging, applicators and the TPS, and these are discussed in this section.

10.1. IMAGING EQUIPMENT

Movement of the CT couch needs to be assessed regularly, particularly if helical scanning is used, in order to verify the accuracy of slice reconstruction and couch movement accuracy. Details on the quality assurance of CT scanners can be found in Refs [57, 58].

When using MR imaging for treatment planning, particular consideration needs to be given to the issue of image distortion. Issues related to the use of MR imaging in radiotherapy are considered in Ref. [57].

Quality control of ultrasound systems has been considered by AAPM Task Group 1 [59] and AAPM Task Group 128 [60].

10.2. APPLICATORS

Commissioning and quality control guidelines for applicators have been published elsewhere [2, 61, 62]. Of particular importance during applicator commissioning is to confirm the distance from the physical end of the applicator to the first source position according to the relevant engineering drawings (see Fig. 5). This can be done using autoradiography. Regular visual inspection of the applicators, including obturators and screws, among other things, should be conducted as well as checks that each channel is free from obstruction before insertion and after each removal.

A quality control method to check applicator reconstruction is illustrated in Fig. 6. The reconstruction of the source pathway for the applicator has to be verified based on representative dwell positions. These representative dwell positions (see the loading pattern in (b) of Fig. 6) have to be determined and verified during the applicator and TPS commissioning process using autoradiography (see Fig. 7). On the autoradiographs, the locations of the ‘irradiated’ spots on the film have to be identical to the locations (dwell positions) along the ‘virtual’ source pathway defined in the TPS. The source pathway is taken from either a built-in applicator library, a standard plan or an independent phantom using direct reconstruction methods (see also Ref. [63]). When applying this method on a per application basis, errors in the reconstruction can be detected by visual inspection of the reconstructed source path in the TPS.

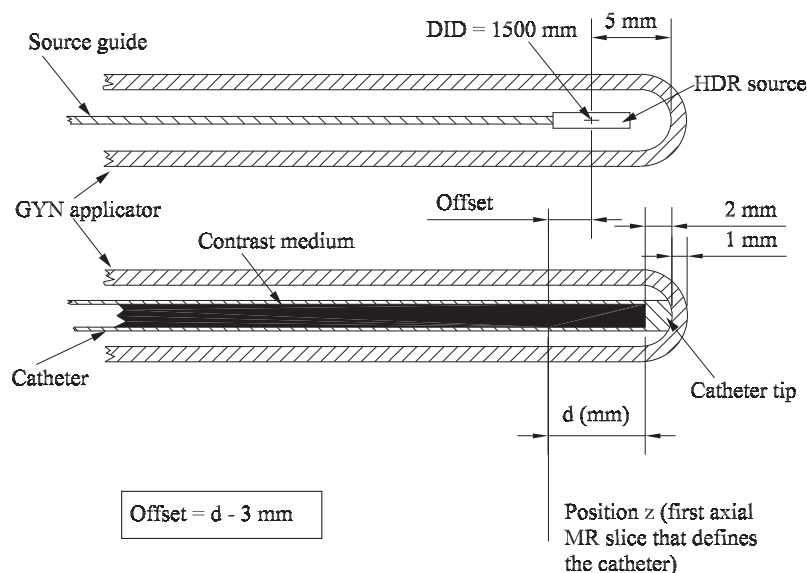


FIG. 5. Schematic diagram of a typical catheter design showing distances relative to the catheter tip (reproduced from Ref. [64] with permission courtesy of Elsevier).

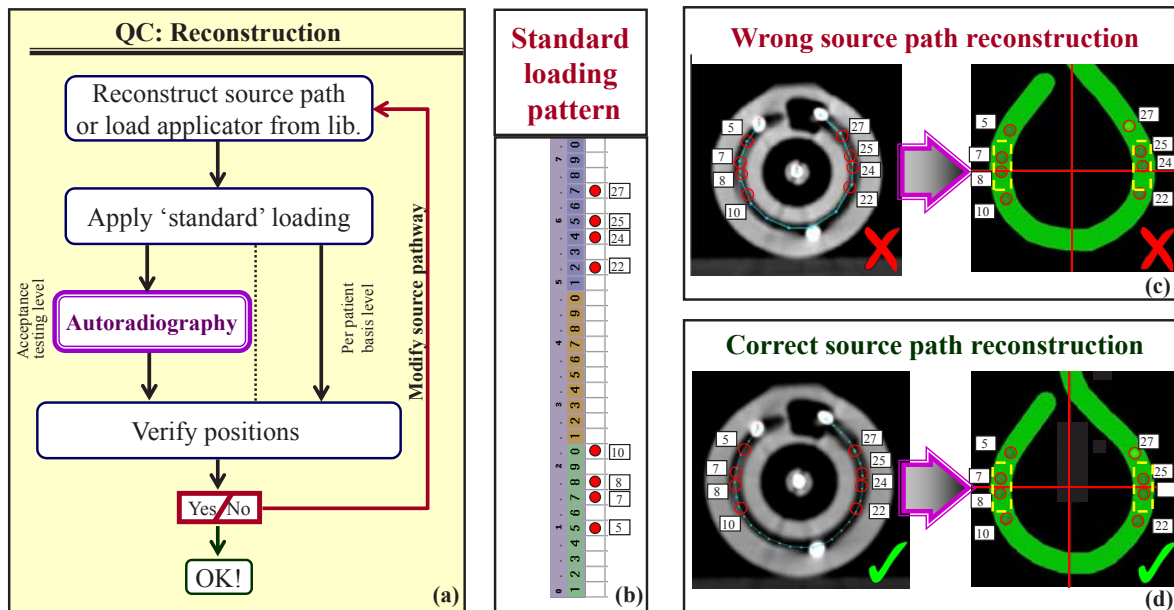
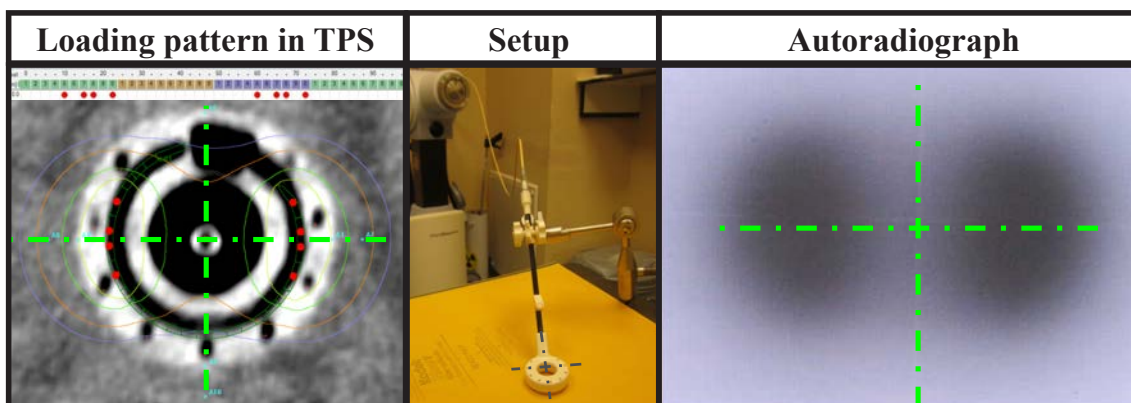


FIG. 6. Illustration of a quality control procedure for applicator reconstruction with (a) the quality control procedure, (b) the standard loading pattern, and illustrations of (c) an incorrect reconstruction resulting in an asymmetric appearance of dwell positions and (d) a correct reconstruction.



Note: This procedure is used to determine a particular loading pattern which will result in a symmetric dose distribution on the film and also to determine the correct source pathway used for reconstruction.

FIG. 7. Illustration of an autoradiograph procedure for applicator commissioning.

10.3. RADIATION TREATMENT PLANNING SYSTEM

The TPS needs to have a number of features particular to brachytherapy. These can be divided into geometric and dose computational features. A list of the general requirements for a TPS is given in Ref. [2], but Ref. [40] should be consulted for a full discussion of TPS commissioning and quality assurance. In the following two subsections, the particular features relevant to brachytherapy are discussed (see sections 9.5 and 9.6 of Ref. [40]).

10.3.1. Geometric features

The TPS needs to be able to handle a large volume dataset, which may include as many as 120 image slices. A narrow slice spacing (approximately 3 mm, range 2–5 mm) is necessary to produce satisfactory applicator and volume reconstructions. Systems for 3-D visualization of anatomy, outlined structures and dose overlay are essential, as well as multiplanar reconstruction of image datasets. Co-registration of images, based on the

brachytherapy applicator or DICOM coordinates, from the same imaging modality (e.g. axial, sagittal and coronal MRI images) or different imaging modalities (e.g. CT and MR) is a useful feature.

Section 9.5.4 of Ref. [40] includes four geometric reconstruction tests for a brachytherapy TPS. Test 1 is concerned with the quality of source reconstruction, whereas tests 2 and 3 relate to source identification. Test 4 is concerned with confirming that the software differentiates between the total source length and active source length.

10.3.2. Dose computation models

The dose calculation tests described in section 9.5.3 of Ref. [40] provide a sound basis for the commissioning and quality control testing of a brachytherapy TPS algorithm. Of particular importance is checking the TPS dosimetric data for each source against the international reference data, for example in AAPM Task Group 43 [42] or the AAPM High Energy Brachytherapy Dosimetry report [65]. Dose display and DVH testing are covered in section 9.6 of Ref. [40].

10.4. AFTERLOADER UNITS

In the transition from 2-D HDR to 3-D HDR brachytherapy, the treatment unit (afterloader) can remain the same. Continued practice of quality control of the afterloader should be conducted. This publication considers the possibility of a transition from 2-D LDR to 3-D HDR brachytherapy in which case commissioning and quality control procedures for a new afterloader will need to be devised and implemented. There are some excellent references in this area, including Refs [2, 57, 61, 66, 67].

Finally, testing the integrity of data transferred electronically to the TPS and afterloader unit is considered an essential part of commissioning and quality control, and necessary if library based standard plans were used prior to the transition to 3-D brachytherapy [40].

10.5. QUALITY ASSURANCE OF THE TRANSITION PROCESS

It is advisable to perform a step by step procedure to verify consistency of the transition process itself. An example of a five step procedure is provided in the following.

10.5.1. Step 1: Phantom studies to evaluate the site specific reconstruction techniques envisaged

A phantom of known geometry containing the applicators should be imaged using both the Level 2 (planar) and Level 3 (volumetric) modalities (see Fig. 8). The geometry of the reconstructed ‘virtual’ applicators should then be evaluated against the known dimensions [61]. Note that it is not necessary to use a commercially available phantom.

10.5.2. Step 2: Clinical parallel imaging and reconstruction

To minimize the risk of a major systematic error in the new imaging and planning workflow, the first few patients should be imaged using both techniques but treated using the Level 2 treatment plan. In this way, the process can be cross-checked and the Level 3 dose reporting methodology using DVHs can be correlated with the Level 2 experience based on the ICRU points. The endpoint of this step is to refine and develop the institutional imaging and delineation guidelines.

10.5.3. Step 3: Adoption of volumetric imaging procedures

In this step, the local imaging procedures for Level 3 are applied, but the Level 2 treatment planning and delivery are maintained.

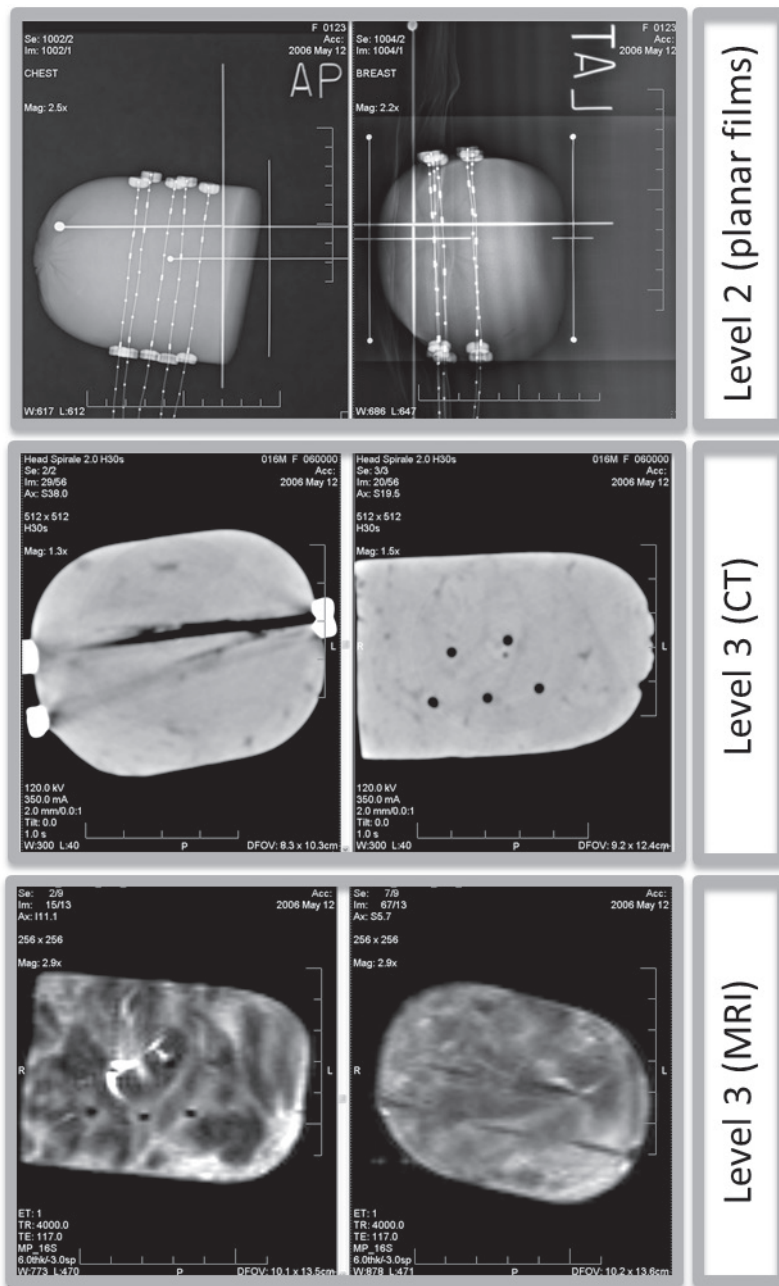


FIG. 8. Planar and volumetric images of a phantom containing applicators to evaluate reconstruction techniques.

10.5.4. Step 4: Volumetric optimization based on the organs at risk volumes

In this step, the Level 2 process is still used for dose prescribing, but a Level 3 treatment is delivered and recorded. This step provides experience in volumetric optimization and plan evaluation but avoids misinterpretation of the Level 3 prescription. Clearly, cognizance needs to be taken of the dose to the target volumes because dose constraints for the target volumes are not included in the optimization. Adjustments to the result of the purely mathematical optimization routine based on the OAR volumes alone may need to be made. The endpoint of this step is to develop competence in clinical optimization.

10.5.5. Step 5: Level 3 optimization, evaluation and prescription

In this step, optimization is based on the targets and OAR volumes. The entire Level 3 process is now used, and the competence gained in Step 4 should reassure the team that the optimal plan has been achieved for the implant.

If there is a failure to achieve the planning aim in any of the steps above, the implant itself needs to be revised or repeated.

10.6. INTERNAL AND EXTERNAL AUDITING

The need for auditing as a quality measure has long been recognized. The IAEA has developed the Quality Assurance Team for Radiation Oncology (QUATRO) methodology [68] for auditing of radiotherapy practices, along with associated detailed medical physics procedures [69]. References [68, 69] contain specific sections on brachytherapy practice auditing. An internal audit of the institution's 3-D HDR brachytherapy practice using the QUATRO methodology should be conducted.

In addition, an internal check of compliance with the self-assessment questionnaire in Appendix I and a review of the documentation of the process used to make the transition to 3-D brachytherapy (e.g. Section 10.5) would be useful internal audit measures.

Regular external on-site audits of brachytherapy practice by recognized experts should be part of the institution's quality assurance programme.

Appendix I

SELF-ASSESSMENT QUESTIONNAIRE

This questionnaire is designed to assist institutions planning to embark on a programme of 3-D HDR brachytherapy to ensure that they have met all the necessary requirements. By the time the first patient is to be treated, the answers to all the questions should be 'Yes'. Where gaps are identified, they will need to be corrected. The questionnaire begins with the resource requirements, and then examines the process of 3-D HDR brachytherapy planning and treatment to identify the issues that need to be addressed.

I.1. RESOURCES

I.1.1. Staffing

1. Have sufficient numbers of staff been employed to implement 3-D HDR brachytherapy whilst continuing the existing brachytherapy practice?
2. Do you have a radiation oncologist who is trained and experienced in the practice of Level 2 brachytherapy?
3. Does the radiation oncologist have the academic knowledge necessary for 3-D HDR brachytherapy with regard to:
 - Cross-sectional anatomy and radiological anatomy;
 - Target volumes and OAR structures;
 - Radiobiological aspects of brachytherapy and dose response data;
 - Applicator characteristics (handling, material, imaging compatibility and dosimetric effectiveness);
 - Brachytherapy source characteristics and treatment delivery system functionality;
 - Radiation safety and protection for brachytherapy (including emergency procedures) and relevant regulations?
4. Has the radiation oncologist had practical training in contouring target volumes and critical structures?
5. Is the radiation oncologist familiar with volumetric image scanning procedures?
6. Has the radiation oncologist had practical training in the operation of the TPS for contouring, image manipulation, dose visualization and plan evaluation?
7. Do you have a medical physicist who is trained and experienced in the practice of Level 2 brachytherapy?
8. Has the medical physicist the academic knowledge necessary for 3-D HDR brachytherapy with regard to:
 - Basic understanding of cross-sectional anatomy and radiological anatomy as it relates to brachytherapy planning and understanding of treatment plans;
 - Target volumes and OAR structures;
 - Basic understanding of radiobiological aspects of brachytherapy and dose response data;
 - Familiarity with applicator characteristics and reconstruction methodologies;
 - Brachytherapy source characteristics and treatment delivery system functionality;
 - Understanding of CT/MR/ultrasound characteristics, technology and imaging limitations;
 - Radiation safety and protection for brachytherapy (including emergency procedures) and relevant regulations;
 - Random and systematic errors in brachytherapy treatment;
 - In vivo dosimetry (e.g. calibration, procedures and dosimeter characteristics);
 - Quality control for brachytherapy equipment and dosimetry equipment;
 - Acceptance and commissioning of an image based 3-D brachytherapy TPS;
 - Quality control of CT/MR/ultrasound scanners, especially in relation to geometry and artefacts?

9. Has the medical physicist had practical training in the operation of the brachytherapy TPS for source and applicator modelling, contouring, image registration, treatment planning, dose optimization and plan evaluation tools?
10. Has the medical physicist had practical training in quality control for 3-D HDR brachytherapy and the related imaging devices?
11. Is there a medical physicist (or information technology expert) available with knowledge of networking and DICOM protocols?
12. If applicable, are the brachytherapy technicians trained and experienced in the additional requirements for 3-D HDR brachytherapy with regard to:
 - Basic understanding of cross-sectional anatomy and radiological anatomy as it relates to brachytherapy and understanding of brachytherapy treatment plans and their documentation;
 - CT operation for brachytherapy planning (if applicable);
 - Patient handling and transfer techniques specific to brachytherapy;
 - HDR afterloader operation and emergency procedures;
 - Daily quality control for HDR afterloaders?

I.1.2. Equipment

13. Is there an imaging scanner suitable for brachytherapy planning with adequate priority access available?
14. Are there sufficient CT/MR compatible applicator sets available?
15. Is there an image based brachytherapy TPS with sufficient spare capacity for:
 - DICOM connectivity between all imaging devices that will be used for brachytherapy treatment planning;
 - Management of 3-D image datasets;
 - 3-D reconstruction and display;
 - 3-D dose calculation and display;
 - DVH calculation and display;
 - Optimization tools?
16. Is the HDR afterloader networked to the brachytherapy TPS?
17. If applicable, is there a provision for regular source replacement?
18. Is there appropriate physics quality control equipment?
19. Is there emergency safety equipment in the brachytherapy afterloader treatment room?

I.2. PROCESS

I.2.1. Imaging

20. Has a check of the CT scanner geometric accuracy been carried out and is it within 1 mm?
21. If appropriate, has MR image distortion been tested for?

I.2.2. Applicators

22. Has commissioning been done on the applicators and their reconstruction to demonstrate geometric accuracy?
23. Are there a policy and procedures in place for regular quality control of applicators?

I.2.3. Treatment planning

24. Have the appropriate source and applicator parameters been entered into the brachytherapy TPS physics database?

25. Has the dose calculation been verified in terms of its geometric and dosimetric accuracy for verifiable geometries?
26. Have the DVH algorithms been tested?
27. Has a policy been written to cover the delineation of GTV and CTV?
28. Has a policy been written to cover the delineation of normal tissue structures including the identification of staff authorized to carry this out?
29. Is there a system in place to ensure that an independent check of the dose calculated by the TPS is carried out before each patient treatment course? For example, checking that the total reference air kerma (TRAK) is in the typical range for the specific tumour site?
30. Have all the network connections been established and have the transfer procedures for imaging and plan data been verified for accuracy, using realistic data?
31. Are appropriate treatment planning policies and procedures in place providing details of techniques and dose calculation parameters for particular sites?
32. Have dose prescription policies for all the relevant sites been produced and do they include dose volume constraints for normal tissues?
33. Is there a policy in place for the evaluation of treatment plans, including 3-D visualization of the target volumes compared with the calculated doses and DVH analysis?

I.2.4. Patient treatment

34. Is there a tested procedure for the transfer of patient data from the planning system to the HDR afterloader and have appropriate responsibilities for the data accuracy and integrity been assigned to the relevant personnel?
35. Are there a policy and procedures in place for regular quality control of the HDR afterloader?
36. Are there a policy and procedures in place for the follow-up of patients after treatment to record treatment outcome?

I.2.5. Transition

37. Have the results of the quality assurance of the transition process outlined in Section 10.5 been documented and internally reviewed?

I.2.6. Audit

38. Has an internal audit of the proposed 3-D HDR brachytherapy programme (e.g. using the QUATRO methodology [68]) been completed and documented?
39. Have institutions been identified that could undertake an external audit of the 3-D HDR brachytherapy programme?

Appendix II

INDICATIVE 3-D BRACHYTHERAPY EQUIPMENT COSTS

TABLE 3. INDICATIVE 3-D BRACHYTHERAPY EQUIPMENT COSTS (US \$, 2013)

Item	Cost
Imaging/treatment simulation	
CT	450 000
MR	700 000–2 000 000
Ultrasound	20 000–80 000
Radiography equipment	100 000
Applicators (CT/MR compatible)	
Intracavitary set	5 000–12 000
Combined intracavitary/interstitial set	5 000–24 000
Treatment delivery	
HDR afterloader	250 000
Source exchange	6 000 per exchange
Planning	
TPS workstation with 3-D brachytherapy software	100 000–200 000
DICOM interface	100 000
Dosimetry and quality control equipment	
Calibrated well type ionization chamber	3 000
Electrometer	5 000–10 000
Radiation survey equipment	3 000
Film dosimetry	1 000

Note: Other costs for consideration include: anaesthesiology, surgical and other medical equipment; maintenance (service and updates) contracts — 10% of capital equipment cost per annum; and consumables and supplies (applicators, needles, accessories, sterilization materials, drugs and medical equipment). CT — computed tomography; DICOM — Digital Imaging and Communications in Medicine; MR — magnetic resonance; TPS — treatment planning system.

Appendix III

EXAMPLE TREATMENT PLAN CHECKLIST

TABLE 4. CHECKLIST FOR INDIVIDUAL TREATMENT PLAN VERIFICATION

Check item	Yes	No
Demographic data of patient are correct (name, date of birth, unique patient ID)		
Image sequence(s) is/are correct (identity, quality, slice thickness) and imported		
In case of MRI, imported sequence order is: first 'para-transverse' (delineation) followed by para-coronal, sagittal, strict axial or transverse, any other		
Applicator reconstruction is correct	Indexer lengths	
	Off-sets (distance from applicator surface to most distal source position)	
	Chanel mapping correct (e.g. 1-right ovoid, 2-left ovoid, 3-tandem)	
Delineation of target(s) and/or OAR is/are existing and consistent with the clinical protocols		
Dose prescription follows the clinical guideline (e.g. D90, Point A, 5 mm tissue depth)		
If applicable, prescription point(s) is/are correctly placed		
Dose reporting points defined (e.g. ICRU, Points A, B, applicator surface points)		
DVH parameters are reported (e.g. Targets: D90, D98, D50, D100; OAR: $D_{0.1cc}$ D_{2cc})		
Magnitude of TRAK and reference volume is reasonable according to the tumour site		
Note planning source strength in units of $cGy \cdot m^2/h$ _____		
Patient specific comments:		

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ABBREVIATIONS

3-D CRT	three dimensional conformal radiotherapy
AAPM	American Association of Physicists in Medicine
CT	computed tomography
CTV	clinical target volume
DICOM	Digital Imaging and Communications in Medicine
DVH	dose volume histogram
EBRT	external beam radiotherapy
GEC–ESTRO	Groupe Européen de Curiethérapie–European Society for Radiotherapy and Oncology
GTV	gross tumour volume
HDR	high dose rate
HR-CTV	high risk clinical target volume
ICRU	International Commission on Radiation Units and Measurements
IR-CTV	intermediate risk clinical target volume
LDR	low dose rate
MR	magnetic resonance
MRI	magnetic resonance imaging
OAR	organs at risk
PET	positron emission tomography
QUATRO	Quality Assurance Team for Radiation Oncology
TPS	treatment planning system
TRAK	total reference air kerma

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