Quality Control in Brachytherapy

Current practice and minimum requirements

NEDERLANDSE COMMISSIE VOOR STRALINGSDOSIMETRIE

Report 13 of the Netherlands Commission on Radiation Dosimetry

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Task Group Quality Control in Brachytherapy
November 2000

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Preface

The Nederlandse Commissie voor Stralingsdosimetrie (NCS, Netherlands Commission on Radiation Dosimetry) was officially established on 3 September 1982 with the aim of promoting the appropriate use of dosimetry of ionizing radiation both for scientific research and practical applications. The NCS is chaired by a board of scientists, installed upon the suggestion of the supporting societies, including the Nederlandse Vereniging voor Radiotherapie en Oncologie (NVRO, Netherlands Society for Radiotherapy and Oncology), the Nederlandse Vereniging voor Nucleaire Geneeskunde (NVNG, Netherlands Society for Nuclear Medicine), the Nederlandse Vereniging voor Klinische Fysica (NVKF, Netherlands Society for Clinical Physics), the Nederlandse Vereniging voor Radiobiologie (NVRB, Netherlands Society for Radiobiology), the Nederlandse Vereniging voor Stralingshygiëne (NVS, Netherlands Society for Radiological Protection), the Nederlandse Vereniging van Radiologisch Laboranten (NVRL, Netherlands Society of Radiographers and Radiological Technologists), the Nederlandse Vereniging voor Radiologie (NVvR, Netherlands Society for Radiology), the Société Belge des Physiciens d'Hôpitaux, Belgische Vereniging van Ziekenhuisfysici (SBPH/BVZF, Belgian Hospital Physicists Association) and the Ministry of Health, Welfare and Sports. To pursue its aims the NCS accomplishes the following tasks: participation in dosimetry standardisation and promotion of dosimetry intercomparisons, drafting of dosimetry protocols, collection and evaluation of physical data related to dosimetry. Furthermore the commission shall maintain or establish links with national and international organisations concerned with ionizing radiation and promulgate information on new developments in the field of radiation dosimetry.

Quality Control in brachytherapy
Current practice and minimum requirements

This report was prepared by a task group of the Netherlands Commission on Radiation Dosimetry (NCS), consisting of Belgian and Dutch scientists. The Dutch part of this work was financially supported by ZorgOnderzoek Nederland (ZON).

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Summary

Brachytherapy is applied in 19 radiotherapy institutions in The Netherlands and in 20 institutions in Belgium. Each institution has its own Quality Assurance (QA) programme to ensure safe and accurate dose delivery to the patient. Because of the various guidelines employed and differences in their interpretation, a large variety of test frequencies, test methods and accuracy criteria of the Quality Control (QC) tests are applied.

To investigate the QC protocols for HDR, PDR and LDR brachytherapy, a questionnaire was sent to all radiotherapy institutions in The Netherlands and Belgium. The questions concerned test frequencies, methods, time required for the tests, and action levels of safety systems and irradiation parameters in brachytherapy. The answers to the questions showed large variations in test frequencies and test methods, and smaller variations in accuracy criteria. Furthermore, there were large variations in time spent on QC, mainly due to differences in QC resources available.

In addition to the questionnaire, the accuracy of implant reconstruction and dose delivery was determined during site visits to 33 institutions and by performing measurements with dedicated phantoms. The average reconstruction accuracy was -0.07 mm (±0.4 mm, 1 SD) for 41 localizers. The average deviation of the measured dose from the prescribed dose was +0.9% (±1.3%, 1 SD) for 21 HDR afterloading systems, +1.0% (±2.3%, 1 SD) for 12 PDR afterloaders, and +1.8% (±2.5%, 1 SD) for 15 LDR afterloaders.

The data gathered from the responses to the questionnaires were compared with existing recommendations for QA of brachytherapy. From this information, a set of minimum requirements for QC procedures of HDR, PDR and LDR brachytherapy has been formulated, suitable for the situation in The Netherlands and Belgium. The recommendations include test frequencies, action levels and test methods for safety systems and physical parameters.

The use of radionuclides has increased rapidly in the field of endovascular brachytherapy to reduce the occurrence of restenosis in patients treated for vascular stenosis. Because of this tendency, it was decided to include a number of basic recommendations for the field of endovascular brachytherapy in this report. Furthermore, QC aspects of the treatment planning specific to brachytherapy are described, such as brachytherapy sources, implant entry, dose calculation models and the data transfer.

Abbreviations

A	Annually
AAPM	American Association of Physicists in Medicine
CT	Computed Tomography
D	Daily
DVH	Dose Volume Histogram
Inc	Incidentally
IVUS	Intravascular Ultrasound
HDR	High Dose Rate
LDR	Low Dose Rate
M	Monthly (2M, once every two months, etc.)
m-LDR	Low Dose Rate remote afterloading with ^{192}Ir wires, ^{137}Cs or ^{192}Ir seeds
MRI	Magnetic Resonance Imaging
NCS	Netherlands Commission on Radiation Dosimetry
NMi	Netherlands Measurements Institute
P	Each patient
PDR	Pulsed Dose Rate
PMMA	Polymethylmethacrylate
PTA	Percutaneous Transluminal Angioplasty
PTCA	Percutaneous Transluminal Coronary Angioplasty
QA	Quality Assurance: Related to all aspects of a procedure which contribute to the quality of the results obtained (including staff training, assessment of equipment performance, organization etc.)
QC	Quality Control: Specification, assessment, optimization and maintenance of a particular aspect, such as the performance of the equipment (including comparison with existing standards and corrective actions)
QCA	Quantitative Coronary Angiography
SD	Standard Deviation
SE	Source Exchange
S-LDR	Low Dose Rate remote afterloading with ^{137}Cs pellets
TLD	Thermo Luminescence Dosimeter
TPS	Treatment Planning System
US	Ultrasound
W	Weekly

1 Introduction

1.1 Background and purpose

The Netherlands Commission on Radiation Dosimetry (NCS) published two reports on brachytherapy. In NCS Report 4 [38], recommendations for the specification of the source strength and the dosimetry of low dose rate (LDR) sources were given. NCS Report 7 [39] dealt with the calibration of iridium-192 high dose rate (HDR) sources. Up to now, no general recommendations for quality control (QC) on brachytherapy equipment exist in The Netherlands and Belgium.

The NCS recently published two reports on Quality Control of radiotherapy equipment. Report 9 [40] dealt with medical linear accelerators, and Report 11 [41] with simulators and CT scanners. Report 11 also included some basic quality control recommendations for treatment planning systems, but this topic will be dealt with in more detail in a forthcoming report of the NCS task group on Quality Assurance (QA) of treatment planning systems [42]. These reports surveyed the current quality control programmes in the radiotherapy institutions and recommended the minimum requirements on quality control to be adopted.

The main goal of the present report is to formulate, in a similar way as has been done in NCS-reports 9 and 11, minimum guidelines for QC procedures for brachytherapy in order to achieve uniformity in the different QC programmes in The Netherlands and Belgium.

To achieve this goal, four stages have been distinguished by the task group:

1. Gain insight into the current practice of QC of brachytherapy
2. Determine the accuracy of dose delivery and implant reconstruction in all institutions
3. Compare the current QC practice with existing recommendations on QC
4. Formulate a set of minimum requirements on QC suitable for the situation in The Netherlands and Belgium.

The current QC practice was investigated by distributing an extensive questionnaire to all radiotherapy institutions in both countries. The questions were related to tests on safety systems, physical irradiation parameters, radiation safety, and total time spent on QC.

Dose delivery and implant reconstruction were checked during site visits to the institutions by performing measurements with dedicated phantoms. The accuracy of the dose delivery was determined by comparing the measured dose with the prescribed dose in a dedicated solid phantom; the reconstruction accuracy was determined by measuring the average deviation between the reconstructed co-ordinates of markers in a solid polymethylmethacrylate (PMMA) phantom and the real co-ordinates of the marker points.

The minimum QC requirements, as formulated in this report, have been established after evaluating the results of the questionnaire, the on-site measurements and recommendations found in the literature.

This report contains QC recommendations on High Dose Rate (HDR), Pulsed Dose Rate (PDR), Low Dose Rate (LDR) remote afterloading brachytherapy, endovascular brachytherapy and QC of brachytherapy treatment planning systems. Although ^{125}I seed implants are becoming an important brachytherapy application, it was decided to include no specific recommendations on QC of ^{125}I seed implants in this report. The reader is referred to AAPM Task Group recommendations [35,36,58] for QC of these implants. Furthermore, no recommendations for QC of eye treatments with beta applicators are formulated in this report. The dosimetry and QC of eye treatments with beta applicators and more extensive recommendations on QC of endovascular brachytherapy are subjects for future NCS recommendations.

The QC requirements of HDR, PDR and LDR brachytherapy presented in this report are based on the results of the questionnaire, the on-site measurements and on the existing recommendations on QC. The recommendations on manual afterloading, endovascular brachytherapy and on the treatment planning systems are based on experiences within the task group, on literature recommendations and on the experience of the users.

Chapter 1 provides general information. Definitions are given, and the general situation with respect to brachytherapy facilities and QC procedures in The Netherlands and in Belgium is described. In chapter 2, the results obtained from the questionnaire on QC of brachytherapy are compared with existing recommendations. From the analysis, national recommendations in the form of minimum requirements and action levels are proposed. Because of the rapid increase in the use of radionuclides in the field of endovascular brachytherapy to reduce the occurrence of restenosis in patients who are treated for vascular stenosis, it was decided to

include a number of basic recommendations for this field in this report. These recommendations are given in chapter 3. Chapter 4 is an extension of NCS report 14 on treatment planning systems. It focuses on those aspects of QC of the treatment planning specific for brachytherapy, such as brachytherapy sources, implant entry, dose calculation models and data transfer. All the recommendations are summarized in chapter 5. For those readers, only interested in the QC recommendations and possible test methods, the contents of this chapter is sufficient. For a more detailed explanation of the recommendations, the reader is referred to chapters 2 to 4. In the appendix, the methods that were used during the site visits to determine the accuracy of implant reconstruction and dose delivery are described. The results of these measurements will be published separately [17].

1.2 Brachytherapy treatments and equipment

The number of brachytherapy treatments, the brachytherapy equipment and the current QC practice was investigated by distributing an extensive questionnaire to all radiotherapy institutions in The Netherlands and Belgium.

The questionnaire was returned by 19 out of the 19 institutions in The Netherlands, and by 18 out of the 20 institutions in Belgium. The questions on the QC practice concerned test frequencies, test methods, time required for the tests, and action levels of safety systems and irradiation parameters in brachytherapy.

The answers to the questionnaire showed that approximately 2200 patients in The Netherlands and 1000 patients (actual number of treatments in 13 out of 20 institutions) in Belgium were treated in 1996 using brachytherapy. The location of the tumours of these treatments is shown in Figure 1-1. As can be seen, brachytherapy is most frequently applied to tumours of the eye (including benign tumours), oesophagus, breast, and gynaecological regions.

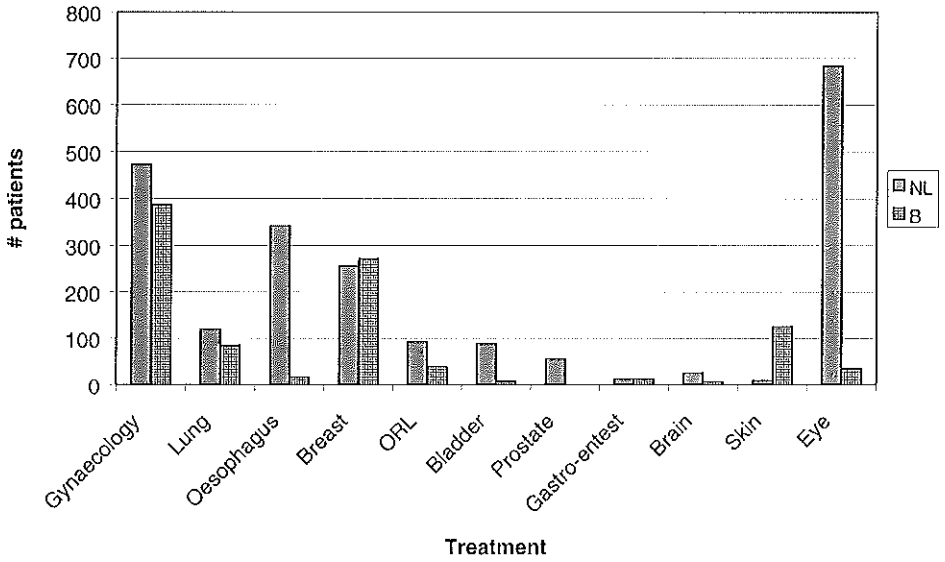


Figure 1-1: Number of brachytherapy treatments per tumour location in The Netherlands and Belgium. Data were available for the year 1996 from 19 out of 19 institutions in The Netherlands, and 13 out of 20 institutions in Belgium. The actual number of treatments in Belgium was higher. The majority of the eye treatments was performed in two Dutch institutions.

The distribution of patients among the institutions is shown in Figure 1-2. It is clear that large differences exist in the number of treatments at different institutions. More than half of the patients in each country are treated in the four largest institutions.

The brachytherapy techniques and numbers of installations in The Netherlands and Belgium in use in December 1998 are summarized in Table 1.1. Apart from HDR, PDR and LDR remote afterloading, manual afterloading brachytherapy using ^{192}Ir, ^{137}Cs and ^{125}I sources and radiation treatment of eye tumours using ^{90}Sr and ^{106}Ru is performed in both The Netherlands and Belgium. The equipment in use for endovascular brachytherapy is shown in chapter 3.

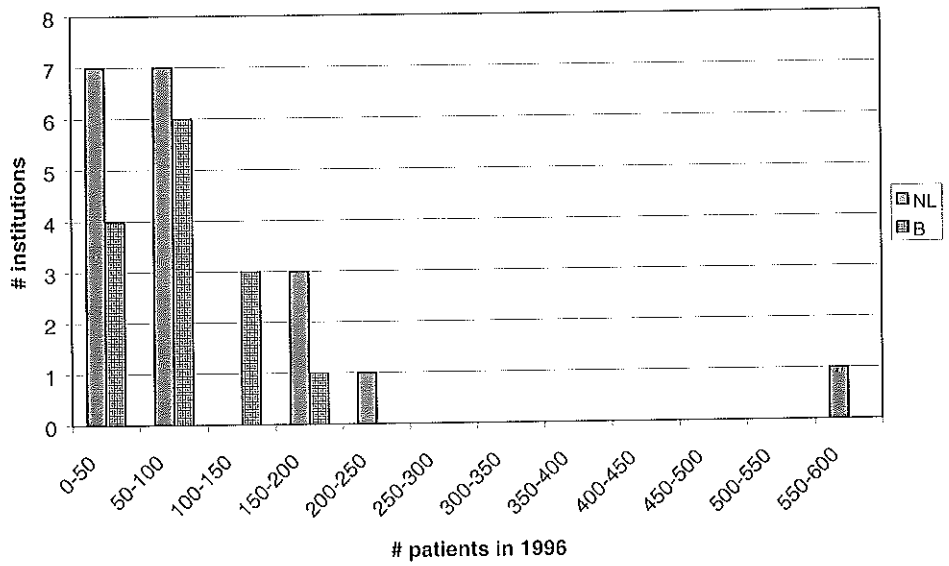


Figure 1-2: Distribution of brachytherapy patients among 33 radiotherapy institutions in The Netherlands and Belgium. The large number (>550) of patients in one institution is the result of eye treatments performed in this institution.

Table 1.1: Brachytherapy techniques used in The Netherlands and Belgium in December 1998.

Brachytherapy techniques	# installations in The Netherlands	# installations in Belgium
HDR (^{192}Ir)	13	8
PDR (^{192}Ir)	6	8
S-LDR (^{137}Cs-pellets)	10	9
m-LDR (^{192}Ir / ^{137}Cs wires / seeds)	10	3
Manual (^{192}Ir)	12	12
Manual (^{137}Cs)	2	3
Manual (^{125}I)	3	4
Eye applicator (^{90}Sr)	8	2
Eye applicator (^{106}Ru)	1	1

Time spent on QC

Each institution has its own QC programme to ensure the safe and accurate application of radiation for treatment of cancer. To illustrate the differences between the institutions, the annual time spent on QC of brachytherapy equipment per institution in The Netherlands is shown in Figure 1-3. The average time spent per institution is approximately 8 hours for HDR, 14 hours for PDR, 6 hours for m-LDR and 4 hours for S-LDR afterloaders. It should be noted that most values are rough estimates and that it is sometimes difficult to distinguish time spent on preventive maintenance from time spent on quality control. Nevertheless, the differences in QC times between the different machines are striking, as well as the inter-institutional differences.

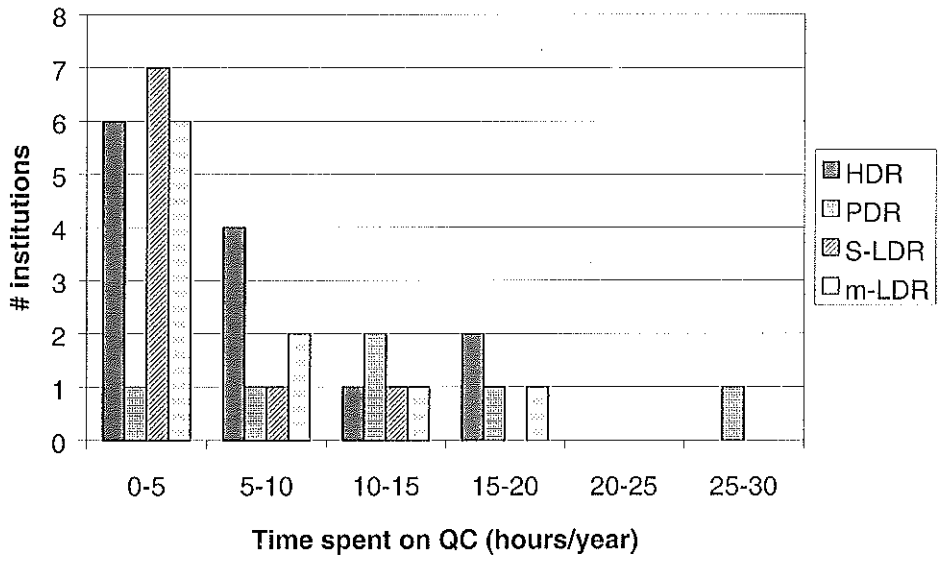


Figure 1-3: Frequency distribution of the annual time spent on quality control of different types of brachytherapy in The Netherlands in 1998.

1.3 Minimum requirements

The recommendations in this report are characterized by a minimum test frequency and, if not obvious, an action level. The suggested test frequencies should be regarded as a **minimum** and not as an **optimum**. An increase in test frequency is required when the stability of a system is suspect, or when a specific patient treatment method demands a special accuracy.

The minimum requirements have been established after evaluating the results of the questionnaire, the on-site measurements and the recommendations found in the literature.

Furthermore, the minimum test frequency for the different checks will depend on :

- the seriousness of the possible consequences of an unnoticed malfunction to patients and/or personnel
- the likelihood of occurrence of a malfunction
- the chances that if a malfunction occurs, this will not be noticed during normal treatment applications

It is emphasized that the recommended test frequencies in this report concern the regular quality control tests. Test methods and results of these tests should be documented. Whenever in this report 4M is used as a recommended minimum test frequency, this is often based on the source exchange period; quality control on remote HDR and PDR afterloading equipment is often combined with a source exchange. On a few occasions, it might be justified to deviate from the recommended test frequencies, for example, in case of a very small number of treatments between two QC checks.

The *action level* specified should be interpreted as described in NCS-report 9 [40]: An action level is defined in such a way that whenever an action level is reached, it is essential that appropriate actions are taken. The radiation equipment should not be used whenever the action level has been exceeded. On few occasions, it might be justified to use the radiation equipment clinically, even if an action level has been exceeded. Such a decision can only be taken after careful consideration by the responsible clinical physicist, with the knowledge of the clinicians and the radiographers and should be documented in all cases.

2 Current practice and recommendations on QC of HDR, PDR and LDR brachytherapy

The current practice of quality control of HDR, PDR and LDR brachytherapy was investigated by distributing a questionnaire on QC procedures. The questions mainly concerned the QC practice of remote afterloading techniques; QC of manual afterloading was only briefly investigated. The results of this investigation are presented in this chapter and compared with existing recommendations on QC [3, 5, 13, 14, 18, 20, 21, 22, 35, 36, 48, 56], of which the most important are those of the AAPM [36], DIN [14], IEC [22], SFPH [48] and Williamson [56]. The reports from SFPH and Williamson only deal with HDR brachytherapy, while the other reports concern all types of remote afterloading brachytherapy, i.e. HDR, PDR and LDR. From this information, minimum QC requirements are formulated. The frequencies of checks described in these reports are recommended test frequencies.

2.1 Safety aspects

In general, the safety aspects in remote afterloading machines can be subdivided into radiation safety, interlocks and emergency aspects. Quality control tests on these safety aspects should prevent system failure. Very often, QC procedures on safety systems are simple functional tests. The inter-institutional survey showed that the test frequency was very divergent, as is shown in the next sections.

2.1.1. Monitoring

Radiation in the treatment room is monitored by warning lights at the entrance and by a radiation monitor. Furthermore, a patient can be monitored using the audio/visual communication system.

Inter-institutional survey

The test frequencies obtained from the inter-institutional survey for these radiation monitoring aspects are shown in Figures 2-1 and 2-2. As can be seen from these figures, there is a wide variety in the applied test frequency.

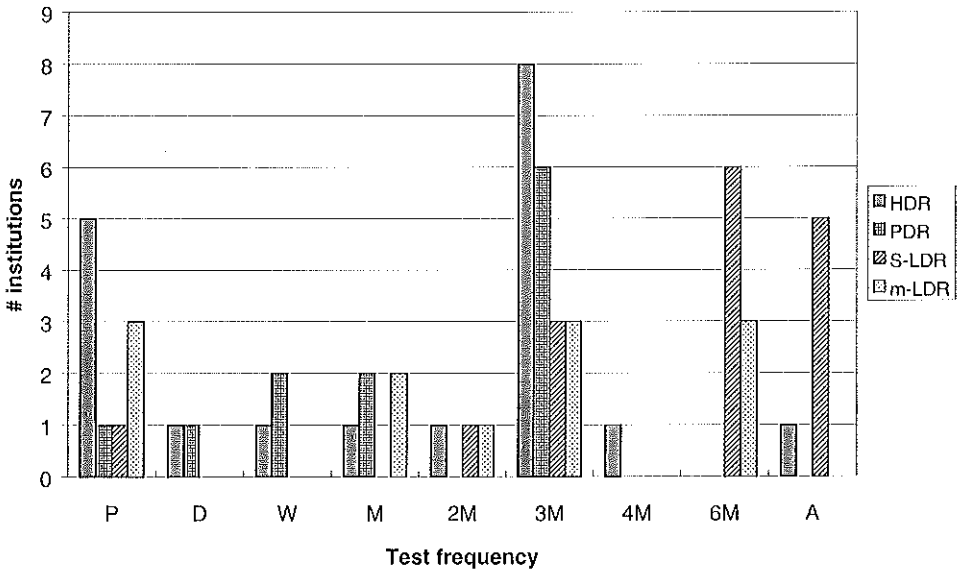


Figure 2-1: Frequency distribution of the test of the radiation warning lights (P=each patient, D=daily, W=weekly, M=monthly, 2M= every two month, A=annually).

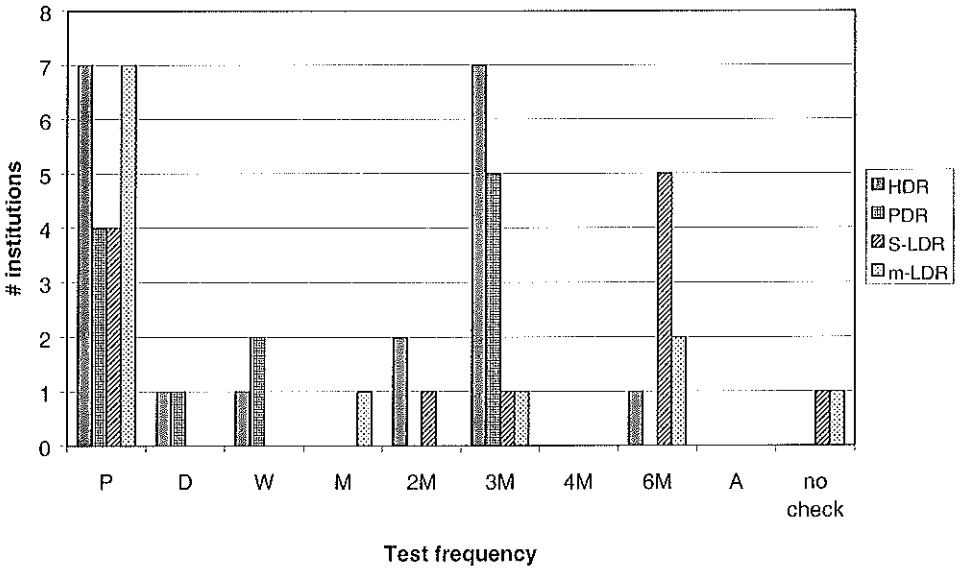


Figure 2-2: Frequency distribution of the test of the room radiation monitor.

Literature recommendations

Report	*Frequency*		
	Warning lights	*Room radiation monitor*	*Audio/visual communication system*
AAPM	D	D	D
SFPH	D	D	D
Williamson	D	D	D

Minimum requirements

Test	Test frequency	
	HDR / PDR	LDR
Warning lights	4M	4M
Room radiation monitor	4M	4M
Audio/visual communication system	4M	4M

At least every four months, a formal check should be done, and the results documented. The suggested minimum test frequencies are considerably lower than the existing recommendations. The reason for the difference is that it is assumed that a malfunction will be quickly noticed by the radiation technologists during their routine work. However, any malfunction during routine work should be immediately reported to the responsible medical physicist.

2.1.2. Interlocks

All remote afterloaders have error detection systems, which are designed to retract the source(s) or to prevent source transfer when an error occurs. Examples of these safety systems are the emergency stop push buttons, the interrupt button, the door interlock, and power loss or air pressure loss detection systems. Furthermore, source transfer should be prevented when the indexer ring is unlocked or an applicator is missing. An obstructed applicator should result in source retraction. The correct functioning of these systems should be checked on a regular basis.

Inter-institutional survey

Figures 2-3 to 2-7 represent the current practice for QC on interlocks. The currently applied test frequencies vary between each patient and annually. In some institutions, correct functioning of interlocks is not checked regularly.

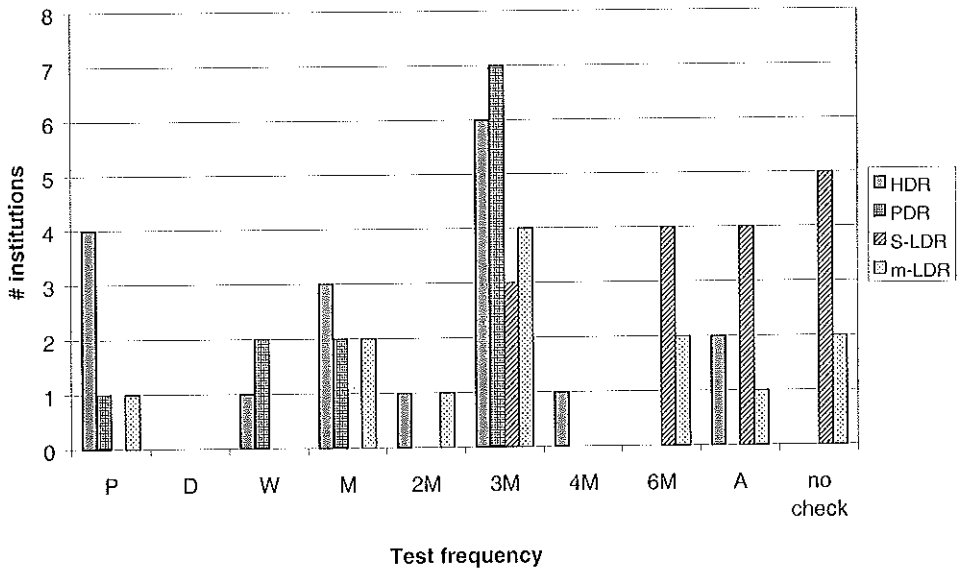


Figure 2-3: Frequency distribution of the test of the emergency stop push buttons.

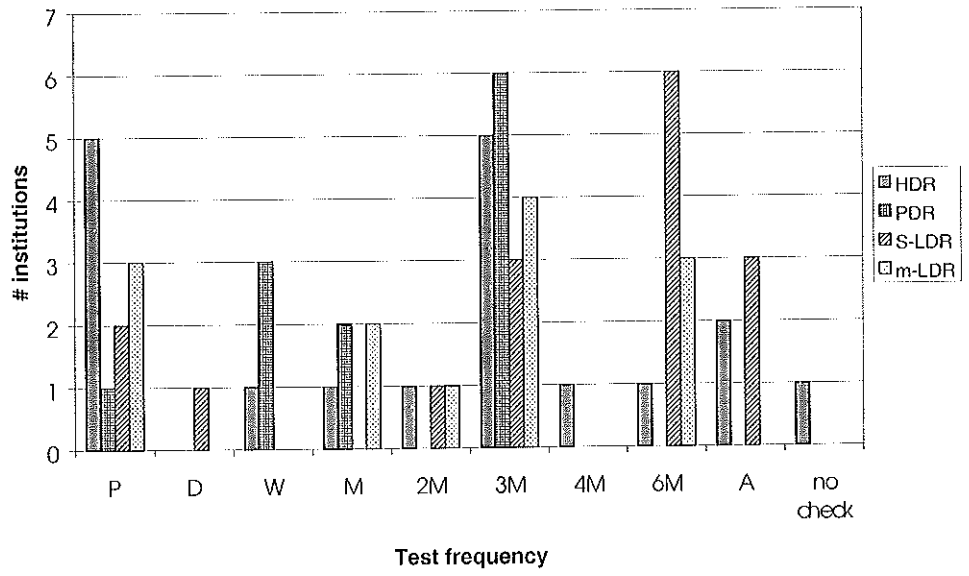


Figure 2-4: Frequency distribution of the test of the interrupt button.

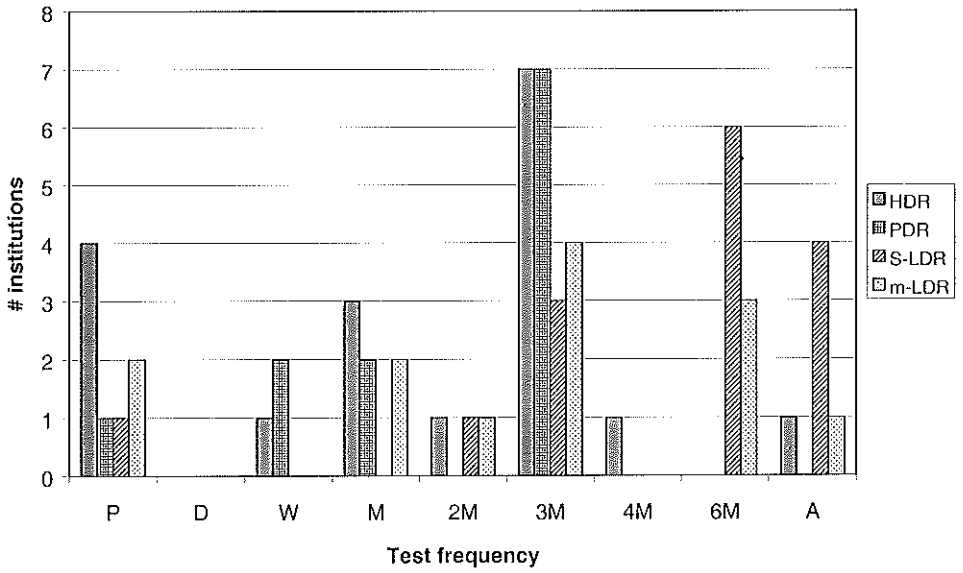


Figure 2-5: Frequency distribution of the test of the door interlock, which should interrupt irradiation when the treatment door is opened.

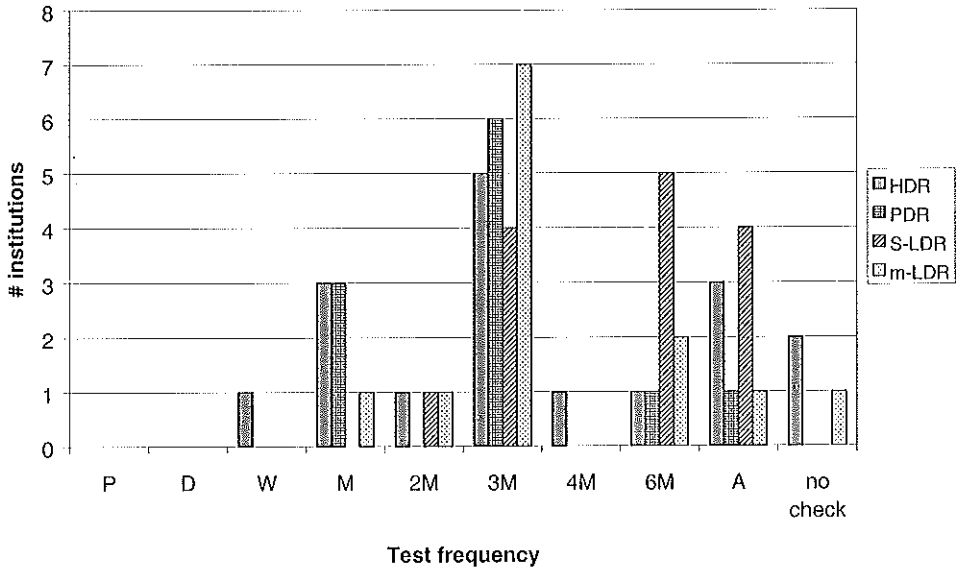


Figure 2-6: Frequency distribution of the test of the power loss, which should result in source retraction.

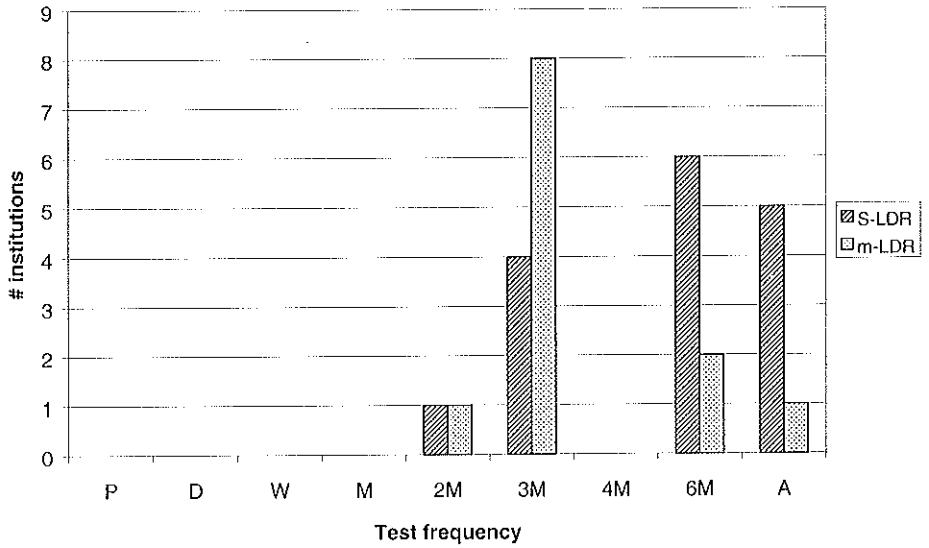


Figure 2-7: Frequency distribution of the test of the air pressure loss on LDR afterloaders, which should result in source retraction.

Literature recommendations

Report	*Frequency*				
	Emergency stop buttons	*Interrupt button*	*Door interlock*	*Power loss*	*Air pressure loss*
AAPM	-	-	D	3M	3M
SFPH	D	D	D	D	-
Williamson	D	D	D	D	-

Report	*Frequency*		
	Unlocked indexer ring	*Obstructed applicator*	*Missing applicator*
AAPM	3M	3M	3M
SFPH	-	-	D
Williamson	3M	3M	D

Minimum requirements

Test	Test frequency	
	HDR / PDR	LDR
Emergency stop push buttons	4M	6M
Interrupt button	4M	6M
Door interlock	4M	6M
Power loss	4M	6M
Air pressure loss	-	6M
Unlocked indexer ring	4M	-
Obstructed applicator	4M	6M
Missing applicator	4M	6M

The correct functioning of these interlocks should be tested at least every four months for HDR / PDR afterloaders. For LDR afterloaders, a test frequency of six months is recommended. The reason for the deviation from literature recommendations is that the likelihood of occurrence of a malfunction is relatively small and that it is assumed that a malfunction will be quickly noticed by the radiation technologists during their routine work. However, any malfunction during routine work should be immediately reported to the responsible medical physicist.

2.1.3. Radiation safety: leakage radiation and radioactive contamination

The recommendations on radiation safety in this section concern the afterloading equipment. No recommendations on radiation safety of the building or the radiological workers are formulated.

The radiation level at a fixed distance from the storage container of the source (leakage radiation) should be as low as reasonably achievable, but certainly below the current national legal requirements. Furthermore, contamination tests should be performed on a regular basis.

Inter-institutional survey

Figures 2-8 and 2-9 represent the current practice for QC on radiation safety. As can be seen, the radiation safety tests are performed regularly in approximately half of the institutions.

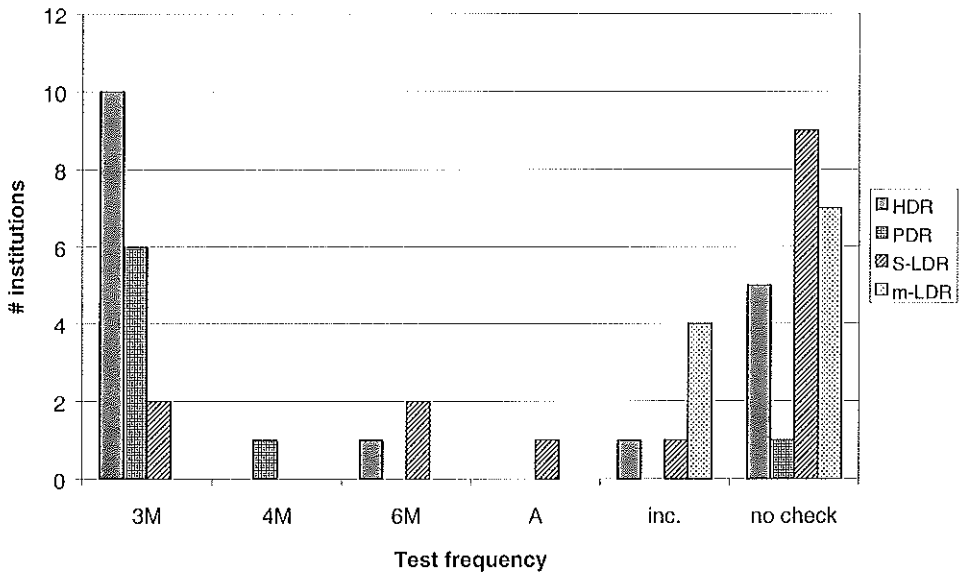


Figure 2-8: Frequency distribution of the test of leakage radiation outside the afterloader with the source retracted.

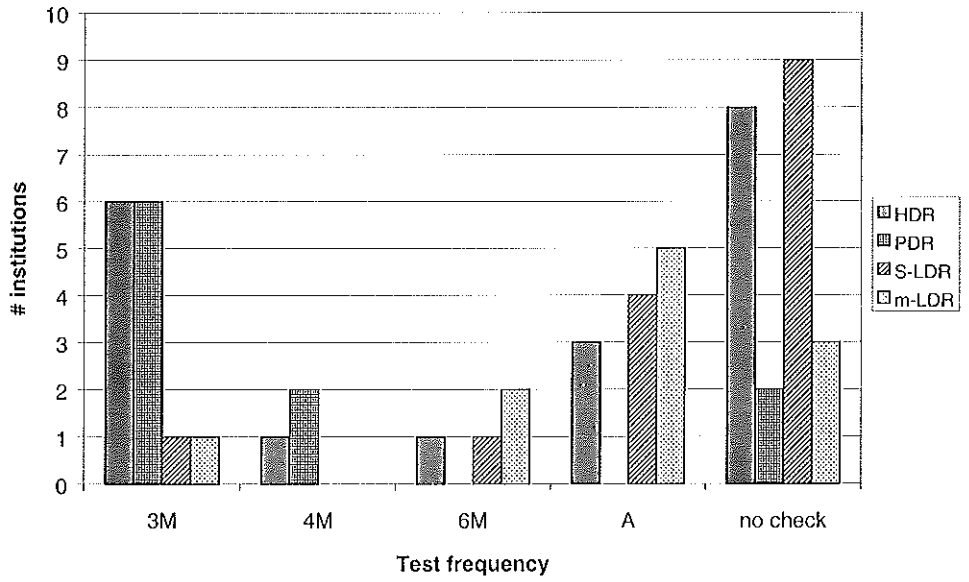


Figure 2-9: Frequency distribution of the test for radiation contamination on the afterloader.

Literature recommendations

Report	*Frequency*	
	Leakage radiation	*Contamination*
AAPM	3M	-
SFPH	SE	-
Williamson	-	-

Minimum requirements

Test	Test frequency	
	HDR / PDR	LDR
Leakage radiation	SE	A
Contamination	SE	A

It is recommended that the radiation level is measured at 10 cm and at 1 m from the source-container of the afterloader during each source exchange for HDR/PDR afterloaders, and annually for LDR afterloaders. The radiation level should be below the current legal regulation. Furthermore, it is recommended to perform contamination tests on transfer tubes, applicators and check cable during each source exchange for HDR/PDR afterloaders, and annually for LDR afterloaders. It is noted that such a contamination test is a check afterwards; whenever a contamination is observed, it is recommended to detect the origin of the contamination and to check the applicators for contamination after each treatment.

2.1.4. Integrity of transfer tubes and applicators

To prevent obstruction of the source in the transfer tubes or applicator, the integrity of transfer tubes and applicators should be checked regularly. This aspect of quality control was not included in the questionnaire that was sent to the institutions. The recommended test frequency is therefore based on literature recommendations and experience of the task group.

Literature recommendations

Report	*Frequency*
	Integrity applicators / Transfer tubes
AAPM	3M
SFPH	D
Williamson	3M

Minimum requirements

Test	Test frequency	
	HDR / PDR	LDR
Integrity of transfer tubes and applicators	6M	6M

It is recommended to perform a visual inspection of the transfer tubes and applicators for kinks and wear and tear at least every 6 months. The recommended test frequency is lower than the literature recommendations, because it is very likely that kinks or bends in transfer tubes or applicators are detected by daily visual inspection or as an obstruction by the remote afterloading device.

2.1.5. Emergency aspects

Although the likelihood of major emergencies, for example source detachment during treatment, is very low, the dose delivered to patients and staff can be very high. During an emergency, the goal is to keep the dose to patient and personnel as low as possible. Clearly, time is the most important factor in cases of an emergency. Therefore, safety equipment (such as the, emergency instructions, forceps, emergency safe, surgical supplies, portable survey meter and operator's manual) should be available during treatments and the emergency procedure should be practised regularly. Furthermore, correct functioning of the hand crank for manual source retraction should be checked regularly for HDR and PDR afterloaders.

Inter-institutional survey

Figure 2-10 shows the current frequency for practising the emergency procedure. As can be seen, the emergency procedure is practised regularly for 30 out of 55 installed afterloaders.

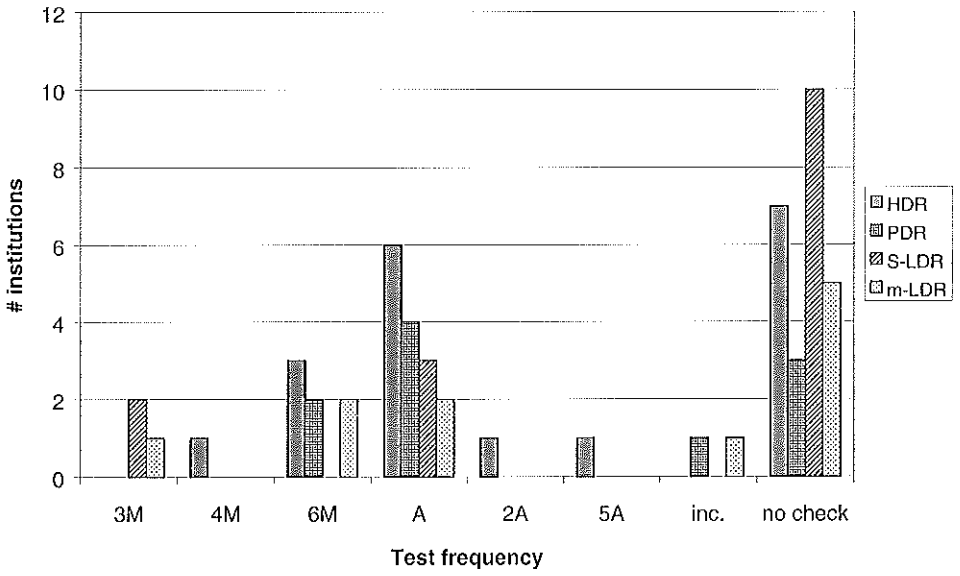


Figure 2-10: Frequency distribution of practising the emergency procedure.

Literature recommendations

Report	*Frequency*		
	Emergency equipment available	*Hand crank functioning*	*Practice emergency procedure*
AAPM	D	A	-
SFPH	D	SE	-
Williamson	D	-	-

Minimum requirements

Test	Test frequency	
	HDR / PDR	LDR
Emergency equipment (emergency instructions, portable survey meter, source handling tools, shielded storage container, forceps, operator's manual)	4M	6M
Hand crank functioning	A	-
Practice emergency procedure	A	A

It is recommended to check the availability and correct functioning of emergency equipment at least every 4 months for HDR/PDR afterloaders and every 6 months for LDR afterloaders. It is recommended that the emergency procedure is practised at least once a year. During each brachytherapy treatment, at least one person should be present who has attended the emergency practice within the last year. The recommended test frequency for correct functioning of the hand crank for manual source retraction is annually. This test can be combined with practising of the emergency procedure.

2.2 Physical parameters

The accuracy of the dose delivery of brachytherapy depends on the accuracy of many physical parameters. Verification of source calibration, source positioning, irradiation timer and implant reconstruction is therefore essential. The test frequencies and action levels of these parameters will be discussed in this section.

2.2.1. Source calibration

Calibration of brachytherapy sources has been the subject of two NCS-reports: NCS-report 4 [38] gives recommendations for the calibration of LDR sources. NCS-report 7 [39] describes several methods specifically for the calibration of ^{192}Ir HDR sources. In house calibrations of ^{192}Ir HDR/PDR sources are based on the use of a reference ionization chamber calibrated at the National Standards Laboratory. NMi and other National Standards Laboratories determine the calibration factor, N_k, for ^{192}Ir HDR/PDR sources using a method which is based on the weighting of the response of the ionization chamber over the full photon spectrum of the ^{192}Ir source. A simplified version of this method is presently in use at NMi [44]. It consists of averaging the N_k factors of the ionization chamber for 250 kV X rays and ^{137}Cs gamma radiation. It is recommended to use the method of the National Standards Laboratory for the determination of the calibration factor of the ionization chamber for ^{192}Ir HDR/PDR sources.

Inter-institutional survey

All but one institution perform an in-house source calibration of HDR or PDR ^{192}Ir sources. In 21 institutions, an in-air measurement using the Nucletron Calibration Jig is used, in seven institutions an in-air calibration with a home-made jig is carried out, in three institutions, an in-phantom calibration using a PMMA cylindrical phantom is performed and in three institutions a well-type chamber is used for calibration of the source. For HDR sources, the *measured* source strength instead of the value of the certificate from the manufacturer is used in the treatment planning computer in 14 out of 21 institutions. For PDR this is done in 10 out of 14 institutions. When comparing calibration results for HDR/PDR ^{192}Ir sources using either the method proposed by NMi (i.e. averaging the N_k factors for 250 kV and ^{137}Cs [44]) or the method based proposed by Goetsch [20], a difference of about 1% is found for the NE-2571

ionization chamber. Although small, this (systematic) difference can be avoided by adopting the procedure followed the National Standards Laboratory.

For the 19 S-LDR afterloading systems, 13 institutions have performed an in-house calibration of the ^{137}Cs pellets. The calibration is performed using an in-phantom method as described in NCS-report 4 in seven institutions, in four institutions a well chamber is used and two institutions have used an in-air method. The in-house measured value is used in the treatment planning computer in five institutions; the remaining institutions use the value on the certificate.

An in-house calibration is performed in all 13 institutions using a m-LDR afterloading system. In 12 institutions, a well-chamber is used, in one institution a local calibration protocol is applied. All but one institution use the value on the certificate in the treatment planning computer.

Literature recommendations

Report	*Test frequency*	*Action level*
	Source calibration	
AAPM	3M	± 5%
SFPH	SE	-
Williamson	3M	± 5%

Minimum requirements

Test	Test frequency	Action level	Spread (1SD)
Calibration ^{192}Ir HDR / PDR sources	SE	± 5%	-
Calibration ^{137}Cs LDR pellets	SE	Mean ± 5%	5%
Calibration ^{192}Ir / ^{137}Cs LDR wires / seeds	SE	Mean ± 10%	-

It is recommended that each new source is calibrated in the institution and that the measured source strength is entered into the treatment planning computer. Furthermore, the measured value for the source strength should be compared with the value on the manufacturer's certificate. If this differs by more than 5% for ^{192}Ir HDR/PDR sources, or if the mean value differs more than 5% for ^{137}Cs pellets or if the mean value for the complete coil differs by more than 10% for Ir/Cs wires, a second measurement should be performed in order to check the results of the first measurement. If in this second measurement the difference with

the certificate's value is confirmed, it is recommended to contact the manufacturer to establish the reason for the deviation.

2.2.2. Source positioning

Source positioning is another important parameter in accurate dose delivery. The accuracy of the position of the source within the applicator should therefore be checked on a regular basis.

Inter-institutional survey

In Figure 2-11 the current practice of QC on source position is shown. Most institutions use an action level of 1 mm. For S-LDR afterloaders this check is performed in five out of 19 institutions. For LDR wire or needle implants, not only the source position, but also the length of the sources is checked for each patient in six institutions. The maximum action level applied is 2 mm.

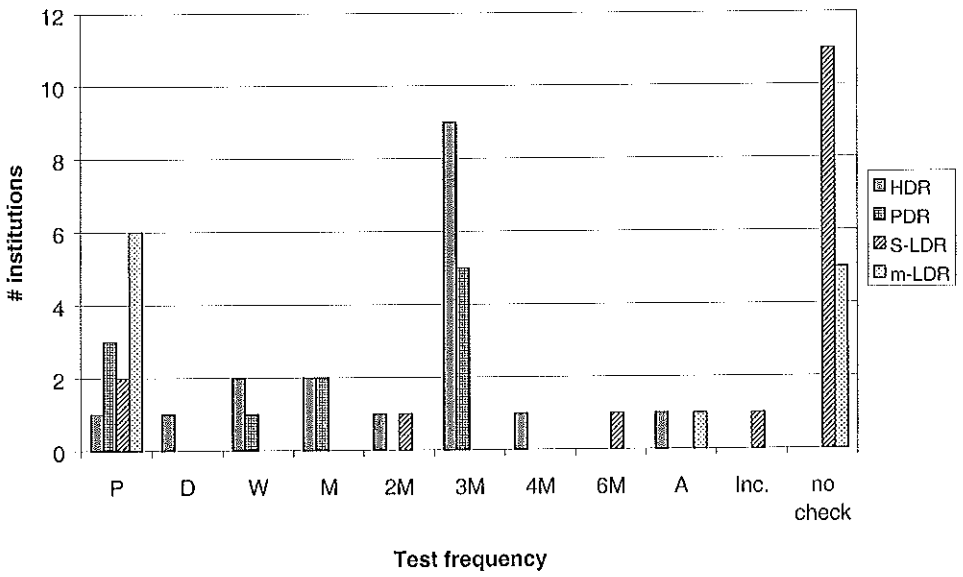


Figure 2-11: Frequency distribution of the test of the source position.

Literature recommendations

Report	*Test frequency source position*	*Action level*
AAPM	D	1 mm
SFPH	M	-
IEC	-	2 mm
Williamson	D	1 mm
DIN	M	-

Minimum requirements

Test	Test frequency			Action level	
	HDR / PDR	S-LDR	m-LDR	HDR / PDR	LDR
Source positioning	4M	6M	P	± 2mm	± 2mm

It is recommended that the source position for HDR and PDR afterloaders is checked at least every 4 months, by measuring at least the location of a single dwell position and comparing it with the expected location. An action level of 2 mm is suggested. For ^{137}Cs source train machines, the dimensions of the sources and spacers should be checked during the acceptance procedure of the machine. Furthermore, it is recommended to check the accuracy of the source positioning for these machines using autoradiography at least every six months, with an action level of 2 mm. The position and length of LDR wire or needle implants should be checked for every patient with an action level of 2 mm.

2.2.3. Irradiation timer

The dose delivered to a patient also depends on the temporal accuracy of the treatment system.

Inter-institutional survey

The current practice of QC on the irradiation timer is shown in Figure 2-12. In institutions that check the accuracy of the timer, action levels between 0%-0.5% or 2 seconds for the total treatment time for HDR / PDR afterloaders and between 0 and 1 minute for LDR afterloaders are applied.

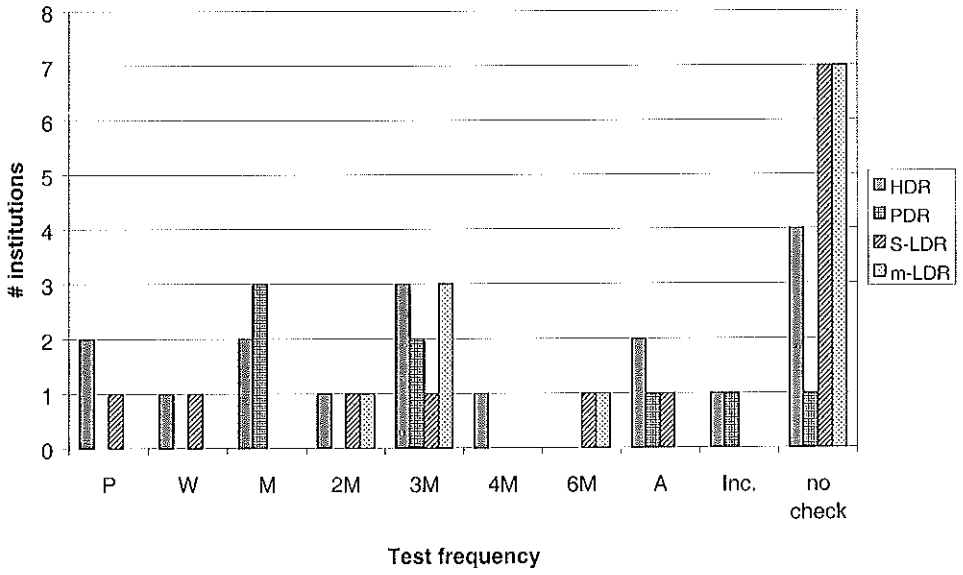


Figure 2-12: Frequency distribution of the test of the accuracy of the irradiation timer.

Literature recommendations

Report	*Test frequency Irradiation timer*	*Action level*
AAPM	D	2%
SFPH	W	-
IEC	-	1%
Williamson	D	1%
DIN	W	-

Minimum requirements

Test	Test frequency	Action level
Timer accuracy and linearity	A	± 1%

It is recommended to test the accuracy and linearity of the irradiation timer at least once a year, with an action level of 1%. The absolute timer accuracy has to be checked only if the source calibration is based on an external time standard. When the machine timer is used both for calibration and for treatment delivery, only the test of the linearity of the timer is required.

2.2.4. Implant reconstruction

To calculate a dose distribution around radioactive sources, the co-ordinates of the sources must be determined relative to an arbitrary reference point. The accuracy of this 3D-reconstruction of the implant depends on the accuracy of localization, digitization and the reconstruction algorithm.

Inter-institutional survey

The accuracy of the implant reconstruction method has been measured in the institutions using a dedicated phantom. The method employed during these measurements is described in the appendix, and the results will be published separately [17]. In most institutions, reconstruction is done using orthogonal films made on a treatment simulator. Some institutions use a C-arm, often in combination with a reconstruction box. The accuracy of the reconstruction method is checked on a regular basis only in a small number of institutions (see Figure 2-13).

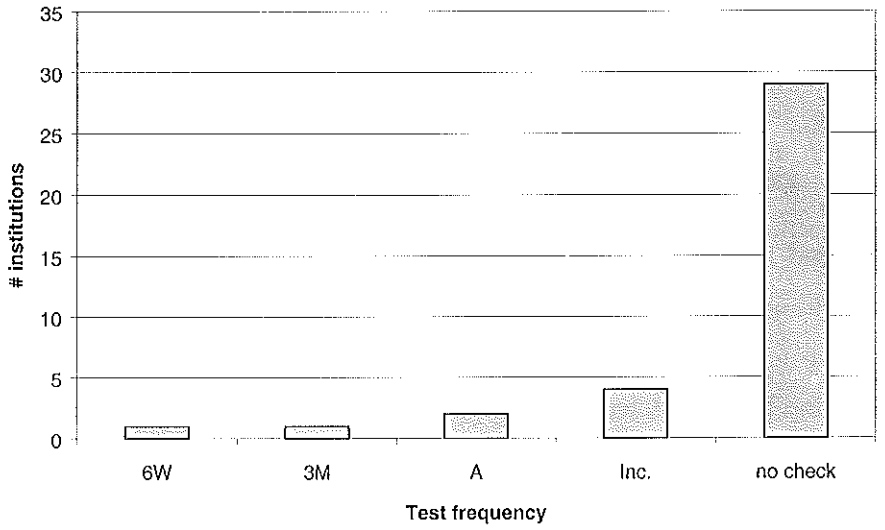


Figure 2-13: Frequency distribution of the test of the implant reconstruction accuracy.

Minimum requirements

Test	Test frequency	Action level
Implant reconstruction	A	95% of reconstructed distances deviation <2 mm

It is recommended to test the accuracy of the implant reconstruction procedure, i.e. the total accuracy of the localizer, digitizer and reconstruction algorithm at least once a year by reconstruction of a phantom with well-known dimensions and geometry (see the appendix for a possible test method). The reconstruction error should be smaller than 2 mm for at least 95% of the reconstructed distances. The accuracy of the reconstruction algorithm has to be tested after the installation of every new software version of the treatment planning system and after changes in the equipment used for reconstruction. Quality control of the treatment planning system is discussed in more detail in chapter 4.

2.2.5. Treatment verification

Measurements have been performed in the institutions to gain insight into the accuracy of the brachytherapy dose delivery. The institutions were asked to prepare a treatment plan to deliver a prescribed dose in a phantom. A description of the measurement procedure can be found in the appendix. The results of these measurements will be presented elsewhere [17].

Inter-institutional survey

Verification of the actual dose delivered during treatment of a patient is difficult. In-vivo measurements using TLD's or rectal diodes are performed in only four out of 37 institutions. All other institutions check the treatment delivery times and error codes on the printout of the treatment console. A check of the calculated treatment time by an independent method is performed in approximately half of the institutions. The independent method is based on standards, spreadsheet calculations or methods described in the literature [18, 33, 52]. Furthermore, the date, time and source strength in the treatment unit and planning computer are checked in most institutions.

Minimum requirements

For HDR and PDR afterloading systems, the date, time and source strength in the treatment unit and planning computer should be checked before each treatment. It is recommended to check the calculated treatment time, whenever possible, with a (rough) independent method, for example as given in [18, 33, 52], to verify that the treatment plan contains no large errors. Furthermore, it is recommended that treatment delivery according to the treatment plan is verified by reading the printout of the treatment console. Routinely performed measurements in patients (in-vivo dosimetry) are not considered mandatory.

3 Recommendations on QC of coronary brachytherapy systems using beta sources

3.1 Introduction

A recently emerged application of brachytherapy is the irradiation of arteries in order to prevent restenosis after percutaneous transluminal angioplasty (PTA). Restenosis is currently the main drawback of PTA procedures, and occurs in 15% - 70% of the cases, depending on treatment site, patient characteristics and technique. In most cases, the restenosis is not caused by a repetition of the primary process but by the excessive proliferation of smooth muscle cells as a reaction to the mechanical trauma induced by balloon inflation, stent placement, atherectomy, etc. Because of the analogy with the treatment of keloid with orthovoltage radiation, it was hypothesized that giving a dose of 10-20 Gy to the vessel wall could prevent this benign proliferation. To this end, a radioactive source is introduced through a dedicated catheter in the lumen as a part of a PTA procedure. In the case of a high-activity source, it is withdrawn after an irradiation time of 3-20 minutes. In the case of a low-activity stent, it is left permanently at the treatment site.

Many radiobiological aspects of this treatment are still largely unknown, such as the target tissue, the optimal dose and the therapeutic window, the risk of late complications, modifying effects of oxygenation. Also the physical aspects (source construction, dosimetry) lead to new problems.

However, since 1990, many clinical trials have been conducted, and several of them showed a statistically significant positive effect. At present, the treatment is showing a rapid increase in patient numbers and equipment diversity, and several products are already available commercially. After being limited to a small number of "early adapting" centres per country, in the coming years a dissemination of the technique among a larger number of vascular interventional laboratories is predicted.

Because the impetus for this treatment comes from outside the radiotherapy community and because of the lack of standards and experience, the NCS task group on the QC of brachytherapy systems decided that a set of recommendations for quality control should play an important role in the starting phase, even though it can only be based on limited experience and is transient in a rapidly evolving treatment modality.

This chapter gives an inventory of the current practice in the Netherlands and Belgium, and formulates a set of recommendations, based on this inventory and on the opinions of the involved physicists and the literature.
Because of the limited experience and literature on this subject, the conclusions are presented as recommendations and not as minimum requirements. However, because the equipment and procedures are still under development, compliance with these recommendations might prevent serious incidents and might increase the quality of the clinical data, both of which are essential for the appropriate use of this treatment.

The following is limited to systems for the treatment of coronary arteries, because until now peripheral arteries are exclusively being treated with standard equipment for oncological therapies. Demands for peripheral vascular brachytherapy are thought to be less stringent, and therefore no additional recommendations in addition to those in the previous chapter are considered necessary.
Although some recommendations are valid for radiation sources in general, the practical aspects are only based on the experience with systems in clinical use in the Netherlands and Belgium at the end of 1999. This limitation excludes gamma-sources, fluid and gaseous radioactive sources, radioactive coated balloons, local delivery of radioactive compounds, intravascular X-ray tubes, etc.

3.2 Current practice

3.2.1. Questionnaire

In order to make an inventory of current practice, a questionnaire has been sent to the nine institutions known to perform coronary brachytherapy. The questionnaire was addressed to the medical radiation physicist responsible for this application, although sometimes the cathlab is located in another institution.
The questionnaire covered the following subjects:

1 systems in use, number of patients per system
2 frequency and tolerances of source activity measurements
3 frequency and tolerances of source homogeneity measurements
4 checks of leakage radiation from source holder
5 checks of contamination

6 checks of equipment integrity and interlocks

7 emergency procedures

Eight out of 9 institutions responded to the questionnaire.

3.2.2. Results

3.2.2.1. Institutions, systems and patients

Table 3.1 gives a list of the participating institutions and some basic figures illustrating the magnitude of the practice.

Table 3.1: Institutions in the Netherlands and Belgium with clinical applications of coronary brachytherapy. The data of Utrecht are included in this table for completeness; this institute has not been included in the questionnaire because this treatment modality was discontinued.

Institution	City, country	# different systems	# patients until 1-12-99
Acad. Zkh / D.den Hoedkliniek	Rotterdam, NL	3	270
Catharina Ziekenhuis	Eindhoven, NL	1	81
Universitair Medisch Centrum	Utrecht, NL	1	11
Onze Lieve Vrouw Ziekenhuis	Aalst, B	4	>170
Clinique Generale St Jean	Brussels, B	1	
UCL Clinique Univ. St Luc	Brussels, B	1	10
Virga Jesse Ziekenhuis	Hasselt, B	1	>30
Universitair Zkh Gasthuisberg	Leuven, B	2	90
General Hospital Middelheim	Antwerpen, B	1	6
Universitair Ziekenhuis Antwerpen	Duffel, B	1	16
Totals		14 (6 types)	>684

The six systems in clinical use were manufactured by Novoste, Guidant, Boston Scientific, Isostent, Radiance, and Mallinckrodt. Some basic characteristics of these systems are shown in Table 3.2.

Table 3.2: Basic characteristics of the systems in use at the end of 1999.

System	Isotope	Loading system	Source configuration
Novoste	$^{90}Sr/^{90}Y$	Manual hydraulic, non centered catheter	Solid 2.5 mm seeds (12)
Guidant	^{32}P	Automatic cable driven, centered catheter	Solid 27 mm line source
Boston / Schneider	^{90}Y	Automatic cable driven, centered catheter	Solid 29 mm line source
Radiance	^{32}P	Manual	Phosphor covered PTCA balloon
Isostent	^{32}P	Manual, permanent	Radioactive stent
Mallinkrodt	^{186}Re, ^{188}Re	Manual	Radioactive fluid in PTCA balloon

From the input of the respondents, several general remarks could be made:

- All institutions treated their patients under clinical trials, initiated by the manufacturers. Therefore, procedures partly reflect the trial protocol and not the viewpoint of the institution/radiotherapy department. However, in all trials, medical physicists were explicitly responsible for dosimetry and safety and radiation oncologists for the radiation treatment.
- The liquid-filled balloon system of Mallinckrodt is often used under the license and responsibility of the Nuclear Medicine department; therefore, data on this treatment could be incomplete in this survey.
- Measurements of activity and homogeneity of radioactive stents are very impractical because they can only be handled in a sterile environment. None of the respondents did any checks on the stents and they are therefore not discussed any further.

3.2.2.2. Dosimetric QC of sources: source activity checks

Six participating institutions performed activity checks with a well-type ionization chamber or a NaI activity calibrator. These detectors were not calibrated for these sources but they were thought to provide an independent constancy check. At two of these six institutions also absolute dose rate measurements were performed with TLDs at the typical prescription

distance of 2 mm from the source axis in a water equivalent phantom. In all but one cases, the dose rate specified by the manufacturer was used for the treatment. All activity checks were done at source exchange. With the Radiance system (disposable source in sterile package; one institution) an activity check could only be done after the patient treatment. Users of the Guidant system had a NIST calibrated well-chamber available with an uncertainty in activity of ±2.2%. The conversion factor to doserate at 2 mm from the source axis had an uncertainty of ±15%.

All participants agreed that, due to uncertainties in absolute dose determination of beta-sources, an accuracy level of < 15% can not be achieved at present. Preliminary clinical data indicate that the therapeutical window is large enough to allow these tolerances. Relative source-to-source checks of activity could be performed with maximum deviations of 5%.

3.2.2.3. Dosimetric QC of sources: source homogeneity checks

Source homogeneity checks at each source exchange were performed with radiochromic film in five institutions. The Guidant sources were checked several times per period of use. Here also large tolerance levels were unavoidable, mainly because of geometrical inaccuracies and film inhomogeneity.

3.2.2.4. Radiation safety checks: leakage radiation

Return of the source into the afterloader/source holder can roughly be checked by measuring the doserate on the outside of the holder. This is mandatory per patient in the protocols for the Novoste system; all other users checked it after a source exchange.

3.2.2.5. Radiation safety checks: contamination

Radioactive contamination of the transport fluid from leaking sources is checked at each patient by the seven users of the Novoste system. All cable driven sources (Guidant, Boston; four institutions) were checked at each source exchange with a wipe test. At two of these four institutions also the catheter is checked on radioactive contamination after each patient treatment.

3.2.2.6. Equipment integrity and interlocks

All institutions performed the checks prescribed by the manufacturers protocol. For all systems, a catheter integrity check is performed before each treatment; the computer-controlled afterloaders (Guidant, Boston) perform these tests automatically. Other checks are not performed with the Novoste systems; automated afterloaders are checked during maintenance by the manufacturer; these checks are extensive but often only partly known by the users. One institution checked the "catheter present" interlock independently. One other institution tested source positioning and interlocks at source exchange.

3.2.2.7. Emergency procedure

When normal retraction of the source fails, irradiation can be terminated by removing the catheter from the patient. This implies handling the source manually or with tweezers while it is inside the catheter and storing it temporarily in an emergency container. All institutions have a procedure and equipment available; two of them have trained this at least once.

3.3 Recommendations for QC in literature

Publications on QC of endovascular brachytherapy are still very sparse. Only a few references are available which deal with this application explicitly. The most extensive one comes from the AAPM Task Group 60 [37], which encompasses a description of the rationale of the procedure, the equipment and techniques, clinical and dosimetric experience, and gives recommendations for the specification of the dosimetric properties of sources, for dosimetric procedures, for prescribing and reporting the dose, and for QC. See Table 3.3.

Table 3.3: Summary of the AAPM TG-60 recommendations for QC of vascular brachytherapy.

1 Document source properties	
2 Develop protocols for:	2.1 purchase, receipt, acceptance testing and commissioning 2.2 storage, access and usage logging 2.3 transport 2.4 sterilization 2.5 disposal 2.6 emergencies with patient or equipment 2.7 roles and responsibilities for each involved individual
3 Check regularly source and equipment integrity	3.1 interlocks 3.2 lights and alarms 3.3 console functions 3.4 switches and batteries 3.5 source guide integrity 3.6 source activity homogeneity 3.7 source positioning accuracy 3.8 timer function 3.9 source activity 3.10 applicator integrity 3.11 response of equipment emergency
4 Develop a method for source activity determination	
5 Develop a form for dose prescription	
6 Develop and document treatment time calculation methods	
7 Verify source identity and parameters for each patient	
8 Monitor and document radiation levels around patient	
9 Inform patients with radioactive stents about safety measures	
10 Routinely train and educate staff	

The QC procedures for equipment have been derived from general procedures, developed for oncological brachytherapy and overlap the recommendations in this NCS report. No recommendations for tolerance levels, frequencies, measurement procedures and equipment are made, mainly because it is thought to be too early for this.

The American Brachytherapy Society gives its viewpoint in [34]; A review is given of indications and clinical experience, and recommendations are given for dose prescription, dose reporting, staffing, responsibilities, QA and radiation protection. The AAPM TG-60 recommendations are endorsed for QA. Here also, the provisional character of the recommendations is emphasized.

3.4 Recommendations

Until now, not enough knowledge is available about the dose-effect relationships and complication rate to justify the specification of minimum requirements. For most aspects, "good clinical practice" is the only available guideline, although it is important to note that many requirements for oncological brachytherapy are attuned to the most demanding tumours, and are probably much too stringent for endovascular brachytherapy. Also, no methods are currently available for the calibration of beta-emitters with the same accuracy as for gamma sources. Nevertheless, simple checks that can be performed with readily available equipment, and which could reduce the uncertainties or prevent incidents, should be made mandatory even if a clinical rationale is not known. The recommendations made in this chapter are based on these considerations, the presented overview of current practice in The Netherlands and Belgium, the personal viewpoints of the interviewed physicists and literature.

Abbreviations for frequencies in this chapter are SE (each source exchange), P (each patient), 4M (every 4 months), A (annually).

3.4.1. Safety aspects

3.4.1.1. Room monitoring

A fixed room monitor is not useful for beta sources because these are too weak. Also, discrimination between Bremsstrahlung and diagnostic X-rays would be necessary. A

manual survey during the irradiation at least at one location is recommended to verify the location of the source.

3.4.1.2. Interlocks

Not all afterloading systems are automated and/or remotely controlled. Any available facility for non-standard source retraction should be tested on a regular basis because malfunctioning will otherwise only be detected too late. Because sometimes mechanical parts are swapped with source exchanges, the frequency of this check should be SE, with long-lived isotopes at least 4M. All afterloaders block source ejection when a catheter is not attached. This facility should be tested with the same frequency. Obstructed catheter testing should be done with every catheter, because they are disposable.

Test	Test frequency
Emergency source retraction system (interrupt button, power backup, manual retraction facility)	SE or 4M, whichever is shorter
Missing catheter	SE or 4M, whichever is shorter
Obstructed catheter	P

3.4.1.3. Radiation safety

The radiation level at a fixed distance from the source holder should be measured at source exchange because it is a test of the correct withdrawal of the source in the holder. For long-lived isotopes this should be repeated annually. Contamination checks are more important than with standard brachytherapy sources because the encapsulation is generally thinner. Leakage of the source can be detected by checking every catheter after each treatment with a contamination monitor.

Test	Test frequency
Leakage radiation	SE or A whichever is shorter
Contamination	P

3.4.1.4. Integrity of transfer tubes and catheter

Because catheters are disposable, each catheter should be checked visually and with a dummy source before treatment. Other, non-disposable parts, which guide the source during transfer are regularly checked in the same way.

Test	Test frequency
Catheter integrity	P

3.4.1.5. Emergency aspects

No other considerations than for standard equipment are valid here.

Test	Test frequency
Emergency equipment functionality	4M
Practice emergency procedures	A

3.4.2. Physical parameters

3.4.2.1. Source calibration

All sources should be checked independently from the manufacturer in order to exclude any manufacturing or administrative error. For gamma sources, calibration of activity is achievable with the dose calibrators (e.g. well-type ionization chambers) available at most Nuclear Medicine departments, or with an adaptation of the measuring protocol for standard LDR or HDR sources. Conversions factors from activity to dose at 2 mm from the source axis should be checked once. For beta-emitters, only relative measurements are possible, since primary and secondary standards are not yet available in most countries. However, most well-type ionization chambers give a large enough current with these high activity beta sources, thus allowing a reliable relative activity check. Preferably, a comparison with an identical source should be done.

Source homogeneity can be checked with film autoradiography (radiochromic film or dose verification film). The AAPM TG-60 requirement of max +/- 10% variation at 2 mm in water is considered achievable.

Test	Test frequency
Source activity	SE
Source homogeneity	SE

3.4.2.2. Source positioning

In most cases, the source is radio-opaque or contains radio-opaque markers which allow a positioning check during each treatment by fluoroscopy. A positioning check should be done after a source exchange to avoid an error during the first treatment, or in case the source is not radio-opaque.

Test	Test frequency
Source positioning	SE

3.4.2.3. Irradiation timer

No other considerations than for standard equipment are valid here.

Test	Test frequency
Timer accuracy and linearity	A

3.4.2.4. Implant reconstruction accuracy

The only geometrical parameter that influences the dose is the vessel diameter and, in the case of stepping sources, also the length, as measured with Quantitative Coronary Angiography (QCA) or Intravascular Ultrasound (IVUS). Data concerning the accuracy of these imaging systems have not been collected. However, since each image has an internal reference (guiding catheter with QCA and catheter with IVUS), this is most likely not a problem. Further investigation, however, would be useful.

3.4.2.5. Treatment verification

Treatment time calculation should be checked independently at each treatment. Execution of the treatment must be checked manually, because not all systems provide a printed registration of the treatment progress. The treatment time in particular should be monitored by two independent timers in the case of a manual afterloader.

4 Recommendations on QC of the treatment planning system

4.1 Introduction

This chapter is an extension of NCS report 14 [42] regarding 'Quality assurance of 3-D treatment planning systems'. Only those aspects of QC that are specific for brachytherapy treatment planning systems (TPS) are dealt with.

From NCS report 14 [42] the following chapters are fully applicable to brachytherapy:

- chapter 2, Anatomical description,
- chapter 6.1, Integrity of software and data files,
- chapter 6.2, Digitizer and plotter,
- chapter 6.3, CT data transfer to the TPS, and
- chapter 7, System management and security.

This chapter deals with brachytherapy sources, implant entry, brachytherapy dose calculation models, plan evaluation and transfer of data.

Whenever available in the Treatment Planning System, it is recommended to use the formalism to calculate dose or dose rate as described in the AAPM Radiation Therapy Committee Task Group No. 43 [35]. An alternative is to use a formalism that is based on a different physical principle, namely on a separation of primary and scatter dose [8, 47]. General considerations on the quality assurance procedures for brachytherapy and brachytherapy treatment planning and dose calculations can be found in [16, 23, 35, 36, 41, 42, 48, 56].

4.2 Sources

Scope

To verify the correct description of the source properties and its dose distribution.

Background

A correct description of the source properties is essential for an accurate calculation of the dose distribution of an implant. For each source used in the institution one should verify whether the data have been entered correctly and consistently into the treatment planning computer. The TPS often has separate files in which specific source data are customized. It is the responsibility of the user of the system to document the contents of such a file in a log-book. This documentation can be used as a reference tool for routine quality control.

Suggested tests

The following tests should be performed for each source type used in the institution. Information regarding these sources should be gathered both from the manufacturer and from the literature.

Verify in the TPS:

a. the method of specification of the source strength and the conversion factors between the various quantities and units [35].
b. the consistency in the use of these quantities and units in the TPS and those used in the treatment unit.
c. the decay constant defined in the TPS and the correct calculation of the decay of the source.
d. the description of the source geometry, if applicable: overall dimensions and dimensions of the active part, thickness and composition of the capsule, filtration.
e. the constants as used for the dose calculations, e.g. absorption and scatter factors according to Meisberger et al. [32] or Kleffens and Star [28], dose rate constant, radial dose function, geometry factor and anisotropy parameters [35].
f. that the source strength of the current source is correctly entered into the system.

Frequency

- Tests a. to e. should be performed after the installation of every new software version.
- Test f. should be performed either at each source exchange in the treatment unit or for each patient (e.g. in case of ^{192}Ir wire)

Action level

- Tests a. to e. are performed to verify the integrity of the data files. Results should be identical to the data in the log-book (action level 0%), and consistent with published data (action level 5%), of the resulting dose calculation.

- Test f. is to verify that the source strength in the TPS is identical to the actual source strength (action level 0%).

Minimum requirements

Test	Test frequency	Action level
Source strength specification and conversion factors	New software	5% published data 0% logbook
Consistency of source strength specification and conversion factors in TPS and treatment unit	New software	5% published data 0% logbook
Decay constant	New software	5% published data 0% logbook
Description of source geometry	New software	5% published data 0% logbook
Dose calculation constants	New software	5% published data 0% logbook
Source strength current source	SE / P	0%

Published data specifically for sources and dose calculation data can be found elsewhere e.g. [1, 4, 7, 9, 11, 12, 16, 19, 24, 25, 29, 31, 35, 43, 49, 54, 55, 57].

4.3 Entry of the implant geometry, source position display and evaluation

Scope

To ensure that the implant geometry is correctly entered into the TPS, either by co-ordinate definition or reconstruction. To ensure that the implant geometry is correctly displayed. To ensure that the implant geometry and the source data, as described in section 4.2, are correctly documented.

Background

Brachytherapy is very sensitive to exact source positioning. Therefore, errors in source position (and source lengths e.g. in case of ^{192}Ir wires) can lead to a treatment considerably differing from that prescribed. The verification that the implant geometry is correctly displayed and that the documentation is correct can be done concurrently.

Suggested tests

From the following suggested tests select only those items that are being used in the institution. While reconstructing a catheter or needle, use either the method of 'catheter describing points' or 'catheter tracking', whatever is being used clinically. While reconstructing a catheter or needle, use both 'connector end' and 'tip end'. While reconstructing marking points, use all definitions available in the TPS, e.g., patient points, applicator points, dose points, normalization point, prescription point, markers. For each method, also add human errors, e.g. misalignment of sources, wrong definition of input parameters such as focus-isocentre-distance, and check that these errors are correctly handled by the TPS.

a. *Co-ordinate definition.* Enter a line source of 10 cm length and add a number of marking points by co-ordinate definition. Verify that the implant geometry is correctly displayed. Check the implant geometry using a plot in three orthogonal planes. Print the protocol of a dose plan and check the implant geometry co-ordinates and source data.

b. *Reconstruction from transversal images (CT / MRI / US).* Make transversal images (CT / MRI / US) of a phantom containing at least one catheter perpendicular to the images, one catheter not perpendicular to the images, one looping catheter and a number of marking points. Transfer the images to the TPS. Reconstruct the sources and the marking points. Verify that the implant geometry is correctly displayed. Check the implant geometry using a plot of three orthogonal or parallel planes. Print the protocol of a dose plan and check the implant geometry co-ordinates and source data.

c. *Reconstruction from projection images, e.g. a pair of radiographs.* Make two or more projection images, using the techniques that are being used in the institution, of a phantom containing at least one straight catheter, one looping catheter and a number of marking points at well known positions. Avoid a symmetrical phantom design which could lead to the over-projection of points. Transfer the images to the TPS.

Reconstruct the sources and the marking points. Verify that the implant geometry is correctly displayed. Check the implant geometry using a plot of three orthogonal or parallel planes. Print the protocol of a dose plan and check the implant geometry co-ordinates and the source data.

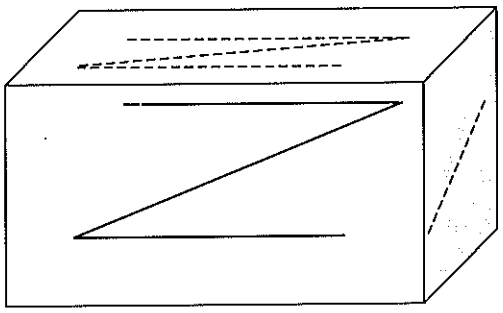


Figure 4-1: An example of a phantom which can be used to check the reconstruction of transversal images. This phantom contains wires in an N-shape, of which the endpoints can be used as marker points. The dashed lines indicate the projection of the N on the side walls of the phantom.

Frequency

These tests should be performed at least once a year and after the installation of a new software version of the TPS in accordance with section 2.2.4 of this report, or after changes in the equipment and/or methods used for the reconstruction.

Action level

- The action level is ± 2 mm.

Minimum requirements

Test	Test frequency	Action level
Co-ordinate definition	A, new software,	± 2 mm
Reconstruction from transversal images	A, new software, change equipment/method	± 2 mm
Reconstruction from projection images	A, new software, change equipment/method	± 2 mm

4.4 Automatic placement of points used for dose normalization and/or optimization

Scope

To ensure that features available in the TPS regarding the automatic placement of points used for dose normalization and/or optimization are correctly implemented.

Background

A TPS may offer tools to place specific points for dose calculation or normalization at anatomically or geometrically determined positions. The test is applicable to all features present in the TPS, e.g. dose points on the target, dose points at the lowest dose, dose points at a specified distance in a specified direction from the implant, basal dose points or points of local minimum doses as defined in the 'Paris System' [16].

Suggested tests

These tests should be performed for each method of automatic placement of points used for dose normalization and/or optimization in the institution. For each method, enter an appropriate implant geometry and define several points. Verify the correct placement of these points either by manual calculation or independent computer calculations.

- Test 1, e.g. Points on the target on transversal images of a phantom with a target indicated.
- Test 2, e.g. Points at a distance from a single line source.
- Test 3, e.g. Points at the lowest dose for an implant consisting of at least three catheters.
- Test 4, e.g. Basal dose points in a non-obtuse triangle (i.e. with angles < 90º) and a square implant (cf. the 'Paris system' [16]).

Frequency

These tests should be performed after the installation of every new software version.

Action level

- A zero action level must be maintained for geometrically defined points[1].

Minimum requirements

Test	Test frequency	Action level
Automatic placement of points for normalization / optimization	new software	0%

4.5 Dose calculation model for a single source

Scope

To ensure that the dose distribution around a single source is correctly calculated and corresponds to input data (see section 4.2).

Background

[1] In this paragraph, as well as in the following paragraphs of this chapter, a 0% action level is recommended for some of the requirements. However, a deviation from this strict action level might occur, for example, if this is due to differences in the choice of the calculation grid. The physical explanation and the acceptability of any resulting (small) deviation must be judged by the responsible medical physicist.

Correct calculation of the dose distribution around a source is an essential prerequisite for an accurate calculation of the dose distribution of a (multi-source) implant. For each source type used in the institution one should verify the algorithm and source data.

Suggested tests

- Enter a single source (surrounded by water/tissue) with a known orientation by co-ordinates. Enter marking points at clinically relevant distances (e.g. from 0.5 up to 3.0 cm) from the source preferably along the lines A, B and C, as indicated in Figure 4-2. Using the source parameters as mentioned in section 4.2, determine by manual calculations or independent computer calculations the dose or dose rate at the marking points. Make a print of the treatment plan and check that the dose or dose rate in the marking points is consistent with the independent computer calculations or manual calculations or with generally accepted literature data.

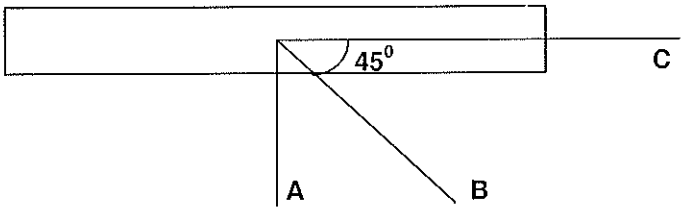


Figure 4-2: Single source geometry for dose calculation at specific points.

- Change the orientation of the implant geometry relative to the co-ordinate system for dose calculation by rotation around the source axis over 45^0 and 90^0. Ensure that the results of the dose calculations at the points are unaffected.

Frequency

These tests should be performed at least after the installation of every new software version.

Action level

- Internal consistency is associated with a zero action level, after the correction for source decay.
- Results should be consistent with published data within 5% of the local dose.

Minimum requirements

Test	Test frequency	Action level
Dose distribution around single source	new software	0% internal 5% published data
Dose distribution around single source after change in orientation	new software	0% internal 5% published data

4.6 Dose calculation for multiple sources and optimization algorithms

Scope

To verify the correct calculation of the dose distribution for implants consisting of multiple sources.

Background

In clinical practice, multiple sources inside specific catheters or needles are used for an implant. In HDR and PDR equipment, the treatment time per dwell position of a stepping source is variable. Optimization algorithms are sometimes available to improve dose distributions, e.g. dose point optimization and geometric optimization [51]. However, different optimization algorithms can lead to different results. The plausibility of the calculation, however, can be checked, and also the stability of the calculation over the time.

Suggested tests

- Enter two sources with a known orientation into the TPS by co-ordinates or by reconstruction. Enter marking points at different distances (e.g. from 0.5 up to 3.0 cm). For the geometry of the sources and the points, data similar to those in Figure 4-2 can be used. Compare with manual addition of dose or dose rate data, or with independent computer calculation.
- Only one specific test is suggested for optimization routines. Enter the configuration as indicated in Figure 4-3, i.e. 20 possible source positions with a spacing of 5 mm and ten optimization points at a distance of 10 mm from the source positions. Compare the

results of the optimized dose distributions with the non-optimized ditribution. Details of these calculations should be documented for future reference.

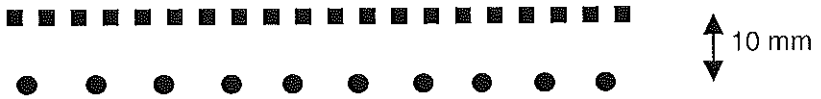


Figure 4-3: Optimization test, with 20 possible source positions (■) and 10 optimization points (•).

- In the case that the parameters of the optimization algorithms can be customized by the user, e.g. distance- or volume optimization in the case of geometric optimization, different normalization doses or weights of points in the case of dose point optimization, one should use all variables and verify the different results. Details of these calculations should be documented for future reference.

Frequency

These tests should be performed at least after the installation of every new software version.

Action level

- Results of the calculation of the 2-source geometry should be consistent with the calculation of the single source geometry, with a zero action level.
- Results of the optimization calculations should correspond with the documented reference calculation, with a zero action level.

Minimum requirements

Test	Test frequency	Action level
Calculation of a 2-source geometry	new software	0%
Optimization calculations	new software	0%

4.7 Shielding

Scope

To verify the correct transmission characteristics and geometrical properties of shielding.

Background

A TPS may offer tools to calculate the dose around an applicator in which high-Z shielding material is applied. To have a correct estimate of the dose in critical structures, it is essential that the dose distribution behind a shield is correctly calculated.

Suggested tests

Information regarding the shielding properties (i.e. transmission and geometry) of the shielded applicator should be gathered from the manufacturer of the applicator or from the literature. Enter the applicator in the TPS and make an isodose plot in at least a plane perpendicular to the shield. Verify the geometry of the shield and the shielded dose distribution. For example, compare the shielded dose distribution with the unshielded dose distribution of the same applicator and compare the transmission derived from the plots with the transmission stated by the manufacturer or the literature [11, 26, 27, 49].

Frequency

These tests should be performed after installation of every new software version.

Action level

Results should be consistent with published data or data of the manufacturer within 5% of the resulting dose calculation.

Minimum requirements

Test	Test frequency	Action level
Dose distribution around shielded applicator	new software	5%

4.8 Plan evaluation

Scope

To verify, apart from the plot and printed protocol of the plan, those extra features, such as Dose Volume Histograms (DVHs) and natural DVHs, that are available for brachytherapy treatment plan evaluation.

Background

Plan evaluation by dose volume histograms of target and normal tissues are discussed in NCS report 14 [42] on 'Quality assurance of 3-D treatment planning systems'. In brachytherapy it is also customary to calculate a dose volume histogram (DVH) within a box around the implant [51]. The natural dose volume histogram is a feature in the evaluation, specific for brachytherapy treatment planning [2].

Suggested tests

For a point source, calculate the natural DVH and verify that it is a straight line [2].

For a well described implant with multiple sources, e.g. relevant clinical examples, calculate the natural DVH and keep the results for future reference.

Ensure in both cases that the number of sampling points is sufficiently high.

Frequency

These tests should be performed after the installation of every new software version.

Action level

Results should be consistent with the documented reference calculation with a zero action level.

Minimum requirements

Test	Test frequency	Action level
Natural DVH of a single source	new software	0%
Natural DVH of a multi-source implant	new software	0%

4.9 Data transfer

Scope

To verify the correct functioning of all available export modalities of the TPS.

Background

In HDR and PDR brachytherapy it is customary that transfer of the treatment plan from the TPS to the treatment unit is performed either via a program card, a diskette or via a network. A feature to export dose distribution data to other modules of the TPS or to another TPS can be available.

Suggested tests

- If a treatment plan is transferred from the TPS to the treatment unit either by program card, a diskette or via a network, compare the printed protocol of the dose plan from the TPS and the treatment data as available in the treatment unit.
- Repeat this test for a source type with a relatively short half-life, for example, ^{192}Ir, with an extended interval (e.g. > 1 day) between preparation of the treatment plan and the entry into the treatment unit.
- If dose grids can be exported either to other modules of the TPS or to another TPS, verify the contents of the dose grid and the correct positioning of the dose distribution in relation to other features (e.g., CT/MRI/US data, external beam dose distribution).

Frequency

The tests on treatment plan transfer to the treatment unit should be performed at least after the installation of each new software version and/or system update of the treatment unit. The test of the transfer of the dose grid to another (module of the) TPS should be performed after every new software version of a TPS.

Action level

- Internal consistency is associated with a zero action level, after correction for source decay, taking into account (limited) differences in source decay factors in the TPS versus the treatment unit.

- Regarding the transfer of dose grids, an action level in the order of the coarsest grid size should be accepted. Internal consistency of the dose values is associated with a zero action level.

Minimum requirements

Test	Test frequency	Action level
Transfer of the treatment plan from the TPS to the treatment unit	new software, update treatment unit	0%
Transfer of the treatment plan from the TPS to the treatment unit with extended interval	new software, update treatment unit	0%
Transfer of dose grid to other (module of the) TPS	new software	grid size / 0%

5 Summary of the recommendations

5.1 Minimum requirements for QC of HDR and PDR brachytherapy

A summary of the current practice and minimum QC requirements, as described in chapter 2, is given in Table 5.1.

PDR-brachytherapy was developed as a combination of the many physical advantages of the single stepping source HDR remote afterloader with the radiobiological advantages of conventional low dose-rate (LDR) brachytherapy. Both HDR and PDR afterloading systems use the same type of source (^{192}Ir), although there are some differences in source construction. In practice, the source strength for HDR applications is approximately ten times higher. PDR brachytherapy simulates continuous LDR brachytherapy by a sequence of small HDR fractions. Since the PDR afterloading system is almost identical to the HDR afterloading system, except for the difference in source strength and control software, the QC procedures for both systems are very similar. For this reason, the QC programme for both machines is discussed in the same section. Whenever there is a difference between the QC procedure of both machines, this is indicated.

Table 5.1: Summary of QC recommendations for HDR/PDR brachytherapy. $f_{50\%}$ denotes the current median test frequency, while $f_{85\%}$ is the frequency defined such that 85% of the institutions perform a test with this or a higher frequency. An 'X' in the $f_{50\%}$ ($f_{85\%}$) column means that at least 50% (15%) of the institutions do not perform this test as part of the QC programme. An '-' in the current practice means that this aspect was not investigated in the questionnaires. An '-' in the recommended action levels means that an action level for this test is not applicable.

Description	*Section*	*Current practice*		*Minimum requirements*	
		$f_{50\%}$	$f_{85\%}$	*Test frequency*	*Action level*
Safety systems					
Warning lights	2.1.1	3M	3M	4M	-
Room monitor	2.1.1	W	3M	4M	-
Audio / visual communication system	2.1.1	-	-	4M	-
Emergency buttons	2.1.2	3M	3M	4M	-
Interrupt	2.1.2	3M	4M	4M	-
Door interlock	2.1.2	3M	3M	4M	-
Power loss	2.1.2	3M	A	4M	-
Unlocked indexer ring	2.1.2	-	-	4M	-
Obstructed applicator	2.1.2	-	-	4M	-
Missing applicator	2.1.2	-	-	4M	-
Leakage radiation	2.1.3	3M	X	SE	-
Contamination test	2.1.3	4M	X	SE	-
Integrity of transfer tubes and Applicators	2.1.4	-	-	6M	-
Emergency equipment	2.1.5	-	-	4M	-
Hand crank functioning	2.1.5	-	-	A	-
Practising emergency procedure	2.1.5	A	X	A	-
Physical parameters					
Source calibration	2.2.1	3M	3M	SE	± 5%
Source position	2.2.2	3M	3M	4M	± 2 mm
Irradiation timer	2.2.3	3M	X	A	± 1%
Implant reconstruction	2.2.4	X	X	A	95% < 2 mm
Treatment verification	2.2.5	P	P	P	-

5.2 Minimum requirements for QC of LDR brachytherapy

A summary of the current practice and minimum QC requirements in LDR brachytherapy is given in Tables 5.2 and 5.3. Because of the difference in operation between S-LDR afterloaders with Cs pellets and m-LDR afterloaders with Ir wires or Ir/Cs seeds, the current QC practice and recommendations are treated in two separate sections.

5.2.1. Cs-LDR brachytherapy

Table 5.2: Summary of QC recommendations for Cs-LDR brachytherapy. $f_{50\%}$ denotes the current median test frequency, while $f_{85\%}$ is the frequency defined such that 85% of the institutions perform a test with this or a higher frequency. An 'X' in the $f_{50\%}$ ($f_{85\%}$) column means that at least 50% (15%) of the institutions do not perform this test as part of the QC programme. An '-' in the current practice means that this aspect was not investigated in the questionnaires. An '-' in the recommended action levels means that an action level for this test is not applicable.

Description	*Section*	*Current practice*		*Minimum requirements*	
		$f_{50\%}$	$f_{85\%}$	*Test frequency*	*Action Level*
Safety systems					
Warning lights	2.1.1	6M	A	4M	-
Room monitor	2.1.1	3M	6M	4M	-
Audio / visual communication system	2.1.1	-	-	4M	-
Emergency buttons	2.1.2	A	X	6M	-
Interrupt	2.1.2	6M	A	6M	-
Door interlock	2.1.2	6M	A	6M	-
Power loss	2.1.2	6M	A	6M	-
Air pressure loss	2.1.2	6M	A	6M	-
Obstructed applicator	2.1.2	-	-	6M	-
Missing applicator	2.1.2	-	-	6M	-
Leakage radiation	2.1.3	X	X	A	-
Contamination test	2.1.3	X	X	A	-
Integrity of transfer tubes and applicators	2.1.4	-	-	6M	-
Emergency equipment	2.1.5	-	-	6M	-
Practising emergency procedure	2.1.5	X	X	A	-
Physical parameters					
Source calibration	2.2.1	SE	X	SE	Mean ± 5%
Source position	2.2.2	X	X	6M	± 2 mm
Irradiation timer	2.2.3	X	X	A	± 1%
Implant reconstruction	2.2.4	X	X	A	95% < 2 mm
Treatment verification	2.2.5	P	P	P	-

5.2.2. LDR brachytherapy with Ir/Cs wires and seeds

Table 5.3: Summary of QC recommendations for LDR brachytherapy with Ir or Cs wires/seeds. $f_{50\%}$ denotes the current median test frequency, while $f_{85\%}$ is the frequency defined such that 85% of the institutions perform a test with this or a higher frequency. An 'X' in the $f_{50\%}$ ($f_{85\%}$) column means that at least 50% (15%) of the institutions do not perform this test as part of the QC programme. An '-' in the current practice means that this aspect was not investigated in the questionnaires. An '-' in the recommended action levels means that an action level for this test is not applicable.

Description	Section	Current practice		Minimum requirements	
		$f_{50\%}$	$f_{85\%}$	Test frequency	Action level
Safety systems					
Warning lights	2.1.1	2M	6M	4M	-
Room monitor	2.1.1	P	6M	4M	-
Audio / visual communication system	2.1.1	-	-	4M	-
Emergency buttons	2.1.2	3M	X	6M	-
Interrupt	2.1.2	3M	6M	6M	-
Door interlock	2.1.2	3M	6M	6M	-
Power loss	2.1.2	3M	6M	6M	-
Air pressure loss	2.1.2	6M	A	6M	-
Obstructed applicator	2.1.2	-	-	6M	-
Missing applicator	2.1.2	-	-	6M	-
Leakage radiation	2.1.3	X	X	A	-
Contamination test	2.1.3	A	X	A	-
Integrity of transfer tubes and applicators	2.1.4	-	-	6M	-
Emergency equipment	2.1.5	-	-	6M	-
Practising emergency procedure	2.1.5	X	X	A	-
Physical parameters					
Source calibration	2.2.1	SE	X	SE	Mean ± 10%
Source position	2.2.2	P	X	P	± 2 mm
Source length	2.2.2	P	X	P	± 2 mm
Irradiation timer	2.2.3	X	X	A	± 1%
Implant reconstruction	2.2.4	X	X	A	95% < 2 mm
Treatment verification	2.2.5	P	P	P	-

5.2.3. Manual afterloading brachytherapy

Manual afterloading brachytherapy is applied mostly for skin, breast and bladder treatments. Quality control of manual afterloading is comparable with QC of LDR brachytherapy with Ir or Cs wires and seeds. Therefore, the reader is referred to section 5.2.2 for a list of minimum requirements (test frequencies and action levels) of the tests applicable to manual afterloading.

In addition, the source strength should be carefully checked before each patient treatment by verifying the source identity and the source strength certificate.

Sufficient shielding should be provided during handling and patient treatment to protect the personnel. After termination of the treatment, it should be carefully checked that all sources are removed from the applicators.

5.3 Test methods for QC of HDR, PDR and LDR brachytherapy

In this section, test methods for the QC checks of HDR, PDR and LDR brachytherapy are described. It is emphasized that the methods indicated here are *possible,* not exclusively the only methods. Institutions may have developed their own method(s), adapted to their situations.

- Warning lights

Check that the warning light functions when the source is transferred

- Room monitor

Check that the radiation light functions when the source is transferred

- Audio / visual communication system

Check that the video and audio contact with treatment room occupants function properly

- Emergency stop buttons

Check that pressing the emergency stop button results in source retraction. Check that the remaining treatment parameters are indicated correctly at the control panel

- Interrupt button

Check that pressing the interrupt button results in source retraction. Check that the programmed treatment parameters and the remaining dwell time are correctly recalled upon treatment resume

- Door interlock

Check that an open treatment room door prevents activation from the console. Check that opening of the door during treatment results in source retraction

- Power loss

Check that an interrupt of the AC power during treatment results in immediate source retraction. Check that, upon restoring the power, the treatment parameters and remaining dwell time are correctly recalled

- Air pressure loss

Check that interruption of the air pressure during treatment results in immediate source retraction. Check that, upon restoring the air pressure, the treatment parameters and remaining dwell time are correctly recalled

- Unlocked indexer ring

Check that the afterloader prevents source transfer when the indexer ring is not locked. Check that the audible and visual error indicators function properly and that the correct error code is displayed

- Obstructed applicator

Check that the afterloader retracts the source if an obstruction is detected. Check that the audible and visual error indicators function properly and that the correct error code is displayed

- Missing applicator

Check that the afterloader prevents source transfer if the applicator is not connected to a programmed channel. Check that the audible and visual error indicators function properly and that the correct error code is displayed

- Leakage radiation

Check that the radiation level with the source retracted at 10 cm and at 1 m from the source container of the afterloader is lower than the legal requirement

- Contamination test

Perform a wipe test at the check-cable, transfer tubes and applicators, and check that the radiation level is not higher than the legal limit

- Integrity of transfer tubes and applicators

Visually inspect the transfer tubes and applicators and connections for wear and tear

- Emergency equipment

Check that emergency instructions, operator's manual, forceps, tweezers, emergency safe, surgical supplies and survey meter are present and function properly. Check that the manual source retraction crank functions properly

- Source calibration

Perform in-house source calibration according to one of the methods described in NCS-reports 4 [38] and 7 [39] Check the measured value with the source strength certificate

- Source position

Check that the position of at least one source position in the catheter is correct using a check ruler, or obtain an autoradiograph and check dwell positions and spacings

- Irradiation timer

Check the absolute accuracy and linearity of the machine timer by comparing the programmed treatment time with a stopwatch

- Implant reconstruction

Check the implant reconstruction by reconstructing an object with well-known dimensions

- Treatment verification

Verify date, time and source strength in treatment unit and planning computer (HDR/PDR). Compare, whenever possible, the calculated total treatment time with standards or literature estimations (see, e.g., Ref. [18, 33, 52]) Verify the printout for correct treatment delivery according to the treatment plan

5.4 *Recommendations for QC of coronary brachytherapy systems using beta sources*

A summary of the recommendations for QC of vascular brachytherapy, as described in chapter 3, is given in Table 5.4.

Table 5.4: Summary of QC recommendations for vascular brachytherapy.

Description	*Section*	*Recommendations*
		Test frequency
Safety systems		
Interrupt	3.4.1.2	SE or 4M
Power loss	3.4.1.2	SE or 4M
Manual retraction	3.4.1.2	SE or 4M
Obstructed applicator	3.4.1.2	P
Missing applicator	3.4.1.2	SE or 4M
Leakage radiation	3.4.1.3	SE or A
Contamination test	3.4.1.3	P
Integrity of applicators	3.4.1.4	P
Emergency equipment	3.4.1.5	4M
Practising emergency procedure	3.4.1.5	A
Physical parameters		
Source activity	3.4.2.1	SE
Source homogeneity	3.4.2.1	SE
Source position	3.4.2.2	SE
Timer accuracy	3.4.2.3	A
Treatment verification	3.4.2.5	P

5.5 *Minimum requirements for QC of the Treatment Planning System*

A summary of the recommendations for QC of the Treatment Planning System, as described in chapter 4, is given in Table 5.5.

Table 5.5. Summary of QC recommendations for the brachytherapy treatment planning system.

Description	*Section*	*Minimum requirements*	
		Test frequency	*Action level*
Source strength specification and conversion factors	4.2	New software	5% published data 0% logbook
Consistency of source strength specification and conversion factors in TPS and treatment unit	4.2	New software	5% published data 0% logbook
Decay constant	4.2	New software	5% published data 0% logbook
Description of source geometry	4.2	New software	5% published data 0% logbook
Dose calculation constants	4.2	New software	5% published data 0% logbook
Source strength current source	4.2	SE, P	0%
Co-ordinate definition	4.3	A, new software	± 2 mm
Reconstruction from transversal images	4.3	A, new software, change equipment/method	± 2 mm
Reconstruction from projection images	4.3	A, new software, change equipment/method	± 2 mm
Automatic placement of points for normalization / optimization	4.4	new software	0%
Dose distribution around single source	4.5	new software	0% internal 5% published data
Dose distribution around single source after change in orientation	4.5	new software	0% internal 5% published data

Calculation of a 2-source geometry	4.6	new software	0%
Optimization calculations	4.6	new software	0%
Dose distribution around shielded applicator	4.7	new software	5%
Natural DVH of a single source	4.8	new software	0%
Natural DVH of a multi-source implant	4.8	new software	0%
Transfer of the treatment plan from the TPS to the treatment unit	4.9	new software, update treatment unit	0%
Transfer of the treatment plan from the TPS to the treatment unit with extended interval	4.9	new software, update treatment unit	0%
Transfer of dose grid to other (module of the) TPS	4.9	new software	grid size / 0%

Appendix 1 Methods for the determination of the accuracy of implant reconstruction and dose delivery

To gain insight into the accuracy of brachytherapy treatments, the accuracy of implant reconstruction and dose delivery has been determined in 39 radiotherapy institutions in The Netherlands and Belgium. The results of these on-site measurements will be published separately [17]. Here, the methods are described which were used to determine the accuracy of the implant reconstruction and the dose delivery. These methods can be used by the individual institutions for QC on their equipment.

A1.1 Determination of the implant reconstruction accuracy

To check the reconstruction methods used with brachytherapy localizers, a cubical PMMA phantom consisting of six identical 20 mm thick slabs was used [5]. At each interface between the slabs, five 2 mm spheres are inserted (see Figure A1). The positions of the spheres is known with an accuracy of ± 0.1 mm (1 SD).

The phantom is reconstructed using the equipment that is routinely used for reconstruction of brachytherapy implants. For this purpose, the phantom is positioned on the treatment table with the central marker close to the isocentre of the localizer. The co-ordinates of the spheres are determined by reconstruction from two X-ray films. From these co-ordinates, 300 inter-sphere distances can be calculated, ranging from 20-140 mm. The reconstructed distances are compared with the true distances. In this way, an average deviation of the 300 inter-sphere distances can be determined. The final result reflects the geometrical accuracy of the localizer equipment, the digitizer and the reconstruction algorithm.

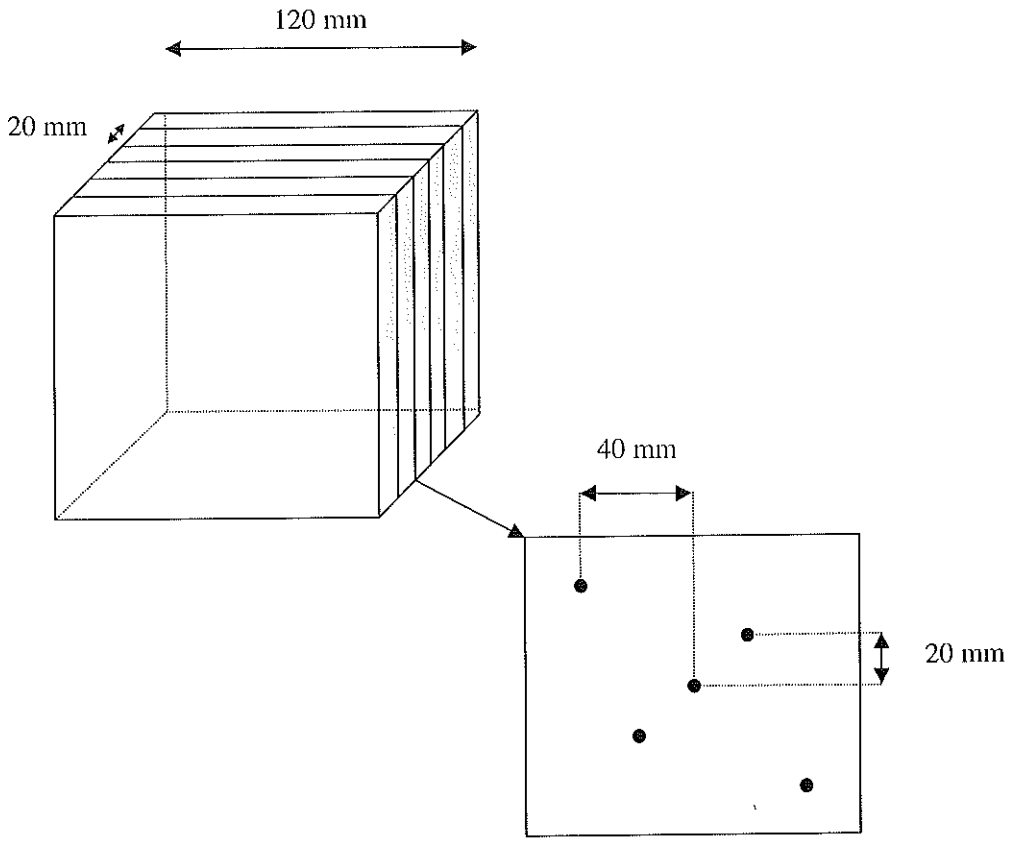


Figure A1: The geometry of the reconstruction phantom. The phantom contains 25 spheres at well-known positions, from which 300 inter-sphere distances can be calculated, varying between 20 and 140 mm.

A1.2 Determination of the dose delivery accuracy

To determine the accuracy of the dose delivery, a solid phantom is used, first described by Meertens [30]. The phantom is a PMMA cylinder with a diameter of 20.0 cm and a height of 15.0 cm. An ionization chamber is positioned centrally in the phantom and three brachytherapy applicators are placed at 5.0 cm from the ionization chamber, equally spaced at 120^0 angles (see Figure A2). The dose delivered during the treatment is measured using an ionization chamber with a build-up cap, in combination with an electrometer. The measured electrometer reading is converted into a dose to water reading by using a set of correction factors. The dose to water reading is then compared with the prescribed dose to determine the accuracy of the dose delivery.

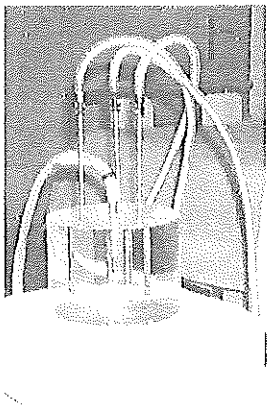


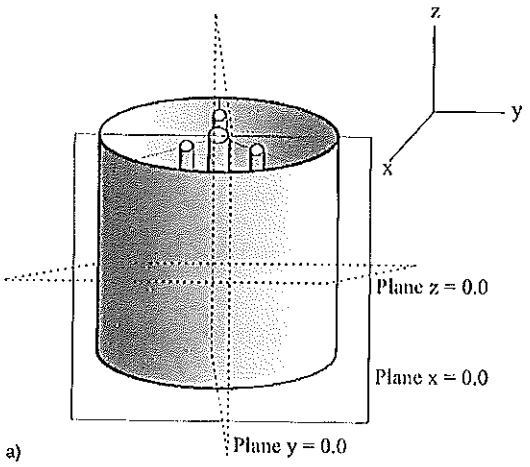
Figure A2: Cylindrical dose phantom. Three applicators are positioned at 5.0 cm from the centrally placed ionization chamber.

A1.2.1 Measurement procedure

A treatment plan is prepared to deliver a prescribed dose in the centre of the ionization chamber using fixed source positions. The source positions are based on the source calibration protocols for ^{192}Ir HDR sources [39] and ^{137}Cs pellets [38] for this phantom. For HDR and PDR afterloaders, one source position per catheter is used in the same plane as the reference point of measurement (the centre of the ionization chamber). For Selectron LDR afterloaders, six sources per catheter are used, three on both sides of the central plane of the phantom at distances 17.5 mm, 20.0 mm and 22.5 mm from that plane (Figure A3).

Because the reconstruction accuracy is measured separately, the source positions are inserted in the treatment planning system (TPS) using co-ordinates and not by reconstruction of the phantom. In this way, the error in dose delivery caused by an error in reconstruction of the setup is ignored. If the source position co-ordinates cannot be inserted directly into the treatment planning systems (as is the case with some TPSs) the geometry has to be reconstructed from a drawing of the experimental setup.

The value for the prescribed dose was determined as a compromise between the accuracy of the electrometer and practical considerations, such as the required measuring time. A prescribed dose value of 75 cGy for HDR, 40 cGy for PDR, and 20 cGy for LDR afterloaders has been used. These doses result in treatment times (depending on source strength) of approximately five minutes for a 2 cGym^2/h HDR ^{192}Ir source, 25 minutes for a 0.22 cGym^2/h ^{192}Ir PDR source, and 45 minutes for 0.004 cGym^2/h ^{137}Cs LDR sources.



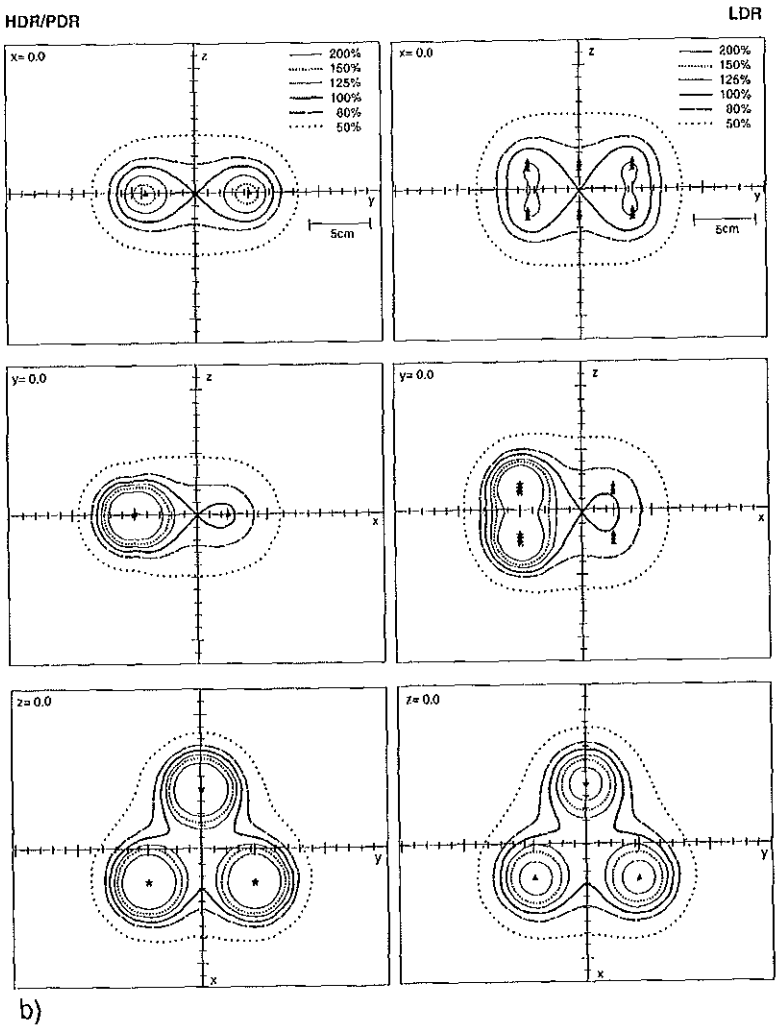


Figure A3: The dose distribution for the cylindrical dose phantom (a) for HDR/PDR and Selectron LDR afterloaders in three orthogonal planes passing through the reference point of measurement of the ionization chamber (b).

After installation of the phantom, air temperature and pressure are recorded. The dose delivery measurement in the phantom is performed three times, using the dwell times calculated by the TPS. The measurement is performed with plastic catheters or needles, corresponding to the normal use for treatments in the institution.

A1.2.2 Conversion of electrometer readings to dose to water

The electrometer reading is converted to a dose to water using the equation [39] :

$$D_w = MN_K \Pi k_i \Pi p_i \Pi f_i S(d) \left(\frac{\mu}{\rho}\right)_{air}^{water} (1-g) \qquad (1)$$

where

$M = M_{uncorr} p_{,} p_p p_{hum} p_{ion} p_{pol}$

$\Pi p_i = p_r p_{ce}$

$\Pi k_i = k_w k_{st} k_{ce}$

$\Pi f_i = f_{tr} f_{ph} f_{geo} f_{cath}$

The meaning and value of these factors are described in Table A.1. Most of these factors were taken from earlier publications [30,38,39,50]. The air kerma calibration factor for ^{192}Ir of the ionization chamber with build-up cap in combination with the electrometer has to be derived from N_k-factors obtained during calibration at the National Standards Laboratory. Values for the mass-energy absorption coefficient $(\mu/\rho)_{air}^{water}$ for ^{192}Ir and ^{137}Cs can be found in literature [13,46]. In treatment planning systems, either the value 1.10 or 1.11 is used. Here, the value of 1.11 is used in the calculations. The influence of the transit dose (f_{tr}) and the applicator attenuation (f_{cath}) has to be determined separately and will be discussed in the next sections.

The dose in water derived from the measurements is then compared with the prescribed dose to determine the accuracy of the dose delivery.

Table A.1. Factors for conversion of the electrometer reading to dose in water for ^{192}Ir and ^{137}Cs sources measured in the PMMA cylindrical phantom using a NE2571 ionization chamber (see also references [30,38,39,50]).

Factor	Description	Value for ^{192}Ir in the phantom	Value for ^{137}Cs in the phantom
M_{uncor}	Uncorrected instrument reading		
p_t	Temperature correction factor	$(T_{meas}+273.15/T_{calibration})$	
p_p	Air pressure correction factor	$(p_{calibration} / p_{meas})$	
p_{hum}	Humidity correction factor	1.000	
p_{ion}	Ion recombination correction factor	1.000	
p_{pol}	Correction factor for polarity effects	1.000	
N_K	Air kerma calibration factor	From calibration	From calibration
p_r	Correction factor for replacement of PMMA by the ionization chamber	1.016	0.997
p_{ce}	Correction factor for the effect of the central electrode during the measurement	1.000	
k_w	Correction factor for attenuation and scatter in the chamber wall	0.984	0.99
k_{st}	Correction for the stem effect during calibration	1.000	
k_{ce}	Correction for the effect of the central electrode during calibration	1.000	
f_{tr}	Correction factor for source transport time	Variable	1.000
f_{ph}	Conversion factor from the specified PMMA phantom to a full-scatter water phantom	1.033	1.041
f_{geo}	Correction factor for absorption and scatter in water	$1 / S(d)$	
f_{cath}	Correction factor for attenuation in plastic catheter / needles	1.000 / 1.009	Included in f_{ph}
$S(d)$	Correction factor for scattering and absorption in the phantom material	See ref. [28,32]	
$(\mu/\rho)_{air}^{water}$	Mass-energy absorption coefficient	1.11	
g	Fraction of kinetic energy of secondary particles converted to bremsstrahlung	0.000	0.003

A1.2.3 Determination of the transit dose correction factor

The clinical treatment planning generally neglects the transit dose, i.e. the dose delivered during transport of the source from the afterloader to the patient. The transit dose depends on the source strength, the velocity of the source transport and the geometry of the setup. To compare the dose measured in the phantom with the dose calculated by the planning system, and to compare measurements in different institutions, the measured dose was corrected for the transit dose using the factor f_{tr} [39]. For a fixed geometry, such as the dose phantom, the value for this factor can be derived from:

$$f_{tr} = 1 - \frac{M_{t0}}{M_t} \qquad (2)$$

Where t is the dwell time, M_{t0} is the electrometer reading at $t=0$ (zero dwell time, only dose contribution during source transport) and M_t is the electrometer reading for dwell time t. The value for $t=0$, M_{t0}, is determined for the specific geometry by programming dwell times in the range of 5 to 120 seconds per channel and by linear extrapolation of the measured doses to $t=0$. Since the transit dose linearly depends on the source strength, and experience has shown that the source transport velocities on identical machines are comparable, its value for identical machines in different institutions can be calculated from the value measured on a single afterloader with reasonable accuracy.

A1.2.4 Attenuation in the applicator wall

To determine the difference in attenuation between plastic catheters and needles during HDR/PDR measurements, a correction factor f_{cath} was determined. For this purpose, an HDR afterloader was connected to three plastic catheters or stainless steel needles which were placed in the solid phantom. The value for f_{cath} was determined as the ratio of the reading obtained when using plastic catheters and the reading obtained when using needles and was found to be 1.009±0.003.

For the Selectron LDR afterloader, the factor f_{cath} for the replacement of water-equivalent catheters by the stainless steel standard catheters is included in the factor f_{ph} [30]. In most treatment planning systems, attenuation of applicators is not taken into account.

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