Canadian Association of Provincial Cancer Agencies

Standards for Quality Control at Canadian Radiation Treatment Centres

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Medical Linear Accelerators

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Developed, revised and approved by THE CANADIAN ORGANIZATION OF MEDICAL PHYSICISTS and THE CANADIAN COLLEGE OF PHYSICISTS IN MEDICINE

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Document development and review process: The quality control documents in this series originated from one of two sources. Some of the source documents were commissioned by CAPCA specifically for the purpose of developing national standards. This is one such document. Others had been previously developed for provincial use by the Physics Professional Affairs Committee of Cancer Care Ontario (formerly the Ontario Cancer Treatment and Research Foundation). The source documents were developed over an extended period of time from 1989 to the present. Each source document was reviewed by one or more independent Canadian medical physicists and the reviews accepted by the task group as they became available. The primary and secondary task group reviewers then examined the source document, the external review(s) and any appropriate published literature to propose quality control standards, objectives and criteria to the full task group. The full task group met electronically and, by a consensus approach, developed the present document. The task group gratefully acknowledges the effort contributed by the author(s) of the source document and the reviewer(s) whose work forms the basis of this document. Extensive review, updating and reformatting have been performed and, for any errors or omissions introduced in this process, the task group takes full responsibility.

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Acronyms, Synonyms and Definitions

AAPM	American Association of Physicists in Medicine
ADCL	Accredited Dosimetry Calibration Laboratory
Al	Aluminum
AMFPI	Active Matrix Flat Panel Imaging Devices
ANSI	American National Standards Institute
BSF	Back-scatter factor
CAPCA	Canadian Association of Provincial Cancer Agencies
CCO	CancerCare Ontario
CCPM	Canadian College of Physicists in Medicine
CNSC	Canadian Nuclear Safety Commission (Successor to the Atomic Energy Control Board - AECB)
COMP	Canadian Organization of Medical Physics
CSA	Canadian Standards Association
CT	Computed Tomography
CTV	Clinical target volume
Cu	Copper
EPI(D)	Electronic portal imaging (device)
FWHM	Full width at half maximum
Gleason score	A numerical system based on major and minor histological patterns
Gy	Gray, unit of absorbed dose (1J/kg)
HVL	Half-value layer
IAEA	International Atomic Energy Agency
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission (Geneva, Switzerland)
IMRT	Intensity modulated radiation therapy
INMS-NRCC	Institute for National Measurement Standards of the National Research Council of Canada
IPEM	Institution of Physics and Engineering in Medicine
IPSM	Institute of Physical Sciences in Medicine

ISO	International Organization for Standardization
Isocentre	The intersection of the axes of collimator and gantry rotation
Linac	Electron linear accelerator
MLC	Multileaf collimator
mMLC	mini- or micro-Multileaf Collimator
MPPAC	Medical Physics Professional Advisory Committee
MRI	Magnetic Resonance Imaging
MU	Monitor unit
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Standards and Technology
NRCC	National Research Council of Canada
NTD	Normal treatment distance
ODI	Optical distance indicator
PMMA	Polymethyl methacrylate
PDD	Percentage depth dose
PSA	Prostate specific antigen
PTV	Planning target volume
QA	Quality assurance (the program)
QC	Quality control (specific tasks)
SSD	Source-to-surface distance
SRS	Stereotactic radiosurgery
SRT	Stereotactic radiotherapy
STP	Standard temperature and pressure
TBI	Total body irradiation
TG-	Publications of various AAPM Quality Assurance Task Groups
TLD	Thermoluminescent dosimeter
U	air-kerma strength (μGy m^2/h)
WHO	World Health Organization
σ	Standard deviation
ε_T	Timer/monitor end error

Frequencies:

Daily:	Once during every treatment day and separated by at least 12 hours.
Weekly:	On average once every 7 days and at intervals of between 5 and 9 days
Monthly:	On average once every four weeks and at intervals of between 3 and 5 weeks
Annually	On average once every 12 months and at intervals of between 10 and 14 months.

Output:

Output constancy check: a daily instrument reading (corrected for temperature and pressure) taken under reproducible geometrical conditions designed to check that the radiation output (e.g. cGy/MU) values in clinical use are not grossly in error.

Output Measurement: a determination of the absorbed dose to water (cGy) at a reference point in the photon beam for a chosen field size and beam quality.

Introduction

Patients receiving treatment in a Canadian cancer centre have a reasonable expectation that the quality of their treatment is independent of their geographic location or the centre they are attending. Insofar as medical physicists contribute to treatment quality, this expectation will be more closely met through the harmonisation of quality control standards across the country. The Canadian Association of Provincial Cancer Agencies (CAPCA) has initiated the process of standardisation of treatment quality in Canada through its draft document "Standards for Quality Assurance at Canadian Radiation Treatment Centres". This present document is an appendix to the CAPCA document and is concerned with quality control standards for use with medical linear accelerators. It is based on a report originally prepared for the Medical Physics Professional Advisory Committee of Cancer Care Ontario.

A quality control program on equipment used to deliver radiotherapy in a Canadian cancer centre must be carried out by, or under the direct supervision of, a qualified medical physicist. Here, a qualified medical physicist is one who is certified in Radiation Oncology Physics by the Canadian College of Physicists in Medicine or who holds equivalent certification. This individual, known as the supervising physicist, is responsible for ensuring compliance with the local quality control protocol, maintaining appropriate documentation, taking appropriate remedial actions and communication with other members of the radiation therapy team concerning the operational state of the equipment. Depending on local circumstances and organisational structure, one physicist may supervise quality control on all equipment or the responsibilities may be dispersed. However, the supervising physicist for a particular piece of equipment must have a direct line of communication to the Quality Assurance Committee for the Radiation Treatment Program.

This document contains specific performance objectives and criteria that the equipment should meet in order to assure an acceptable level of treatment quality. However, it does not recommend how the tests should be carried out. It is the responsibility of the supervising physicist to ensure that locally available test equipment and procedures are sufficiently sensitive to establish compliance or otherwise with the objectives and criteria specified here. There are several other publications dealing with the performance, specifications and quality control of medical linear accelerators (Van Dyk, 1999; IPEM 1999; AAPM 1994). Many of these publications have extensive reference lists. Some have detailed descriptions indicating how to conduct the various quality control tests.

Radiation safety activities are beyond the scope of this report. However, such activities may be integrated into routine quality control programs of equipment.

A successful quality assurance program is critically dependent upon adequately trained staff and a culture of continuous quality improvement. Educational opportunities to be offered to quality control staff must include new staff orientation, in-house continuing education, conference participation and manufacturer's courses as appropriate. All such

educational activities must be documented as part of the quality assurance program. Continuous quality improvement embodies the concepts of documentation, monitoring, review and feedback.

The standards promoted in this document are based on the experience of the authors and reviewers and are broadly consistent with recommendations from other jurisdictions (AAPM, 1994; IPEM, 1999; IAEA 2003). Although this document has undergone extensive review it is possible that errors and inaccuracies remain. It is hoped that the users of these standards will contribute to their further development through the identification of shortcomings and advances in knowledge that could be incorporated in future versions.

Performance Objectives and Criteria

Objectives and criteria for the evaluation of the performance of radiotherapy equipment fall into several categories.

1. Functionality. Equipment systems and sub-systems for which the criterion of performance is "Functional" are either working correctly or not. Such systems are commonly associated with the safety features of the equipment or installation. Operating a facility which has failed a test of functionality has the potential to expose patients and staff to hazardous conditions.

2. Reproducibility. The results of routine quality control tests, for which reproducibility is the criterion, are assessed against the results obtained at installation from the accepted unit. Tolerances and action levels may be set for parameters that can be quantified.

3. Accuracy. Accuracy is the deviation of the measured value of a parameter from its expected or defined value. Examples are isocentre diameter and reference dosimetry (cGy/MU).

4. Characterisation and documentation. In some cases it is necessary to make measurements to characterise the performance of a piece of equipment before it can be used clinically. An example is the measurement of the ion collection efficiency.

5. Completeness. The use of this term is restricted to the periodic review of quality control procedures, analysis and documentation.

For quantities that can be measured, tolerance and action levels may be defined.

i. Tolerance Level. For a performance parameter that can be measured, a tolerance level is defined. If the difference between the measured value and its expected or defined value is at or below the stated tolerance level then no further action is required as regards that performance parameter.

ii. Action Level. If the difference between the measured value and its expected or defined value exceeds the action level then a response is required immediately. The ideal response is to bring the system back to a state of functioning which meets all tolerance levels. If this is not immediately possible, then the use of the equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance. The decision concerning the most appropriate response is made by the supervising physicist in conjunction with the users of the equipment and others as appropriate. If the difference between the measured value and its expected or defined value lies between the tolerance and action levels, several courses of action are open. For a problem that is easily and quickly rectifiable, remedial action should be taken at once. An alternative course of action is to delay remedial action

until the next scheduled maintenance period. Finally, the decision may be made to monitor the performance of the parameter in question over a period of time and to postpone a decision until the behaviour of the parameter is confirmed. Once again, this will be a decision made by the supervising physicist in consultation with the users of the equipment and others as appropriate.

Documentation of equipment performance is essential and is discussed later. However, at the conclusion of a series of quality control tests it is essential to inform the users of the equipment of its status. If performance is within tolerance verbal communication with the users is sufficient. If one or more parameters fails to meet Action Level criteria, and immediate remedial action is not possible, then the users of the equipment must be informed in writing of the conditions under which the equipment may be used. Compliance with Action Levels but failure to meet Tolerance Levels for one or more parameters may be communicated verbally or in writing depending on the parameters and personnel involved. The judgement of those involved will be required to make this decision.

It is recognized that older equipment, which either was not designed to or is currently unable to meet the standards described here, is still providing a useful service to patients in many centres. In such cases, the equipment may fail to meet all action level requirements and the use of such equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance.

System Description

Medical linear accelerators (linacs) are cyclic accelerators which accelerate electrons to kinetic energies from 4 MeV to 25 MeV using non-conservative microwave RF fields in the frequency range from 103 MHz (L band) to ~10^4 MHz (X band), with the vast majority running at 2856 MHz (S band).

In a linear accelerator the electrons are accelerated following straight trajectories in special evacuated structures called accelerating waveguides. Electrons follow a linear path through the same, relatively low potential difference several times; hence, linacs also fall into the class of cyclic accelerators just like the other cyclic machines that provide curved paths for the accelerated particles (e.g., betatron).

The high power RF fields, used for electron acceleration in the accelerating waveguides, are produced through the process of decelerating electrons in retarding potentials in special evacuated devices called magnetrons and klystrons.

Various types of linacs are available for clinical use. Some provide x-rays only in the low megavoltage range (4 MV or 6 MV) while others provide both x-rays and electrons at various megavoltage energies. A typical modern high energy linac will provide two or three photon energies [usually a combination of a low (4 to 10 MV) and a high (12 to 25 MV) photon beam] and several electron energies (ranging from 4 to 22 MeV).

Detailed descriptions of the principles and practice of medical linear accelerators may be found elsewhere (Karzmark, 1998; Metcalfe, 1997).

Increasingly, technologically complex accessories are being added to medical linear accelerators. Separate standards have been developed for many of these such as multileaf collimators and electronic portal imaging devices. These standards are described in other documents in this series.

Acceptance Testing and Commissioning

Medical linear accelerators that are newly acquired or substantially upgraded require acceptance testing before being put into clinical service. Acceptance tests have three purposes:

- to ensure that the unit meets stated specifications,
- to establish baseline parameters for the future quality control program,
- to familiarize the customer with operation of the unit.

In addition acceptance testing of the equipment and facility will include establishing compliance with applicable radiation safety codes. These are included in federal and/or provincial regulations and it is the supervising physicist or designate's responsibility to be familiar with these requirements and to demonstrate compliance. Decommissioning of radiotherapy equipment and facilities may also be regulated by provincial and/or federal authorities.

Acceptance tests are customarily described in a document prepared by the vendor, although the purchaser may wish to specify additional tests. The document is signed by the purchaser upon satisfactory completion of testing, before which formal purchase of the unit should not be completed.

The standards for medical linear accelerator acceptance testing should be consistent with routine quality control objectives and criteria applied subsequently. In particular, there is no reason why a new or upgraded linac, and its associated safety systems, should not meet the Tolerance Levels detailed later in this document (Table 1). Optical, mechanical, radiological and safety tests must be included. The tests should be performed by, or under the supervision of, a qualified medical physicist.

Adherence to these standards (Table 1) must be demonstrated and documented, in or outside of the vendor's acceptance testing protocol, before a new medical linear accelerator or major upgrade is accepted, and put into clinical service. Also, an appropriate subset of acceptance tests must be performed after any repair or preventive maintenance interventions on the linac. The extent of testing required must be judged by a qualified medical physicist.

Commissioning generally refers to the acquisition of additional measured data from a unit after most acceptance testing is completed, with two purposes:

- for subsequent calculations, for example, involving radiation dose,
- to establish baseline parameters for the future quality control program.

Clearly all the tests listed in Table 1 must be performed at this time with the intended local test equipment and protocols if meaningful baselines are to be established.

Quality Control of Equipment

The purpose of a quality control program is to assure that operational standards for a unit that were considered acceptable at time of purchase continue to be maintained, as closely as possible, over the life of the unit. Thus, quality control tests typically are periodic repetitions, partial or full, of acceptance and commissioning tests. For medical linear accelerators, tests are required for optical, mechanical, radiological and safety systems.

The standards for medical linear accelerator quality control are listed in Table 1. These minimum standards consist of a series of tests to be performed, along with their minimum frequency. The tests are derived from the published literature and, in particular, the standards laid out in the AAPM document, TG-40, (AAPM, 1994) and the IPEM document, Report 81 (IPEM, 1999). The Tolerance Level is typically set at 50-75% of the Action Level.

The tests should be performed by a qualified medical physicist, or a suitably trained individual working under the supervision of a qualified medical physicist. Independent verification of the results of quality control tests is an essential component of any quality control program. To ensure redundancy and adequate monitoring, a second qualified medical physicist must independently verify the implementation, analysis and interpretation of the quality control tests at least annually. This independent check must be documented.

Daily tests must be scheduled at the beginning of each working day. For other tests, testing at less than the minimum frequency is permissible only if experience has established that the parameters of interest are highly stable. Documentary evidence supporting this decision is essential. It is unlikely that a frequency of less than half those specified here could be justified. Conversely, a higher frequency of testing may be necessary in some circumstances where a parameter shows unacceptable instability. More frequent testing is at the discretion of the supervising physicist.

In the event that the equipment does not meet the stated performance objectives and criteria, an adjustment or repair should be effected. If it is not immediately possible to restore the equipment to full performance, then the use of the equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance. The decision on the most appropriate response is made by the supervising physicist in conjunction with the users of the equipment and others as appropriate.

Preventive maintenance schedules and interventions are recommended by the manufacturer of the equipment and should be adhered to diligently. Following preventive maintenance or repair, the appropriate quality control tests selected from those listed in Table 1 must be performed before the unit is returned to clinical service. The extent of testing required must be judged by a qualified medical physicist. Frequently, machine repairs and quality control testing are performed by different persons. In such cases, good communication and reporting between the various staff involved are essential.

As pointed out previously, radiation safety activities are beyond the scope of this report. However, such activities may be integrated into routine quality control programs of equipment.

Documentation

Appropriate documentation is an essential component of a quality assurance program. All documents associated with the program should contain, as a minimum, the following information:

1. the name of the institution
2. the name of the originating department
3. the name (s) of the document's author(s)
4. the name of the individual(s) or group who approved the document for clinical use
5. the date of first issue
6. the number and date of the current revision

Further guidelines on the design of appropriate documentation may be found elsewhere (ISO 1994, Quality 2000).

Documents for use in a quality control program may be conveniently separated into two major categories: protocols and records. The protocols must be included in the Policy and Procedure Manual of the Radiation Treatment Quality Assurance Committee.

The quality control protocol contains the standards, or performance objectives and criteria, to be applied to the piece of equipment. Such standards are based on documents such as this. In addition to the specification of standards, the protocol should provide sufficient detail on the test equipment and procedures to be followed that there can be no ambiguity in the interpretation of the test results.

The quality control record contains the results of the tests, the date(s) on which they were performed and the identification of the tester and the supervising physicist. When the number of tests to be performed on a particular occasion is limited and the test procedure is simple it may be advantageous to combine the protocol and record into a single document.

In addition to the protocol and record, it is essential to have a means of documenting any corrective action that takes place, together with any subsequent tests. Deviations from the locally approved protocol, such as those resulting from clinical pressure to access the equipment, must, of course, also be documented.

It is also necessary to maintain appropriate records of education, training, skills and experience of those involved with any aspect of the quality control program.

The documentation may be in any form or type of medium according to institutional policies.

Finally, all documentation related to the quality control program must be retained for at least ten years.

Table 1: Quality Control Tests

Designator	Test	Performance	
		Tolerance	Action
Daily			
DL1	Door interlock/last person out	Functional	
DL2	Motion interlock	Functional	
DL3	Couch brakes	Functional	
DL4	Beam status indicators	Functional	
DL5	Patient audio-visual monitors	Functional	
DL6	Room radiation monitors	Functional	
DL7	Beam interrupt/ counters	Functional	
DL8	Lasers/crosswires	1	2
DL9	Optical distance indicator	1	2
DL10	Optical back pointer	2	3
DL11	Field size indicator	1	2
DL12	Output constancy - photons	2%	3%
DL13	Dynamic wedge factors	1%	2%
DL14	Output constancy - electrons	2%	3%
Monthly			
ML1	Emergency off	Functional	
ML2	Wedge, tray cone interlocks	Functional	
ML3	Accessories integrity and centering	Functional	
ML4	Gantry angle readouts	0.5°	1°
ML5	Collimator angle readouts	0.5°	1°
ML6	Couch position readouts	1	2
ML7	Couch isocentre	1	2
ML8	Couch angle	0.5^{o}	1^{o}
ML9	Optical distance indicator	1	2
ML10	Crosswire centering	1	2
ML11	Light/radiation coincidence	1	2
ML12	Field size indicator	1	2
ML13	Relative dosimetry	1%	2%
ML14	Central axis depth dose reproducibility	1%/2mm	2%/3mm
ML15	Beam flatness	2%	3%
ML16	Beam symmetry	2%	3%
ML17	Records	Complete	
Annually			
AL1	Reference dosimetry – TG51	1%	2%
AL2	Relative output factor reproducibility	1%	2%
AL3	Wedge transmission factor reproducibility	1%	2%
AL4	Accessory transmission factor reproducibility	1%	2%
AL5	Output reproducibility vs. gantry angle	1%	2%
AL6	Beam symmetry reproducibility vs. gantry angle	2%	3%
AL7	Monitor chamber linearity	1%	2%

AL8	End monitor effect	0.1 MU	0.2 MU
AL9	Collimator rotation isocentre	1	2
AL10	Gantry rotation isocentre	1	2
AL11	Couch rotation isocentre	1	2
AL12	Coincidence of collimator, gantry, couch axes	1	2
AL13	Coincidence of isocentres	1	2
AL14	Couch deflection	3	5
AL15	Independent quality control review	Complete	

Tolerances and action levels are specified in millimetres unless otherwise stated

Notes

Daily Tests

DL1-7 The configuration of these tests will depend on the design of the facility and equipment. Safety is the concern and tests should be designed accordingly. As a minimum, manufacturer's recommendations and applicable regulations must be followed.

DL8 Alignment of crosswires and appropriate lasers for collimator angle 0°, gantry angles 0°, 90° and 270° at an SSD of SAD-10 cm

DL9 Gantry angle 0° and at the isocentre

DL10 Gantry angle 0° and at the isocentre

DL11 Gantry angle 0°, 100cm SAD, field sizes of 10x10 and 20x20 cm^2. Tolerances and Action Levels apply to each edge of a rectangular field.

DL12 All energies in use on the particular treatment day. Standard local geometry.

DL13 "Dynamic wedge factors" for a representative set of soft wedges in use on a particular treatment day must be verified. Standards are relative to open beam outputs.

DL14 All energies in use on the particular treatment day. Standard local geometry.

Monthly Tests

ML1 Proper functioning of the emergency stop buttons, indicators and emergency circuits. Manufacturer's recommendations and applicable regulations must be followed and may specify more frequent testing. For operational reasons it may be more convenient to schedule such tests at the end of a regular working day and cycle through them over a period of time rather than perform all the tests on one occasion.

ML2 Latching, interlocks.

ML3 Physical integrity and centering of accessories, including wedges, trays and cones, as appropriate.

ML4	Mechanical and digital gantry angle readouts must be verified using a spirit level, or other appropriate leveling device, for at least 0°, 90°, 180° and 270°.
ML5	Mechanical and digital collimator angle readouts must be verified using a spirit level, or other appropriate leveling device, for at least 0°, 90° and 270°.
ML6	Mechanical and digital couch position readouts must be verified over an appropriate clinical range in the directions of the three cardinal axes.
ML7	Rotation of the couch about the optical collimator rotation axis must be verified.
ML8	The couch rotation angle must be verified over an appropriate clinical range.
ML9	A mechanical device, calibrated against the true radiation isocentre, is used to provide the base reading for the check of the optical distance indicator. The standards stated in the Table apply at the isocentre. The optical distance indicator should be checked over a clinically relevant range of SSD and gantry angle. The tolerance and action level may be twice as large (i.e. 2 and 4mm) at the clinical limits of the optical distance indicator's range.
ML10	The trajectory of the optical image of the crosswires is measured at the appropriate SSD for collimator angles of 0°, 90° and 270°. Tolerances and Action Levels refer to the optical isocentre so measured.
ML11	Geometric alignment of the radiation and optical field edges must be established over a range of field sizes at gantry angles 0°, 90° and 270°. Representative half blocked fields must be included if available. A minimum of six field sizes will be required for this test. Tolerances and Action Levels apply to each edge of a rectangular field.
ML12	Compliance of the radiation and optical field sizes with the indicated dimensions must be established over a range of field sizes at gantry angles 0°, 90° and 270°. Representative half blocked fields must be included if available. A minimum of six field sizes will be required for this test. Different field sizes may be examined at different gantry angles if appropriate and efficient.
ML13	Using a dosimetry system calibrated against the local secondary standard the output of all available beams is checked against yearly reference dosimetry.
ML14	Measurements at two depths in an appropriate phantom serve to confirm that depth dose has not changed since commissioning the unit. Tolerances and Action Levels are specified in % for photon beams and mm for electron beams. Clinically relevant depths are used for these measurements
ML15,16	Flatness and symmetry, defined according to the protocol specified in the initial purchase document, are compared with those measured at acceptance. A single, convenient gantry angle may be chosen.

ML17 Documentation relating to the daily quality control checks, preventive maintenance, service calls and subsequent checks must be complete, legible and the operator identified

Annual tests

AL1 A full TG51 calibration is performed annually.

AL2-4 These tests confirm that essential parameters used for treatment time calculations have not changed due to, for example, a wedge being remounted. All accessories available in the treatment room must be checked.

AL5 An ion chamber with build up cap may be used in air for these measurements. The chamber may be positioned at the isocentre or may be mounted on the head of the unit. In the latter case, effects due to head sag will not be observed.

AL6 Film and optical densitometry is used to confirm symmetry of the radiation output and hence proper centering of the source with respect to the primary collimator. A large field, e.g. 30x30 cm^2, and gantry angles of 0°, 90° and 270°, should be used.

AL7,8 From a series of radiation measurements with different monitor units the linearity and the end monitor effect are determined.

AL9-11 Using film, star or spoke patterns are produced and the three radiation axes of rotation are determined. Tolerances and Action Levels refer to the diameters so measured.

AL12 By referencing the films in 9-11 above to the laser system the relative locations of the three axes of rotation at the isocentre may be determined

AL13 The radiation, optical and mechanical isocentres are determined with reference to the laser system and their degree of coincidence determined.

AL14 Couch deflection is measured with 70 kg at the end with the couch extended to the isocentre.

AL15 To ensure redundancy and adequate monitoring, a second qualified medical physicist must independently verify the implementation, analysis and interpretation of the quality control tests at least annually.

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