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American National Standard

procedures for periodic inspection of cobalt - 60 and cesium - 137 teletherapy equipment



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American National Standard Procedures for Periodic Inspection of Cobalt-60 and Cesium-137 Teletherapy Equipment

Secretariat for N44

Institute of Electrical and Electronics Engineers, Inc

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Foreword

(This Foreword is not a part of ANSI N449.1-1978, Procedures for Periodic Inspection of Cobalt — 60 and Cesium — 137 Teletherapy Equipment.)

These guidelines for inspection of teletherapy equipment are the product of Subcommittee N44.2, and its original draft of 1973 was written by Peter Veerling. Priority for the attention of N44.2 on this subject of periodic inspection was suggested by the Bureau of Radiological Health (BRH) of the United States Department of Health, Education and Welfare. For those several early years of N44.2 the BRH was the sponsor of the subcommittee and some of the most productive work on this standard (ANSI N449.1-1978) was done at meetings in BRH headquarters. Urgency for promulgation of standards for periodic inspection of teletherapy apparatus was stimulated by a fatality occurring when a patient was crushed by a cobalt teletherapy whose deficiency might have been corrected by appropriate maintenance and inspection. It is a tribute to teletherapy apparatus, in general, that few serious accidents have been reported with such machines which became the "conventional radiotherapy devices" of the 1950's, 1960's and even the 1970's.

Complacency can follow decades of safe and dependable use of cobalt and cesium teletherapy machines, and this maintenance guide is designed to avoid accidents and inaccuracies of output.

When the BRH deemed it in conflict with their bureau to continue sponsorship of N44.2, the subcommittee on standards for radiotherapy equipment IEEE took on the task of continued sponsorship of N44.2, and the task of completion of this maintenance standard by obtaining final approval by formal balloting.

Members of N44.2 assisted Peter Veerling in their numerous reviews and meetings, but the brunt of the work in developing N449.1 was borne by Peter Veerling, himself. Consensus and suggestions of overlapping pertinent standards from other national and international agencies were supplied by members of the subcommittee.

N44.2 aimed its efforts toward supplying useful information on periodic inspections of teletherapy apparatus to users (physicians and physicists), manufacturers, and regulators (for example, BRH). During the multiple meetings and discussions on safety for teletherapy, the increase in numbers of linear accelerators was recognized, and the importance of promulgating standards for these complex devices was noted. But the relatively simpler job of establishing standards for cobalt teletherapy machines was elected because of the need for such a standard, and also to afford a prototype standard for subsequent promulgation of similarly needed guides for linear accelerators.

The membership of the Committees, Subcommittee and Working Group at the time of approval of this standard were as listed below.

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American National Standard Procedures for Periodic Inspection of Cobalt-60 and Cesium-137 Teletherapy Equipment

1. Scope

This guideline provides suggested procedures for the inspection of cobalt-60 and cesium-137 teletherapy equipment which may identify and quantify malfunctions or maladjustments of the safety and radiation defining components. This guideline is a companion document to ANSI N449-1974 [1],[1] which specifies tests and suggested frequencies for the inspection and maintenance of teletherapy equipment.

2. Objective

The objective of the standard is to provide users of the teletherapy units with suggested procedures for performing the periodic inspection of their equipment as specified in ANSI N449-1974 [1]. Methods and equipment are listed for each procedure.

3. General Considerations

The procedures included in this document are not intended to be all-inclusive. Other procedures may be equally satisfactory. However, the procedures described here have been used successfully and will give results with sufficient accuracy to meet the recommended tolerances when performed by competent people with appropriate equipment. Appropriate equipment means equipment which is functioning properly and of relevant accuracy and reproducibility. Persons performing the test shall be competent in use of the test equipment, the teletherapy unit, and the procedures performed. A "qualified expert" as defined by the NCRP is acceptable in this regard.

NOTE: *Qualified Expert*: With reference to radiation protection, a person having the knowledge and training to measure ionizing radiation, to evaluate radiation safety techniques, and to advise regarding protection needs. With reference to the calibration of radiation therapy equipment, a person having, in addition to the above qualifications, training and experience of the clinical applications of radiation physics to radiation therapy [2].

Persons performing service and maintenance of the teletherapy unit shall be trained and experienced in radiation safety and operation of the teletherapy unit and its components, and properly equipped with replacement parts, handling equipment, and other special equipment dictated by the individual service procedure. Upon completion of *any* service operation no matter how minor and before commencing use of the teletherapy unit or accessories, the unit and ancillary equipment shall be tested to assure mechanical, electrical, and radiation safety of the equipment.

NOTE: These tests should not be construed as taking the place of constant vigilance in observation of the patient and equipment by therapy personnel during use of the equipment since electrical and mechanical failures may occur despite frequent testing of machines and associated equipment.

4. Test Procedures

4.1 General. Table 1 gives the tests and a suggested sequence of tests to check the teletherapy unit for compliance with the recommended objective and specification. Performance of the tests in the suggested sequence should minimize the need for repetitive testing and duplication of effort and provide redundant checks on radiation beam and mechanical parameters.

As a matter of general good practice, a minimum of three instrument readings should be taken at each data point. For example, three

[1] Numbers in brackets correspond to those of the references listed in Section 7 of this standard.

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Table 1
Tests in their Recommended Sequence

Tests	Objective	Specifications
Source-condition indicator (see Sec 4.2)	source position or condition	on—off
Door interlock (see Sec 4.3)	fail-safe operation	yes—no
Source holder/shutter movement (see Sec 4.4)	smooth and rapid movement	reproducible, mfr specs
Source housing leakage (see Sec 4.5)	safe leakage radiation level	less than 2 mR/h average and 10 mR/h maximum at 1 m
Head movement (see Sec 4.6)	smooth, stable, indicator accurate	indicator ± 1°
Beam orientation (see Sec 4.7)	limit switches working	yes—no
Source leakage (see Sec 4.8)	no removable contamination	less than 50 nCi*
Central-axis indicator (see Sec 4.9)	centrally located	± 2 mm
Light-radiation-field (see Sec 4.10)	congruence	± 3 mm on any side for a 10 X 10 field at depth of dose maximum
Isocenter position (see Sec 4.11)	stable isocenter	within a sphere not greater than 4 mm in diameter
SSD indicator (see Sec 4.12)	accurate and reproducible	± 3 mm
Source output (see Sec 4.13)	calibration and output	accurate/reproducible within ± 3 percent
Timer (see Sec 4.14)	accurate and reproducible	reproducible
Stand-stretcher (see Sec 4.15)	stable and accurate indicators	—
Manual source/shutter return (see Sec 4.16)	equipment available and usable	—
Pneumatic system (see Sec 4.17)	functioning properly	free of water and pressurized

*NOTE: Since publication of ANSI N449-1974, certain state regulatory agencies have lowered the allowable limit for removable contamination from 50 nCi to 5 nCi. The US Nuclear Regulatory Commission's limit remains at 50 nCi.

readings of source transit time to "on" and three readings to "off" should be made. All readings are recorded and the average used as the data point. When using an ionization chamber for radiation measurements, the irradiation time and instrument scale should be chosen so as to utilize the most accurate and reproducible part of the scale. For instance, if a condenser R-chamber was calibrated at 50 percent of full scale and is shown to be linear between 20 and 80 percent of full scale, irradiation times should be utilized which will result in readings between 20 and 80 percent of full scale.

Maintenance operations for individual teletherapy units which are ordinarily performed by manufacturer or distributor service personnel are so indicated and are not included in this document. The reader is directed to individual service manuals for each machine as well as consultation with the manufacturer.

The tests will be applicable only to machines which possess the characteristic or component being tested, eg, isocenter specifications and testing are only applicable to isocentrically mounted rotational units and not to floor-stand units.

4.2 Source-condition Indicator (see 4.1.1 in ANSI N449-1974 [1]). The operability of "on" and "off" position indicators at the control console and on the machine head and stand shall be confirmed visually. The patient viewing system (closed-circuit television or mirror) should be used for treatment room source "on" condition checks.

4.3 Door Interlock (see 4.1.2 in ANSI N449-1974 [1]). The test of the interlock shall be carried out by bringing the source to the "on" position, opening the door to break the interlock, and observing the sequence required to bring the source back to the "on" position. The interlock switch shall be adjusted such that any position other than the fully closed position of the door will break the circuitry and cause the source to return to the safe condition.

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The machine control mechanism shall require manual reactivation from the control console before resuming exposure.

4.4 Source Holder/Shutter Movement (see 4.1.3 in ANSI N449-1974 [1]). "The time and ease of movement of the source holder/shutter mechanism should remain within the specifications given by the manufacturer, increased time indicating a need for servicing of the movement mechanism." The movement should be smooth and rapid for any orientation of the head. A stop watch may be used for timing the movement from fully "off" to fully "on" and vice versa. The measurements should be done with the head in two or three clinically used orientations, that is, vertically down and up and horizontal. The movement may be heard either through an intercom or by listening for the open and close stops. Observations of the on—off indicators by closed circuit TV or mirrors may also help in determining "on" and "off" movements.

4.5 Protective Source Housing, Beam-Off Leakage (see 4.1:19 in ANSI N449-1974 [1]). Exposure rate measurements shall be made at 14 primary points located 1 m from the source in the fully safe position. Fig 1 illustrates the 14 points referenced in NCRP Rep No 33 [2]. The average of readings shall not exceed 2 mR/h and no point shall exceed 10 mR/h.[2] The survey instrument shall be capable of measuring exposure rates in the range of 0.5 to 20 mR/h to an accuracy of ± 10 percent for cobalt-60 and cesium-137 gamma ray energies. The instrument shall have been calibrated within the previous one year and its constancy over the ranges used shall be verified before performing the survey. Refer to ICRU Rep 20 [4] for a complete description of radiation protection instrumentation.

4.6 Head Movement (see 4.1.8 in ANSI N449-1974 [1]). Operation of the head movement controls within the treatment room shall be exercised and all angulations and positions of the head shall be checked for ease of movement, stability, and accuracy by visual means. A level attached (magnetically or mechanically)

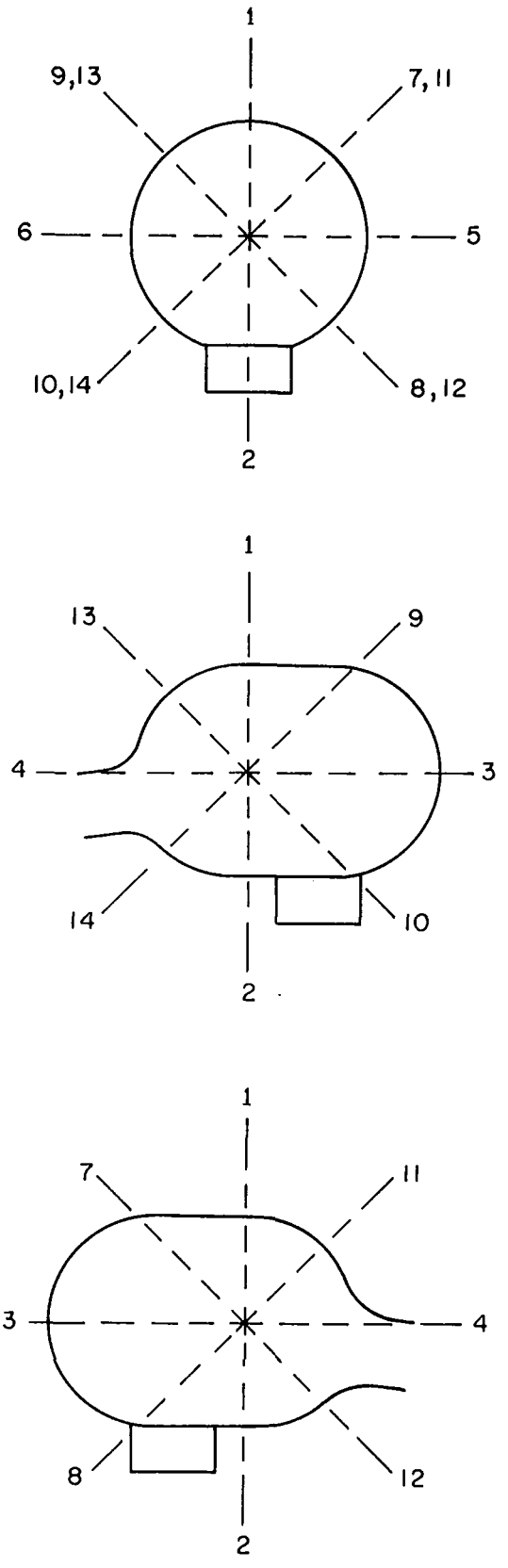


Fig 1
Fourteen Primary Points for Beam-Off Leakage

[2]The ICRP Subcommittee 3 [3] recently instituted another beam-off leakage criterion. It recommends a maximum of 20 mR/h at any readily accessible position 5 cm from the surface.

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to the head should be used to check the indicators at 0°, 90°, 180°, 270°, and 360°.

4.7 Beam Orientation (see 4.1.11 in ANSI N449-1974 [1]). Electrical or mechanical stops may be installed for the purpose of limiting the direction of the primary beam. The head and gantry shall be operated from all possible control stations through the extreme limitation of motion. If these extreme limits of motion exceed the facility requirements or if mechanical or electrical stops are inoperable, these stops shall be adjusted or repaired.

4.8 Source Leakage (see 4.1.14 in ANSI N449-1974 [1]). A cotton swab, paper disk, or cloth disk may be used for obtaining a smear sample. The swab or disk should be smeared along the nearest accessible surfaces to the source, that is, inner surfaces of collimator and upper surfaces of blocking trays. *Be sure the radioactive source is (a) in the fully "safe" position before approaching the teletherapy head and (b) remains there during the entire sampling procedure.* This sample shall be scanned with a low level survey meter to check for gross contamination and then placed within a vial, glassine envelope, or other suitable holder. A laboratory analysis should be made with a calibrated laboratory counter, that is, sodium iodide (NaI) scintillation or Geiger-Müller counter. The source shall be considered not leaking if the amount of removable activity as judged from laboratory analysis of the smear sample is less than 50 nCi.

NOTE: Since publication of ANSI N449-1974 [1], certain state regulatory agencies have lowered the allowable limit for removable contamination from 50 nCi to 5 nCi. The US Nuclear Regulatory Commission's limit remains at 50 nCi.

4.9 Central-Axis Indicator (see 4.1.12 in ANSI N449-1974 [1]). "The central axis is the straight line passing through the center of the source and the center of symmetry of the beam-defining system (collimators)" [1]. Indication of the central axis may be by optical or mechanical means such as cross hairs in a light field, mechanical rod, back pointers, pin and arc devices, etc. Misalignment of the light beam, cross hairs, and mechanical axis of the collimator should be tested and corrected (if necessary) at this point in the procedure. The test may be performed using a rigid rod attached by magnets or thumb screw to the collimator with the tip of this device located in the center of the light field. A piece of white paper may be positioned on a flat surface perpendicular to the central axis and the pointer aligned with the center of the light field. The collimator is then rotated through its full movement, and the limits of movement of the pointer from this central position should be no greater than ± 2 mm for the commonly used distance(s) and both vertical and horizontal head angulations. The test should be repeated using only the image of the cross hairs on the white paper. Stability of the central axis indicator shall be tested for lateral and vertical positions of the head since there may be mechanical looseness in the movement.

4.10 Light-Radiation-Field Congruence (see 4.1.7 in ANSI N449-1974 [1]). The light field and the 50 percent penumbra line[3] of the radiation field shall coincide at the distance of dose maximum (nominal treatment distance +5 mm for cobalt-60 and +1.2 mm for cesium-137) to within ± 3 mm on each side of a 10 × 10 cm field (see Fig 2).

NOTE: "For a machine designed and built with the light and radiation fields congruent at other than the 50 percent penumbra line, the criterion for conformance shall be ± 3 mm on any side for the specified alignment" [1].

4.10.1 *Film.* Make two irradiations with a film placed at the nominal treatment distance and perpendicular to the central axis of the beam with a minimum of 5 cm of tissue-equivalent material beneath and a buildup layer (5 mm for cobalt-60, 1.2 mm for cesium-137) above. The light field (sides or corners or both) should be marked on the film by any one of several methods, eg, ball-point pen markings through a paper cassette or film packaging, metal strips or coins along edges, or at corners, pin hole at corners, etc. One irradiation should be made with collimator orientation noted and a second irradiation made on an unexposed part of the film with the collimator rotated 180°. The film is irradiated to yield an optical density in the linear range of the film, usually between 1 and 2. After developing, the film is scanned on a densitometer in two directions perpendicular to each other and both passing through the geometric center. The readings are

[3]The 50 percent penumbra line is the locus of points in the penumbra region or periphery of the radiation field determined to be 50 percent of the intensity at the central axis. Other terms used are 50 percent decrement line [5] or 50 percent isodose line.

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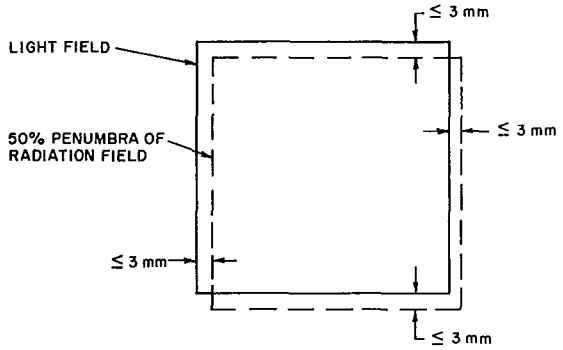


Fig 2
Light-Radiation-Field Congruence

plotted on graph paper to determine the position of the 50 percent radiation intensity level relative to the light field. The linearity of the film in the density range used for analysis should be established prior to readout of these films (see Fig 3).

NOTE: The word intensity is used in this document to mean exposure rate or dose rate or a measured quantity proportional to one of these two physical quantities.

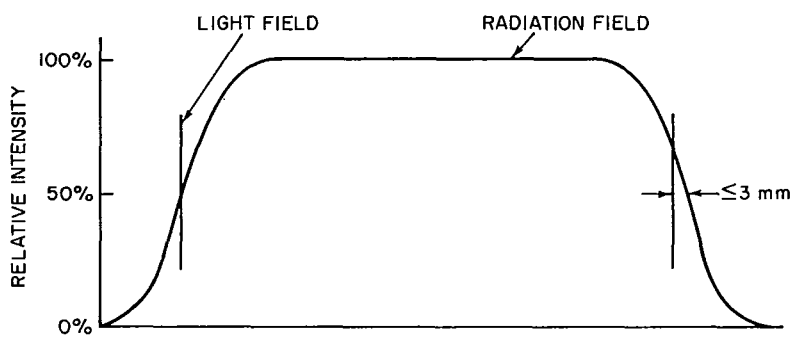
4.10.2 *Relative Intensity Measurement.* An ionization chamber or solid-state diode linked to a remote readout or recording device or both may be used to scan the field at the depth of dose maximum to record the fractional intensity of the radiation beam as one proceeds out from the center of the field in four directions for a rectangular field. Once again, the 50 percent radiation intensity line should coincide with the light field. The scans should be repeated with the collimator rotated 180°. The detector should be sufficiently small (less than approximately 6 mm diameter) to maintain validity of measurements in the penumbra region of the beam.

4.10.3 *Linagraph Direct Print Paper.* Kodak Type 1895 Linagraph Direct Print Paper is a photographic paper which responds to both ionizing radiation and visible light, but in opposite ways. Since the density of the darkening cannot be quantitated and the image fades upon exposure to fluorescent light, this method should be used only as a check on alignment. Place the paper on a flat surface, perpendicular to the central axis of the beam. Irradiate the paper to at least 250 rads. A dark image of the radiation beam will "develop" by exposing the paper to 150—200 foot candles of fluorescent light (approximately 1 min using a desk lamp). Without moving the paper, turn on the light localizer. The light field may be compared to the radiation field by either marking the light field with a pencil on the darkened paper or after 2 min of this second exposure, the differences between the two fields will show as light or dark areas. Refer to [5] for further information on this technique. These irradiations should be taken for two collimator orientations 180° apart as in Subsection 4.10.1.

4.11 Isocenter Position (see 4.1.13 in ANSI N449-1974 [1]). Fig 4 is a pictorial representation of the isocenter.

The radiation beam is influenced by mechanical alignment of the source, collimator, and support structures. Additional guidance or localizing systems such as lasers or other high-intensity light sources or mechanical pointers are intended to indicate the position of the isocenter. If the radiation beam isocenter is within tolerance, the mechanical indicating—localizing systems can be checked and aligned

Fig 3
Plot of Radiation Field Intensity and Light Field



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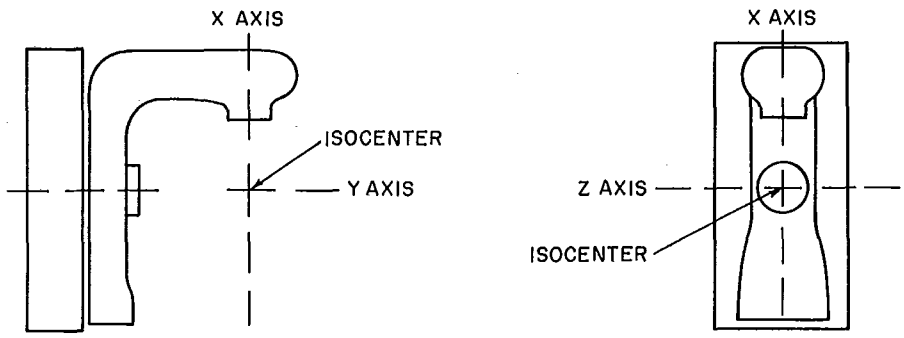


Fig 4
Isocenter and Orthogonal Orientation

to coincide. If the radiation beam isocenter is too large, the mechanical structures should be adjusted and serviced, if necessary, and the isocenters retested.

Ideally, both radiation and mechanical isocenter tests should be performed. Practically speaking, either test may be performed for an isocenter determination. The radiation and mechanical adjustments are further checked in tests of the central-axis indicators (see Section 4.9), light-radiation-field congruence (see Section 4.10), and source-skin distance (see Section 4.12).

In all measurements of the isocenter, the machine should be rotated through gantry angles of 0°—360° and the movement should be smooth with no sudden movements of the cross hairs. An erratic movement may indicate a mechanical problem with the gantry rotation linkage.

4.11.1 *Radiation Beam Isocenter.* A film in light-tight package is held rigidly in place in a vertical plane perpendicular to that of the axis of rotation, i e, in x—z plane. One pair of collimator jaws is closed to as narrow as possible and the width at the axis of rotation measured. For many machines, the narrowest opening is 3 or 4 cm. The opposing jaws are opened as far as possible. The slit is parallel to the axis of rotation, ie, along the Y axis. A series of nine irradiations (gantry angles of 0°, 40°, 80°, 120°, 160°, 200°, 240°, 280°, and 320°) are made with the film remaining in place. The time for each irradiation should be that required to yield a film density of approximately 0.2 for each exposure at the intersection of the slits. A second film is exposed with the film horizontal on the treatment couch at the distance of the isocenter. The position of the central axis should be marked on the film for later reference. The narrow slit is now in the direction perpendicular to the axis of rotation, ie, along the z axis. A series of nine irradiations is made for the same gantry angles.

The intersection of the beam images on the first film, a so-called "star shot," yields a geometric figure at the isocenter in the x—z plane. The size of the image may be analyzed as follows. The points of intersection of the lateral margins of each adjacent sector, ie, right and left margin of 0° and 40° sector, 40° and 80°, etc, are marked. Each of these marks is connected to form a figure which should be nearly circular in shape (see Fig 5(a)). The greatest diameter of the figure should not be greater than the field width plus 4 mm. On the second film, the intersection of the beam images yields a slender bow tie-shaped figure in the y—z plane. The width of the image at the position of the central axis is the y dimension at the isocenter. The difference between the width of the image at the position of the "isocenter" and the set field width should not be greater than 4 mm (see Fig 5 (b)).

4.11.2 *Mechanical Isocenter.* The mechanical isocenter also has x, y, and z dimensions. The dimensions in the x—z plane may be determined by mounting a pointer on the collimator and a sheet of paper in the x—z plane (as the first film in Subsection 4.11.1). The figure scribed on the paper by the pointer as the machine is rotated from 0° thru 360° should have a maximum diameter of 4 mm (see Fig 6(a)). The y dimension may be determined using a rod, which is square in cross section, wrapped with a piece of paper, and aligned as carefully as possible along the x axis. A square rod is used to facilitate initial alignment of the pointer and rod for all gantry angles. The

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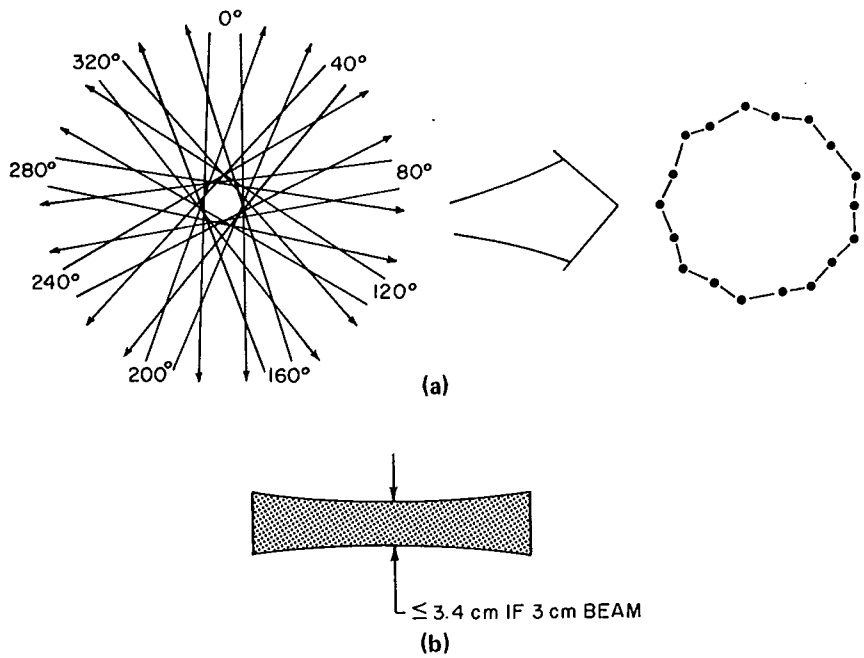


Fig 5
Radiation Beam Isocenter Using Film (a) "Star Shot" and Magnified Isocenter (b) *Y* Dimension

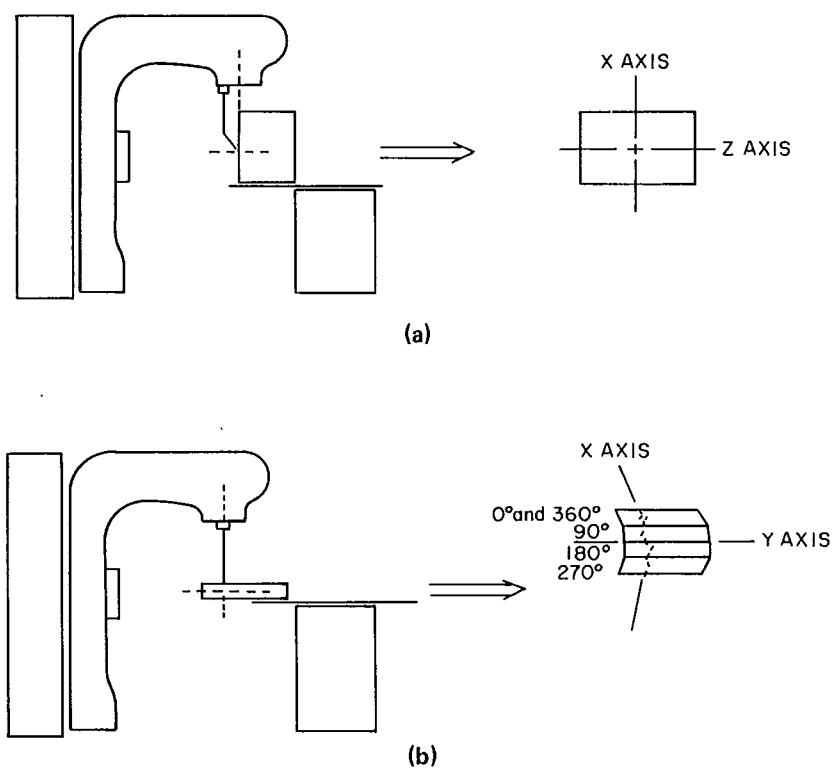


Fig 6
Mechanical Isocenter
(a) *X* and *Z* Dimension (b) *Y* Dimension

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pointer should be adjusted to a distance slightly less than the source-axis distance (SAD) to enable it to clear the rod as the machine is rotated. Gantry angles of 0°, 90°, 180°, 270°, and 360° are used. The motion in the y direction of the tip of the pointer mounted on the collimator will yield the y dimension of the "isocenter" as the machine is rotated 0° through 360° (see Fig 6(b)).

4.11.3 *Rapid Checks of Mechanical Isocenter.* A more rapid check of the mechanical isocenter may be made using a plastic cube, such as is available for mounting photographs, which has been lined or covered with white paper and on which the center of each side of the cube has been marked with dark cross lines. Initially, the beam is directed vertically toward the floor, the light cross hairs aligned with the cube cross lines, and the distance adjusted so that the SAD falls at the middle of the cube. The side light localizers should fall on the cube's lateral cross lines. After all vertical and horizontal adjustments have been optimized, the variation between the positions of the light cross hairs and indicated distances are noted and recorded for gantry angles of 0°, 90°, 180°, 270°, and 360°.

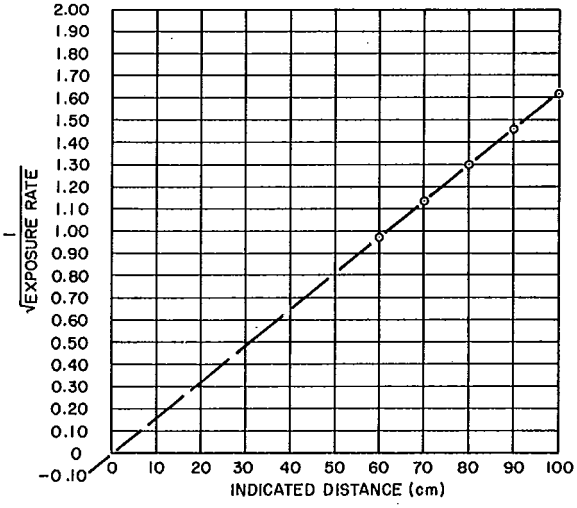
A second method utilizes a mechanical pointer aligned along the central axis and a narrow diameter (2 mm or less at the point of measurement) rod held horizontal along the y axis. The pointer is adjusted to a height of (SAD − 2 mm). As the gantry with pointer attached is rotated, the distance between the end of the pointer and the "point" designated by the rod tip is measured. The diameter of the solid figure defined by these points should be not greater than 8 mm in the x—z direction and not greater than 4 mm in the y direction to be reasonably certain the isocenter specification of 4 mm diameter is met.

4.12 Source-Skin Distance (SSD) (see 4.1.4 in ANSI N449-1974 [1]). The source-skin distance (SSD) indicator system(s) used clinically may be mechanical or optical or both. The periodic tests should provide a means of checking to within ± 3 mm the producibility of the distance systems over the range of distances used clinically.

4.12.1 Measurements of radiation intensity versus distance from the source utilize the inverse square behavior of point sources. While collimated sources within a teletherapy head are not true point sources, the inverse square relationship should hold over the usual range of treatment distances. Initial measurements on a machine to establish a distance measuring system, such as optical range finder lights and distance rods, should be done using radiation measuring instruments and plotting of the data. With the collimator opening remaining fixed during the course of all readings, that is, 10 cm × 10 cm measured at 80.0 cm SSD, place an ionization chamber along the central axis of the beam. Take a series of measurements with the chamber placed at several different distances from the source over the range of distances commonly used clinically, that is, 65—100 cm for a machine with 80 cm nominal SSD. The readings should be in terms of exposure rate. Plot the indicated distance as measured by light or mechanical rod versus (exposure rate)$^{-½}$ on linear graph paper. A straight line fit of the data points and extrapolation to the apparent zero distance may be done using linear regression analysis or informal drawing of the line which appears to fit the points (see Fig 7). Verification that the projected source position is within 1 percent of the origin of the distance scale (± 8 mm for 80 cm nominal treatment distance machine) will maintain inverse square calculated exposure rates within 2 percent, assuming the measured distances are correct.

4.12.2 The simplest check method is comparing the two clinically useful SSD indicators: the optical system and the rigid mechanical rod

Fig 7
Plot of Chamber Data for Source Position Determination



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attached magnetically or mechanically to the head. Place a white piece of paper on the treatment table. Attach the rod and adjust the head or table or both so that the rod is within 1 mm of the paper. Remove the rod and observe the distance indicated by the optical system. These should coincide to within 3 mm.

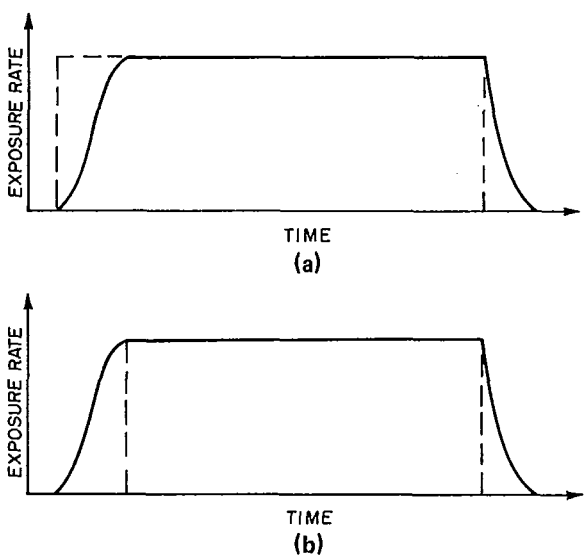
4.12.3 A spot check of validity of the distance measuring devices may be done by comparing two ionization chamber measurements, one at a close distance and one at a far distance with these distances known. An inverse square calculation is used to go from one to the other, and the results of the chamber measurements and inverse square calculations compared. This is done as a rapid check on distance markers but should not be substituted for the previous plotting method during initial calibration of a machine.

4.13 Source Output (see 4.1.5 in ANSI N449-1974 [1]).

4.13.1 *Calibration.* A full calibration of the teletherapy unit shall be performed in accordance with accepted standards of practice, such as those recommended by the American Association of Physicists in Medicine, Hospital Physicists' Association, International Commission on Radiation Units and Measurements, or the National Council on Radiation Protection and Measurements [1], [7]—[14].

4.13.2 *Spot Check Measurements.* "Spot-check measurements are used as constancy checks to verify the calibrated output of the machine. In the case of new cobalt-60 sources, spot checks are made to confirm the predicted rate of radioactive decay as well as to check on machine performance. The spot check is a determination of the exposure rate, dose rate, or other quantity directly related to the calibration [1]." At the time of machine calibration, the spot check method should be established as a basis for future comparisons. The method should be easily reproduced, simple, and utilize reliable instrumentation. An example of such a method is an ionization chamber with equilibrium cap, chamber center at the nominal treatment distance, 10 cm × 10 cm field size, collimator at a reproducible position, beam vertical toward floor, no blocking tray. Time error (see Section 4.14) and temperature-pressure corrections (when applicable) shall be included. Other radiation detectors such as solid-state diode or thermoluminescent dosimeters (TLD) may be used as long as the reproducibility of these systems is verified as commensurate with the required information.

Fig 8
Timer
(a) Source Starts Movement "ON" at Start of Timer; Movement "OFF" at End of Elapsed Time (b) Timer Starts when Source is Fully "ON"; Source Starts Movement "OFF" at End of Elapsed Time



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4.14 Timer (see 4.1.6 in ANSI N449-1974 [1]). There is a finite error in source output measurements due to the source travel time from "off" to "on" and return. This time error should be included in calibration and spot check measurements. Fig 8 illustrates the phenomenon involved. There is a short period of time at the beginning and at the end of each irradiation when the exposure rate rises from zero (source fully shielded in "off" position) to a constant value (source fully "on") and then returns to zero. The radiation detector "sees" a variable portion of the source during the travel time but the timer mechanism is tripped only at a definite point in this travel. Hence, the length of time of source travel is reflected in the time error measurement.

The appropriate time correction term should be applied during calibration of the machine. A correction also should be applied during use of the machine if the time error results in an error in the dose delivered of greater than 2 percent. "An erratic or inconsistent timer mechanism shall be replaced [1]."

A malfunctioning timer could also introduce an error. An erratic or inconsistent time error is indicative of malfunction of timer or source movement mechanism or both.

Several methods for checking time error are given below. The first three utilize integrating dosimeters. The fourth is not a true measure of time error but is helpful in separating source travel problems from timing mechanism malfunction.

4.14.1 *Time Correction Term, Alpha (α).* The dosimeter with equilibrium cap is placed at the center of the field and the source turned "on" for a single irradiation (R_1). The dosimeter is zeroed and left at the same location for multiple irradiations before being read out (R_2). The total set times for single long and multiple short exposures need not be the same, but equality helps minimize errors due to instrument nonlinearity and operator error in setting times. The mathematical relationship used to calculate α, the time correction term, is:

$$\frac{R_1}{t_1 + \alpha} = \frac{R_2}{t_2 + n\alpha} \qquad \text{(Eq 1)}$$

$$\alpha = \frac{t_1 R_2 - t_2 R_1}{nR_1 - R_2}. \qquad \text{(Eq 2)}$$

When $t_1 = t_2$,

$$\alpha = \frac{t(R_2 - R_1)}{nR_1 - R_2} \qquad \text{(Eq 3)}$$

where

α = effective time difference due to source "on—off" and timer "on—off" mechanisms
R_1 = average of dosimeter readings for set time t_1
R_2 = average of dosimeter readings for set time t_2 (n cumulative irradiations)
t_1 = time for single long irradiation
t_2 = time for cumulative irradiation
n = number of irradiations during cumulative irradiation

The true time for the single long irradiation is $(t_1 + \alpha)$, where the time error may be positive or negative. If α is positive, the net irradiation time is longer than the timer setting; and vice versa. The time-corrected radiation intensity would be $R_1/(t_1 + \alpha)$.

4.14.2 *Time Correction Term, Epsilon (ϵ).* The epsilon method utilizes the same principles as the alpha method but expresses the error in a slightly different manner. This method is a special case of that described in 4.14.1 where n=2 and t_1=t_2.

$$R_T = 2R_1 - R_2 \qquad \text{(Eq 4)}$$

$$\alpha = \frac{t(R_2 - R_1)}{R_T} \qquad \text{(Eq 5)}$$

where

ϵ = time error associated with the combined starting and stopping of the timer–source exposure mechanisms
R_1 = average of dosimeter readings for a single set time t
R_2 = average of dosimeter readings, each reading an accumulation over two irradiations of set time $t/2$
t = time for single long irradiation
R_T = dosimeter reading corrected for time error

The time-corrected radiation intensity would be $R_T/t = (2R_1 - R_2)/t$; and epsilon is used as a numerical expression of time error. If ϵ is positive, the net irradiation time is longer than the timer setting; and vice versa.

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4.14.3 *Serial Irradiation and Plotting.* A number of irradiations, using times from very short through much longer intervals, are made and the integrated readings plotted against the respective irradiation times. A straight line fit of the data points and extrapolation to zero time may be done using linear regression analysis or informal drawing of the line which appears to fit the points. The measurements can be performed only within the established linearity range of the measuring instrument.

4.14.4 *Stop Watch.* A stop watch may be used to measure the elapsed time versus the clock time on the machine as well as source transit time "off" to "on" and "on" to "off." This should be done for several set irradiation times and repeated with the difference in stop watch and machine timer noted.

4.15 Stand and Stretcher (see 4.1.10 in ANSI N449-1974 [1]). "Moving parts shall be properly cleaned and lubricated and all parts inspected for mechanical and electrical damage [1]" and tightness. The following safety systems shall be tested specifically:

(a) Collision detecting devices on treatment head and stretcher

(b) Emergency "off" switches inside and outside the treatment room

"The equipment shall be stable in any position in which it is to be used, and all indicator and movement systems shall function properly [1]." Tests of these assemblies should be done by activating all possible controls both under load and free of stress.

4.16 Manual Source/Shutter Return (see 4.1.9 in ANSI N449-1974 [1]). A visual inspection should be made to verify that equipment necessary to manually return the source to the safe or "off" condition is both available in the immediate vicinity of the machine and capable of being used. Simulation of a sticking source or shutter *shall not* be attempted because of possible danger to personnel and damage to equipment.

4.17 Pneumatic System (see Subsection 4.1.15 in ANSI N449-1974 [1]). The user should limit his operations to those recommended by the machine manufacturer. These operations may be limited to draining moisture from air reservoirs and maintaining indicated air pressures according to manufacturers' specifications. Disassembly of any air lines ordinarily should be done only by service representatives thoroughly versed in the particular machine and possible radiation hazards. Failure to secure the source transport or shielding mechanisms during maintenance could result in a serious radiation hazard to anyone in the vicinity of the machine.

4.18 Overhaul of Electrical, Mechanical, and Source Assemblies (see 4.1.17, 4.1.18, and 4.1.20 in ANSI N449-1974 [1]). Overhaul of these assemblies should be performed by service representatives thoroughly versed and experienced in all aspects of a particular model machine. Overhaul of the source assembly shall be performed only by individuals specifically licensed by the US Nuclear Regulatory Commission or an Agreement State to perform these operations. After completion of all overhaul operations, a representative of the medical institution shall review the service procedures and perform such independent tests (as in ANSI N449-1974 [1]) to be certain the machine has been serviced and tested prior to releasing the unit for treatment of patients.

5. Radiation Safety

Radiation safety of personnel is of paramount importance during testing, inspection, and maintenance procedures. "It must be emphasized that individuals performing the inspection and maintenance shall be suitably equipped and qualified (by both training and experience) to handle safely the radioactive sources and equipment with which they are working. Calibration measurements, protection surveys, and tests for detection of contamination arising from the leaking radioactive sources shall be carried out by a qualified expert [1]."

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6. Records

A written record of all tests performed, preferably in a bound logbook, should be kept as a part of a permanent record and running account of the performance of the therapy machine. This record may be useful in detecting trends in machine performance and also for reference at a later date. The logbook should contain all data taken during the testing operations as well as the results, conclusions, and recommendations. All entries should be dated and signed by the individual performing the operations.

7. References

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