



Technical White Paper: An Educational Report on CyberKnife® Quality Assurance Testing

Developed by CRCPD's H-26 Task Force for Cyberknife®

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EXECUTIVE SUMMARY

The Cyberknife® is a cancer therapy modality that is used most commonly to treat individual lesions. Cyberknife® radiotherapy is a non-invasive (non-surgical) treatment in which high doses of focused radiation beams are delivered from multiple locations outside of the body to destroy a tumor or lesion within the body. Although the Cyberknife® is a technology that has been in use for several years, it is not widely used at this time. It is, however, becoming more prolific. This White Paper describes the Cyberknife®, contains shielding design issues, describes a quality assurance program for the Cyberknife®, and describes some of the aspects of the Cyberknife® that should be given consideration during inspections.

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INTRODUCTION

The main considerations for using the Cyberknife[®] are treatment planning and proper beam alignment. The operator must be trained in the specific treatment planning for this modality of treatment. The robotic arm and laser beams must be monitored to assure that the alignment is within specifications.

The safety aspects of the Cyberknife[®] are distinct from other cancer therapy accelerators. The use of the pencil beam to treat specific lesions does not lead to the same patient dosimetry concerns as broad beam applications. The surrounding healthy tissue receives lower radiation doses from this type of treatment.

Regulatory oversight should include review of the shielding design, shielding calculations, and the quality assurance (QA) program. When performing an inspection, the inspector should review the daily, monthly, quarterly, and annual QA records. A licensed medical health physicist that is knowledgeable in the various aspects of the Cyberknife[®] should perform the QA testing.

GENERAL OPERATION PRINCIPLES

The Cyberknife[®] is a type of stereotactic radiotherapy, a non-invasive (non-surgical) treatment in which high doses of focused radiation beams are delivered from multiple locations outside of the body to destroy a tumor or lesion within the body. This minimizes radiation exposure to healthy tissue surrounding the tumor, and allows for full-body radiotherapy using image-guided robotics. This flexibility of the robotic arm allows for treatment of areas of the body that cannot be treated by other radiosurgery techniques.

The Cyberknife[®] system uses a distinctive radiotherapy device with a linear accelerator (Linac), producing the radiation while mounted on a robotic arm. Through the image-guided cameras, the Cyberknife[®] localizes on the position of the tumor and the Linac attached to the robotic arm is then used to deliver multiple beams of radiation to the tumor while minimizing exposure to surrounding tissue. With submillimeter accuracy, the Cyberknife[®] is used to treat vascular abnormalities, tumors, and functional disorders of the body.

It utilizes the skeletal structure of the body as a reference frame – no invasive frame is needed, and it continually tracks and monitors patient position during treatment. Imaging information is transferred from the computer's operating system to the robot so that it may compensate for any changes in patient position by repositioning the Linac.

The Cyberknife[®] uses real-time x-rays to establish the position of the lesion during treatment and then dynamically brings the radiation beam into alignment with the observed position of the treatment target. Each beam is aimed independently—without a fixed isocenter. When the target moves, the process detects the change and corrects the beam pointing in near real-time.

DEFINITIONS

Birdcage/Toolstand - Common name for the ion chamber holder, this tool connects to the collimator receiver and holds a standard Farmer chamber at 80 cm SDD.

Field Size - The size of the radiation field, usually defined at a reference SAD. The Cyberknife's[®] field sizes are defined at 80 cm SAD.

OAR - Off Axis Ratio - The ratio of absorbed dose at a given off-axis point to the dose at the central axis at the same depth.

OF - Output Factor (sc, p)- The ratio of the absorbed dose of a particular field size to the dose at a reference field size. For the Cyberknife[®], the reference field size is 6 cm and the reference conditions are 1.5 cm depth and 8 cm source-to-detector-distance.

PDD - Percent Depth Dose - The ratio of the absorbed dose at any depth to the absorbed dose at a fixed reference depth using a constant SSD specified as a percentage.

SAD – Source-to-Axis Distance - The distance from the radiation source to the axis of rotation. The Cyberknife's[®] nominal SAD is 80 cm.

SSD – Source-to-Surface Distance - The distance from the radiation source (x-ray target) to the surface of the phantom.

TPR - Tissue Phantom Ratio - The ratio of absorbed dose at a given point to the dose at a fixed reference depth using a constant source-to-detector distance. The Cyberknife's[®] reference depth is 1.5 cm.

SHIELDING/ANALYSIS DESIGN

Leakage

The current limit for leakage is 0.1% at the isocenter. It is recommended that leakage be measured both in the patient plane and at one meter from the beam line of the Linac.

Cyberknife[®] has a variable SAD (65 cm to 100 cm), but for shielding we assume 80 cm, which also defines the position of the patient plane.

Position of the Room Isocenter

The treatment room isocenter is the center of the imaging field, which is also the tip of the isopost calibration tool. In a rectangular room the location of the room isocenter can be found by drawing a line from the center of the robot joint axis to the treatment room keeping a 45-degree angle with respect to the wall.

Range of Field Size as the Isocenter

For 80 cm SAD there are 12 nominal field sizes with Full Width Half Max (FWHM) width ranging from 5 to 6 mm (5, 7.5, 10, 12.5, 15, 20, 25, 30, 35, 40, 50, 60). These

field sizes scale proportionally with the available SADs of 65 cm and 100 cm, giving a total range of field sizes 4 mm to 75 mm.

Position of the Treatment Isocenter

The treatment isocenter is located close to the room isocenter. In most cases the treatment isocenter is within 10 cm of the room isocenter. There are no limits to the location of the treatment isocenter. However, using distances over 20 cm would significantly increase treatment error and is not recommended.

Highest Angle that the Cyberknife® Can Point

Cyberknife® does not point higher than 22 degrees above the horizontal. The beams will also pass within 12 cm of the room isocenter. Thus, the highest intersection with a wall would be a beam with an angle 22 degrees above horizontal, traveling through a point 12 cm above the room isocenter and striking the closest wall to the isocenter.

Calculating the Primary Barrier of Standard Density Concrete [2.35 g/cm³]

NCRP 49 states that tenth value layer (TVL) of a 10x10 cm 6 MV photon beam is 34.5 cm. As the beam becomes narrower there is reduced scatter into the beam and thus the TVL decreases. NCRP does not give data on this. However, measurements using a survey meter have shown the following:

Collimator	TVL, cm
60	30.7
40	29.9
20	28.6

☐ **Applying NCRP 49**

$$\text{"useful beam"} = P = B_{ux}X_u$$

$$\text{"leakage beam"} = P = B_{LX}X_L$$

$$\text{"scattered beam"} = P = B_{sx}X_s$$

P= Permitted exposure/week (uncontrolled) = 0.002R ~ 0.002 cGy

B= Barrier transmission factor

X= X-ray exposure (or dose) at point of interest

A) Primary (Useful) Beam

$$X_u = W_{\text{SAD}} (\text{SAD}/d_{\text{pri}})^2 UT$$

X_u = Unattended weekly dose at point of interest from useful beam

W_{sad} = Weekly workload i.e. 200kMU

$(\text{SAD}/d_{\text{pri}})^2$ = Inverse square law

U = Use factor

T = Occupancy factor

B) Simple Calculation Use Factor

Worse Case: 20 beams/patient, all patients identical

$$U = 1/20 = .05$$

Best Case: 50 beams/patient, beams repeat after 10

$$U = 1/500 = .002$$

C) Calculating Secondary Barrier

- Predicting Cyberknife[®] leakage is not a simple matter. For now, the best estimation technique is to develop an average from all of the possible treatment positions. This assumes equal weighting of each treatment position.
- You could make an elementary estimate of leakage by assuming the Linac stayed at this position for the entire treatment. At least, it is a better estimate than using the room isocenter as the average position.

Beam-On Commissioning

- Specific data is measured and entered into the treatment planning system.
- Details of measuring the beam vary considerably; therefore each facility may perform this function as specified by their own physics professional(s). The physicist(s) must be familiar with the specific treatment planning system in use.

Treatment Planning Systems require the following beam system data tables:

- A. Output Factor Data Table
- B. Tissue Phantom Ratio Table
- C. Off-Center Ratio Data Tables for Each Collimator

FREQUENCY OF QUALITY ASSURANCE PROCEDURES

DAILY

1. System Status Check
2. Linac Output Constancy Check
3. Safety Interlock Check

MONTHLY

1. Beam Parameters
2. Robot Mastering Check (Visual)
3. Imaging Targeting Check
4. Imaging Alignment (Image Isopost with Treatment Software)
5. Beam Energy (TPR2010 or PDD2010)
6. Film Phantom Target Test (or 2 Month Interval)

QUARTERLY

1. Target Locating System Tracking Test (or After Significant Change Due to Maintenance).
2. Linac Laser Mechanical alignment check
3. Linac Laser/Radiation Field alignment check

ANNUALLY

1. Beam Commissioning Spot Checks
2. Treatment Planning System Tests
3. Beam Calibration Check
4. Safety Systems Tests
5. Robot Mastering (Electronic)
6. Couch Indexing Accuracy

QUALITY ASSURANCE PROCEDURES

DAILY QUALITY ASSURANCE

1. System Status Check

Certain parameters should be checked daily to make sure that the Cyberknife[®] is running well and to monitor any drift in operating parameters. It is recommended by the manufacturer that the following parameters be checked on a daily basis and the values recorded and saved. This data is valuable when service is needed for diagnosing problems.

Parameter	Location	Acceptable Range
SF ₆ Pressure (psi)	J-Box	≥ 30 psi
Water Pressure (psi)	Chiller Side	80 ± 5 psi
Water Temperature (°C)	Chiller Front Panel	19 ± 2 °C
Water Flow Rate (gpm)	Chiller Flow Meter	≥ 0.6 gpm

Parameter	Location	Acceptable Range
Steering Coil 1 (amps)	MCC Front Panel	No Drift
Steering Coil 2 (amps)	MCC Front Panel	No Drift
Steering Coil 3 (amps)	Inside MCC	No Drift
Steering Coil 4 (amps)	Inside MCC	No Drift
Magnetron Heater (VAC)	Modulator	9.5 ± 0.2 (Standby)
Gun Heater (VAC)	Modulator	5.8 ± 0.2
Ion Pump (μA)	Modulator	N/A
Magnetron Tuner	MCC Front Panel	N/A
Dose Rate (R/min)	MCC Front Panel or SGI Physics Mode	≥ 300 R/min ≥ 400 R/min Express Version

The acceptable range for the parameters are somewhat machine dependent, and your particular machine may be set up differently. If any of the parameters drift substantially from their expected values, contact your service provider.

Environmental factors

Parameter	Location	Acceptable Range
Humidity	Globally	30% - 80%

For measurement of environmental factors that include humidity, the recommended barometer is the CNMC model 4195 Digital Barometer, which comes with a traceable certificate of calibration for pressure temperature and humidity.

2. Linac Output Constancy Check/Calibration

The Cyberknife[®] uses ion chambers that are vented to the atmosphere. Therefore, changes in atmospheric pressure and x-ray head temperature can affect output. It is recommended that the output be checked at least daily. If the environment where your Cyberknife[®] is installed changes dramatically throughout the day, you may have to check more often.

It is also recommended that a dedicated Farmer chamber be used for this check. This is to ensure that the chamber is set up the same way each time. At the time of the initial beam calibration, attach a Farmer chamber to the birdcage/toolstand chamber holder.

3. **Safety Interlock Check**

It is important to check some of the important safety interlocks on a daily basis. At a minimum, it is recommended that the door interlock and the operator panel E-stop button be checked daily.

MONTHLY QUALITY ASSURANCE

1. **Beam Parameters Check**

It is important to monitor a few beam characteristics on a monthly basis. It is recommended that beam symmetry, flatness, and penumbra be monitored monthly.

Equivalent methods such as water phantom scanning can be used. Beam energy should also be checked.

2. **Robot Mastering Check (visual)**

Move the robot to the perch position and verify that all six witness marks on the robot arm line up. Since the Kuka robot has no witness marks, it is necessary to mark each axis with a permanent pen for use as a reference alignment.

3. **Visual Targeting Check (v3.2.0 and later) (Optional)**

This is a quick visual check to verify that all subsystems are working properly. This test is sometimes referred to as the "BB test." Because this test is qualitative it is most useful for the early stages of targeting alignment, usually during acceptance and commissioning. It is included here as an optional test also useful for demonstrations of Cyberknife[®] capabilities.

4. **Imaging Alignment (Optional)**

It is sometimes advisable to check the imaging system mechanical alignment. This is especially important if there has been an earthquake or other significant perturbation of the camera stands or ceiling mounted x-ray sources.

5. **Film Targeting Test**

This test, often referred to as the "end-to-end test," is designed to show that the Cyberknife[®] as a system is highly accurate. That is, we show that the system, which integrates treatment planning, robot, image processing, Linac, and the safety subsystem, performs as a whole with a high degree of accuracy.

QUARTERLY QUALITY ASSURANCE

1. **Target Locating System Tracking (TLS) Test**

The TLS subsystem is responsible for measuring and reporting patient motion.

2. **Linac Laser Mechanical Alignment Check**

The Cyberknife[®] uses a point laser that is coincident with the radiation field as a QA tool. The laser is reflected off an adjustable mirror. The alignment must be checked periodically.

ANNUAL QUALITY ASSURANCE

1. **Beam Commissioning Spot Checks**

Checking the beam data on an annual basis is recommended to make sure nothing has drifted. Spot check, TPR, profile, and output factor data are necessary.

2. **Treatment Planning System (TPS) Tests**

Performing selected items from the system acceptance test is recommended on an annual basis to make sure that nothing has changed.

○ **Treatment Planning Display**

This test will verify that the CT image is displayed correctly in TPS. In addition to performing this test annually, this test should be performed any time a new CT machine is commissioned.

○ **TPS Distance Measurement**

This test will verify that TPS correctly interprets the geometrical distances from the CT. In addition to performing this test annually, this test should be performed any time a new CT machine is commissioned.

○ **TPS Calculations**

This test verifies the accuracy of calculating dose due to a single beam based on the beam central axis properties.

3. **Beam Calibration Check**

Using an established protocol (AAPM: TG21 or TG51; IAEA: TRS277, TRS398), check the calibration of the beam and calculate a cross calibration factor for the birdcage/toolstand chamber. Usually, either solid water or a small water phantom is used for this. The 60 mm collimator is usually used for calibration, so a standard 0.6 cc calibrated ion chamber can be used.

4. **Target Locating System Tracking (TLS) Test**

The TLS subsystem is used for measuring and reporting patient motion.

5. Safety Systems Checks

On an annual basis, test the following safety interlocks:

- All EPO buttons
- All the EMO (E-stop) Buttons
- Door Interlock
- Pause Button on SGI Display
- Water Flow Interlock
- A Spot Check of the PDP Model and Interlock

6. Robot

- On Kuka Robots Perform Mastering Check
- On all Robots Perform Search2 Calibration

7. Couch Position Indication Accuracy

Using a meter-stick measure couch movements and compare with values indicated on display. Values shall be correct to within $\pm 5\%$ ¹.

¹ Cyberknife Commissioning and Quality Assurance, P/N 019420 Rev C, Accuray, Inc.

CRCPD: A Partnership Dedicated to Radiation Protection

The Conference of Radiation Control Program Directors, Inc. (CRCPD) is a 501(c)(3) nonprofit non-governmental professional organization dedicated to radiation protection. CRCPD was formed in 1968.

- We promote radiological health in all aspects and phases;
- We encourage and promote cooperative enforcement programs with federal agencies and between related enforcement agencies within each state;
- We encourage the interchange of experience among radiation control programs;
- We collect and make accessible to the membership of the CRCPD such information and data as might be of assistance to them in the proper fulfillment of their duties;
- We promote and foster uniformity of radiation control laws and regulations;
- We encourage and support programs that will contribute to radiation control for all;
- We assist the membership in their technical work and development; and
- We exercise leadership with radiation control professionals and consumers in radiation control development and action.

CRCPD's mission is "to promote consistency in addressing and resolving radiation protection issues, to encourage high standards of quality in radiation protection programs, and to provide leadership in radiation safety and education."

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