CALIBRATION AND QUALITY ASSURANCE OF A THYROID UPTAKE MEASUREMENT UNIT

CENTER FOR MEDICAL AND RADIATION PHYSICS

AIM:

- To Study the Calibration of the Thyroid Uptake Measurement Unit.
- Perform the Quality Assurance tests of the Thyroid Uptake Measurement Unit.
- Determine the percentage of Radioiodine uptake using a patient's measured data.

Equipment Required:

- Thyroid uptake measurement unit (CAPTUS 4000e thyroid uptake probe with a computer system)
- Check sources: Cs^{137} & Eu^{152}
- Source holder
- Neck Phantom

Theory:

Nuclear medicine is a branch of medical speciality that uses a unique drug known as radiopharmaceuticals, which contain radioisotope-labelled pharmaceuticals. These radiopharmaceuticals are used to diagnose and treat diseases like cancer and hyperthyroidism and to perform functional studies of specific organs like the thyroid, heart, kidney, etc.

Thyroid uptake measurement is a nuclear medicine procedure used to evaluate thyroid function by assessing the amount of radiotracer absorbed by the thyroid gland. The measurement test can be done by quantifying or measuring the amount of radioactive iodine absorbed by the thyroid gland within a specified time frame (like immediately after administration, after 2hr, or after 24 hours). The isotopes of Iodine used for this purpose are I^{123} and I^{131} and are commonly available in capsule or liquid form. The dose administered is generally 10μCi to 30μCi for I^{123} and I^{131}. The measurement can be carried out with specially designed equipment known as a thyroid uptake measurement unit.

Instrument and Its Accessories:

A thyroid uptake measurement unit consists of a thyroid uptake measurement probe and a computer readout system. The thyroid uptake measurement probe consists of a sodium iodide (NaI:(Tl)) scintillation crystal integrated with a multi-channel analyzer with suitable lead shielding and a flat field collimator.

The thyroid uptake probe, CAPTUS 4000e, is a comprehensive Nuclear Medicine Measurement System with specific software modules for thyroid uptake, bioassay, wipe tests and automated quality assurance tests. The system includes a fully functional 1024-channel MCA with automatic and manual calibration. The well-type detector is an optional device for the assembly, but its presence is very useful in Bioassay and wipe tests. The complete setup is shown in Figure 1 below, and detailed technical specifications of the thyroid uptake system are given in Table 1 below.

Figure 1: CAPTUS 4000e Unit

Table - 1

Specification			**Detailed**
Make			Mirion - Capintec
Model			CAPTUS 4000e
Detector	Probe	Detector Material	NaI(Tl)
		Dimension	2"X2"
		Resolution	≤9.5% or better for Cs137
	Well	Detector Material	NaI(TI) well-type crystal
		Dimension	2"X2"
		WELL Diameter	1.6CM
		WELL Depth	3.8CM
		Resolution	≤10.0% or better for Cs137
		Shielding Material	Lead lined with brass to minimise backscattering
MCA	Type		CAP MCA
	Channel		1024
	Maximum Count Rate		200000Cps
	ROI's Selection		Automatic and Manual
Operational Environment Requirement	Temperature Range		10^0C to 30^0C
	Pressure Range		91 to 105KiloPascal
	Humidity Range		Maximum relative humidity < 95%

NECK Phantom:

The Neck Phantom (Biodex Neck Phantom) is designed to simulate a patient's neck. The phantom is made up of Lucite, and it has a two-part insert that allows counting from a bottle, vial, or capsule. A capsule holder is supplied to enable the user to count from capsules directly. The standard count rate is obtained by placing the pharmaceutical (Radioiodinated pharmaceutical either in capsule or liquid form) in the holder part of the phantom, as shown in Figure 2 (c), and measuring the counts at a 25cm distance from this phantom. The setup picture is shown below.

(a) Biodex Neck Phantom

(b)Inner Insert for vial placement

(c) Setup for standard dose measurement

Figure 2: Design of a Neck Phantom

To measure the thyroid uptake accurately, the probe must be calibrated with a standard source. The calibration method used in CAPTUS 4000e is a direct method integrated with the software itself and known by the name "AUTO CALIBRATION". Apart from this calibration procedure, routine quality assurance checks need to be followed for better equipment performance: the linearity test, constancy test, accuracy check, Chi-square test, and MDA test. The details of the tests are briefly described below.

Tests to Be Performed:

Calibration of Thyroid uptake measurement unit:

The calibration simply means the detector's energy calibration. The goal of energy calibration is to find a relation between the channel numbers of the MCA and the corresponding energies of a standard radioactive source. So, in our case, the detector, along with the software, is calibrated in such a way that it will always show a peak at a predefined location or channel number for a particular standard radioactive source with known energy. Hence, each time we start the calibration, the software will automatically adjust its parameters like Gain and zero offset to bring the known energy peak to its predefined Channel number. This adjustment is possible in one attempt or may require two to three iterations. Such a type of calibration process is known as auto-calibration. Sometimes, the auto-calibration process is accompanied by energy resolution calculation. For flat-faced detectors like NaI (Tl) thyroid probes, the energy resolution should be <9.5%, and For Well detectors, the resolution should be <10.0% measured at the Cs^{137} 662 keV peak. The energy resolution generally changes slightly over several years (increases by 1% to 3%).

Linearity Test:

After the energy calibration, linearity tests are performed to check whether the software gives the correct energy value corresponding to the channel number for a known source. It will be easier if we take a source emitting multiple known energies. The software-calculated energy and its deviation from the true energy value will be displayed on the software screen.

Constancy Test

This test compares the standard source activity with the activity measured. The activity of the standard source is entered into the setup during installation. During the measurement, the decay-corrected activity is compared with the decay corrected by the software. It increases the accuracy of a measurement. The counts measured are converted to activity using efficiency values using the Isotope Library of the standard source. The deviation between the calculated and measured activity is the percent error and should be within ±10%. This percentage deviation should not change for two or three consecutive measurements on the same day and for consecutive days. The percentage of deviation between measured and calculated activity shows the accuracy of the Detector Probe. The accuracy of the software result can also be verified by manually calculating the decay corrected activity from the source data.

Chi-Square Test:

The Chi-Square test provides a sensitive check of the system's overall counting performance. This test will check the difference between observed and expected counts for a particular number of iterations. The software uses the 662 keV peak of the Cs^{137} source. Chi-square values are given in the following table for 5, 10, 15, and 20 repetitions. The Chi-Square Test results should fall between the 0.95 and 0.05 probability values in the table below almost all the time.

# Repetitions	0.95	0.90	0.10	0.05
5	.711	1.06	7.78	9.49
10	3.33	4.17	14.7	16.9
15	6.57	7.79	21.1	23.7
20	10.1	11.7	27.2	30.1

Note: This table is taken from the CAPTUS 4000e Owner's Manual

The Chi-Square value can be obtained from the equation given below-

$$\chi^2 = \frac{1}{x_{av}} \sum_{i=1}^{n} \left(x_i - x_{av} \right)^2$$

Where,

n is the number of iterations
X_i = Counts for measurement of i^{th} time
X_{av}= Average of the n measurements.

So, for 10 iterations, the chi-square value should be within 3.33 to 16.9, 90% of the time. The software will automatically calculate this value and give us the result.

Minimum detectable Activity (MDA) Test:

This test measures counts and calculates activity in the Region of Interest (ROI) for the isotope selected in the Setup. As isotopes of interest are already loaded in the software library, the ROI region for the energy peaks is already known, or you can add the ROI manually. The measurement is performed without any source placed in the detector, which therefore gives a value for the Minimum Detectable Activity (MDA)

Measurement of Uptake:

The thyroid uptake measurement is generally performed in intervals, such as just after administering the dose, between 2hr-6hr, and after 24hr. The uptake is usually measured at 25 cm between the face of the crystal and the anterior neck of the patient or phantom. Neck counts, lower thigh counts (body background), calibrated standard in neck phantom counts (Administered Counts) and room background counts are obtained at each counting session. By using these counts, the % of thyroid uptake can be calculated using the following formula:

$$RAIU = \frac{P-T}{C-B} X100 \qquad — \qquad (1)$$

Where RAIU= Radioactive Iodine Uptake

P= Patient Neck count rate (direct counts 25cm from the neck of an administered patient)

T = Patient Background count rate (counts from the thigh of the administered patient)

C = Dose (standard) count rate (Counts obtained using Neck Phantom and standard source to be administered)

B = Room background count rate (Counts without any source)

Dose (standard) count rate or Administered counts are obtained by counting the tracer administered to the patient or a standard (equivalent to the administered dose) in a neck phantom, with correction for decay if necessary.

Procedure:

Auto Calibration: (Direct Method)

- To perform auto calibration, click on the auto calibration tab on the CAPTUS® 4000e Main screen, and after clicking it, the Auto calibration screen will appear as shown in the figure below.
- On the **Select Detector** in the right corner of the auto-calibration window, select the desired detector (i.e. **Probe or Well**) to perform calibration. By default, PROBE is always selected.
- Select the Start Procedure button to start the calibration procedure.
- After clicking the start button, the software will prompt you to place the Cs^{137} source on the selected detector (Probe or well). Place the Cs^{137} rod source in the selected detector. To ensure reproducible source placement for the Uptake Probe, turn the Uptake Probe so that the Collimator opening faces the ceiling. Gently place the active end of the rod source onto the middle surface of the crystal. Use a rod source holder to ensure the rod stands freely and does not lean to the side.
- Select the OK button to proceed with the calibration process. As counting progresses, the live spectra will appear on the screen as shown. The system will count for as long as necessary until sufficient calibrations are acquired.

Figure 3: CAPTUS 4000e Main Screen

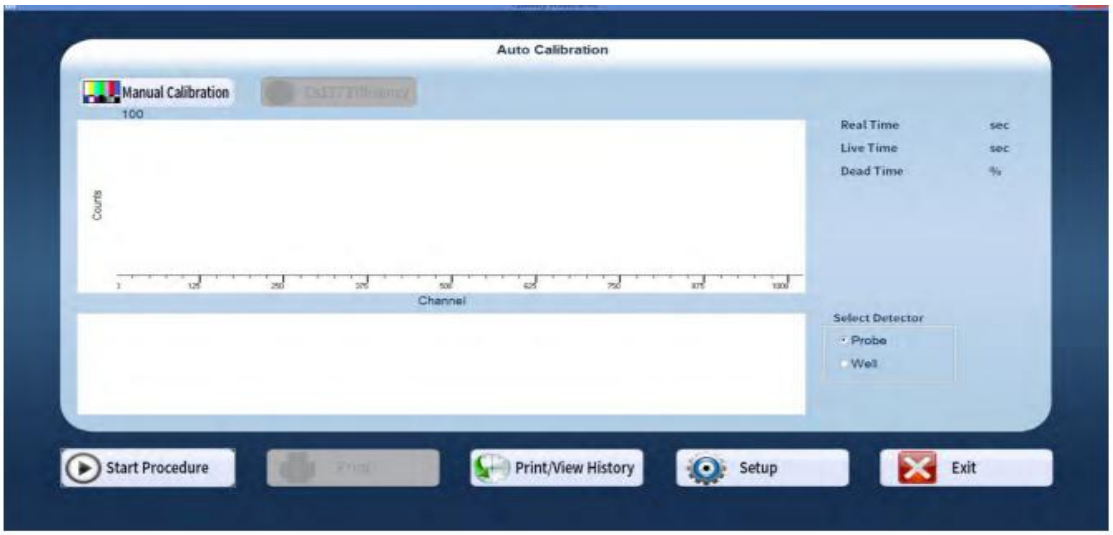


Figure 4: Auto Calibration Screen

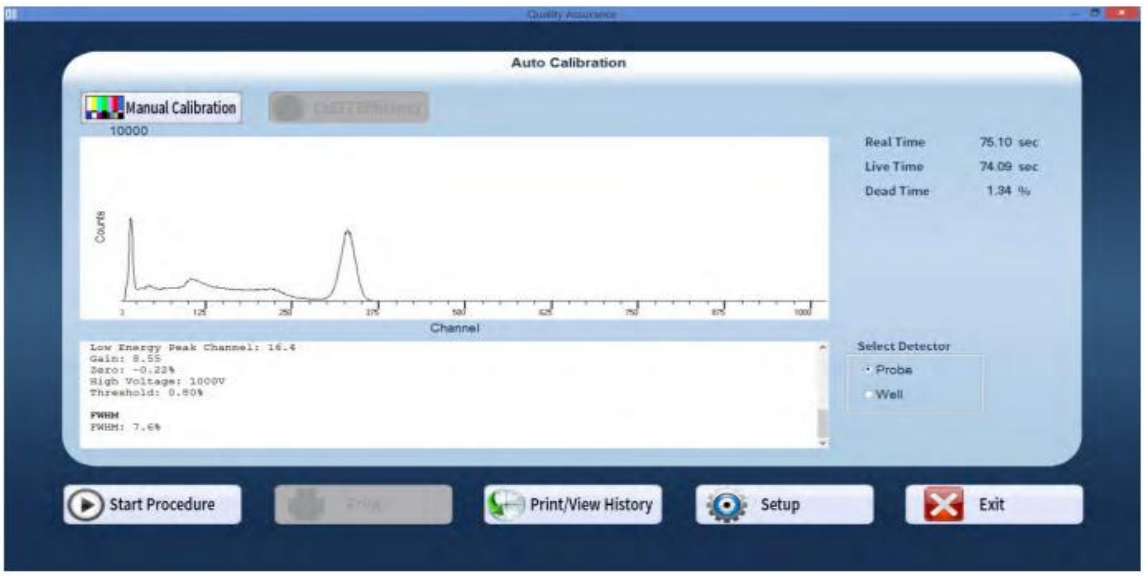
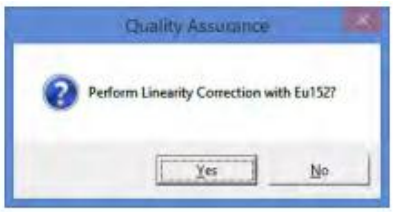


Figure 5: Cs-137 Spectrum in Auto Calibration Process

- During the Auto Calibration, the software will adjust parameters like Gain and zero offset to bring the 662KeV peak of Cs-137 to Channel number 331. So, within 2 to 3 iterations, it will be achieved, and successful calibration will appear in the result box.
- The result box will also show the FWHM value for the detector.
- A similar process can also be followed to calibrate the Well detector.

Linearity Test:

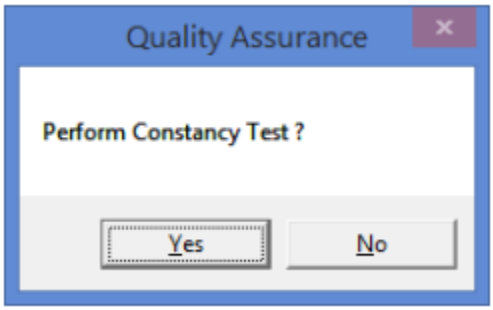
- After successful auto-calibration, the screen appears as shown in Figure below, prompting to perform Linearity Correction using Eu^{152}.



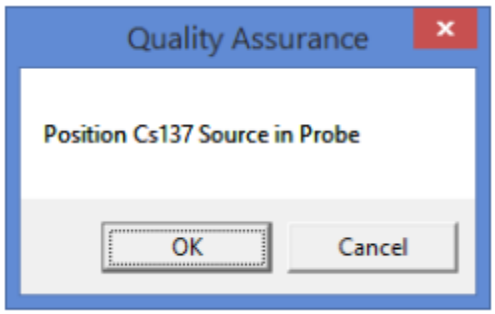
- Select the **Yes** button to proceed with further calibration, place the Eu152 source in the selected detector in the same position as Cs137, and select the OK button.
- After the count collection is over, the system is fully calibrated. Complete results are displayed in the lower half of the screen, and all the data is automatically stored in the system.

Constancy Check:

- If the calibration is successful, Eu152 Linearity Correction results appear on the screen, and the software prompts you to perform the Constancy Test as shown in the figure.



- Select the **Yes** button to proceed. The figure will be displayed



- Place the Cs^{137} source rod in the selected detector. The source must be placed in the same position each time the Constancy Test is performed.
- Select the **OK** button to proceed with the test. As the counting progresses, the live spectra and measurement time are displayed on the screen.
- After the test is completed, the test results appear in the box below the measurement spectrum, as shown in Figure. Note the displayed Deviation value.

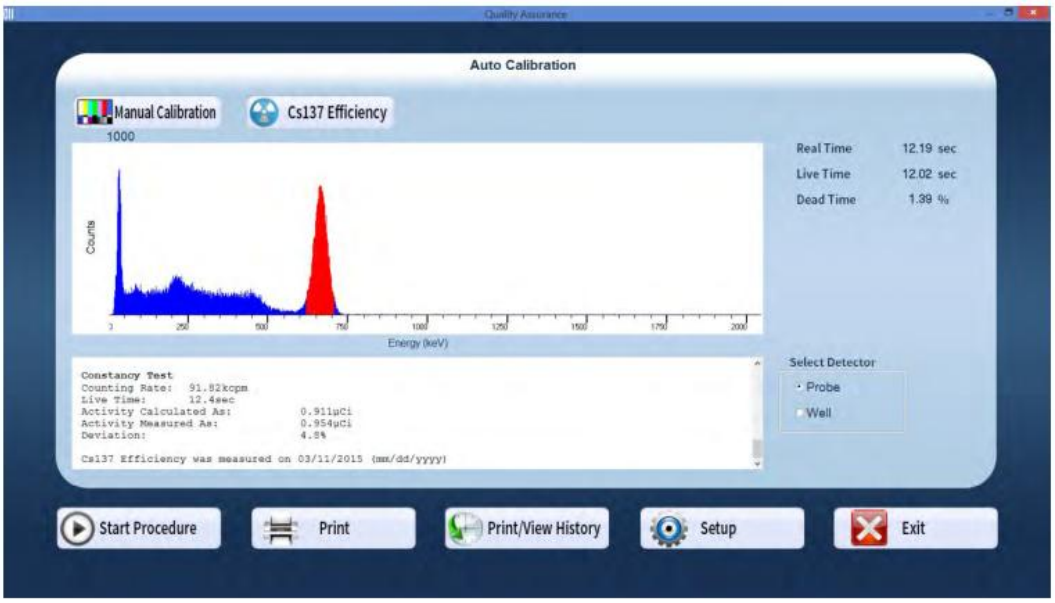
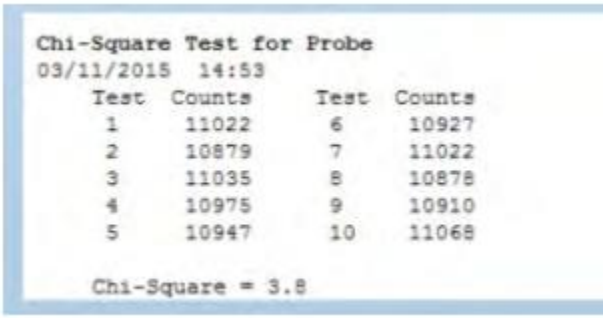


Figure 6: Constancy Test Result

Chi-Square Test:

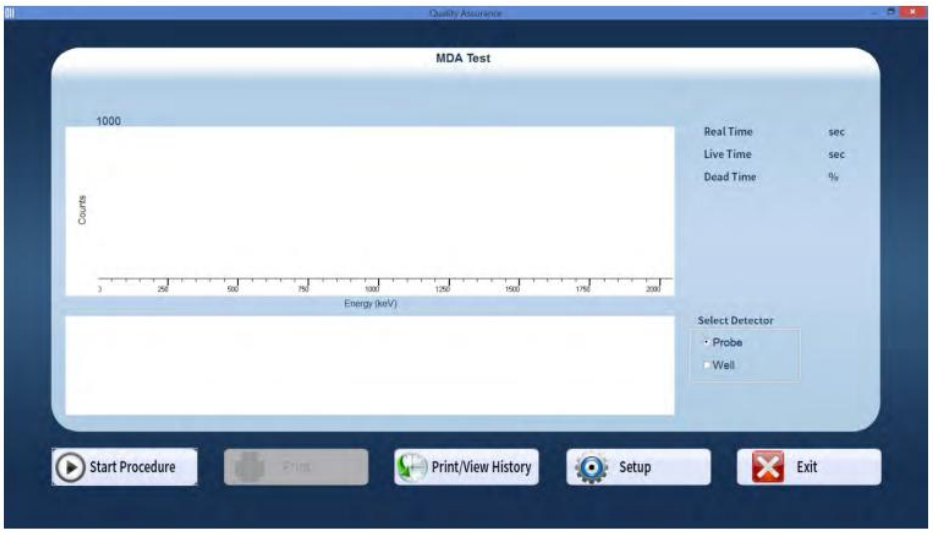
- Make sure Auto Calibration is done before performing the Chi-square test.
- Click on the Chi-Square test in the CAPTUS 4000e Main screen, and then the Chi-Square test screen will appear.
- Click on the start button. The software will quickly prompt the Cs-137 source to be placed in the selected detector. After putting the source, click ok.
- The software then starts taking the counts; typically, it will perform a 10-repetition test. The screen displays live spectra, measurement time (upper right corner) and the remaining repetitions.

- After 10 repetitions, the test is completed, and the test results appear in the results box, as shown in the figure below.
- If the Chi-Square value is out of range, perform the test again. If the test passes the second time, the system functions properly.

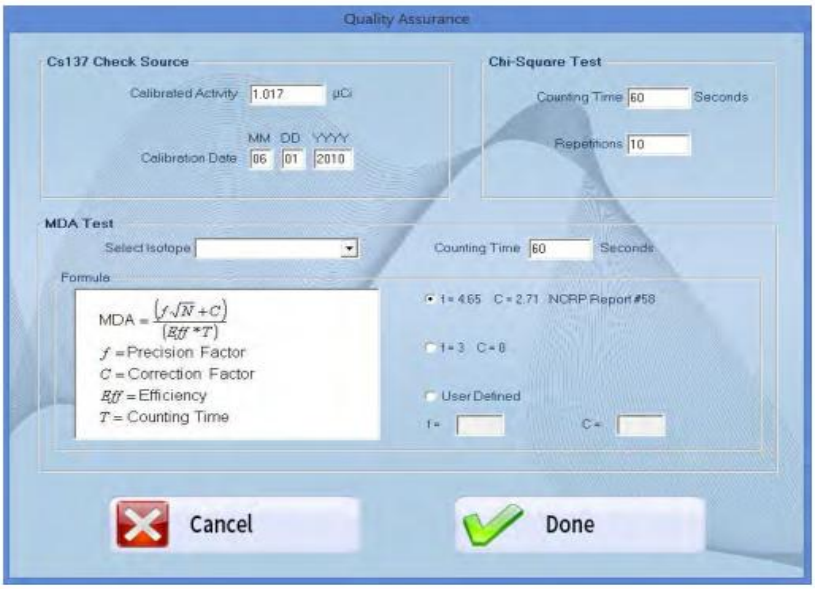


Minimum Detectable Activity test (MDA test):

- Select the **MDA Test** button on the Quality Assurance Main Screen. MDA Test Screen will appear like the figure below



- Note that in the **Select Detector** frame, **PROBE** is selected by default. To change the detector to Well, select the **WELL** radio button.
- Select the **Setup** button, and the Quality Setup Screen will appear. Only the **MDA Test** frame values are used in this test.



- To change the **Counting Time**, click in the text box and input the new value. To select another isotope, click in the **Selected Isotope** drop-down box and click on the desired isotope to select it. This sets a new ROI for count measurement
- To alter values used in the formula for MDA calculation, select the desired radio button in the Formula frame.
- Select the **Done** button to save the added information, return to the MDA Test Screen, and Select the **Start Procedure** button. The software will quickly prompt you to Remove all sources.
- Remove any radioactive source from the vicinity and select the **OK** button to proceed with the test.
- When the measurement is completed, the screen appears like that shown in the Figure, displaying the Minimum Detectable Activity (MDA) measured in the selected isotope's ROI.

Figure 7: MDA test screen

Thyroid uptake procedure:

- Prepare two identical radiopharmaceutical source samples, one for standard reference dose measurement and the other for patient dose administration.
- Before the dose administration, measure the standard dose counts using neck phantom, as shown in the figure below.

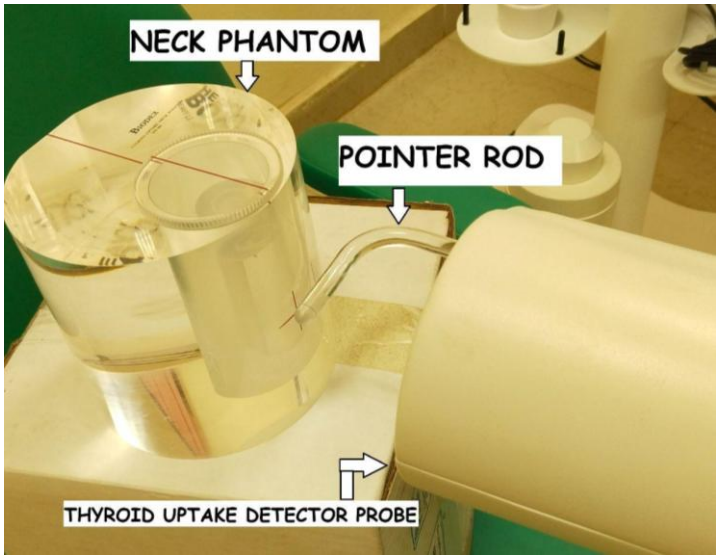
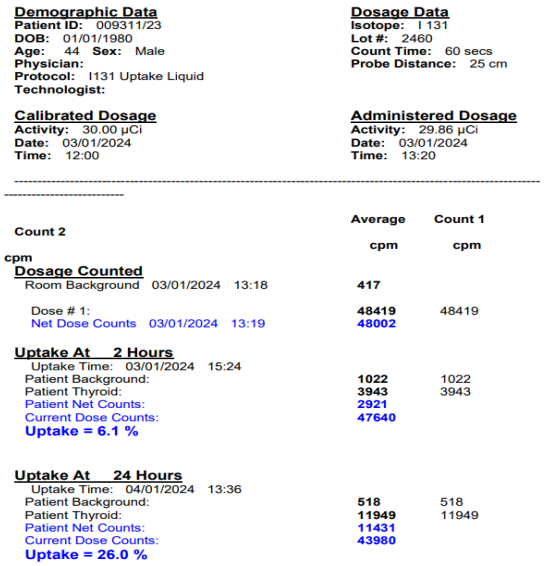


Figure 8: Standard dose measurement setup using neck phantom and thyroid probe at 25cm

- Keep the detector at 25cm from the neck phantom with the help of a pointer rod.
- Before the measurement, background counts should be measured without any source in the room.
- Before administering the radiopharmaceutical to the patient, background counts should be measured from the patient's thigh.
- After the dose administration, measurement is done by keeping a 25cm distance from the neck.
- A similar procedure should be followed for successive measurements of the background and the patient's neck after 2 hrs and 24 hrs to calculate the percentage of thyroid uptake.



Demographic Data
Patient ID: 009311/23
DOB: 01/01/1980
Age: 44 **Sex:** Male
Physician:
Protocol: I131 Uptake Liquid
Technologist:

Dosage Data
Isotope: I 131
Lot #: 2460
Count Time: 60 secs
Probe Distance: 25 cm

Calibrated Dosage
Activity: 30.00 µCi
Date: 03/01/2024
Time: 12:00

Administered Dosage
Activity: 29.86 µCi
Date: 03/01/2024
Time: 13:20

Count 2 cpm	Average cpm	Count 1 cpm
Dosage Counted		
Room Background 03/01/2024 13:18	417	
Dose # 1:	48419	48419
Net Dose Counts 03/01/2024 13:19	48002	
Uptake At 2 Hours		
Uptake Time: 03/01/2024 15:24		
Patient Background:	1022	1022
Patient Thyroid:	3943	3943
Patient Net Counts:	2921	
Current Dose Counts:	47640	
Uptake = 6.1 %		
Uptake At 24 Hours		
Uptake Time: 04/01/2024 13:36		
Patient Background:	518	518
Patient Thyroid:	11949	11949
Patient Net Counts:	11431	
Current Dose Counts:	43980	
Uptake = 26.0 %		

- A patient's software calculated thyroid uptake is shown. You can calculate the % of thyroid uptake for the same patient and verify with software using the decay equation for the corresponding time as the type of radionuclide administered is provided and by equation 1.

Calculation:

Half-life of I-131 = 8.06 days

Before Administration	Room Background count = 417 CPM	Net initial count before administration = 48002 CPM

Nature of readings	After 2 hours of administration	After 24 hours of administration
Patient background count	1022 CPM	518 CPM
Patient Thyroid count	3943 CPM	11949 CPM
Net patient dose count	2921 CPM	11431 CPM
Remaining activity ($A_o e^{-\lambda t}$)	47659 CPM	44047 CPM
Thyroid Uptake	6.1%	25.9%

Precaution

- Wear gloves while handling radiopharmaceuticals during measurements.
- Wash your hands with soap and water after the experiment.
- Never put sharp instruments like a knife or pen into the well or probe.

References:

- Captus 4000e Manual