

Appendix I: Artefacts and Trouble-shooting

Slide set of 101 slides based on the chapter authored by E. Busemann Sokole, N.J. Forwood of the IAEA publication (ISBN 978–92–0–143810–2):

*Nuclear Medicine Physics:
A Handbook for Teachers and Students*

Objective:

To familiarize the student with trouble-shooting methods, problem minimization, and recognizing the cause of artefacts that may be encountered in nuclear medicine imaging systems



IAEA

International Atomic Energy Agency

Slide set prepared in 2015
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- I.1 The art of trouble-shooting
- I.2 Image artefacts
- I.3 Minimizing problems
- I.4 Image artefacts in PET/CT
- I.5 Importance of regular quality control

I.1 THE ART OF TROUBLE- SHOOTING

I.1.1 Basics

I.1 THE ART OF TROUBLE-SHOOTING

I.1.1 Basics

Trouble-shooting

- ❑ Trouble-shooting refers to the process of recognizing and identifying the cause of an artefact, a malfunction or a problem in an instrument.
- ❑ Types of problems
 - Obvious: e.g. instrument is not working.
 - Less obvious: e.g. abnormality in the expected result.
- ❑ Artefact refers to an abnormal result, e.g. in a calibration, quantitative evaluation, a clinical image or quality control image, and is often a less obvious problem.

I.1 THE ART OF TROUBLE-SHOOTING

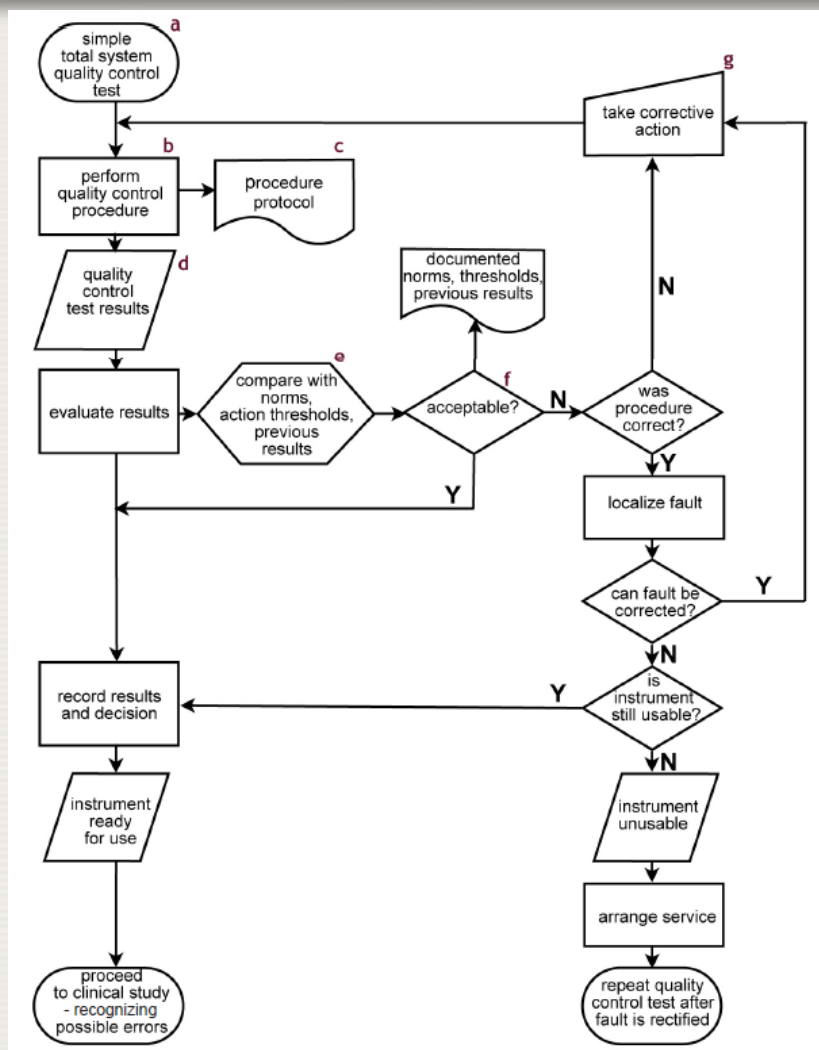
I.1.1 Basics

Malfunctions and actions

- ❑ Malfunctions can occur at any time, even during a patient investigation.
- ❑ The actions in this case should minimize the distress to the patient, identify the problem and correct it, if possible, and decide what to do with the investigation (continue, do it on another instrument, reschedule, or other).
- ❑ Action flow-charts are useful in the decision making process. An example is shown in the next slide, following a QC test.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.1 Basics



The symbols indicate:
a — start or end;
b — process to be performed;
c — protocol;
d — intermediate results;
e — checks required;
f — decision to be made;
g — action taken.
Question answer:
Y — yes; N — no.

Decision tree suggested for performance, evaluation and follow-up of a QC test.

I.1 THE ART OF TROUBLE- SHOOTING

I.1.2 Processes in trouble-shooting

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting

Trouble-shooting in clinical environments

- ❑ Trouble-shooting in a clinical environment requires immediate action by a group of qualified personnel, in order to reduce down time.
- ❑ When setting up a trouble-shooting system in the department, several elements have to be taken into account, regarding the personnel involved and the priority of the actions to be taken.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting

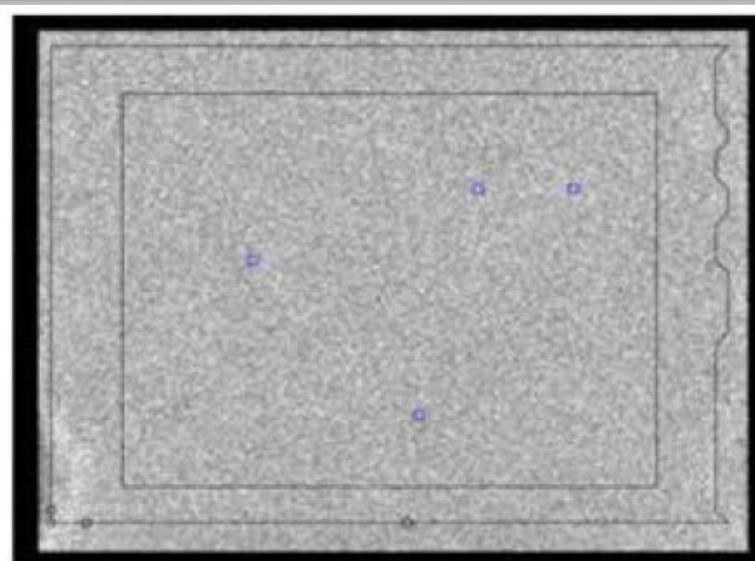
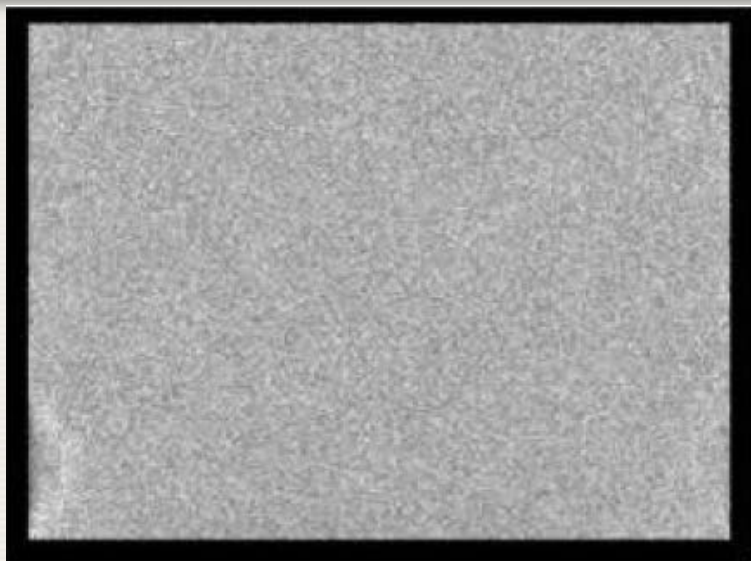
Elements to consider in a trouble-shooting system

- ❑ Identify a qualified person to be responsible for communication and decisions once a problem occurs. This person will be called on as first-line support.
- ❑ Investigate as soon as possible if the problem can be solved immediately or if it will take time.
- ❑ If solving the problem requires time, it should be decided if the equipment is usable with limitations until repaired or totally unusable.
- ❑ If the problem occurs during a clinical study, minimize anxiety to the patient.



I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting

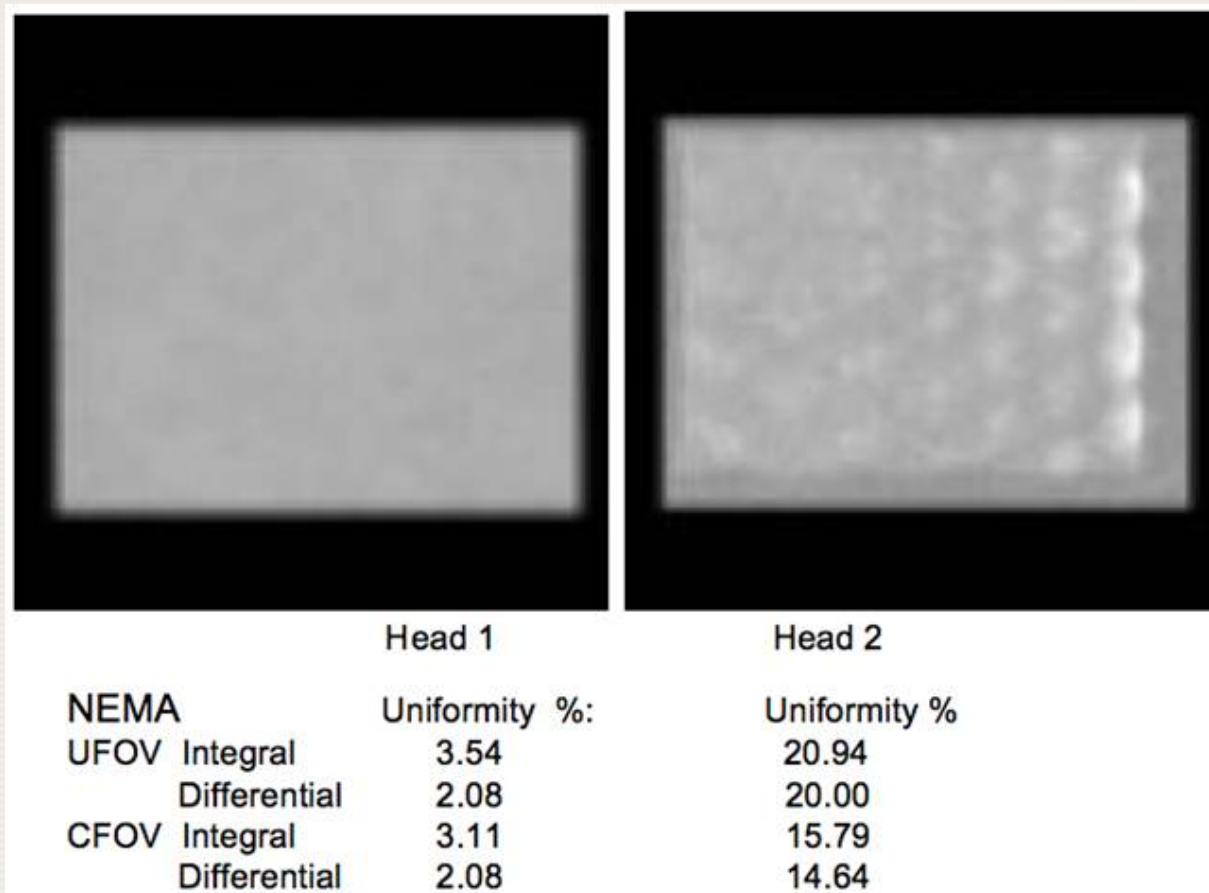


NEMA		Uniformity(%)	Specifications(%)
UFOV	Integral	9.53	<3.6
	Differential	6.4	<3.0
CFOV	Integral	3.72	
	Differential	2.79	

The defect affected imaging at the edge of the field of view. This detector could therefore still be used for imaging within the central field of view.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting



The non-uniformity of head 2 was extensive and thus imaging with this detector had to be suspended until the problem was solved.

I.1 THE ART OF TROUBLE-SHOOTING


I.1.2 Processes in trouble-shooting

Information on malfunctions

- To assist in solving the problem, as much information as possible regarding the circumstances at the time of the malfunction should be documented.
- Enter all problems and as much related data as possible into the log book specific to the instrument. The solutions should also be documented.
- This log book should be started at installation and maintained throughout the lifetime of the instrument.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting

Nieuwe Storing.		Dupliceer dit record	Verslaag dit record !
Probleemomschrijving: Driver voltage test, error #72, PSD is pressed, voltage			
Apparaat: Camera-Gantry		Prioriteit: 5 Today !	
Inventaris nummer:		AMC locatie: GE-Millie	
Melder: Bastiaan		Reporting Date: 25/06/2002	
Voor exit (engels-talig): priority: Solve today !			
Wie er mee bezig is: Arjen		Volgende afspraak:	
Het wachten is op: Peter		Storing-ID/plan_ID: StoNG133	
Leverancier: GE Medical Systems		Telefoon: 0800-0994442	
Straat en nummer: Hambakenwetering 1		fax:	
Postcode en plaats: 5231 DD 's		Ref. code:	
Contactpersoon: Peter		ZIS-nr:	
			
StoNG133: Driver voltage test, error #72, PSD is pressed, voltage disconnected.			
Log Driver voltage test, error #72, PSD is pressed, voltage disconnected.			
Ik was vanochtend begonnen met de preheat van de CT. Bij 41 sek. stopte de Gantry en begon te piepen (interval van 1 sek.). De camera gaf een melding op zijn display: System paused PSD activated Ik heb gecontroleerd of er iets tussen de camera's en het bed was gekomen en dit was niet het geval. Verder heb ik gekeken of de infrarood detectoren van de camera's bedekt/wies waren, dit was niet zo. De Gantryhoek is 253 graden, collimator is de LEHR (VPC-45), tafelstanden 79 hoog en 30 lengte (deze tafelstanden gebruik ik altijd voor de QC).			
<i>Log Translation: This morning I started with the preheat of the CT. At 41s the Gantry stopped and started to peep (at 1 s intervals). The camera gave a message on its display. System paused PSD activated I checked whether anything had got between the camera heads and bed, but this was not the case. I also checked if the infrared detectors of the camera were covered or dirty, not so. The gantry angle is 253 degrees, collimator is LEHR, bed position 79 high and 30 length (I always use these table positions for the QC).</i>			

Example of log book, describing the related circumstances at the time of malfunction detection.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting

Assuming a starting time for malfunctions

- ❑ At the moment of discovering a problem in a QC test, it is uncertain when the malfunction causing the artefact or calibration failure first occurred.
- ❑ The assumption is that it may have occurred at any time between the current and previous QC test.

I.1 THE ART OF TROUBLE-SHOOTING

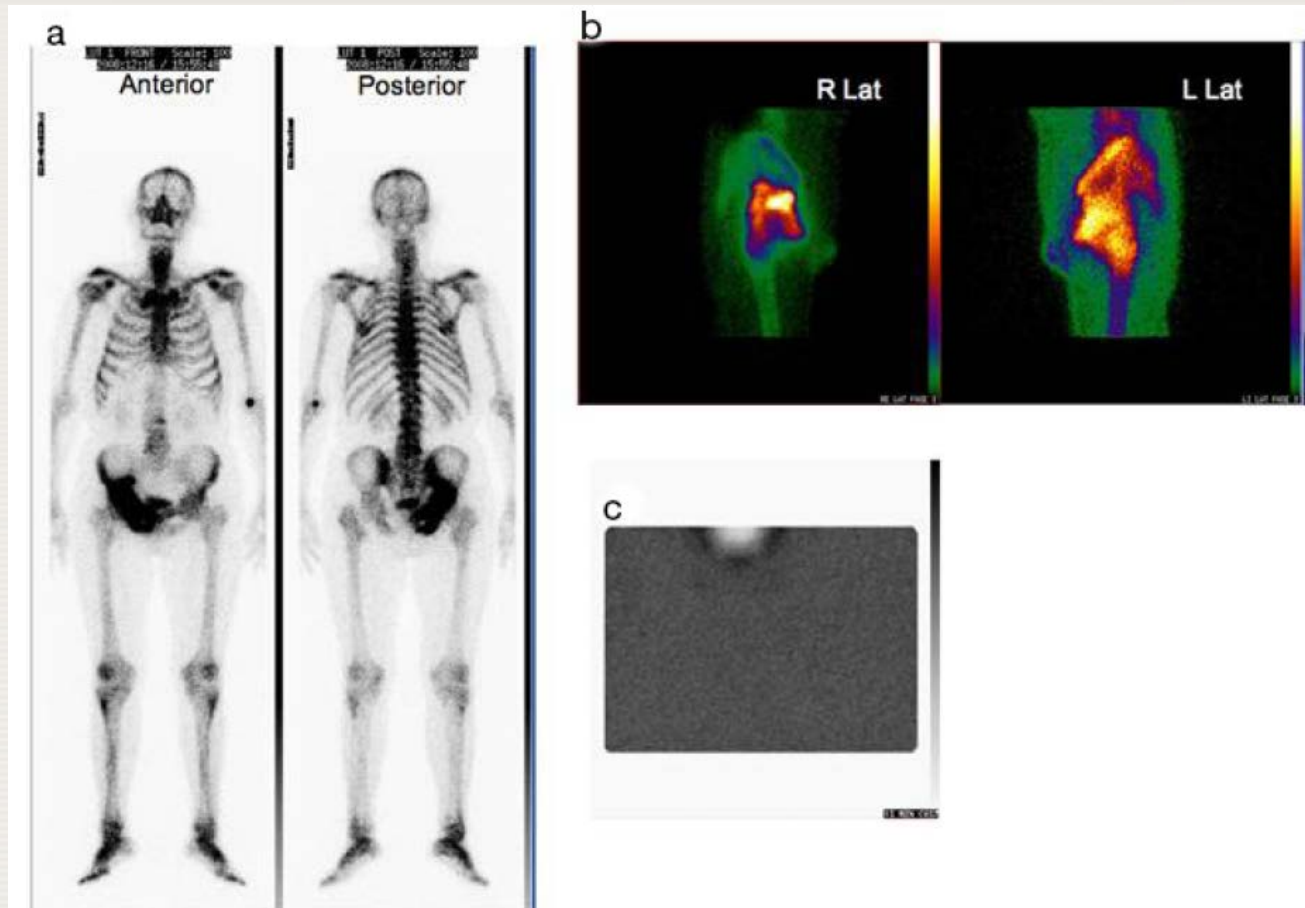
I.1.2 Processes in trouble-shooting

Clinical studies and erroneous QC results

- ❑ The clinical studies prior to the QC test with erroneous results should, therefore, be carefully reviewed in order to ascertain when the artefact first occurred.
- ❑ In the event that the artefact in the clinical images may have resulted in an incorrect diagnostic report, it must be communicated to the nuclear medicine physician to decide what should be done with the patient.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting



Defect was found during a routine QC test. This camera required a service, but could still be used with caution for planar imaging within a limited part of the detector.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting

Repetitive abnormal patterns in clinical images and data

- ❑ Particular care must be exercised at all times to be alert to artefacts in clinical images, abnormal quantitative values and data analysis results.
- ❑ If the same or a very similar abnormal pattern is observed in successive clinical images from different patients, then the abnormal pattern may be caused by a malfunction in the instrument.

I.1 THE ART OF TROUBLE-SHOOTING

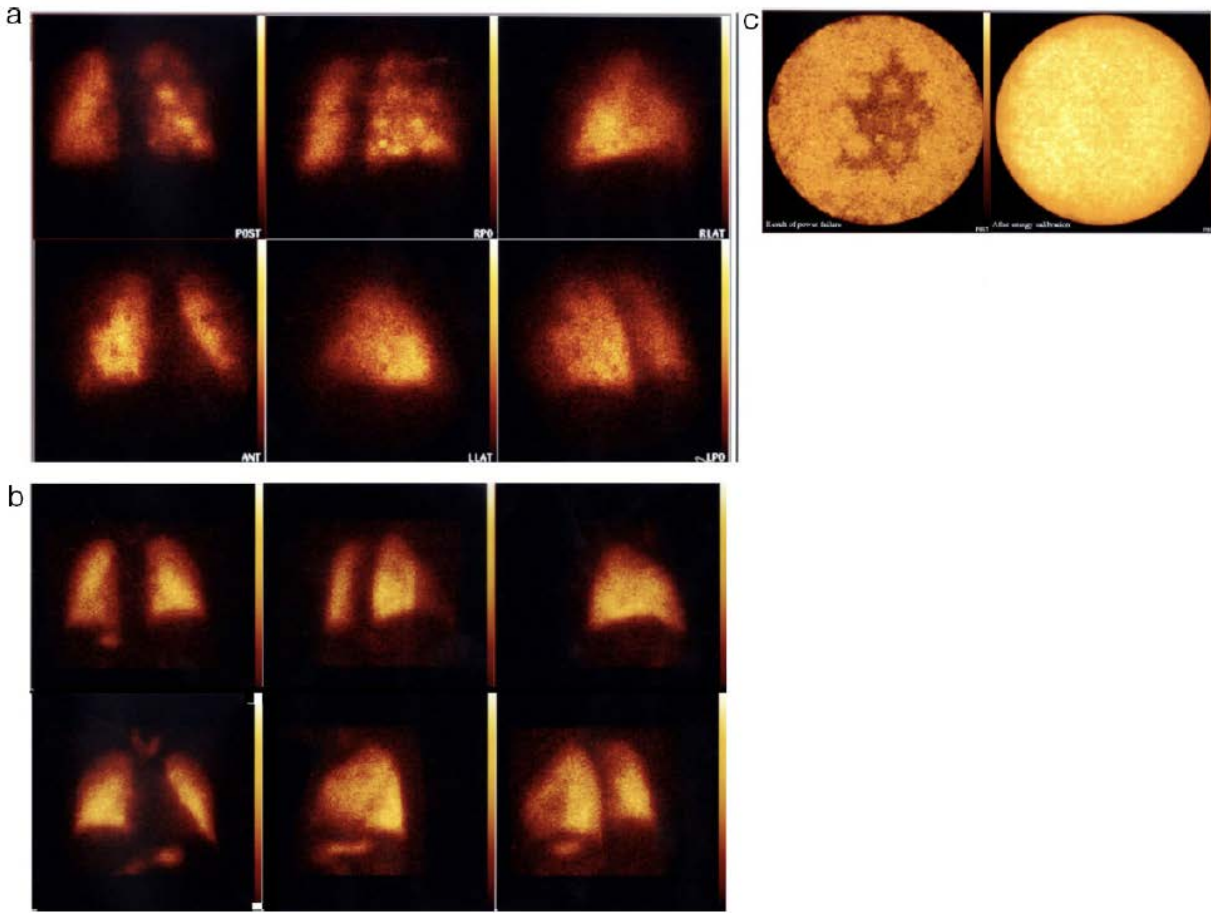
I.1.2 Processes in trouble-shooting

Repetitive abnormal patterns in clinical images and data

- ❑ Radiopharmaceuticals should also be investigated as a probable cause.
- ❑ The problem should first be investigated before further patients are injected and imaged.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting



Abnormal pattern

Patchy pattern (a) found on the lung scans due to untuned camera, confirmed by QC test (left c). After retuning (right c), new images were obtained (b), without the patchy pattern.

I.1 THE ART OF TROUBLE-SHOOTING

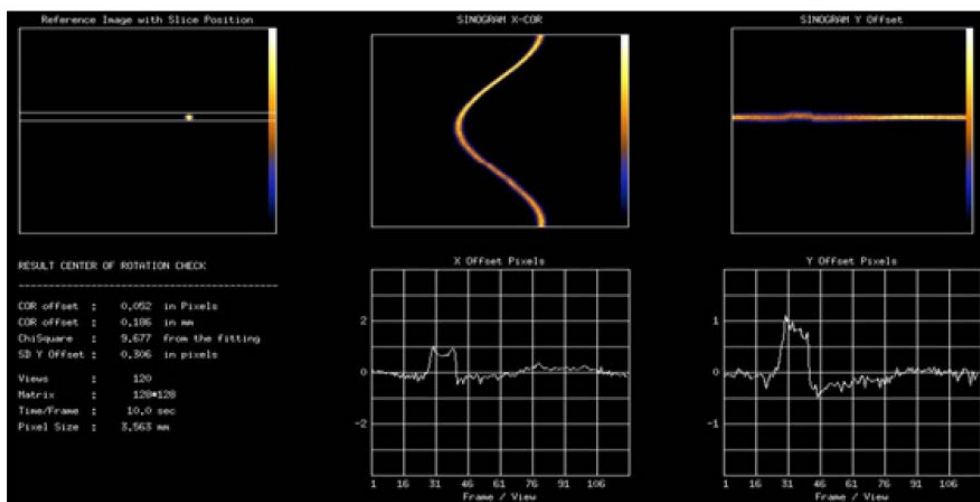
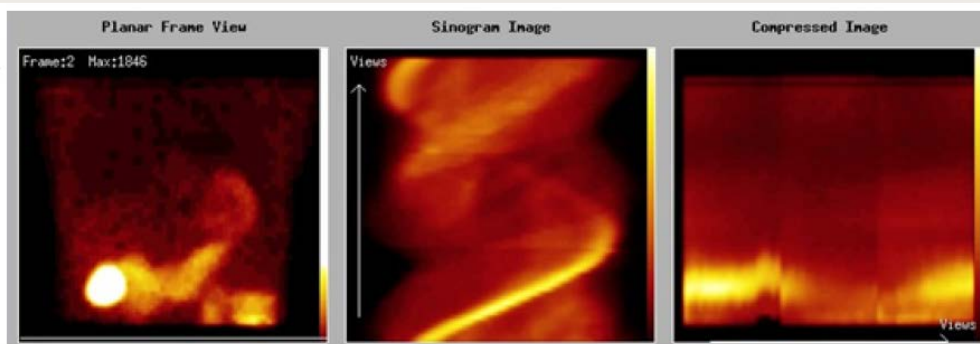
I.1.2 Processes in trouble-shooting

Verification of solved problems

- After a problem has been solved, the instrument should be tested for correct functioning before being released for clinical use.
- After changes in software or hardware, restart the system to ensure correct functioning after power down.
- Validate quantitative results after any changes in hardware or software.
- Be aware of an intermittent or repetitive problem. Even after a problem appears to be solved, it may still be present because of instability in a component.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.2 Processes in trouble-shooting



Abnormal quantitative results

Offsets are seen in both X and Y in detector 1 data, identified clearly by the jump in offset in both X and Y on the quantitative analysis.

The problem was due to a decrease in voltage to the signal board of detector head 1 at certain projection angles.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.3 Trouble-shooting remedies

I.1 THE ART OF TROUBLE-SHOOTING

I.1.3 Trouble-shooting remedies

Trouble-shooting tactics and hints

- ❑ Various first-line trouble-shooting tactics can be useful before resorting to contacting the service.
- ❑ Some general hints to be considered are given, although the circumstances are left to the discretion of the trouble-shooter.
- ❑ The trouble-shooting section of the instrument's instruction manual should also be consulted.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.3 Trouble-shooting remedies

In the event of failure or instability of an instrument or component

- Check electrical power, circuit breakers, fuses, cables and cable connections, fans.
- For accessible batteries, check the level of battery power within the instrument that regulates a specific function.
- Check for dust, and cleanliness of sensors and metal contacts.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.3 Trouble-shooting remedies

Computer and network

- ❑ If a program halts, exit and restart the program. If this is unsuccessful, shut down and restart the computer.
- ❑ For a suspected communications failure between the instrument and the computer, shut down and restart the computer.
- ❑ If this does not solve the problem, shut down both the computer and the instrument, and, after about 30 s, restart the instrument and then the computer.
- ❑ **NOTE:** ensure that the patient is not on the imaging pallet when turning off and restarting the computer or instrument.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.3 Trouble-shooting remedies

Computer and network

- If peripheral equipment (such as a printer) stops functioning or produces an error message, shut down and restart that equipment.
- Check the computer network and communications.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.3 Trouble-shooting remedies

Errors and artefacts in clinical results

- Check first the radiopharmaceutical and injection quality, study parameters and instrument settings, and patient positioning.
- If these are correct, then investigate instrument malfunction.
- Always consult the department procedure manuals.

I.1 THE ART OF TROUBLE-SHOOTING

I.1.3 Trouble-shooting remedies

Errors and artefacts in QC test results

- For the specific QC test, check that the test method was correct.
- Initiate appropriate supplementary QC tests, as necessary.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Artefacts, problems and causes

- ❑ Image artefacts manifest themselves in different ways as a result of different factors.
- ❑ Relating an artefact to the underlying problem is a developing process of understanding the instrument and how it should be used.
- ❑ A particular instrument may show characteristic artefact patterns that repeat and become familiar over time.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Problems encountered in gamma camera images for different performance parameters

- Distortion of the energy spectrum, photopeak shape, loss of energy resolution.
- Decrease in detector sensitivity.
- Poor image uniformity of a gamma camera.
- Poor image spatial resolution and image contrast.
- Abnormal results in clinical investigations.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Causes of distortion of the energy spectrum, photopeak shape, loss of energy resolution

- Poor tuning or energy calibration.
- Malfunctioning photomultiplier (PMT) or preamplifier.
- Inadequate or unstable electrical grounding.
- Instability in electrical contact in the detector power supply.
- Deteriorating detector material.
- Interference from nearby radionuclides.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Causes of decrease in detector sensitivity

- Incorrect centering of the photopeak window.
- Change in the PMT tuning values or gain values.
- Malfunctioning PMT.
- Deteriorating detector material.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Causes of poor image uniformity of a gamma camera

Inadequate corrections and procedures

- Inadequate energy correction for radionuclides other than ^{99m}Tc .
- Offset in centering of the image with respect to the image matrix and corrections.
- Asymmetrical or erroneous position of the energy window on the photopeak.
- Improper QC procedure, including errors due to phantom preparation, e.g. size of a point source, flood source filling, source positioning.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Causes of poor image uniformity of a gamma camera (cont.)

Photomultipliers (PMTs)

- Poor tuning of the PMTs.
- Malfunctioning or defective PMT(s).
- Loss of optical coupling between PMT and light guide, light guide and crystal surface, or PMT and crystal surface.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Causes of poor image uniformity of a gamma camera (cont.)

Damaged detector

- Deterioration in detector properties, so that energy and/or linearity corrections no longer correspond.
- Crystal hydration.
- Broken detector crystal (due to impact or thermal changes).

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

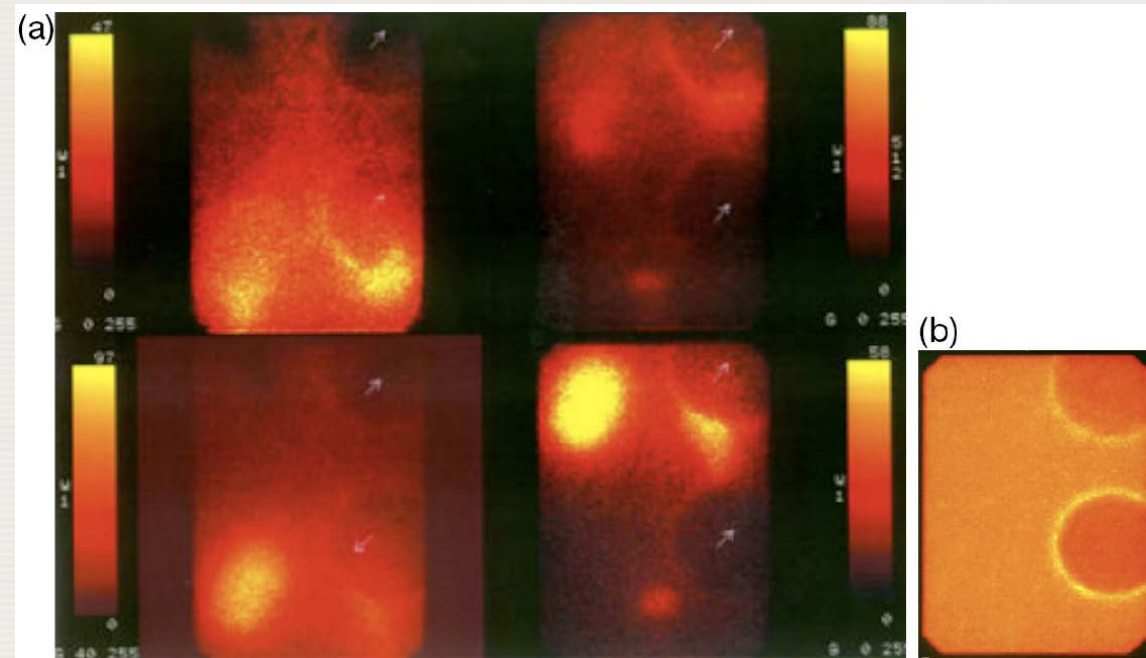
Causes of poor image uniformity of a gamma camera (cont.)

Damaged collimator and contamination

- Defects in the collimator (extrinsic uniformity).
- Radioactive contamination on the collimator or detector crystal.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes



Uniformity defect due to PMTs

(a) Each image of the clinical study showed two large, diffuse, circular colder areas (indicated by arrows).

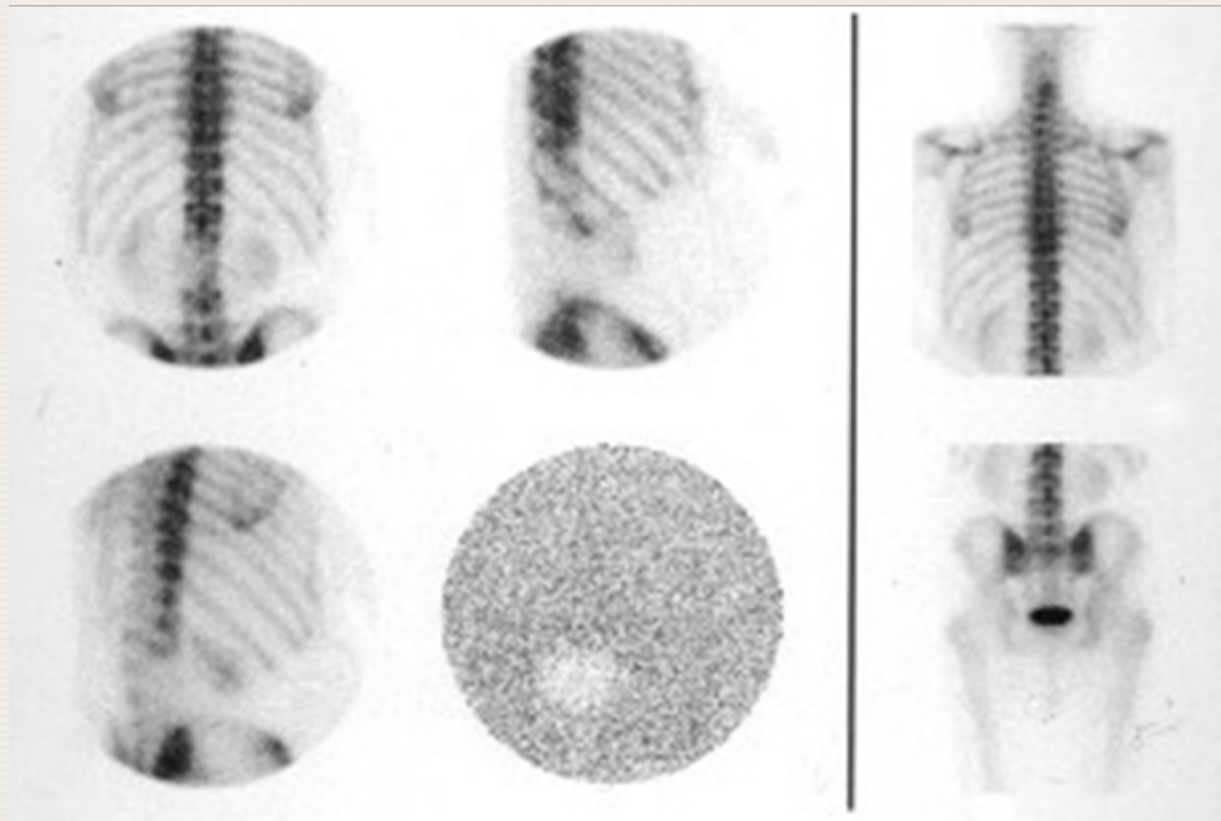
(b) Uniformity image with cold areas due to faulty PMT.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Camera A

Camera B



Uniformity defect due to PMTs

In camera A an area of apparent decreased activity is observed in the lower spine .

Repeated study on camera B shows a normal distribution.

Uniformity image of camera A demonstrates defective PMT.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Use of asymmetric energy window images

- ❑ A uniformity test is the most sensitive QC test to perform when an image artefact is suspected.
- ❑ If non-uniformity in a QC test is diffuse or unclear, a sensitive trouble-shooting method is to make two further uniformity QC images with asymmetrically positioned energy windows high and low over the photopeak.
- ❑ Non-uniformities are highlighted in such asymmetric images, with cold areas in the one image corresponding to hot areas in the other image.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

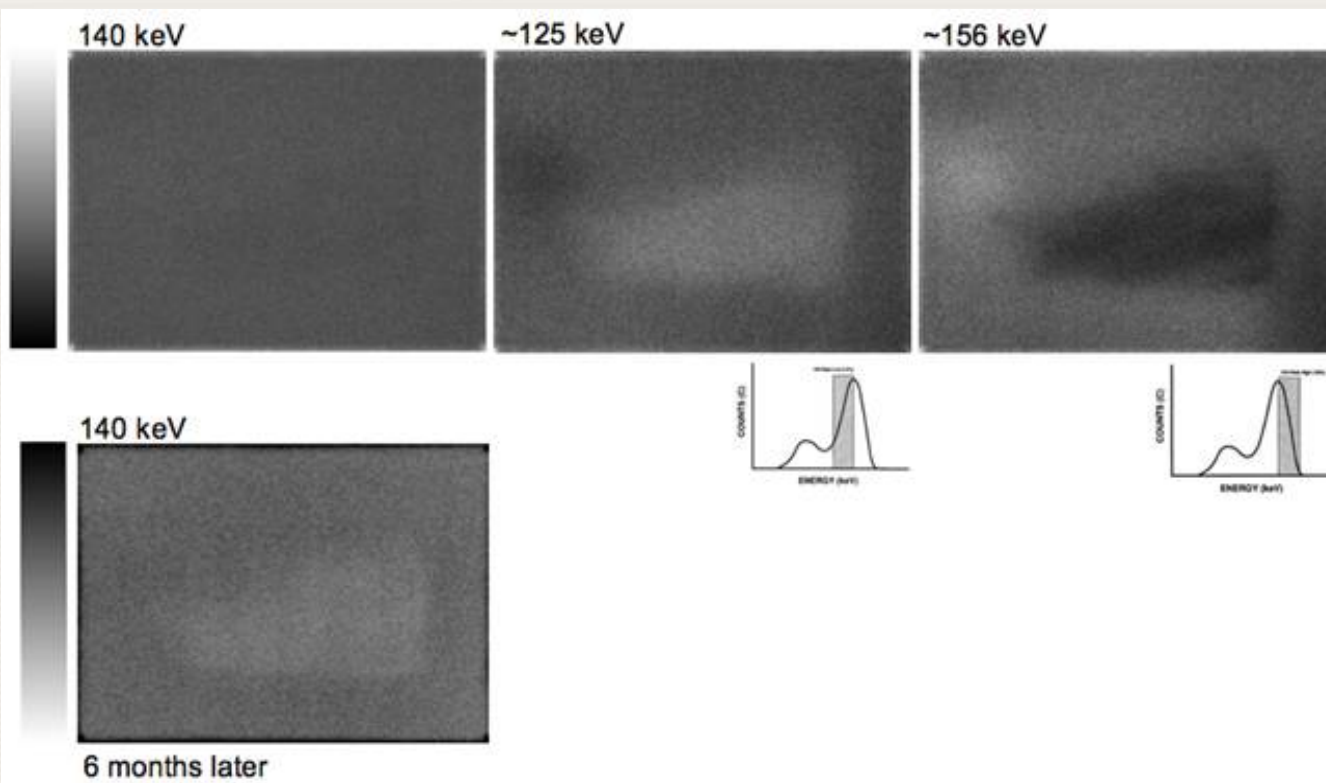
Use of asymmetric energy window images

Asymmetric images highlight

- poor tuning
- problems with an energy correction map
- ADC problems
- crystal hydration

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

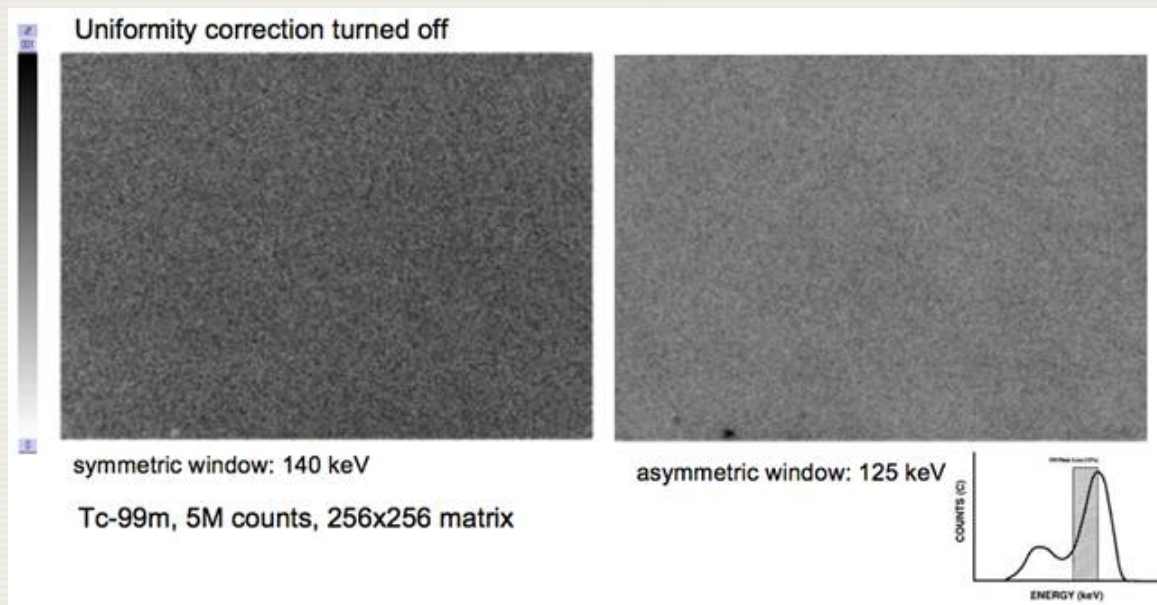


Asymmetric images

Early appearance in asymmetric images of defect, that 6 months later appears in the symmetric image, attributed to separation of the light pipe from the crystal.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

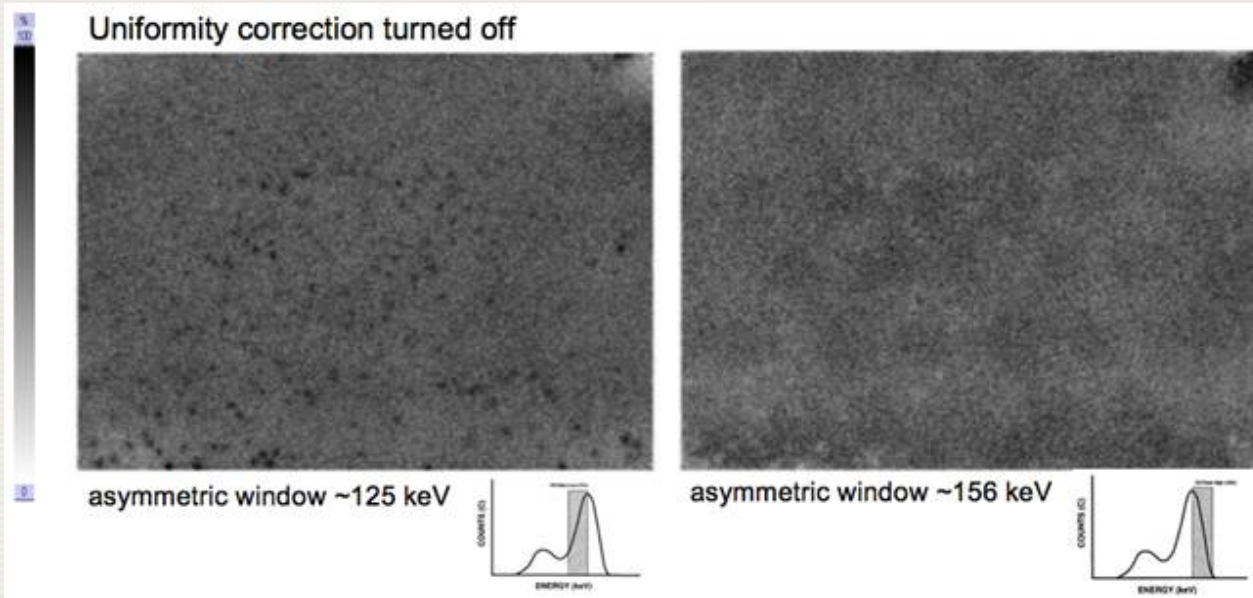


Asymmetric images

Early detection of crystal defect in newly installed camera seen in asymmetric image.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes



Asymmetric images

Example of hydration and poor tuning is shown in the asymmetric images.

I.2 IMAGE ARTEFACTS

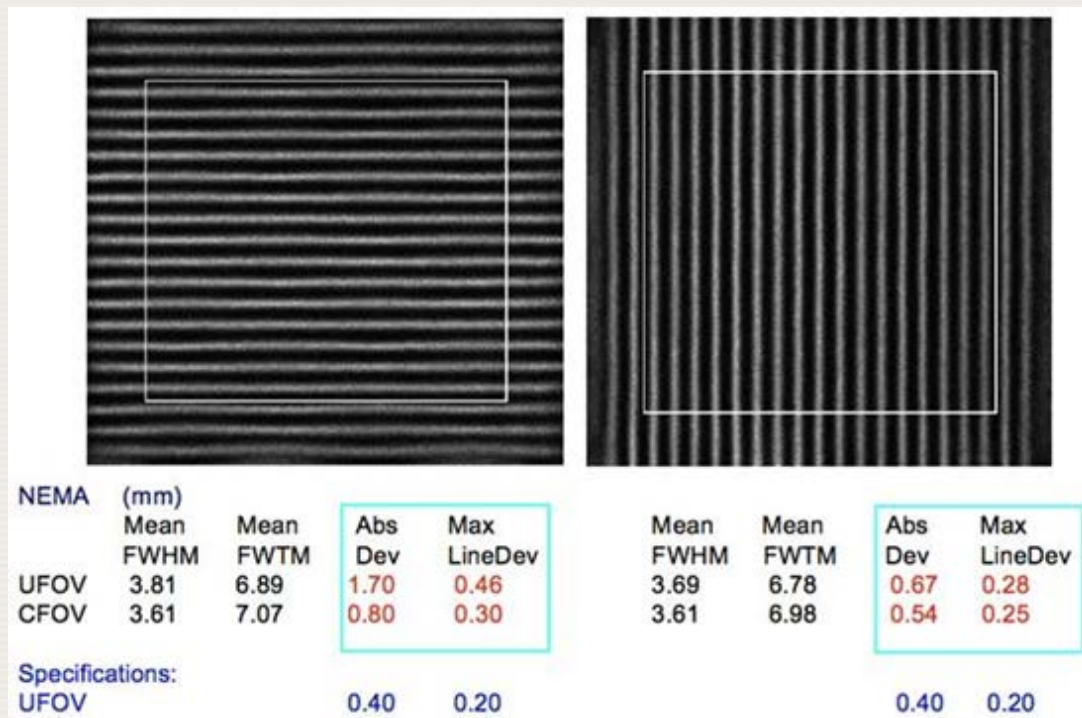
I.2.1 Recognizing image artefacts and their underlying causes

Causes of poor image spatial resolution and image contrast

- Too large a distance between the patient and collimator.
- Poor linearity corrections of the detector.
- As visual evaluation of linearity is subjective and difficult to assess, linearity should be quantified if software is available.
- Poor multiple energy window registration.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes



Poor linearity correction

Linearity (absolute deviation: Abs Dev; maximum line deviation: Max LineDev) are out of specifications in both the X and Y directions. The linearity correction maps needed re-calibration.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Causes of decrease in image contrast:

- Incorrect position of the energy window. This may be an operator error.
- Performing an automatic 'peaking' procedure with the patient as the radioactive source includes unnecessary scatter in the image.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

In SPECT, a decrease in resolution and contrast may be caused by:

Imaging technique and calibration

- ❑ The imaging technique (e.g. excessively large radius of rotation, poor choice of acquisition and reconstruction parameters).
- ❑ Inadequate instrument calibration (offset in centre of rotation in X or Y directions, detector tilt in Y direction, poor alignment of multiple detector heads, inadequate uniformity correction).

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

In SPECT, a decrease in resolution and contrast may be caused by:

Artefacts

- Artefacts in acquired data (e.g. missing projections, PMT artefact).
- Artefacts in reconstructed data (e.g. ring artefacts from non-uniformity).

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Data review

- Always review the acquired clinical study image data before the patient leaves the department.
- A review of the acquired data is always essential before processing and quantification.
- The department clinical procedures manual should state how to make this review and how to proceed when erroneous data are found.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

Data review

Looking for erroneous data

- ❑ For SPECT data, a cine, sinogram and linogram can suffice to review the clinical data for
 - patient movement.
 - missing projections.
 - instability (an artefact that appears in only some projections).
 - inadequate continuity of data from multiple detectors.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes

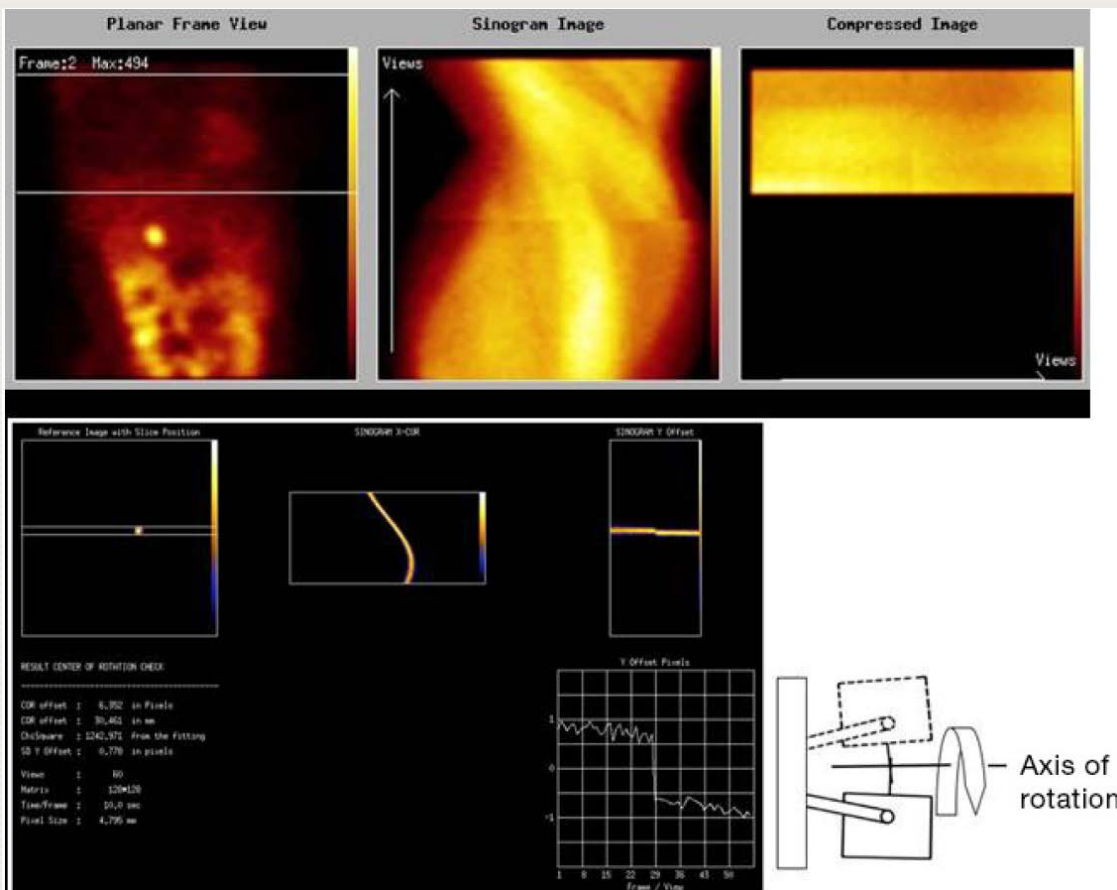
Data review

Repeating studies

- If the review reveals such errors, then the study may need to be repeated.
- The final decision must be made by the medical specialist, who evaluates if the study is still clinically useful and other specific considerations concerning the patient, and the additional dose due to a repeated study.

I.2 IMAGE ARTEFACTS

I.2.1 Recognizing image artefacts and their underlying causes



Head tilt problem

QC following recalibration of camera head alignment, showing a remaining problem of head tilt.

I.3 MINIMIZING PROBLEMS

I.3 MINIMIZING PROBLEMS

How to minimize problems

- ❑ A way to minimize the likelihood of problems occurring is to take appropriate precautions on time.
- ❑ These measures should be taken with a systemic approach, by considering the most frequent causes of problems and minimizing their occurrence or their effect.

I.3 MINIMIZING PROBLEMS

I.3.1 Siting and room preparation

I.3 MINIMIZING PROBLEMS

I.3.1 Siting and room preparation

Location selection and site preparation

- The location of an instrument and the site preparation prior to installation are vital initial steps.
- Considerations for room preparation should include the following:
 - Construction
 - Electrical
 - Environmental

I.3 MINIMIZING PROBLEMS

I.3.1 Siting and room preparation

Considerations for room preparation

Construction

- Necessary wall shielding from extraneous radiation and magnetic fields.
- Floor weight support and floor levelling.
- Window placement with respect to the instrument position to avoid drafts and influence from direct sunlight.
- Positioning of the instrument within the room to minimize interference from external radioactive sources.

I.3 MINIMIZING PROBLEMS

I.3.1 Siting and room preparation

Considerations for room preparation

Electrical installation

- Continuous stable electrical power supply.
- Sufficient strategically placed power outlets for peripherals.
- Lighting and switches (to exclude electrical interference with equipment).

I.3 MINIMIZING PROBLEMS

I.3.1 Siting and room preparation

Considerations for room preparation

Environmental

- Stable air conditioning with respect to temperature (maximum, minimum, fluctuating temperatures) and humidity (non-condensing).
- Dust free environment.

I.3. MINIMIZING PROBLEMS

I.3.2 Electrical power conditioning

I.3. MINIMIZING PROBLEMS

I.3.2 Electrical power conditioning

Voltage stability and electrical grounding

- ❑ The stability and correct voltage level of the electrical supply is crucial to reducing the likelihood of obtaining an instrument malfunction.
- ❑ This may be achieved by use of a surge protector, a constant voltage transformer or a UPS (battery backup).
- ❑ The electrical conditioning includes appropriate grounding, and shielding of cables, especially for signal cables and data transmission cables.

I.3 MINIMIZING PROBLEMS

I.3.3 Regular preventive maintenance

I.3 MINIMIZING PROBLEMS

I.3.3 Regular preventive maintenance

Preventive maintenance and service

- ❑ Regular preventive maintenance and a service contract can help to minimize the chance of an unexpected problem occurring and to minimize the down time when a problem has occurred.
- ❑ A service contract should ensure fast response and priority access to spare parts.
- ❑ In-house access to trained personnel is also essential for first-line trouble-shooting.

I.3 MINIMIZING PROBLEMS

I.3.4 Acceptance testing and routine quality control testing

I.3 MINIMIZING PROBLEMS

I.3.4 Acceptance testing and routine quality control testing

Acceptance testing

- ❑ Thorough and careful acceptance testing is the first step towards ensuring that an instrument is performing according to specifications and as expected for clinical use.
- ❑ Any problems or suspected problems encountered at this early stage require instant rectification as the instrument is still under the guarantee period.

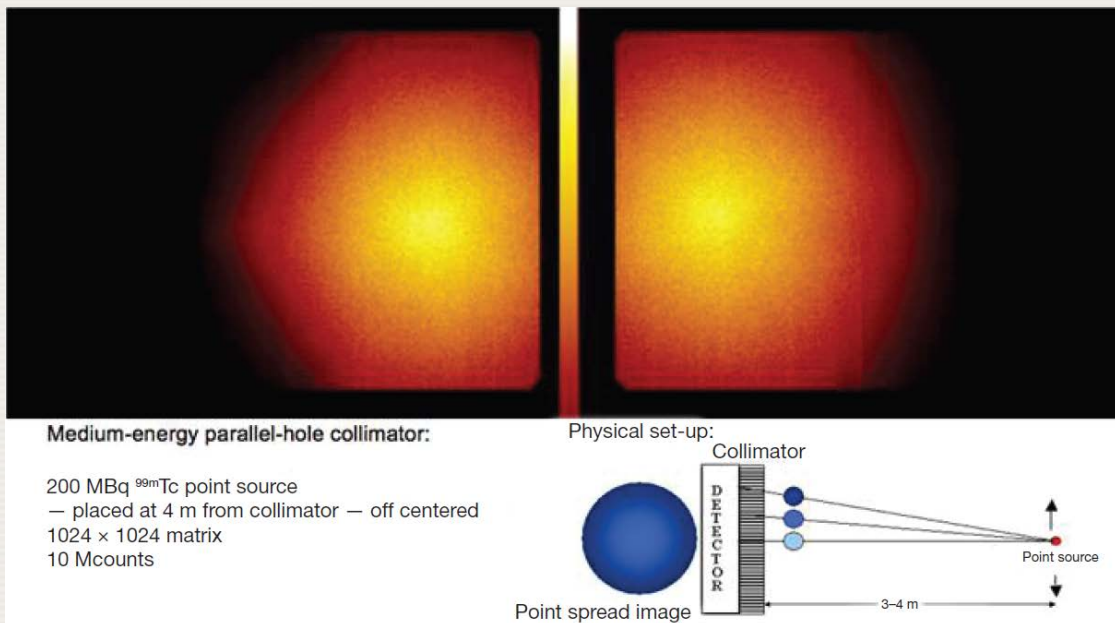
I.3 MINIMIZING PROBLEMS

I.3.4 Acceptance testing and routine quality control testing

Acceptance testing findings

Collimator tested for hole angulation at acceptance testing.

There are vertical discontinuities evident, probably from the manufacturing process. This collimator was replaced within the guarantee period.



I.3 MINIMIZING PROBLEMS

I.3.4 Acceptance testing and routine quality control testing

Routine quality control tests

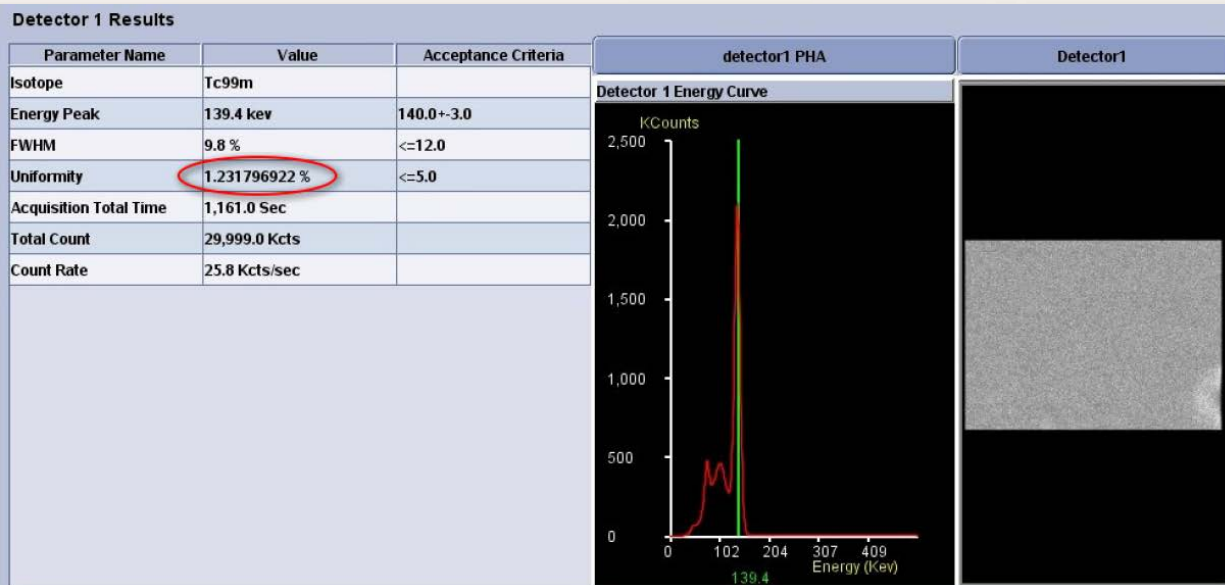
- Routine QC tests are performed on the gamma camera and SPECT system in order to assess performance of the instrument at a specific moment.
- Monitoring the results of successive QC tests can indicate a stable functioning condition, deterioration or impending problem.
- The visual as well as quantitative results must always be reviewed together.
- Routine QC tests are valuable in troubleshooting and should not be neglected.

I.3 MINIMIZING PROBLEMS

I.3.4 Acceptance testing and routine quality control testing

Visual inspection and quantitative data

In the uniformity test, the quantitative uniformity value appears to be acceptable, whereas the image shows there is a PMT problem at the border. Both results must be reviewed together.



I.4 IMAGE ARTEFACTS IN PET/CT

I.4 IMAGE ARTEFACTS IN PET/CT

PET and PET/CT artefacts

- ❑ PET and combined PET/CT artefacts are quite distinct from those which may be seen in SPECT or SPECT/CT due to the intrinsically different modes of acquisition.
- ❑ Although the artefacts are different, the user must be aware of their appearance in clinical images to detect early malfunctioning.

I.4 IMAGE ARTEFACTS IN PET/CT

PET and PET/CT artefacts

It is useful to classify PET/CT artefacts into the following categories:

- tomographic artefacts
- attenuation correction artefacts
- co-registration artefacts
- movement artefacts

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.1 Tomographic artefacts

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.1 Tomographic artefacts

Tomographic artefacts causes

- ❑ Tomographic artefacts are those which appear when some fundamental aspect of the tomographic system performs below specification or else fails entirely.
- ❑ Scan abnormalities can be due to incorrect normalization. Normalization corrects for the sensitivity difference between different lines of response (LORs).

I.4 IMAGE ARTEFACTS IN PET/CT

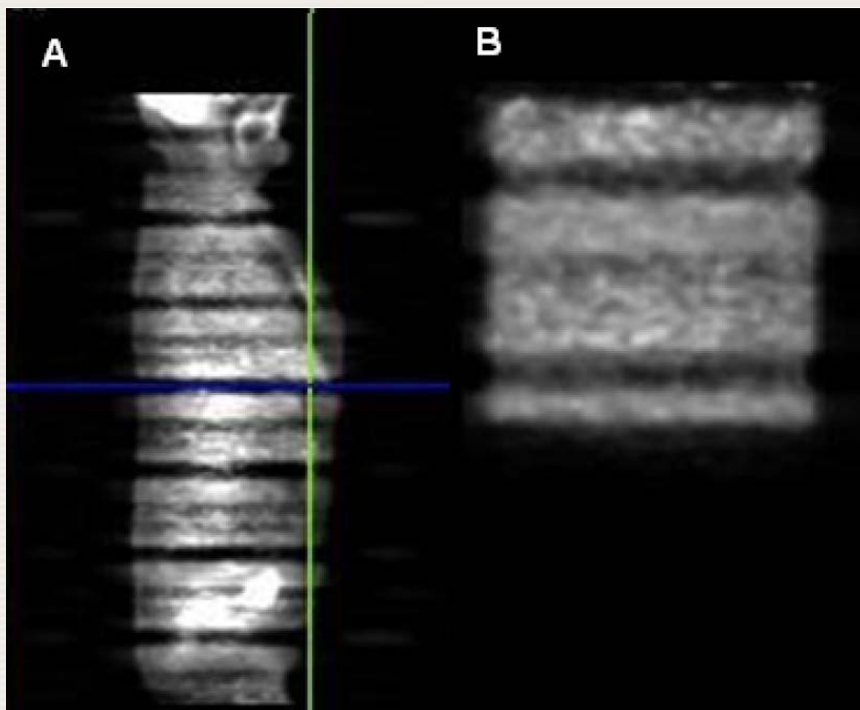
I.4.1 Tomographic artefacts

Tomographic artefacts causes

- ❑ The daily quality assurance routine is a good way to detect unexpected sudden normalization errors.
- ❑ Some quality assurance routines involve scanning a cylindrical phantom filled uniformly with radioactivity (e.g. ^{68}Ge , ^{18}F).

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.1 Tomographic artefacts



Artefact from normalization errors

(A) Clinical whole body images obtained on a PET system.
(B) QC image of a uniformly filled cylindrical phantom, showing streaks indicative of errors in normalization table.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.1 Tomographic artefacts

Diagnosing causes of tomographic artefacts

Diagnosing detector block failure

- Geometry is often the key in diagnosing tomographic artefacts.
- Examination of the sinogram (also in clinical images) is a good way to test for block failure, as it appears as a distinctive diagonal streak on the sinogram.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.1 Tomographic artefacts

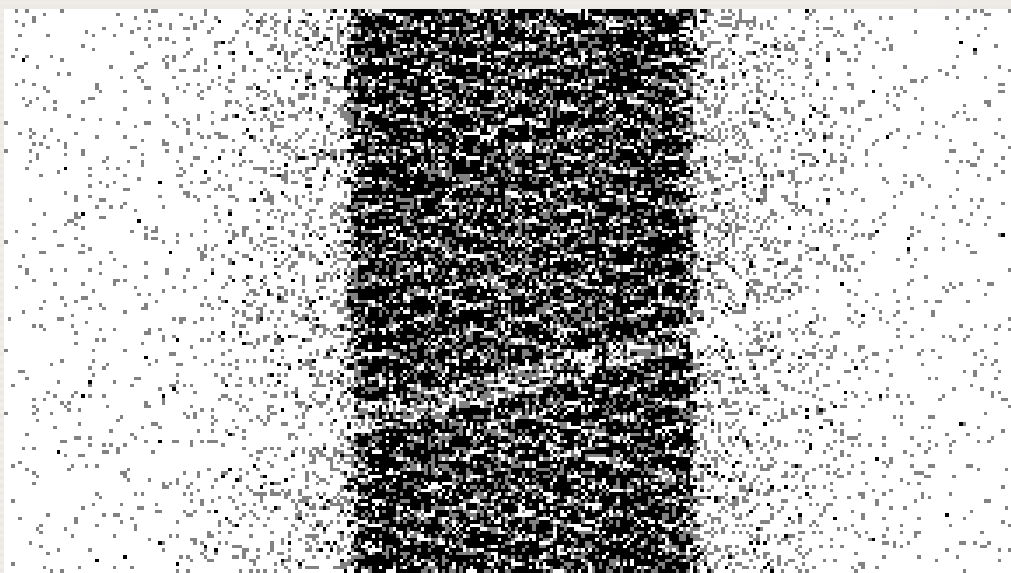
Diagnosing causes of tomographic artefacts

Influence of block failure

- Detector block failure may not contraindicate the clinical use of a PET system since modern scanners have many detectors and the absence of one block may have little statistical impact.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.1 Tomographic artefacts



Detector block failure

Sinogram from a PET system showing streak caused by a detector block failure. With only one streak visible which is several pixels wide, it would be appropriate to assume that a whole detector block has failed.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.2 Attenuation correction artefacts

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.2 Attenuation correction artefacts

AC artefacts due to metals and contrast media

- ❑ Attenuation correction (AC) artefacts occur when the CT AC algorithm leads to a hot or cold spot in the attenuation corrected reconstructed data.
- ❑ The non-AC images should always be reviewed whenever any dubious finding is suspected in the AC images.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.2 Attenuation correction artefacts

AC artefacts due to metals and contrast media

Characteristic pattern

- When the CT image shows a highly attenuating material (such as metal implants or contrast media) in a group of voxels, then the total counts along all lines of response that pass through those voxels are increased, and the group of voxels appears hot.

I.4 IMAGE ARTEFACTS IN PET/CT

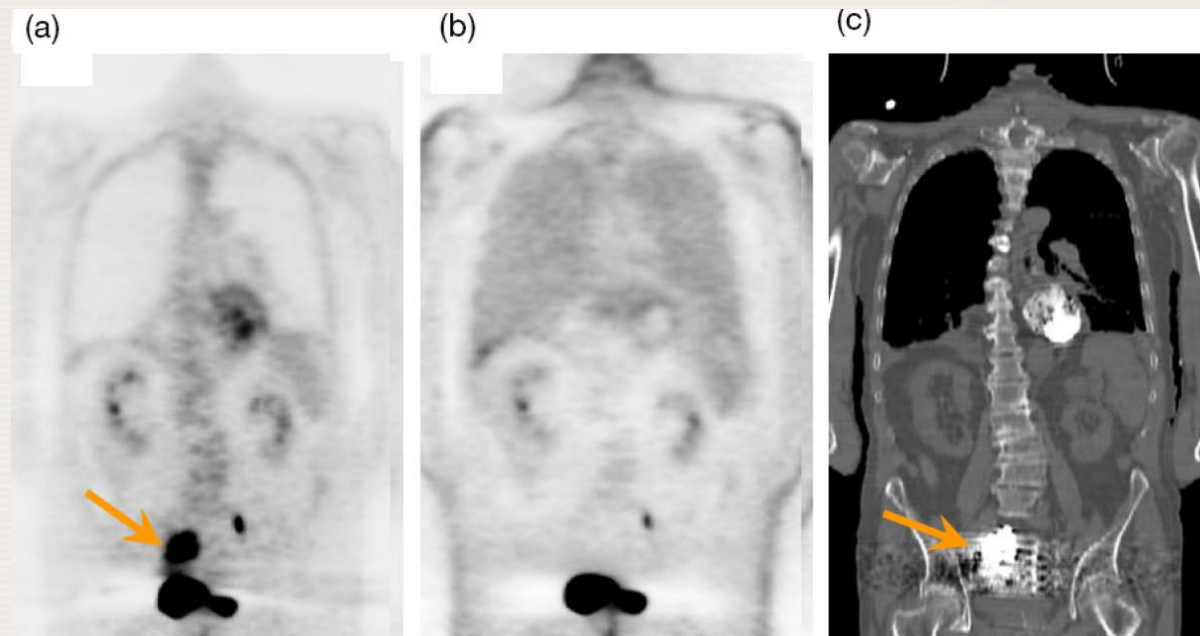
I.4.2 Attenuation correction artefacts

Attenuation correction artefact

(a) CT attenuation corrected image of a patient showing a focal hot spot (indicated by the arrow).

(b) Non-attenuation corrected image. The hot spot is no longer visible.

(c) CT image showing a high density artefact from barium contrast pooled in the bowel.



I.4 IMAGE ARTEFACTS IN PET/CT

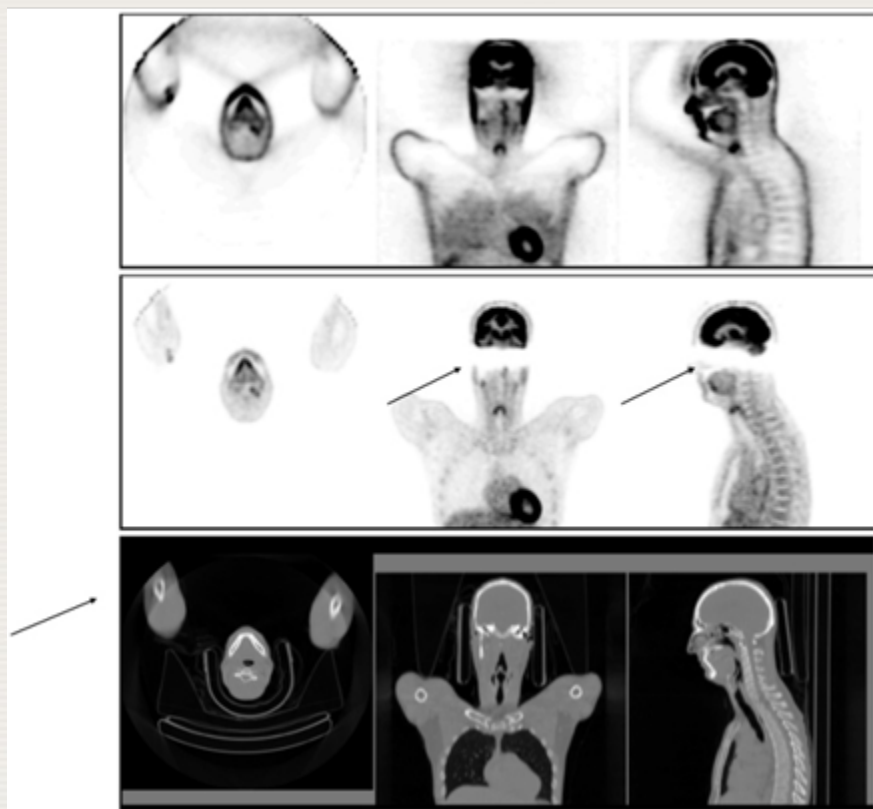
I.4.2 Attenuation correction artefacts

Truncation artefacts

- ❑ Another AC artefact is due to truncation, where the CT and PET fields of view are not the same size.
- ❑ Parts of the anatomy outside the CT FOV are thus not corrected for by the AC algorithm.
- ❑ This often occurs when the patient's arms (which are raised above the head during the acquisition) are outside the CT FOV.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.2 Attenuation correction artefacts



Truncation artefact

Top row: non-attenuation and scatter corrected PET images.
Middle row: the corresponding slices with attenuation and scatter correction.

Bottom row: CT images.
Cold bands (arrows) in corrected images are due to truncation of patient's arms in CT images.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

Co-registration artefacts

- ❑ Problems in co-registration in PET/CT are common and can be due to a system error or caused by movement of the patient.
- ❑ The system must be tested and recalibrated periodically, whereby a transform matrix is created to co-register PET and CT data
- ❑ Errors in the co-registration can occur either suddenly or gradually and can be a sign that there is a problem with the mechanism that controls the bed motion.

I.4 IMAGE ARTEFACTS IN PET/CT

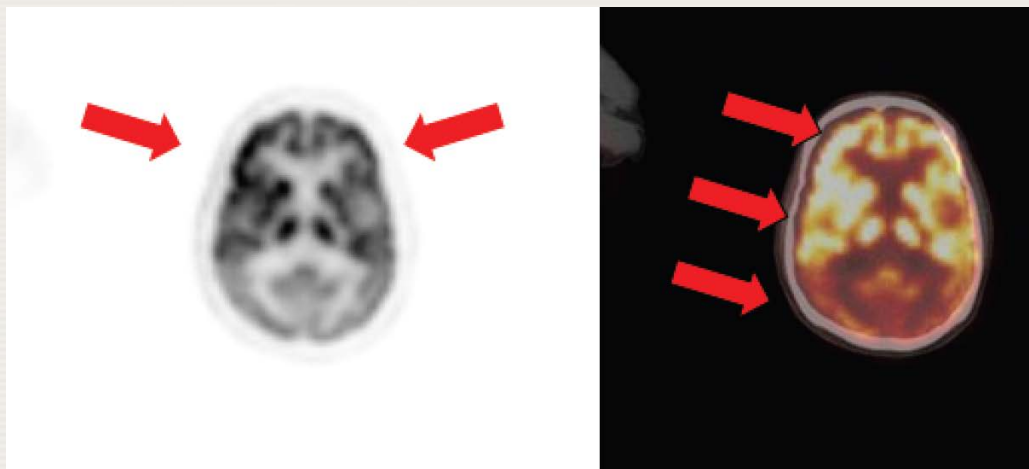
I.4.3 Co-registration and motion artefacts

Co-registration artefacts

- ❑ Alignment errors originating from patient motion are problematic and can have an effect on the medical interpretation of the image.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts



Misalignment artefact

Apparent asymmetrical uptake of [^{18}F]-fluorodeoxyglucose in the brain (left) caused by the slight misalignment of the PET and CT images (right).

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

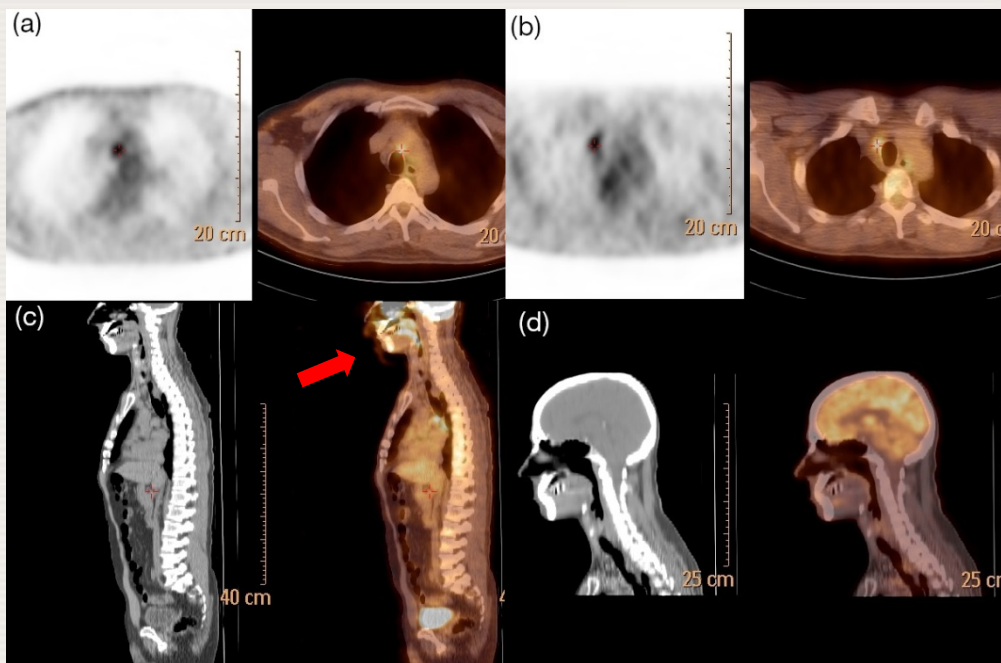
Motion artefacts

- ❑ Patient motion artefacts can be easily missed and lead to an incorrect diagnosis.
- ❑ In whole body PET scans, it is possible for the patient to move during the acquisition so that some part of the anatomy is accurately registered between PET and CT, while in another part of the anatomy the registration is poor.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

Mis-registration artefact



(a) A whole body PET/CT scan shows a point of focal uptake in the upper torso.

(b) Separate head and neck acquisition of the same patient.

(c) Whole body fused images show good registration of bladder, spine and heart, but a clear mis-registration of the head (indicated by the red arrow).

(d) In the separate head views good registration is observed.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

Respiratory motion artefacts

- Another movement artefact often seen is due to respiratory motion.
- PET images are acquired over many respiratory cycles, such that the final image is an average activity distribution across the respiratory cycle.
- The CT images are acquired far more quickly and thus demonstrate blurring over only a small component of the respiratory cycle.

I.4 IMAGE ARTEFACTS IN PET/CT

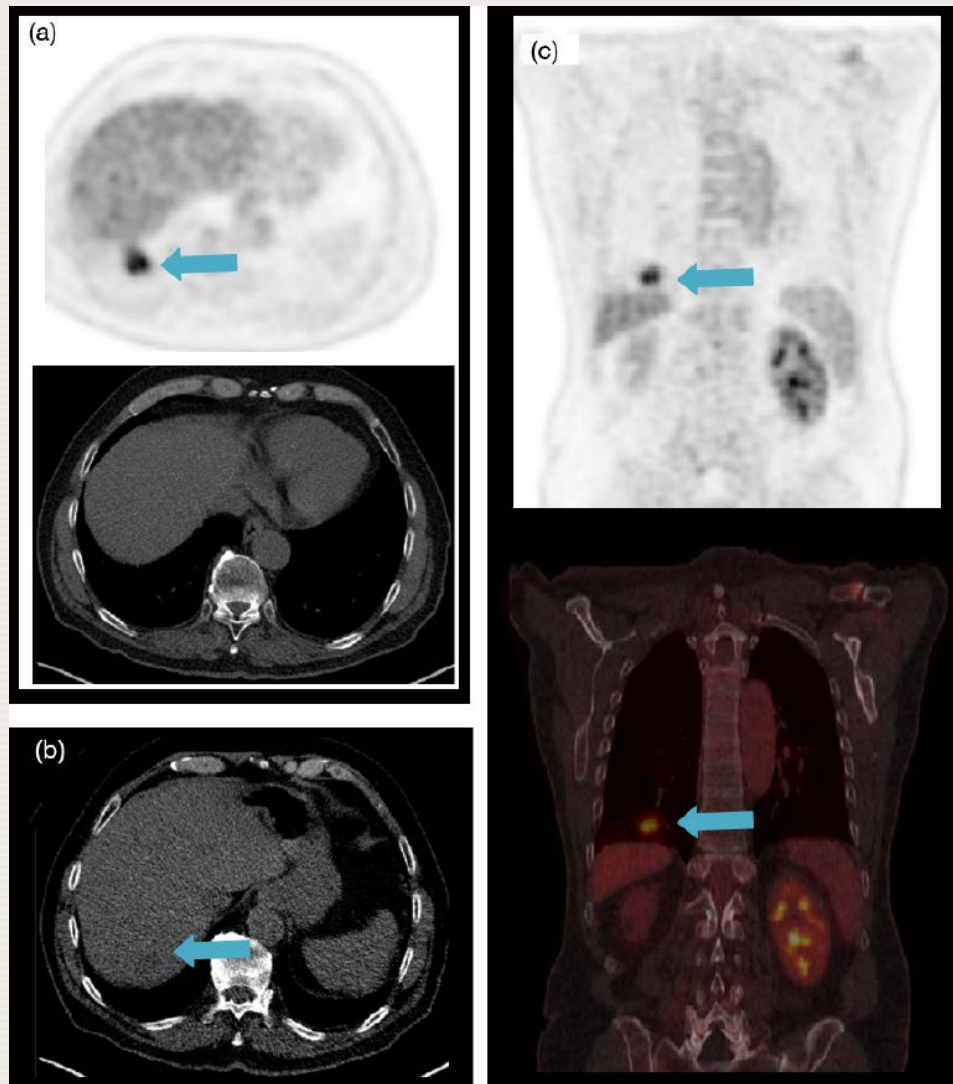
I.4.3 Co-registration and motion artefacts

Respiratory motion artefact

(a) Transaxial PET and CT images show a focal lesion, which appears to be in the lung.

(b) The CT image shows the same lesion appearing to be in the liver.

(c) Coronal view of PET and fused PET/CT where the lesion appears largely displaced from the liver.



I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

Mis-registration artefact



(a) Coronal PET image shows an area of focal uptake that appears to be both in the liver and in the lung, as well as another larger area that appears to be entirely in the lung.

(b) Fused coronal PET/CT image shows a mis-registration in the larger lesion.

I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

Characteristics of respiratory motion artefacts

- ❑ Respiratory motion artefacts can also be seen in the CT image itself where the liver is not correctly rendered during reconstruction of the CT data because the patient is breathing during acquisition.
- ❑ This can be seen when there is a characteristic artefact repeated along the axis of motion, leading to unclear definition of organ boundaries.

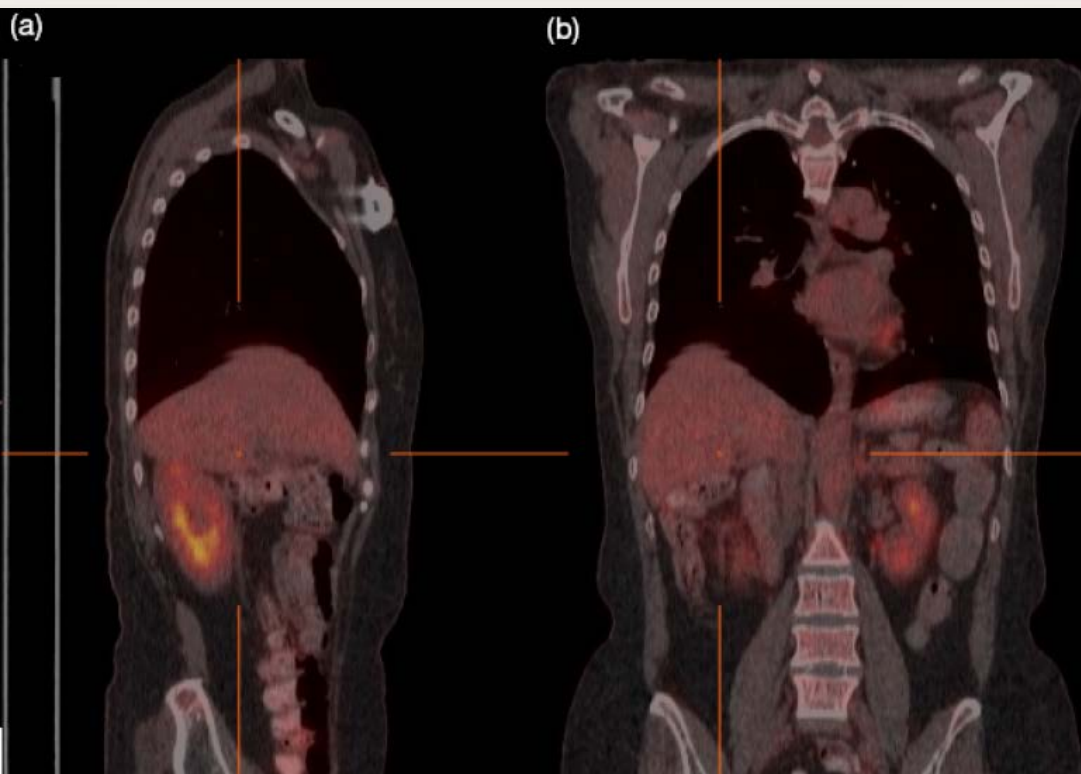
I.4 IMAGE ARTEFACTS IN PET/CT

I.4.3 Co-registration and motion artefacts

Respiratory motion artefact

(a) Sagittal image shows a step-like artefact in the liver.
(b) The same step-like artefact is seen on the coronal views.

This problem is caused by the patient breathing during the CT acquisition and distorting the size of the liver.



I.5 IMPORTANCE OF REGULAR QUALITY CONTROL

I.5 IMPORTANCE OF REGULAR QUALITY CONTROL

Daily QC in PET often requires

- ❑ Checking the gantry status
 - Voltages
 - Temperatures, etc.
- ❑ Generation of the normalization from a high count emission image to ensure image quality, checking
 - Block noise and efficiency
 - Scatter ratio
 - Time alignment, etc.

I.5 IMPORTANCE OF REGULAR QUALITY CONTROL

Daily QC packages

- ❑ The system vendor should provide a daily QC package that automates all of the above requirements.
- ❑ Daily QC is normally done by the user, in a limited time not to interfere with clinical studies. The QC package should be simple to use and efficient, and fulfil the requirements of this task.
- ❑ The daily QC procedure should produce a report, indicating unsatisfactory results that require attention and allow for systematic monitoring of the scanner.

I.5 IMPORTANCE OF REGULAR QUALITY CONTROL

Periodic QC

- ❑ The Standardized Uptake Value (SUV) is an important quantitative parameter, dependent on both the clinical protocol and the scanner calibration relative to the department dose calibrator.
- ❑ A monthly check of the scanner SUV should be performed using a phantom of known volume, which, if activity is homogeneous and the scanner and dose calibrator are correctly calibrated, should produce an SUV of 1.0.
- ❑ Erroneously low SUVs may indicate that the physicist needs to recalibrate the dose calibrator and PET scanner, through the calculation of a new calibration factor.

I.5 IMPORTANCE OF REGULAR QUALITY CONTROL

Routine QC in clinical practice

- ❑ Regular QC is a crucial factor in reducing artefacts due to the tomographic and/or CT system.
- ❑ Users of PET and PET/CT should be alert at all times to unexpected artefacts.
- ❑ A comparison between attenuation and scatter corrected images with non-corrected images should be part of routine clinical practice.