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QUALITY CONTROL OF NUCLEAR MEDICINE INSTRUMENTS

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QUALITY CONTROL OF NUCLEAR MEDICINE INSTRUMENTS

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FOREWORD

This document, which gives detailed guidance on the quality control of the various electronic instruments used for radiation detection and measurement in nuclear medicine, stems from the work of two Advisory Groups convened by the International Atomic Energy Agency (IAEA). A preliminary document, including recommended test schedules but lacking actual protocols for the tests, was drawn up by the first of these groups, meeting at the IAEA Headquarters in Vienna in 1979. A revised and extended version, incorporating recommended test protocols, was prepared by the second Group, meeting likewise in Vienna in 1982. This version is the model for the present text. The document should be of value to all nuclear medicine units, and especially to those in developing countries, in the initiation or revision of schemes for the quality control of their instruments. Its recommendations have provided the basis for instruction in two IAEA regional technical co-operation projects in the subject field, one initiated in 1981 for countries of Latin America and one initiated in 1982 for countries of Asia and the Pacific.

Acknowledgement is due to the following members of the Advisory Groups concerned, experts participating in the regional technical co-operation projects mentioned and members of the staff of the Medical Applications Section, IAEA, for their contributions : H. Bergmann and R. Höfer (Austria), A. Dias-Neto (Brazil), P. Ambro (Hungary), K.D. Herath (Sri Lanka), P.W. Horton, R.F. Mould and A.E. Todd-Pokropek (United Kingdom), A.B. Brill, J.J. Erickson, N. Herrera, P.Paras and J.J. Touya (United States of America) and E.H. Belcher, E.U. Buddemeyer, R.A. Dudley, B. Vavrejn, P.H. Vuister and A.V. Wegst (IAEA). The collaboration of the World Health Organization in certain aspects of the work is also acknowledged.

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1. GENERAL CONSIDERATIONS

1.1. QUALITY ASSURANCE AND QUALITY CONTROL IN NUCLEAR MEDICINE

It is now widely recognized that the attainment of high standards of efficiency and reliability in the practice of nuclear medicine, as in other specialities based on advanced technology, requires an appropriate quality assurance programme.

The concept of quality in the term "quality assurance" expresses the closeness with which the outcome of a given procedure approaches some ideal, free from all errors and artefacts. Quality assurance embraces all efforts made to this end. The term "quality control" is used in reference to the specific measures taken to ensure that one particular aspect of the procedure is satisfactory. A clear distinction between these terms should be made.

Hence, quality assurance in nuclear medicine should cover all aspects of clinical practice. Specifically, quality control is necessary in the submission of requests for procedures; the preparation and dispensing of radiopharmaceuticals; the protection of patients, staff and the general public against radiation hazards and accidents caused by faulty equipment; the scheduling of patients; the setting-up, use and maintenance of electronic instruments; the methodology of the actual procedures; the analysis and interpretation of data; the reporting of results and, finally, the keeping of records.

The present document deals with a single, albeit highly important, component of such a comprehensive programme, namely quality control of instruments.

1.2. PRINCIPLES OF QUALITY CONTROL OF INSTRUMENTS

A fundamental principle in the quality control of nuclear medicine instruments is that it should be undertaken as an integral part of the work of the nuclear medicine unit and by members of the unit staff themselves. However, some aspects must be treated in collaboration with maintenance staff.

The quality control of each instrument should have as its starting-point the selection and acquisition of the instrument itself, since instruments may differ widely in their performance. The choice of an appropriate site for installation of the instrument should likewise be considered within the scope of quality control, in as far as it may influence performance.

Once received and installed, an instrument should be submitted to a series of acceptance tests designed to establish whether its initial performance conforms with the manufacturer's specifications. At the same time, reference tests should be carried out to provide data against which its subsequent performance can be assessed by routine testing weekly, monthly, quarterly, yearly etc. Finally operational checks, carried out each day the instrument is used, should be put in force. Careful records of the results of all these tests should be kept and, if these reveal unsatisfactory performance, appropriate corrective action should follow. Such quality control does not, of course, obviate the need for the usual preventive maintenance procedures, which should still be carried out on a regular basis.

The success of such a scheme depends above all on its understanding and acceptance by all concerned. It further requires a clear definition of responsibilities, strict adherence to test schedules and protocols, and proper facilities for the follow-up of test results.

1.3. SELECTION AND ACQUISITION

The selection of an instrument with respect to manufacturer, model etc. should be based not only on its suitability for the particular procedures to be carried out, as judged from its technical specifications, but also on such considerations as its ease, reliability and safety in operation, its compatibility with other instruments, the facilities and personnel available for its maintenance and the supply of spare parts. Technical advice on these points is often needed; the experience of other nuclear medicine units in the area, or in comparable areas, can be valuable in this respect.

Much care is necessary in negotiations for instrument purchase. Full technical specifications should be solicited from manufacturers. Such specifications should cover all components in the instrument and all options and should include power supply requirements; operational limitations as to temperature, humidity etc.; requirements for expendable items such as film and magnetic tape; availability of such items; and compliance with international and other standards. Quotations should indicate the price and terms; the date, mode and cost of delivery; the nature and duration of warranty; and the cost and specific coverage of service contracts. Also included in the quotations should be the manufacturer's arrangements for installation; the accessories, spare parts, manuals, test devices and expendables to be provided; the location and content of the training to be given to different categories of staff; the servicing facilities and personnel available; and the facilities for the supply of spare parts. Further, the quotation should detail the purchaser's arrangements for acceptance testing, the minimum acceptable performance characteristics and the action to be taken if these are not met. Quotations should be compared with all these points in mind.

The wise purchaser will especially examine the servicing facilities and personnel offered by different manufacturers or their representatives. An instrument with average performance characteristics but good servicing facilities may well be preferred, on grounds of reliability, to one with outstanding performance characteristics but inadequate servicing facilities. Maintenance of an instrument, including the supply of spare parts, has to be foreseen for its expected lifetime. This should be taken into account when costs are compared. Purchase price is an unreliable guide to what may be the total cost of an instrument to the nuclear medicine unit.

It is imperative that operation and service manuals, fully updated, accompany every instrument. Appropriate radiation sources, phantoms and other test devices needed for quality control should be provided or, if not, purchased separately at the time of instrument acquisition. Special tools, extension boards and other items needed for maintenance procedures should be similarly anticipated.

Purchase orders should clearly define the instrument's technical and performance specifications, and should again indicate the price and terms; the date, mode and cost of delivery; the arrangements for installation and acceptance testing; the minimum acceptable performance characteristics and the action to be taken if these are not met; the

nature and duration of the warranty; the accessories, spare parts, manuals, test devices and expendables to be provided; the training to be given and any service contract involved. Finally, it is important to mention that purchase orders should be jointly prepared by the responsible administrative and technical staff.

1.4. SITING

The siting of an instrument is largely determined by its expected use in relation to work patterns within the nuclear medicine unit. The availability of space, electrical power supplies, environmental factors such as temperature, humidity and air pollution and background radiation levels should also be taken into account.

The availability of sufficient space for the instrument seems an obvious requirement, but consideration should also be given to the separate needs of clinical practice, quality control testing and maintenance procedures, especially if these involve the use of other equipment in conjunction with the instrument.

Poor quality electrical power is recognized as a major cause of instrument malfunction and failure. Power supplies must, of course, match instrument specifications as regards both voltage and frequency. In addition, a dedicated power line for electronic instruments, fed directly from the final step-down transformer in the institution, and a dedicated earth line are desirable, sometimes essential, to limit voltage fluctuations, surges, transients and electrical "noise" caused by other equipment in the vicinity. Drop-out relays, including varistors, should be fitted to guard against the consequences of total power failure. These serve to disconnect an instrument from the power line immediately after power fails and to leave it disconnected until some time, minutes or more, after power is restored; this gives protection against most of the voltage surges and transients that accompany power failure and all of those that accompany power restoration. For instruments requiring restoration of high voltage in a controlled manner, drop-out relays which can only be reset manually should be installed. Additional protection against poor quality power may be provided through power conditioners incorporating constant voltage transformers, which suppress voltage fluctuations and surges and filter out transients and "noise".

High temperature, high humidity and air pollution can cause grievous damage to electronic instruments, above all in tropical and sub-tropical environments. Fast temperature gradients, which can be caused by sudden direct exposure to sunlight or the cold air stream of an air conditioner, particularly threaten the crystals in scintillation detectors. Nevertheless, air conditioners with properly deflected air streams and dehumidifiers should be provided and used day and night as appropriate to give continuous protection against the adverse effects of temperature and humidity. Further protection should be provided through the insulation of walls and ceilings and the installation of double windows (e.g., with plastic sheeting). The positions of windows should be such that they are not in the direct sunlight. If this is not the case, instruments should be positioned so that they themselves are not in the direct sunlight. Air filters should be fitted to limit intake of dust. If such devices are used, proper closing of doors and windows must be assured. Instruments should not be installed where they may be exposed to dust, smoke or chemical fumes. Covers should be provided so that instruments can be protected when not in use.

Background radiation levels within the unit are likely to be markedly influenced by the location of the radiopharmacy, the storage and movement of radioactive materials, and the movement of patients incorporating these materials. Other radiation sources in the vicinity (e.g. X-ray machines, linear accelerators or ^{60}Co devices for radiotherapy) may contribute. Such influences are important in relation to the siting of radionuclide calibrators and counting systems for radiation measurements in vitro, but also bear upon the siting and permitted orientation of counting systems for radiation measurements in vivo and imaging systems.

1.5. ACCEPTANCE AND REFERENCE TESTING

The acceptance of an instrument following its receipt and installation is a critical step towards the achievement of high quality performance, and should be subject to correspondingly careful testing. Acceptance testing is undertaken to ensure that the performance of an instrument meets the technical and performance specifications quoted by the manufacturer. It should be carried out immediately after installation so that the supplier can be informed of any damage, deficiencies or flaws before the warranty has expired. No instrument should be put into routine use unless it has been shown through acceptance testing to be performing optimally. An instrument that does not perform correctly at installation has a high likelihood of never doing so.

Acceptance testing is of concern to the maintenance staff, the manufacturer's agent and the eventual users of the instrument, and all should be involved in some degree. As already indicated, it is important to establish in the negotiations for purchase the manner in which such testing will be carried out and the minimum acceptable performance characteristics. Tests should be stringent and carried out according to clearly defined protocols. If they require specialized equipment, arrangements should be made for its provision. For the acceptance testing of any major instrument, a representative of the manufacturer should always be present and should be able to initiate remedial action if specifications are not met. Otherwise, the onus for this falls on the purchaser. The practice of withholding payment of a part of the purchase price until acceptance testing has been satisfactorily completed is effective in many countries.

At the time of acceptance testing, reference tests should be carried out, from the results of which the subsequent performance of the instrument may be assessed in routine testing. These reference tests may be the acceptance tests themselves or less sophisticated versions of these that are more suitable for routine testing. Such tests should be repeated, as appropriate, to give a new set of reference data after major failure of the instrument and its subsequent repair, or when it is moved to a new site. Similarly, if for any reason an existing instrument did not undergo proper acceptance testing, the relevant tests should be performed with the instrument in as good working condition as possible at the time when routine testing is initiated, to provide a set of reference data .

1.6. ROUTINE TESTING

Routine tests are those which should be carried out regularly on an instrument to ensure its optimum performance at all times and to determine the rate and extent of any deterioration in that performance

with time. Such tests fall into two categories; first, tests that have previously been carried out as reference tests and are repeated weekly, monthly, quarterly, yearly etc., and second, daily or operational checks to be carried out each day the instrument is used.

It is clear that routine tests should always be executed in like manner if successive results are to be comparable. Again, therefore, they should be carried out according to clearly defined protocols. When appropriate, limits of acceptability for the results and courses of action to be taken if these limits are exceeded should be specified. Operational checks should be simple and so designed that they can be completed in an acceptably short time (e.g. 15 min for a scintillation camera), according to a defined sequence by an experienced person.

Unavoidably, test schedules constitute a compromise between what is desirable and what is feasible. The choice of tests and the frequencies with which they are carried out have to take account of the situation in the individual nuclear medicine unit and the status of its instruments. It is important that staff in all categories develop an attitude of alertness to possible instrument malfunction and that all appropriate aspects of the nuclear medicine procedure are tested whenever clinical results are suspect. No schedule can be established for such occurrences.

1.7. PREVENTIVE AND CORRECTIVE MAINTENANCE

The major maintenance procedures carried out on an instrument by maintenance staff or the manufacturer's agent and its quality control and simple maintenance by the staff of the nuclear medicine unit should be seen as complementary to each other. Maintenance procedures are intended to put an instrument into the best possible working condition, but they cannot guarantee that it remains so, nor that it is used correctly in a given procedure. Quality control gives the users confidence in the latter respects. On the other hand, while quality control may show that a failure has occurred, it rarely provides the exact diagnostic information needed for repair. A close liaison between the persons involved in the two activities is thus indispensable and should commence with the acceptance testing of the instrument.

Regular preventive maintenance is vital to the continuing satisfactory performance of any instrument. Simple cleaning is necessary to maintain it externally immaculate and internally free from dust and dirt. Moving parts have to be lubricated and short-lived components replaced. Systematic inspections are necessary to detect failures, incipient or actual, before they develop into major breakdowns. Particularly important in the latter respect are mechanical and electrical inspections that relate to the safety of patients and staff.

Certain tests used in quality control may have to be repeated during preventive maintenance or after corrective maintenance for the repair of a failure. It is then very important that these tests are always carried out according to the same protocols and that their results are always compared with the reference data.

1.8. QUALITY CONTROL RECORDS

Record keeping is of great importance in such a quality control scheme. The operational, quality control and maintenance records for each instrument should be assembled in a single log-book retained with the instrument. The first part of this book should give up-dated

operating conditions for all clinical procedures and all radionuclides in current use. The main part should include a record of the results of the acceptance, reference and routine tests carried out for quality control, a record of preventive maintenance carried out and a record of failures, with details of their repair. All entries should be signed by the responsible person. In addition, it is helpful to assemble and maintain a complete procedure manual detailing all clinical and test protocols.

It is essential that all concerned appreciate the meaning of the records kept. Record sheets should be so designed that they are appropriate, easy to complete and easy to understand; explanatory notes should be provided, if necessary. Only essential data and results should be recorded; raw data can be kept in a separate book or file. Control charts and graphs displayed on the wall near the instrument are helpful in quickly ascertaining its long-term stability, and in stimulating regular testing. Images obtained in quality control testing should be kept in chronological order, preferably in the log-book, affixed to the page detailing the relevant imaging parameters and the results of other quality control tests on the instrument, otherwise in a separate file, equally clearly identified. They should be frequently reviewed for evidence of deterioration in performance, which may not be initially apparent. Records showing repeated failure and/or progressive degradation of performance provide unquestionable evidence for complete instrument overhaul or replacement.

1.9. ORGANIZATIONAL ASPECTS

A basic requirement for the successful introduction of such a quality control scheme is that the head of the nuclear medicine unit recognizes its necessity. The support of the administrative authorities is also required so that the means to carry it through can be secured. Detailed arrangements then have to be made, and responsibilities clearly defined, for acceptance and reference testing, routine testing, evaluation of test results and periodic review of results in relation to quality assurance as a whole. Regular meetings of all concerned, including both professional and technical staff, should be held for the latter purpose. Lack of adequate organization will foster a careless attitude in which tests are carried out irregularly, or only if malfunction is suspected. Proper quality control is impossible on such a basis.

A single person should have supervisory responsibility for the entire scheme, and the authority to enforce it and act on its findings. This person should be fully cognizant of the technical details of the tests and should be involved in the evaluation and periodic review of their results. However, he or she need not actually undertake testing.

It is important that tests on a given instrument be carried out by a person or persons familiar with its use. Responsibility for daily and operational tests, at least, should rest with its regular users. This has the virtue of developing in the users an awareness of the principles of quality control.

If the results of a particular test do not fall within the specified limits of acceptability, a decision has to be taken whether or not to withdraw the instrument from operational use pending corrective action. Responsibility for such a decision should again be clearly defined. This is especially important if the test is carried out by a member of the para-medical staff.

The scheme should be sufficiently flexible to accomodate changes, based on accumulated experience, in respect of the tests included, their detailed protocols and the frequencies with which they are carried out.

The significance of such a scheme is not limited to the individual nuclear medicine unit. In some countries, a comprehensive quality assurance programme including the quality control of instruments is a prerequisite for the approval of nuclear medicine facilities in order to obtain the accreditation of hospitals. Links with national atomic energy and health authorities, professional associations and working groups are in any case desirable, as are contacts with manufacturers and their agents. Thus, certain tests, scheduled relatively infrequently and requiring special test devices, may more conveniently be organized on a national basis than within the individual unit. The routine control of accuracy of radionuclide calibrators, for example, may be undertaken in this manner by a central laboratory having the necessary certified sources.

Intercomparisons of instrument performance in different nuclear medicine units, often organized on a national, regional or even international basis, may be instructive and stimulating to participating units, as well as of considerable scientific interest. It should be realized, however, that such quality assessment or quality surveillance schemes, usually undertaken on an occasional basis and testing either the overall performance of instruments of a particular class (e.g. scintillation cameras) or even particular performance parameters of such instruments, are in no way substitutes for true quality control schemes providing continuing control of all instruments in a unit.

1.10. IMPLEMENTATION OF QUALITY CONTROL

The sections that follow contain recommended schedules and protocols for acceptance and routine testing of different classes of instruments, namely radionuclide "dose" calibrators (activity meters), counting systems for gamma-radiation measurements in vitro, counting system for gamma-radiation measurements in vivo, rectilinear scanners and scintillation cameras.

It is emphasized that the test schedules and test protocols presented are intended for guidance only. As previously indicated, the choice of tests and the frequencies with which they are carried out have to take account of the situation in the individual nuclear medicine unit and the status of its instruments. Furthermore, it is not possible to draw up detailed test protocols applicable to all instruments in a particular class. Nuclear medicine units should, therefore, modify the given protocols to suit their own individual instruments and test devices. What is indispensable is that once appropriate individualized schedules and protocols have been agreed upon, they should be strictly followed.

An example of a step-wise approach to the establishment of a complete quality assurance and preventive maintenance programme incorporating the concepts described in this chapter is presented in Annex I.

2. RADIONUCLIDE "DOSE" CALIBRATORS (ACTIVITY METERS)

2.1. INTRODUCTION

2.1.1. Basic Principles

A radionuclide calibrator is in essence a well-type gas ionization chamber into the well of which a radioactive material is introduced for measurement. The activity of the material is measured in terms of the ionization current produced by the emitted radiations which interact in the gas. The chamber is sealed, usually under pressure, and has two co-axial cylindrical electrodes maintained at a voltage difference derived from a suitable supply, the axial space constituting the well (Fig. 2-1).

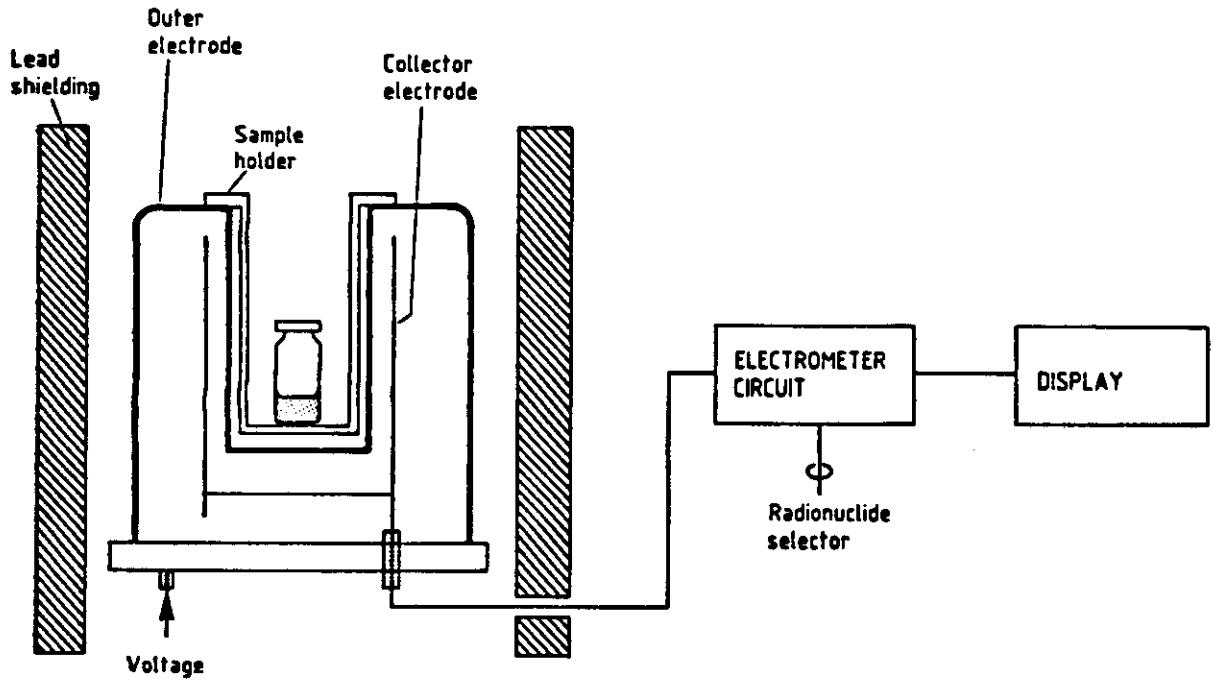


Fig. 2-1. Radionuclide calibrator

In the associated electrometer, the ionization current is converted to a voltage signal, which is amplified, processed and finally displayed, commonly in digital form in units of activity - becquerels (Bq) or curies (Ci). This is possible since for a given radionuclide, assuming a fixed geometry and a linear response, ionization current is directly proportional to activity. However, the response of an ionization chamber to the radiations from different radionuclides varies according to the types, energies and abundances of these radiations, the primary consideration being the rate of emission of photon energy. Appropriate adjustment of the amplification of the voltage signal is thus necessary, if the display with different radionuclides is always to be in units of activity. Most radionuclide calibrators have selector switches, selector push-buttons or plug-in modules for different radionuclides, which achieve this adjustment by selecting a fixed resistor determining the amplification. Alternatively or additionally, a continuously variable resistor (potentiometer) with a dial which can be set to a specified number according to the radionuclide to be measured may be provided.

Lead shielding around the ionization chamber provides protection to personnel against radiation hazards and reduces its response to environmental radiation, but a residual background response remains. Some radionuclide calibrators have a continuously adjustable zero control by which this response may be "backed off". Otherwise, it must be noted and subtracted, if significant, from subsequently measured activities. A removable liner that can be easily cleaned in the event of accidental radioactive contamination of the chamber well is usually provided.

2.1.2. Operational Considerations

The accuracy of a radionuclide calibrator depends upon several factors. Every such instrument is factory-calibrated with a set of certified sources that, at best, are within $\pm$ 1% of their stated activities, but may be only within $\pm$ 3%, or even $\pm$ 5%, limiting the initial accuracy. This initial accuracy may change with time as a result of changing pressure of the chamber gas and slow electronic drift. The addition of lead shielding may also significantly affect the accuracy of a radionuclide calibrator because of the extra contribution of scattered radiation from the added shielding, necessitating changes in calibration settings. Further, the accuracy of any individual measurement is dependent upon the similarity of the measured material to the original calibration source. Especially with radionuclides giving low-energy radiations, differing radiation absorption characteristics of the material may cause significant measurement errors.

All radionuclide calibrators show some dependence on measurement geometry; this effect diminishes with increasing depth of the well. With many such instruments, tables are provided giving correction factors to be applied in measurements on different radionuclides in syringes, vials and other containers of different sizes and types. However, nuclear medicine units should determine correction factors appropriate to their own situations. It should be appreciated that correction factors for syringes depend on whether or not a needle is attached.

Simple operational checks of reproducibility of performance and background response are needed each day a radionuclide calibrator is used. In addition, regular quality control should cover its precision, its accuracy and the linearity of its activity response.

2.2. TEST SCHEDULE

Table 2-1 lists the recommended quality control tests for a radionuclide calibrator, with suggested frequencies for the repetition of reference tests in routine testing. The operational checks should be carried out each day the instrument is used .

Table 2-1

Test Schedule for Radionuclide Calibrator

Test No.	Test	Acceptance	Reference	Frequency in routine testing		
				Weekly	Quarterly	Half-yearly
	Acceptance and Reference Tests					
2.3.1.	Physical Inspection	x				
2.3.2.	Test of Precision and Accuracy	x	x		x	
2.3.3.	Test of Linearity of Activity Response	x	x		x	
2.3.4.	Test of Background Response	x	x	x		
	Operational Checks					
2.4.1.	Check of Reproducibility					
2.4.2.	Check of Background Response					

2.3. ACCEPTANCE AND REFERENCE TESTS

2.3.1: PHYSICAL INSPECTION

Purpose of test

To inspect a radionuclide calibrator for general condition.

Procedure

1. Inspect the instrument housing for evidence of damage. Particularly examine the surroundings of the ionization chamber for signs of deformation or indentation.

2. Inspect all controls, plug-in modules, push-buttons and switches. Check for loose knobs, controls that are difficult to adjust, plug-in modules that cannot be correctly seated and switches that cannot be securely thrown.

3. Inspect all connectors. Check that none are missing and examine cables, plugs and sockets for evidence of damage.

4. Inspect all accessories such as remote handling devices, source holders, well liners and ^{99}Mo breakthrough kits. Check that none are missing or damaged.

5. Check any accompanying sealed radiation sources for external radioactive contamination or leakage.

6. Check that both operation and service manuals are available.

7. Note the location of all fuses and check that replacements are available.

8. Check the compatibility of the power supply requirements with the available supply and make any necessary adjustments.

9. Note the location of any container for drying agent and check the condition of the agent. If it shows a high water content, remove, oven-dry and replace it.

10. Initiate the instrument log-book, making an inventory of the instrument and its accessories and recording their condition on receipt, with particular reference to any damage, deficiencies or flaws and the action taken to correct them.

Observations

Physical inspection should be carried out immediately on receipt of an instrument, so that the supplier may be informed of any damage, deficiencies or flaws before the warranty has expired.

2.3.2: TEST OF PRECISION AND ACCURACY

Purpose of test

To test the precision and accuracy of a radionuclide calibrator in activity measurements in standard geometry at selected gamma-radiation energies.

Materials

Sealed low-, medium- and high-energy gamma-radiation sources (standard vial-type), certified to ± 5% overall uncertainty or less, e.g.:

Radionuclide	Principal photon energies	Half-life	Activity SI units	Activity Non-SI units
^{57}Co	122 keV	271 d	185 MBq	5 mCi
^{133}Ba	81, 356 keV	10.7 y	9.3 MBq	250 μCi
^{137}Cs	662 keV	30.0 y	7.4 MBq	200 μCi
^{60}Co	1 173, 1 332 keV	5.27y	1.9 MBq	50 μCi

Source holder
Remote handling device for sources

Procedure

For each gamma-radiation source in turn:

1. Select the operational conditions appropriate to the radionuclide concerned.

2. Note the background reading to be subtracted from subsequently measured activities. Alternatively, if an adjustable zero control is provided, adjust this for zero reading.

3. Insert the source into the source holder by means of the remote handling device and introduce the source holder into the instrument.

4. Allow sufficient time for the reading to stabilize.

5. Measure and record the activity, subtracting the background reading if necessary.

6. Repeat step 5 to a total of 10 successive measurements.

7. Remove the source holder from the instrument and extract the source by means of the remote handling device.

Data analysis

1. To assess precision, calculate for each source the percentage differences between the individual measured activities, A_i, and their mean, $\bar{A}$, that is:

$$\frac{100(A_i - \bar{A})}{\bar{A}} \%$$

Record results of calculations.

2. To assess accuracy, calculate for each source the percentage difference between the mean measured activity, $\bar{A}$, and the certified activity of the source corrected for radioactive decay to the day of measurement, C, that is:

$$\frac{100(\bar{A} - C)}{C} \%$$

Record results of calculations.

Observations

If the operating conditions for the radionuclide concerned can be selected either by means of a selector switch, selector push button or plug-in module or by means of a potentiometer with a dial, the relevant procedure should be carried out twice, first with one than the other enabled. The results should agree.

The procedure described tests the accuracy of the instrument in measurements on the radionuclides used in the test, but not necessarily in measurements on other radionuclides. This may be a significant limitation, especially with instruments having selector switches, selector push-buttons or plug-in modules for different radionuclides. When therapy with unsealed radionuclides is carried out, it is especially recommended that the accuracy of the instrument used for activity measurements be additionally tested annually with certified sources of the radionuclides concerned.

If a certified source for a radionuclide of particular interest is not available, an estimate of the accuracy of the instrument in measurements on this radionuclide may be obtainable from results with another radionuclide through knowledge of the decay schemes of the two radionuclides and the energy response function of the ionization chamber. Thus, a certified ^{57}Co source may be used to estimate the accuracy of the instrument in measurements on $^{99}Tc^{m}$. The advice of the manufacturer may be sought in this regard. The expedient is likely to involve significant errors, however, when the radiation energies involved are low.

Interpretation of results

The results may reveal imprecision (random errors), bias (systematic errors), or both.

Limits of acceptability

The limits of acceptability for the results of the test are determined by the precision and accuracy of the instrument specified by the manufacturer. In general, however, for measurements on sources such as those specified, the precision should be such that all individual measured activities on any source are within $\pm$ 5% of the mean measured activity, provided that radioactive decay has a negligible effect over the measurement period, and the accuracy should be such that the mean measured activity is within $\pm$ 10% of the certified value corrected for radioactive decay to the day of measurement.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

2.3.3: TEST OF LINEARITY OF ACTIVITY RESPONSE

Purpose of test

To test the linearity of the activity response of a radionuclide calibrator over the range of activities for which it is to be used.

METHOD 1 : DECAYING SOURCE METHOD

Materials

Short-lived radionuclide (e.g. $^{99}Tc^{m}$ or $^{113}In^{m}$) in solution, initial activity equal to or greater than the highest activity for which the instrument is to be used (e.g. 3.7 GBq (100 mCi)).

Sample vial
Remote pipetting device
Source holder
Remote handling device for sample vial
Log-linear graph paper (3- or 4-cycle)

Procedure

1. Transfer the radionuclide solution to the sample vial by means of the remote pipetting device. Cap the vial firmly.

2. Select the operational conditions appropriate to the radionuclide concerned.

3. Note the background reading to be subtracted from subsequently measured activities. Alternatively, if an adjustable zero control is provided, adjust this for zero reading.

4. Insert the sample vial into the source holder by means of the remote handling device and introduce the source holder into the instrument.

5. Allow sufficient time for the reading to stabilize.

6. Measure and record the activity, subtracting the background reading if necessary. Record the exact time of day corresponding to the measurement.

7. Remove the source holder from the instrument and extract the sample vial by means of the remote handling device.

8. Repeat steps 2-7 regularly over a period several times greater than the physical half-life of the radionuclide, sufficient for the source to decay to an activity equal to or less than the lowest activity for which the instrument is to be used.

Data analysis

1. Record the results on a graph showing measured activity against lapsed time on 3- or 4-cycle log-linear paper (Fig. 2-2).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points in the lower activity region. Extrapolate this line upward to obtain an activity value corresponding to the time of the initial reading measurement.

3. Check the negative slope of the line to ensure that it is consistent with the known physical half-life of the radionuclide. This may conveniently be done by dividing the time for the measured activity to fall to 1/10 of its initial value, determined in step 2, by 3.32 and comparing the result with the physical half-life.

4. Examine the graph for systematic departures of the data points from the fitted straight line; such discrepancies indicate non-linearity of the activity response of the instrument.

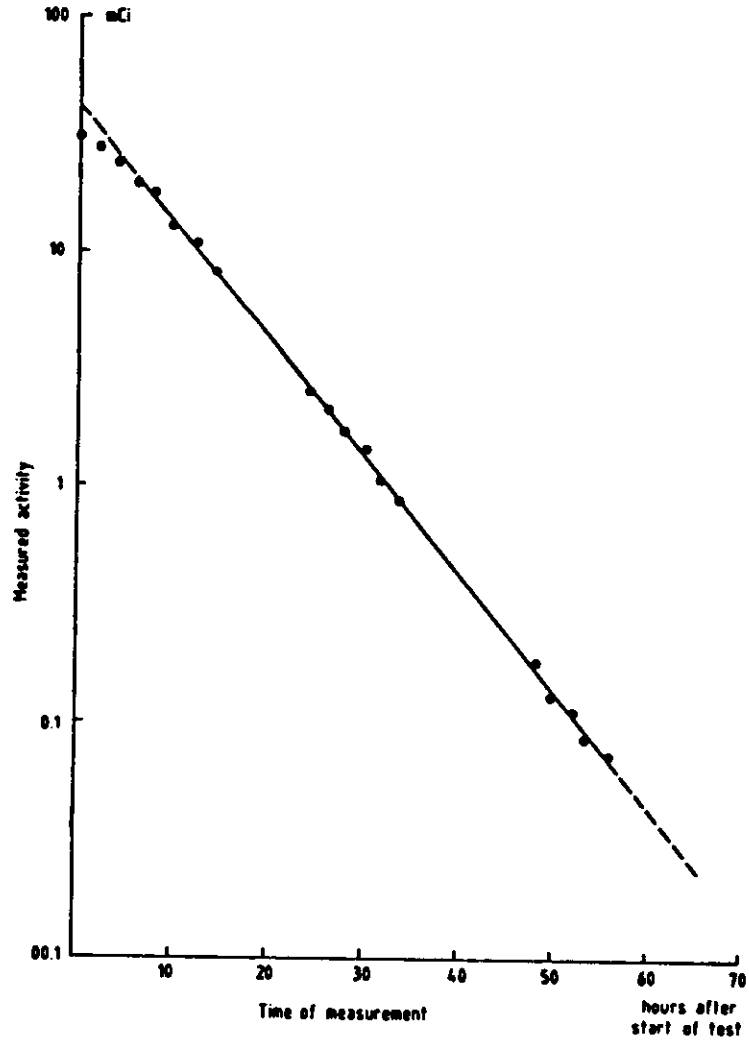


Fig. 2-2. Test 2.3.3: Test of Linearity of Activity Response: Decaying Source Method. A $^{99}Tc^{m}$ source having an initial activity of about 1.5 GBq (41 mCi) was used. Non-linearity is apparent in the upper part of the graph.

Observations

A long-lived radionuclidic impurity in the radionuclide used in the test (e.g. ^{99}Mo in $^{99}Tc^{m}$ or ^{113}Sn in $^{113}In^{m}$) may reveal itself in apparent levelling out of the activity in the final part of the graph. Any such impurity can be detected, however, as long-lived residual radioactivity after completion of the test procedure. Changes in instrument sensitivity over the period of the test may likewise mimic non-linearity in activity response, but may be detected by test 2.4.1: Check of Reproducibility.

An accurate value of the physical half-life of the radionuclide should be used. It should be appreciated, when the slope of the line fitted to the data points is checked against the half-life, that the use of a value for the half-life that may be only approximate can introduce appreciable errors in activities predicted over periods of several half-lives.

Interpretation of results

Low measured activities in the upper part of the graph may indicate saturation effects in the instrument - a common failing, which may be the result of deteriorating components.

Departures from linearity near to zero activity in an instrument without an adjustable zero control may indicate a maladjusted preset zero adjustment.

Discontinuities at changes in range (e.g. between mCi and Ci readings) indicate bias (systematic errors) in at least one of the ranges concerned.

Limits of acceptablity

In general, the linearity of the activity response should be such that all individual activities measured in the test are within ± 10% of the values corresponding to the straight line fitted to the data points. It may still be feasible, however, to utilize an instrument under conditions in which saturation effects cause deviations from linearity of up to 25%, provided that the deviations are stable and the measured activities appropriately corrected.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

METHOD 2: GRADED SOURCES METHOD

Materials

Radionuclide of moderate half-life (e.g. ^{131}I) in solution, activity equal to or greater than twice the highest activity for which the instrument is to be used (e.g. 7.4 GBq (200 mCi)).

Sample vials
Remote pipetting device
Source holder
Remote handling device for sample vials
Log-log graph paper (2- or 3-cycle)

Procedure

Caution: The extensive handling of a large amount of radioactive material in this method necessitates the use of gloves, radiation shields and remote pipetting and handling devices. If ^{131}I is used, it must be pipetted and stored for decay in a fume hood with adequate air flow. If these protective devices are not available, do not proceed.

1. Pipette into a series of sample vials by means of the remote pipetting device decreasing volumes of the radionuclide solution, with activities covering the range of interest (e.g. 10, 5, 2, 1, 0.5, 0.2, 0.1 ml of a solution having an activity about 370 MBq/ml (10 mCi/ml)). Bring up the total volume in each vial to constant volume (e.g. 20 ml) with water. Cap the vials firmly.

2. Select the operating conditions appropriate to the radionuclide concerned.

3. Note the background reading to be subtracted from subsequently measured activities. Alternatively, if an adjustable zero control is provided, adjust this for zero reading.

4. Insert the sample vial having the highest activity into the source holder by means of the remote handling device and introduce the source holder into the instrument.

5. Allow sufficient time for the reading to stabilize.

6. Measure and record the activity, subtracting the background reading if necessary.

7. Remove the source holder from the instrument and extract the sample vial by means of the remote handling device.

8. Repeat steps 4-7 for each of the other sample vials in turn.

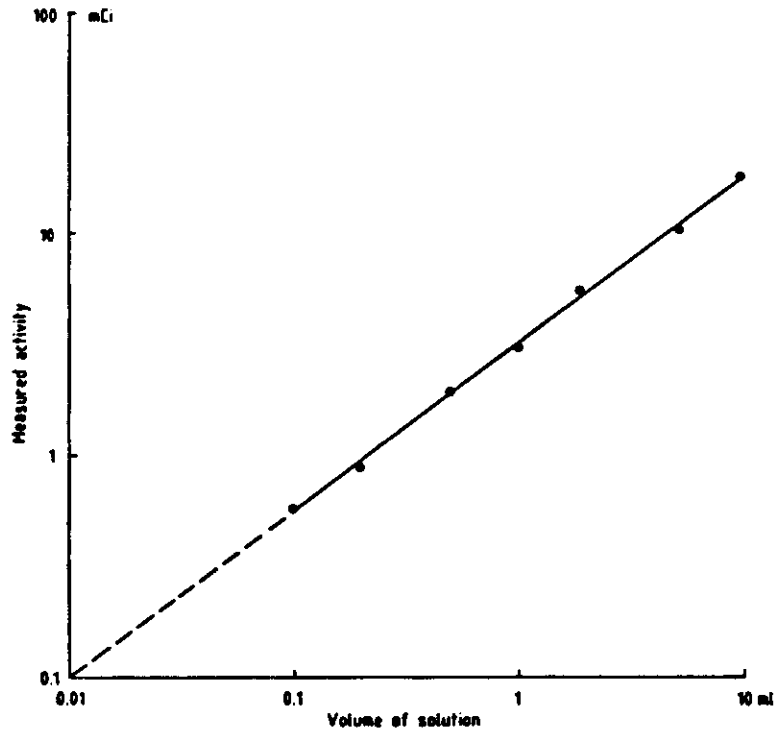


Fig. 2-3. Test 2.3.3: Test of Linearity of Activity Response: Graded Sources Method. The sources were prepared from a solution of ^{131}I having an activity concentration of about 78 MBq/ml (2.1 mCi/ml).

Data analysis

1. Record the results on a graph showing measured activity against volume of radionuclide solution on 2- or 3-cycle log-log paper (Fig. 2-3).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points in the lower activity region.

3. Extrapolate the line to cover the full range of measured activities.

4. Examine the graph for systematic departures of the data points from the fitted straight line; such discrepancies indicate non-linearity of the activity response of the instrument.

Observations

Inaccurate pipetting of the radionuclide solution, whether due to poor technique or to the use of poorly calibrated pipettes, may introduce artefacts into the results.

Interpretation of results

As for Method 1: Decaying Source Method.

Limits of acceptability

As for Method 1: Decaying Source Method.

Conclusion

As for Method 1: Decaying Source Method.

2.3.4: TEST OF BACKGROUND RESPONSE

Purpose of test

To test the background response of a radionuclide calibrator under conditions in which any increase in response is most readily observable.

Procedure

1. Select operational conditions appropriate to any chosen radionuclide with a low rate of emission of photon energy as evidenced by a low gamma-radiation dose constant (e.g. ^{51}Cr or ^{133}Xe).

2. Record the background reading in activity units of the radionuclide concerned. Alternatively, if an adjustable zero control is provided, adjust this for zero reading and record its setting.

Observations

It should be appreciated that the addition of lead shielding around the ionization chamber of a radionuclide calibrator to reduce its background response may significantly affect the accuracy of its response.

Interpretation of results

A radionuclide calibrator without an adjustable zero control should show a measureable background response. Failure to do so may indicate a maladjusted preset zero adjustment, leading to errors in activity measurements, especially at low activities. The general background due to environmental radiation may be subject to fluctuations, but gross changes in background response as compared with that observed at acceptance or reference testing are not to be expected. A significant increase in response may indicate either radioactive contamination of the instrument or increased environmental radiation from local sources. If such an increase is observed, the liner of the instrument well should be removed and the test procedure repeated. A return to the previous

response would indicate contamination of the liner, which should then be replaced. The contaminated liner may be retained for re-use, if desired, after appropriate cleaning and/or storage. Persistently high response would suggest other contamination of the instrument or increased environmental radiation from local sources. These possibilities should then be explored.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background response of 20% or greater would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

2.4. OPERATIONAL CHECKS

2.4.1: CHECK OF REPRODUCIBILITY

Purpose of test

To check the day-to-day reproducibility of performance of a radionuclide calibrator in measurements on commonly used radionuclides.

Materials

Long-lived sealed medium-energy gamma-radiation source, activity about 3.7 MBq (100 μCi). A ^{133}Ba, ^{137}Cs or ^{226}Ra source is suitable. A certified source may be used, through the manner of its use does not require that its activity be known.

Source holder
Remote handling device for source
Linear graph paper

Procedure

1. Select the operating conditions appropriate to the radionuclide in most common use (e.g. $^{99}Tc^{m}$).

2. Note the background reading to be subtracted from subsequently measured activities. Alternatively, if an adjustable zero control is provided, adjust this for zero reading.

3. Insert the gamma-radiation source into the source holder by means of the remote handling device and introduce the source holder into the instrument.

4. Allow sufficient time for the reading to stabilize.

5. Measure and record the apparent activity, subtracting the background reading if necessary.

6. Remove the source holder from the instrument and extract the source by means of the remote handling device.

7. Repeat steps 1-6 under operating conditions appropriate to each other radionuclide in common use.

Data analysis

Record the results on a control chart showing apparent activity plotted against date on linear graph paper (Fig. 2-4). Results on successive days should be closely distributed about a straight line corresponding to the radioactive decay of the source. An initial point on this line may be established as the mean of ten replicate measurements on the day concerned. The negative slope is determined by the physical half-life of the radionuclide constituting the source. For the purpose of the test, decay may be considered linear over a period short compared with the half-life (e.g. 1 year). Limits of acceptability may be indicated by two other straight lines parallel to the first, but respectively above and below it at a distance determined by the precision of the instrument as specified by the manufacturer (e.g. $\pm$ 5% of expected activity). If an individual result lies outside these limits, this may be taken to indicate faulty performance. The procedure should then be carried out a second time, but with step 5 repeated to a total of 10 successive measurements, and the individual measured activities examined for evidence of imprecision (random errors), bias (systematic errors), or both.

Observations

It should be appreciated that since the operational conditions selected for the test are not, in general, those appropriate to the

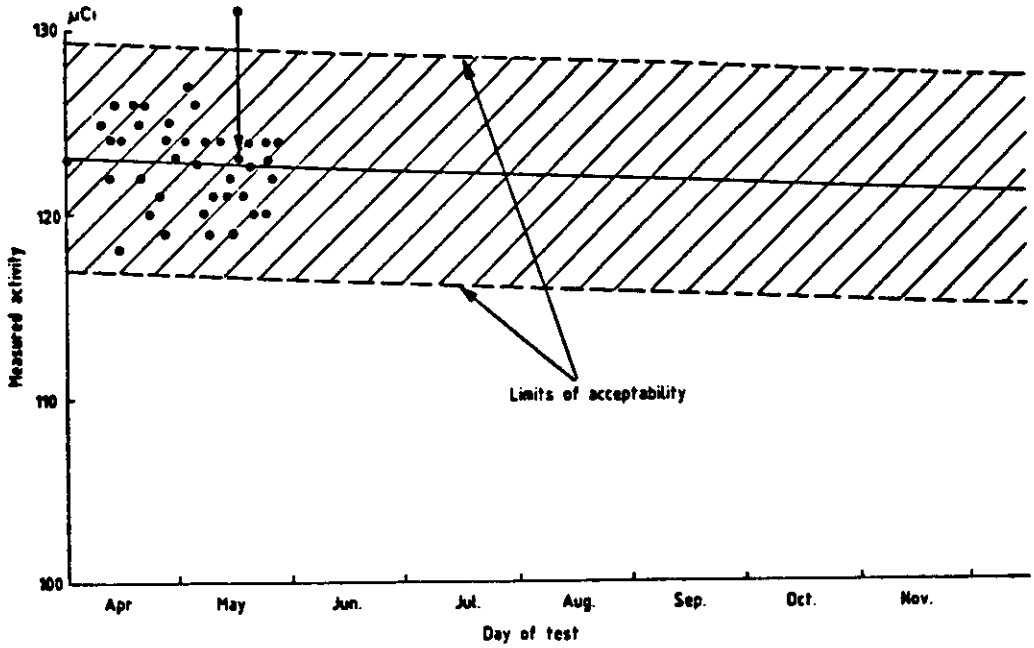


Fig. 2-4. Test 2.4.1: Check of Reproducibility. Part of control chart. The ^{137}Cs source used had a mean measured activity of 4.55 MBq (123 µCi) on 1 April. The limits of acceptability indicated correspond to ± 5% of the expected activity. The initial discrepant result on 17 May arose from failure to allow sufficient time for the reading to stabilize.

radionuclide constituting the source, the apparent activity recorded may differ greatly from the true activity. This is unimportant in testing simple reproducibility of performance. It should also be appreciated, however, that the procedure described checks the reproducibility of performance of the instrument under the operational conditions selected, but not necessarily under those appropriate to other radionuclides. This is a significant limitation, especially with instruments having selector switches, selector push-buttons or plug-in modules for different radionuclides. With such instruments, the procedure should periodically be extended to cover all radionuclides for which specific provision is made, the apparent activity being recorded for each set of conditions in turn. Again, if the operating conditions for the radionuclide concerned can be selected either by means of a selector switch, selector push button or plug-in module or by means of a potentiometer with a dial, the relevant procedure should be carried out twice, first with one than the other enabled. The results should agree.

Some manufacturers of radionuclide calibrators will supply a long-lived radiation source with the instrument at the time of purchase. It is then possible to request that the apparent activity of this source under the operating conditions for each radionuclide for which a selector switch position, push button or plug-in module is provided or for which a potentiometer dial reading is specified be determined in the course of factory calibration, and that the values thus found be quoted to the purchaser. The values may then be confirmed with the same source as part of acceptance testing and re-determined quarterly thereafter in routine quality control, serving to indicate whether changes in the accuracy of the instrument have occurred.

Interpretation of results

Discrepant results may imply imprecision, bias, or both, as indicated by the results of replicate measurements. Whatever the nature

of such discrepancy, the defective instrument should be withdrawn from operational use pending corrective action.

Limits of acceptability

The limits of acceptability for the results of the test are determined in part by the precision of the instrument specified by the manufacturer. In general, however, for measurements on sources such as that specified, the reproducibility of performance should be such that all individual measured activities are within ± 5% of the mean measured activity, provided that radioactive decay has a negligible effect over the measurement period.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

2.4.2: CHECK OF BACKGROUND RESPONSE

Purpose of test

To check the background response of a radionuclide calibrator under the operational conditions appropriate to a particular radionuclide.

Procedure

1. Select the operational conditions appropriate to the radionuclide concerned.

2. Record the background reading to be subtracted from subsequently measured activities. Alternatively, if an adjustable zero control is provided, adjust this for zero reading and record its setting.

Interpretation of results

A significant increase in background response may indicate either radioactive contamination of the instrument or increased environmental radiation from local sources. If such an increase is observed, the liner of the instrument well should be removed and the test procedure repeated. A return to the previous response would indicate contamination of the liner, which should then be replaced. The contaminated liner may be retained for re-use, if desired, after appropriate cleaning and/or storage. Persistently high response would suggest other contamination of the instrument or increased environmental radiation from local sources. These possibilities should then be explored.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background response of 20% or greater would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3. MANUAL AND AUTOMATIC COUNTING SYSTEMS FOR GAMMA-RADIATION MEASUREMENTS IN VITRO

3.1. INTRODUCTION

3.1.1. Basic Principles

Virtually all counting systems for gamma-radiation measurements in vitro are based on scintillation detectors embodying a thallium-activated sodium iodide (NaI(Tl)) crystal. A NaI(Tl) crystal with either an axial well or a transverse hole may be employed, the sample vial containing the sample to be measured being lowered into the well or positioned in the hole. Gamma rays absorbed or scattered in the crystal cause light scintillations which, in turn, give rise to electrical pulses at the photocathode of the photomultiplier to which the crystal is optically coupled. These pulses are amplified by the photomultiplier and the amplified pulses appearing at its final anode are fed to the associated electronics for further amplification, pulse-height analysis and counting (Fig. 3-1a).

Because of the diverse processes by which gamma radiation may interact with matter, the scintillations emitted in the crystal vary in intensity and the resulting electrical pulses vary correspondingly in height. For gamma radiation of a given energy, the typical pulse-height spectrum (Fig. 3-1b) comprises a prominent peak, the total absorption peak, representing absorption events in which virtually all the energy of the gamma ray is transferred to the crystal and, at smaller pulse heights, a broad continuum representing scattering events in which only part of the energy is so transferred. (The peak is sometimes termed the photopeak and the continuum the Compton continuum after the processes - photoelectric absorption and Compton scattering - from which they in part result.) The width of the total absorption peak, an indication of the ability of the detector to resolve radiations of different energies, is governed by statistical factors depending on the dimensions and other characteristics of the crystal. The "percentage full width at half-maximum" (% FWHM) of the peak for the 662 keV gamma radiation of ^{137}Cs is conventionally used as a parameter of energy resolution.

Most counting measurements are based on events in the total absorption peak. In a given counting situation, it is desirable to maximize the ratio of the frequency of such events to that of events in the total spectrum (peak-to-total ratio). This may be accomplished by increasing the dimensions of the crystal according to the energies of the radiations involved. The sensitivity of a NaI(Tl) scintillation detector for gamma-radiation measurements in vitro depends thus on the dimensions of the crystal. For medium energies, a standard well-type crystal 45 mm in diameter with a well 16 mm in diameter is satisfactory. Larger crystals give improved sensitivities at higher energies, while in detectors designed primarily for radioimmunoassay and related procedures with ^{125}I, for which the photon energy is only about 30 keV, the crystal thickness may be greatly reduced.

Since sodium iodide is hygroscopic, the NaI(Tl) crystal must be hermetically sealed in a suitable housing (e.g. of aluminium). Care is necessary in handling the crystal assembly to avoid damaging the housing or destroying the hermetic seal. In addition, lead shielding is invariably provided around the detector to reduce its response to environmental radiation, but a residual background count rate remains and results must be duly corrected. A removable liner is usually provided as a guard against accidental contamination of the crystal well.

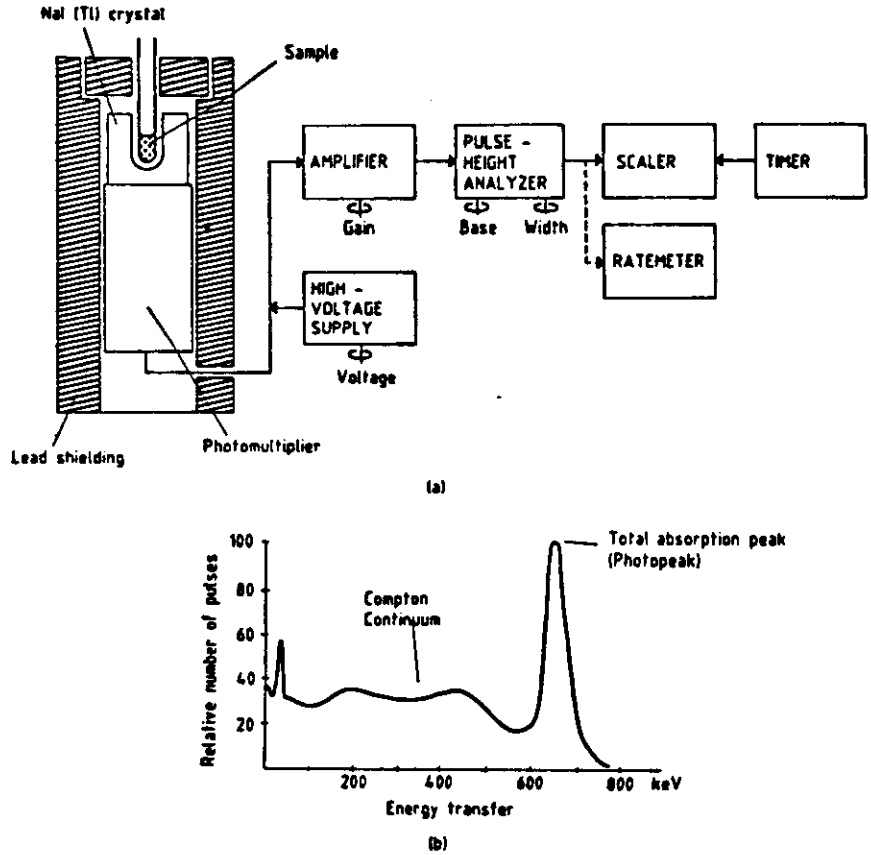


Fig. 3-1. (a) Counting system for gamma-radiation measurements in vitro.

(b) Pulse-height spectrum for ^{137}Cs.

The associated electronics in a counting system for gamma-radiation measurements in vitro typically comprise an amplifier, a pulse-height analyzer, a scaler-timer and possibly a ratemeter. There must also be a high-voltage supply for the photomultiplier. A small pre-amplifier may form part of the detector assembly.

The function of the pre-amplifier and amplifier is to provide whatever further amplification of the pulses is needed before they can be subjected to pulse-height analysis and counting, the overall gain (or amplification) being the product of the gain of the photomultiplier and that of the associated electronics. The photomultiplier gain may be increased or decreased by increasing or decreasing the high voltage applied to it. Amplifier gain controls are sometimes labelled "attenuator" or even (energy) "range". In some systems, coarse and fine controls are provided, the former being a selector switch giving fixed increments in gain, the latter a continuously adjustable control. In other systems, such continuous control of amplifier gain is not available, in which case the overall gain must be controlled by varying the high voltage on the photomultiplier. It should be noted in this regard that photomultiplier gain is a rapidly varying non-linear function of applied voltage.

Provided the amplifier system is linear, the pulse-height spectrum of the pulses fed to the pulse-height analyzer is identical in form to that of the pulses from the detector. The function of the pulse-height analyzer is to accept pulses within a chosen range of pulse heights for counting, rejecting all others. The acceptance range is usually

determined by the settings of two discriminator controls defining its lower and upper limits. These controls may act in various ways. The first, which may be designated "base" or "threshold", usually defines the lower limit of acceptance, though it may indicate the mid-point of the acceptance range. The second usually defines the interval between the lower and upper limits, sometimes as a percentage of the mid-point value. It may then be designated "width" or "window". In this mode of operation, designated "differential", the pulse-height analyzer accepts that part of the pulse-height spectrum within the window for counting, rejecting both smaller and larger pulses. Operating in the differential mode is particularly advantageous in measurements on radionuclides emitting gamma radiation of one predominant energy, since the window may be arranged to include the corresponding total absorption peak, but to exclude unwanted pulses in other spectral regions, whether due to scattered radiation or extraneous background.

In most counting systems, the further possibility exists to switch out of circuit the upper limit discriminator control. In this mode of operation, designated "integral", the pulse-height analyzer accepts all pulses with heights greater than a chosen limit. Operating in the integral mode may be preferable in certain situations, for example, in measurements on radionuclides emitting gamma radiations of several energies or in simultaneous measurements on several radionuclides, but this mode generally results in higher background count rate.

It is convenient to calibrate the entire system so that a relationship exists between the heights of the pulses at the amplifier output and the energies of the interactions in the crystal from which these pulses result. The settings of the pulse-height analyzer controls may then be read directly in energy units (keV or MeV), or multiples or sub-multiples of these, and total absorption peaks corresponding to gamma radiations of different energies appear at the appropriate settings of the "base" or "threshold" control. Such calibration may be effected by appropriate adjustment of the photomultiplier voltage and/or amplifier gain controls, with the aid of a test source giving gamma radiation of known energy; a ^{137}Cs test source is suitable. Operating conditions appropriate to any radionuclide may then be predicted from a knowledge of the energies of its gamma radiation.

Many counting systems for gamma-radiation measurements in vitro have selector switches, selector push-buttons or plug-in modules, by means of which the appropriate operating conditions for routine measurements on particular radionuclides may be obtained through preset analyzer facilities.

The scaler-timer usually gives a digital read-out of either the total count accumulated in a chosen time (preset time) or the time required to accumulate a chosen count (preset count). The ratemeter, if included, gives a direct analogue display of count rate as a meter deflection, usually with a range selector switch and a time-constant selector switch. A test facility utilizing a 50 Hz or 60 Hz signal to test the function of these circuits may be provided.

Automatic counting systems for gamma-radiation measurements in vitro may accept several hundred samples for sequential measurements after a single loading, with print-out of results on a lineprinter or teletypewriter, often with appropriate data-processing. Such systems may incorporate two or more independent electronic channels allowing simultaneous measurements on more than one radionuclide. Systems with

several detectors (multi-head systems), in which simultaneous measurements may be made on a number of samples, are also available.

3.1.2. Operational Considerations

Loss of count due to the finite resolving time of the circuits involved may limit the performance of counting systems for gamma-radiation measurements in vitro at count rates greatly in excess of 1 000 c/s.

It is important to appreciate that all counting systems for gamma-radiation measurements in vitro show some dependence on measurement geometry, with respect to volume of sample, size and type of sample vial etc. All samples in a given batch should therefore be alike in these respects. If this is not possible (e.g. if samples of different volumes have to be compared), appropriate corrections should be applied to the results.

Simple operational checks of analyzer peak setting and background count rate are needed whenever a counting system for gamma-radiation measurements in vitro is used. In addition, regular quality control should cover the function of its counting circuits, its energy calibration, energy resolution, sensitivity, counting precision, linearity of energy response, background count rate, linearity of activity response and preset analyzer facilities. Tests may involve the use of a scaler-timer, a ratemeter, or both.

Tests on systems with two or more independent electronic channels or on multi-head systems should be carried out on each individual channel or each individual detector as appropriate.

3.2. TEST SCHEDULE

Table 3-1 lists the recommended quality control tests for a counting system for gamma-radiation measurements in vitro, with suggested frequencies for the repetition of reference tests in routine testing. The operational checks should be carried out each day the system is used.

All tests require the use of a scaler-timer with a digital display, but tests 3.3.2 and 3.3.9 may additionally be carried out using a ratemeter with an analogue display. Alternative procedures, (a) using a scaler-timer and (b) using a ratemeter, are presented for these tests. With a system having a ratemeter as well as a scaler-timer, both alternatives should be followed.

Table 3-1

Test Schedule for Counting System
for Gamma-radiation Measurements in vitro

Test No.	Test	Acceptance	Reference	Frequency in routine testing		
				Weekly	Quarterly	Half-yearly
	Acceptance and Reference Tests					
3.3.1.	Physical Inspection	x				
3.3.2.	Test of Function of Scaler-timer/Ratemeter	x	x	x		
3.3.3.	Test of Energy Calibration	x	x	x		
3.3.4.	Test of Energy Resolution (% FWHM)	x	x			x
3.3.5.	Test of Sensitivity	x	x	x		
3.3.6.	Test of Counting Precision (χ^2 test)	x	x		x	
3.3.7.	Test of Linearity of Energy Response	x	x			x
3.3.8.	Test of Integral Background Count Rate	x	x	x		
3.3.9.	Test of Linearity of Activity Response	x	x			x
3.3.10.	Test of Preset Analyzer Facilities	x	x			x
	Operational Checks					
3.4.1.	Check of Analyzer Peak Setting					
3.4.2.	Check of Background Count Rate					

3.3. ACCEPTANCE AND REFERENCE TESTS

3.3.1: PHYSICAL INSPECTION

Purpose of test

To inspect a counting system for gamma-radiation measurements in vitro for general condition.

Procedure

1. Inspect the instrument housing for evidence of damage. Particularly examine the casing of the NaI(Tl) crystal(s) for signs of indentation or puncture.

2. Inspect all controls, plug-in modules, push-buttons and switches. Check for loose knobs, controls that are difficult to adjust, plug-in modules that cannot be correctly seated and switches that cannot be securely thrown.

3. Inspect all connectors. Check that none are missing and examine cables, plugs and sockets for evidence of damage.

4. Inspect all accessories such as sample vial holders and well liners. Check that none are missing or damaged.

5. Check that both operation and service manuals are available.

6. Note the location of all fuses and check that replacements are available.

7. Check the compatibility of the power supply requirements with the available supply and make any necessary adjustments.

8. Check the function of the sample changer mechanism, if appropriate.

9. Initiate the instrument log book, making an inventory of the instrument and its accessories and recording their condition on receipt, with particular reference to any damage, deficiencies or flaws and the action taken to correct them.

Observations

Physical inspection should be carried out immediately on receipt of an instrument, so that the supplier may be informed of any damage, deficiencies or flaws before the warranty has expired.

3.3.2: TEST OF FUNCTION OF SCALER-TIMER/RATEMETER

Purpose of test

To test the function of a scaler-timer and/or ratemeter in a counting system for gamma-radiation measurements in vitro.

Procedure

1. Switch in the 50 Hz or 60 Hz (or other) test facility.

2. (a) Preset a counting time sufficient to test the scaling and timing circuits

or

2. (b) Select a count-rate range appropriate to the test facility.

3. (a) Perform a count and record the count rate

or

3. (b) Measure and record the count rate. A long time constant should be selected and a time at least four times the time constant should be allowed for the reading to stabilize.

4. Switch out the test facility. (If this is not done, the system may continue to register the test signal during operation!)

Observations

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel.

Interpretation of results

The results should conform closely with that expected from the known frequency of the test signal. A discrepant result may indicate a failure in the counting circuits or, in the case of increased count rate, the presence of electrical "noise". Appropriate corrective action should in any case be initiated.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.3.3: TEST OF ENERGY CALIBRATION

Purpose of test

To effect, and subsequently to test, the energy calibration of a counting system for gamma-radiation measurements in vitro.

Materials

Sealed ^{137}Cs gamma-radiation source (rod-type), activity about 3.7 kBq (0.1 μCi). A certified source such as is required in test 3.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Procedure

1. Set the photomultiplier voltage and amplifier gain controls so that full scale (1 000 units) on the pulse-height analyzer base (threshold) control corresponds approximately to 1 000 keV. This may be done according to the operation manual or on the basis of previous experience, or by trial and error by proceeding to step 5 and repeating this step at progressively higher initial settings of the controls.

2. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls for a narrow-width (e.g. 10 units) window centred at 662 units, corresponding to the 662 keV gamma radiation of ^{137}Cs.

3. Position the ^{137}Cs gamma-radiation source in the detector.

4. Preset a suitable counting time.

5. Depending on whether the calibration is effected by adjustment of photomultiplier voltage or amplifier gain, increase the setting of the relevant control from a low initial setting until counts first appear. Further increase the setting of the control stepwise, performing a count at each step and noting the count rate. This rises to a maximum and than falls as the total absorption peak for the 662 keV gamma radiation traverses the pulse-height analyzer window. Determine the exact setting of the control for maximum count rate. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500.

6. Record the settings of all photomultiplier voltage and amplifier gain controls corresponding to the maximum count rate. These are the calibration settings for which the pulse-height analyzer settings may be read directly in energy units (keV) and the total absorption peak for the 662 keV gamma-radiation is centred at 662 units on the base (threshold) control.

7. Remove the ^{137}Cs gamma-radiation source from the detector.

Observations

It should be appreciated that the test is carried out with a narrow width (e.g. 10 keV) window. Settings of the pulse-height analyzer base (threshold) and width (window) controls for routine measurements on ^{137}Cs are obtained by opening the window to a width (e.g. 150 keV) sufficient to include virtually the whole of the total absorption peak for the 662 keV gamma radiation when centred on the peak. This usually implies a base (threshold) setting of (662 - 150/2), or 587 units and a width (window) setting of 150 units. The width needed may be judged from the shape of the peak determined in test 3.3.4.: Test of Energy Resolution.

Background corrections should be unnecessary under the narrow-window conditions of the test.

Settings for routine measurements on other radionuclides may be predicted from a knowledge of the energies of their photon emissions. Thus, a 150 keV window for ^{131}I, for which the predominant gamma radiation has energy 364 keV, would require a base (threshold) setting of (364 - 150/2), or 289 units and a width (window) setting of 150 units. To accomodate gamma radiation of other energies a change in amplifier gain may be needed. Radionuclides emitting low energy radiations are preferably measured at higher gain. Conversely, radionuclides emitting gamma radiations of energy greater that 1 000 keV must be measured at lower gain. A gain twice that used for calibration gives an energy range of 500 keV on the base (threshold) control; a gain half that used for calibration gives a range of 2 000 keV.

Thus, a 150 keV window for the 140 keV gamma radiation of $^{99}Tc^{m}$ would require at a range of 500 keV a base (threshold) setting of 2(140 - 75), or 130 units and a width (window) setting of 2x150, or 300 units.

For radionuclides emitting gamma radiations of more than one energy, it may be preferable to choose a window wide enough to include more than one total absorption peak. Thus, for the mixed 1 099 and 1 292 keV gamma radiations of ^{59}Fe, the window may be set to extend from 75 keV below the lower energy to 75 keV above the upper energy, or from 1 024 to 1 367 keV. At a range of 2 000 keV this would require a base (threshold) setting of 1 024/2, or 512 units and a width (window) setting of (1 367 - 1 024)/2, or 172 units.

While it is possible to predict settings for routine measurements in this way, they should be established in reference testing by exploring the pulse-height spectrum of the radionuclide concerned in a manner similar to that described in test 3.3.4: Test of Energy Resolution. This is necessary for two reasons. First, the energy response of the system may not be exactly linear. Second, the width of the window should be matched to the shape of the total absorption peak, which varies with radiation energy.

For counting systems designed primarily for measurements on ^{125}I in radioimmunoassay and related procedures, high gain is required because this radionuclide has a photon energy of only about 30 keV. It should be appreciated that the pulse-height spectrum of ^{125}I obtained in such systems has two main peaks, one at about 30 keV and the other at about twice that energy. The latter, a sum peak, is produced by the detection of two simultaneously emitted photons of the lower energy. Settings for routine measurements on ^{125}I should be established by exploring the pulse-height spectrum and choosing a window wide enough to include both peaks. The longer-lived radioisotope, ^{129}I, does not have a sum peak.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-head systems, the procedure should be carried out on each individual detector.

Interpretation of results

Fluctuations in the calibration settings of a counting system for gamma-radiation measurements in vitro may arise from an unstable power supply, temperature changes or electronic faults. Long-term drift may indicate deterioration of the NaI(Tl) crystal or the photomultiplier in the detector. Both short-term and long-term fluctuations should be apparent from inspection of the relevant records in the instrument log-book.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.3.4: TEST OF ENERGY RESOLUTION (% FWHM)

Purpose of test

To test the energy resolution of a counting system for gamma-radiation measurements in vitro in terms of its "percentage full width at half-maximum" (% FWHM) for ^{137}Cs gamma radiation.

Materials

Sealed ^{137}Cs gamma-radiation source (rod-type), activity about 3.7 kBq (0.1 μCi). A certified source such as is required in test 3.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Linear graph paper

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 3.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to differential mode. Set the width (window) control for a narrow (e.g. 10 keV) window.

3. Position the ^{137}Cs gamma-radiation source in the detector.

4. Preset a suitable counting time.

5. Commencing with a setting of the pulse-height analyzer base (threshold) control of about 800 keV, decrease the setting in 10 keV steps to about 500 keV, performing a count at each step and recording the count rate. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the 662 keV gamma radiation of ^{137}Cs. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500.

6. Remove the ^{137}Cs gamma-radiation source from the detector.

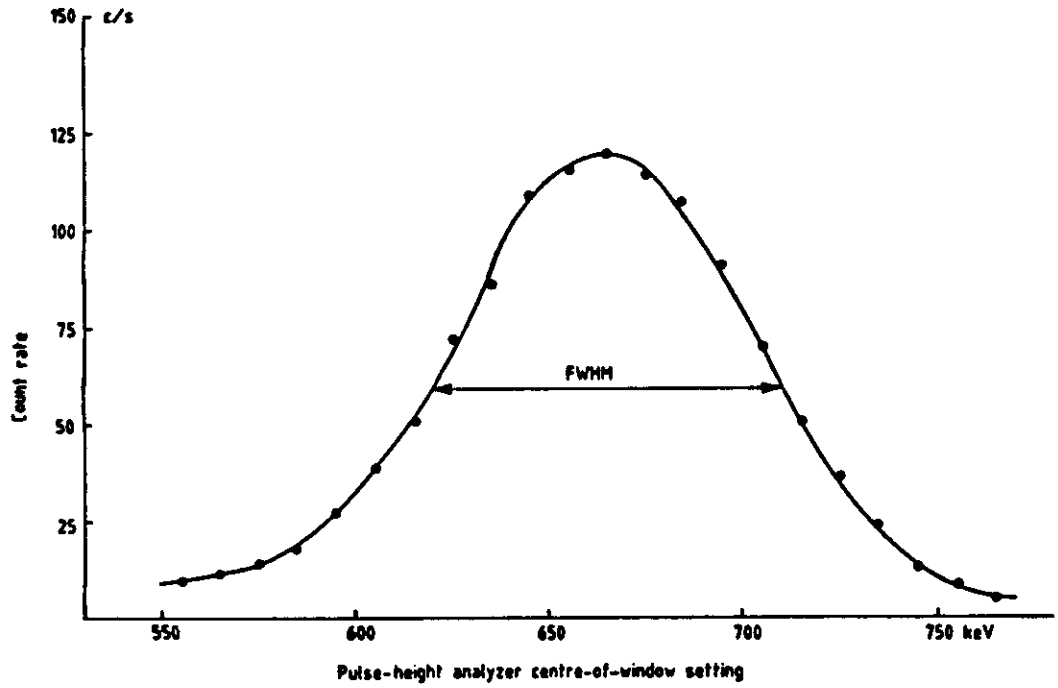


Fig. 3-2. Test 3.3.4: Test of Energy Resolution (% FWHM). The value of FWHM is 90 keV and the corresponding value of % FWHM is 13.6%.

Data analysis

1. Record the results on a graph showing count rate against centre-of-window setting of the pulse-height analyzer on linear graph paper (Fig. 3.2.).

2. Note the maximum count rate, identify the two centre-of-window settings corresponding to half the maximum count rate and determine FWHM (in keV) as the difference between them.

3. Calculate % FWHM from the expression:

$$\% \text{ FWHM} = \frac{\text{FWHM}}{662} \cdot 100$$

Observations

It should be appreciated that the width of the pulse-height analyzer window used in the test procedure influences the value of % FWHM obtained, a narrower window giving a more accurate value. The test should therefore always be carried out with as narrow a window as possible and at the same width setting.

Background corrections should be unnecessary under the narrow-window conditions of the test.

For counting systems designed primarily for measurements on ^{125}I in radioimmunoassay and related procedures, for which radionuclide the photon energy is only about 30 keV, a modified procedure using a ^{125}I source, may be devised. A high gain setting should be used, and it is important to include both the primary peak and the sum peak, to avoid confusion.

For multi-head systems, the procedure should be carried out on each individual detector.

Interpretation of results

A typical value for % FWHM would be 9%, but values depend very much on the shape and dimensions of the NaI(Tl) crystal to which they relate. The value for a given counting system should therefore be compared with that quoted by the manufacturer or obtained at acceptance testing. A likely cause of a sudden increase in % FWHM is a cracked crystal. A progressive increase may imply a deteriorating crystal because of a faulty seal leading to the entry of moisture and subsequent yellowing of the crystal, or a deteriorating photomultiplier.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.3.5: TEST OF SENSITIVITY

Purpose of test

To test the sensitivity of a counting system for gamma-radiation measurements in vitro by measurements on a certified ^{137}Cs gamma-radiation source.

Materials

Sealed ^{137}Cs gamma-radiation source (rod-type), activity about 3.7 kBq (0.1 μCi) certified to ± 10% overall uncertainty or less.

Linear graph paper.

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 3.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on ^{137}Cs (see Observations, test 3.3.3: Test of Energy Calibration).

3. Position the ^{137}Cs gamma-radiation source in the detector.

4. Preset a suitable counting time.

5. Perform a count. Record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000.

6. Remove the ^{137}Cs gamma-radiation source from the detector.

Data analysis

1. Record the results on a control chart showing count rate plotted against date on linear graph paper (Fig. 3-3). Results in successive tests should be closely distributed about a straight line corresponding to the radioactive decay of the source. An initial point on this line may be established as the mean of ten replicate measurements on the day concerned. The negative slope is determined by the physical half-life of ^{137}Cs (30.0 y), corresponding to about 2.3% per year. For the purpose of the test, decay may be considered linear for a period short compared with the half-life (e.g. 1 year). Limits of acceptability may be indicated by two other straight lines parallel to the first, but respectively above and below it at a distance corresponding to twice the standard deviation for the random counting error, i.e. $2\sqrt{n/t}$ where n is the initial mean count rate and t the counting time. Ninety-five percent of all results should lie within these limits. If an individual result lies outside them, but only marginally so, the procedure should be repeated. If the second result also lies outside, this may then be taken to indicate a change in sensitivity.

2. In acceptance and reference testing, calculate the counting efficiency of the system for ^{137}Cs gamma radiation from a knowledge of the certified activity of the source corrected for radioactive decay to the day of measurement:

Equation 1, if source calibrated in μCi:

$$E = \frac{n}{3.7 \times 10^4 \, sfa} \cdot 100$$

where E = counting efficiency (%)
n = observed count rate, corrected for background if necessary (c/s)
s = activity of source on day of reference (μCi)
f = decay factor for source to day of measurement
a = fractional abundance of detected radiation per disintegration (for ^{137}Cs - $^{137}Ba^m$ this factor is 0.832)
and 3.7×10^4 is the disintegration rate per μCi (d/s)

Equation 2, if source calibrated in Bq:

$$E = \frac{n}{sfa} \cdot 100$$

where E, n, f and a are the same as in Equation 1
and s = activity of source on day of reference (Bq)

This calculation is unnecessary in routine testing.

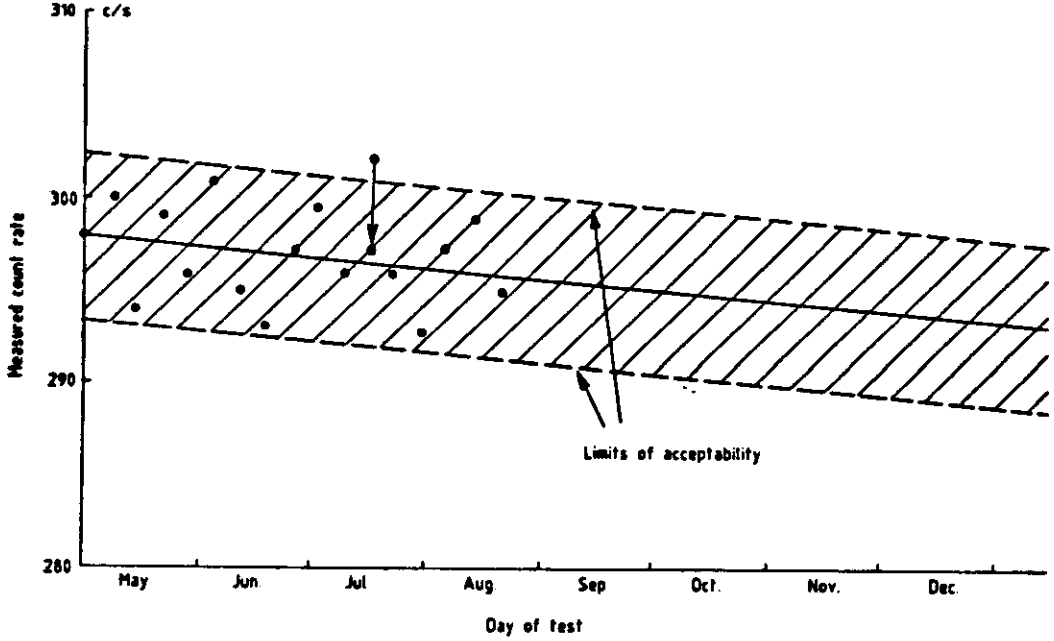


Fig. 3-3. Test 3.3.5: Test of Sensitivity. Part of control chart. The ^{137}Cs source used had a mean measured count rate of 298 c/s on 1 May. The limits of acceptability indicated correspond to a counting time of 1 minute. The initial marginally outlying result on 17 July gave way to an acceptable result on repeating the test.

Observations

It should be appreciated that the width of the pulse-height analyzer window used considerably influences the test results. The test should, therefore, always be carried out at the same width (window) setting.

Background corrections should be unnecessary under the conditions of the test.

For counting systems designed primarily for measurements on ^{125}I in radioimmunoassay and related procedures, for which radionuclide the photon energy is only about 30 keV, a modified procedure using a sealed ^{129}I radiation source may be devised. The settings of the base (threshold) and width (window) controls should then be those for routine measurements on ^{125}I (see Observations, test 3.3.3: Test of Energy Calibration).

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-head systems, the procedure should be carried out on each individual detector.

Interpretation of results

Discrepant results would suggest incorrect energy calibration of the system, impaired energy resolution or both. Test 3.3.3.: Test of Energy Calibration and test 3.3.4.: Test of Energy Resolution should then be carried out and follow-up action taken as appropriate.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.3.6: TEST OF COUNTING PRECISION (χ^2 TEST)

Purpose of test

To test the counting precision of a counting system for gamma-ray measurements in vitro.

Materials

Sealed ^{137}Cs gamma-radiation source (rod-type), activity about 3.7 kBq (0.1 μCi). A certified source such as is required in test 3.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 3.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on ^{137}Cs (see Observations, test 3.3.3: Test of Energy Calibration).

3. Position the ^{137}Cs gamma-radiation source in the detector.

4. Preset a counting time for which the count is at least 10 000.

5. Perform 10 replicate counts, recording the results on an appropriate form (Table 3-2).

6. Remove the ^{137}Cs gamma-radiation source from the detector.

Data analysis

1. Analyze the data as indicated in Table 3-2, the value of χ^2 being calculated from the relationship

$$\chi^2 = \frac{\Sigma(C_i - \bar{C})^2}{\bar{C}}$$

where C_i is an individual count and $\bar{C}$ the mean of the 10 counts.

For a sample size of 10, and thus 9 degrees of freedom, the 95% confidence limits for χ^2 are respectively 16.92 and 3.32. A value for χ^2 greater than 16.92 thus indicates variation greater than can be plausibly attributed to chance alone. A value less than 3.32 similarly indicates variation less than can be expected from chance alone. If the result falls outside these limits, the test should be repeated. If the second result also falls outside, this may be taken to indicate faulty performance.

Observations

Background corrections are unnecessary in the test.

For counting systems designed primarily for measurements on ^{125}I in radioimmunoassay and related procedures, a modified procedure using a sealed ^{129}I radiation source or ^{125}I in solution in a sample vial may be devised.

TABLE 3-2

Test of Counting Precision (χ^2 test)

Replicate i	Count Ci	(Ci - C̄)	(Ci - C̄)²
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
$\Sigma C_i =$		$\Sigma (C_i - \bar{C})^2 =$	

$$\bar{C} = \frac{\Sigma C_i}{10} =$$

$$\chi^2 = \frac{\Sigma (C_i - \bar{C})^2}{\bar{C}} =$$

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-head systems, the procedure should be carried out on each individual detector.

Interpretation of results

Imprecision indicated by a value of χ^2 greater than 16.92 may result from spurious pulses from random electrical "noise", from unstable power supply, from temperature changes or from electronic faults. A value of χ^2 less than 3.32 may imply counting losses arising because of an unduly high count rate or may result from spurious pulses from ordered electrical noise of constant frequency.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.3.7: TEST OF LINEARITY OF ENERGY RESPONSE

Purpose of test

To test the linearity of the settings of the pulse-height analyzer base (threshold) control of a counting system for gamma-radiation measurements in vitro with respect to radiation energy.

Materials

Radiation sources consisting of radionuclides emitting gamma radiations of various energies (e.g. $^{99}Tc^{m}$, ^{131}I, $^{113}In^{m}$, ^{137}Cs and ^{22}Na) in solution in sample vials, activity concentrations about 37 kBq/ml (1 μCi/ml), or in other form suitable for measurement, such as encapsulated in plastic rods. Sets of appropriate long-lived radionuclide sources are manufactured for this purpose.

Sample vials
Pipettes and pipetting devices
Linear graph paper

Procedure

1. For radionuclides in solution, pipette into sample vials about 1 ml of each of the solutions.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 3.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the width (window) control for a narrow (e.g. 10 keV) window.

For each radionuclide in turn:

4. Position the sample vial in the detector.

5. Preset a suitable counting time.

6. Commencing with a setting of the pulse-height analyzer base (threshold) control about 50 keV above the energy of the predominant gamma radiation of the radionuclide, decrease the setting in 10 keV steps, performing a count at each step and noting the count rate. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the gamma radiation concerned. Determine the exact setting of the control for maximum count rate. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500.

7. Remove the sample vial from the detector.

Data analysis

1. Record the results on a graph showing centre-of-window pulse-height analyzer setting against gamma-radiation energy on linear graph paper (Fig. 3-4).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points.

3. Extrapolate the line towards the origin.

4. Examine the data for evidence of curvature or zero offset.

Observations

Background corrections should be unnecessary under the narrow window conditions of the test.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-head systems, the procedure should be carried out on each individual detector.

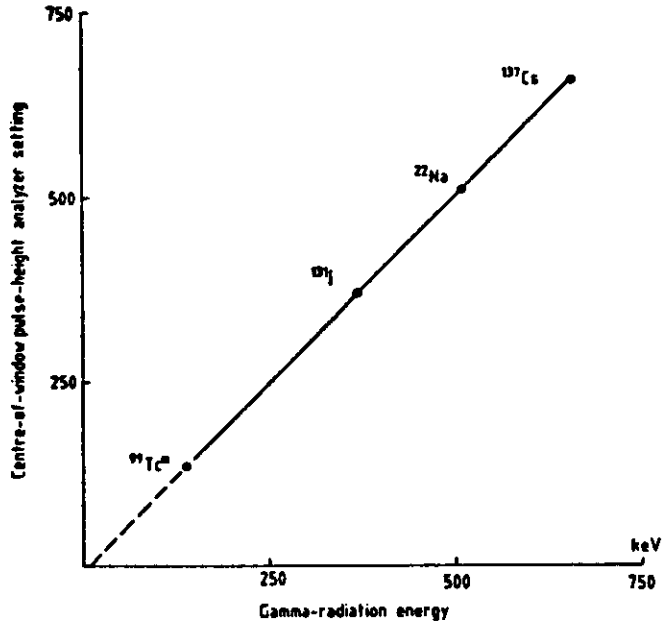


Fig. 3-4. Test 3.3.7: Test of Linearity of Energy Response. A small zero offset is apparent in the results.

Interpretation of results

Non-linearity in the results may be caused by non-linear behaviour in the amplifier. Zero offset is more likely to be due to maladjustment in the pulse-height analyzer circuits. Slight non-linearity or zero offset may be tolerated provided that the pulse-height analyzer settings for routine measurements on any individual radionuclide are confirmed as indicated in Observations, test 3.3.3: Test of Energy Calibration.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.3.8: TEST OF INTEGRAL BACKGROUND COUNT RATE

Purpose of test

To test the background count rate of a counting system for gamma-radiation measurements in vitro under conditions in which any increase in count rate is most readily observable.

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 3.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to integral mode. Set the base (threshold) control to a defined low threshold (e.g. 20 keV).

3. Preset a suitable counting time.

4. Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 1 000.

Observations

For counting systems with two or more independent electronic channels the procedure should be carried out on each individual channel. Likewise, for multi-head systems, the procedure should be carried out on each individual detector.

Interpretation of results

A counting system for gamma-radiation measurements in vitro should show a measurable background count rate arising from background radiation. An additional component of background count rate may be generated by a electrical "noise" if the base (threshold) is set at an abnormally low energy (e.g. less than 20 keV) or if the instrument is defective. The background count rate may be subject to fluctuations, but gross changes in count rate compared with that observed at acceptance or reference testing are not to be expected. A significant increase in count rate may indicate radioactive contamination of the detector or increased environmental radiation from local sources. If such an increase is observed, the liner of the detector should be removed and the procedure repeated. A return to the previous count rate would indicate contamination of the liner, which should then be replaced. The contaminated liner may be retained for re-use, if desired, after appropriate cleaning and/or storage. A persistently high count rate could suggest other contamination of the instrument or increased environmental radiation from local sources; alternatively, it may indicate electrical "noise". These possibilities should then be explored.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background count rate of 20% or greater would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.3.9: TEST OF LINEARITY OF ACTIVITY RESPONSE

Purpose of test

To test the linearity of activity response of a counting system for gamma-radiation measurements in vitro with respect to the activity of the measured sample.

METHOD 1: DECAYING SOURCE METHOD

Materials

Short-lived radionuclide (e.g. $^{99}Tc^{m}$ or $^{113}In^{m}$) in solution, activity concentration about 185 kBq/ml (5 μCi/ml).

Sample vial
Pipettes and pipetting device
Log-linear graph paper (3- or 4-cycle)

Procedure

1. Pipette into the sample vial about 1 ml of the radionuclide solution. Cap the vial firmly.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 3.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 3.3.3: Test of Energy Calibration).

4. Position the sample vial in the detector.

5. (a) Preset a suitable counting time

or

(b) Select a suitable count rate range.

6. (a) Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000. Record the exact time of day corresponding to the mid-point of the measurement

or

(b) Measure and record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize. Record the exact time of day corresponding to the measurement.

7. Repeat step 6 regularly over a period 6 or 7 times the physical half-life of the radionuclide, sufficient for the count rate to fall by two orders of magnitude.

8. Remove the sample vial from the detector.

Data analysis

1. Record the results on a graph showing count rate against lapsed time on 3- or 4-cycle log-linear paper (Fig. 3-5).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points in the lower count-rate region. Extrapolate this line upward to obtain a count-rate value corresponding to the time of the initial measurement.

3. Check the negative slope of the line to ensure that it is consistent with the known physical half-life of the radionuclide. This may conveniently be done by dividing the time for the measured count rate to fall to 1/10 of its initial value, determined in step 2, by 3.32 and comparing the result with the physical half-life.

4. Examine the graph for systematic departures of the data points from the fitted straight line; such discrepancies indicate non-linearity of the activity response of the instrument.

Observations

The test must be applied to each read-out device (e.g. scaler, ratemeter) that is used for quantitative measurements. It may also be applied to devices used only qualitatively.

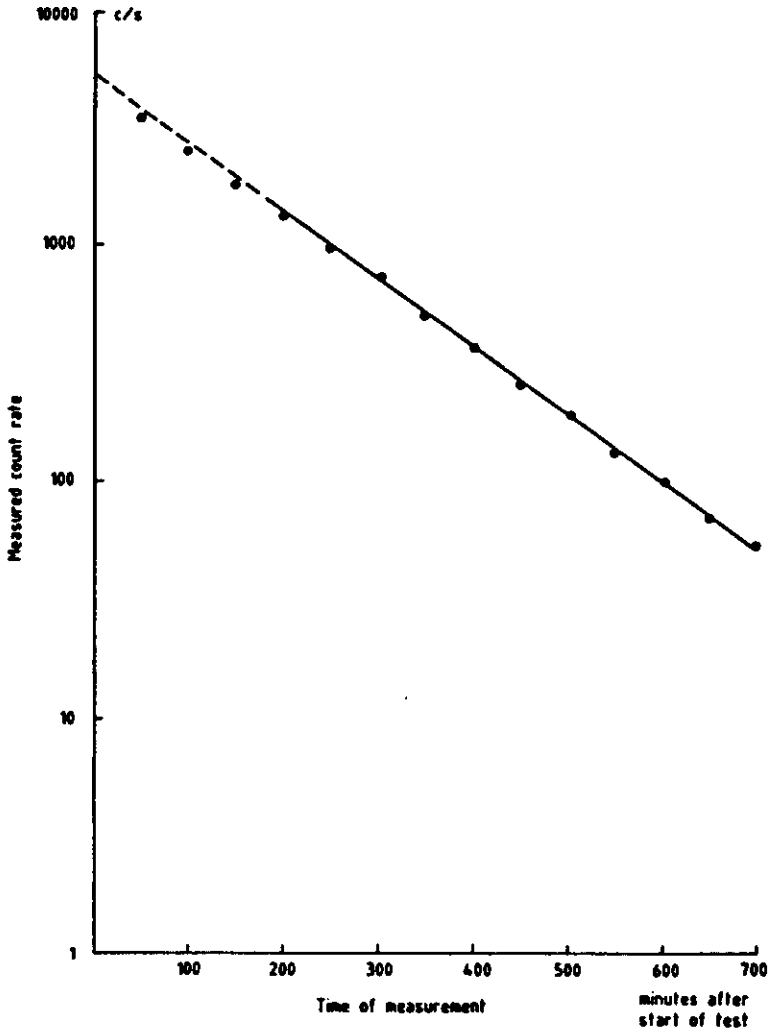


Fig. 3-5. Test 3.3.9: Test of Linearity of Activity Response: Decaying Source Method, with scaler-timer. An $^{113}In^{m}$ source having an initial count rate of about 5 000 c/s was used. The slight non-linearity apparent in the upper part of the graph corresponds to a stated resolving time of 10 μs.

Background corrections should be unnecessary under the conditions of the test, except perhaps at the lowest measured count rates.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel.

A long-lived radionuclidic impurity in the radionuclide used in the test (e.g. ^{99}Mo in $^{99}Tc^{m}$ or ^{113}Sn in $^{113}In^{m}$) may reveal itself in apparent levelling out of the count rate in the final part of the graph. Any such impurity can be detected, however, as long-lived residual radioactivity after completion of the test procedure. Changes in instrument sensitivity over the period of the test may likewise mimic non-linearity in activity response, but may be detected by test 3.4.1: Check of Analyzer Peak Setting.

An accurate value of the physical half-life of the radionuclide should be used. It should be appreciated, when the slope of the line fitted to the data points is checked against the half-life, that the use of a value for the half-life that may be only approximate can introduce appreciable errors in count rates predicted over periods of several half-lives.

Interpretation of results

Increasing loss of count and, hence, increasing departure from linearity of activity response at higher count rates are to be expected in any counting system for gamma-radiation measurements as a consequence of its finite resolving time. This effect is described by the relationship

$$n = \frac{n'}{(1-n't)}$$

where n = true count rate (c/s)
n' = observed count rate (c/s)
t = resolving time (s).

It follows from this relationship that the count loss for a resolving time of 10 μs reaches 1% at a count rate of 1 000 c/s. Losses are unlikely to be observed at count rates lower than this value, but become increasingly significant above it.

In tests carried out with a ratemeter, departure from linearity at low count rates may indicate a maladjusted preset zero adjustment. Discontinuities at changes of range (e.g. at 100 c/s) indicate bias (systematic errors) in at least one of the ranges concerned.

Limits of acceptability

The limits of acceptability for the results of the test are determined by the performance characteristics of the counting system. In particular, departure from linearity of response at higher count rates should conform with the stated resolving time.

In general, appropriate corrections should be applied to all measured count rates for which counting losses exceed 1%.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

METHOD 2: GRADED SOURCES METHOD

Materials

Radionuclide of moderate half-life (e.g. ^{131}I) in solution, activity concentration about 185 kBq/ml (5 μCi/ml).

Sample vials
Pipettes and pipetting device
Log-log graph paper (2- or 3-cycle)

Procedure

1. Pipette into a series of sample vials decreasing volumes of the radionuclide solution (e.g. 5, 2, 1, 0.5, 0.1, 0.05 ml). Bring up the total volume in each vial to constant volume (e.g. 5 ml) with water. Cap the vials firmly.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 3.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 3.3.3: Test of Energy Calibration).

4. Position the sample vial having the highest activity in the detector.

5. (a) Preset a suitable counting time

or

(b) Select a suitable count rate range.

6. (a) Perform a count. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000. Record the count rate

or

(b) Measure and record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant should be allowed for the reading to stabilize.

7. Remove the sample vial from the detector.

8. Repeat steps 4-7 for each of the other sample vials in turn.

Data analysis

1. Record the results on a graph showing count rate against volume of radionuclide solution on 2- or 3-cycle log-log paper (Fig. 3-6).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points, in the lower count-rate region.

3. Extrapolate the line to cover the full range of measured count rates.

4. Examine the graph for systematic departures of the data points from the fitted straight line; such discrepancies indicate non-linearity of the activity response of the instrument.

Observations

This test must be applied to each read-out device (e.g. scaler, ratemeter) that is used for quantitative measurements. It may also be applied to devices used only qualitatively.

Background corrections should be unnecessary under the conditions of the test, except perhaps at the lowest measured count rates.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel.

Inaccurate pipetting of the radionuclide solution, whether due to poor technique or to the use of poorly calibrated pipettes, may introduce artefacts into the results.

Interpretation of results

As for Method 1: Decaying Source Method.

Limits of acceptability

As for Method 1: Decaying Source Method.

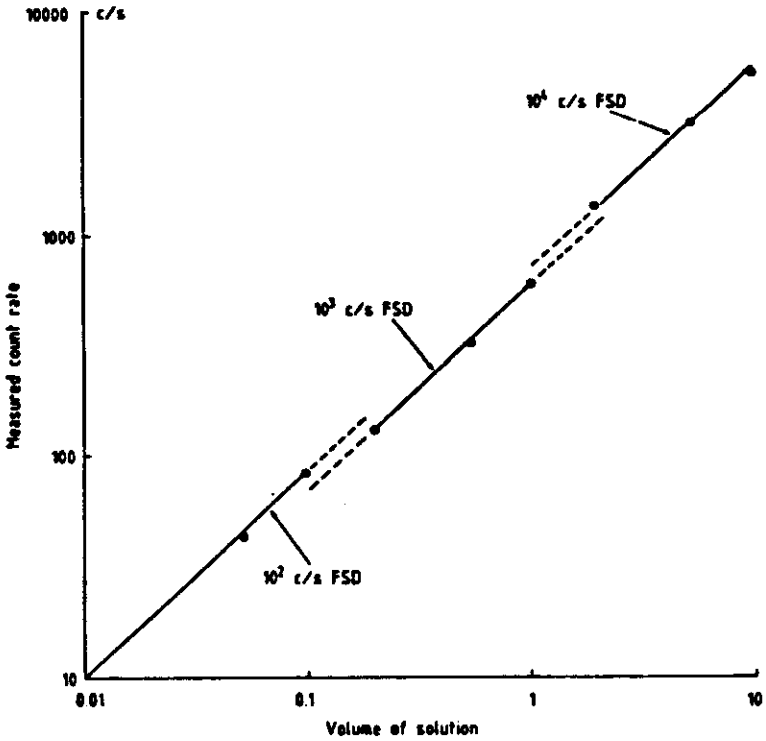


Fig. 3-6. Test 3.3.9: Test of Linearity of Activity Response: Graded Sources Method, with ratemeter. The sources were prepared from an ^{131}I solution giving a count rate of about 1 000 c/s per ml. The discontinuities apparent at around 100 and 1 000 c/s indicate systematic errors in the 1 000 c/s full-scale-deflection (FSD) count-rate range.

Conclusion

As for Method 1: Decaying Source Method.

3.3.10: TEST OF PRESET ANALYZER FACILITIES

Purpose of test

To test preset pulse-height analyzer facilities for routine measurements on particular radionuclides in a counting system for gamma-radiation measurements in vitro.

Materials

Radiation sources consisting of the radionuclides concerned in solution, activity concentrations about 3.7 kBq/ml (0.1 μCi/ml), or in other form suitable for measurement.

Sample vials
Pipettes and pipetting device

Procedure

1. For radionuclides in solution, pipette into sample vials about 1 ml of each of the solutions.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in Test 3.3.3: Test of Energy Calibration.

For each radionuclide in turn:

3. Set the pulse-height analyzer to differential mode, set the base (threshold) and width (window) controls to the settings for the preset facility quoted by the manufacturer or otherwise determined.

4. Position the sample vial in the detector.

5. Preset a suitable counting time.

6. Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000.

7. Switch in the corresponding preset analyzer facility.

8. Repeat step 6.

9. Switch out the preset analyzer facility.

10. Remove the sample vial from the detector.

Data analysis

Calculate for each radionuclide the percentage change in count rate on switching from the manual settings to the preset facility.

Observations

To ensure correct energy calibration, test 3.3.3: Test of Energy Calibration should be carried out immediately before the test. The appropriateness of the pulse-height analyzer base (threshold) setting for each radionuclide may then be checked by test 3.4.1: Check of Analyzer Peak Setting.

If the pulse-height analyzer settings, particularly the width (window) settings, for the preset facilities are not quoted by the manufacturer, they should be identified at acceptance testing by determining the manual settings that give the same count rates.

Background corrections should be unnecessary under the conditions of the test.

For counting systems with two or more independent counting channels with preset pulse-analyzer facilities, the procedure should be carried out on each individual channel.

Interpretation of results

Change in count rate on switching from manual setting to the preset facility implies maladjustment of the latter. However, if all preset facilities appear maladjusted, this would suggest incorrect energy calibration of the system. Test 3.3.3: Test of Energy Calibration should then be repeated.

Limits of acceptability

A discrepancy in count rates greater than 10% would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.4. OPERATIONAL CHECKS

3.4.1: CHECK OF ANALYZER PEAK SETTING

Purpose of test

To check that the "peak" setting of the pulse-height analyzer of a counting system for gamma-radiation measurements in vitro is appropriate for routine measurements on a particular radionuclide.

Materials

Radiation source consisting of radionuclide concerned, in solution in sample vial or in other form suitable for measurement, activity about 3.7 kBq (0.1 μCi).

Procedure

1. Set all controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 3.3.3: Test of Energy Calibration).

2. Position the sample vial in the detector.

3. Preset a suitable counting time.

4. Perform a count and note the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000.

5. Perform further counts with the pulse-height analyzer base (threshold) control set respectively higher (e.g. by 10%) and lower (e.g. by 10%) than its peak setting and note the count rates. Check that these both fall below the value noted in step 4.

6. Remove the sample vial from the detector.

Observations

If a preset analyzer facility is used, step 5 of the procedure may be modified by adjusting a photomultiplier voltage or an amplifier gain control instead of the pulse-height analyzer base (threshold) control.

Background corrections should be unnecessary under the conditions of the test.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-head systems, the procedure should be carried out on each individual detector.

The test may be unsuitable to check the pulse-height analyzer settings for routine measurements on a radionuclide with more than a single peak in its pulse-spectrum. A notable example is ^{125}I . For such radionuclides of moderate half-life, simple count-rate measurements on an uncertified source may provide a basis for checking day-to-day reproducibility of performance.

Interpretation of results

Discrepant results would suggest incorrect energy calibration of the system or, possibly, non-linearity of its energy response. Test 3.3.3: Test of Energy Calibration and test 3.3.7: Test of Linearity of Energy Response should then be carried out as appropriate.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

3.4.2: CHECK OF BACKGROUND COUNT RATE

Purpose of test

To check the background count rate of a counting system for gamma-radiation measurements in vitro under the conditions for routine measurements on a particular radionuclide.

Procedure

1. Set all controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 3.3.3: Test of Energy Calibration).

2. Preset a suitable counting time.

3. Perform a count and record the count rate.

Observations

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-head systems, the procedure should be carried out on each individual detector.

Interpretation of results

A significant increase in background count rate may indicate radioactive contamination of the detector or increased environmental radiation from local sources. If such an increase is observed, the liner of the detector should be removed and the procedure repeated. A return to the previous count rate would indicate contamination of the liner, which should then be replaced. The contaminated liner may be retained for re-use, if desired, after appropriate cleaning and/or storage. Persistently high count rate would suggest other contamination of the instrument or increased environmental radiation from local sources. Alternatively, it could suggest electrical "noise". These possibilities should then be explored.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background count rate of 20% or greater would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4. SINGLE AND MULTI-PROBE COUNTING SYSTEMS FOR GAMMA-RADIATION MEASUREMENTS IN VIVO

4.1 INTRODUCTION

4.1.1. Basic Principles

As with corresponding systems for measurements in vitro, virtually all counting systems for gamma-radiation measurements in vivo, are based on scintillation detectors embodying thallium-activated sodium iodide NaI(Tl) crystals. A solid cylindrical NaI(Tl) crystal is usually employed in these systems. Associated electronics provide for amplification, pulse-height analysis and counting of the pulses from the detector assembly (Fig. 4-1).

Once again, the sensitivity of the detector depends on the dimensions of the crystal in relation to the energies of the radiations involved. For medium energies, a crystal 50 mm in diameter and 25 mm thick is satisfactory. Larger crystals will give improved sensitivities, especially at higher energies.

Lead shielding is almost invariably provided around the detector to reduce its response to environmental radiation, and a simple lead collimator is mounted in front of the crystal to confer the necessary directional characteristics. The shielded and collimated detector, often termed a probe, is usually mounted in an adjustable support allowing it to be appropriately positioned in relation to the patient. Interchangeable collimators are usually provided so that the directional characteristics of the probe may be matched to the particular clinical situation.

The associated electronics in a counting system for gamma-radiation measurements in vivo typically comprise an amplifier, a pulse-height analyzer, a scaler-timer and/or a ratemeter. The latter is commonly an analogue ratemeter feeding a strip-chart recorder, but may be a "digital ratemeter" feeding a list printer. There must also be a high-voltage supply for the photomultiplier. A small pre-amplifier may form part of the detector assembly. For dynamic studies, a ratemeter coupled to a strip-chart recorder is usually used. The functions and modes of operation of the various components of such a system are essentially the same as for a system for measurements in vitro.

Such systems may again incorporate two or more independent electronic channels allowing simultaneous measurements on more than one radionuclide. Systems with two or more detectors (multi-probe systems) with which simultaneous measurements may be made over a like number of body sites, are also available.

4.1.2 Operational Considerations

Simple operational checks of collimator and probe mountings, analyzer peak setting, background count rate and function of strip-chart recorder are needed whenever a counting system for gamma-radiation measurements in vivo is used. In addition, regular quality control should cover the function of its counting circuits, its energy calibration, energy resolution, sensitivity, counting precision, linearity of energy response, background count rate, linearity of activity response and preset analyzer facilities. The protocols of the tests employed for these purposes are essentially the same as for a

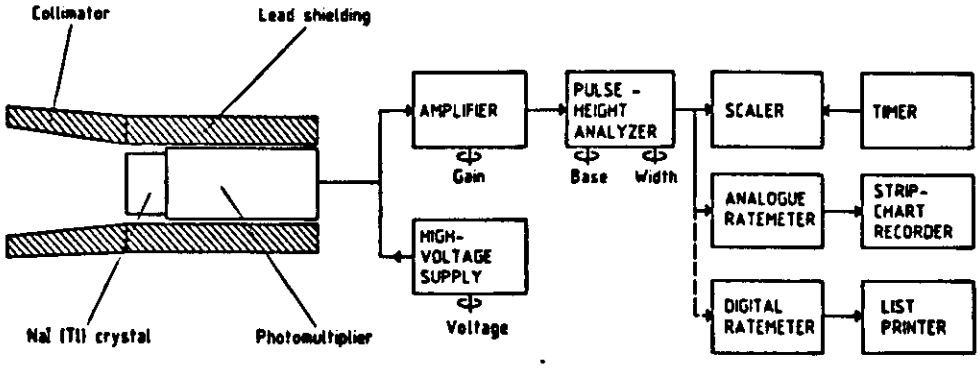


Fig. 4-1. Counting system for gamma-radiation measurements in vivo.

system for measurements in vitro. Additional tests of strip-chart recorder function may also be necessary. Tests may involve the use of a scaler-timer, a ratemeter, or both.

Tests on systems with two or more independent electronic channels or on multi-probe systems should be carried out on each individual channel or each individual probe as appropriate.

4.2 TEST SCHEDULE

Table 4-1 lists the recommended quality control tests for a counting system for gamma-radiation measurements in vivo, with suggested frequencies for the repetition of reference tests in routine testing. The operational checks should be carried out each day the system is used.

Test 4.3.6. requires the use of a scaler-timer with a digital display, but may be carried out on a system that does not have such facilities by feeding the output of the pulse-height analyzer to an external scaler-timer.

Tests 4.3.2 - 4.3.5, 4.3.7 - 4.3.10 and 4.4.3 - 4.4.5 may be carried out using either a scaler-timer with a digital display or a ratemeter with an analogue display. Alternative procedures, (a) using a scaler-timer and (b) using a ratemeter, are presented for these tests. With a system having both a scaler-timer and a ratemeter, both alternatives should be followed in tests 4.3.2 and 4.3.9. Otherwise, either may be followed, but the use of a scaler-timer is to be preferred as giving more precise results.

Table 4-1

Test Schedule for Counting System
for Gamma-radiation Measurements in vivo

Test No.	Test	Acceptance	Reference	Frequency in routine testing		
				Weekly	Quarterly	Half-yearly
	Acceptance and Reference Tests					
4.3.1.	Physical Inspection	x				
4.3.2.	Test of Function of Scaler-timer/Ratemeter	x	x	x		
4.3.3.	Test of Energy Calibration	x	x	x		
4.3.4.	Test of Energy Resolution (% FWHM)	x	x			x
4.3.5.	Test of Sensitivity	x	x	x		
4.3.6.	Test of Counting Precision (χ^2 test)	x	x		x	
4.3.7.	Test of Linearity of Energy Response	x	x			x
4.3.8.	Test of Integral Background Count Rate	x	x	x		
4.3.9.	Test of Linearity of Activity Response	x	x			x
4.3.10.	Test of Preset Analyzer Facilities	x	x			x
4.3.11.	Test of Linearity of Response of Recorder	x	x			x
4.3.12.	Test of Chart Drive of Recorder	x	x			x
	Operational Checks					
4.4.1.	Check of Collimator and Probe Mountings					
4.4.2.	Check of Recorder Function					
4.4.3.	Check of Analyzer Peak Setting					
4.4.4.	Check of Probe Sensitivity					
4.4.5.	Check of Background Count Rate					

4.3. ACCEPTANCE AND REFERENCE TESTS

4.3.1: PHYSICAL INSPECTION

Purpose of test

To inspect a counting system for gamma-radiation measurements in vivo for general condition.

Procedure

1. Inspect the instrument support and housing for evidence of damage. Particularly examine the casing of the NaI(Tl) crystal(s) for signs of indentation or puncture.

2. Inspect all controls, plug-in modules, push-buttons and switches. Check for loose knobs, controls that are difficult to adjust, plug-in modules that cannot be correctly seated and switches that cannot be securely thrown.

3. Inspect all connectors. Check that none are missing and examine cables, plugs and sockets for evidence of damage.

4. Inspect all collimators and other accessories. Check that none are missing or damaged.

5. Check that both operation and service manuals are available.

6. Note the location of all fuses and check that replacements are available.

7. Check the compatibility of the power supply requirements with the available supply and make any necessary adjustments.

8. Check all collimator and probe mountings for freedom from mechanical defects, with particular regard to the safety of patients and staff.

9. Initiate the instrument log book, making an inventory of the instrument and its accessories and recording their condition on receipt, with particular reference to any damage, deficiencies or flaws and the action taken to correct them.

Observations

Physical inspection should be carried out immediately on receipt of an instrument, so that the supplier may be informed of any damage, deficiencies or flaws before the warranty has expired.

4.3.2: TEST OF FUNCTION OF SCALER-TIMER/RATEMETER

Purpose of test

To test the function of a scaler-timer and/or ratemeter in a counting system for gamma-radiation measurements in vivo.

Procedure

1. Switch in the 50 Hz or 60 Hz (or other) test facility.

2. (a) Preset a counting time sufficient to test the scaling and timing circuits

or

(b) Select a count-rate range appropriate to the test facility.

3. (a) Perform a count and record the count rate

or

(b) Measure and record the count rate. A long time constant should be selected and a time at least four times the time constant should be allowed for the reading to stabilize.

4. Switch out the test facility. (If this is not done, the system may continue to register the test signal during operation!)

Observations

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel.

Interpretation of results

The results should conform closely with that expected from the known frequency of the test signal. A discrepant result may indicate a failure in the counting circuits or, in the case of increased count rate, the presence of electrical "noise". Appropriate corrective action should in any case be initiated.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.3: TEST OF ENERGY CALIBRATION

Purpose of test

To effect, and subsequently to test, the energy calibration of a counting system for gamma-radiation measurements in vivo.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular type), activity about 370 kBq (10 μCi). A certified source such as is required in test 4.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Source mounting

Procedure

1. Set the photomultiplier voltage and amplifier gain controls so that full scale (1 000 units) on the pulse-height analyzer base (threshold) control corresponds approximately to 1 000 keV. This may be done according to the operation manual or on the basis of previous experience, or by trial and error by proceeding to step 5 and repeating this step at progressively higher initial settings of the controls.

2. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls for a narrow-width (e.g. 10 units) window centred at 662 units, corresponding to the 662 keV gamma radiation of ^{137}Cs.

3. Position the ^{137}Cs gamma-radiation source, in the source mounting, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

4. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

5. (a) Depending on whether the calibration is effected by adjustment of photomultiplier voltage or amplifier gain, increase the setting of the relevant control from a low initial setting until counts first appear. Further increase the setting of the control stepwise, performing a count at each step and noting the count rate. This rises to a maximum and then falls as the total absorption peak for the 662 keV gamma radiation traverses the pulse-height analyzer window. Determine the exact position of the control for maximum count rate. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500

or

(b) Depending on whether the calibration is effected by adjustment of photomultiplier voltage or amplifier gain, increase the setting of the relevant control from a low initial setting until counts first appear. Further increase the setting of the control stepwise, noting the count rate at each step. This rises to a maximum and then falls as the total absorption peak for the 662 keV gamma radiation traverses the pulse-height analyzer window. Determine the exact position of the control for maximum count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant should be allowed for each reading to stabilize.

6. Record the settings of all photomultiplier voltage and amplifier gain controls corresponding to the maximum count rate. These are the calibration settings for which the pulse-height analyzer settings may be read directly in energy units (keV) and the total absorption peak for the 662 keV gamma radiation is centred at 662 units on the base (threshold) control.

7. Remove the ^{137}Cs gamma-radiation source and source mounting.

Observations

It should be appreciated that the test is carried out with a narrow width (e.g. 10 keV) window. Settings of the pulse-height analyzer base (threshold) and width (window) controls for routine measurements on ^{137}Cs are obtained by opening the window to a width (e.g. 150 keV) sufficient to include virtually the whole of the total absorption peak for the 662 keV gamma radiation when centred on the peak. This usually implies a base (threshold) setting of (662 - 150/2), or 587 units and a width (window) setting of 150 units. The width needed may be judged from the shape of the peak determined in test 4.3.4: Test of Energy Resolution.

Background corrections should be unnecessary under the narrow-window conditions of the test.

Settings for routine measurements on other radionuclides may be predicted from a knowledge of the energies of their gamma radiations. Thus, a 150 keV window for the predominant 364 keV gamma radiation of

^{131}I would require a base (threshold) setting of (364 - 150/2), or 289 units and a width (window) setting of 150 units. If a change in amplifier gain is needed, the settings required may be calculated as described in Observations, test 3.3.3: Test of Energy Calibration.

While it is possible to predict settings for routine measurements in this way, they should be established in reference testing by exploring the pulse-height spectrum of the radionuclide concerned in a manner similar to that described in test 4.3.4: Test of Energy Resolution. This is necessary for two reasons. First, the energy response of the system may not be exactly linear. Second, the width of the window should be matched to the shape of the total absorption peak, which varies with radiation energy.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-probe systems, the procedure should be carried out on each individual detector.

Interpretation of results

Fluctuations in the calibration settings of a counting system for gamma-radiation measurements in vivo may arise from an unstable power supply, temperature changes or electronic faults. Long-term drift may indicate deterioration of the NaI(Tl) crystal or the photomultiplier in the detector. Both short-term and long-term fluctuations should be apparent from inspection of the relevant records in the instrument log-book.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.4: TEST OF ENERGY RESOLUTION (% FWHM)

Purpose of test

To test the energy resolution of a counting system for gamma-radiation measurements in vivo in terms of its "percentage full width at half-maximum" (% FWHM) for ^{137}Cs gamma radiation.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular type), activity about 370 kBq (10 μCi). A certified source such as is required in test 4.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Source mounting
Linear graph paper

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to differential mode. Set the width (window) control for a narrow (e.g. 10 keV) window.

3. Position the ^{137}Cs gamma-radiation source, in the source mounting, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

4. (a) Preset a suitable counting time

or

(b) Select a suitable count rate range.

5. (a) Commencing with a setting of the pulse-height analyzer base (threshold) control of about 800 keV, decrease the setting in 10 keV steps to about 500 keV, performing a count at each step and recording the count rate. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the 662 keV gamma radiation of ^{137}Cs. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500

or

(b) Commencing with a setting of the pulse-height analyzer base (threshold) control of about 800 keV, decrease the setting in 10 keV steps to about 500 keV, recording the count rate at each step. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the 662 keV gamma radiation of ^{137}Cs. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for each reading to stabilize.

6. Remove the ^{137}Cs gamma-radiation source and source mounting.

Data analysis

1. Record the results on a graph showing count rate against centre-of-window setting of the pulse-height analyzer on linear graph paper (see Fig. 3-2).

2. Note the maximum count rate, identify the two centre-of-window settings corresponding to half the maximum count rate and determine FWHM (in keV) as the difference between them.

3. Calculate % FWHM from the expression:

$$\% \text{ FWHM} = \frac{\text{FWHM}}{662} \cdot 100$$

Observations

It should be appreciated that the width of the pulse-height analyzer window used in the test procedure influences the value of % FWHM obtained, a narrower window giving a more accurate value. The test should therefore always be carried out with as narrow a window as possible and at the same width setting.

Background corrections should be unnecessary under the narrow-window conditions of the test.

For multi-probe systems, the procedure should be carried out on each individual detector.

Interpretation of results

A typical value for % FWHM would be 9%, but values depend very much on the shape and dimensions of the NaI(Tl) crystal to which they relate. The value for a given counting system should therefore be compared with that quoted by the manufacturer or obtained at acceptance testing. A likely cause of a sudden increase in % FWHM is a cracked crystal. A progressive increase may imply a deteriorating crystal because of a faulty seal, leading to the entry of moisture and subsequent yellowing of the crystal, or a deteriorating photomultiplier.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.5: TEST OF SENSITIVITY

Purpose of test

To test the sensitivity of a counting system for gamma-radiation measurements in vivo by measurements on a certified ^{137}Cs gamma-radiation source.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular-type), activity about 370 kBq (10 μCi) certified to $\pm$ 10% overall uncertainty or less.

Source mounting
Linear graph paper

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on ^{137}Cs (see Observations, test 4.3.3: Test of Energy Calibration).

3. Position the ^{137}Cs gamma-radiation source, in the source mounting, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

4. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

5. (a) Perform a count. Record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a

time at least four times the time constant allowed for the reading to stabilize.

6. Remove the ^{137}Cs gamma-radiation source and the source mounting.

Data analysis

Record the results on a control chart showing count rate plotted against date on linear graph paper (see Fig. 3-3). Results in successive tests should be closely distributed about a straight line corresponding to the radioactive decay of the source. An initial point on this line may be established as the mean of ten replicate measurements on the day concerned. The negative slope is determined by the physical half-life of ^{137}Cs (30.0 y), corresponding to about 2.3% per year. For the purpose of the test, decay may be considered linear for a period short compared with the half-life (e.g. 1 year). Taking into account the additional error that may be involved in positioning the ^{137}Cs gamma-radiation source with respect to the detector, limits of acceptability may be indicated by two other straight lines parallel to the first, but respectively above and below it at a distance corresponding to three times the standard deviation for the random counting error, i.e. $3\sqrt{n/t}$ where n is the initial mean count rate and t the counting time. Ninety-five percent of all results should lie within these limits. If an individual result lies outside them, but only marginally so, the procedure should be repeated. If the second result also lies outside, this may then be taken to indicate a change in sensitivity.

Observations

It should be appreciated that the width of the pulse-height analyzer window used and the distance between source and detector considerably influence the test results. The test should, therefore, always be carried out under conditions identical in these respects.

Background corrections should be unnecessary under the conditions of the test.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-probe systems, the procedure should be carried out on each individual detector.

Interpretation of results

Discrepant results would suggest incorrect energy calibration of the system, impaired energy resolution or both. Test 4.3.3: Test of Energy Calibration and test 4.3.4: Test of Energy Resolution should then be carried out and follow-up action taken as appropriate.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.6: TEST OF COUNTING PRECISION (χ^2 TEST)

Purpose of test

To test the counting precision of a counting system for gamma-ray measurements in vivo.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular-type), activity about 370 kBq (10 μCi). A certified source such as is required in test 4.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Source mounting

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on ^{137}Cs (see Observations, test 4.3.3: Test of Energy Calibration).

3. Position the ^{137}Cs gamma-radiation source, in the source mounting, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

4. Preset a counting time for which the count is at least 10 000.

5. Perform 10 replicate counts, recording the results on an appropriate form (see Table 3-2).

6. Remove the ^{137}Cs gamma-radiation source and source mounting.

Data analysis

Analyze the data as indicated in Table 3-2, the value of χ^2 being calculated from the relationship

$$\chi^2 = \frac{\Sigma(C_i - \bar{C})^2}{\bar{C}}$$

where C_i is an individual count and $\bar{C}$ the mean of the 10 counts.

For a sample size of 10, and thus 9 degrees of freedom, the 95% confidence limits for χ^2 are respectively 16.92 and 3.32. A value for χ^2 greater than 16.92 thus indicates variation greater than can be plausibly attributed to chance alone. A value less than 3.32 similarly indicates variation less than can be expected from chance alone. If the result falls outside these limits, the test should be repeated. If the second result also falls outside, this may be taken to indicate faulty performance.

Observations

Background corrections are unnecessary in the test.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-probe systems, the procedure should be carried out on each individual detector.

Interpretation of results

Imprecision indicated by a value of χ^2 greater than 16.92 may result from spurious pulses from random electrical "noise", from unstable power supply, from temperature changes or from electronic faults. A value of χ^2 less than 3.32 may imply counting losses arising because of an unduly high count rate or may result from spurious pulses from ordered electrical noise of constant frequency.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.7: TEST OF LINEARITY OF ENERGY RESPONSE

Purpose of test

To test the linearity of the settings of the pulse-height analyzer base (threshold) control of a counting system for gamma-radiation measurements in vivo with respect to radiation energy.

Materials

Radiation sources consisting of radionuclides emitting gamma radiations of various energies (e.g. $^{99}Tc^{m}$, ^{131}I, $^{113}In^{m}$, ^{22}Na) in solution in sample vials, activity concentrations about 3.7 MBq/ml (100 μCi/ml) or in other form suitable for measurement.

Sample vial holder
Sample vials
Pipettes and pipetting devices
Linear graph paper

Procedure

1. For radionuclides in solution, pipette into sample vials about 1 ml of each of the solutions.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the width (window) control for a narrow (e.g. 10 keV) window.

For each radionuclide in turn:

4. Position the sample vial, in the sample vial holder, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

5. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

6. (a) Commencing with a setting of the pulse-height analyzer base (threshold) control about 50 keV above the energy of the predominant gamma radiation of the radionuclide, decrease the setting in 10 keV steps, performing a count at each step and noting the count rate. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the gamma radiation concerned. Determine the exact setting of the control for maximum count rate. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500

or

(b) Commencing with a setting of the pulse-height analyzer base (threshold) control about 50 keV above the energy of the predominant gamma radiation of the radionuclide, decrease the setting in 10 keV steps, noting the count rate at each step. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the gamma radiation concerned. Determine the exact setting of the control for maximum count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for each reading to stabilize.

7. Remove the sample vial and sample vial holder.

Data analysis

1. Record the results on a graph showing centre-of-window pulse-height analyzer setting against gamma-radiation energy on linear graph paper (see Fig. 3-4).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points.

3. Extrapolate the line towards the origin.

4. Examine the data for evidence of curvature or zero offset.

Observations

Background corrections should be unnecessary under the narrow window conditions of the test.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-probe systems, the procedure should be carried out on each individual detector.

Interpretation of results

Non-linearity in the results may be caused by non-linear behaviour in the amplifier. Zero offset is more likely to be due to maladjustment in the pulse-height analyzer circuits. Slight non-linearity or zero offset may be tolerated provided that the pulse-height analyzer settings for routine measurements on any individual radionuclide are confirmed as indicated in Observations, test 4.3.3: Test of Energy Calibration.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.8: TEST OF INTEGRAL BACKGROUND COUNT RATE

Purpose of test

To test the background count rate of a counting system for gamma-radiation measurements in vivo under conditions in which any increase in count rate is most readily observable.

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3 : Test of Energy Calibration.

2. Switch the pulse-height analyzer to integral mode. Set the base (threshold) control to a defined low threshold (e.g. 20 keV).

3. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

4. (a) Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 1 000

or

(b) Record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the recording to stabilize.

Observations

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-probe systems, the procedure should be carried out on each individual detector.

Interpretation of results

A counting system for gamma-radiation measurements in vivo should show a measurable background count rate arising from background radiation. An additional component of background count rate may be generated by electrical "noise" if the base (threshold) is set at an abnormally low energy (e.g. less than 20 keV) or if the instrument is defective. The background count rate may be subject to fluctuations, but gross changes in count rate compared with that observed at acceptance or reference testing are not to be expected. A significant increase in count rate may indicate radioactive contamination of the detector or increased environmental radiation from local sources. Alternatively, it may indicate electrical "noise". These possibilities should then be explored.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background count rate of 20% or greater would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.9: TEST OF LINEARITY OF ACTIVITY RESPONSE

Purpose of test

To test the linearity of the count rate of a counting system for gamma-radiation measurements in vivo with respect to the activity of the radioactive material in the field of view.

METHOD 1: DECAYING SOURCE METHOD

Materials

Short-lived radionuclide (e.g. $^{99}Tc^{m}$ or $^{113}In^{m}$) in solution, activity concentration about 18.5 MBq/ml (500 μCi/ml).

Sample vial holder
Sample vial
Pipettes and pipetting device
Log-linear graph paper (3- or 4-cycle)

Procedure

1. Pipette into the sample vial about 1 ml of the radionuclide solution. Cap the vial firmly.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 4.3.3: Test of Energy Calibrations).

4. Position the sample vial, in the sample vial holder, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

5. (a) Preset a suitable counting time

or

(b) Select a suitable count rate range.

6. (a) Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000. Record the exact time corresponding to the mid-point of the measurement

or

(b) Measure and record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize. Record the exact time of day corresponding to the measurement.

7. Repeat step 6 regularly over a period 6 or 7 times the physical half-life of the radionuclide, sufficient for the count rate to fall by two orders of magnitude.

8. Remove the sample vial and sample vial holder.

Data analysis

1. Record the results on a graph showing count rate against lapsed time on 3- or 4-cycle log-linear paper (see Fig. 3-5).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points in the lower count-rate region. Extrapolate this line upward to obtain a count-rate value corresponding to the time of the initial measurement.

3. Check the negative slope of the line to ensure that it is consistent with the known physical half-life of the radionuclide. this may conveniently be done by dividing the time for the measured count-rate to fall to 1/10 of its initial value, determined in step 2, by 3.32 and comparing the result with the physical half-life.

4. Examine the graph for systematic departures of the data points from the fitted straight line; such discrepancies indicate non-linearity of the activity response of the instrument.

Observations

The test must be applied to each read-out device (e.g. scaler, ratemeter) that is used for quantitative measurements. It may also be applied to devices used only qualitatively.

Background corrections should be unnecessary under the conditions of the test, except perhaps at the lowest measured count rates.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel.

A long-lived radionuclidic impurity in the radionuclide used in the test (e.g. ^{99}Mo in $^{99}Tc^{m}$ or ^{113}Sn in $^{113}In^{m}$) may reveal itself in apparent levelling out of the count rate in the final part of the graph. Any such impurity can be detected, however, as long-lived residual radioactivity after completion of the test procedure. Changes in instrument sensitivity over the period of the test may likewise mimic non-linearity in activity response, but may be detected by test 4.4.3: Check of Analyzer Peak Setting.

An accurate value of the physical half-life of the radionuclide should be used. It should be appreciated, when the slope of the line fitted to the data points is checked against the half-life, that the use of a value for the half-life that may be only approximate can introduce appreciable errors in count rates predicted over periods of several half-lives.

Interpretation of results

Increasing loss of count and, hence, increasing departure from linearity of activity response at higher count rates are to be expected in any counting system for gamma-radiation measurements as a consequence of its finite resolving time. This effect is described by the relationship

$$n = \frac{n'}{(1-n't)}$$

where n = true count rate (c/s)
n' = observed count rate (c/s)
t = resolving time (c/s)

It follows from this relationship that the count loss for a resolving time of 10 µs reaches 1% at a count rate of 1 000 c/s. Losses are unlikely to be observed at count rates lower than this value, but become increasingly significant above it.

In tests carried out with a ratemeter, departure from linearity at low count rates may indicate a maladjusted preset zero adjustment. Discontinuities at changes of range (e.g. at 100 c/s) indicate bias (systematic errors) in at least one of the ranges concerned.

Limits of acceptability

The limits of acceptability for the results of the test are determined by the performance characteristics of the counting system. In particular, departure from linearity of response at higher count rates should conform with the stated resolving time.

In general, appropriate corrections should be applied to all measured count rates for which counting losses exceed 1%.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

METHOD 2: GRADED SOURCES METHOD

Materials

Radionuclide of moderate half-life (e.g. ^{131}I) in solution, activity concentration about 18.5 MBq/ml (500 µCi/ml).

Sample vial holder
Sample vials
Pipettes and pipetting device
Log-log graph paper (2- or 3 cycle)

Procedure

1. Pipette into a series of sample vials decreasing volumes of the radionuclide solution (e.g. 5, 2, 1, 0.5, 0.1, 0.05 ml). Bring up the total volume in each vial to constant volume (e.g. 5 ml) with water. Cap the vials firmly.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 4.3.3: Test of Energy Calibration).

4. Position the sample vial having the highest activity in the sample vial holder, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

5. (a) Preset a suitable counting time

or

(b) Select a suitable count rate range.

6. (a) Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Measure and record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant should be allowed for the reading to stabilize.

7. Remove the sample vial and sample vial holder.

8. Repeat steps 4-7 for each of the other sample vials in turn, ensuring that each vial is positioned at exactly the same distance from the exposed face of the crystal housing.

Data analysis

1. Record the results on a graph showing count rate against volume of radionuclide solution on 2- or 3-cycle log-log paper (see Fig. 3-6).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points in the lower count-rate region.

3. Extrapolate the line to cover the full range of measured count rates.

4. Examine the graph for systematic departures of the data points from the fitted straight line; such discrepancies indicate non-linearity in the activity response of the instrument.

Observations

The test must be applied to each read-out device (e.g. scaler, ratemeter) that is used for quantitative measurements. It may also be applied to devices used only qualitatively.

Background corrections should be unnecessary under the conditions of the test.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel.

Inaccurate pipetting of the radionuclide solution, whether due to poor technique or to the use of poorly calibrated pipettes, may introduce artefacts into the results.

Interpretation of results

As for Method 1: Decaying Source Method.

Limits of acceptability

As for Method 1: Decaying Source Method.

Conclusion

As for Method 1: Decaying Source Method.

4.3.10: TEST OF PRESET ANALYZER FACILITIES

Purpose of test

To test the preset pulse-height analyzer facilities for routine measurements on particular radionuclides in a counting system for gamma-radiation measurements in vivo.

Materials

Radiation sources consisting of the radionuclides concerned in solution, activity concentrations about 370 kBq/ml (10 μCi/ml), or in other form suitable for measurement.

Sample vial holder
Sample vials
Pipettes and pipetting device

Procedure

1. For radionuclides in solution, pipette into sample vials about 1 ml of each of the solutions.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

For each radionuclide in turn:

3. Set the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for the preset facility quoted by the manufacturer or otherwise determined.

4. Position the sample vial, in the sample vial holder, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

5. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

6. (a) Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a

time at least four times the time constant allowed for the reading to stabilize.

7. Switch in the corresponding preset analyzer facility.

8. Repeat step 6.

9. Switch out the preset analyzer facility.

10. Remove the sample vial and sample vial holder.

Data analysis

Calculate for each radionuclide the percentage change in count rate on switching from the manual settings to the preset facility.

Observations

To ensure correct energy calibration, test 4.3.3: Test of Energy Calibration should be carried out immediately before the test. The appropriateness of the pulse-height analyzer base (threshold) setting for each radionuclide may then be checked by test 4.4.3: Check of Analyzer Peak Setting.

If the pulse-height analyzer settings, particularly the width (window) settings, for the preset facilities are not quoted by the manufacturer, they should be identified at acceptance testing by determining the manual settings that give the same count rates.

Background corrections should be unnecessary under the conditions of the test.

For counting systems with two or more independent counting channels with preset pulse-height analyzer facilities, the procedure should be carried out on each individual channel.

Interpretation of results

Change in count rate on switching from manual setting to the preset facility implies maladjustment of the latter. However, if all preset facilities appear maladjusted, this would suggest incorrect energy calibration of the system. Test 4.3.3: Test of Energy Calibration should then be repeated.

Limits of acceptability

A discrepancy in count rates greater than 10% would call for further investigation.

Conclusions

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.11: TEST OF LINEARITY OF RESPONSE OF RECORDER

Purpose of test

To test the linearity of response of a strip-chart recorder in a counting system for gamma-radiation measurements in vivo.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular-type), activity about 370 kBq (10 μCi). A certified source such as is required in test 4.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Source mounting
Linear graph paper

Procedure

1. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 4.3.3: Test of Energy Calibration.

2. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on ^{137}Cs (see Observations, test 4.3.3: Test of Energy Calibration).

3. Position the ^{137}Cs gamma-radiation source, in the source mounting, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

4. Select a count-rate range such that the count rate corresponds approximately to full-scale deflection of the ratemeter count rate display.

5. Select a low chart speed on the strip-chart recorder and switch on the chart drive.

6. Remove the ^{137}Cs gamma-radiation source. Adjust the zero control of the strip-chart recorder for zero reading. Replace the source.

7. Increase or decrease the setting of the pulse-height analyzer width (window) control to obtain a count rate corresponding exactly to full-scale deflection of the ratemeter count-rate display. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

8. If a strip-chart recorder sensitivity control is provided, adjust this for full-scale pen deflection. Otherwise, register the actual pen deflection on the chart.

9. Decrease the setting of the pulse-height analyzer width (window) control to obtain a count rate corresponding to 90% full-scale of the ratemeter count-rate display, again allowing a time at least four times the time constant for the reading to stabilize. Register the strip-chart recorder pen deflection on the chart.

10. Repeat step 9 with successive 10% decrements of the count rate on the ratemeter display down to 10% full-scale.

11. Remove the ^{137}Cs gamma-radiation source and source mounting. Register the strip-chart recorder zero reading on the chart.

12. Switch off the strip-chart recorder chart drive.

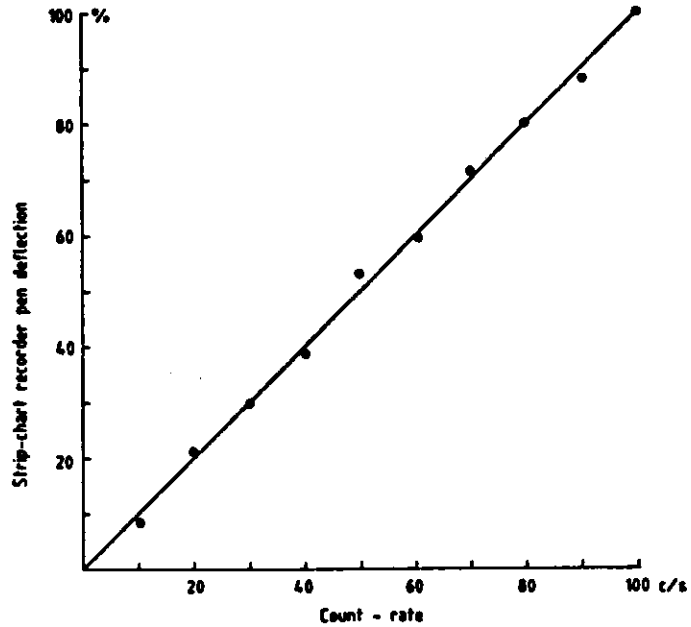


Fig. 4-2. Test 4.3.11. Test of Linearity of Response of Recorder.

Data analysis

1. Record the results on a graph showing strip-chart recorder pen deflection against count rate indicated by the ratemeter count-rate display on linear graph paper (Fig. 4-2).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points.

3. Examine the graph for systematic departures of the data points from the fitted straight line; such discrepancies indicate non-linearity in the strip-chart recorder response.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.3.12: TEST OF CHART DRIVE OF RECORDER

Purpose of test

To test the chart drive of a strip-chart recorder in a counting system for gamma-radiation measurements in vivo with respect to exactness and uniformity of chart speed.

Materials

Stop watch

Procedure

1. Select a chart speed, starting with the highest speed available.

2. Switch on the chart drive.

3. Using the stop watch, measure the time for the chart to advance with respect to the pen by a selected distance between chart gradations.

4. Repeat step 3 for a total of 5 successive measurements.

5. Switch off the chart drive.

6. Repeat steps 1-5 for each of the other chart speeds available.

Data analysis

1. For each chart speed available, calculate the mean value and the dispersion of the individual values of observed speed.

2. Compare the observed and expected speeds.

Interpretation of results

Exactness and uniformity of chart speed are both required if a recorder is to display faithfully the time course of dynamic events. The data should be examined in both respects in relation to operational requirements.

Limits of acceptability

The limits of acceptability for the results of the test are determined by the characteristics of the recorder as specified by the manufacturer and by operational requirements.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.4. OPERATIONAL CHECKS

4.4.1: CHECK OF COLLIMATOR AND PROBE MOUNTINGS

Purpose of test

To check the collimator and probe mountings in a counting system for gamma-radiation measurements in vivo.

Procedure

Inspect all collimator and probe mountings for freedom from mechanical defects, with particular regard to the safety of patients and staff.

Interpretation of results

Any abnormal finding should dictate immediate withdrawal of the instrument from operational use, pending corrective action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

TEST 4.4.2: CHECK OF RECORDER FUNCTION

Purpose of test

To check the function of a strip-chart recorder in a counting system for gamma-radiation measurements in vivo.

Procedure

1. Check that sufficient chart paper is available for the intended operations and that the chart drive runs correctly.

2. Check that sufficient ink is available to the pen and that the pen writes correctly.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.4.3: CHECK OF ANALYZER PEAK SETTING

Purpose of test

To check that the "peak" setting of the pulse-height analyzer of a counting system for gamma-radiation measurements in vivo is appropriate for routine measurements on a particular radionuclide.

Materials

Radiation source consisting of radionuclide concerned, in solution in sample vial or syringe, or in other form suitable for measurement, activity about 370 kBq (10 μCi).

Sample vial holder

Procedure

1. Set all controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 4.3.3: Test of Energy Calibration).

2. Position the sample vial, in the sample vial holder, in front of the detector, on its axis and at a defined distance from the exposed face of the crystal housing.

3. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

4. (a) Perform a count and note the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Note the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

5. (a) Perform further counts with the pulse-height analyzer base (threshold) control set respectively higher (e.g. by 10%) and lower (e.g. by 10%) than its peak setting and note the count rates. Check that these both fall below the value noted in step 4

or

(b) Note the count rates with the pulse-height analyzer base (threshold) control set respectively 50 units above and 50 units below its peak setting. Check that these both fall below the value noted in step 4.

6. Remove the sample vial and sample vial holder.

Observations

If a preset analyzer facility is used, step 5 of the procedure may be modified by adjusting a photomultiplier voltage or an amplifier gain control instead of the pulse-height analyzer base (threshold) control.

Background corrections should be unnecessary under the conditions of the test.

For counting systems with two or more independent electronic channels, the procedure should be carried out on each individual channel. Likewise for multi-probe systems, the procedure should be carried out on each individual probe.

Interpretation of results

Discrepant results would suggest incorrect energy calibration of the system or, possibly, non-linearity of its energy response. Test 4.3.3: Test of Energy Calibration and test 4.3.7: Test of Linearity of Energy Response should then be carried out as appropriate.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.4.4: CHECK OF PROBE SENSITIVITIES

Purpose of test

To equalize the sensitivities of the individual probes of a multi-probe counting system for gamma-radiation measurements in vivo on a particular radionuclide.

Materials

Radiation source consisting of the radionuclide concerned, in solution in sample vial or syringe, or in other form suitable for measurement, activity about 370 kBq (10 μCi).

Sample vial holder

Procedure

1. Set all controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 4.3.3: Test of Energy Calibration).

2. Position the sample vial, in the sample vial holder, in front of the detector of the first probe, on its axis and at a defined distance from the exposed face of the crystal housing.

3. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

4. (a) Perform a count and note the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Measure and note the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

5. Re-position the sample vial, in the sample vial holder, in front of the detector of the second probe, on its axis and at exactly the same distance from the exposed face of the crystal housing.

6. Repeat step 4.

7. Increase or decrease the setting of the width (window) control of the relevant pulse-height analyzer, repeating step 4 as necessary, to raise or lower the count rate to the value for the first probe.

8. Repeat steps 5-7 for each of the other probes in turn.

9. Remove the sample vial and sample vial holder.

Observations

Only small changes in the settings of the controls concerned should be necessary.

If a counting system does not allow the equalization of probe sensitivities by adjustment of pulse-height analyzer width (window) control settings, the same may be possible by adjustment of

photomultiplier voltage or amplifier gain controls. If this method is adopted, the probe(s) giving the higher initial count rate(s) should be adjusted by decreasing the setting(s) of the corresponding photomultiplier voltage or amplifier gain control(s).

Interpretation of results

The operation of a multi-probe system for gamma-radiation measurements in vivo usually requires that the individual probes have equal sensitivities. Minor differences between individual scintillation detectors make equalization necessary.

Limits of acceptability

Measured count rates for the individual probes, after adjustment, should not differ by more than 4%.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

4.4.5: CHECK OF BACKGROUND COUNT RATE

Purpose of test

To check the background count rate of a counting system for gamma-radiation measurements in vivo under the conditions for routine measurements on a particular radionuclide.

Procedure

1. Set all controls to the settings for routine measurements on the radionuclide concerned (see Observations, test 4.3.3: Test of Energy Calibration).

2. (a) Preset a suitable counting time

   or

   (b) Select a suitable count-rate range.

3. (a) Perform a count and record the count rate

   or

   (b) Record the count rate.

Observations

For counting systems with two or more independent counting channels, the procedure should be carried out in each individual channel. Likewise for multi-probe systems, the procedure should be carried out on each individual probe.

Interpretation of results

A significant increase in background may indicate radioactive contamination of the detector or increased environmental radiation from local sources. Alternately, it may indicate electrical "noise". These possibilities should then be explored.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background count rate of 20% or greater would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5. RECTILINEAR SCANNERS

5.1. INTRODUCTION

5.1.1. Basic Principles

In nuclear medicine, a rectilinear scanner is an instrument designed to produce a two-dimensional image of a distribution of radioactivity by scanning the region of interest in successive rectilinear passes made with a shielded and collimated thallium-activated sodium iodide (NaI(Tl)) crystal scintillation detector - the scanner head. Associated electronics provide for amplification and pulse-height analysis of the electrical pulses from the scanner head. The output pulses from the pulse-height analyzer are further transformed by a display processor and then fed to one or more display devices rigidly connected to the scanner head so that they follow its movement. These devices may present the "scan" image as a distribution of monochrome or coloured marks produced by an electromechanical tapper on paper (printer display) or as shades of grey produced by a flashing light source on photographic film (photodisplay) (Fig. 5-1a). Rectilinear scanners are complex electromechanical instruments with a number of partially independent components, the performance of which can be separately assessed in quality control. The production of high-quality images requires that all be in good functioning order.

5.1.2. Components of a Rectilinear Scanner

5.1.2.1. Scanner head

The scintillation detector in the scanner head incorporates a solid cylindrical NaI(Tl) crystal, commonly 75 mm or 125 mm in diameter and 50 mm thick. The sensitivity of the instrument greatly depends on these dimensions.

Interchangeable collimators, usually of lead, are provided for use in different clinical situations. These collimators are of the multi-hole focussing type, the axes of the individual holes having a common point of intersection at the focal point (Fig. 5-1b). In the region of the focal point, the fields of view of all the holes coincide, so that the sensitivity of the collimated detector is much higher than elsewhere; hence the focussing effect. The plane perpendicular to the axis of the collimator through the focal point is the focal plane and the distance from the exposed face of the collimator to the focal point is the focal distance. If not specified, the focal distance may be calculated from geometrical considerations as

$$\frac{dt}{(D - d)}$$

where d = maximum diameter of array of holes at exposed face of collimator
D = maximum diameter of array of holes at face of collimator nearest to NaI(Tl) crystal
t = thickness of collimator

Two other important performance parameters for focussing collimators are the spatial resolution, which expresses the ability to perceive detail in the distribution of radioactivity in the focal plane, and the depth of focus, which expresses the manner in which this ability falls off along the axis on either side of the focal plane. At lower gamma-radiation energies, these characteristics depend primarily on geometrical design. However, the required thickness of the septa between

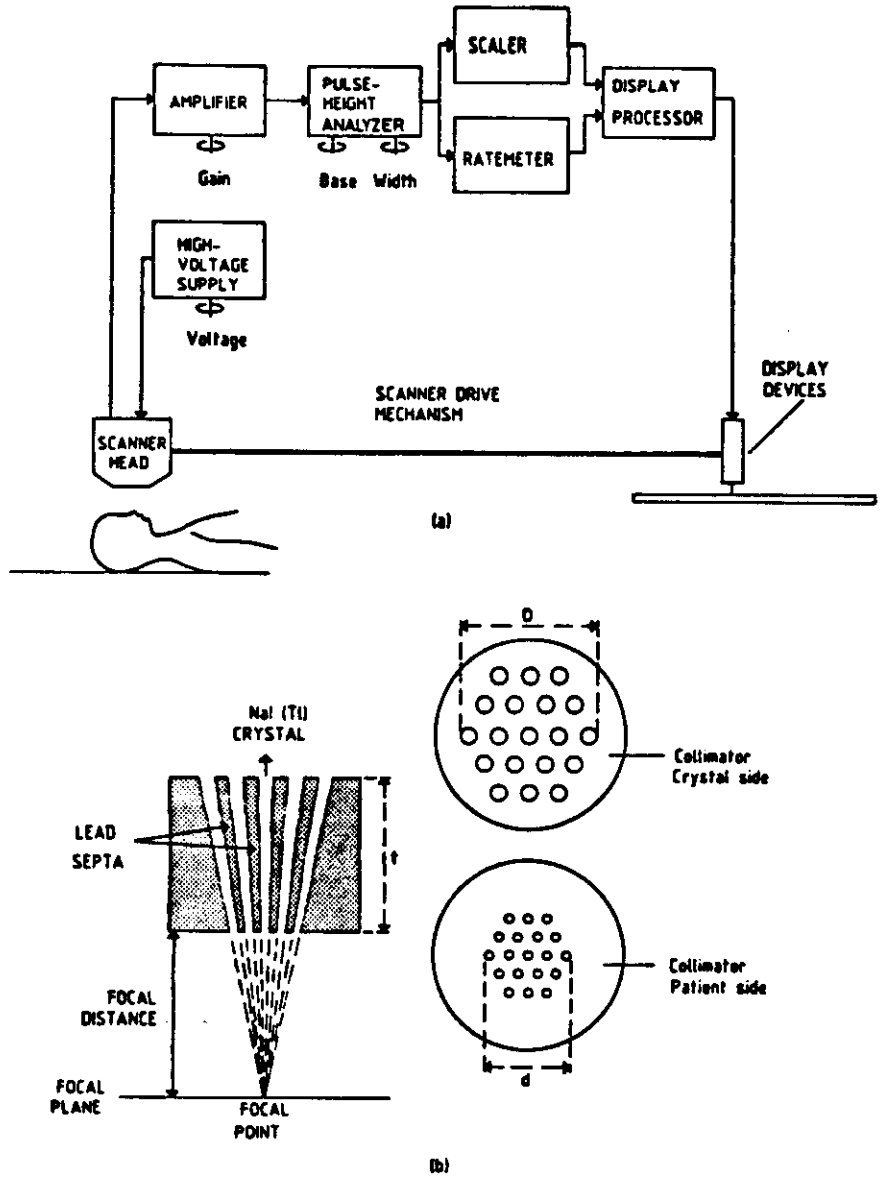


Fig. 5-1. (a) Rectilinear scanner.

(b) Focussing collimator (after Rollo, 1977).

adjacent holes and, hence, the number and size of holes in a given collimator are determined by the energies of the gamma radiations for which the collimator is intended. At higher energies, fewer holes and thicker septa are obligatory; even so, some radiation may pass through the septa, making collimation less effective, thereby degrading spatial resolution. The thicker septa also diminish the useful area of the crystal face and significantly reduce the sensitivity - the count rate per unit activity.

The correct choice of collimator is essential to the realization of high-quality clinical images with a rectilinear scanner. The collimators provided should, therefore, be carefully examined at acceptance and should be labelled to ensure that they are used only in clinical situations to which they are suited. Requirements as to focal distance, spatial resolution and depth of focus, as well as the energies of the gamma radiations involved, have all to be considered in this regard.

5.1.2.2. Associated electronics .

The associated electronics in a rectilinear scanner typically comprise a pre-amplifier, an amplifier, a pulse-height analyzer, possibly a scaler-timer and/or a ratemeter, and a high-voltage supply for the photomultiplier. The functions of these components are essentially the same as for counting systems for gamma-radiation measurements in vitro or in vivo. Special care has to be taken, however, that the pulse-height analyzer window in a scanner is correctly set, since high quality clinical images require the rejection of as much scattered radiation as possible, albeit without undue sacrifice of sensitivity. This may be achieved by selecting a window centred exactly on the total absorption peak for the gamma radiation concerned and with a width equal to 20-30% of the centre-of-window setting. Such care is equally necessary with scanners having selector switches, selector push-buttons or plug-in modules for particular radionuclides.

5.1.2.3. Display processor

The function of the display processor is to transform the signals from the associated electronics just mentioned so that they are suitable for feeding to the display devices.

It may be necessary first to scale down the count rates to levels compatible with the inertia of the electromechanical tapper of a printer display or with the light intensity requirements of the light source-film combination of a photodisplay. In some scanners, after a scanning speed satisfying statistical requirements has been selected (see 5.1.3. Operational Considerations), charts or tables may be used to select an appropriate tap factor or intensity setting. In others, these adjustments are made automatically.

In addition to exercizing this primary function, the display processor may provide two other processing modalities. These are background subtraction, for monochrome and colour printer display, and contrast enhancement, for colour printer display and photodisplay.

In background subtraction, all parts of the image corresponding to count rates below a selected level, expressed as a percentage of the maximum count rate, are completely suppressed. The remaining parts appear as they would have without background subtraction.

In contrast enhancement, which implicitly includes background subtraction, all parts of the image corresponding to count rates below a selected level are again completely suppressed, but all intensity levels available for the particular display are then spread between the suppression level and a selected count rate, which may be the maximum observed.

It should be appreciated that while background subtraction and contrast enhancement may in some circumstances improve image quality, such processing modalities are irreversible unless the original data are stored and can be redisplayed using various display parameters. They should, therefore, be avoided unless there are clear indications for their use, and even then should be used with great caution.

5.1.2.4. Display devices

With printer display, the electromechanical tapper, usually with an inked ribbon, moves synchronously with the scanner head over a sheet of paper. The tapper is activated by the output pulses from the display

processor, each pulse producing a single mark so that the tapping frequency corresponds to the output pulse count rate. In monochrome printer display, all marks are the same colour and changes in count rate are indicated simply by changes in the density of printing. In colour printer display, a multi-coloured ribbon is used and the colour of printing is arranged to depend on the count rate. Changes in count rate are still accompanied by changes in the density of printing, but the colour shifts provide additional semi-quantitative visual indications of such changes.

Some instruments with colour printer display provide an alternative mode of operation, with constant tapping frequency but colour of printing still arranged to depend on the count rate. The colour shifts are then the only indications of changes in count rate.

With photodisplay, the light source moves synchronously with the scanner head over a sheet of photographic film in a light-tight box. The light source is switched momentarily on by each output pulse from the display processor so that the frequency of the light flashes corresponds to the output pulse count rate. The light source is collimated through a narrow aperture so that each light flash blackens a small area of film similar in appearance to the imprint of the tapper. In the absence of background subtraction or contrast enhancement, the intensities of the light flashes are controlled by the display processor in such a way that the density of the developed film increases continuously with the count rate.

The ability of both printer display and photodisplay devices to respond to high count rates is limited by saturation effects. It is therefore important to set up the display processor so that the available range of operation of the display device is fully utilized, yet saturation effects are avoided.

Display devices are usually connected with the scanner head so that they exactly follow its movement on a 1:1 scale. Some scanners, however, particularly instruments designed for whole-body imaging, provide for minification of the image.

5.1.2.5. Scanner drive mechanism

The movement of the scanner head and the display device(s) on a rectilinear scanner is accomplished by a complex drive mechanism employing stepping motors, timing circuits, microswitches etc. A wide choice of scanning speeds is provided, and also different patterns for the movement of the head. It should be appreciated that relatively heavy parts may have to be moved at high speed, and therefore rapidly accelerated and decelerated, during scanning. The forces exerted on the parts concerned may be quite high. Regular preventive maintenance is essential to limit mechanical wear in any such instrument.

5.1.3. Operational Considerations

Choice of scanning speed in a given clinical situation is dictated primarily by statistical considerations. If the speed is too high, the counts registered within individual image elements are too low for statistical reproducibility and image quality is impaired. A convenient parameter that reflects the statistical quality of an image is the information or count density, given by the expression

$$I = \frac{r}{SL}$$

where I = information density (c/cm^2)
r = count rate (c/s)
S = scanning speed (cm/s)
L = line spacing (cm)

The count rate is measured at the pulse-height analyzer output or display processor input.

As a general rule, given the limited spatial resolutions of the best focussing collimators (about 1 cm FWHM), a count density of about 800 c/cm^2 is optimal for rectilinear scanners. The choice of a higher value is not rewarded by any significant improvement in the ability to perceive image detail. (It should be noted that the corresponding value for gamma cameras is several times higher).

Double-headed scanners, with two opposed heads each with its own associated electronics, offer higher sensitivities and greater depths of focus through the combination of anterior and posterior images or right and left lateral images obtained simultaneously.

Simple checks of collimator and scanner head mountings, tapper function, analyzer peak setting and background count rate are needed whenever a rectilinear scanner is used. In addition, regular quality control should cover the function of its counting circuits, its energy calibration, energy resolution, sensitivity, counting precision, linearity of energy response, background count rate, and preset analyzer facilities. The protocols of the tests employed for the latter purposes are essentially the same as for counting systems for gamma-radiation measurements in vitro and in vivo. The tests may involve the use of a scaler-timer, a ratemeter, or both. Further tests of the system linearity, background subtraction, contrast enhancement and scanner drive should be carried out as appropriate. Finally, a test of total performance of the instrument under conditions simulating clinical imaging is desirable.

Tests on double-headed scanners should be carried out on each individual detector head and its associated electronics as appropriate.

5.2. TEST SCHEDULE

Table 5-1 lists the recommended quality control tests for a rectilinear scanner, with suggested frequencies for the repetition of reference tests in routine testing. The operational checks should be carried out each day the instrument is used.

Test 5.3.6 requires the use of a scaler-timer with a digital display, but may be carried out on an instrument that does not have such facilities by feeding the output of the pulse-height analyzer to an external scaler-timer.

Tests 5.3.2 - 5.3.5, 5.3.7 - 5.3.10 and 5.4.3 - 5.4.4 may be carried out using either a scaler-timer with a digital display or a ratemeter with an analogue display. Alternative procedures, (a) using a scaler-timer and (b) using a ratemeter, are presented for these tests. With an instrument having both a scaler-timer and a ratemeter, both alternatives should be followed in tests 5.3.2 and 5.3.10. Otherwise, either may be followed, but the use of a scaler-timer is to be preferred as giving more precise results.

Table 5-1

Test Schedule for Rectilinear Scanner

Test No.	Test	Acceptance	Reference	Frequency in routine testing		
				Weekly	Monthly	Half-yearly
	Acceptance and Reference Tests					
5.3.1	Physical Inspection	x				
5.3.2	Test of Function of Scaler-timer/Ratemeter	x	x	x		
5.3.3	Test of Energy Calibration	x	x	x		
5.3.4	Test of Energy Resolution (% FWHM)	x	x			x
5.3.5	Test of Sensitivity	x	x	x		
5.3.6	Test of Counting Precision (χ^2 test)	x	x		x	
5.3.7	Test of Linearity of Energy Response	x	x			x
5.3.8	Test of Integral Background Count Rate	x	x	x		
5.3.9	Test of Preset Analyzer Facilities	x	x			x
5.3.10	Test of System Linearity	x	x		x	
5.3.11	Test of Background Subtraction	x	x			x
5.3.12	Test of Contrast Enhancement	x	x			x
5.3.13	Test of Scanner Drive	x	x			x
5.3.14	Test of Total Performance	x	x	x		
	Operational Checks					
5.4.1	Check of Collimator and Scanner Head Mountings					
5.4.2	Check of Tapper Function					
5.4.3	Check of Analyzer Peak Setting					
5.4.4	Check of Background Count Rate					

5.3. ACCEPTANCE AND REFERENCE TESTS

5.3.1: PHYSICAL INSPECTION

Purpose of test

To inspect a rectilinear scanner for general condition.

Procedure

1. Inspect the instrument frame and housing and the scanner head(s) for evidence of damage. Particularly examine the casing of the NaI(Tl) crystal(s) for signs of indentation or puncture.

2. Inspect the scanner drive mechanism. Check that it moves freely by hand.

3. Inspect all controls, plug-in modules, push-buttons and switches. Check for loose knobs, controls that are difficult to adjust, plug-in modules that cannot be correctly seated and switches that cannot be securely thrown.

4. Inspect all connectors. Check that none are missing and examine cables, plugs and sockets for evidence of damage.

5. Inspect all collimators and other accessories. Check that none are missing or damaged.

6. Check that both operation and service manuals are available.

7. Note the location of all fuses and check that replacements are available.

8. Check the compatibility of the power supply requirements with the available supply and make any necessary adjustments.

9. Check all collimator and scanner head mountings for freedom from mechanical defects, with particular regard to the safety of patients and staff.

10. Initiate the instrument log book, making an inventory of the instrument and its accessories and recording their condition on receipt, with particular reference to any damage, deficiencies or flaws and the action taken to correct them.

Observations

Physical inspection should be carried out immediately on receipt of an instrument, so that the supplier may be informed of any damage, deficiencies or flaws before the warranty has expired. In the event of major damage, acceptance testing must usually be halted until this is rectified. If only an isolated component (e.g. a collimator) is involved, acceptance testing may proceed after notification of the damage.

5.3.2: TEST OF FUNCTION OF SCALER-TIMER/RATEMETER

Purpose of test

To test the function of a scaler-timer and/or ratemeter in a rectilinear scanner.

Procedure

1. Switch in the 50 Hz or 60 Hz (or other) test facility.

2. (a) Preset a counting time sufficient to test the scaling and timing circuits

or

(b) Select a count-rate range appropriate to the test facility.

3. (a) Perform a count and record the count rate

or

(b) Measure and record the count rate. A long time constant should be selected and a time at least four times the time constant should be allowed for the reading to stabilize.

4. Switch out the test facility. (If this is not done, the system may continue to register the test signal during operation!)

Observations

For double-headed scanners with two independent electronic channels, the procedure should be carried out on each individual channel.

Interpretation of results

The results should conform closely with that expected from the known frequency of the test signal. A discrepant result may indicate a failure in the counting circuits or, in the case of increased count rate, the presence of electrical "noise". Appropriate corrective action should in any case be initiated.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.3: TEST OF ENERGY CALIBRATION

Purpose of test

To effect, and subsequently to test, the energy calibration of a rectilinear scanner.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular type), activity about 370 kBq (10 μCi). A certified source such as is required in test 5.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Procedure

1. Turn the scanner head to face vertically downward. Remove the collimator.

2. Set the photomultiplier voltage and amplifier gain controls so that full scale (1 000 units) on the pulse-height analyzer base (threshold) control corresponds approximately to 1 000 keV. This may be done according to the operation manual or on the basis of previous experience, or by trial and error by proceeding to step 7 and repeating this step at progressively higher initial settings of the controls.

3. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls for a narrow-width (e.g. 2% of the centre-of-window setting) window centred at 662 units, corresponding to the 662 keV gamma radiation of ^{137}Cs.

4. Place the ^{137}Cs gamma-radiation source on a horizontal support on the patient bed.

5. Adjust the position of the scanner head so that the ^{137}Cs gamma-radiation source is on the axis of the detector at a defined distance from the exposed face of the crystal housing.

6. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

7. (a) Depending on whether the calibration is effected by adjustment of photomultiplier voltage or amplifier gain, increase the setting of the relevant control from a low initial setting until counts first appear. Further increase the setting of the control stepwise, performing a count at each step and noting the count rate. This rises to a maximum and then falls as the total absorption peak for the 662 keV gamma radiation traverses the pulse-height analyzer window. Determine the exact position of the control for maximum count rate. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500

or

(b) Depending on whether the calibration is effected by adjustment of photomultiplier voltage or amplifier gain, increase the setting of the relevant control from a low initial setting until counts first appear. Further increase the setting of the control stepwise, noting the count rate at each step. This rises to a maximum and then falls as the total absorption peak for the 662 keV gamma radiation traverses the pulse-height analyzer window. Determine the exact position of the control for maximum count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant should be allowed for each reading to stabilize.

8. Record the settings of all photomultiplier voltage and amplifier gain controls corresponding to the maximum count rate. These are the calibration settings for which the pulse-height analyzer settings may be read directly in energy units (keV) and the total absorption peak for the 662 keV gamma radiation is centred at 662 units on the base (threshold) control.

9. Remove the ^{137}Cs gamma-radiation source.

10. Replace the collimator.

Observations

It should be appreciated that the test is carried out with a narrow width (e.g. 10 keV) window. Settings of the pulse-height analyzer base (threshold) and width (window) controls for routine measurements on ^{137}Cs are obtained by opening the window to a width (e.g. 150 keV) sufficient to include virtually the whole of the total absorption peak for the 662 keV gamma radiation when centred on the peak. This usually implies a base (threshold) setting of (662 - 150/2), or 587 units and a width (window) setting of 150 units. The width needed may be judged from the shape of the peak determined in test 5.3.4: Test of Energy Resolution.

Background corrections should be unnecessary under the narrow-window conditions for the test.

Settings for routine clinical imaging with other radionuclides may be predicted from a knowledge of the energies of their gamma radiations. Thus, a 20% window for the predominant 364 keV gamma radiation of ^{131}I would require a base (threshold) setting of (364 - 73/2), or 328 units and a width (window) setting of 73 units. If a change in amplifier gain is needed, the settings required may be calculated as described in Observations, test 3.3.3: Test of Energy Calibration.

While it is possible to predict settings for clinical imaging in this way, they should be established in reference testing by exploring the pulse-height spectrum of the radionuclide concerned in a manner similar to that described in test 5.3.4: Test of Energy Resolution. This is necessary for two reasons. First, the energy response of the instrument may not be exactly linear, especially if a change in amplifier gain is involved. Second, the width of the window should be matched to the shape of the total absorption peak, which varies with the gamma-radiation energy.

For double-headed scanners the procedure should be carried out on each individual detector system.

Interpretation of results

Fluctuations in the calibration settings of a rectilinear scanner may arise from an unstable power supply, temperature changes or electronic faults. Long-term drift may indicate deterioration of the NaI(Tl) crystal or the photomultiplier in the detector. Both short-term and long-term fluctuations should be apparent from inspection of the relevant records in the instrument log-book.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.4: TEST OF ENERGY RESOLUTION (% FWHM)

Purpose of test

To test the energy resolution of a rectilinear scanner in terms of its "percentage full width at half-maximum" (% FWHM) for ^{137}Cs gamma radiation.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular type), activity about 370 kBq (10 μCi). A certified source such as is required in test 5.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Linear graph paper

Procedure

1. Direct the scanner head vertically downwards. Remove the collimator.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 5.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the width (window) control for a narrow (e.g. 10 keV) window.

4. Place the ^{137}Cs gamma-radiation source on a horizontal support on the patient bed.

5. Adjust the position of the scanner head so that the ^{137}Cs gamma-radiation source is on the axis of the detector at a defined distance from the exposed face of the crystal housing.

6. (a) Preset a suitable counting time

or

(b) Select a suitable count rate range.

7. (a) Commencing with a setting of the pulse-height analyzer base (threshold) control of about 800 keV, decrease the setting in 10 keV steps to about 500 keV, performing a count at each step and recording the count rate. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the 662 keV gamma radiation of ^{137}Cs. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500

or

(b) Commencing with a setting of the pulse-height analyzer base (threshold) control of about 800 keV, decrease the setting in 10 keV steps to about 500 keV, recording the count rate at each step. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the 662 keV gamma radiation of ^{137}Cs. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for each reading to stabilize.

8. Remove the ^{137}Cs gamma-radiation source.

9. Replace the collimator.

Data analysis

1. Record the results on a graph showing count rate against centre-of-window setting of the pulse-height analyzer on linear graph paper (see Fig. 3-2).

2. Note the maximum count rate, identify the two centre-of-window settings corresponding to half the maximum count rate and determine FWHM (in keV) as the difference between them.

3. Calculate % FWHM from the expression:

$$\% \text{ FWHM} = \frac{\text{FWHM}}{662} \cdot 100$$

Observations

It should be appreciated that the width of the pulse-height analyzer window used in the test procedure influences the value of % FWHM obtained, a narrower window giving a more accurate value. The test should therefore always be carried out with as narrow a window as possible and at the same width setting.

Background corrections should be unnecessary under the narrow-window conditions of the test.

For double-headed scanners, the procedure should be carried out on each individual detector system.

Interpretation of results

A typical value for % FWHM would be 9%, but values depend very much on the shape and dimensions of the NaI(Tl) crystal to which they relate. The value for a given rectilinear scanner should therefore be compared with that quoted by the manufacturer or obtained at acceptance testing. A likely cause of a sudden increase in % FWHM values is a cracked crystal. A progressive increase may imply a deteriorating crystal because of a faulty seal, leading to the entry of moisture and subsequent yellowing of the crystal, or a deteriorating photomultiplier.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.5: TEST OF SENSITIVITY

Purpose of test

To test the sensitivity of a rectilinear scanner by measurements on a certified ^{137}Cs gamma-radiation source.

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular-type), activity about 370 kBq (10 μCi) certified to ± 10% overall uncertainty or less.

Linear graph paper

Procedure

1. Turn the scanner head to face vertically downward. Remove the collimator.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 5.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on ^{137}Cs (see Observations, test 5.3.3: Test of Energy Calibration).

4. Place the ^{137}Cs gamma-radiation source on a horizontal support on the patient bed.

5. Adjust the position of the scanner head so that the ^{137}Cs gamma-radiation source is on the axis of the detector at a defined distance from the exposed face of the crystal housing.

6. (a) Preset a suitable counting time

   or

   (b) Select a suitable count-rate range.

7. (a) Perform a count. Record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

8. Remove the ^{137}Cs gamma-radiation source.

9. Replace the collimator.

Data analysis

Record the results on a control chart showing count rate plotted against date on linear graph paper (see Fig. 3-3). Results in successive tests should be closely distributed about a straight line corresponding to the radioactive decay of the source. An initial point on this line may be established as the mean of ten replicate measurements on the day concerned. The negative slope is determined by the physical half-life of ^{137}Cs (30.0 y), corresponding to about 2.3% per year. For the purpose of the test, decay may be considered linear for a period short compared with the half-life (e.g. 1 year). Taking into account the additional error that may be involved in positioning the ^{137}Cs gamma-radiation source with respect to the detector, limits of acceptability may be indicated by two other straight lines parallel to the first, but respectively above and below it at a distance corresponding to three times the standard deviation for the random counting error, i.e. $3\sqrt{n/t}$ where n is the initial mean count rate and t the counting time. Ninety-five percent of all results should lie within these limits. If an individual result lies outside them, but only marginally so, the procedure should be repeated. If the second result also lies outside, this may then be taken to indicate a change in sensitivity.

Observations

It should be appreciated that the width of the pulse-height analyzer window used and the distance between the source and the detector considerably influence the test results. The test should, therefore, always be carried out under conditions identical in these respects.

Background corrections should be unnecessary under the conditions of the test.

For double-headed scanners, the procedure should be carried out on each individual detector system.

Interpretation of results

Discrepant results would suggest incorrect energy calibration of the system, impaired energy resolution or both. Test 5.3.3: Test of Energy Calibration and test 5.3.4: Test of Energy Resolution should then be carried out and follow-up action taken as appropriate.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.6: TEST OF COUNTING PRECISION (χ^2 TEST)

Purpose of test

To test the counting precision of a rectilinear scanner

Materials

Sealed ^{137}Cs gamma-radiation source (disc- or rectangular-type), activity about 370 kBq (10 μCi). A certified source such as is required in test 5.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Procedure

1. Turn the scanner head to face vertically downward. Remove the collimator.

2. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 5.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the base (threshold) and width (window) controls to the settings for routine measurements on ^{137}Cs (see Observations, test 5.3.3: Test of Energy Calibration).

4. Place the ^{137}Cs gamma-radiation source on a horizontal support on the patient bed.

5. Adjust the position of the scanner head so that the ^{137}Cs gamma-radiation source is on the axis of the detector at a defined distance from the exposed face of the crystal housing.

6. Preset a counting time for which the count is at least 10 000.

7. Perform 10 replicate counts, recording the results on an appropriate form (see Table 3-2).

8. Remove the ^{137}Cs gamma-radiation source. Replace the collimator.

Data analysis

Analyze the data as indicated in Table 3-2, the value of χ^2 being calculated from the relationship

$$\chi^2 = \frac{\Sigma(Ci-\bar{C})^2}{\bar{C}}$$

where C_i is an individual count and $\bar{C}$ the mean of the 10 counts.

For a sample size of 10, and thus 9 degrees of freedom, the 95% confidence limits for χ^2 are respectively 16.92 and 3.32. A value for χ^2 greater than 16.92 thus indicates variation greater than can be plausibly attributed to chance alone. A value less than 3.32 similarly indicates variation less than can be expected from chance alone. If the result falls outside these limits, the test should be repeated. If the second result also falls outside, this may be taken to indicate faulty performance.

Observations

Background corrections are unnecessary in the test.

For double-headed scanners, the procedure should be carried out on each individual detector system.

Interpretations of results

Imprecision indicated by a value of χ^2 greater than 16.92 may result from spurious pulses from random electrical noise, from unstable power supply, from temperature changes or from electronic faults. A value of χ^2 less than 3.32 may imply counting losses arising because of an unduly high count rate or may result from spurious pulses from ordered electrical noise of constant frequency.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.7: TEST OF LINEARITY OF ENERGY RESPONSE

Purpose of test

To test the linearity of the settings of the pulse-height analyzer base (threshold) control of a rectilinear scanner with respect to radiation energy.

Materials

Radiation sources consisting of radionuclides emitting gamma radiations of various energies (e.g. $^{99}Tc^{m}$, ^{131}I, $^{113}In^{m}$, ^{22}Na) in solution in sample vials, activity concentrations about 3.7 MBq/ml (100 μCi/ml) or in other form suitable for measurement.

Sample vial holder
Sample vials
Pipettes and pipetting devices
Linear graph paper

Procedure

1. For radionuclides in solution, pipette into sample vials about 1 ml of each of the solutions.

2. Turn the scanner head to face vertically downward. Remove the collimator.

3. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 5.3.3: Test of Energy Calibration.

3. Switch the pulse-height analyzer to differential mode. Set the width (window) control for a narrow (e.g. 10 keV) window.

For each radionuclide in turn:

4. Position the sample vial, in the sample vial holder, on a horizontal support on the patient bed.

5. Adjust the position of the scanner head so that the sample vial is on the axis of the detector at a defined distance from the exposed face of the crystal housing.

6. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

7. (a) Commencing with a setting of the pulse-height analyzer base (threshold) control about 50 keV above the energy of the predominant gamma radiation of the radionuclide, decrease the setting in 10 keV steps, performing a count at each step and noting the count rate. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the gamma radiation concerned. Determine the exact setting of the control for maximum count rate. To keep statistical variations within acceptable limits, the counting time should be such that counts in the region of the maximum are at least 2 500

or

(b) Commencing with a setting of the pulse-height analyzer base (threshold) control about 50 keV above the energy of the predominant gamma radiation of the radionuclide, decrease the setting in 10 keV steps, noting the count rate at each step. This rises to a maximum and then falls as the pulse-height analyzer window traverses the total absorption peak for the gamma-radiation concerned. Determine the exact setting of the control for maximum count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for each reading to stabilize.

8. Remove the sample vial holder.

9. After repeating steps 4-8 for each radionuclide in turn replace the collimator.

Data analysis

1. Record the results on a graph showing centre-of-window pulse-height analyzer setting against gamma-radiation energy on linear graph paper (see Fig. 3-4).

2. With the aid of a transparent ruler, fit the best straight line possible to the data points.

3. Extrapolate the line towards the origin.

4. Examine the graph for evidence of curvature or zero offset.

Observations

Background corrections should be unnecessary under the narrow window conditions of the test.

For double-headed scanners, the procedure should be carried out on each individual detector system.

Interpretation of results

Non-linearity in the results may be caused by non-linear behaviour in the amplifier. Zero offset is more likely to be due to maladjustment in the pulse-height analyzer circuits. Slight non-linearity or zero

offset may be tolerated provided that the pulse-height analyzer settings for clinical imaging with any individual radionuclide are confirmed as indicated in Observations, test 5.3.3: Test of Energy Calibration.

Conclusions

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.8: TEST OF INTEGRAL BACKGROUND COUNT RATE

Purpose of test

To test the background count rate of a rectilinear scanner under conditions in which any increase in count rate is most readily observable.

Procedure

1. Turn the scanner head to face vertically downward. Remove the collimator.

2. Adjust the position of the scanner head so that it is above the centre of the patient bed with the exposed face of the crystal at a defined distance (e.g. 50 cm) from the bed surface.

3. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 5.3.3: Test of Energy Calibration.

4. Switch the pulse-height analyzer to integral mode. Set the base (threshold) control to a defined low threshold (e.g. 50 keV).

5. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

6. (a) Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

7. Replace the collimator.

Observations

For double-headed scanners, the procedure should be carried out on each individual detector system.

Interpretation of results

A rectilinear scanner should show a measurable background count rate arising from background radiation. An additional component may be generated by electrical "noise" if the base (threshold) control is set at an abnormally low energy (e.g. less than 20 keV) or if the instrument is defective. The background count rate may be subject to fluctuations, but

gross changes in count rate compared with that observed at acceptance or reference testing are not to be expected. A significant increase in count rate may indicate radioactive contamination of the instrument or its surroundings,or increased environmental radiation from local sources. Alternatively, it may indicate electrical "noise". These possibilities should then be explored. Radioactive contamination could be on the instrument itself, particularly on the scanner head, on the patient bed, on the floor or in the waste bin. Local radiation sources may include patients to whom radioactive materials have been administered. If such contamination is suspected, the test should be repeated with the bed removed, and with the scanner head in different positions to identify the locations involved. If contamination is confirmed, clinical imaging should be deferred until decontamination procedures have reduced the count rate again to an acceptable value.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background count rate of 20% or greater would call for further investigation.

Conclusions

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.9: TEST OF PRESET ANALYZER FACILITIES

Purpose of test

To test the preset pulse-height analyzer facilities for clinical imaging with particular radionuclides in a rectilinear scanner.

Materials

Radiation sources consisting of the radionuclides concerned in solution, activity concentrations about 370 kBq/ml (10 μCi/ml), or in other form suitable for measurement.

Sample vial holder
Sample vials
Pipettes and pipetting device

Procedure

1. For radionuclides in solution, pipette into sample vials about 1 ml of each of the solutions.

2. Turn the scanner head to face vertically downward. Remove the collimator.

3. Set all photomultiplier voltage and amplifier gain controls to the calibration settings determined in test 5.3.3: Test of Energy Calibration.

For each radionuclide in turn:

4. Set the pulse-height analyzer to differential mode, set the base (threshold) and width (window) controls to the settings for the preset facility quoted by the manufacturer or otherwise determined.

5. Position the sample vial, in the sample vial holder, on a suitable horizontal support under the scanner head.

6. Adjust the position of the scanner head so that the sample vial is on the axis of the detector at a defined distance from the exposed face of the crystal housing.

7. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

8. (a) Perform a count and record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

9. Switch in the corresponding preset analyzer facility.

10. Repeat step 8.

11. Switch out the preset analyzer facility.

12. Remove the sample vial and sample vial holder.

13. After repeating steps 4-12 for each radionuclide in turn, replace the collimator.

Data analysis

Calculate for each radionuclide the percentage change in count rate on switching from the manual settings to the preset facility.

Observations

To ensure correct energy calibration, test 5.3.3: Test of Energy Calibration should be carried out immediately before the test. The appropriateness of the pulse-height analyzer base (threshold) setting for each radionuclide may then be checked by test 5.4.4: Check of Analyzer Peak Setting.

If the pulse-height analyzer settings, particularly the width (window) settings, for the preset facilities are not quoted by the manufacturer, they should be identified at acceptance testing by determining the manual settings that give the same count rates.

Background corrections should be unnecessary under the conditions of the test.

For double-headed scanners, the procedure should be carried out on each individual detector system.

Interpretation of results

Change in count rate on switching from manual setting to the preset facility implies maladjustment of the latter. However, if all preset facilities appear maladjusted, this would suggest incorrect energy calibration of the system. Test 5.3.3: Test of Energy Calibration should then be repeated.

Limits of acceptability

A discrepancy in count rates greater than 10% would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.10: TEST OF SYSTEM LINEARITY

Purpose of test

To test the linearity of the response (tap density of printer display or film density of photodisplay) of a rectilinear scanner with respect to the activity of the radioactive material in the field of view.

Materials

Short-lived radionuclide (e.g. $^{99}Tc^{m}$ or $^{113}In^{m}$) in solution, activity concentration about 37 MBq/ml (1 mCi/ml).

Emission-type step-wedge phantom (Fig. 5-2a)
Syringes and needles
Linear graph paper
Hand-held tally counter (for quantitative printer display evaluation)
Film densitometer (for quantitative photodisplay evaluation, if included)

Procedure

1. Transfer an appropriate volume of the radionuclide solution to the step-wedge phantom by means of a syringe. If the background subtraction and contrast enhancement modalities are also to be tested, the total activity of the solution should be about 93 MBq (2.5 mCi). If only the system linearity is to be tested, it need not exceed 18 MBq (500 μCi). Add water nearly to fill the phantom, but leaving an air bubble at the top, insert and tighten the sealing plugs and invert the phantom several times to ensure that the contents are well mixed. Remove the sealing plugs, top up completely with water, again insert and tighten the sealing plugs and check for freedom from leakage.

2. Turn the scanner head to face vertically downward. Mount a collimator appropriate to the gamma-radiation energy of the radionuclide concerned on the head.

3. Set all controls to the routine settings for the radionuclide concerned (see test 5.3.3: Test of Energy Calibration), with background subtraction and contrast enhancement disabled.

4. Place the phantom on a horizontal support on the patient bed with the plane side of the wedge upwards and its length parallel to the direction of scan.

5. Adjust the position of the scanner head vertically so that the focal plane of the collimator is about 1 cm below the upper surface of the phantom.

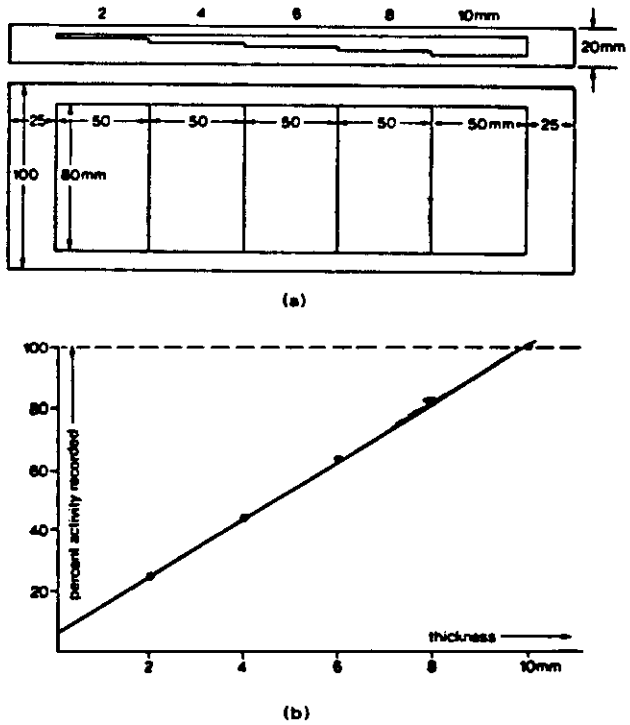


Fig. 5-2 (a) Emission-type step-wedge phantom, fabricated in plastic (e.g. Lucite, Perspex)

(b) Test 5.3.10: Test of System Linearity. Percentage count rate against wedge thickness. The step-wedge phantom used contained 74 MBq (2.0 mCi) $^{99}Tc^{m}$. The results show a zero offset.

6. Adjust the position of the scanner head horizontally so that the focal point of the collimator is in the region of the centre of the 10 mm (thickest) section of the wedge.

7. (a) Preset a suitable counting time

or

(b) Select a suitable count rate range.

8. (a) Perform a count. Record the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Record the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

9. Repeat steps 6-8 for each of the other sections of the wedge in turn.

10. Select scan parameters (tap factor, light intensity, scanning speed, line spacing etc.) as for clinical imaging, using the centre of the 10 mm section of the wedge as the reference point for 100% count rate and ensuring an appropriate count density (e.g. 1 000 c/cm^2) in this region, but with the individual marks on the printer display still clearly discernible.

11. Obtain an image of the entire phantom by each of the display devices available.

12. For quantitative printer display evaluation, determine the tap density (marks/cm^2) in the region of the centre of each section of the image by visual counting of marks within a defined area by means of the hand-held tally counter.

13. For quantitative photodisplay evaluation, if included, determine the film density in the region of the centre of each section of the image by means of the film densitometer. This step is optional, but if it is omitted, photodisplay evaluation is limited to the visual comparison of images.

14. Remove the phantom. Empty, rinse with clean water and allow to dry. The latter operations may be deferred until decay of the radionuclide is nearly complete.

Data analysis

1. Visually compare the images with the reference images and with those obtained on recent occasions of testing. For printer display,examine the changes in tap density from section to section. For colour printer display, also examine the accompanying progression of colours. For photodisplay, examine the changes in film density.

2. Express the observed count rates as percentages of that for the 10 mm section of the wedge. Record the results on a graph showing percentage count rate against wedge thickness on linear paper (Fig. 5-2b).

3. With the aid of a transparent ruler, fit the best straight line possible to the data points.

4. Examine the graph for evidence of curvature or zero offset.

5. Analyze similarly the values of tap density and film density obtained in evaluation of the corresponding displays.

Observations

It should be appreciated that background subtraction and contrast enhancement both introduce non-linearity into the response of a rectilinear scanner. The test must, therefore, be carried out with these modalities disabled.

If a short-lived radionuclide (e.g. $^{99}Tc^{m}$ or $^{113}In^{m}$) is not available, a radionuclide of moderate half-life (e.g. ^{131}I) may be used for the test, and for tests 5.3.11 and 5.3.12 which follow, but non-radioactive sodium iodide (NaI) carrier must then be added to the solution to limit radioactive contamination of the phantom and checks for such contamination carried out before the phantom is used again.

Interpretation of results

Non-linearity of response in a rectilinear scanner is objectionable in that it restricts the quantitative interpretation of images. If the test reveals non-linearity in the tap density or film density results and also in the count-rate results, the cause should be sought in the scanner head and its associated electronics. If the count-rate results are linear but the tap density or film density measurements are not, the cause is more likely to be found in the corresponding display processor circuits or display devices.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, in general the individual data points should lie

within ± 10% of the values corresponding to the straight line fitted to them.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.11: TEST OF BACKGROUND SUBTRACTION

Purpose of test

To test the background subtraction modality of a rectilinear scanner.

Materials

Short-lived radionuclide (e.g. $^{99}Tc^{m}$ or $^{113}In^{m}$) in solution, activity concentration about 37 MBq/ml (1 mCi/ml).

Emission-type step-wedge phantom (see Fig. 5-2a)
Syringes and needles
Linear graph paper

Procedure

This test may conveniently be carried out as an adjunct to test 5.3.10: Test of System Linearity.

1. Proceed as in test 5.3.10: Test of System Linearity up to step 11. Then obtain a further image as follows (Fig. 5-3).

2. Adjust the position of the scanner head horizontally so that the focal point is in the region of the centre of the 2 mm (thinnest) section of the wedge.

3. Adjust the background subtraction control so that suppression of the display is almost, but not quite, complete.

4. Adjust the detector head scanning limits to scan just inside the border of the phantom and across the step between the 2 mm and 4 mm sections of the wedge, extending the scan about 3 cm on either side of the step. Switch on the scanner drive. Register two scan lines. Switch off the scanner drive. Record on the image, adjacent to the lines, the setting of the background subtraction control.

5. Increase the setting of the background subtraction control by a defined amount (e.g. 2.5%). Switch on the scanner drive. Again register two scan lines. Switch off the scanner drive. Record the setting of the background subtraction control.

6. Repeat step 5 until the 2 mm section of the wedge is no longer visible on the image. Note the setting of the background subtraction control at which this section is just suppressed.

7. Repeat steps 4-6 for each of the other steps of the wedge.

8. Remove the phantom. Empty, rinse with clean water and allow to dry. The latter operations may be deferred until decay of the radionuclide is nearly complete.

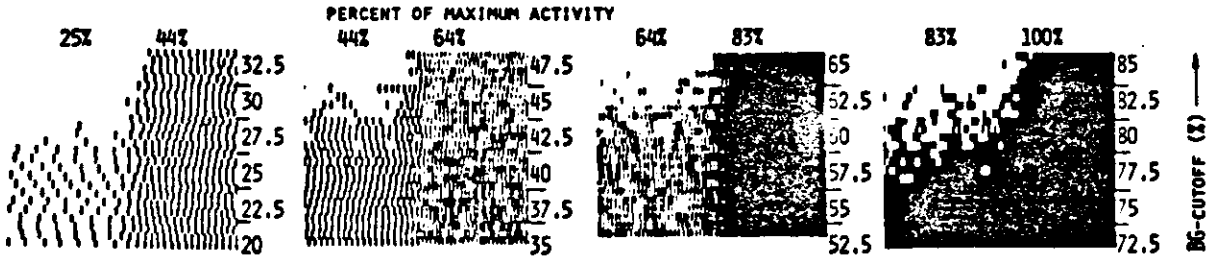


Fig. 5-3. Test 5.3.11: Test of Background Subtraction. Typical image pattern obtained with emission-type step-wedge phantom.

Data analysis

1. Compare the image with the reference image and with those obtained on recent occasions of testing.

2. Record the results on a graph showing suppression setting against percentage count rate as determined in test 5.3.10: Test of System Linearity on linear graph paper.

3. Examine the graph for systematic departure of the data points from the expected linear relationship.

Interpretation of results

Significant departure of the data points from the expected linear relationship would indicate malfunction of the background subtraction modality. Such malfunction could take the form of zero offset, non-linearity, or both. The decision whether to withdraw the instrument from operational use pending corrective action would then depend on whether the fault was confined to the background subtraction circuits in the display processor. If other tests showed this to be so, clinical imaging without background subtraction could still continue.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.12: TEST OF CONTRAST ENHANCEMENT

Purpose of test

To test the contrast enhancement modality of a rectilinear scanner.

Materials

Short-lived radionuclide (e.g. $^{99}Tc^{m}$ or $^{113}In^{m}$) in solution, activity concentration about 37 MBq/ml (1 mCi/ml).

Emission-type step-wedge phantom (see Fig. 5-2a)
Syringes and needles
Film densitometer (for quantitative photodisplay evaluation, if included)

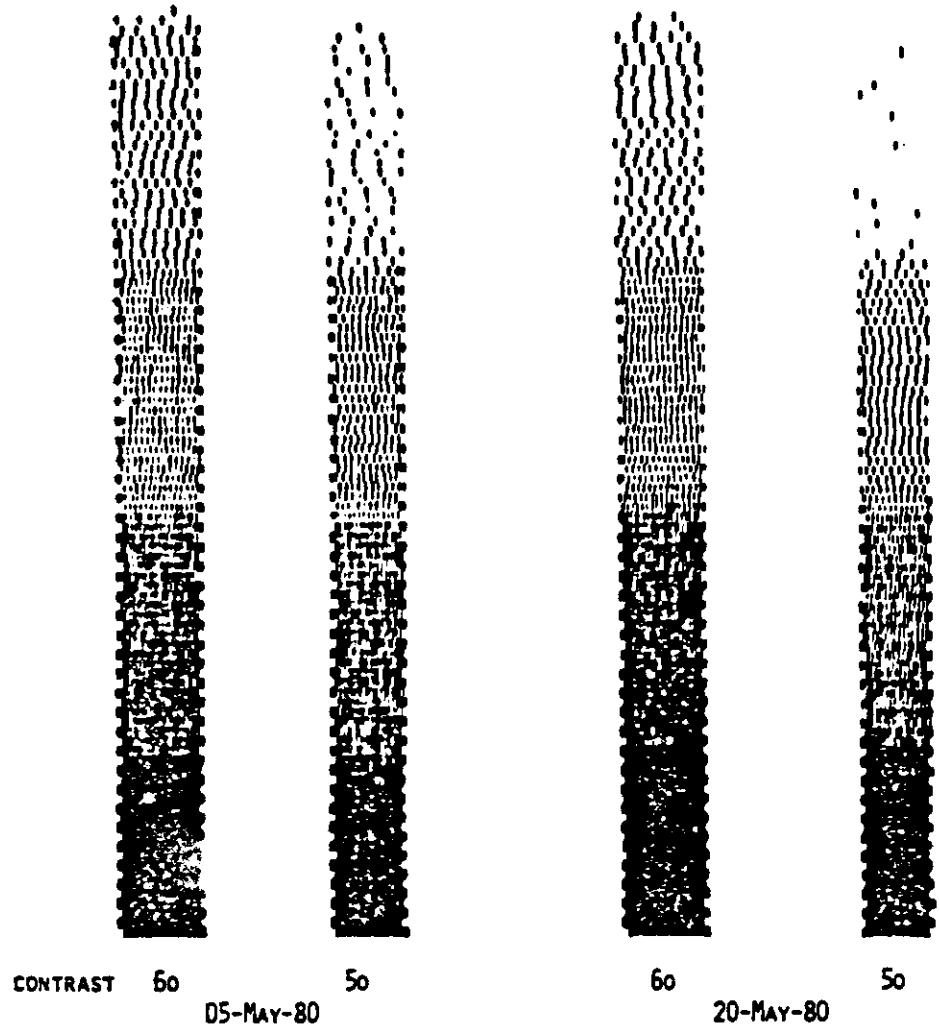


Fig. 5-4. Test 5.3.12: Test of Contrast Enhancement. Images of emission-type step-wedge phantom at various contrast enhancement settings in repeated testing.

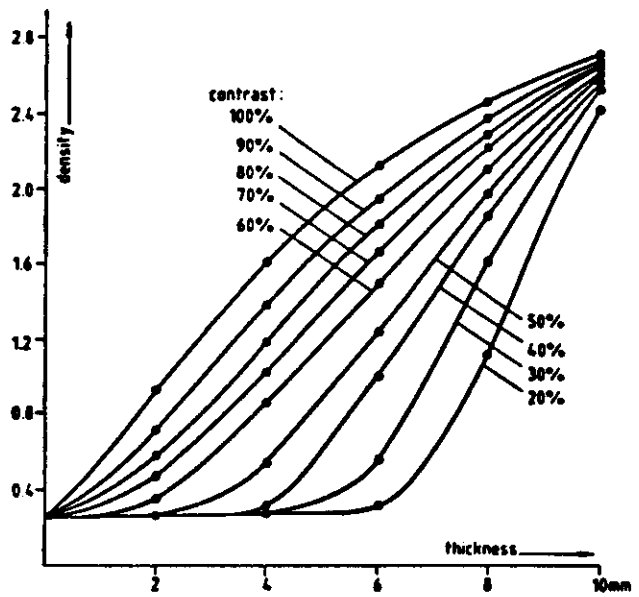


Fig. 5-5. Test 5.3.12: Test of Contrast Enhancement. Curves of film density against wedge thickness for various settings of contrast enhancement.

Procedure

This test may conveniently be carried out as an adjunct to test 5.3.10: Test of System Linearity.

1. Proceed as in test 5.3.10: Test of System Linearity up to step 11.

2. Repeat step 11 at selected settings of the contrast enhancement control. For acceptance testing, the settings selected (e.g. 80%, 60%, 40%, 20%) should cover the entire range between no enhancement (which may in fact be the 100% setting) and full enhancement. For routine testing, it is sufficient to select a single typical setting (e.g. 60%) (Fig. 5-4).

3. For quantitative photodisplay evaluation, if included, determine the film density in the region of the centre of each section of each image by means of the film densitometer. This step is optional, but if it is omitted, photodisplay evaluation is limited to the visual comparison of images.

4. Remove the phantom. Empty, rinse with clean water and allow to dry. The latter operations may be deferred until decay of the radionuclide is nearly complete.

Data analysis

1. Visually compare the images with the reference images and with those obtained on recent occasions of testing. For colour printer display examine the changes in tap density and the accompanying progression of colours from section to section. For photodisplay, examine the changes in film density.

2. Record the results of the film density measurements (if included) on a graph showing film density against wedge thickness on linear graph paper, for each of the settings of the contrast enhancement control (Fig. 5-5).

Interpretation

Significant differences between the results and those obtained in reference testing would suggest malfunction of the contrast enhancement modality. The decision whether to withdraw the instrument from operational use pending corrective action would then depend on whether the fault was confined to the contrast enhancement circuits in the display processor. If other tests showed this to be so, clinical imaging without contrast enhancement could still continue.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.13: TEST OF SCANNER DRIVE

Purpose of test

To test the drive mechanism of a rectilinear scanner with respect to exactness and uniformity of scanning speed.

Materials

Sealed ^{137}Cs gamma-radiation source, disc- or rectangular type, activity about 370 kBq (10 μCi). A certified source such as is required in test 5.3.5: Test of Sensitivity may be used, though the manner of its use does not require that its activity be accurately known.

Pointer, to be fixed to the scanner head
Adhesive tape
Stop watch
Linear graph paper

Procedure

1. Turn the scanner head to face vertically downward. Mount a collimator regularly used in clinical imaging on the head. Fix the pointer to the head.

2. Fix a sheet of linear graph paper to a horizontal support on the patient bed.

3. Adjust the position of the scanner head vertically so that the pointer just clears the paper. Align the latter with the direction of scan (Fig. 5-6).

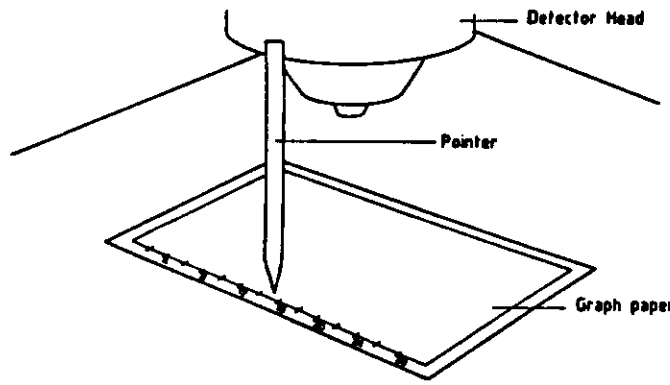


Fig. 5-6. Test 5.3.13: Test of Scanner Drive (Rollo, 1977).

4. Select the highest scanning speed available.

5. Switch on the scanner drive. Using the stop watch, measure the time for the scanner head to move a defined distance (e.g. 25 cm) over the paper.

6. Repeat step 5 with the movement in the opposite direction. Switch off the scanner drive.

7. Repeat steps 4-6 for each of the other scanning speeds available.

8. Set all controls for routine measurements on ^{137}Cs (see test 5.3.3: Test of Energy Calibration) with background subtraction and contrast enhancement disabled.

9. Tape the ^{137}Cs gamma-radiation source to the scanner head in a position giving a count rate of about 1 000 c/s and set the display processor controls as in routine clinical imaging.

10. Obtain an image of the entire scan field at a typical high scanning speed.

11. Move the ^{137}Cs gamma-radiation source to a position giving a count rate of about 200 c/s and set the display processor controls as in routine clinical imaging.

12. Obtain an image of the entire scan field at a typical low scanning speed.

13. Remove the ^{137}Cs gamma-radiation source.

Data analysis

1. Visually inspect the images for evidence of non-uniformity in scanning speed or improper line spacing.

2. For each scanning speed available, calculate the actual speed in each direction.

3. Compare the observed and expected speeds.

Interpretation of results

Exactness and uniformity of both scanning speed and line spacing are important to image quality in rectilinear scanners. Both are involved in the expression for count density, while non-uniformity of either may give rise to image artefacts. The results of the test allow both aspects to be controlled.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.3.14: TEST OF TOTAL PERFORMANCE

Purpose of test

To test all components of a rectilinear scanner under simulated clinical conditions.

Materials

Appropriate radionuclide (e.g. $^{99}Tc^{m}$ or ^{131}I for a thyroid phantom, $^{99}Tc^{m}$ or $^{113}In^{m}$ for a liver-slice phantom) in solution at suitable activity concentration.

Total performance phantom (e.g. thyroid phantom (Fig. 5-7) or liver-slice phantom(Fig. 5-8)) having simulated "cold" and/or "hot" lesions of various sizes.

Syringes and needles.

Procedure

1. Transfer an appropriate volume of the radionuclide solution to the phantom by means of a syringe, simulating clinical conditions. For a thyroid phantom about 7.4 MBq (200 μCi) $^{99}Tc^{m}$ or 370 MBq (10 μCi) of ^{131}I would be suitable and for a liver-slice phantom about 74 MBq (2.0 mCi) of $^{99}Tc^{m}$ or a similar activity of $^{113}In^{m}$. Add water nearly to fill the phantom, but leaving an air bubble at the top,

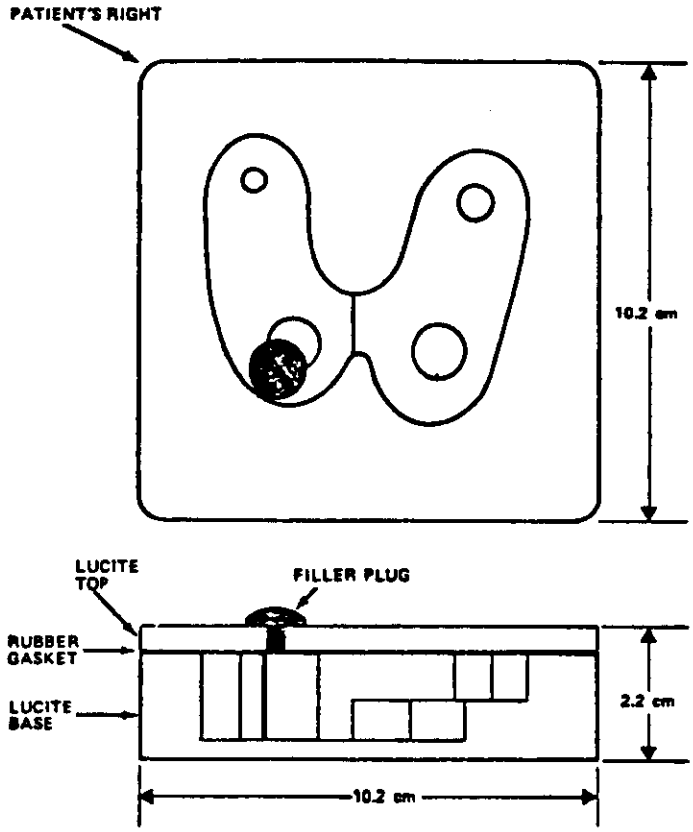


Fig. 5-7. Test 5.3.14: Total Performance Test. Thyroid phantom, fabricated in tissue-equivalent plastic (e.g. Lucite, Perspex).

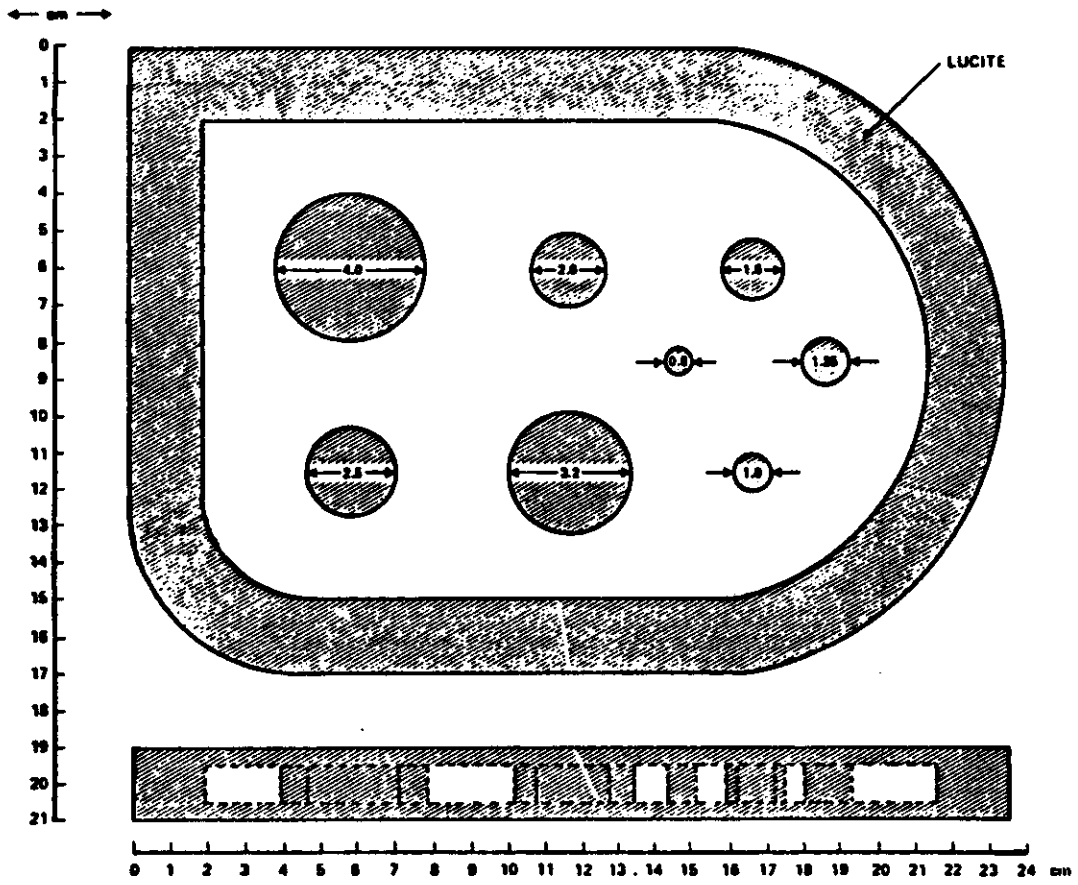


Fig. 5-8. Test 5.3.14: Total Performance Test. Liver-slice phantom, fabricated in tissue-equivalent plastic (e.g. Lucite, Perspex).

insert and tighten the sealing plug(s) and invert the phantom several times to ensure that the contents are well mixed. Remove the sealing plugs, top up completely with water, again insert and tighten the sealing plug(s) and check for freedom from leakage.

2. Mount the usual collimator for the clinical conditions simulated on the scanner head.

3. Set all controls to the routine settings for the radionuclide concerned (see test 5.3.3: Test of Energy Calibration).

4. Position the phantom according to the clinical conditions simulated, ensuring that the middle of the phantom is in the focal plane of the collimator.

5. Obtain an image by each of the display devices available, following usual clinical practice throughout.

6. Remove the phantom. Empty, rinse with clean water and allow to dry. The latter operations may be deferred until decay of the radionuclide is nearly complete.

Data analysis

Visually compare the images with the reference images and with those obtained on recent occasions of testing, with particular regard to the visibility or otherwise of the simulated lesions.

Observations

The basis of the test is the visibility or otherwise of lesions in images acquired at regular intervals under identical conditions. Any deterioration in performance is detected earlier in such a test than in clinical imaging because the constant shape of the phantom and constant position and size of the simulated lesions allow direct comparison of images. The choice of phantom and radionuclide should reflect the clinical workload.

Interpretation of results

Comparison of the images with the reference images and with those obtained on recent occasions should show no degradation in performance and should satisfy clinical requirements within the capabilities of the instrument.

Special regard should be given to the visibility of the smallest simulated lesions, since this provides the most sensitive criterion by which performance may be assessed. Should a change be evident, more specific tests should be carried out to ascertain its cause.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.4. OPERATIONAL CHECKS

5.4.1: CHECK OF COLLIMATOR AND SCANNER HEAD MOUNTINGS

Purpose of test

To check the collimator and scanner head mountings in a rectilinear scanner.

Procedure

Inspect all collimator and scanner head mountings for freedom from mechanical defects, with particular regard to the safety of patients and staff.

Interpretation of results

Any abnormal finding should dictate immediate withdrawal of the instrument from operational use pending corrective action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.4.2: CHECK OF TAPPER FUNCTION

Purpose of test

To check the function of the tapper in a rectilinear scanner.

Materials

Gamma-radiation source consisting of radionuclide in solution in sample vial or syringe, or in other suitable form.

Procedure

1. Set all controls to the settings for routine measurements on the radionuclide concerned (see test 5.3.3: Test of Energy Calibration).

2. Move the gamma-radiation source within the field of view of the collimator.

3. Check that the tapper marks correctly at high and low count rates.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.4.3: CHECK OF ANALYZER PEAK SETTING

Purpose of test

To check that the "peak" setting of the pulse-height analyzer of a rectilinear scanner is appropriate for clinical imaging with a particular radionuclide.

Materials

Radiation source consisting of radionuclide concerned, in solution in sample vial or syringe, or in other form suitable for measurement, activity about 370 kBq (10 μCi).

Source mounting

Procedure

1. Turn the scanner head to face vertically downward.

2. Set all controls to the routine settings for the radionuclide concerned (see test 5.3.3: Test of Energy Calibration).

3. Place the radiation source on a horizontal support on the patient bed.

4. Adjust the position of the scanner head so that the radiation source is within the field of view of the collimator.

5. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

6. (a) Perform a count and note the count rate. To keep statistical variations within acceptable limits, the counting time should be such that the count is at least 10 000

or

(b) Note the count rate. To keep statistical variations within acceptable limits, a long time constant should be selected and a time at least four times the time constant allowed for the reading to stabilize.

7. (a) Perform further counts with the pulse-height analyzer base (threshold) control set respectively higher (e.g. by 10%) and lower (e.g. by 10%) than its peak setting and note the count rates. Check that these both fall below the value noted in step 6

or

(b) Note the count rates with the pulse-height analyzer base (threshold) control set respectively 50 units above and 50 units below its peak setting. Check that these both fall below the value noted in step 6.

8. Remove the radiation source.

Observations

If a preset analyzer facility is used, step 7 of the procedure may be modified by adjusting a photomultiplier voltage or an amplifier gain control instead of the pulse-height analyzer base (threshold) control.

Background corrections should be unnecessary under the conditions of the test.

For double-headed scanners, the procedure should be carried out on each individual detector system.

Interpretations of results

Discrepant results would suggest incorrect energy calibration of the system or, possibly, non-linearity of its energy response. Test 5.3.3: Test of Energy Calibration and test 5.3.7: Test of Linearity of Energy Response should then be carried out as appropriate.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

5.4.4: CHECK OF BACKGROUND COUNT RATE

Purpose of test

To check the background count rate of a rectilinear scanner under the conditions for routine clinical imaging with a particular radionuclide.

Procedure

1. Turn the scanner head to face vertically downward.

2. Adjust the position of the scanner head so that it is over the centre of the patient bed.

3. Set all controls to the routine settings for the radionuclide concerned (see test 5.3.3: Test of Energy Calibration).

4. (a) Preset a suitable counting time

or

(b) Select a suitable count-rate range.

3. (a) Perform a count and record the count rate

or

(b) Record the count rate.

Observations

For double-headed scanners the procedure should be carried out on each individual detector system.

Interpretation of results

A significant increase in count rate may indicate radioactive contamination of the instrument or its surroundings, or increased environmental radiation from local sources. Alternatively, it may indicate electrical "noise". These possibilities should then be explored. Radioactive contamination could be on the instrument itself, particularly on the scanner head, on the patient bed, on the floor or in the waste bin. Local radiation sources may include patients to whom radioactive materials have been admininistered. If such contamination is

suspected, the test should be repeated with the bed removed, and with the scanner head in different positions to identify the locations involved. If contamination is confirmed, clinical imaging should be deferred until decontamination procedures have reduced the count rate again to an acceptable value.

Limits of acceptability

While specific limits of acceptability cannot be laid down for the results of the test, an increase in background count rate of 20% or greater would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6. SCINTILLATION CAMERAS

6.1. INTRODUCTION

6.1.1. Basic Principles

The scintillation camera is an imaging device utilizing a thin but large-diameter thallium-activated sodium iodide (NaI(Tl)) crystal viewed by an array of photomultipliers as the radiation detector. The design of scintillation cameras varies considerably, but to illustrate the basic principles, the most common type will be described. Fig. 6-1 depicts a section through the detector head of a typical Anger-type scintillation camera, together with the key electronic units. Photons emitted by radionuclides in the patient or test source reach the crystal after passing through a lead collimator, which defines the directions of acceptance. Most collimators are of the parallel-hole (Fig. 6-1), diverging, converging, slant-hole or pin-hole type.

The crystal is viewed from its back surface, either directly or through a light guide, by the photomultipliers, which are all fed from a common high voltage supply, the voltage or gain being slightly adjustable at each tube. A photon interaction in the crystal at a given spatial location defined in an X-Y co-ordinate system (Fig. 6-2) produces at the point of interaction, a light scintillation which spreads through the crystal. The fraction of this light which strikes the photocathode of each photomultiplier varies inversely with the distance of the photomultiplier from the point of interaction. The amplitude distribution of the pulses from all the photomultipliers in the array due to a single photon interaction contains positional information. The pulses are processed by the scintillation camera to give a flash of light on the face of a cathode-ray tube at the same position on a similar X,Y co-ordinate system as the site of the original interaction. The cathode-ray tube registers the flash only if the energy of the original photon interaction is within a preset range, which may be selected to correspond to the energy of the photons emitted by the radionuclide in use. The energy of the interaction is defined by the amplitude of a Z pulse obtained by summing the outputs of all the photomultipliers.

To achieve these processes electronically, the pulses from all photomultipliers, after a pre-amplification stage, are sent simultaneously to X, Y and Z pulse-arithmetic circuits. The X and Y circuits are networks which scale the pulse amplitudes in proportion to the X or Y position of the originating photomultiplier in the co-ordinate system. Two analogue signals result, the X and Y, with amplitudes proportional to the spatial co-ordinates of the original scintillation. In the Z circuit, the pulses are summed to provide a Z signal proportional to the total energy deposited in the crystal by the photon interaction. Since the intensity of the scintillations and hence the photomultiplier output increases with photon energy, the X and Y signals must be normalized so that the positional information is not dependent upon the photon energy. This is done in the energy correction circuit by dividing the X and Y signals by the Z signal. The Z signal is also sent to the pulse-height analyzer (PHA). If the Z signal falls within the PHA window set for the radionuclide in use, the PHA enables the X/Z and Y/Z signals to record the event. This is usually achieved in a cathode-ray oscilloscope in which the electron beam is normally blocked from the oscilloscope face by a negatively biased grid. When the amplitude of the Z signal falls within the preset PHA window, an unblanking signal is generated which causes the grid to go positive and allows the beam to pass. At the same time the X/Z and Y/Z signals are

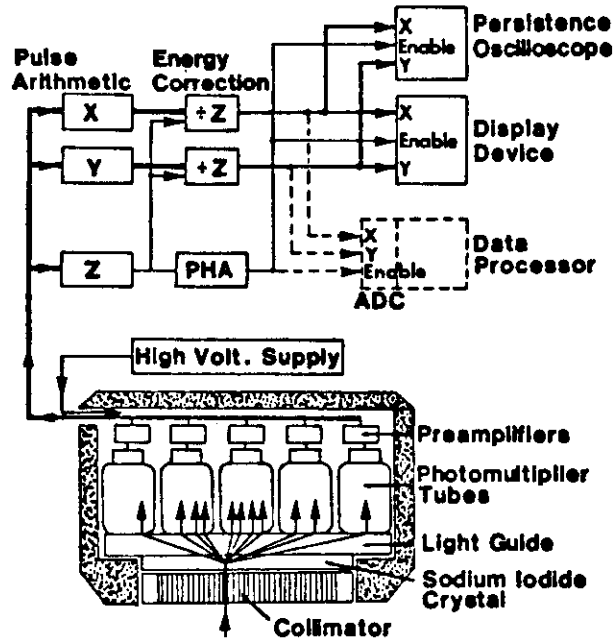


Fig. 6-1. Cut-away diagram of the detector head of an Anger-type scintillation camera, with key electronic units.

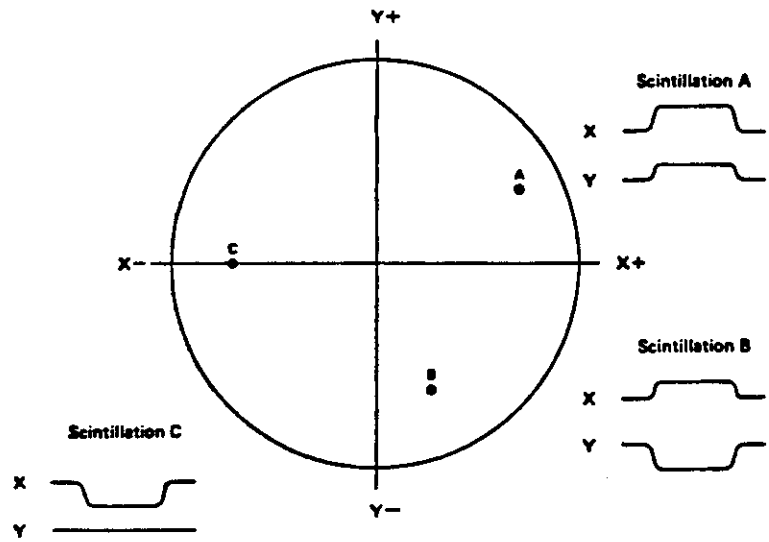


Fig. 6-2. The X-Y co-ordinate system of a scintillation camera shown superimposed on the crystal face. Outside the co-ordinate system are shown examples of the X and Y signals (short-duration voltage pulses) resulting from scintillation events occuring in different parts of the crystal.

used to deflect the beam so that a brief flash appears on the oscilloscope face at a position corresponding to that of the original scintillation. If a persistence oscilloscope is used, the flashes remain visible sufficiently long to form an image on the persistent phosphor screen. If a conventional oscilloscope or an image formatting device incorporating such an oscilloscope is used, a permanent record of the image is obtained by recording the flashes on film for a preset count or a preset time. The X/Z and Y/Z signals may also be digitized by analogue-to-digital converters (ADC's) for storage and later processing on a computer directly interfaced to one or more scintillation cameras, the Z pulse being used to start the digitization of the position pulses.

6.1.2. Components of a Scintillation Camera

6.1.2.1. NaI(Tl) scintillation crystal

NaI(Tl) crystals are generally available in two diameters, corresponding to a small field-of-view (300 mm) and a large field-of-view (400 mm), as well as in several thicknesses ranging from 3.2 to 12.7 mm. The crystal diameter determines, in part, the area of the patient viewed in a single image. The crystal thickness influences several performance parameters, in particular spatial resolution and sensitivity. Thin crystals yield better spatial resolution; however, their sensitivity is significantly reduced for photon energies over 140 keV. For general use, a thickness of 9.5 mm is often selected.

Any damage to the crystal results in an inoperable scintillation camera and requires costly replacement of the crystal. The large surface area, as well as the hygroscopic and brittle nature of the crystal, call for constant care to avoid puncturing the housing or otherwise damaging the crystal, especially in the process of changing collimators. Leaving a collimator on the instrument when it is not in use protects the crystal from mechanical shock and rapid fluctuation of room temperature. Nevertheless, sudden or gradual damage may occur unwittingly. For this reason, monitoring of the crystal is an important feature of quality control.

6.1.2.2. Photomultiplier array

All photomultipliers in the array, which may contain 37, 61 or even more tubes, must have matched amplification (gain) characteristics in order to provide a uniform count density (flood-field uniformity) when the crystal is "flooded" with a spatially uniform flux of gamma radiation. If one photomultiplier has a markedly lower gain than those surrounding it, the area of the image corresponding to the location of that tube will appear as one of lower sensitivity and if the tube fails, zero sensitivity. Such conditions are unacceptable in diagnostic imaging. Prior to installation of tubes in a new instrument, the gains are carefully matched. However, each tube ages at its own rate, so periodically the gains must be re-matched by slight adjustment of the high voltage to each tube. This, usually performed by a service representative of the manufacturer, is called tuning the head. The more photomultipliers, the more difficult the task. Daily quality control is necessary to alert the user to the need for this maintenance service.

The full width at half-maximum (FWHM) of the Z-signal photopeak of a scintillation camera is wider than that of a single-photomultiplier detector. In addition, the width of the photopeak is highly dependent upon the precise adjustment of the gains of the photomultipliers. Each photomultiplier produces a unique photopeak, and when these are summed to form the Z signal, all photopeaks should coincide. However, because of small gain differences between individual photomultipliers, this is rarely the case; photomultipliers with gains lower than the average contribute information to the low side of the composite photopeak and those with gains higher than the average contribute to the high side. (Fig. 6-3). In order to achieve a uniform flood-field image, the window width of the PHA must encompass the contributions of all photomultipliers. For this reason, typically a 20% window is used. This, centred on the 140 keV photopeak of $^{99}Tc^{m}$, would have a width of approximately 30 keV, ranging from 125 to 155 keV. Such a window includes a significant amount of scattered radiation originating from photon interactions within the patient and leads to loss of image

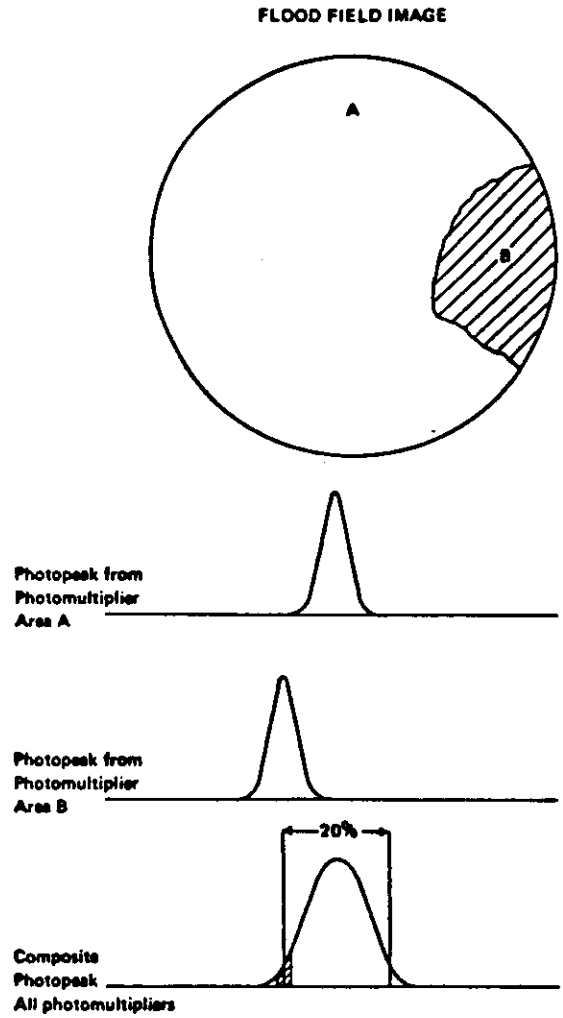


Fig. 6-3. Relationship of photomultiplier gain to flood-field uniformity. In the flood-field image, area A appears as one of uniform count density. Area B has perceptibly lower count density. The upper pulse-height spectrum shows the photopeak from a photomultiplier within area A. The middle pulse-height spectrum shows the photopeak from a photomultiplier at the centre of area B. The lower pulse-height spectrum shows the photopeak of the Z signal, which is the composite of those from all the photomultipliers in the detector head, with the corresponding 20% PHA window and (cross-hatched) the position of the contributions from the photomultiplier at the centre of area B. A significant proportion of the pulses from the latter fall below the window and, hence, are rejected. This is the reason for the lower count density in the area in question.

resolution and contrast. Newer cameras allow the use of a narrower window by employing uniformity correction circuits which will be discussed in section 6.1.2.5. If the window is offset to the high side of the photopeak, the information contributed by the lower-gain photomultipliers will be progressively eliminated and the image areas corresponding to these tubes will have a lower count density. Correspondingly, if the window is offset to the low side of the peak, the information contributed by the higher-gain photomultipliers will be progressively eliminated and the areas corresponding to these tubes will have a lower count density. If the window width is narrowed but remains centred on the photopeak, areas corresponding to photomultipliers both of lower gain and of higher gain will be progressively eliminated. Thus, uniformity across the field of view is a function of proper placement of

the PHA window, which can only be achieved by daily calibration. Uniformity is also a function of the window width and the proper tuning of all photomultipliers (Fig. 6-3).

6.1.2.3. Pulse arithmetic circuits

The X and Y position circuits, separate but identical, contain amplifiers that, if properly adjusted, assure equal amplification in both X and Y directions, i.e. a round object will give a round image. A drift of one amplifier will cause a round object to give an oval image. For this reason, the measurement of any object-to-image parameter should be performed in both X and Y directions. Object-to-image relationships may also be affected by non-linearities in the Z signal. This is of consequence only if the outputs of more than one PHA are used simultaneously to produce a composite image, for example, in ^{67}Ga imaging in which photons of two or three energies may be summed, or to produce a corrected image in which photons of one energy are subtracted from those of another. If non-linearities exist in the Z signal, when the X and Y signals are divided by the Z signal (see 6.1.1) the spatial amplifications for different Z signals will differ. The superposition of several images will then result in a loss of resolution.

6.1.2.4. Pulse timing circuits

The X, Y and unblanking signals must arrive at the oscilloscope in exactly the right sequence. The X and Y signals, stretched in time to correctly display the light flash, must be perfectly flat during the unblanking pulse which allows the flash to occur. X and Y signals that arrive early or late with respect to the unblanking pulse, or signals that slope, will cause the flashes to appear as lines, even with properly adjusted display controls. Careful observance of clinical and quality control images will alert the user to this problem.

The duration of the pulses has a significant effect upon the count-rate capabilities of the scintillation camera. The pulses resulting from every scintillation must be processed through the camera electronics, whether or not the event is finally selected for display as a consequence of the acceptance of its Z signal by the PHA. Within this processing period, there is a time, the pulse-pair resolving time, τ , largely determined by the duration of the pulses, during which the camera electronics are not capable of responding to further scintillations. At high count rates, the camera behaves largely as a "paralyzable" system; that is, every further scintillation that occurs during this dead time extends it. Thus, if the intensity of incident gamma radiation and the input count rate (the count rate that would be observed if there were no count loss) increase, the observed count rate increases to a maximum and then decreases as a larger and larger proportion of the scintillations occur during the extended dead time.

The measurement of should correctly be made under conditions of only moderate count loss and with no radiation scatter. From its value under these conditions, it is possible to deduce the relationship between input and observed count rates and to calculate, for example, the input count rate, $R_{-20\%}$, for a 20% count loss and the corresponding observed count rate, $C_{-20\%}$. This constitutes a useful acceptance test, since $R_{-20\%}$ measured with no radiation scatter is a performance index specified by many camera manufacturers.

$R_{-20\%}$ measured with no radiation scatter is not, however, relevant to clinical situations. In clinical imaging, scintillations due

to lower-energy scattered radiation arising from the patient, while not themselves displayed, may significantly increase the effective value of τ . $R_{-20\%}$ and $C_{-20\%}$ measured with radiation scatter are lower than those measured without scatter. $C_{-20\%}$ measured with scatter should not be exceeded in any clinical study. Operating the camera at higher observed count rates may compromise its spatial resolution and will give only a small increase in observed count rate for a large increase in administered radioactivity and, hence, radiation dose to the patient.

6.1.2.5. Uniformity correction circuits

Several schemes have been introduced to improve the uniformity across the field-of-view by microprocessor techniques. The first were based upon either adding or subtracting counts to each of the approximately 4 000 elements (pixels) of a 64x64 matrix. The number added or subtracted is derived from the sensitivity of that pixel relative to the mean of all pixels in a previously stored flood-field image. These methods introduce errors into the quantitation of regions-of-interest in the image and are limited by the statistical uncertainties inherent in the count data.

Scintillation cameras of newer design use a multi-stage process. First, to take account of photomultiplier gain variations, a small correction is applied to each Z signal, dependent upon its specific X,Y location, so that the photopeaks for all locations exactly coincide. This results in a narrower composite photopeak and allows the use of a narrower PHA window. The second stage is the application of a small correction to each X and Y pulse, dependent upon its specific location, to eliminate spatial non-linearities. The correction is often derived by using an image of a series of line sources, in both X and Y directions, and computing the deviation of the image from the actual lines over the face of the crystal. A third stage may utilize a count addition or subtraction process as described above. The final image is uniform to 5% or 6% and is essentially free of spatial non-linearities.

Some cameras contain a pulsed light source fibre-optically fed to each photomultiplier so that the individual gains can be adjusted every few milliseconds. This technique was developed for tomographic rotational cameras to allow for changes in photomultiplier gain with the orientation of the camera relative to the earth's magnetic field.

6.1.2.6. Display devices

A scintillation camera may be equipped with several types of display devices for the purpose of visualizing the radioactive concentrations as detected by the camera and recording it on film. Both processes require an oscilloscope which produces a flash of light on the face of a cathode-ray tube (CRT) at the same position on a similar X-Y co-ordinate system as the site of the original interaction in the crystal.

Immediate visualization of the image is possible using a persistence oscilloscope in which the flashes remain visible so as to form an image on the persistent phosphor screen. The length of the time the flashes remain visible is variable by a "duration" control and their brightness by an "intensity" control. This device is helpful in positioning the patient so that the area of interest is properly centred in the recorded image. The poor quality of the image on the persistence oscilloscope, however, prevents its further use.

The image is recorded from a non-persistence oscilloscope producing very brief flashes of light. A photographic camera is mounted so that the CRT face is in view and in focus. The "hard copy" image is obtained on film by opening the camera shutter for either a preset number of flashes (preset count) or a preset duration (preset time). Adjustment of "focus" and "astigmatism" controls allows sharpening of the flashes and adjustment of an "intensity" control allows proper film exposure for each clinical procedure performed. The proper setting of the intensity control is initially determined by trial and error. This setting should then be recorded for future reference.

Photographic cameras using either Polaroid or transparency roll-film (35 or 70 mm) may be used. Polaroid film has the advantage of requiring no facilities for development and allows immediate viewing of the image. However, it is expensive and it has a very limited density range and poor contrast. Roll-film has a wider density range and, as an additional advantage, can be rapidly advanced manually or by a motor-driven mechanism. The user of roll film should be cautioned to record carefully the identity of each image at the time of acquisition to prevent later confusion.

Multi-format imaging devices may be connected directly to the output of the scintillation camera or to the output of an image processor. These devices use X-ray type film, (typically 20x25 cm) in cassettes. They can be programmed to allow the operator to acquire different numbers of images, e.g. 1, 2, 4, 9, on the same sheet of film, thus offsetting the higher film cost. The images are electronically advanced and therefore the device is compatible with rapid sequence studies.

6.1.3. Basis of Schemes for Testing Scintillation Camera Performance

Various levels of performance testing are required in the life of any scintillation camera. Initially, manufacturers perform a set of tests on each camera in the factory to determine if published specifications are met. In the United States of America, factory testing is done according to protocols developed by the National Electrical Manufacturers' Association (NEMA) and the results for each camera are compared with the published specifications before shipment is authorized. The NEMA performance standards are becoming recognized throughout the world; hence for new cameras one manufacturer's specification are directly comparable to another's. The tests involved are for the most part intrinsic, that is, they are tests on the camera without collimator or other accessories, so that they reflect the camera's characteristics only, not necessarily its operating performance under clinical conditions.

The next level of testing involves the acceptance testing of the camera by the user after installation to determine if, once installed, it performs according to the specifications of the manufacturer. This testing must be rigorous and be similar enough to the NEMA protocols that comparable results are obtained. The American Association of Physicists in Medicine (AAPM) has prepared two publications detailing acceptance-test protocols. The first describes methods which can be used for a scintillation camera with analogue imaging, the second for a scintillation camera interfaced to a digital image processor. In both cases the tests are designed to yield results which are equivalent to the NEMA performance standards. At the same time as the acceptance tests are performed, reference tests which reflect operating performance under

clinical conditions and can be repeated in routine testing should be initiated. These tests are often system tests performed with collimator mounted and added accessories, and are more suitable to be carried out by the user. A number of organizations have developed test protocols for reference tests, among them the AAPM, the United Kingdom Hospital Physicists' Association (HPA) and the International Electrotechnical Commission (IEC). These tests, along with some acceptance tests, provide the basis of routine testing. Lastly, but most importantly, operational checks to be performed each day the instrument is used must be initiated.

6.1.4. Performance Characteristics

Only by proper testing can it be determined that a scintillation camera is operating as it should. The instrument is more complex than any yet described in this document, as are the concepts used to describe its performance. Those of concern in acceptance and routine testing will now be identified, along with the major design and operational factors that influence them.

6.1.4.1. Spatial resolution

Spatial resolution is a performance characteristic of a scintillation camera that describes its ability to resolve two separate point or line sources of radiation as separate entities.

Spatial resolution is conventionally quantified either as the full width at half-maximum (FWHM) of the response to a thin line source perpendicular to the long axis of the source, or as the minimum separation of two sources that can just be distinguished from each other. (Thus a small width or separation corresponds to good or "high" spatial resolution.) The spatial resolution, R_i, exhibited by the detector alone is called the intrinsic resolution. The collimator alone exhibits a spatial resolution, R_c, which is best when the source is located at the surface of the collimator and deteriorates as its distance from the collimator increases. The system resolution, R_s, of the detector with collimator mounted can be estimated for a source positioned at any stated distance from the collimator by

$$R_s = \sqrt{R_i^2 + R_c^2}$$

In general, intrinsic spatial resolution improves with increase in number of photomultipliers for the same crystal diameter (implying a decrease in the diameter of each tube) or energy of incoming photons, and with decrease in thickness of crystal or light guide, width of PHA window, proportion of scattered photons, and count rate. Collimator resolution improves with increase in the number or length of holes and decrease in the diameter of holes or thickness of septa.

The major factors that degrade intrinsic spatial resolution are electronic component failures, poor alignment of the gains of the photomultipliers, defects in or deterioration of the crystal, and high count rate. In some cameras, switching to the high count-rate mode decreases spatial resolution. System resolution is affected by the choice of the collimator and degrades as the distance from the radiation source to the collimator surface increases.

6.1.4.2. Energy resolution

Energy resolution is a performance characteristic of a scintillation camera that describes its ability to distinguish between

photons of different energies, in particular between primary and scattered radiation. It is conventionally quantified as % FWHM, the full width at half-maximum of the photopeak measured in energy units and expressed as a percentage of the gamma-radiation energy. (Thus a small % FWHM corresponds to good or "high" energy resolution.)

The major factors that degrade energy resolution are poor alignment of the gains of the photomultipliers, failure of one or more photomultipliers, defects in or deterioration of the crystal, physical separation of the photomultiplier-light guide assembly from the crystal, and high count rate.

6.1.4.3. Response to uniform irradiation (flood-field uniformity)

The response to uniform irradiation (flood-field uniformity) is a performance characteristic of a scintillation camera that describes the degree of uniformity of count density in the image when the detector is "flooded" with a spatially uniform flux of incident gamma radiation, or alternatively, the degree of constancy of count rate from a collimated point source when the source is moved over the field-of-view.

Flood-field uniformity may be quantified as the degree of uniformity exhibited by the detector itself (intrinsic uniformity) or by the detector with collimator mounted (system uniformity). It may also be quantified in terms of the maximum variation in count density over the entire field-of-view (integral uniformity) or in terms of the maximum rate of change of count density over a specified distance (differential uniformity). (Thus a small variation or rate of change corresponds to good or "high" uniformity.)

The major factors that degrade intrinsic uniformity are poor alignment of the gains of the photomultipliers, failure of one or more photomultipliers, spatial non-linearities, defects in or deterioration of the crystal, physical separation of the photomultiplier-light guide assembly from the crystal, incorrect setting of the position or width of the PHA window, and high count rate. Additional factors that degrade system uniformity are defects in or damage to the collimator.

6.1.4.4. Spatial distortion (spatial linearity)

Spatial distortion is a performance characteristic of a scintillation camera that describes the amount of spatial distortion of the image with respect to the object. Spatial linearity describes the degree of linearity in the image of a linear object.

Spatial linearity may be quantified as the maximum spatial displacement over the field-of-view, and can be estimated by inspecting the image of a linear object. (Thus a small displacement corresponds to good or "high" linearity.)

Spatial distortion and flood-field uniformity are closely related. If severe spatial displacements occur, the uniformity will be poor in the same area. The major factors that degrade spatial distortion are those listed for flood-field uniformity.

6.1.4.5. Count-rate performance

The count-rate performance of a scintillation camera describes the non-linearity in the relationship between the count rate and the

intensity of incident gamma radiation, and also the spatial displacements in the image that occur as a result of high count rates.

Several measurements are required to characterize the count-rate performance. The intrinsic count-rate performance with an increasing flux of incident gamma radiation is first measured with the source positioned so that no scattered radiation reaches the camera. This may be achieved by suspending the radiation source in air, away from material objects (Fig. 6-4) or by using copper absorbers to filter out the scatter component (Fig. 6-5).

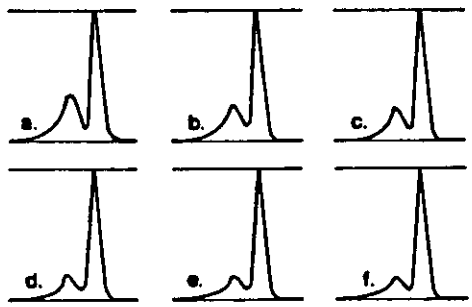


Fig. 6-4. $^{99}Tc^{m}$ spectra observed with the multi-channel analyzer of an Ohio-Nuclear scintillation camera. (a) Open source on floor. (b) Open source on plaster wall. (c) Open source 10 cm from plaster wall. (d) Source on light foam pad 22 cm above floor and 36 cm from plaster wall. (e) Source on light foam pad 22 cm above wood tray table in open doorway. (f) Source suspended on tape in open doorway. Significant scatter is evident at all positions. (After Adams.)

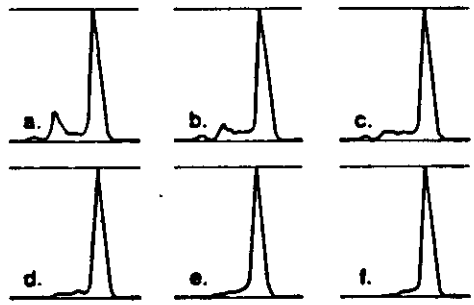


Fig. 6-5. $^{99}Tc^{m}$ spectra observed with the multi-channel analyzer of an Ohio-Nuclear scintillation camera with copper absorbers covering source. (a) No absorber. (b) 1 absorber. (c) 2 absorbers. (d) 3 absorbers. (e) 4 absorbers. (f) 5 absorbers. Each copper absorber has a thickness of 1.28 mm. Six mm or more of filtration by copper produces a clean scatter-free spectrum, which is not altered by additional thicknesses of copper. (After Adams.)

The same is then done with the source in a carefully controlled scattering medium. These measurements are then repeated as system measurements with a collimator mounted and all peripherals enabled. From the resulting graphs, the count rate for a 20% count loss and the maximum count rate under the respective measurement conditions may be determined. Alternatively, the count-rate performance may be characterized by determining the pulse-pair resolving time at a specified count rate. Finally, the spatial resolution and flood-field uniformity should be measured at some specified high count rate.

The major factor that degrades count-rate performance is a decrease in the ratio of observed to detected events. This may be caused by a narrowed PHA window or by an increase in the scattered photon component. In some cases, the addition of digital computers may affect the count-rate performance especially if they are used in a "zoom" mode which magnifies the image in a region-of-interest.

6.1.4.6. Plane sensitivity

Plane sensitivity is a performance characteristic of a scintillation camera that describes the probability of observing gamma radiation incident on the detector.

Plane sensitivity is conventionally quantified as the count rate per unit of activity for a flat source of defined diameter at a defined distance from the exposed face of the crystal housing of the uncollimated camera (intrinsic sensitivity) or from the exposed face of the collimator (system sensitivity).

In general, intrinsic sensitivity is directly related to the thickness of the crystal and width of the PHA window, and inversely related to the photon energy. System sensitivity is, in addition, directly related to the ratio of the crystal area not covered by the collimator septa to the total area, and inversely related to the collimator thickness.

The major factors that degrade intrinsic plane sensitivity are count loss due to high count rate, poor alignment of the gains of the photomultipliers , failure of one or more photomultipliers, spatial non-linearities, defects in the or deterioration of the crystal, physical separation of the photomultiplier-light guide assembly from the crystal, and incorrect setting of the position or width of the PHA window. Additional factors that degrade system sensitivity are defects in or damage to the collimator.

6.1.4.7. Detector-head shielding leakage

Detector-head shielding leakage is a measure of the adequacy of the lead shielding incorporated in the detector head to eliminate background radiation.

Detector-head shielding leakage is evaluated by measuring the count rates from radiation sources emitting gamma radiation of various energies positioned at different sites around the detector head.

6.1.5. Operational Considerations

6.1.5.1 General operating conditions

In view of the complexity of scintillation cameras, special care and attention must be paid to their operation. Adoption of the following practices will help to maintain stable operating conditions.

1. The high-voltage supply to the photomultipliers should be interrupted as little as possible. A drop-out relay should be fitted in the electrical supply so that the full operating voltage is not re-applied immediately after interruption of the supply. Automatic changeover to a battery source to maintain the high voltage and to retain a

uniformity correction matrix (if correction circuitry is fitted) is desirable.

2. Oscilloscopes and display devices should be switched off overnight and for longer periods of disuse. The brilliance of oscilloscopes should be reduced between studies. This avoids deterioration of the phosphors which may result in image artefacts.

3. When left for long periods, the camera should always be positioned with the crystal face horizontal and directed downward. This helps to prevent separation of the photomultiplier-light guide assembly from the crystal.

4. A collimator should be attached to the detector head at all times to provide mechanical and thermal protection for the crystal.

5. The detector head, collimators and collimator mountings should be checked for damage whenever collimators are changed.

6. Photographic cameras should always be securely fastened to their mountings and in the correct focal positions.

7. The film rollers of Polaroid cameras should be cleaned to remove residues before the insertion of each new film pack.

8. To avoid crystal fracture, the room temperature should not be allowed to change rapidly.

9. Radioactive contamination of the collimators and the detector head should be avoided. It is good practice when placing radioactive materials on the face of the crystal housing or collimator to first cover the face with plastic sheeting.

10. Film-processing devices should be kept in good working order.

11. Strict adherence to radiation safety practices should be maintained.

6.1.5.2. Test conditions

Specific test conditions applicable to acceptance, reference and routine testing of a scintillation camera are now described and should be followed during all testing procedures.

1. No electrical or mechanical modifications to the instrument should be made prior to testing.

2. The PHA should be adjusted before any tests are carried out, so that the specified window is used and centred on the appropriate photopeak.

3. Background radiation levels should be reduced to a minimum by removing extraneous radiation sources, including patients to whom radiopharmaceuticals have been administered.

4. The count rate in any test, unless otherwise specified, should not exceed 10 000 c/s in cameras manufactured before 1978 and 20 000 c/s in newer cameras.

5. The radionuclide, source configuration, collimator, instrument settings, imaging parameters and test results should be recorded in the instrument log book, accompanied by the images whenever possible.

6. At acceptance testing, a representative of the manufacturer should be present.

6.1.5.3. Tests to be carried out

Simple operational checks of collimator and detector head mountings, energy calibration of the PHA, flood-field uniformity, sensitivity and background count rate are needed whenever a scintillation camera is used, as are checks that the oscilloscope and film handling and processing devices are in good working order. In addition, regular quality control of its spatial resolution and spatial linearity should be carried out on a weekly basis, together with a test of total performance of the instrument under conditions simulating clinical imaging. Further tests of preset and manual PHA window settings, intrinsic and system flood-field uniformity, spatial resolution and count-rate performance and maximum count rate are needed quarterly or half-yearly. If the outputs of more than one PHA are used simultaneously to produce a composite image, as in ^{67}Ga imaging, a test of multiple-window spatial resolution should be carried out half-yearly. Acceptance testing should also include tests of system plane sensitivity and detector head shielding leakage.

An example of a form on which to record the results of the operational checks and weekly routine tests in a log-book is presented in Annex II.

Tests on double-headed scintillation cameras should be carried out on each individual detector head and its associated electronics as appropriate.

6.1.5.4 Radiation sources and other items required

A number of items are required for more than one testing procedure, and are now described to avoid repetition.

1. Unsealed radionuclides in solution, e.g. $^{99}Tc^{m}$, $^{113}In^{m}$, in solution, for point, flood and line sources.

2. Long-lived radionuclide flood source, in the form of an extended sheet of rigid plastic, with gamma-radiation energy similar to that of the radionuclide in clinical use e.g., ^{57}Co flood source (122 keV) for $^{99}Tc^{m}$ (140 keV).

3. Point-source containers. Small, e.g. 1 ml, disposable plastic syringes into which radionuclide solution can be drawn are suitable.

4. Source mounting for a point source in its container, on the central axis of the detector at a distance from its face equal to five times the diameter of the useful field-of-

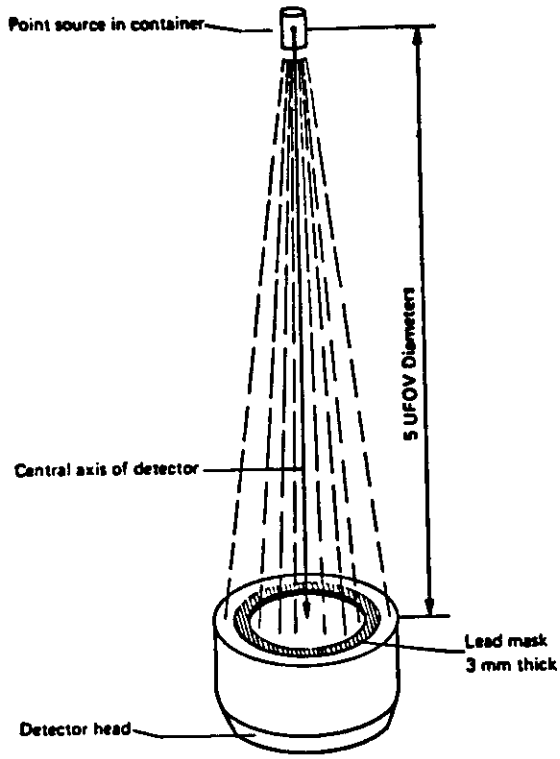


Fig. 6-6. Mounting of point source in its container on the central axis of the detector at a distance from its face equal to five times the diameter of the useful field-of-view as defined by the lead mask.

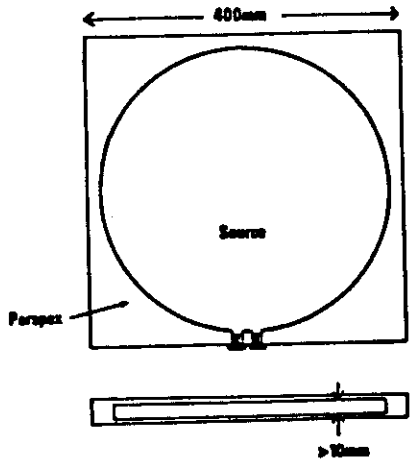


Fig. 6-7. Flood phantom, fabricated in plastic (e.g. Lucite, Perspex) and giving flood source when filled with $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution.

The diameter of the liquid-filled area should be 5 cm greater than the useful field-of-view.

view (here defined by the largest circle that could be inscribed within the area of the crystal face seen through the collimators, the crystal being assumed circular) (Fig. 6-6).

5. Lead mask, annular, at least 3 mm thick, masking the crystal beyond the useful field-of-view (as so defined). (Fig. 6-6).

6. Flood-field uniformity phantom ("flood phantom") (Fig. 6-7). To fill, an appropriate volume of radionuclide solution at a given activity concentration is introduced

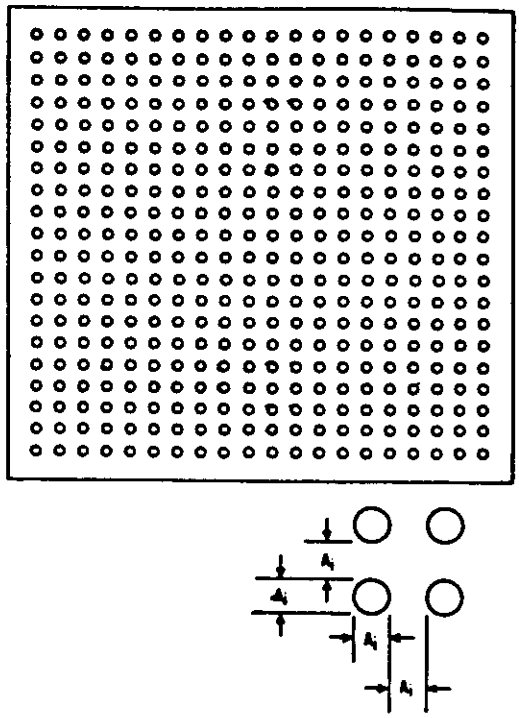


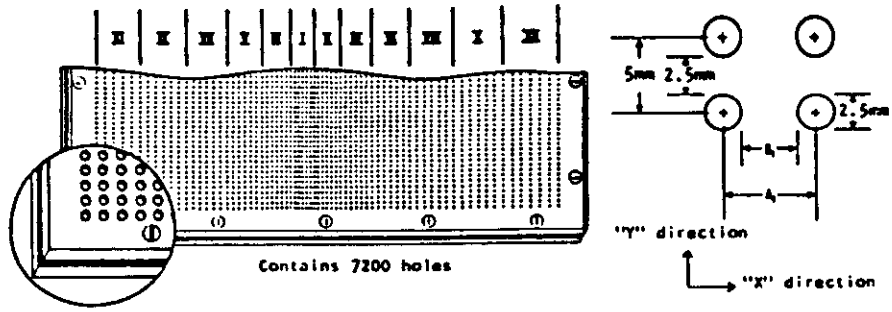
Fig. 6-8. Orthogonal-hole transmission pattern (OHTP) phantom.
The phantom consists of a sheet of lead about 3 mm thick with a regular pattern of circular holes, sandwiched between two sheets of plastic. The minimal lead spacings, A_1, are equal to the hole diameters, A_1.

from a syringe with attached needle, water is added nearly to fill the phantom, but leaving an air bubble at the top, the sealing plugs are inserted and tightenend and the phantom is inverted several times to ensure that the contents are well mixed. At the same time, the sealing plugs are checked for freedom from leakage. Care should be taken not to overfill, which may cause bulging at the centre. Emptying after use may conveniently be deferred until radioactive decay of the radionuclide is nearly complete. Indeed, if the phantom is in regular use, only partial emptying may be necessary between tests. Periodically, however, it should be emptied and washed with clean water, then with dilute sodium hypochlorite solution to discourage growth of algae.

7. Spatial-resolution phantoms of differing design. (Figs. 6-8, 6-9, 6-10). These are transmission phantoms used in conjunction with a point source or flood source.

8. Intrinsic-resolution phantom (Fig. 6-11). To fill, radionuclide solution at an appropriate activity concentration is introduced into the polyethylene tubing from a syringe, with corresponding manipulation of the screw clip.

9. System-resolution phantom (Fig. 6-12). To fill, radionuclide solution at an appropriate activity concentration is introduced into the polyethylene tubing from a syringe, with corresponding manipulation of the screw clip.



Schematic section of BRH Test Pattern. Center-to-center hole separation (A_i) and minimal lead spacing between the holes (B_i) vary in the X direction in groups of six holes each as follows:

Group	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
A_i (mm)	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
B_i (mm)	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0

Fig. 6-9. Bureau of Radiological Health (BRH) graded-spacing-hole phantom. The phantom consists of a sheet of lead about 3 mm thick with a varying pattern of circular holes, sandwiched between two sheets of plastic.

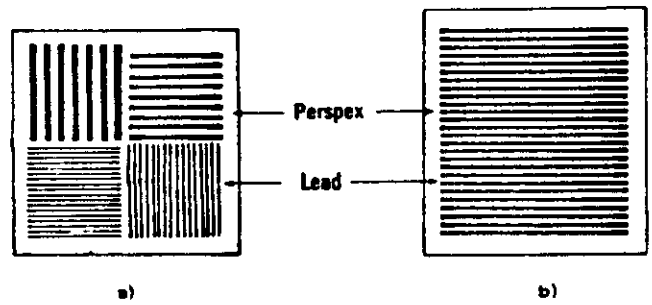


Fig. 6-10. Other spatial-resolution phantoms.

a) Quadrant-bar phantom.
b) Parallel-line equal-spacing (PLES) phantom.

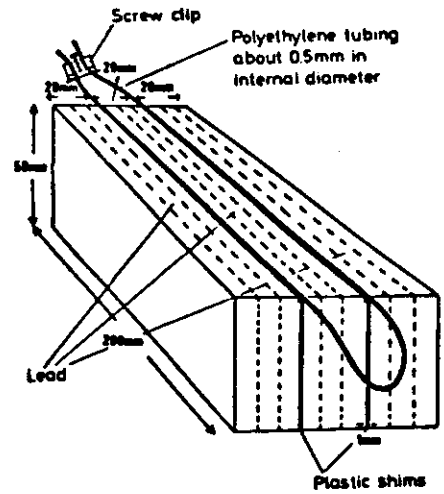


Fig. 6-11. Intrinsic-resolution phantom giving two parallel collimated line sources when filled with $^{99}Tc^{m}$ in solution. The solution is contained in polyethylene tubing about 0.5 mm in internal diameter, closed by a screw clip. Sheets of lead separated by plastic shims provide collimation.

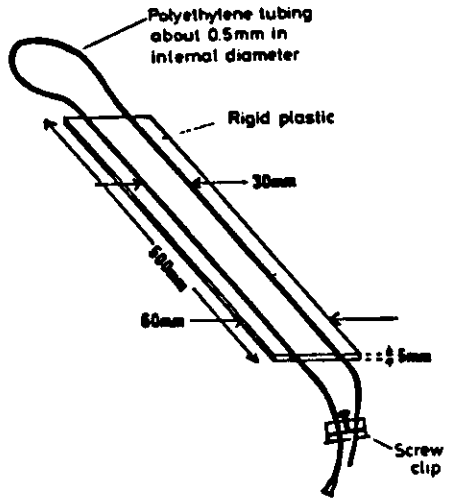


Fig. 6-12. System-resolution phantom giving two parallel line sources when filled with $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution. The solution is contained in polyethylene tubing about 0.5 mm in internal diameter, closed by a screw clip and mounted on a sheet of rigid plastic (e.g. Lucite, Perspex).

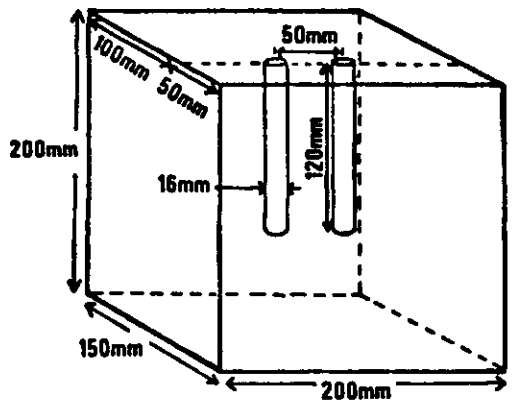


Fig 6-13. Two-source scatter phantom, fabricated in tissue-equivalent plastic (e.g. Lucite, Perspex). (After Adams.)

10. System count-rate performance phantom ("two-source scatter phantom") (Fig. 6-13). A container containing a radio-nuclide solution at an appropriate activity concentration may be placed in each of the wells. The level of the solution in the containers, when inserted in the phantom, should be approximatley 1 cm below the top surface of the phantom.

11. Plane-sensitivity phantom. A circular flat-bottomed plastic container 10 cm in diameter and 1 cm deep into which an accurately known activity of the radionuclide concerned in 25 ml solution can be introduced is suitable.

12. Total performance phantoms, e.g. thyroid phantom (see Fig. 5-7) or liver-slice phantom (see Fig. 5-8), having simulated "cold" and/or "hot" lesions of various sizes. The filling procedure is detailed on p. 125.

6.2. TEST SCHEDULE

Table 6-1 lists the recommended quality control tests for a scintillation camera, with suggested frequencies for the repetition of reference tests in routine testing. The operational checks should be carried out each day the instrument is used.

Table 6-1

Test Schedule for Scintillation Camera

Test No.	Test	Acceptance	Reference	Frequency in routine testing		
				Weekly	Quarterly	Half-yearly
	Acceptance and Reference Tests					
6.3.1.	Physical Inspection	x				
6.3.2.	Test of Preset and Manual PHA Window Settings		x			x
6.3.3.	Test of Intrinsic Flood-field Uniformity	x	x		x	
6.3.4.	Test of Flood-field Uniformity over available PHA Window Widths		x			x
6.3.5.	Test of Flood-field Uniformity at Energies other than 140 keV or 392 keV		x			x
6.3.6.	Test of System Flood-field Uniformity		x			x
6.3.7.	Test of Intrinsic Spatial Resolution	x	x			x
6.3.8.	Test of System Spatial Resolution	x				
6.3.9.	Test of Intrinsic Count-rate Performance (Alternative I)	x	x			x
6.3.10.	Test of Intrinsic Count-rate Performance (Alternative II)	x	x			x
6.3.11.	Test of Maximum Count Rate	x	x			x
6.3.12.	Test of System Count-rate Performance		x		x	
6.3.13.	Test of System Plane Sensitivity	x				
6.3.14.	Test of Detector Head Shielding Leakage	x				

Table 6-1 (cont.)

Test Schedule for Scintillation Camera

Test No.	Test	Acceptance	Reference	Frequency in routine testing		
				Weekly	Quarterly	Half yearly
6.3.15.	Test of Spatial Resolution and Spatial Linearity		x	x		
6.3.16.	Test of Total Performance		x	x		
6.3.17.	Test of Multiple-window Spatial Registration	x	x			x
	Operational Checks					
6.4.1.	Check of Collimator and Detector Head Mountings					
6.4.2.	Check of Energy Calibration of PHA					
6.4.3.	Check of Flood-field Uniformity and Sensitivity					
6.4.4.	Check of Background Count Rate					
6.4.5.	Check of Oscilloscope					
6.4.6.	Check of Film Handling and Processing					

6.3. ACCEPTANCE AND REFERENCE TESTS

6.3.1: PHYSICAL INSPECTION

Purpose of test

To inspect a scintillation camera, control console and data storage and display devices for shipping damage and production and design flaws.

Procedure

1. Detector Housing and Support Assembly: Inspect the aluminium casing surrounding the NaI(Tl) crystal for signs of indentation or puncture, and the support stand for loose parts or mechanical difficulties.

2. Control Console: Inspect the dials, switches and other controls for loose or broken knobs. Check for dials that are difficult to turn or are noisy and switches that do not throw securely.

3. Image Display Devices: Inspect the display screen for scratches, finger prints, dust or other debris.

4. Image Recording Devices: Inspect the mechanical operation of rollers or film transfer mechanism. If possible, make certain that the movement is smooth and positive. Clean the rollers and check camera lenses for scratches, finger prints, dust or other debris.

5. Hand Control: Inspect the hand control for proper mechanical operation and confirm that the cable has acceptable strain relief at maximum extension.

6. Collimators: Inspect the collimators for damage.

7. Electrical Connections, Fuses and Cables: Inspect for any loose or broken cable connectors and pinched or damaged cables. Locate all fuses and circuit breakers to enable prompt checking during equipment failure.

8. Data Storage and Display Devices (if supplied): Steps 2, 3 and 4 above are applicable.

9. Operation and Service Manuals: Check that all appropriate documentation, including performance specifications, is available:

Observations

This test is intended to be performed as an acceptance test.

Physical inspection should be carried out immediately on receipt of an instrument, so that the supplier may be informed of any damage, deficiencies or flaws before the warranty has expired. In the event of major damage, acceptance testing must usually be halted until this is rectified. If only an isolated component (e.g. a collimator) is involved, acceptance testing may proceed after notification of the damage. If performance specifications are not available, they should be requested and obtained from the manufacturer's representative before further acceptance testing.

6.3.2: TEST OF PRESET AND MANUAL PHA WINDOW SETTINGS

Purpose of test

To test that the preset PHA facilities for clinical imaging with particular radionuclides in a scintillation camera correspond to the manual settings.

Materials

Point sources (see p. 147) consisting of the radionuclides concerned, activities about 4 MBq (100 μCi), in suitable containers.

Source mounting for point source (see p.147)
Lead mask (see p. 147)

Procedure

1. Remove the collimator from the detector head. Align the head and the source mounting.

2. Position the lead mask centrally on the crystal housing.

For each radionuclide in turn:

3. Mount the source in the source mounting.

4. Set the manual controls of the PHA to the energy setting for the radionuclide concerned and to the window width used in the corresponding preset mode.

5. Measure the count rate in the manual mode at a preset count of 10^4.

6. Change to the preset mode for the radionuclide concerned. Again measure the count rate at preset count of 10^4.

7. Remove the source.

8. After repeating steps 3-7 for each radionuclide in turn, remove the lead mask. Replace the collimator.

Data analysis

Calculate for each radionuclide the percentage change in count rate on changing from the manual mode to the preset mode.

Observations

This test is intended to be performed as a reference test at the time of acceptance, and at half-yearly intervals.

If the PHA settings, particularly the width (window) settings, for the preset facilities are not quoted by the manufacturer, they should be identified at acceptance testing by determining the manual settings that give the same count rates.

Deterioration in image quality may result if the PHA window changes in position so that it is no longer centred on the photopeak or, equally, if it changes in width. Preset windows may change in both position and width in the course of time because of aging of electronic components or mechanical defects which may influence the potentiometer settings. Manually set windows may change similarly. A changed manually set window

can readily be re-centred on the photopeak, but its width cannot so readily be restored. A change in either the preset window or the manually set window for a given radionuclide may lead to differing count rates in the test.

Interpretation of results

Change in count rate on switching from manual setting to the preset facility may indicate maladjustment of the latter. However, if all preset facilities appear maladjusted, this would suggest incorrect energy calibration of the system. Test 6.4.1: Check of Energy Calibration of PHA should then be repeated.

Limits of acceptability

A discrepancy in count rate greater than 10% would call for further investigation. Under such circumstances, it would be better to use the manual mode of operation until maintenance action has been taken.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.3: TEST OF INTRINSIC FLOOD-FIELD UNIFORMITY

Purpose of test

To test the intrinsic response of a scintillation camera to a spatially uniform flux of incident gamma radiation over the field-of-view.

Materials

Point source (see p. 147) consisting of 10-20 MBq (0.3-0.5 mCi) $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution in suitable container, giving a count rate not greater than 30 000 c/s with a 20% PHA window.

Source mounting for point source (see p. 147)
Lead mask (see p. 147)

Procedure

1. Remove the collimator from the detector head. Align the head and the source mounting.

2. Position the lead mask centrally on the crystal housing.

3. Mount the source in the source mounting.

4. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

5. Acquire an analogue image on the display device with hard copy, at a preset count of 1.5×10^{7}. If a digital image processor is available, also acquire a digital image. For the latter, use a 64x64 matrix with the diameter of the flood-field image fitted to 60 pixels. The above preset count will result in a count of about 4 000 in the centre pixel.

6. Remove the source and lead mask. Replace the collimator.

Data analysis

METHOD 1: ANALOGUE IMAGE METHOD

Visually inspect the image for variations in brightness or density.

METHOD 2: DIGITAL IMAGE METHOD

1. Smooth the image data in the image processor once using a nine-point smoothing function having the following pattern of weightings:

$$\begin{matrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{matrix}$$

2. Delineate the half-height circumference of the image by locating the pixels around the edge having a count one half of that in the centre pixel. This may require interpolation between pixels adjacent to the half-height position. Then define the useful field-of-view, UFOV, on the digital image as that within the circle with a radius which is 95% of the mean half-height radius. Similarly define the central field-of-view, CFOV, as that within the circle with a radius which is 75% of the mean half-height radius (Fig. 6-14).

3. Determine the maximum (Max) and minimum (Min) counts in the pixels lying within the UFOV and the CFOV. The integral uniformity, IU, is then given by:

$$IU = 100\left(\frac{Max - Min}{Max + Min}\right)$$

4. Determine for each row or column of pixels in the X and Y directions within the UFOV and the CFOV, the maximum count difference in any 6 contiguous pixels. Determine the highest value of this maximum count difference in the sets of rows and columns. The differential uniformity, DU, is then given by:

$$DU = 100\left(\frac{Hi - Low}{Hi + Low}\right)$$

where Hi and Low are the pixel counts giving the highest value of the maximum count difference.

Observations

This test is intended to be performed as an acceptance and reference test, and at quarterly intervals.

In both the analogue image and the digital image method, if the scintillation camera is fitted with a uniformity correction circuit, the test should, if possible, be performed with and without the circuit enabled.

The digital image method can be followed with appropriate software to perform the analysis automatically or, more laboriously, with a print-out of the count in each pixel of the 64x64 matrix.

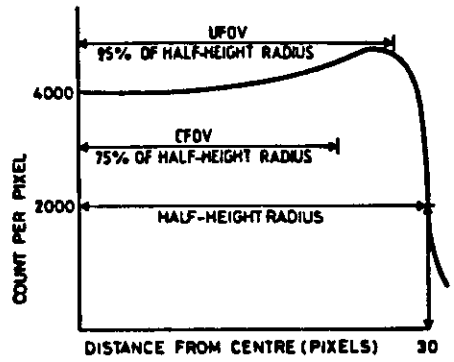


Fig. 6-14. Test 6.3.3: Test of Intrinsic Flood-field Uniformity. Definitions of useful field-of-view (UFOV) and central field-of-view (CFOV) from digital count profile of intrinsic flood-field image.

Interpretation of results

METHOD 1: ANALOGUE IMAGE METHOD

At acceptance testing, the images should be compared with those acquired by the manufacturer at the factory or by his representative at installation.

At routine testing, the images should be compared with the reference images.

METHOD 2: DIGITAL IMAGE METHOD

At acceptance testing, the values of integral and differential uniformity for the useful and central fields-of-view should be compared with the manufacturer's worst-case values.

At routine testing, the values should be compared with the reference values.

The uniformity of most scintillation cameras with a uniformity correction circuit but with the circuit disabled will be poorer than with the circuit enabled. This does not represent a malfunction. Uncorrected reference images should be obtained at the time of acceptance or after major repair and further images obtained weekly thereafter to monitor for defects which may be hidden in the corrected images (see Observations, test 6.4.2: Check of Flood-field Uniformity). If the defects appear to worsen, maintenance should be scheduled, as eventually the correction device will be unable to produce a uniform response. Further, if count addition or subtraction processes are employed in the uniformity circuit, the number of added or subtracted counts will become an increasing significant fraction of the total as the uncorrected uniformity worsens, and any quantifications based on the corrected images, such as ejection fraction calculations, will contain increasingly significant errors.

Limits of acceptability

METHOD 1: ANALOGUE IMAGE METHOD

There are no absolute limits of acceptability for this method. At acceptance testing, if the image obtained from the display device appears to differ from that obtained at the factory or at installation, corrective action should be initiated through the manufacturer's representative.

At routine testing, the image should be comparable to the reference image. Its shape should be round or hexagonal, as appropriate, and its uniformity adequate for clinical imaging. Evident non-uniformities would call for follow-up action.

METHOD 2: DIGITAL IMAGE METHOD

At acceptance testing, a value of integral or differential uniformity that is 10% or more above the manufacturer's worst-case value would call for corrective action initiated through the manufacturer's representative.

At routine testing, a value 20% or more above the reference value would call for follow-up action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.4: TEST OF INTRINSIC FLOOD-FIELD UNIFORMITY OVER AVAILABLE PHA WINDOW WIDTHS.

Purpose of test

To test the intrinsic flood-field response of a scintillation camera throughout the range of available PHA window widths.

Materials

Point source (see p.147) consisting of 10-20 MBq (0.3-0.5 mCi) $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution in suitable container, giving a count rate not greater than 30 000 c/s with a 20% PHA window.

Source mounting for point source (see p.147)
Lead mask (see p. 147)

Procedure

1. Remove the collimator from the detector head. Align the head and the source mounting

2. Position the lead mask centrally on the crystal housing.

3. Mount the source in the source mounting

4. Centre the narrowest PHA window available on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

5. Acquire an analogue image on the display device with hard copy, at a preset count of 10^6 for a small field-of-view camera or $2x10^6$ for a large field-of-view camera.

6. Repeat steps 4 and 5, incrementing the window width in 5% steps to the widest window available, checking each time that the window remains centred on the photopeak.

7. Remove the source and lead mask. Replace the collimator.

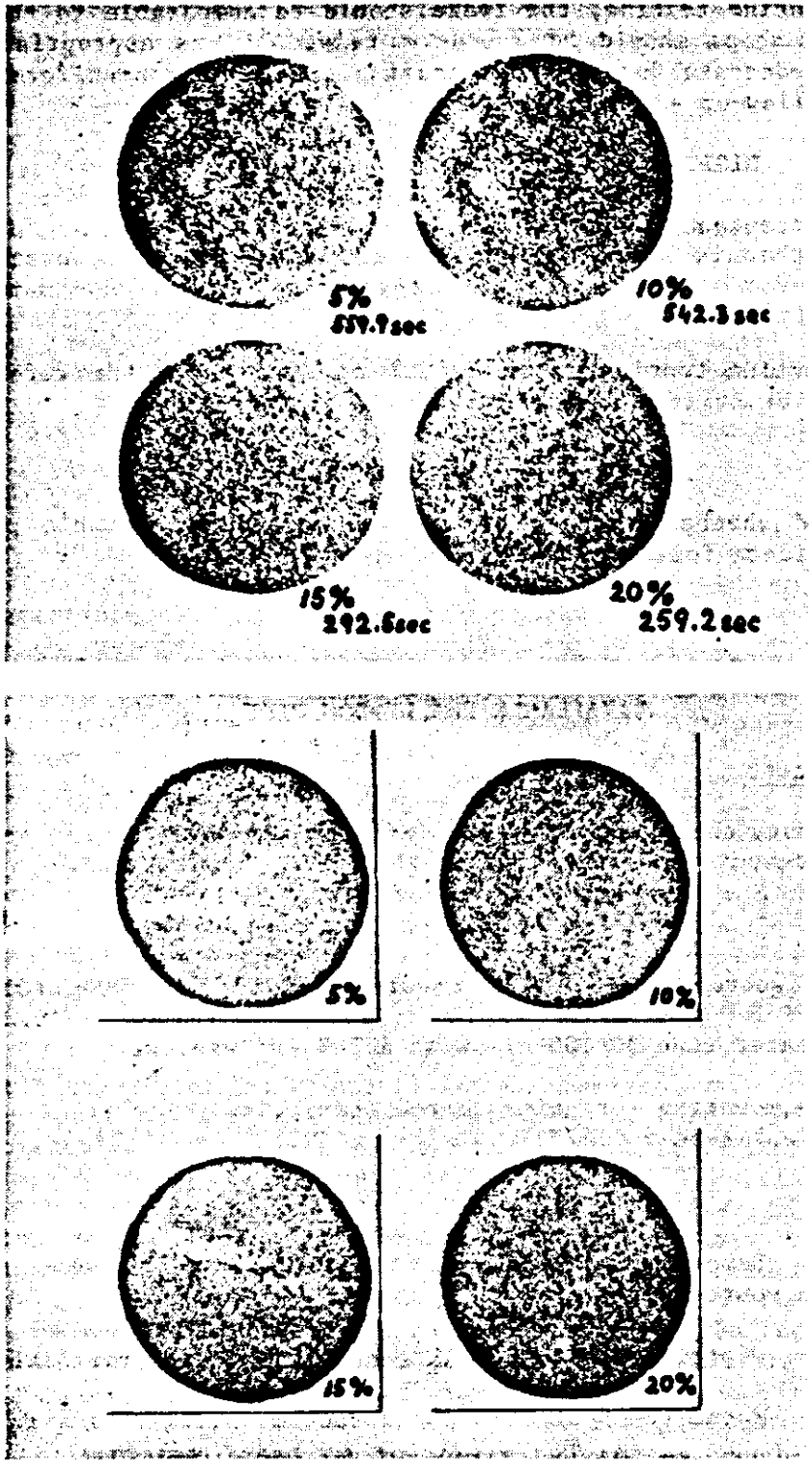


Fig. 6-15. Test 6.3.2: Test of Intrinsic Flood-field Uniformity over available PHA Window Widths.

a) Analogue images obtained at acceptance testing showing increased non-uniformities on narrowing the window progressively from 20% to 5% while keeping it centred on photopeak. Investigation by the manufacturer's representative showed that the light guide had separated from the crystal during shipment.
b) Corresponding digital images obtained after recoupling light guide to crystal.

Data analysis

Visually compare the images, noting particularly any increased variations in brightness or density at narrower PHA windows (Fig. 6-15).

Observations

This test is intended to be performed as a reference test at the time of acceptance, and at half-yearly intervals.

If the scintillation camera is fitted with a uniformity correction circuit, the test should, if possible, be performed with and without the circuit enabled.

It is possible to perform this test quantitatively as described in test 6.3.3: Test of Intrinsic Flood-field Uniformity. However, careful inspection of the images is sufficient, unless quantitative clinical studies are to be performed with narrow PHA windows.

Interpretation of results

A scintillation camera without a uniformity correction circuit should still maintain its intrinsic flood-field uniformity throughout the range of available PHA window widths. If the uniformity degrades on narrowing the window, corrective action should be initiated. The integrity of the optical coupling between the photomultiplier/light guide assembly and the NaI(Tl) crystal should particularly be checked by the manufacturer's representative.

A scintillation camera with a uniformity correction circuit and the circuit enabled should likewise maintain its intrinsic flood-field uniformity throughout the range of available window widths. If the uniformity degrades on narrowing the window or when the correction circuit is disabled, corrective action should be similarly initiated.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.5: TEST OF INTRINSIC FLOOD-FIELD UNIFORMITY AT ENERGIES OTHER THAN 140 keV ($^{99}Tc^{m}$) OR 392 keV ($^{113}In^{m}$).

Purpose of test

To test the intrinsic flood-field response of a scintillation camera for all appropriate other photon energies.

Materials

Point sources (see p.147) consisting of containing 10-20 MBq (0.3-0.5 mCi) of radionuclides used for clinical imaging in solution in suitable containers.

Source mounting for point source (see p.147)
Lead mask (see p.147)

Procedure

1. Remove the collimator from the detector head. Align the head and the source mounting.

2. Position the lead mask centrally on the crystal housing.

For each radionuclide in turn:

3. Mount the source in the source mounting.

4. Centre the clinically used PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

5. Acquire an analogue image on the display device with hard copy, at a preset count of 10^6 for a small field-of-view camera or 2×10^6 for a large field-of-view camera.

6. Remove the source.

7. After repeating steps 3-6 for each radionuclide in turn, remove the lead mask. Replace the collimator.

Data analysis

Visually compare the images, noting particularly any increased variations in brightness or density at lower or higher photon energies.

Observations

This test is intended to be performed as a reference test at the time of acceptance, and at half-yearly intervals.

If the scintillation camera is fitted with a uniformity correction circuit, the test should, if possible, be performed with and without the circuit enabled.

It is possible to perform this test quantitatively as described in test 6.3.3: Test of Intrinsic Flood-field Uniformity. However, careful inspection of the images is sufficient.

It is important to perform this test to assure that the uniformity of the flood-field response is independent of photon energy. It is above all essential to confirm this if the scintillation camera has a uniformity correction circuit which uses a single stored reference flood-field image to derive the correction matrix for images at all photon energies. It is important to note that such a reference flood-field image should be acquired with an extended flood source, so as to include radiation scatter. The test can then be modified with an appropriate source configuration to test the uniformity with a collimator mounted.

Interpretation of results

A scintillation camera, whether without a uniformity correction circuit or with a uniformity correction circuit and the circuit enabled, should maintain its system flood-field uniformity for all appropriate photon energies, with the circuits enabled that are used in clinical imaging. If not, corrective action should be initiated.

If, in a scintillation camera with a uniformity correction circuit and the correction circuit disabled, the system flood-field uniformity

changes significantly with photon energy, corrective action should be similarly initiated.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.6: TEST OF SYSTEM FLOOD-FIELD UNIFORMITY

Purpose of test

To test the system flood-field response of a scintillation camera with all multi-hole collimators used.

Materials

Flood phantom (see p. 147) containing 70-200 MBq (2-5 mCi) $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution

or

^{57}Co flood source of similar activity.

Procedure

1. Mount the collimator to be tested on the detector head. Turn the head to face vertically upward.

2. Place the flood phantom or flood source on the collimator face.

3. Centre the clinically-used PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

4. Acquire an analogue image on the display device with hard copy, at a preset count of 10^6 for a small field-of-view camera or $2x10^6$ for a large field-of-view camera, with the uniformity correction circuit, if fitted, enabled.

5. Remove the flood phantom or flood source.

6. Repeat steps 1-5 for all multi-hole collimators used.

Data analysis

Visually inspect the images, noting particularly any increased variations in brightness or density not apparent in the corresponding intrinsic flood-field image acquired in test 6.3.3: Test of Intrinsic Flood-field Uniformity.

Observations

This test is intended to be performed as a reference test at the time of acceptance, and at half-yearly intervals or if damage to a collimator is suspected.

It is important to perform this test to assure that the flood-field response remains uniform for all collimators used. Low-energy collimators in particular may be damaged during shipment, as the lead septa are thin and can separate if subjected to an impact. Separation of

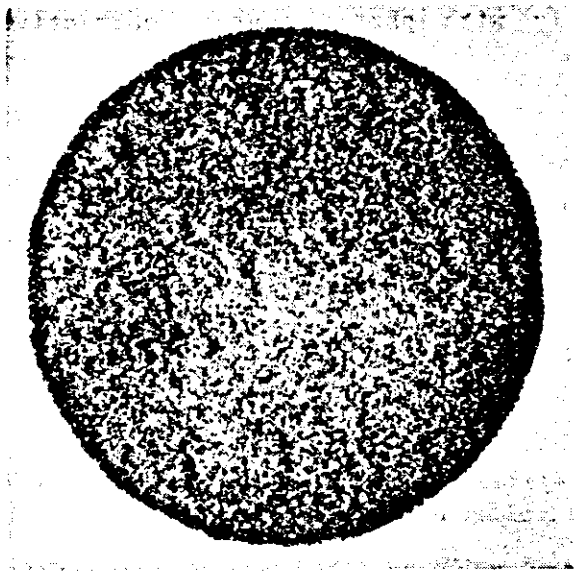


Fig. 6-16. Test 6.3.6: Test of System Flood-field Uniformity. System flood-field response of scintillation camera with high-resolution low-energy collimator damaged during shipment. The lines of increased density are the result of separation of rows of lead septa.

the septa will appear on the images as parallel lines of increased count density (Fig. 6-16). If an object has hit the collimator face, an area of reduced count density will be seen where the septa have been bent.

If a flood phantom is used it should be checked that the contents are thoroughly mixed to provide a uniform source. If poor mixing is suspected, the phantom should be rotated through 90° and a new image acquired. Poor mixing is confirmed if the non-uniform features move with the phantom.

It may be noted that some uniformity correction circuits require a reference flood image to be acquired for each collimator, in which case it is important to follow carefully the recommendations of the manufacturer.

Interpretation of results

A scintillation camera should maintain its uniformity of flood-field response for all multi-hole collimators used, with the circuits enabled that are used in clinical imaging. If any variations in uniformity not apparent in the intrinsic flood-field image are observed, a replacement collimator should be obtained from the manufacturer's representative.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.7: TEST OF INTRINSIC SPATIAL RESOLUTION

Purpose of test

To test the intrinsic spatial resolution of a scintillation camera in terms of the full width at half-maximum (FWHM) of its line-spread function.

METHOD 1: ANALOGUE IMAGE METHOD

To be used if a digital image processor is not available.

Materials

Point source (see p. 147) consisting of 20–40 MBq (0.5 - 1 mCi) $^{99}Tc^{m}$ in solution in suitable container.

Quadrant-bar phantom (see p. 147)
Lead mask (see p. 147)

Procedure

1. Remove the collimator from the detector head. Align the head and the source mounting.

2. Position the lead mask centrally on the crystal housing.

3. Mount the source in the source mounting.

4. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

5. Position the quadrant-bar phantom so that it is supported on the detector head housing and as close to the crystal housing as possible, with the bars carefully aligned with the X and Y axes of the detector face.

6. Acquire an analogue image on the display with hard copy, at a preset count of 10^6 for a small field-of-view camera or $2x10^6$ for a large field-of-view camera.

7. Rotate the quadrant-bar phantom through 90° and repeat step 6. Repeat this process, with inversion of the phantom, until each of the four sets of bars has been imaged in the X and Y directions in each of the four quadrant positions. This will require 8 images.

8. Remove the source, source mounting, quadrant-bar phantom and lead mask. Replace the collimator.

9. Accurately measure the widths, B, of the bars in the quadrant-bar phantom.

Data analysis

1. Determine, by visual inspection of the images, the widths of the smallest bars that the scintillation camera can resolve in the X and Y directions. Note any areas of poor spatial resolution, which may correspond to the location of a phototube or may be at the edge of the image.

2. Estimate the intrinsic spatial resolutions in the X and Y directions in terms of the full widths at half-maximum, FWHM, of the line-spread function, using the relationship

FWHM = 1.75B

where B is the width of the smallest bars that the camera can resolve.

3. Average the values in the X and Y directions.

Observations

This test is intended to be performed as an acceptance and reference test, and at half-yearly intervals.

The quadrant-bar phantom must be matched to the spatial resolution of the scintillation camera, so that at least one set of bars is not resolved. The increments of bar width from one quadrant to the next should be small, so that the spatial resolution can be estimated with reasonable accuracy.

The test may be performed with a Bureau of Radiological Health (BRH) graded-spacing-hole phantom in place of the quadrant-bar phantom. The phantom should then be imaged in two positions at 90° to each other and the diameters of the smallest holes that the scintillation camera can resolve in the two directions should be determined.

Interpretation of results

At acceptance testing, the estimated values for FWHM in the X and Y directions should be compared with the manufacturer's worst-case values.

At routine testing, the estimated values should be compared with the values obtained at acceptance.

Limits of acceptability

At acceptance testing, a value of FWHM that is 20% or more above the manufacturer's worst-case value would call for corrective action initiated through the manufacturer's representative.

At routine testing, follow-up action should be initiated if the average value of FWHM is 20% or more above the reference value, or if areas within the useful field-of-view show significant worsening of the spatial resolution.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

METHOD 2: DIGITAL IMAGE METHOD

To be used if an appropriate digital image processor is available.

Materials

Intrinsic-resolution phantom (see p.147) containing about 40 MBq (1 mCi) $^{99}Tc^{m}$ in solution in each line source.

Linear graph paper

Procedure

1. Remove the collimator from the detector head. Turn the head to face vertically downward.

2. Position the intrinsic-resolution phantom, inverted, below the detector head on a sturdy elevator mechanism by means of which it may be slowly raised by hand (Fig. 6-17). Carefully raise the phantom until it is adjacent to, but not quite touching, the exposed face of the crystal housing, with the line sources parallel to the X axis of the detector face and spaced equally about the axis. Take extreme care that neither the elevator mechanism nor the phantom accidentally hits the crystal housing or a damaged crystal may result. Cover the protruding tubing with lead shielding.

3. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

4. Acquire a digital image at a preset count of 2×10^6 in a 256x256 matrix or in a 128x128 matrix in "zoom" mode.

5. Re-position the intrinsic-resolution phantom with the line sources parallel to the Y axis of the detector face and spaced equally about the axis. Repeat step 4.

6. Carefully lower the intrinsic-resolution phantom. Remove the phantom and elevator mechanism. Replace the collimator.

7. Accurately measure the spacing, D, of the line sources in mm.

Data analysis

1. Obtain a print-out of counts in successive pixels in a narrow section perpendicular to the pair of lines in the first digital image. The section may be up to 3 pixel elements broad (Fig. 6-18a).

2. Plot the data as a profile of total count per pixel number against pixel number on linear graph paper. Draw a smooth curve through the data points (Fig. 6-18b).

3. Determine the separation, S, of the peaks in pixels.

4. For each peak, calculate the full width at half-maximum, W, in pixels, by linear interpolation between adjacent pixels, using the highest pixel count in the peak as the maximum.

5. Calculate the full width at half-maximum, FWHM, of each peak in mm as

$$FWHM = \frac{WD}{S}$$

6. Average the FWHM values for the two peaks.

7. Repeat steps 1-6 for 3 or 4 additional sections chosen at different positions along the line. Average all the FWHM values.

8. Similarly determine the full width at tenth-maximum, FWTM, by repeating steps 1-7 but at one-tenth the maximum counts.

9. Repeat steps 1-8 for the second image so as to obtain FWHM and FWTM values in both X and Y directions.

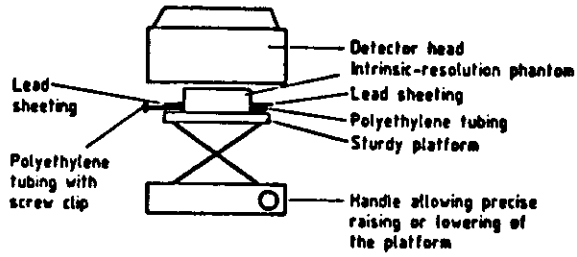


Fig. 6-17. Test 6.3.7: Test of Intrinsic Spatial Resolution. Positioning of intrinsic-resolution phantom with detector head facing vertically downward and phantom carefully raised by means of a sturdy elevator mechanism.

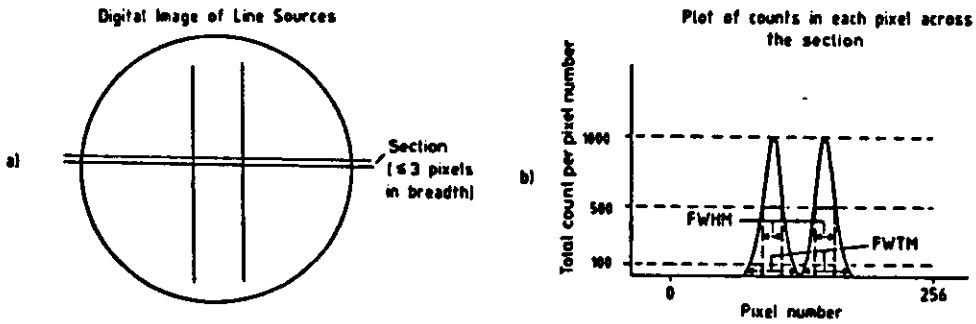


Fig. 6-18. Test 6.3.7: Test of Intrinsic Spatial Resolution; Test 6.3.8: Test of System Spatial Resolution

a) Method of obtaining a count profile across the pair of lines in the digital image of the intrinsic-resolution or system-resolution phantom from a print-out of counts in successive pixels in a narrow section perpendicular to the lines.

b) Profile obtained in (a) above, showing full width at half-maximum, FWHM, and full width at tenth-maximum, FWTM.

Observations

This test is intended to be performed as an acceptance and reference test, and at half-yearly intervals.

The fine digitization matrix is required to assure that there are at least 10 pixels within the FWHM.

The slit width of the lead collimation should not exceed 1 mm, otherwise broadening of the peaks will occur.

To increase the successive counts in the profile, it is possible to take a section more than 3 pixels broad. If this is done, however, care must be taken to align the sources accurately so that the images of the lines lie exactly parallel to the X or Y axis of the image matrix. If not, broadening of the peaks will occur.

Background is assumed to be negligible in the calculations of FWHM and FWTM. A significant background will result in erroneous values for these parameters. If the background count is found to be a significant fraction of the counts in the profiles, steps should be taken to reduce it before proceeding.

Interpretation of results

At acceptance testing, the calculated values of FWHM in the X and Y directions should be compared with the manufacturer's worst-case values.

At routine testing, the calculated values should be compared with the reference values.

If small areas within the useful field-of-view appear to have worsened resolution, Method 1 should be performed to determine the extent of the resolution loss and corrective action initiated, if this loss is significant.

Limits of acceptability

At acceptance testing, a value of FWHM or FWTM that is 10% or more above the manufacturer's worst-case value would call for corrective action initiated through the manufacturer's representative.

At routine testing, follow-up action should be initiated if a value of FWHM or FWTM is 20% or more above the reference value, or if areas within the useful field-of-view show significant deterioration in spatial resolution.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.8: TEST OF SYSTEM SPATIAL RESOLUTION

Purpose of test

To test the system spatial resolution of a scintillation camera in terms of the full width at half-maximum, FWHM, of its line-spread function.

METHOD 1: ANALOGUE IMAGE METHOD

To be used if an appropriate digital image processor is not available.

Materials

Flood phantom (see p. 147) containing about 200 MBq (5 mCi) $^{99}Tc^{m}$

or

^{57}Co flood source of similar activity.

Quadrant-bar-phantom (see p. 147) with bar widths and bar spacings of about 4, 8, 12 and 16 mm.

Procedure

1. Mount the collimator to be tested on the detector head. Turn the head to face vertically upward.

2. Position the quadrant-bar phantom on the face of the collimator, with the bars carefully aligned with the X and Y axes of the detector face.

3. Place the flood phantom or flood source on the quadrant-bar phantom.

4. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

5. Acquire an analogue image on the display device with hard copy, at a preset count of 2×10^6 for a small field-of-view camera or 4×10^6 for a large field-of-view camera.

6. Rotate the quadrant-bar phantom through 90° and repeat step 5. Repeat this process, with inversion of the phantom, until each of the four sets of bars has been imaged in the X and Y directions in each of the four quadrant positions. This will require 8 images.

7. Repeat steps 2-6, but with the quadrant-bar phantom at a distance of 10 cm from the face of the collimator in air.

8. Repeat steps 1-6, but with the quadrant-bar phantom at a distance of 10 cm from the face of the collimator and a tissue-equivalent scattering medium between the phantom and the collimator.

9. Repeat steps 1-8 for all available low-energy multi-hole collimators.

10. Remove the flood phantom or flood source, and quadrant-bar phantom.

11. Accurately measure the widths, B, of the bars in the quadrant-bar phantom.

Data analysis

1. Determine, by visual inspection of the images, the widths of the smallest bars that the scintillation camera can resolve in the X and Y directions with the phantom at the face of the collimator, at a distance of 10 cm from the face in air and at a distance of 10cm in a scattering medium. Note any areas of poor spatial resolution which may correspond to collimator damage.

2. Estimate the system spatial resolution in the X and Y directions, for each of the imaging conditions, in terms of the full width at half-maximum, FWHM, of the line spread function using the relationship

$$FWHM = 1.75B$$

where B is the width of the smallest bars that the camera can resolve.

3. Average the values in the X and Y directions.

Observations

This test is intended to be performed as an acceptance test for collimators.

The quadrant-bar phantom must be matched to the spatial resolution of the scintillation camera, so that at least one set of bars is not resolved. Such a phantom can be made locally from lead sheeting at least 3 mm thick.

A tissue equivalent scattering medium can be fashioned from layers of plastic (e.g. Perspex, Lucite) or chipboard. Alternatively, a plastic or wooden box filled with uncooked rice may be used.

The test may be performed with a Bureau of Radiological Health (BRH) graded-spacing-hole phantom in place of the quadrant-bar phantom. The phantom should then be imaged in two positions at 90° to each other and the diameters of the smallest holes that the scintillation camera can resolve in the two directions should be determined.

Interpretation of results

The estimated values of FWHM for each collimator, averaged over the X and Y directions, at a distance of 10 cm from the face of the collimator in air and at a distance of 10 cm in a scattering medium should be compared with the manufacturer's worst-case values.

The values determined at the collimator face and at 10 cm should be compared for the set of available low-energy collimators. Collimators with the largest widening of the line-spread function at depth should be reserved for superficial organ studies or dynamic studies.

Limits of acceptability

If a value of FWHM is obtained that is 20% or more above the manufacturer's worst-case value for the collimator in question, the collimator should be checked for damage and action initiated through the manufacturer's representative with a view to its replacement.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

METHOD 2: DIGITAL IMAGE METHOD

To be used if an appropriate digital image processor is available.

Material

System-resolution phantom (see p. 147) containing about 200 MBq (5 mCi) $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution in each line source.

Linear graph paper

Procedure

1. Mount the collimator to be tested on the detector head. Turn the head to face vertically upward.

2. Position the system-resolution phantom on the face of the collimator with the line sources parallel to the X axis of the detector face and spaced equally about the axis.

3. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

4. Acquire a digital image at a preset count of 2×10^{6} in a 128x128 matrix.

5. Re-position the system-resolution phantom with the line sources parallel to the Y axis of the detector face and spaced equally about the axis. Repeat step 4.

6. Repeat steps 2-5, but with the system-resolution phantom at a distance of 10 cm from the face of collimator in air, acquiring the data in a 64x64 matrix.

7. Repeat steps 2-5, but with the system-resolution phantom at a distance of 10 cm from the face of the collimator and a tissue-equivalent scattering medium between the phantom and the collimator, again acquiring the data in a 64x64 matrix.

8. Repeat steps 1-7 for all available multi-hole collimators.

9. Remove the system resolution phantom.

10. Accurately measure the spacing, D, of the line sources in mm.

Data analysis

1. Obtain a print-out of counts in successive pixels in a narrow section perpendicular to the pair of lines in the first digital image. The section may be up to 3 pixel elements broad (see Fig. 6-18a).

2. Plot the data as a profile of total count per pixel number against pixel number on linear graph paper. Draw a smooth curve through the data points (see Fig. 6-18b).

3. Determine the separation, S, of the peaks in pixels.

4. For each peak, calculate the full width at half-maximum, W, in pixels by linear interpolation between adjacent pixels, using the highest pixel count in the peak as the maximum.

5. Calculate the full width at half-maximum, FWHM, of each peak in mm as

$$FWHM = \frac{WD}{S}$$

6. Average the FWHM values for the two peaks.

7. Repeat steps 1-6 for 3 or 4 additional sections chosen at different positions along the line. Average all the FWHM values.

8. Similarly determine the full width at tenth-maximum, FWTM, by repeating steps 1-7 but at one-tenth the maximum counts.

9. Repeat steps 1-8 for the second image so as to obtain FWHM and FWTM values in both X and Y directions.

10. Repeat steps 1-9 for the images with the phantom at a distance of 10 cm from the face of the collimator in air and at a distance of 10 cm in a scattering medium.

11. Repeat steps 1-10 for all available multi-hole collimators.

Observations

This test is intended to be performed as an acceptance test for collimators.

To increase the successive counts in the profile, it is possible take a section more than 3 pixels broad. If this is done, however, care must be taken to align the sources accurately so that the images of the

lines lie exactly parallel to the X or Y axis of the image matrix. If not, broadening of the peaks will occur.

A tissue-equivalent scattering medium can be fashioned from layers of plastic (e.g. Lucite, Perspex) or chipboard. Alternatively, a plastic or wooden box filled with uncooked rice may be used.

Interpretation of results

The calculated values of FWHM and FWTM for each collimator, averaged over the X and Y directions, at 10 cm from the face of the collimator in air and at a distance of 10 cm in a scattering medium should be compared with the manufacturer's worst-case values.

The values determined at the collimator face and at 10 cm should be compared for the set of available collimators. Collimators with the largest widening of the line-spread function at depth should be reserved for superficial organ studies or dynamic studies.

Limits of acceptability

If a value of FWHM or FWTM is obtained that is 10% or more above the manufacturer's worst-case value for the collimator in question, action should be initiated through the manufacturer's representative with a view to its replacement.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.9: TEST OF INTRINSIC COUNT-RATE PERFORMANCE (ALTERNATIVE I)

Purpose of test

To test the intrinsic count-rate performance of a scintillation camera in terms of its response to an increasing flux of incident gamma-radiation.

Materials

Radiation source consisting of $^{99}Tc^{m}$ in solution contained in a small vial placed in an open lead pot with walls and floor about 6 mm thick. The initial activity should be about 10 MBq (600 μCi).

Fifteen absorbers fabricated in sheet copper about 0.25 cm thick, each about 6x6 cm square, numbered consecutively 1 to 15.

Lead mask (see p. 147)

Linear graph paper

PART I: CALIBRATION OF ABSORBERS

The absorbers must first be accurately calibrated with respect to their attenuation of $^{99}Tc^{m}$ gamma radiation. This may be done as follows:

Procedure

1. Remove the collimator from the detector head. Turn the head to face vertically downward.

2. Position the lead mask centrally on the crystal housing.

3. Position the source on the central axis of the detector at a distance of about 1.5 metres from its face (Fig. 6-19).

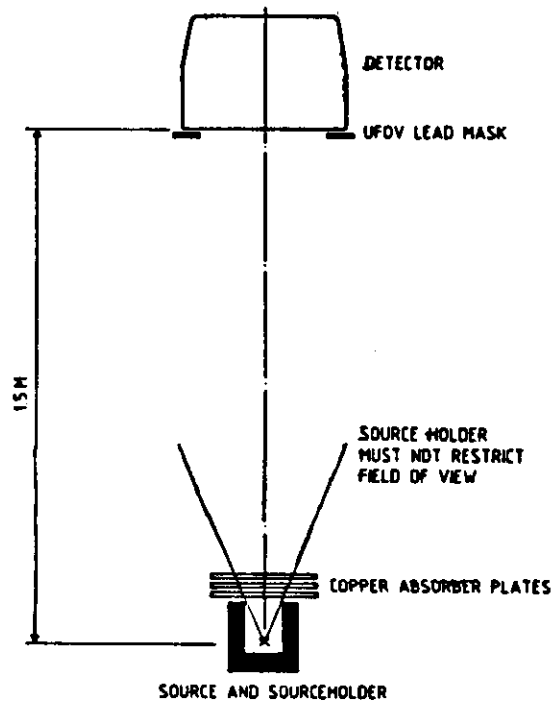


Fig. 6-19. Test 6.3.9: Test of Intrinsic Count-rate Performance (Alternative I). Positioning of radiation source in relation to detector.

4. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

5. Remove the source. Register the background count for a preset time of 100 seconds. Note the background count rate. Replace the source.

6. Adjust the source activity so that the observed count rate is in the range 1 000 - 3 000 c/s with absorbers 13-15 in place over the source in numerical order, with absorber 13 uppermost. (These absorbers remain in place for the rest of the procedure, providing scatter-free transmitted radiation (see Fig. 6-5).)

7. With absorbers 13-15 in place as described, register the count for a preset time of 200 seconds. Record on an appropriate form (Table 6-2) the exact time of day corresponding to the mid-point of the measurement and the net count rate, A_0, corrected for background.

For each of the absorbers 1-12 in turn:

8. Add the absorber on top of absorber 13. Register the count (reduced by attenuation in the added absorber) for a preset time of 100 seconds. Record on the form the exact time of day corresponding to the mid-point of the measurement and the net count rate, A_1, A_2, A_3 ..., corrected for background. Remove the absorber.

TABLE 6–2

Identity of added absorber	Time of day	Count rate without added absorber* (c/s)	Count rate with added absorber (c/s)	Attenuation factor
–		(A_0)		
1		(A_0')	(A_1)	($f_1 = A_1/A_0'$)
2		(A_0'')	(A_2)	($f_2 = A_2/A_0''$)
3		(A_0''')	(A_3)	($f_3 = A_3/A_0'''$)
4		-	-	-
5				
6				
7				
8				
9				
10				
11				
12				

*Corrected for radioactive decay to the time of the relevant measurement.

Data analysis

1. Correct the value of A_0 measured in step 7 for radioactive decay to the times of day corresponding to the mid-points of each of the measurements of step 8. Enter on the form the corrected count rates A_0^I, A_0^{II}, A_0^{III} ....

2. For each of the absorbers 1-12, calculate the attenuation factor, f, given by the ratio of the count rate A_1, A_2, A_3 ... to the corresponding corrected value of A_0, A_0', A_0^{II}, A_0^{III} .... This factor is the ratio of transmitted to incident gamma radiation flux for the absorber in question. Enter on the form the values of f. (With sheet copper absorbers 0.25 cm thick, they should be about 0.6.)

3. Calculate the mean, $\bar{f}$, of the individual values of f and examine the dispersion of the latter about the former. If the uniformity of thickness of the sheet copper from which the absorbers are fabricated is such that no individual value differs from $\bar{f}$ by more than 1%, the single value $\bar{f}$ may be used in their place. Otherwise, the individual measurements are to be used.

PART 2: DETERMINATION OF COUNT-RATE PERFORMANCE

If the test begins with Part 1: Calibration of Absorbers, it continues as now indicated. Once calibrated, however, absorbers should rarely require recalibration. If pre-calibrated absorbers are available, only steps 1-5 of the procedure of Part 1 are necessary. The test then again continues as indicated.

Procedure

1. Increase the source activity so that the observed count rate is in the range 1 000 - 3 000 c/s with absorbers 1-15 in place over the source in numerical order, with absorber 1 uppermost.

2. With absorbers 1-15 in place as described, register the count for a preset time of 100 seconds. Record on an appropriate form (Table 6-3) the exact time of day corresponding to the mid-point of the measurement and the net observed count rate, C_0, corrected for background. (At this relatively low count rate, count loss should be negligible and, hence, the input count rate, R_0, and the observed count rate, C_0, should be equal.)

3. Remove the uppermost absorber, absorber 1, thereby increasing the incident gamma-radiation flux and the input count rate in inverse proportion to the attenuation factor of the absorber removed. Register the count for a preset time of 20 seconds. Record on the form the exact time of day corresponding to the mid-point of the measurement and the net count rate, C_1, corrected for background.

4. Remove absorber 2. Again register the count for preset time of 20 seconds. Record on the form the exact time of day corresponding to the mid-point of the measurement and the net count rate, C_{1-2}, corrected for background.

5. So continue until only absorbers 13-15 remain over the source.

6. Remove the source and lead mask. Replace the collimator.

Data analysis

1. Correct the value of C_0 measured in step 2 for radioactive decay to the times of day corresponding to the mid-points of each of the measurements of steps 3-5. Enter on the form the corrected count rates, C_0', C_0'', C_0''' .... If the total time between the mid-points of the measurement of step 2 and the final measurement of step 5 is less than 10 minutes, this correction may be omitted and the uncorrected value of C_0 used in calculation. (It should be noted that all points on the curve are calculated on the basis of C_0. Therefore, this measurement must be highly accurate. Note also that if corrections for radioactive decay are applied, this must be done as indicated. In particular, it is not permissible to refer back the observed count rates recorded in steps 3-5 to the time of the measurement of step 2.)

2. Assuming that count loss is negligible under the conditions of the measurement of step 2, so that the corrected values of C_0 also represent the input count rates with all absorbers in place, calculate the input count rates, R_1, R_{1-2}, R_{1-3} ..., for the conditions of each of the measurements of steps 3-5, by dividing the corrected values of C_0 by the corresponding cumulative attenuation factors for the absorbers removed. (Thus the input count rate after removal of absorber 1 is given by C_0'/f_1; the rate after removal of absorbers 1 and 2 is

TABLE 6–3

Absorbers removed	Time of day	Observed count rate with all absorbers in place* (c/s)	Observed count rate with one or more absorbers removed (c/s)	Cumulative attenuation factor	Input count rate (c/s)
–		(C_o)			($R_o = C_o$)
1		(C_o')	(C_1)	(f_1)	($R_1 = C_o'/f_1$)
1–2		(C_o'')	(C_{1-2})	($f_1 \cdot f_2$)	($R_{1-2} = C_o''/f_1 \cdot f_2$)
1–3		(C_o''')	(C_{1-3})	($f_1 \cdot f_2 \cdot f_3$)	($R_{1-3} = C_o'''/f_1 \cdot f_2 \cdot f_3$)
1–4		-	-	-	-
1–5					
1–6					
1–7					
1–8					
1–9					
1–10					
1–11					
1–12					

*Corrected for radioactive decay to the time of the relevant measurement.

given by $C_o^N/f_1 \cdot f_2$; the rate after removal of absorbers 1, 2 and 3 is given by $C_o^N/f_1 \cdot f_2 \cdot f_3$ and so on). If, as previously indicated, the dispersion of the individual values of f is sufficiently small, the single value $\bar{f}$ may be used in their place; the cumulative attenuation factors then become $\bar{f}$, $\bar{f}^2$, $\bar{f}^3$ .... Otherwise the individual values are to be used. Enter on the form the input count rates.

3. Record the results on a graph showing observed count rate, C, against input count rate, R, on linear graph paper (Fig. 6-20).

4. Determine from the graph the values of C and R for which

$$C = 0.8R$$

These values correspond to a 20% count loss and are thus those for $C_{-20\%}$ and $R_{-20\%}$.

5. Determine from the graph the maximum (observed) count rate.

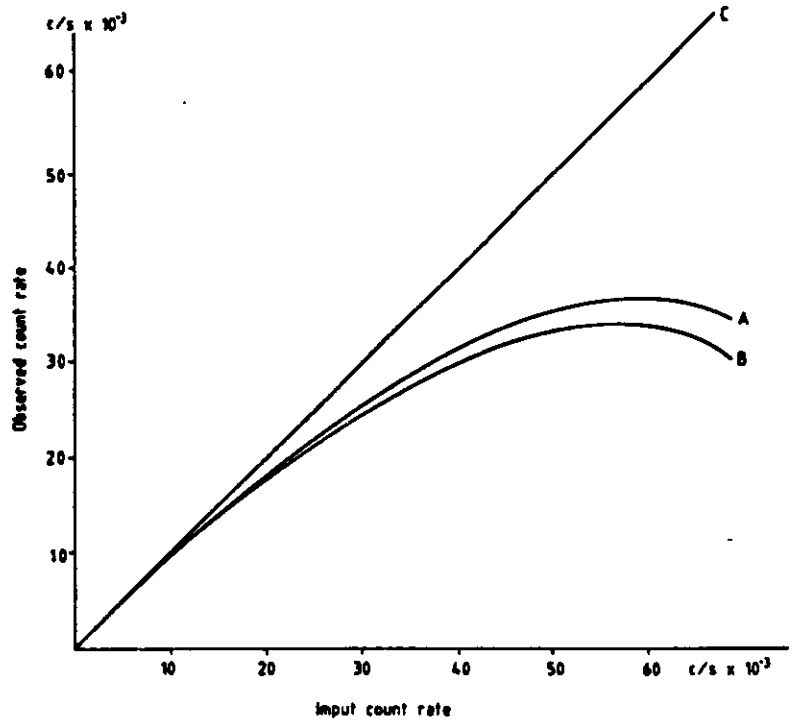


Fig. 6-20. Test 6.3.9: Test of Intrinsic Count-rate Performance (Alternative I). Graph of observed count rate against input count rate.

A: Observed count rate data obtained with scintillation camera alone.

B: Observed count rate data obtained on digital image processor.

C: Line of identity for no count loss.

Observations

This test is intended to be performed as an acceptance and reference test, and at half-yearly intervals.

If the scintillation camera is fitted with a high count-rate mode circuit, the test should be repeated with this circuit enabled. If a digital image processor is available, the observed count-rate data should also be acquired on the processor using the counts in a region-of-interest encompassing the entire digital image in the low and high count-rate modes. Similarly, if the camera is fitted with a uniformity correction circuit, the test should, if possible, be performed under all the above conditions with and without the circuit enabled.

At acceptance testing, it may be desirable to determine the performance at high count rate more accurately. This may be achieved by incrementing the total absorber thickness in steps of 0.1 cm instead of 0.25 cm, e.g. by using ten absorbers each 0.1 cm thick in place of the four absorbers 8-12 0.25 cm thick. The calibration of the thinner absorbers may be carried out as described for those 0.25 cm thick. (The corresponding values of f should be about 0.8.)

Interpretation of results

At acceptance testing, the graph of observed count rate against input count rate should be compared with the manufacturer's worst-case specifications. The values of $R_{-20\%}$ in the low and high count-rate

modes should similarly be compared with the manufacturer's worst-case values. The value of maximum count rate should be similarly treated. The effect of added peripherals such as a digital image processor should be particularly investigated.

At routine testing, the values of $R_{-20\%}$ and maximum count rate should be compared with the reference values.

Limits of acceptability

At acceptance testing, a value of $R_{-20\%}$ that is 10% or more below the manufacturer's worst-case value would call for corrective action initiated through the manufacturer's representative.

The acquisition of data on a digital image processor may cause some count loss resulting in a lower value of $R_{-20\%}$. A value of $R_{-20\%}$ obtained with data acquired on a digital image processor that is 10% or more below the corresponding value for the scintillation camera alone, would call for corrective action initiated through the representative of the image processor manufacturer.

At routine testing, a change in the value of $R_{-20\%}$ or maximum count rate by more than $\pm$ 20% from the reference value would call for follow-up action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.10: TEST OF INTRINSIC COUNT-RATE PERFORMANCE (ALTERNATIVE II)

Purpose of test

To test the intrinsic count-rate performance of a scintillation camera in terms of the count rate corresponding to a 20% count loss (Two-source method).

Materials

Two point sources each consisting of about 2 MBq (50 μCi) $^{99}Tc^{m}$ in solution in suitable containers. The count rate from both sources together under the conditions of the test should be similar to the manufacturer's specified or worst-case value for the observed count rate corresponding to a 20% count loss. The activities of the sources should be within 10% of each other.

Lead mask (see p. 147)

Procedure

1. Remove the collimator from the detector head. Turn the head to face horizontally.

2. Position the lead mask centrally on the crystal housing.

3. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

4. Suspend one source in air near the central axis of the detector and away from other objects so as to minimize radiation scatter, at a distance of 1 metre or more from the detector face.

5. Register the count for a sufficient time to accumulate a count of 10^6. Record the count rate.

6. Suspend the second source beside the first, but so that neither interferes the detector's view of the other. Register the count for the two sources for the same time period. Record the count rate.

7. Remove the first source. Register the count for the second source alone for the same time period. Record the count rate.

8. Remove the second source. Register the background count for the same time period. Record the background count rate.

9. Repeat steps 5, 6 and 7, reversing the order of the sources.

10. Remove the remaining source and lead mask. Replace the collimator.

Data analysis

1. Express all data as net count rates (c/s) corrected for background.

2. Calculate for each set of data the pulse-pair resolving time, τ, in seconds by

$$\tau = \frac{2R_{12}}{(R_1 + R_2)^2} \ln\left(\frac{R_1 + R_2}{R_{12}}\right)$$

where R_1 and R_2 are the net count rates of the first and second sources and R_{12} is the net count rate of the two sources together, all in c/s. Average the two values of τ to obtain $\bar{\tau}$.

3. Calculate the input count rate for a 20% loss, $R_{-20\%}$, by

$$R_{-20\%} = \frac{1}{\bar{\tau}} \ln\left(\frac{10}{8}\right) = \frac{0.2231}{\bar{\tau}}$$

4. Calculate the observed count rate for a 20% count loss, $C_{-20\%}$, by

$$C_{-20\%} = 0.8\, R_{-20\%}$$

Observations

This test is intended to be performed as an acceptance and reference test, and at half-yearly intervals. It may be performed as an alternative to test 6.3.9: Test of Intrinsic Count-rate Performance, Alternative I, but test 6.3.11: Test of Maximum Count Rate must then also be performed.

If the manufacturer's specifications are not available, the count rate of the two sources together should be about 20 000 c/s for scintillation cameras manufactured after 1978, and 10 000 c/s for cameras manufactured earlier.

In order to eliminate the effect of radioactive decay, the same lapsed time should be maintained between the three measurements in each data set.

An alternative to suspending the sources in air, is to place them 1 metre from the detector face with 6 mm or more thickness of sheet copper

interposed between source and detector. This method will also minimize radiation scatter (see Fig. 6-5).

If the scintillation camera is fitted with a high count-rate mode circuit, the test should be repeated with this circuit enabled. If a digital image processor is available, the observed count-rate data should also be acquired on the processor using the counts in a region-of-interest encompassing the entire digital image in the low and high count-rate modes. Similarly, if the camera is fitted with a uniformity correction circuit, the test should, if possible, be performed in all the above configurations with and without the circuit enabled.

Interpretation of results

At acceptance testing, the values of $R_{-20\%}$ in the low and high count-rate modes should be compared with the manufacturer's worst-case values.

At routine testing, the values of $R_{-20\%}$ should be compared with the reference values.

Limits of acceptability

At acceptance testing, a value of $R_{-20\%}$ that is 10% or more below the manufacturer's worst-case value would call for corrective action initiated through the manufacturer's representative.

The acquisition of data on a digital image processor may cause some count loss, resulting in a lower value of $R_{-20\%}$. A value of $R_{-20\%}$ obtained with a digital image processor that is 10% or more below the corresponding value for the scintillation camera alone, would call for corrective action initiated through the representative of the processor manufacturer.

At routine testing, a change in the value of $R_{-20\%}$ by more than $\pm$ 20% from the reference value would call for follow-up action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.11: TEST OF MAXIMUM COUNT RATE

Purpose of test

To test the maximum count rate of a scintillation camera. This test is to be performed only in conjunction with test 6.3.10: Test of Intrinsic Count-rate Performance, Alternative II.

Materials

Point source (see p.147) consisting of about 4 MBq (100 µCi) $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution in suitable container.

Lead mask (see p.147)

Movable stand with mounting for point source

Procedure

1. Remove the collimator from the detector head. Turn the head to face horizontally.

2. Position the lead mask centrally on the crystal housing.

3. Centre a 20% PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

4. Mount the source on the movable stand. Position the latter so that the source is on the central axis of the detector (Fig. 6-21). To minimize radiation scatter, the source should be away from other objects.

5. Register counts as the source is moved progressively closer to the detector face. The count rate will increase to a maximum and then decrease. Record the maximum count rate.

6. Remove the source, stand and lead mask. Replace the collimator.

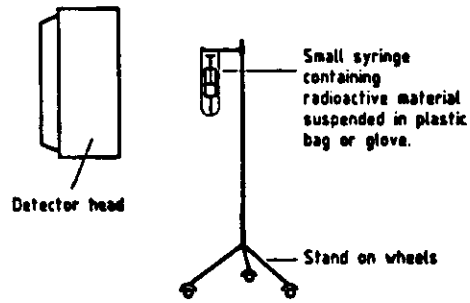


Fig. 6-21. Test 6.3.11: Test of Maximum Count Rate. Positioning of point source in relation to detector.

Observations

This test is intended to be performed as an acceptance and reference test, and at quarterly intervals.

If the scintillation camera is fitted with a high count-rate mode circuit, the test should be repeated with this circuit enabled. If a digital image processor is available, the observed count-rate data should also be acquired on the processor using the counts in a region-of-interest encompassing the entire digital image in the low and high count-rate modes. Similarly, if the camera is fitted with a uniformity correction circuit, the test should, if possible, be performed in all the above configurations with and without the circuit enabled.

Interpretations of results

At acceptance testing, the value of maximum count rate should be compared with the manufacturer's worst-case value with like circuits enabled.

This parameter is useful only as a camera characteristic which can be measured easily and routinely. In clinical imaging, the camera cannot be operated at the maximum count rate (see test 6.3.12: Test of System Count-rate Performance).

Limits of acceptability

At acceptance testing, a value of maximum count rate that is 10% or more below the manufacturers' worst-case value would call for corrective action initiated through the manufacturer's representative.

At routine testing, a change in the value of maximum count rate by more than ± 20% from the reference value would call for follow-up action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.12: TEST OF SYSTEM COUNT-RATE PERFORMANCE

Purpose of test

To test the system count-rate performance of a scintillation camera in terms of the count rate corresponding to a 20% count loss with the sources placed in a scattering medium (Two-source method).

Materials

Two radiation sources, each consisting of 70-260 MBq (2-7 μCi) $^{99}Tc^{m}$ in solution, in a volume of 5 ml and in containers which fit the wells of the phantom to be used. The count rate from both sources together under the conditions of the test should be similar to the manufacturer's specified or worst-case value for the count rate corresponding to a 20% count loss. The activities of the sources should be within 10% of each other.

Two-source scatter phantom (see p. 147) or one of comparable design.

Procedure

1. Mount a low-energy high-sensitivity parallel-hole collimator on the detector head. The same collimator must be used consistently in the test. Turn the head to face horizontally.

2. Centre the clinically-used PHA window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

3. Position the two-source scatter phantom on a support so that it is centrally against the face of the collimator with the wells vertical and 50 mm from the face.

4. Place one source in the phantom. Register the count for a sufficient time to accumulate a count of 10^6. Record the count rate.

5. Place the second source in the phantom. Register the count for the two sources for the same time period. Record the count rate.

6. Remove the first source from the phantom. Register the count for the second source alone for the same time period. Record the count rate.

7. Remove the second source from the phantom. Register the background count for the same time period. Record the background count rate.

8. Repeat steps 4, 5 and 6, reversing the order of the sources.

9. Remove the remaining source, phantom and support.

Data analysis

1. Express all data as net count rates (c/s) corrected for background.

2. Calculate for each set of data the effective pulse-pair resolving time, τ, in seconds by

$$\tau = \frac{2R_{12}}{(R_1 + R_2)^2} \ln\left(\frac{R_1 + R_2}{R_{12}}\right)$$

where R_1 and R_2 are the net count rates of the first and second sources and R_{12} is the net count rate of the two sources together, all in c/s. Average the two values of τ to obtain $\bar{\tau}$.

3. Calculate the input count rate for a 20% loss, $R_{-20\%}$, by

$$R_{-20\%} = \frac{1}{\bar{\tau}} \ln\left(\frac{10}{8}\right) = \frac{0.2231}{\bar{\tau}}$$

4. Calculate the observed count rate for a 20% count loss, $C_{-20\%}$, by

$$C_{-20\%} = 0.8\, R_{-20\%}$$

Observations

This test is intended to be performed as a reference test at the time of acceptance, and at quarterly intervals.

If the manufacturer's specifications are not available, the count rate of the two sources together should approximate 20 000 c/s for scintillation cameras manufactured after 1978 and 10 000 c/s for cameras manufactured earlier.

In order to eliminate the effect of radioactive decay, the same lapsed time should be maintained between the three measurements in each data set.

If the scintillation camera is fitted with a high count-rate mode circuit, the test should be repeated with this circuit enabled. If a digital image processor is available, the observed count-rate data should also be acquired on the processor using the counts in a region-of-interest encompassing the entire digital image in the low and high count-rate modes. Similarly, if the camera is fitted with a uniformity correction circuit, the test should, if possible, be performed in all the above configurations with and without the circuit enabled.

The two-source scatter phantom can be constructed locally from low-density materials if a plastic (e.g. Lucite, Perspex) phantom is not available. Suitable materials would be a plastic or wooden box filled with uncooked rice.

Interpretation of results

The values of $R_{-20\%}$ and $C_{-20\%}$ will be lower than the intrinsic values determined in Test 6.3.9: Test of Intrinsic Count-rate Performance, Alternative I or test 6.3.10: Test of Intrinsic Count-rate Performance, Alternative II, for which there should be manufacturer's specifications.

This test is, however, of more direct practical value, as $C_{-20\%}$ with scatter should not be exceeded in clinical studies, especially in quantitative cardiac studies. During the first-pass phase, the bolus of the radioactivity administered to the patient remains largely within the field-of-view. Its amount should be such that the count rate at this time remains well below the $C_{-20\%}$ limit obtained with data acquired on the digital image processor.

Limits of acceptability

At routine testing, a change in the value of $C_{-20\%}$ by more than $\pm$ 20% from the reference value would call for follow-up action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.13: TEST OF SYSTEM PLANE SENSITIVITY

Purpose of test

To test the response of the a scintillation camera to a radionuclide source of known activity.

Materials

Plane sensitivity phantom (see p. 147) containing an accurately known activity, about 40 MBq (1 mCi), of $^{99}Tc^{m}$ or ^{131}I in solution. The activity is determined by measuring in a radionuclide (dose) calibrator the syringe containing the radionuclide solution to be transferred to the phantom, measuring the residual activity in the syringe after the transfer and subtracting the latter from the former. The exact time of day corresponding to the activity determination is also recorded. A separate phantom is required for each radionuclide used.

Procedure

1. Mount a low-energy parallel-hole collimator on the detector head. Turn the head to face vertically upward.

2. Cover the face of the collimator with a plastic sheet. Place the phantom containing $^{99}Tc^{m}$ on the covered face.

3. Centre a 20% window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

4. Register the count for a sufficient time to accumulate a count of 10^4. Record the count rate and the exact time of day corresponding to the mid-point of the count.

5. Remove the phantom and register the background count for the same time period. Record the background count rate.

6. Repeat steps 1-5 for all other multi-hole collimators with energy ratings in the range 140-360 keV.

7. Repeat steps 1-6 with the phantom containing ^{131}I for all multi-hole collimators with energy ratings above 360 keV.

Data analysis

1. Express all data as net count rates (c/s) corrected for background.

2. Refer all net count rates to the time of day corresponding to the activity determination, making due allowance for radioactive decay.

3. Calculate the plane sensitivity for each collimator in c/s per Bq.

Observations

This test is intended to be performed as an acceptance test for collimators.

The accuracy of the results is clearly limited by the accuracy with which the activity of the radionuclide can be determined, which in turn depends on the accuracy of the radionuclide calibrator used. If this is within $\pm$ 5%, it is sufficient to indicate whether the sensitivities of different collimators are comparable to the manufacturer's specifications.

Even if the activity cannot be determined accurately, sensitivities may still be evaluated relative to that of a selected collimator. Manufacturer's specifications are commonly in terms of relative sensitivities, with the exception of one collimator for which the absolute sensitivity is given.

The test is instructive in illustrating the wide variation in imaging times which will be required to attain a given count using different collimators.

Interpretation of results

At acceptance testing, the sensitivity value for each collimator should be compared with the manufacturer's worst-case value, allowance being made for the accuracy with which the activity can be determined.

Limits of acceptability

If a sensitivity value is obtained that is 10% or more below the manufacturer's worst-case value for the collimator in question, the collimator should be checked for damage and action initiated through the manufacturer's representative with a view to its replacement.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.14: TEST OF DETECTOR HEAD SHIELDING LEAKAGE

Purpose of test

To test that the detector head of a scintillation camera responds only to radiation incident upon the crystal after transmission through the collimator.

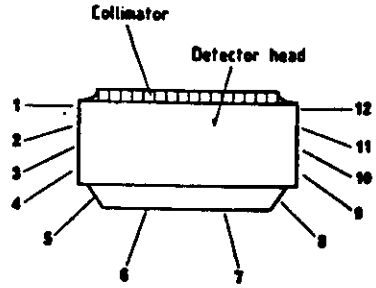


Fig. 6-22. Test 6.3.14: Test of Detector Head Shielding Leakage. Twelve sites around detector head shielding at which to position point source to test for shielding leakage.

Materials

Point source (see p. 147) consisting of about 4 MBq (100 μCi) of the radionuclide with the highest gamma-radiation energy, among those in common use, in small volume of solution in suitable container.

Procedure

1. Mount a collimator appropriate to the gamma-radiation energy of the source on the detector head.

2. Centre the clinically-used PHA window for the radionuclide concerned on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

3. Position the source consecutively at twelve sites around the detector head shielding and record the count at each site for a preset time of 100 seconds (Fig. 6-22). In addition, investigate sites of joints in the shielding, exit points of cables and other reduced shielding areas.

4. Remove the source and measure the background count, B, for the same time period.

Data analysis

Calculate the standard deviation of the background count, $\sqrt{B}$, and note any sites at which the count exceeds the background by more than three standard deviations, i.e. is greater than $(B + 3\sqrt{B})$.

Observations

This test is intended to be performed as an acceptance test.

Interpretation of results and limits of acceptability

The measured count should nowhere exceed the background count by more than three standard deviations. If any abnormal results are recorded, the test should be repeated after checks to make sure that there are no nearby radiation sources, including patients to whom radioactive materials have been administered, and that there is no radioactive contamination of the instrument or its surroundings. If the abnormality persists, the extent of the leakage should be thoroughly investigated and corrective action initiated through the manufacturer's representative.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.15: TEST OF SPATIAL RESOLUTION AND SPATIAL LINEARITY

Purpose of test

To test the spatial resolution and spatial linearity of a scintillation camera on a weekly basis.

METHOD 1: FLOOD SOURCE METHOD

To be used if an flood source is available.

Materials

Flood phantom (see p. 147) containing about 200 MBq (5 mCi) $^{99}Tc^{m}$

or

^{57}Co flood source of similar activity.

Orthogonal-hole transmission pattern (OHTP) phantom (see p. 147) matched to camera resolution. Optimal hole diameter and minimum inter-hole spacing, s, is given by s = FWHM/1.75.

Procedure

1. Mount a low-energy high-resolution parallel hole collimator on the detector head. The same collimator must be used consistently in the test. Turn the head to face vertically upward.

2. Position the OHTP phantom on the face of the collimator with the pattern carefully aligned with the X and Y axes of the detector face.

3. Place the flood phantom or flood source on the OHTP phantom.

4. Centre the clinically-used PHA window on the photopeak of the radionuclide concerned (see test 6.4.2: Check of Energy Calibration of PHA).

5. Acquire an analogue image on the display device with hard copy, at a preset count of at least 10^6.

6. Remove the flood phantom or flood source, and OHTP phantom.

Data analysis

Visually inspect the image, noting particularly whether the images of the holes are distinct and separated from each other by dark spaces over the entire field-of-view, and whether there are significant deviations from linearity in the X or Y direction over the field.

Observations

This test is intended to be performed as a reference test at the time of acceptance, and at weekly intervals.

The test may be performed with a Bureau of Radiological Health (BRH) graded-spacing-hole phantom, a quadrant-bar phantom or a parallel-line equal-spacing (PLES) phantom in place of the OHTP phantom. The OHTP phantom has the advantage that it allows the entire field-of-view to be examined simultaneously in both the X and Y

directions. However, its hole diameter and inter-hole spacing must be matched to the spatial resolution for a critical test. Selection of the appropriate phantom thus requires a prior knowledge of the resolution (unless a set of phantoms of differing hole sizes is available.

The BRH graded-spacing-hole phantom provides an estimate of the resolution, but must be imaged in two series of positions at 90° to each other for an examination of the entire field-of-view in the X and Y directions. The quadrant-bar phantom likewise provides an estimate of the resolution, but must be imaged eight times in all for an examination of the entire field-of-view in the X and Y directions.

If a PLES phantom is used, its bar width and inter-bar spacing must be matched to the resolution for a critical test. As with the OHTP phantom, therefore, selection of the appropriate phantom requires a prior knowledge of the resolution (unless a set of phantoms of differing bar widths is available). Moreover such a phantom must be imaged in two positions at 90° to each other for an examination of the entire field-of-view in the X and Y directions.

Interpretation of results

The image should be compared with the reference image and with recently acquired images to identify any changes and trends in either spatial resolution or spatial linearity.

If deterioration in resolution is noted in the entire image and a digital image processor is available, test 6.3.7: Test of Intrinsic Spatial Resolution, Method 2 should be performed to quantify the change. If the deterioration is partial, the same test should be performed for the region involved. If no image processor is available, test 6.3.7: Test of Intrinsic Spatial Resolution, Method 1 should be performed to estimate the extent of the change. Alternatively, an image should be acquired for this purpose with the OHTP phantom having the next larger hole diameter and inter-hole spacing.

Small deviations from linearity are to be expected, particularly with scintillation cameras without a uniformity correction circuit, but are difficult to quantify.

Deterioration in either spatial resolution or spatial linearity and would call for follow-up action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

METHOD 2: POINT SOURCE METHOD

To be used if an flood source is not available.

Materials

Point source (see p. 147) consisting 40-100 MBq (1-3 mCi) $^{99}Tc^{m}$ in solution in suitable container.

Source mounting for point source (see p. 193).

Orthogonal-hole transmission pattern (OHTP) phantom (see p. 149) matched to camera resolution. Optimal hole diameter and inter-hole spacing, s, is given by s = FWHM/1.75.

Procedure

1. Remove the collimator from the detector head. Align the head and the source mounting.

2. Position the OHTP phantom so that it is supported on the detector-head housing, and as close to the crystal housing as possible, with the rows of holes carefully aligned with the X and Y axes of the detector face.

3. Mount the source in the source mounting.

4. Centre the clinically-used PHA window on the photopeak (see Observations, test 6.4.1: Check of Energy Calibration of PHA).

5. Acquire an analogue image on the display device with hard copy, at a preset count of at least 10^6.

6. Remove the source and OHTP phantom. Replace the collimator.

Data analysis

As for Method 1: Flood Source Method

Observations

If $^{99}Tc^m$ is used, the point source method has the advantage of requiring a lower activity than does the flood source method. Further, it does not require the filling of a phantom and thus exposes personnel to a lower radiation dose. Its disadvantage is that it requires the collimator to be removed from the detector head, with increased chance of crystal damage. Whichever method is chosen, it should be performed consistently.

Interpretation of results

As for Method 1: Flood Source Method.

Conclusion

As for Method 1: Flood Source Method.

6.3.16: TEST OF TOTAL PERFORMANCE

Purpose of test

To test all components of a scintillation camera, including the display device and digital image processor under simulated clinical conditions.

Materials

Total performance phantom (see p. 147), either thyroid phantom containing about 7 MBq (200 μCi) $^{99}Tc^m$ or 0.4 MBq (10 μCi) ^{131}I or liver-slice phantom containing about 70 MBq (2 mCi) $^{99}Tc^m$ or a similar activity of $^{113}In^m$.

Procedure

1. Mount the usual collimator for the clinical conditions simulated on detector head.

2. Set all controls to the routine settings for the radionuclide concerned.

3. Centre the clinically-used window for the radionuclide concerned on the photopeak (See test 6.4.2: Check of Energy Calibration of PHA).

4. Position the phantom in a reproducible way close to the face of the collimator according to the clinical condition simulated.

5. Acquire an analogue image on the hard copy device, following the usual clinical techniques of the simulated procedure. If a digital image processor is available, also acquire a digital image. For the analogue image, adjust the intensity of the display so that the most active part of the image just fails to saturate the display medium.

Data Analysis

Visually compare the images with the reference image and with those obtained on recent occasions of testing, with particular regard to the visibility or otherwise of the simulated lesions.

Observations

This test is intended to be performed as a reference test at the time of acceptance, and at weekly intervals.

The basis of the test is the visibility or otherwise of the lesions in images acquired at regular intervals under identical conditions. Any deterioration in performance is detected earlier in such a test than in clinical imaging because the constant shape of the phantom and constant position and size of the simulated lesions allow direct comparison of images. The choice of phantom and radionuclide should reflect the clinical workload.

Interpretation of results

Comparison of the images with the reference images and with those obtained on recent occasions should show no degradation in performance and should satisfy clinical requirements within the capabilities of the instrument.

Special regard should be given to the visibility of the smallest simulated lesions, since this provides the most sensitive criterion by which performance may be assessed. Should a change be evident, more specific tests should be carried out to ascertain its cause.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.3.17: TEST OF MULTIPLE-WINDOW SPATIAL REGISTRATION (IF APPLICABLE)

Purpose of test

To test that the X and Y gains of each PHA are adjusted so that the images acquired at different photon energies superimpose when more than one PHA is used simultaneously in an additive or subtractive mode.

Materials

Point source consisting of about 40 MBq (1 mCi) ^{67}Ga in solution in a small vial, in a lead shield 6 mm thick and having a circular aperture 3 mm in diameter.

Procedure

METHOD 1 ANALOGUE IMAGE METHOD

To be used if an appropriate digital image processor is not available.

1. Remove the collimator from the detector head. Turn the head to face horizontally. Put a table directly adjacent to the scintillation camera as a source support. Place the source on the table.

2. If the scintillation camera has two PHA's, centre one 20% window on each of the 93 keV and 296 keV photopeaks. If three PHA's are available, centre two windows as above and centre a third 20% window on the 184 keV photopeak.

3. Adjust the source activity so that the count rate does not exceed 10 000 c/s in any PHA channel when the source is placed close to the exposed face of the crystal housing.

4. Position the source on the X^+ axis of the detector face at about 75% of the distance from the centre to the edge, noting the exact source position.

5. Acquire separate analogue images through each of the PHA channels on the display device with hard copy, at a preset count of at least 20 000 using the largest image size available. Adjust the intensity control so that no "ballooning" of the images occurs because of over-exposure of the film.

6. Repeat step 4 and 5 for a source position on the X^- axis at about 75% of the distance from the centre to the edge, and for similar positions on the Y^+ and Y^- axes.

7. Remove the source. Measure accurately the distances between the two X and the two Y source positions.

8. Replace the collimator.

METHOD 2: DIGITAL IMAGE METHOD

To be used if an appropriate digital image processor is available

1. Perform steps 1-4 of Method 1.

2. Acquire separate digital images in a 128x128 matrix through each of the PHA channels, acquiring a count of about 10 000 in the pixel with the highest count.

3. Repeat step 4 of Method 1 and step 2 above for a source position on the X^- axis at about 75% of the distance from the centre to the edge, and for similar positions on the Y^+ and Y^- axes.

4. Remove the source. Measure accurately the distance between the two X and two Y source positions.

5. Replace the collimator

6. Obtain print-outs of the counts in successive pixels in sections through the X and Y source positions on each image.

Data analysis

1. In Method 1, for each of the four source positions examine whether the locations at which the source appears in the analogue images obtained through the different PHA channels coincide when the films are exactly overlaid. In Method 2, for each of the four source positions examine whether the addresses of the pixels with highest counts in the digital images obtained through the different PHA channels coincide.

2. If the locations at which the sources appear or the addresses of the pixels with highest counts do not coincide, determine the displacements, in mm, in the X and Y direction for each image, using the measured distances between the source positions to derive a scale or a conversion factor in mm/pixel relating image distance to object distance.

Observations

This test is intended to be performed as an acceptance and reference test, and at half-yearly intervals. It should also be performed if degradation in the quality of images acquired with the simultaneous use of more than one PHA is noted.

Interpretation of results

At acceptance testing, preferably carried out by Method 2, the values of X and Y displacements should be compared with the manufacturer's worst-case values. The analogue method is not accurate enough to determine small displacements, but will alert the user to a large displacement that would affect the use of the multiple-PHA capability.

At routine testing, the values of X and Y displacements should be compared with the reference values. If the multiple-PHA capability is used clinically, the test should be performed on a routine basis.

Limits of acceptability

At acceptance testing by Method 2, a value of X or Y displacement that is 10% or more above the manufacturers' worst-case value would call for corrective action initiated through the manufacturer's representative.

At routine testing by Method 2, a change in displacement by more than $\pm$ 20% from the reference value would call for similar corrective action.

At either acceptance or routine testing by Method 1, significant observed displacement would call for follow-up action.

Pending corrective action, clinical studies with a single PHA channel could continue.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

TEST 6.4. OPERATIONAL CHECKS

6.4.1: CHECK OF COLLIMATOR AND DETECTOR HEAD MOUNTINGS

Purpose of test

To check the collimator and detector head mountings in a scintillation camera.

Procedure

Inspect all collimators and detector head mountings for freedom from mechanical defects with particular regard to the safety of patients and staff. Check the detector head drive mechanism for correct function.

Interpretation of results

Any abnormal finding should dictate immediate withdrawal of the instrument from operational use pending corrective action.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.4.2: CHECK OF ENERGY CALIBRATION OF PHA

Purpose of test

To centre the clinically-used PHA window of a scintillation camera on the photopeak.

Materials

Point source (see p. 147) consisting of about 40 MBq (1 mCi) $^{99}Tc^{m}$, $^{113}In^{m}$ or other radionuclide to be used clinically, in solution in suitable container, giving a count rate not greater than 30,000 c/s after completion of the calibration procedure.

Mounting for point source (see p. 147)

Procedure

METHOD 1:

Recommended method for scintillation cameras fitted with a multi-channel analyzer (MCA).

1. Without removing the collimator from the detector head, align the head and the source mounting.
2. Mount the source in the source mounting.
3. Set the PHA to the gamma-radiation energy of the radionuclide in use.
4. Centre the clinically-used PHA window on the photopeak, using the MCA display for this purpose.
5. Record all relevant control settings.

METHOD 2:

Alternative method for scintillation cameras not fitted with a MCA.

1. Without removing the collimator from the detector head, align the head and source mounting.

2. Mount the source in the source mounting.

3. Set the PHA to the gamma-radiation energy of the radionuclide in use.

4. Proceed according to the instructions in the operation manual.

5. Record all relevant control settings.

METHOD 3:

Alternative method for scintillation cameras not fitted with a MCA, if relevant instructions are not available.

1. Without removing the collimator from the detector head, align the head and source mounting.

2. Mount the source in the source mounting.

3. Set the PHA to the gamma-radiation energy of the radionuclide in use.

4. Select the clinically-used PHA window.

5. Increase the setting of the high-voltage control stepwise from a low initial setting, performing a count at each step and noting the count rate. Determine the exact setting of the control for maximum count rate.

Data analysis

Record the results on a control chart designed to cover an interval of about 3 months and showing high-voltage or PHA setting plotted against date on linear graph paper. If a change from previous values is observed, the procedure should be repeated several times in succession and frequently thereafter to monitor for short-term fluctuations.

Observations

The test can be performed with the collimator removed, provided that a point source consisting of about 4 MBq (0.1 mCi) of the radionuclide is used.

Interpretation of results

The high-voltage or PHA setting should be compared with the reference value and with recent values to identify any changes or trends.

Short-term fluctuations in the high-voltage or PHA setting of a scintillation camera may arise from unstable power supplies, temperature changes or electronic circuit faults. Long-term trends in the setting may indicate failure in one or more photomultipliers, deterioration of the crystal of physical separation of the photomultiplier-light guide assembly from the crystal. If short-term fluctuations occur, it will not

be possible to use the camera clinically until corrective action has been taken. If, however, the settings change only slowly, it may be possible to continue to use the camera, provided the energy calibration of the PHA is checked before each patient study.

Limits of acceptability

A change in high voltage or PHA setting by more than ± 10% from the reference value would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.4.3: CHECK OF FLOOD-FIELD UNIFORMITY AND SENSITIVITY

Purpose of test

To check the flood-field uniformity and, coincidentally, the sensitivity of a scintillation camera.

METHOD 1: FLOOD SOURCE METHOD

To be used if a flood source is available.

Materials

Flood phantom (see p. 147) containing an accurately known activity of $^{99}Tc^{m}$ or $^{113}In^{m}$, about 70 MBq (2 mCi) for a small field-of-view camera or 200 MBq (5 mCi) for a large field-of-view camera. The activity is determined by measuring in a radionuclide (dose) calibrator the syringe containing the radionuclide solution to be transferred to the phantom, measuring the residual activity in the syringe after the transfer, and subtracting the latter from the former. The exact time of day corresponding to the activity determination is also recorded.

or

^{57}Co flood source of similar known activity.

Procedure

1. Mount a low-energy, parallel-hole collimator on the detector head. The same collimator must be used consistently in the test. Turn the head to face vertically upward.

2. Place the flood phantom or flood source on the face of the collimator.

3. Centre the clinically-used window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

4. Acquire an image on the display device with hard copy, at a preset count of 10^6 for a small field-of-view camera or $2x10^6$ for a large field-of-view camera.

5. Record all imaging parameters, including the preset count, the count time and the time of day corresponding to the mid-point of the count.

6. Remove the flood phantom or flood source.

Data analysis

1. Visually inspect the image for non-uniformities.

2. For a flood phantom, calculate the activity of the contents at the time of day corresponding to the mid-point of the count by correcting for radioactive decay from the time of the activity determination. For a flood source, calculate the activity of the source by correcting for decay on a weekly basis.

3. Calculate the sensitivity in c/s per Bq.

Observations

The test should be performed on a daily basis in a manner to check the condition of the camera for clinical studies. Thus, if the camera has a uniformity correction circuit, the test should be performed on a daily basis with the circuit enabled. However, at the start of each week the test should, if possible, also be performed with the circuit disabled, to monitor for defects that may be hidden in the corrected images, e.g. from early failure of a photomultiplier.

It should be appreciated that the width of the PHA window considerably influences the measured sensitivity. The test should, therefore, always be performed at the same window width.

If a flood phantom is used, it should be checked that the contents are thoroughly mixed to provide a uniform source. If poor mixing is suspected, the phantom should be rotated through 90° and a new image acquired. Poor mixing is confirmed if the non-uniform features in the image move with the phantom.

Interpretation of results

The image should be compared with the reference image and with recent images to identify any changes or trends. The sensitivity value should likewise be compared with the reference value and with recent values.

No significant change in uniformity should be detectable. If non-uniform features are present, it may be possible to take account of them and proceed with clinical studies. This will depend on the nature of such features. In any case, the person who will interpret the clinical results must inspect the flood-field image and take responsibility for proceeding. Any corrective action needed should be initiated as soon as possible.

Change in sensitivity may indicate incorrect energy calibration of the PHA or could result from impaired energy resolution or non-uniformity in flood-field response.

Limits of acceptability

Any detectable change in uniformity would call for further investigation.

A change in sensitivity by more than ± 10% from the reference value would likewise call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

METHOD 2: POINT SOURCE METHOD

To be used if a flood source is not available.

Materials

Point source (see p. 147) consisting of a known activity, 20–40 MBq (0.5–1 mCi), of $^{99}Tc^{m}$ or $^{113}In^{m}$ in solution in suitable container. The activity is determined by measurement in a radionuclide (dose) calibrator, the exact time of day corresponding to the activity determination being also recorded.

Source mounting for point source (see p. 147)
Lead mask (see p. 147)

Procedure

1. Remove the collimator from the detector head. Align the detector head and source mounting.

2. Position the lead mask centrally on the crystal housing.

3. Mount the source in the source mounting.

4. Centre the clinically-used window on the photopeak (see test 6.4.2: Check of Energy Calibration of PHA).

5. Acquire an analogue image on the display device with hard copy, at a preset count of 10^6 for a small field-of-view camera or $2x10^6$ for a large field-of-view camera.

6. Record all imaging parameters including the preset count, the count, time, and the time-of-day corresponding to the mid-point of the count.

7. Remove the source and source mounting. Replace the collimator.

Data analysis

1. Visually inspect the image for non-uniformities.

2. Calculate the activity of the source at the time of day corresponding to the mid-point of the count by correcting for radioactive decay from the time of the activity determination.

3. Calculate the sensitivity in c/s per Bq.

Observations

The test should be performed on a daily basis in a manner to check the condition of the camera for clinical studies. Thus, if the camera has a uniformity correction circuit, the test should be performed on a daily basis with the circuit enabled. However, at the start of each week the test should, if possible, also be performed with the circuit

disabled, to monitor for defects that may be hidden in the corrected images, e.g. from early failure of a photomultiplier.

It should be appreciated that the width of the PHA window considerably influences the measured sensitivity. The test must, therefore, always be performed at the same window width. Equally, the distance between the source and the detector face must be kept constant.

If $^{99}Tc^{m}$ is used, this method has the advantage of requiring a lower activity than Method 1: Flood Source Method. Further, it does not require the filling of a phantom and thus exposes personnel to a lower radiation dose. Its disadvantage is that it requires the collimator to be removed from the detector head, with increased risk of crystal damage. Whichever method is chosen, it should be performed consistently.

Interpretation of results

As for Method 1: Flood Source Method.

Limits of acceptability

As for Method 1: Flood Source Method.

Conclusion

As for Method 1: Flood Source Method.

6.4.4: CHECK OF BACKGROUND COUNT RATE

Purpose of test

To check the background count rate of a scintillation camera under the conditions for routine clinical imaging with a particular radionuclide.

Procedure

1. Mount the collimator to be used on the detector head. Turn the head to face vertically downward.

2. Adjust the position of the detector head so that it is over the centre of the patient bed.

3. Set all controls to the routine settings for the radionuclide concerned (see test 6.4.2: Check of Energy Calibration of PHA).

4. Perform a count for a time of 100 seconds with no radiation sources in the vicinity. Record the background count rate.

Interpretation of results

The value of the background count rate should be compared with the reference value and with recent values to identify any changes or trends.

A significant increase in background count rate may indicate radioactive contamination of the instrument or its surroundings, or increased environmental radiation from local sources. Alternatively, it

may indicate electrical "noise". Radioactive contamination may be on the instrument itself, particularly on the collimator face, on the patient bed, on the floor, in the waste bin or even on the person carrying out the test. Local radiation sources may include patients to whom radioactive materials have been administered.

If an abnormal result is recorded, the test should be repeated after checks to make sure there are no nearby radiation sources, and that there is no radioactive contamination of the instrument or its surroundings. If contamination is detected, the area involved should be cleaned. Studies may then usually proceed if the detector and collimator are not directly contaminated.

An unaccountably increased background count rate should be monitored over a period of days to see whether it falls with radioactive decay or whether it persists. In the latter case, an electrical fault may be suspected.

Limits of acceptability

A change in background count rate by more than $\pm$ 20% from the reference value would call for further investigation.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.4.5: CHECK OF OSCILLOSCOPE

Purpose of test

To check the size and shape of the flashes on the display device with hard copy of a scintillation camera.

Procedure

1. With the flood or point source in place for test 6.4.3: Check of Flood-field Uniformity and Sensitivity, inspect the transient flashes on the oscilloscope screen.

2. Adjust the focus and astigmatism controls until the flashes are small and circular.

Observations

Large out-of-focus flashes will cause loss of image quality.

If an image formatter is used, this test is not applicable.

Interpretation of results

Failure to achieve well-focussed flashes may indicate that the oscilloscope is faulty. If the flashes appear as lines, the X or Y pulses produced by the scintillation camera electronics may not be flat, or the pulse-timing circuits may be out of adjustment. In any case, such a fault should be rectified forthwith.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

6.4.6: CHECK OF FILM HANDLING AND PROCESSING

Purpose of test

To check the adequacy of the film handling and processing for a scintillation camera.

Procedure

1. Visually inspect the flood-field image obtained in test 6.4.3: Check of Flood-field Uniformity and Sensitivity for lack of clarity, irregular background, streaks, smudges, signs of static discharge or any other defects such as may be due to inadequate film handling or processing techniques.

2. Check the temperature of the film developer.

Observations

The dark room should be free from light leaks and fitted with proper safety lights. The humidity must be sufficiently high to prevent static discharges which may occur when separating boxed film or loading or unloading film cassettes.

The chemicals used in processing must be replenished regularly and kept at a controlled temperature to assure consistent film density. Inadequate mixing of the developer will result in streaking or smudging.

Interpretation of results

Any inadequacies in film handling or processing techniques revealed by defects in the image should be rectified forthwith.

Conclusion

Record whether or not the results confirm acceptable performance. If not, indicate follow-up action taken.

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ANNEX I

Suggested Steps in Implementing a Quality Control and Maintenance Programme for Instruments in Nuclear Medicine

1. Inventory all instruments and accessories available in the laboratory, noting wherever possible manufacturer, model number, serial number, institute's inventory number, date of purchase, price and nearest representative responsible for maintenance and repair.

2. Collect into a centralized file the original documents for all instruments and accessories and (if possible) make copies of sections needed for general use. Include

   a) instruction manuals,
   b) maintenance manuals,
   c) spare-parts lists,
   d) trouble-shooting charts,
   e) circuit diagrams.

3. Designate a person to be responsible for overall quality assurance and maintenance activities in the laboratory.

4. Designate a person to be responsible for the routine quality control and record keeping for each particular instrument.

5. Formulate clearly written task descriptions for the persons nominated in steps 3 and 4.

6. Formulate the quality control and simple preventive maintenance procedures to be carried out on each instrument by the operational personnel. Specify for each procedure the person to perform the task and the frequency with which it is to be carried out. Further specify the person who is to review the results and make decisions concerning the operational status of the instruments.

7. Formulate the test and maintenance procedures to be carried out on each instrument by the maintenance personnel. Specify for each procedure the person who is to perform the task and the frequency with which it is to be carried out. The same person as specified in step 6 should review the results and make decisions concerning the operational status of the instrument.

8. Establish a log-book for each instrument. Include in the log-book the results of all installation, acceptance, reference and routine tests. Also include maintenance records. Organize the recording of test results by devising clear and concise forms.

9. Draw up flow charts for operational personnel, outlining stepwise processes for the performance of quality control and simple preventive maintenance procedures, the review of results, the decision alternatives regarding the status of the instrument, the steps to be taken to obtain maintenance services in the event of instrument failure.

10. Draw up flow charts for maintenance personnel outlining stepwise procedures for the performance of preventive maintenance and repair, including the procurement of spare parts.

11. Formulate instructions dealing with cleanliness within the laboratory.

12. Formulate a power-conditioning policy, including instructions for laboratory staff to follow in the event of a power failure.

13. Formulate policies and procedures dealing with the use of air-conditioners, dehumidifiers and ventilators.

14. Formulate policies and procedures dealing with the daily care and quality control of film processing equipment.

15. Formulate policies and procedures dealing with the safety and radiation protection practices for personnel and patients.

16. Formulate a patient flow policy with due regard to transient and background levels of radiation.

17. Procure necessary test devices for the implementation of quality control procedures.

18. Procure necessary tools for the implementation of preventive maintenance procedures.

19. Review administrative and budgetary policy to ensure allotments for the replacement of quality control and preventive maintenance devices as well as for the repair of instruments and the procurement and replenishment of spare parts.

ANNEX II

Scintillation Camera Quality Control
(Please attach images to back of sheet)

Instrument _____ Date _____ Time _____
Collimator _____ Orientation setting _____

RADIONUCLIDE _____ (identify)

Liquid Phantom _____ Sheet Source _____ Point source _____ (check one)
Activity _____ mCi Gamma Energy _____ keV

INSTRUMENT SETTINGS

Auto Peak _____ Manual Peak _____ (check one)
Photopeak setting (gain, "centerline" or preset) _____ Window _____%
If multiple PHAs, please identify 1 _____ 2 _____ 3 _____
Dot focus check on CRT (if accessible) YES _____ N/A _____ (please check)
Display format: transparency _____ polaroid _____ analog _____ digital _____
(check if applicable)

IMAGE PARAMETERS

	Field Uniformity Test	Spatial Resolution Test
Phantom Used	N/A	_____
CRT Intensity	_____	_____
Preset Count	_____ $X10^3$	_____ $X10^3$
Time (Seconds)	_____ s	_____ s
Background count	_____ c/s	

EVALUATION

Calculate photopeak consistency _____ % change (applicable only for manual settings)
Calculate sensitivity from field uniform acquisition data _____ c/s/mCi

Background Acceptable yes or no
Does image appear symmetrical on flood? _____
Does image appear uniform on flood? _____
If not, is uniformity clinically acceptable? _____
Smallest pattern resolved? _____ cm. Is pattern distorted? _____ If so, is distortion localized? _____
Other comments (any noticeable items needing attention)

_____ Technologist

_____ Reviewer