Chapter 9

MAINTENANCE OF NUCLEAR MEDICINE INSTRUMENTS

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Introduction

Maintenance of instruments is generally of two kinds:

(a) corrective maintenance, on a non-scheduled basis, to restore equipment to a functional status by repairs;

(b) preventive maintenance, to keep equipment in a specified functional condition by providing systematic inspection, quality control, detection and correction of early malfunctions.

Most of the instruments used in nuclear medicine are rather complex systems built from mechanical, electrical and electronic parts. Any one of these components is liable to fail at some time or other. Repair could be done only by a specialist who is able to evaluate the condition of the various parts ranging from cables to connectors, from scintillators to photomultipliers, from microprocessors to microswitches. The knowledge of the intricacies of the various electronic components required for their repairs is quite wide and varied. The electronics industry turns out more and more multi-purpose chips which can carry out the functions of many parts used in the instruments of the earlier generation. This provides protection against unauthorized copying of the circuits but it serves another purpose as well of inhibiting repairs by non-factory personnel. The situation is further complicated by the fact that most of the manufacturers do not supply manuals required for the repairs with the instrument. This practice dictates the present state-of-the-art of repair technology. The factory engineer usually repairs the instruments by board-swapping, where the faulty board is replaced by a factory tested one. Board diagnostics are done with a computerized tool. This style of repairs is undoubtedly quicker and efficient than the old style of on-site manual trouble shooting and component replacement. On the other hand, the redeeming feature of the new instruments is the fact that the reliability of the newer electronic components is far superior to that of the earlier parts. This means longer periods between failures and less calls for repairs.

These trends of the instrument design should be taken into consideration when a policy has to be developed for the repairs of the hospital based equipment.

The term **preventive maintenance** is not so well defined. Ask any ten maintenance engineers, to describe preventative maintenance, and you will get ten different meanings, because it varies widely in scope and intensity of application. Some think of preventative maintenance only in terms of periodic inspections to prevent breakdowns, some add repetitive servicing upkeep and overhaul to it. Further along the way are those who study the maintainability, safety, and fitness of the equipment for the intended task before it is purchased and installed. It is well established that prevention is better then cure and that a well designed preventative maintenance program will yield benefits far in excess of its cost.

The main reasons for establishing a planned preventative maintenance can be summarized as follows:

(a) to protect investment in equipment, through regular and adequate maintenance, thereby ensuring a long life expectancy of the instrument.

(b) to safeguard return on investment by maximizing equipment utilization with minimum downtime,

(c) to ensure performance quality,

(d) to prevent waste of materials, tools and spares,

(e) to guide and activate maintenance personnel,

(f) to help in cost containment.

Engineering demands

Before determining a policy for the maintenance of equipment, one should take an overview of the needs of the institution or existing system for services. These will be dependent upon many factors and may differ widely between hospitals and countries.

Maintenance requirements are dictated by the number of instruments, their use (and abuse), environmental conditions that may accelerate degradation and failure. The number and type of instruments depend on the size of the hospital, the nature of its speciality services, local health problems, the extent of liaison with other nearby medical facilities and economic resources.

The number and the nature of existing instruments are good primary indices of service requirements. Climatic conditions will influence service demands. Electrical and electronic components are vulnerable to damage from high humidity. Solid-state circuits are sensitive to excessive heat. Scintillators might crack due to quick temperature changes. Dust or similar airborne pollution can deteriorate equipment.

A large nuclear medical centre has unique demands for maintenance expertise, depending upon the services it offers. Generally the consequence of equipment failure must be considered in assessment of technical service requirement. The question can be put whether a delay in repairing an instrument would endanger lives by delaying diagnosis and treatment and increasing the period of the patient's stay in the hospital. If so, in-house trained technical staff or quick access to external help must be considered as a basic requirement.

The quality of public utilities (such as electric power supply) also affects the overall maintenance demands. Nuclear medicine instruments are vulnerable to transient voltage fluctuations beyond the normal limits of tolerance.

What kind of service facilities are required depends on what kind of work the nuclear medicine unit is set up to do. The nuclear medicine units are classified as follows:

Type C: only in vitro assays are done. No in vivo work.

Type B: In vitro plus a limited amount of in vivo work such as thyroid uptakes, renogram, and imaging with rectilinear scanner.

Type A: In vitro plus comprehensive in vivo nuclear medicine facilities including gamma camera and a computer.

Table I
A summary of services usually associated with various types of nuclear medicine units described above

Services	Type of nuclear medicine unit		
	A	**B**	**C**
Radiation safety inspection	-	X	X
Instrument calibration	X	X	X
In-house repairs	-	-	X
Emergency repairs	-	X	X
Preventive maintenance	X	X	X
Purchase evaluation	-	X	X
Site preparation	-	X	X
Acceptance testing	X	X	X
User instructions	X	X	X
Physicist, part-time	-	X	-
Physicist, full-time	-	-	X
Engineer,full-time	-	-	X
Technician, mechanic	-	-	X
Technician, electronics	-	X	X
Coordinated training for staff on quality control	X	X	X

In all units, there is a need for daily routine radiation safety inspection, instrument calibration/quality control and periodical technical instruction on the use of instruments. The Type C Unit is primarily an in vitro diagnostic centre, where a failure of the instrument does not require emergency repairs. Often Type B Units are unable to keep an in-house staff for repairs. But in small units the medical, paramedical and the nursing staff traditionally accept some responsibility for the basic maintenance and safe use of their instruments.

In most countries, inspection service for new equipment is not available and purchase evaluation is done only for major investments like computers and cameras.

What is the best maintenance policy?

The dependence of modern health care upon technology, makes maintenance of all medical instrumentation a vital necessity. Obviously, equipment will need maintenance and medical institutions at all levels must consider the establishment of a service structure for this purpose.

The determination of a maintenance service must take into accounts the restraints imposed by socio-economic conditions, geographic location, the environment, the level of medical expertise, the available technical know-how, and even political factors.

The economic aspects of hospital equipment maintenance are based on the standard managerial concepts. Unfortunately, it is not usually realized that it may cost more to maintain equipment than to buy it, and that such continuing expenditures must be considered as part of the total investment.The additional costs are incurred at breakdown because of disruption of normal procedures and possible non-utilization of the radiopharmaceuticals. In economic terms, poor maintenance will lead eventually and inevitably to a waste of the nuclear medicine unit's overall assets.

An effective program for management of nuclear medicine equipment must be based on a realistic appraisal of its cost and available financial resources. It will be always dependent on the money available. One must therefore eliminate areas of service that are out of economic reach.

If a local health care authority chooses to establish its own service agency, it should examine the cost of staff, training, testing and repair facilities, spare parts, communication and transport etc. It should then compare these costs with those incurred in hiring commercial services plus occasional dispatching of defective equipment for repairs to an outside agency. Sometimes it is practical to utilize the maintenance services of government departments, research laboratories, or universities, but the consequence of inadequate repair or excessive delay must also be considered in deciding on such an alternative. The effectiveness of maintenance and repair may be influenced by accessibility, in terms of time rather then distance.

A comprehensive maintenance policy may include both in-house and contracted services. It is realistic to use the latter where available and concentrate the in-house facilities for services that are less accessible in the region. Hospital directors mostly support the contracted services concept on the basis that it often provides better services for less cost. The general recommendation expressed in simple words is "do not compete with outside services, collaborate with them".

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It is an almost inevitable conclusion that some in-house technical maintenance will be required in Type A Units. It is rather important that it should not be merged with the regular hospital maintenance services. Such form of organization has been tried in many centres all over the world with little success.

The central service agency concept works well if provision is made for prompt response to the needs of more remote parts of the system. It may be supplemented by regional representatives whose function is to provide routine preventative maintenance and minor repairs.

Within the framework of combined Co-ordinated Research and Technical Co-operation Projects in South-East Asia and Latin America, the International Atomic Energy Agency helped the participating Member States in the development and implementation of national quality control and preventative maintenance programs.

The development policy recommended by the IAEA is rather straightforward. In all nuclear medicine units, the quality control of the instruments should be introduced. Preventive maintenance programs were suggested and supported under the first phase of the project to overcome environmental and power-line related hazards on the equipment. During the second phase, the IAEA helped to improve the skills in local repair facilities and provided the necessary tools needed for such a work.

Some facts: The national program on instrument quality control in Asia was initiated in Thailand and India in 1983, the Republic of Korea in 1984, and in Sri Lanka and Pakistan in 1986. Now in Asia over 120 Nuclear Medicine Centres participate and every year 3 - 5 more laboratories join it.

In Latin America nearly 200 laboratories were surveyed by the national project supervisors. Now in more then 150 laboratories quality control and preventative maintenance are regularly practised using the IAEA-TECDOC-317 as a guide book.

Personnel

Most of the instruments used in nuclear medicine laboratories are rather expensive. They are complex devices with thousands of components in a maze of interrelated circuits. The development of a new gamma camera electronics system might take years of work of a team of ten to fifteen highly skilled specialists.

It is understandable that no matter how highly skilled an engineer may be, he will not be competent to carry out repairs on a highly complex proprietary instrument, like a camera, unless he or she has had a training in the factory of the manufacturer. The problem is that most designs contain patented solutions to certain problems. Unless specifically trained by the manufacturer, one has to nearly re-invent the maintenance procedure; for example, the fine tuning procedure of a linearity correction. The situation might be further complicated if even the circuit diagrams are not available. Under such conditions a capability is required from the engineer to evaluate his/her limits in knowledge on the "least replaceable part" basis in specific cases.

Factories may authorize their trainees to conduct repairs on their instruments but only after acquiring the requisite skills. It is a general rule in industrial countries to allow repairs on cameras only by factory authorized personnel. Translating the concept into medical terms: one might not expect successful brain surgery from a dentist, although both might do drilling of some sort.

What training should the technical staff have in a nuclear medicine laboratory and where can they obtain it?

Since nobody is allowed to work in a radioisotope laboratory without a training on radiation safety this should be the first item on the list. Local courses for this purpose are available in most countries.

The entrance criteria for the technical staff should be set to a standard of at least a BTEC National or City and Guilds Part II Certificate or equivalent. Technical High schools can provide information on the compatibility of their degrees to those mentioned here.

For an in-plant camera course, a BTEC Higher National or City and Guilds Part III Certificate, a minimum of three years of practical experience and a successful language test are necessary.

According to experience the Part II Certificate holders can be effectively trained for the quality control tests but they should be provided with a technology guidance in a local language.

Some remarks: The curricula of the physicists in most countries do not contain the practical trouble shooting skills which are included in the Part II Certificate training. Do not expect such skills from physicists. You can be sure that the certificate level personnel will learn the quality control procedures in half a day. Strangely enough, most of the university graduates in electronics have similar problems, they are effective only in a team with a technician. Only thing, one can hopefully expect from an engineer or a physicist is an ability to read the instrument manuals and TECDOCS in their original versions!

It is worthwhile to list here the knowledge required from the maintenance staff for adequate servicing.

- Personal safety know-how in quality control, preventative maintenance and repairs (radiation, electrical, and mechanical)
- Quality control and operation of the instruments
- Test instrument selection and operational know-how
- Component tests and evaluation
- Circuit operation, expected signals and voltages in a good system
- Capability to understand operation and repair manuals
- Parts removal and replacement skills
- Safety of valuable components during testing and repair
- Diagnosis of faulty instruments
- Environmental hazards and protection measures
- Preventive maintenance planning
- Parts procurement, inventories, budget, costing.
- Self-evaluation on "least replaceable part" level.

What services can be expected from a Part III Certificate holder technician in a nuclear medicine laboratory?

He or she can reduce the number of faults traceable to environmental effects. They can repair most of the power-supply breakdowns. They can effectively run a preventative maintenance program. But they are unable to repair a computer or a camera without specialized training.

Selection of equipment

Choice of correct equipment to satisfy a specific clinical need is a complex medical, technical and a financial task. If coordination between specialists is poor, efficiency of the desired medical service will be impaired. It is often said that commitment to Quality Assurance starts from the purchase decision. One should join an ante-natal clinic soon after conception and not after delivery of the instrument.

Too often hospital administration is guided by the promotional literature, offered by manufacturers or agents, or on the opinion of a specialist who has just returned from a tour abroad. Often the technical guidance of the people likely to be involved in maintenance is omitted from the decision making process.

Ideally, the local technical staff can and should evaluate maintenance needs, and the general maintainability of the available instruments in the local milieu.

It may come as a surprise to many that initial investment in equipment may be smaller than the overall cost of its maintenance, site preparation and the installation. Often a relatively small savings, due to procurement on lowest tender basis, does not take into account the life long maintenance cost. Ultimately it may turn out to be a case of penny wise and pound foolish!

The wise purchaser should examine the after-sales policy of the seller, are they prepared to provide good services at reasonable price, do they have the proper number of factory trained engineers, is their spare parts backup from the factory is well organized, are they financially sound to survive market fluctuations.

One should try to collect as much information as is possible about the manufacturers from as many sources as possible. Sometimes it may be wiser to buy the same brand which is in use at other institutions and where the manufacturer has built up a good reputation for maintenance. In such cases, it is much easier to solve the problems of maintenance, personnel training, spare part stock keeping and, since other users are nearby, one can gain from their experience.

A few words on donated instruments. It could be rather frustrating to receive an expensive system which is not fitting into the local infrastructure. One should examine these cases in the same way as for a fresh purchase because we have to take care of it latter on. The rule is not to be shy, speak-up in time, it is much more embarrassing to say one year after the arrival that the donated instrument is not operating because its maintenance contract is so expensive that the hospital is unable to support it. Similar situations can develop from bad estimation on operating costs. Say the colour hard-copy printer of the camera needs an ink set twice monthly for a cost of US $189.99, but the hospital has the budget of only US $500 per year for all consumables.

One should be rather careful with the ordering of the equipment. The delivery should be requested so that when it arrives everything should be ready for its reception. Sometimes the building is not ready, or the air-conditioners will arrive much later than the expensive instrument. It could happen that the electrical network in the hospital is unable to give the required amount of kiloWatts and severe voltage fluctuations due to this may inhibit operations. Nothing is more frustrating than to observe a huge instrument case rotting unopened in the monsoon rains in the backyard of the hospital of a developing country.

Sometimes the buyers do not know that not only the instrument deteriorates out in the rain or under the sun, but all legal claims on damages can be lost if they are reported after the expiry date of the factory warranty. It is a general rule that all efforts should be made to install the new instruments as soon as possible.

Sometimes special accessory options are offered by the vendors for important investigations. Often they are unable to provide complete information on the special talents, if any, of the new instrument. One should analyze all offers carefully before the buying decision.For example one should not spend money on evaluating software for lung ventilation investigations done with $^{99}Tc^{m}$ labelled aerosols if the aerosol generator is unlikely to be available in the Unit.

Much care is necessary in negotiations for instrument purchase. Before one makes a decision the full technical specification should be obtained from all bidders. Such specifications should cover all components of the system and all options as well. Information must be available on power requirements. For example in SPECT systems rather powerful motors rotate the detectors. When they are turned on, the high current transients might trip fuses which were designed on the static power uptake data only. It is proper to seek advice from the manufacturer on capacity, and load distribution parameters of the line stabilizers. One can receive good answers if proper information is provided on local conditions like line voltage and frequency fluctuations and precise well formulated questions are asked.

Information should be at hand on temperature and relative humidity. Manufacturers can give information on requirements for expendable, their prices and availability in users area.

Quotations should indicate the price and terms, the date, mode and cost of delivery options (rail, ship, air), the nature and duration of warranty, and the cost and specific coverage of service contracts. Bear in mind that a factory engineer's service trip is rather expensive, when you have to pay for the travel expenses, hotel and daily allowance, service charges plus the price of the replaced components after the warranty period. One should be rather careful to make full use of the warranty given support.

The quotation should give information on the arrangements for installation, training on use, the accessories, spare parts, users and repair manuals, test devices, extension boards without which no repair or even board testings could be performed and expendable for the first year.

If you have an engineer or a technician with the above mentioned basic skills (Part III Certificate) a factory training could be negotiated. Some factories offer the training on the system which will be delivered, so your engineer might take part in the final quality control procedures on the same unit he or she will take care in the future. Such in-plant training could be very beneficial, because often the manuals leave out items considered "trivial" for the factory staff, but which could be essential for the understanding of the system to a new man who can ask for explanations on the spot. Certainly the efficiency of the training depends on the language, technical and learning skills of the delegated. It is good to send someone who will be able to train personnel at home on subjects learnt abroad.

A few words on selection policy. An instrument with average performance but with good service support may well be preferred, 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. Purchase price is an unreliable guide to what may be the total cost of an instrument. It is essential to allocate a reasonable sum, between 7% to 14 % of the capital cost annually, in order to keep instrument downtime under reasonable limits. Spare stocking is not a good investment. According to various surveys, an average of six percent was utilized in repairs only, the others lost value and were scrapped within ten years.

Site preparation

The placement of an instrument is largely determined by its expected use in relation to work patterns within the nuclear medicine unit. The availability of sufficient space, floor loading capacity in the case of heavy instruments like a SPECT, electrical power line and grounding, temperature and humidity control, protection against sand and air carried pollutants, good ventilation and lighting, easily washable floor and walls meeting isotope laboratory standards are all needed and should be taken into account appropriately.

One can have information from the manufacturers on required space, floor and electrical line ratings. They can provide drawings on recommended physical layouts, electrical connections and power requirements.

Less information is usually available for the proper design of the temperature and humidity control of these areas. The solution could be simple if the unit has been connected to the central air-conditioning system of the building. In such case one should follow up whether the services are on all day or only during daytime. If it is only a half-day type of service one should install an out-door type chilled water cooler to maintain stabilized temperature in the laboratory. According to the recommendations of the manufacturers the instruments should run day and night. In their stand-by mode they are dissipating several hundred Watts of heat which has to be removed.

If central facilities are not available an out-door type cooler should be installed. The window type units need more maintenance. Forced ventilation should be provided in compliance with the regulations for radiological laboratories and hospitals.

It could happen that due to energy saving regulations you encounter an opposition when you want to keep up the 24 hours cooling of the laboratory. Then fight. Temporarily, even for a week, a properly sized de-humidifier might save the condition of the instruments if they are switched-on. Under the worst conditions, you should try to turn on the instruments minimum twice weekly for two hours to dry them out. Under such conditions the instruments should be covered while idling.

A few words on the temperature of the instrument area. One should try to maintain a stable temperature between 24°C and 27°C in the laboratory. Much cooler,say 18°C, might cause problems in two ways. The first is related to the maximum temperature gradient which may occur in case of a lasting power break during daytime. Scintillators in the camera detectors are guaranteed for only less than ± 5°C/hour temperature changes, if this is greater then this, the crystal may break due to internal stresses. The greater the temperature difference between the inside and the outside temperature, the greater is the likelihood that the dangerous differential may crack a five to seven thousand dollars worth component.

The second problem with the cold laboratories is the moisture condensation on the equipment during power failures. If the instruments are switched-off they cool down to room temperature, say 18°C. If outside humid air enters the laboratory, moisture formation will take place on the coldest surface in the room that is on the instruments. The moisture might affect the high-voltage system first, then the corrosion of the mechanical parts will follow with increasing failure rate and latter with general degradation.

Power supply

Mains operated electronic instruments are designed to receive energy in form of alternating current within a specified frequency and voltage range. Instrument performance could not be maintained if the mains voltage or the frequency drops below the limits given in the specifications.

Voltage fluctuations may result from many reasons, some types need emergency interventions by electricians, others could be solved only by investments.

Symptoms of power failures and the remedies

Lights abruptly flare-up and diminish in intensity. In such cases all instruments, refrigerators, air conditioners should be disconnected as soon as possible to prevent burn-downs. Electrician should be called to check the ground cable connection at the three phase distribution box. This failure is caused by a loose electrical wire connection which has a high resistance. This resistance might heat-up, if high current flows through and it may cause fire. One can test the condition of the junctions by touching them, certainly in switched-off condition. This can give a rough but quick guidance what should be done. The exact approach is to measure the voltage drop on it with a sensitive voltmeter under full load.

Slow voltage variations with regular daily patterns is the typical case of an overloaded electrical distributing network. In a hospital, one should know whether the same variation appears at the main step-down transformer too. If not, then the problem could be overcome by means of a "dedicated power-line" serving only the nuclear medicine unit directly from transformer. If the same level of fluctuation could be measured, then a constant voltage transformer or a voltage stabilizer should be introduced between the instrument and the power line.

In some locations, the power failures are frequent during the working hours, resulting in a loss of measured data. The cheapest solution is to install a small motor generator. For five hundred dollars, one can buy a 250 VA unit which can overcome the problems of a Type C Unit. Some laboratories raise money for a so-called Un-interruptible Power Supply or UPS. This units contain batteries which are continuously charged from the mains. The stored energy of the battery is converted into AC and this feeds the instruments. The capacity of the batteries and the load determines how long can the UPS keep up the services during a power break. For example a 1 kVAh unit can deliver 2 kVA's for a half hour or 3 kVA's for 20 minutes. A local strategy should be developed for the power failures. One should decide on the priorities on the basis of available kVAh capacity. The running cost of a UPS is rather high, mainly due to the periodical battery replacement requirements.

In some areas severe problems might develop after the power brake. For a few seconds, the line voltage can be 50% higher then the nominal value. To overcome this problem drop-out-relays (DOR) are connected before the instruments. The DOR provides protection by a delayed action switch which gives energy to the instruments only after a minute when the switching-on transient has safely ringed down. Many air-conditioners and refrigerators are still not protected against this effect. In such cases the use of the DOR can be beneficial.

The IAEA has developed a DOR with some additional protective features against line voltage surges often encountered during tropical thunderstorms. If lightning strikes the overhead cables, short but very high voltage pulses might reach the instruments. The IAEA DOR can provide a high level of protection against such occurrences.

There are companies manufacturing voltage stabilizers or constant voltage transformers with built in DOR and surge arresters. These units are available in a wide range of power ratings meeting all kinds of needs.

A few words on instrument stabilization after a power brake. One should rely on the data provided by the manufacturer. This is the basic rule. Counters, sample changers and scanners are ready for use after 15 minutes in most cases. Some cameras without automatic uniformity and field correction might need two to twelve hours for stabilization. The best approach is to perform the IAEA recommended quality control tests after all fresh start-ups.

Air-conditioning

The operational temperature range of most nuclear medicine instruments is between 10° and 27°C. If the outside temperature is higher then this, the instrument area should be provided with proper cooling, sufficient to remove the heat generated by persons, instruments, lights etc.

One should take it into consideration, that in all nuclear laboratories, it is necessary to change the air several times every hour according to the Nuclear Safety Regulations. A scintillation camera and computer system plus patients, operators and medical staff together might represent 5 kWh or 12.400 BTU/hour maximum heat dissipation during working hours. This amount is less at night when the instruments are in their stand-by mode.

Without cooling, say, due to the breakdown of the central air-conditioning system of the hospital, the instrument area will be soon dangerously warm for the electronic system. In such cases, the instruments should be switched-off. Some instruments have thermal cut-off relays providing protection against overheating. However this is not available in all instruments and one should ask from the manufacturer on its availability in their product. If it is not available, one should be bought and installed.

If central air-conditioning is not available, then the use of out-door units are preferred against the window type air-conditioners. The periodical maintenance of these systems are essential for the safe operation of the electronics instruments. Filters should be cleaned regularly otherwise ice formation will take place and this increases the electricity bill.

Dust-free environment

As in all radioisotope laboratories the dust-free environment is a sine quo non condition. Floors and walls should be washable according to radiation safety regulations. It helps if street footwear and clothes are not brought into the laboratory. Frequent floor washing with clean water after vacuum-cleaning helps to keep up the necessary standards. Sweeping should be avoided. In some laboratories, the windows and the doors are not closely fitting. In such cases, first the necessary repairs should be carried out before the installation of the equipment. An un-clean radioisotope laboratory is a potential health hazard to the patients and the staff as well. The instruments are badly affected by the dirt in the laboratory environment. If dust collects on the surface of the electronics components, their cooling suffers and the elevated operational temperature leads to an earlier failure. Bad effect of sand on all mechanical systems is well known. During sand storms it is very important to switch-off and properly cover the instruments. The switching-off is needed to stop sand transfer into the systems by their own fans. After the storms, all air filters should be cleaned before returning to normal work.

Humidity control

Continuously running instruments are warm and since moisture formation takes place on the coldest surface in a closed system they are not affected by high relative humidity. Problems start when the instruments are not operating. Under such conditions, the instruments tend to be the coldest surfaces. If a de-humidifier operates in the room, the cooling coil of this device will be the coldest surface so the moisture condensation will be limited to that place. When a de-humidifier is not available, all instruments should be kept covered, this keeps them warmer by a few tenths of a degree and this can effectively inhibit the condensation.

Obviously de-humidifiers have only a limited capacity and they are efficient if the doors and windows are tightly closed. Rooms with persons and often opened doors could not be controlled properly by such techniques because a typical 200 watts power up-take unit can handle only 400 ml per hour while under tropical conditions more then 50 ml water can be present in a cubic meter of air.

Spares

In present day corrective maintenance, the circuit boards are replaced if they are faulty and the actual board repair is done in the factory with computer assisted diagnostic tools. Keeping in stock all the circuit boards which might be necessary for kind of eventual failures in the instrument, is a rather expensive approach. A typical board costs four to six thousand dollars. If the board is sent back to the factory for repairs, they charge 40% of the board's price even if it is a US $50 component which has to be replaced. The average cost of a service trip from Europe to Africa or from the United States to Latin America starts from US $6000. In an average camera there are eight to twelve boards so the spare kit will tie down a minimum of US $48 000. The interest from this sum if invested can provide for a service engineer's visit. The economics of spare keeping improves if more systems could be serviced by a central repair agency, having factory trained personnel with special tools, extension boards, pulsars and simulators supplied by the manufacturer.

The IAEA-TECDOC-426 [Troubleshooting of Nuclear Instruments] gives a list on components,tools and instruments needed in repair workshops.

Manuals

About ten years ago, it was natural to get not only the operators instructions with the equipment but the circuit diagrams as well. At the present time manufacturers provide circuit diagrams only on special order and the non-factory trained troubleshooters rarely have access to them. What is the problem and why did the manufacturers change their policy during the past years?

The development of complex systems like a SPECT is rather costly, it might be a few million dollars at least. The competition is strong and the unlawful utilization of technical achievements are easy if access to circuit diagrams is freely permitted. However there are other reasons too, for example, the protection of the local suppliers service organization. Only if the drawings are made available to them, there is some chance for a successful repair attempt by other parties.

Even if the drawings are available but you do not have the description of the alignment procedure, it takes quite a lot of sweat and luck to reinvent an efficient approach.

Sometimes the electronics boards are of the multi-layer type with surface-mounted parts, just like in computers. Without proper tools and parts-removal technology generally the repair attempts end up in the complete destruction of the board. A faulty, destructed board might cause more harm, so the policy of the manufacturer is not to provide any information in order to deter tampering.

The form of the operating manual has also changed. Earlier, it was a listing of the control elements only, latter some applications were included, now some contain a self-paced educational package with multiple choice tests as well. Some companies offer the manual both in paper and diskette form. The latter has advantages, one can make as many copies as it is needed and the loss of the diskette is less likely. Most company service engineers take their "repair manuals" in such form too instead of the heavy fat books.

Even if one might succeed in getting the repair manuals from the factory, one can make real use of it only if a factory-based training was provided.

Role of the international organizations

The IAEA has various programs to co-operate in the training of local specialists for nuclear medicine instrument maintenance. Within the frame work of the Asian and latter in the Latin American Regional Co-operative Agreements, national and multi-national training courses and work-shops were organized with the participation of local and foreign lecturers, on quality control, preventive maintenance and repair of instruments in nuclear medicine. In 1990, a similar program has started for Africa.

For individual training, fellowships are available both from the IAEA and from the WHO. Such programs are really beneficial if the delegated person already has acquired a good repair practice, has no language problems and is willing to transfer the acquired knowledge to the colleagues. The length of such fellow-ships range from one to six months. The in-plant training are rather intensive and more efficient then the others, because they are focused on that special equipment which is likely to be installed in the nuclear medicine unit.

According to surveys, out of four trained persons, one person is lost after the first year and a second leaves after the third year on an average from the delegating nuclear medicine unit. This is an area where the international organizations are unable to help. The proper "fixation" of the trained specialists has to be solved locally by providing adherent incentives.

Since 1979, the IAEA operates an emergency spare part supplying service, to overcome local convertible currency problems inhibiting the repairs. Every year, few hundred institutions are served from this spare part bank in Vienna with hard-to-get components.

Role of the PC in maintenance

In all fields of activities efficiency could be achieved only by good planning and conscious supervision. Personal computers can help these efforts if proper software are available. Organization of maintenance requires information from several data bases. First there should be an inventory on all the items which has to be taken care, second a data base must be available providing data on the estimated repair costs of the items and on their life expectancy. A data base should cover the available skills, tools, manuals, for the repair of the items. Data should be stored on the instrument locations , environmental and supply conditions. For work load capacity calculations there should be data on the estimated repair times and on the time required for the regular preventive maintenance and quality control inspections. If the number of items one should take care is under thirty the planning work could be done manually if proper training is available in the house to do this job. The advantage of the computer is that one can feed in data requested by the soft-ware and the organizational work, budget and replacement planning, preventive maintenance scheduling will be done automatically. The great advantage of the PC that it efficiently can monitor and supervise the work done. It can evaluate the local efficiency against the international standards and it can pin-point in which areas should be the available skills further developed.

A PC based system is able to analyze minute trend changes in instrument parameters, warning signals can be had much before major breakdowns occur. For example isotope orderings can be adjusted in a planned way to expected repairs or overhauls, such actions can save money and down-time.

In the future more and more educational soft wares will be available on quality control, and the operational and repair manuals will be on diskettes so the need for a PC will increase.

Troubleshooting

Standard electronics skills are not enough for the efficient repair of the nuclear medicine instruments, even nuclear instrument practice is not enough to handle properly a problem in a scintillation camera detector system. The minimal know how was condensed into the IAEA-TECDOC-426. Anybody wishing to know more on the subject should refer to this book as an introductory material.

The reliability of the electronics systems is increasing but the improvements are rather few in respect to cable and connector failures. The first question of the service engineers arriving to a bad instrument are generally whether the instrument was moved recently to a new location, because most of the cable problems are developed during such operations.

Often the board connectors are affected by the transportation and the engineer has to pull them out and push it back only to overcome the tiny misplacement leading to faulty operations.

The next item is to check the back-up battery of the computer memory unit. Sometimes even after a few days of switched off state, a two or more years old rechargeable battery might stop operations of an otherwise completely good system.

The next item on the quick diagnostic check-list is the power supply. To be able to check it certainly one should know where and what should be present for good operation. This test requires practice because a bad setting of a meter for example set for current measurements when the high voltage is attempted to be measured might destroy a H.V.

power-supply and even can cause a severe electrical shock. The rule is do not allow tampering with expensive instruments. Only personnel with proven and certified knowledge should plan the diagnostics and make decisions on the repairs. Generally power supply related problems are easy to identify and repair.

All operators should be informed how to switch-off the instruments in case of emergency:

- when smoke or burning cable smell is present,
- when sound of sparking is heard or displays blink,
- when loud or unusual sounds are heard from the system during operations,
- if collimator could not be securely fixed
- if movements are uncontrollable
- if detectors were contaminated by patients.

If outside help is needed for the repairs it is advantageous if information could be provided on the nature of the problem. It is absolutely essential to write down in the instruments log book the so called reference settings of the instruments. Before any diagnostic procedures, one should put all control elements into this reference setting and only after this one should start with the functional checks. If skills are available one should try to follow the signal in the instrument. Say if a radioactive source is before the detector, do we have the scintillation pulse, does the clock operate in the CPU etc. During the factory training all check-points are explained, even on some drawings, this information is provided so with some skill one could find out where the fault originates.

All information related to the instrument should be entered into a log book. The first page should be dedicated to the reference settings, on the second page should be the names of those operators who passed the test in operation skills. It is a good practice to have it in a written form who is permitted to operate the device.

The log-book should contain short description of the quality control procedure in *local language* and the results of the tests should be entered with date and signature. It is a good practice to mark on wall-charts the most important parameters of the tests. This approach helps to motivate personnel on the continuation of the quality control tests. If the head of the laboratory checks on every occasion this and explains the efforts of the staff to visitors. After the daily work a closing remark should be entered on special occurrences, if there were any.

It is very important that the last operator's name should be available in the records because in case of a breakdown, the service engineer will need information on the last hours of operation.

All repairs, transfers, room modifications, air-conditioner and voltage stabilizer repairs should be entered in the log book. It is a good practice to enter the cost of the repair as well to increase the feeling of the responsibility of the staff for the high value of the instrument.

Cost

Preventive maintenance proved to be a rather efficient approach for the reduction of the repair and major breakdowns related expenditures. Airlines spend more on preventive maintenance testings then on actual repairs because this is the only way to secure the necessary reliability needed for airborne transportation. In space technology, the spending is even higher on the preventive maintenance because the failure of a rocket might cost hundreds of million dollars. The relationship between reliability and cost of repairs and cost of preventive maintenance are given in the **Fig. 9.1.**

The important feature of the diagram is that a minimum exists in the total cost curve as the preventive maintenance is increased. It is a well established fact that bad environmental conditions reduce the mean time between failures compared to laboratories in mild climate The same laws apply for the electronic instruments, in this respect, as for human health or for automobiles.

The total cost curve, however, changes during the life of the instruments, they need more care as they are aging. It is a very important financial aspect of this problem, how long should one keep alive the instruments? The cost analysis gives different solutions in different economical systems. In high GNP category countries, the limit is under five years. In poor countries when they try to extend the life of already old instruments, they more often loose than gain. Old instruments fail more often, this increases the repair costs, down time increases and the cost of the old components is always higher because they are hard to get. In addition, the climatic stress also becomes more troublesome. In the preventive maintenance soft-ware of the IAEA some data is provided on the life expectancy of various instruments under various climatic conditions.

Mechanical safety hazards

More attention is usually paid to the electronics maintenance and repairs but the electrical and the mechanical components of the instrument are equally likely to break down.

To improve the signal-to-noise ratio of the nuclear detectors heavy metal shielding is put around them. They consist of two parts. A fixed part serves to reduce the background and an interchangeable part called collimator determines the field-of-view of the detector. The weight of the shielding of a single probe detector might be between 15 and 30 kg. In a scanner, this can be up to 60 kg, while it could be several hundred kilograms in a camera.

The weight of the collimators range between 7 and 25 kg.

Many accidents have been reported from time to time with these heavy parts from all over the world. While the mechanical designs of the modern systems have improved the safety features, many old units, still in use, are potential hazards. By regular preventive maintenance check-ups and proper administrative measures this problem could be overcome.

About 60 % of the accidents happen during the changing of the collimators. It happens often when the technician tries to change the heavy collimator without the factory supplied tool. It slips out from the hands and after falling can break bones, furniture and floor. In many cases, the part itself is distorted as well. Another 38% happens after the collimator is inserted into its place but the position securing mechanism is not functioning properly due to worn out screws, disabled locking mechanisms or plain carelessness in securing the locking system or screws as much as necessary. In such cases, the component may not drop too far down and with a little bit of luck, no one may be injured seriously but in any case, such accidents are quite unnerving to both the patients and the technicians.

In accident prevention, it is an effective administrative measure to give out orders that collimator changing should be done only with the proper factory supplied tools and after the insertion a second person should check the safe locking of the fixing mechanism. (Sometimes the problem is related to the physical strength of the technician; one should take care of this too).

The preventive maintenance check-up should evaluate the safety of the fixing elements and their operation, no worn-out or missing screws, distorted locking elements should be tolerated. The safety awareness of the operators should be maintained by repeated training on this subject.

Another hazard exists around the supporting and positioning mechanisms of the detector shields. Some of the probe stands are spring or weight balanced to make the positioning of the heavy detectors easy, and few have motors to move the detectors. In many of these stands, a steel rope and a pulley system connects the balancing system to the detector. Neglected maintenance, such as greasing of the rope and the pulley, might lead to accident because of the deterioration of these components. Care should be taken of the emergency brakes as well, because a corroded mechanism could not save the patient from a falling detector.

In the motor-driven-stands an acme screw system positions the detector in vertical direction. Preventive maintenance should be performed on a routine basis around this component. During a visual inspection, one should check for any debris from the bottom of the acme screw. All debris should be carefully removed and checked for metallic parts, because this is the early sign of wear or beginning of misalignment. The screw should be greased as often as possible with proper factory recommended quality and brand. It is very important that the grease should be rubbed on full acme screw length and the trolley must be run up and down to spread the grease evenly.

During the greasing, all loose bolts should be tightened. Cables near the screw should be checked for fraying, wear or friction effects because they can lead to accidents. The checking should include the operation of all limit switches and safety relays as well.

It is a sound practice to check the correct operation of the patient contour safety switches before each investigation to overcome physical trauma or discomfort to the patient.

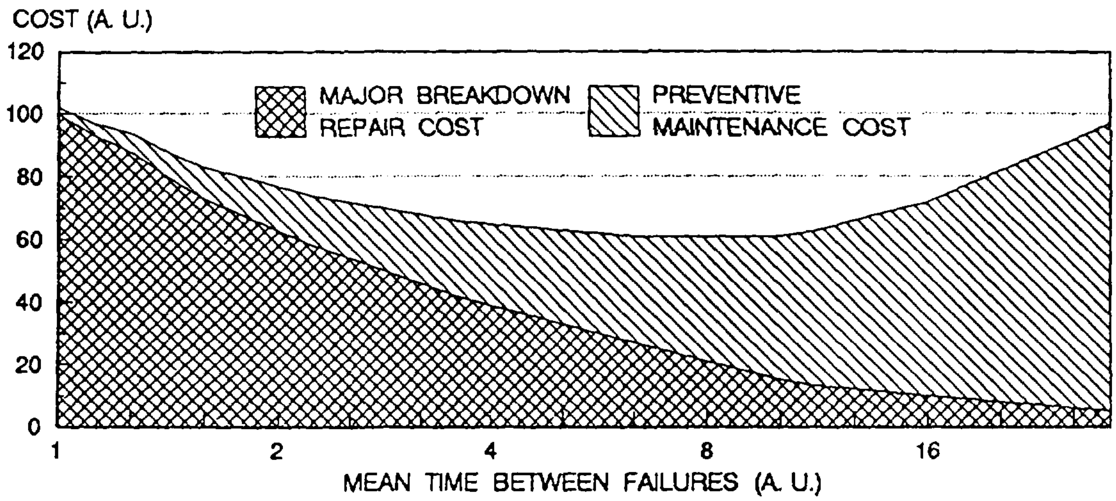

Fig. 9.1 Typical measuring instrument maintenance cost distribution versus mean time between failures.