Nuclear instrument maintenance – problems, solutions, and obstacles

by P.H. Vuister*

To guarantee reliable results and effective use of invested capital, maintenance and quality control of instruments are essential for laboratories involved in research, analysis of samples, and medical diagnostics. Badly maintained or inoperable instruments entail important economic losses and social hardship. Nevertheless, expert reports, technical co-operation requests, recent surveys on use and maintenance of nuclear medicine instruments, and many other sources, reveal frequent breakdowns and insufficient maintenance and quality control of nuclear equipment. Nuclear medicine instruments in particular, which are expensive and relatively sophisticated, need regular checks and are difficult to maintain in good working order, especially in developing countries.

Nearly all the IAEA's technical co-operation projects concerned with nuclear medicine have encountered problems with instrument maintenance. The Medical Applications Section of the Agency's Division of Life Sciences has therefore undertaken several actions on maintenance and quality control to remedy this situation. An advisory group met in December 1975 to evaluate the maintenance of nuclear medicine instruments in developing countries and, restricting itself to a qualitative description of the situation, recommended that unbiased surveys be conducted to determine more quantitatively the nature and extent of existing difficulties [1].

The Agency conducted the recommended surveys in approximately 200 laboratories in Southeast Asia, Latin America, and Africa over the years 1977 to 1980. The surveys gave a much clearer insight into the technical problems of instrument maintenance and also highlighted the human aspects of the problem [2, 3].

Based on the results of these surveys the Agency started a series of actions in 1979 to improve the efficiency, reliability, and quality of the work done in laboratories using nuclear instruments. This strategy has three components: laboratory conditioning; more effective strategies and practices in maintenance and quality control; and related training programmes.

Reasons for equipment failure

The surveys highlighted the following points:

- Equipment actually used in nuclear medicine laboratories was out of order on average at least 11% of the time; only a few laboratories practised regular quality control and preventive maintenance;
- Poor quality mains alternating current (AC) supply, lack of preventive maintenance, and often high humidity, were the main causes of breakdowns;
- Many of the faulty instruments were not repaired because spare parts were not available, or because laboratory staff and the manufacturer's representatives were inadequately trained. Often too, bureaucratic delay hindered the speedy repair of instruments.

The survey showed that it was the way repair cases were being handled rather than any possible poor quality in the instruments themselves which caused the long periods of instrument unavailability. Other information, gathered during recent regional meetings, suggests that instrument users and operators, the management and administration of the institutes and governments do not appreciate the value of maintenance. There is a corresponding lack of interest in quality control and preventive maintenance; unnecessarily sophisticated instruments are bought; budgets make no provision in either foreign or local currencies for maintenance and spare parts; the salaries of maintenance technicians are too low; and the purchase of parts, locally or abroad, is governed by cumbersome administrative rules.

Remedial actions based on this information have been formulated and partly brought into operation. They deal with the "conditioning" of the laboratories, that is, the instrument environment; the formulation and implementation of laboratory maintenance plans; the training of instrument users, operators, and maintenance staff in maintenance and quality control; the supply of spare parts; and the streamlining of administrative rules and regulations governing maintenance and spare part supply. The first two actions and, in part, the third are aimed at reducing the number of instrument breakdowns, whereas the others are aimed at reducing the down-time of the instruments once they have failed.

The actions are being undertaken in the framework of two co-ordinated research programmes: The RCA* project on the maintenance of nuclear instruments in Asia and the Pacific; and the co-ordinated research programme on the formulation and implementation of maintenance plans in Latin America. Both are being

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* Regional Co-operative Agreement for research, development, and training related to nuclear science and technology in Asia and the Pacific region.

supported and strengthened by an interregional technical co-operation project on the maintenance of nuclear instruments.

In the co-ordinated programmes, a total of 16 National Supervisors, nominated by their governments, have accepted a contractual obligation to engage in maintenance planning and practice in pilot laboratories, as well as in training activities, as proposed in the action plans adapted to local conditions. This obligation enhances the necessary development of laboratory- or country-based activities on instrument maintenance, quality control, and training. It creates an "I-do-it-myself" attitude needed to integrate these activities in the regular workplan of the participating laboratories and countries. The technical co-operation project supports these activities by regular visits of an itinerant expert and by the provision of the necessary equipment. The linkage of these two activities has proved to be very fruitful.

The progress and problems of the projects are discussed in yearly meetings in which the national supervisors, the itinerant expert and the project officer take part. The annual cost of this programme is approximately US $70 000 for the contracts, US $20 000 for the meetings, US $90 000 for technical co-operation, and US $5000 for travel of the project officer.

The surveys suggested that the number of instrument failures can be appreciably reduced by supplying good-quality AC power to the equipment, by controlling air temperature and humidity of the laboratories, and by preventing dust from entering the laboratories. To achieve these goals only a few, rather inexpensive technical measures are necessary.

AC power-conditioning

Electric power supplied to laboratories and houses is far lower in quality than is generally supposed. This has many causes: the ever increasing demand for electric power for industrial and domestic purposes in many countries causes overload of power plants and public distribution systems. The electric power for laboratories, housing areas, and small enterprises is often supplied through common stepdown transformers and distribution networks causing interference between the different consumers. The increasing use of electric appliances in laboratories and particularly in hospitals causes an overload in the internal distribution grid of those institutions. And, last but not least, in tropical regions contacts corrode and overhead supply lines are exposed to frequent lightning strokes.

All these features result in voltage fluctuations, short duration under- and over-voltages (sags and surges), power cuts and transients. Transients are voltage pulses that are very short (from 10 nanoseconds to several milliseconds) and very large (up to 10 000 V). They are caused, for example, by the switching of heavy loads and by lightning strokes.

Voltage fluctuations may cause instruments to malfunction and occasionally, in case of over-voltage, to break down. Power cuts and transients frequently cause breakdowns. Moreover, transients may also cause pulse-handling equipment, computers, and instruments controlled by microprocessors, to malfunction.

AC voltage was monitored in all 40 pilot laboratories involved in this programme to evaluate the quality of the mains supply and to find out what preventive measures had to be taken. An example of a 72-hour AC voltage recording in a hospital is given in Figure 1. Measurements were taken every two seconds. The figure shows that during working hours in the first day the mean voltage was around 220V, but that during the night it was 30V higher. During the day the voltage fluctuated continuously due to the ever-changing load on the supply lines. The voltage-drops at regular intervals were caused by the intermittent functioning of the compressor of an air-conditioner. The second day of the recordings was a public holiday on which less electricity was consumed for industrial purposes. The mean voltage during that day was higher than the day before and the fluctuations were fewer and less intense. Around 5.15 p.m. there was a slow voltage drop caused by the increasing use of electricity for lighting. During the third day, another holiday, the fluctuations had a somewhat larger amplitude and the air-conditioner seems to have been switched on again. The morning of the fourth day, a working day, showed many severe fluctuations and a drop in mean voltage to 220 V. The recorded points, as much as 20V below the mean, corresponded to sags caused by motors, for example in air-conditioners, being switched on. Transients are not visible in this recording because of their short duration. They are certainly present on the supply lines since they accompany all switching events, and it is clear from the recording that the latter occur frequently.

There is no doubt that the laboratory in this particular hospital needs power-conditioning, i.e. AC voltage stabilization, and filtering of transients. Most of the recordings made in other pilot laboratories show similar effects, indicating a general need for power-conditioning. Therefore, simple robust devices have been developed and tested to protect instruments from malfunctioning and breakdown caused by voltage fluctuations, power cuts, and transients. They consist of a drop-out relay, varistors, and gas discharge-tubes, as well as a specially-designed constant-voltage transformer. A drop-out relay disconnects an instrument from the mains at the moment when the power fails, so that the instrument is not exposed to the surges, sags, and transients that commonly accompany the restoration of power. The instrument can be reconnected to the mains manually or automatically two or three minutes after power has been restored. Varistors and gas-discharge tubes limit the amplitude of transients and absorb a large part

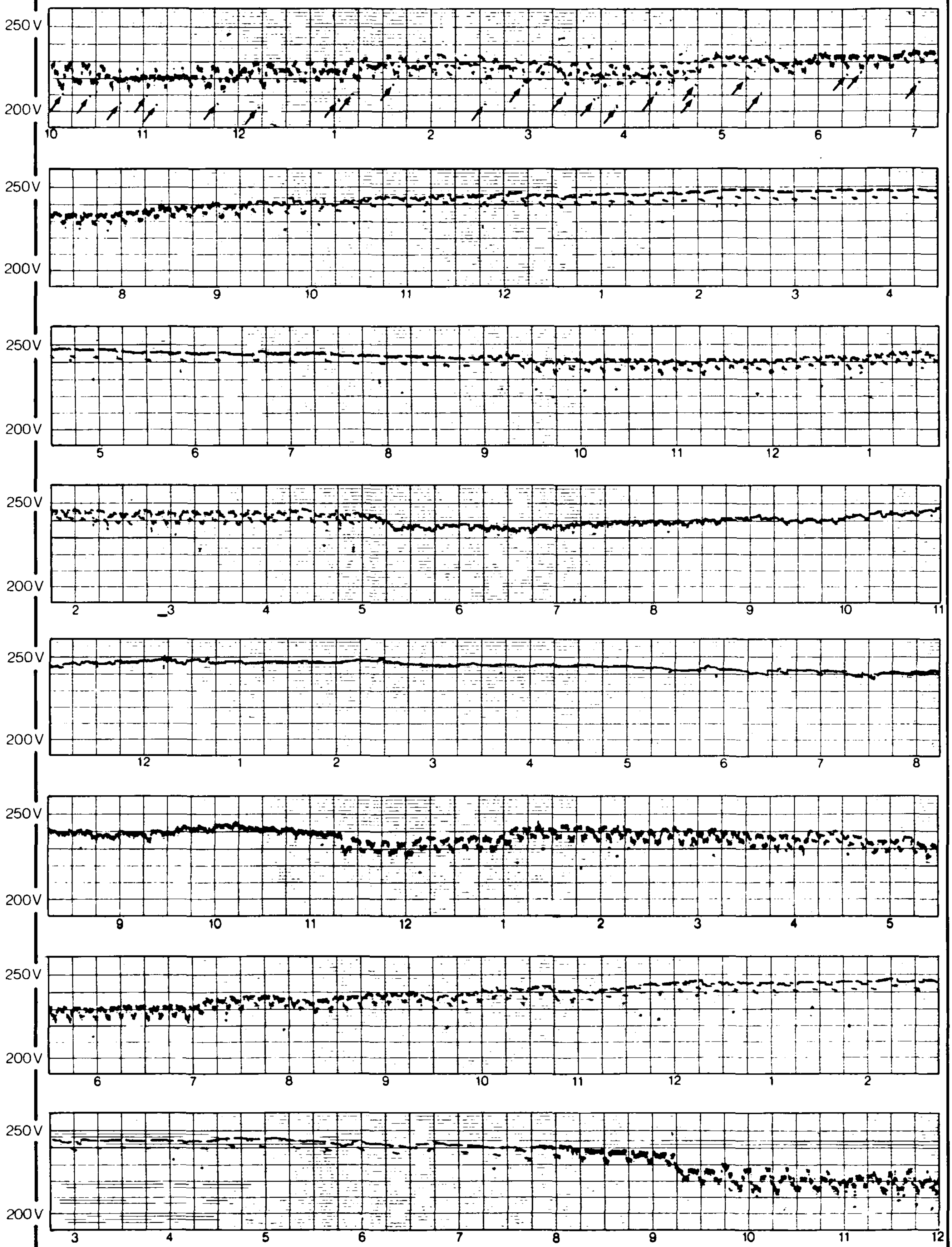

Figure 1. AC voltage as recorded in a hospital during 72 hours. The fluctuations shown are due to overload of, and parasitic resistance in, the utility- and institution-distribution systems.

of the energy contained therein. Constant-voltage transformers filter out the remaining part of the transients and stabilize the voltage. These power-conditioning devices can be used for most instruments. Over 50 of them have been installed in the pilot laboratories. For instruments containing motors which draw high currents when starting up, a slightly different approach is necessary. The Agency is currently preparing a detailed description of AC power problems and power-conditioning measures, including the appropriate approach for instruments containing motors.

Air-conditioning

It is generally believed that air-conditioning serves only the well-being of laboratory personnel. But modern equipment needs a stable temperature and moderate air humidity if it is to function reliably over long periods of time. When air-conditioning *is* provided, people usually assume that window air-conditioners will create environmental conditions suitable for instruments. Recent measurements, made in the framework of the projects, have shown that this is not necessarily true.

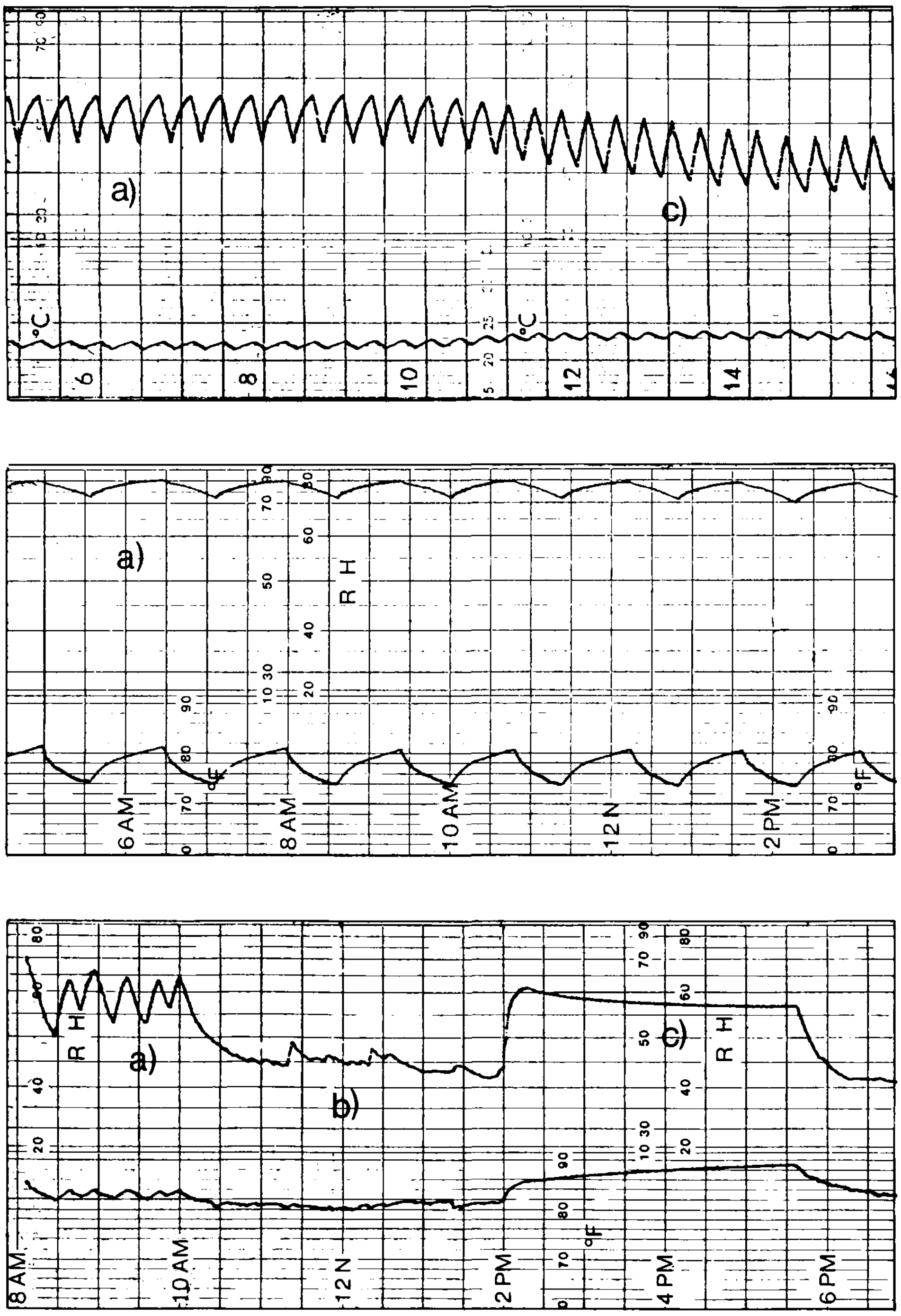

Figure 2.
Typical recordings of the relative humidity and temperature in rooms with window air-conditioners.
(a) Coincident rises and falls in humidity and temperature are seen during periods in which the air-conditioners are controlled by their thermostats.
(b) A relatively steady low relative humidity interrupted by rises caused by opening of doors is seen when the air-conditioners cool the air continuously.
(c) The mean relative humidity falls when the temperature rises, as is expected for enclosed humid air.

The fundamental problem is that high-voltage equipment often breaks down in a very humid environment. Moreover, fungal growth and corrosion slowly create pathways for leakage currents and poor contacts, respectively, giving rise to malfunctioning of instruments.

A survey was done of the effectiveness of the existing air-conditioning systems in the pilot laboratories, recording the air temperature and humidity. The results showed that most of the air-conditioners were in use only during working hours. This allowed the humidity to build up and water to condense on cold instruments during the rest of the day. It was also found that during working hours the air-conditioning systems were often insufficient because the heat insulation of the buildings was inadequate and because windows and doors had not been properly sealed against inadvertent intake of humid and warm air. It was also a great surprise to discover that window air-conditioners are sufficient dehumidifiers only when they are cooling the air continuously. When their cooling action is controlled by a thermostat, as is common, periods of decreasing temperature and relative humidity alternate with periods of increasing temperature and humidity. This can give rise to occasions when the relative humidity is higher than acceptable for the instruments. This effect is shown in Figure 2. Air entering the laboratory through poorly sealed windows and doors could not cause this effect. Apparently humidity is brought into the laboratories via the window air-conditioners themselves when, during non-cooling periods, the water previously condensed on the cold grid is evaporated again.

In the Agency's projects, simple measures are being taken to reduce heat and humid-air intake into the laboratories. They consist mainly of mounting automatic door-closing devices, and installing double windows by fixing transparent plastic sheets in front of existing windows. When properly mounted, these sheets prevent humid air and dust from entering the laboratories and, since the air enclosed between window and sheet acts as insulator, they diminish appreciably the laboratory's heat intake through conduction. Tests are being carried out in the pilot laboratories to determine the effectiveness of these measures. It is planned to investigate also whether the large fluctuations in humidity can be reduced by using two small-capacity air-conditioners instead of one large-capacity device. One would be used to cool the air continuously day and night, while the other would be used only during working hours. The energy saved by the measures described will also be investigated.

Difficulties with maintenance management

One would not expect to encounter many difficulties in making and executing a laboratory maintenance plan which contains a time-schedule, and a description of all quality control and preventive maintenance actions which have to be undertaken to guarantee an effective and proper use of all instruments and equipment. What actually has to be done can be deduced from the work carried out with the instruments and from their maintenance manuals. One would also not expect a physician or a scientist using the instruments to have great difficulty in implementing such plans. The surveys and investigations have proved that such difficulties are common.

In three training courses, two seminars, several local workshops and training courses, and five co-ordination meetings, the principles of quality control and preventive maintenance have been taught and discussed. An itinerant expert and the project officer have visited almost all pilot laboratories. National supervisors have tried continuously to introduce maintenance strategies. Flowcharts, organization charts, maintenance and quality control schedules and protocols have been written. Despite all these actions, only some four out of 40 laboratories have been able to practise quality-control and preventive maintenance.

Why is there this resistance to quality control and preventive maintenance? At present, only observations and preliminary conclusions of the regional project meetings can be reported: Many users of instruments and heads of laboratories do not seem to appreciate the value of quality control and preventive maintenance for the proper functioning of their laboratories. The positive influence these activities may have on their work does not appear to be recognized. From the side of the management and the administration one often hears complaints about lack of maintenance. However, maintenance staff's requests for budget provisions, for maintenance and spare parts, for petty cash in local and foreign currency to buy urgently needed replacement parts, for more maintenance personnel, for better salaries for technicians, for more co-operation with the maintenance personnel, for more training, for better tools and workshop facilities, and many others – these requests remain unanswered by the administrators.

Other circumstances which hinder the implementation of quality control and maintenance plans are: frequent changes in staff due to the "brain-drain" of staff members to better-paid jobs in private firms and industry; lack of motivation on the part of instrument operators and maintenance technicians because of poor pay, lack of recognition of the value of their work, and low status; frustration among maintenance staff due to lack of co-operation on the side of the administration; insufficient skill in the maintenance of the more sophisticated instruments; and lack of maintenance tools and spare parts.

Despite the difficulties mentioned, national supervisors are continuing their efforts to implement maintenance strategies in the pilot laboratories. They make a strong appeal to all administrators, managers, and government officials involved to give the necessary support to their efforts to create well-functioning laboratories, to prevent the loss of big investments, and to stop the disappointment of so many people who suffer under the present situation, for example, hospital patients whose illnesses are wrongly diagnosed, or not diagnosed at all, as a result of defective equipment.

Training the trainers

Training is the best investment one can make in maintenance and quality control. The more people who know about maintenance and quality control, the higher will be the awareness of their value, the better will be the quality of the work carried out, and the lower the losses on investments made in laboratories and instruments.

The Agency has always recognized the value of training. An appreciable part of its technical co-operation programme consists of training [4]. But training needs are much greater than the Agency can ever fulfill and Member States can never become self-reliant in the nuclear field if they are not able to train their staff in the main aspects of nuclear instrumentation. Therefore, local training has to be promoted. In any case, training abroad is very expensive. The cost per student of a three-month training course is as high as the cost of a six-week expert's mission. In six weeks an expert could help local teachers set up local training courses for ten or more technicians and if necessary help conduct the first of them. This, together with the fact that the costs for board and lodging are much lower locally than abroad shows that such training would be more cost-effective. Local training would have many other advantages. It would promote the development of local skill and infrastructure for training in instrumentation. It would promote the status of training to what it should be: a natural and integral part of nuclear institutions. It would facilitate coping with the frequent loss of trained manpower to better-paid jobs. And, last but not least, it would save money for advanced training which can only be realized abroad. Additionally, the candidates for such advanced foreign training could be better selected on the basis of their skill and willingness to return to their respective institutes after their training abroad.

To promote local training a Train-the-Trainers Workshop was conducted in 1981 in Kuala Lumpur, Malaysia, in the framework of the RCA project on the maintenance of nuclear instruments in co-operation with the RCA/UNDP Industrial Project. Twenty participants from ten different countries discussed and practised many facets of preparing and conducting training courses for maintenance technicians and for instrument users and operators.

During 1981 and 1982 a total of 14 local training courses were prepared and conducted by former Workshop participants. Special attention was paid to practical exercises and to mechanical, electrical and electronic tests, and maintenance of instruments. In two of the participating countries the courses were given in the local language. The itinerant expert of the interregional technical co-operation project and two other experts assisted in 10 of these courses by occupying themselves with those topics for which local training skill was not yet adequate. Electronic parts and equipment needed for these courses have also partially been provided under the interregional project.

Syllabuses, results, and possible improvements of these courses have been discussed during the annual meetings. One possible improvement brought forward is the introduction of one-subject courses lasting only a week instead of the courses on many subjects lasting four to six weeks given until now. Such short courses would hamper less the regular task of the teachers and allow for a better selection of the students.

The Train-the-Trainers Workshop and the following local courses have proven the existence in the Asian and Pacific region of many skills and much interest in training.

The regional projects on the improvement or introduction of instrument maintenance and quality control in pilot laboratories in Asia and the Pacific and in Latin America have been partially successful. Clear progress has been made in the fields of power- and air-conditioning and local training and maintenance technicians. The execution of preventive maintenance and quality control programmes is still hampered by the lack of appreciation of their value. Projects on spare-part supply and streamlining of administrative rules and regulations are under preparation. The combination of co-ordinated research programmes (which require an "I-do-it-myself" attitude and enhance a friendly rivalry through yearly regional evaluation meetings) with an interregional technical co-operation project, which supplies the assistance of an itinerant expert and some equipment, has proved to be very fruitful. It is the view of all participants in the projects that a real break-through in maintenance planning and execution can be made only after the administration and management of the institution and the governments give the necessary full support for these economically and socially important actions.

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