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RESEARCH AND TEACHING NUCLEAR SCIENCES AT UNIVERSITIES IN DEVELOPING COUNTRIES

REPORT OF A TECHNICAL COMMITTEE MEETING
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CONTENTS

FOREWORD

The success of a nuclear programme in a developing country depends to a large extent on the ability of the local educational institutions to train scientists, engineers and technicians. The establishment of a workable training scheme in a given field is not an easy task. It depends on many factors: the needs of the country, the experience and inclination of the professional teaching staff, the availability of the experimental facilities or funds for their acquisition, the degree of industrial development.

The increasing interest of developing countries to form good local training opportunities is demonstrated in the large number of technical assistance project proposals received by the IAEA every year. The Agency's staff is requested to advise on such projects, and implement them if they are approved. In all stages of the projects' implementation, the Agency is seeking and receiving assistance from experienced scientists and academic teachers in the Member States.

Another step in this direction was made in 1981. From 1 to 5 June, a group of experts met in Argonne National Laboratory, following an invitation by the Government of the United States of America. Under the title of a Technical Committee on Research and Teaching Nuclear Sciences at Universities in Developing Countries, the group tried to formulate a set of ground rules to be applied when introducing or improving nuclear science training.

The Committee was composed of physicists, chemists and electronics experts. Accordingly, the summary of their observations and recommendations refers only to physical science: physics, chemistry and electronics, although many of the general statements can be applied to other branches of university-taught subjects.

It is realised that the present summary of the discussions of this meeting is not to be considered as a complete analysis and an ultimate recommendation on introducing and promoting nuclear science training. Nevertheless, it might be of interest and use for the staff of those universities in developing countries that are initiating the activities in nuclear science and technology.

PART 1.

Nuclear Science in the University

A decision to introduce or expand nuclear science teaching at a university can follow one or more of the following initiatives.

1. The national authority responsible for nuclear affairs can develop a programme on nuclear activities in the country, and can present manpower requirements schemes to higher educational institutions. Such a programmed demand is not unusual in those countries with serious intentions of embarking on a nuclear power programme. It is, however, seldom found in the topics of applying nuclear techniques and radioactive isotopes in the national economy.

2. The request for suitable academic education can appear directly from the institutions dealing with research and application of nuclear methods: medical laboratories, agricultural research centres or industry. However, a clearly specified request from such institutions is a rarity: only in exceptional cases are they mature and advanced enough to consider nuclear methods in their work.

3. Most frequently, the staff of a university, by itself, realises the challenge of nuclear science research and education, and formulates a programme - almost as a rule copying a nuclear programme of a university or technical school of an advanced country.

Whatever the history of the decision to go "nuclear", the introduction of nuclear topics in the university curriculum, requires two kinds of resources: manpower (professors, assistants, technicians) and equipment (for laboratories for experimental work). In particular for graduate studies, the costs of the necessary resources can be very high.

Some general arguments in favour of nuclear science at a univerity are summarized below:

A. Frequently, a simple analysis of the nuclear technology and science manpower demand in a country speaks strongly in favour of nuclear science training. As a rule, the nuclear medical centres in developing countries show a severe shortage of qualified radiochemists, radiation protection and dosimetry physicists, and instrumentation maintenance staff. Those agricultural research centres which utilize nuclear techniques are usually understaffed. If a country has reached a certain level of industrialization, the needs for analytical chemists familiar with nuclear techniques rapidly increases. It obviously calls for an appropriate university training scheme in which manpower requirements can be documented.

B. By examples from countries where nuclear techniques and methods have been successfully introduced in industry, it is not difficult to demonstrate the economic relevance of these techniques. There should be an institution in every country where nuclear methods can be studied, to enable the transfer of nuclear technology from advanced to developing countries, and from the research stage to application. An appropriate university programme can fulfil this function.

Problems of development in a country cannot simply be solved by importing the necessary technology from advanced countries. A given technology is usually designed for a particular physical-social-economic environment and so it is necessary to modify technologies when they are transferred. This will be successful only if a number of good scientists are available and qualified to adapt to new technology. This is the reason why education should be extended on a large scale, from the secondary school to the university.

C. It might be advisable to relate the introduction of nuclear science to a university with a concrete project, particularly in countries where the specialized research laboratories do not exist. Use of nuclear techniques in geological mapping, studies of malnutrition effects, or determination of trace elements in plants are some examples. The parallel development of such a project and the training capability can be a good way to start.

D. It is possible to demonstrate the power of a nuclear technique by contributing to an on-going project. The special features of nuclear methods, for example by using radioactive tracers, can add a new dimension or a better solution to a given problem.

E. There are a number of nuclear techniques which are unique or superior to classical methods. The high sensitivity of nuclear analytical methods, the application of radioactive isotopes or accelerators in industrial radiography, the speed and resolution of nuclear medical diagnostics cannot be neglected. At some time, every developing country reaches the level when the use of such techniques becomes an absolute necessity. Operation of the associated nuclear detection equipment, its maintenance, the evaluation and interpretation of measured data requires trained staff.

F. Most of the conventional scientific methods employ macroscopic techniques. Among one of the unique features of nuclear methods is their ability to investigate on a microscopic level. In many modern research and development projects, this use of nuclear methods is indispensible. For example: metabolic pathway studies or chemical reaction mechanisms.

F. For the measurement of radioactive fallout as a result of nuclear tests in other countries, and the inclusion of nuclear aspects in civil defense, qualified and trained staff is needed.

G. It is very important for every country to develop its own capability for assessment of new advanced technologies. The nuclear field combines many elements of contemporary technologies: electronics, high vacuum, low temperatures, on-line application of computers. Since nuclear resaerch is interdisciplinary by its nature, a research and teaching effort can serve as a focal point for developing up-to-date capabilities in such technological branches. A good nuclear science group at the university can frequently contribute to reliable evaluation of projects which include locally new technologies.

H. A good university should offer instruction at the M.Sc. and Ph.D. level. For such programmes, nuclear science provides suitable thesis problems.

I. For a country in which a nuclear power capability is planned, a strong training programme in nuclear engineering is essential. A training programme in radiation protection must be developed simultaneously. It is much easier to establish such a programme if the nuclear sciences are a part of the university curriculum, and thus a reserve of potential teachers and practitioners exist.

The use of any argument in favour of nuclear sciences at a university, obviously depends on the country, its needs and development trends. In any case, a thorough analysis should precede any decision on the nuclear science programme at a university, and the size and financial commitments of such a programme should be carefully balanced to match the country's demands.

Some of the arguments above are elaborated upon in more detail in Part 3 of this report.

PART 2

Requirements

The list below presents some general areas that must be considered before organizing a nuclear science programme in a developing country:

Information
Extrauniversity interaction
Management
Data handling
Supporting activities (small tools, workshops)
Equipment
Improvisation
Motivation.

Elaboration of the entries in the above list, leads to a number of conclusions and recommendations concerning a successful nuclear training programme.

Information:

Lack of suitable systems for retrieval of data needed in teaching and research, shortage of contemporary textbooks (frequently coupled with the language problem), non-availability of current scientific journals, represent a serious handicap, and can endanger the progress of university activity. As the funds for ordering scientific literature are, in most developing countries severely limited, a very careful selection must be made. The advice of scientists who are familiar with the literature current in a given field can be of great value. It should be emphasized that a certain minimal level on the technical literature is an essential condition for educational and research work.

Extra university interaction:

The observations of higher training institutions in developing countries, indicate that the bonds between the university and the local national economy institutions, in very exceptional cases only, reaches a meaningful level. This lack of interaction with the immediate environment can have detrimental consequences: without listening to the demands of the country, the educational and research programmes can be completely misplaced. The national authorities would unwillingly support programmes which are not related to the country's needs. At a later stage of development, the importance of direct links of the university with industry, medical institutions and agriculture can pay dividends in the form of contracts for research or development activities. A discussion of the relations of universities with lower school and the general public is given in Part 4.

Management:

Management of a university's activity is a highly specialized decision making job. Usually management is done by scientists who manage their laboratories and department as an additional duty to their teaching and research tasks - and probably there is no alternative to this solution. It should be realised, however, that management is an activity requiring specific skills which have to be learned, and which, to a large extent, depend on the social and political situation in a country. It would be a valuable asset if the scientists who has to also perform managerial duties would receive some special training in "organization and management of scientific projects".

In this context, it must be noted that the universities in some countries, adhere to a very rigid structure where a member of the faculty staff can communicate with the outside world through his superiors only. Such a system tends to destroy individual initiative and seldom leads to good results. A manager on all levels, inside the university should be given enough latitude to be able to interact with partners both inside and outside the university. As a rule, his role must be an active one.

Data handling:

The lack of suitable facilities and experience in data handling is another serious handicap in developing countries. As the university is obviously the place where the techniques of data acquisition and analysis must be taught, it is essential that the contemporary computer methods be introduced as early as is financially possible. The price of small computers (such as TRS 80, PET, APPLE) is within the reach of most teaching institutions. It seems that the introduction of the use of computer languages in the curriculum is of paramount importance; otherwise a new gap is being formed between the developing and advanced countries - one that is relatively easy to bridge at a reasonable price.

Supporting activity:

Experimental work (albeit related to teaching or to research) cannot be developed without suitable support. In developing countries it can frequently be observed that a scientific department orders and receives a sophisticated piece of instrumentation while the most simple tools are unavailable. The slightest malfunction of equipment can cause extended periods of inactivity before the fault is rectified, usually through intervention from outside. Well equipped and suitably staffed workshops, of a size corresponding to the volume of activities are essential. In support of nuclear resarch, an electronics workshop should have the staff, testing equipment and components to maintain and repair electronic instruments, and to perform small scale development of special items such as interfacing units. A mechanical workshop should be capable of producing parts as needed in experimental work, seldom available commercially. A glassblowing workshop is a valuable asset, particularly if radiochemistry is emphasized. Frequently, direct contact with a similar institution in an advanced country can be of great help.

Equipment:

It is always difficult to obtain funds for the acquisition of equipment needed in research, even more so in a developing country. Before a decision can be made on the type, size and brand of the equipment to be ordered, a careful study should be made. In cases where the local staff is not experienced, outside help should be sought from an unbiased party. Universities in advanced countries, and also international organizations (such as UNESCO and the IAEA) can provide assistance with advice.

The equipment problem is usually not solved when the ordered instrumentation is delivered and installed. All too frequently, the relatively small additional funds needed for the maintenance of instruments, for the acquisition of spare parts, or for sending the equipment for repair abroad, are not envisaged, and the breakdown of instruments has a strong, sometimes fatal effect on the implementation of the project. Another consideration is the relatively rapid obsolescence of modern research equipment. It should be realised that the continuous upgrading of instrumentation is necessary and will require appropriate funding.

When ordering the equipment, special attention should be given to assure that every instrument is delivered with complete technical documentation, service and operation manuals, electronic circuits diagrams, description of replacement parts, and if possible, a repair kit. These items should be a mandatory addition to every order. For sophisticated equipment, the installation, testing and instructing of local staff, by the company's field engineer, should be foreseen.

Improvisation:

The ability to improvise is a necessity in most developing countries and is frequently well developed in experimentalists.

Motivation:

This seems also to be a virtue, strongly present in scientists from developing countries. In cases where there is interaction between corresponding institutions in developing and advanced countries, it can frequently be observed that the enthusiasm of scientists from developing countries can produce a spark of new interest in their colleagues from industrialised societies.

Work in nuclear science can begin with just one highly motivated person. The first steps can be made without committees, agencys and large grants. It requires only hard work from one motivated individual to improvise on a new educational concept within an existing educational frame.

Part 3A:

Nuclear Physics

1. At secondary level, and during the first years of university, nuclear science topics should be taught as chapters in other existing courses.

2. The teaching of nuclear physics may be suitably introduced as a one-year course at the level of the 3rd or 4th year of the undergraduate curriculum. The programme of nuclear physics could be a formal one, as found in just about any nuclear physics textbook that is in current use. It can be observed, however, that students often do not receive the appropriate experimental support to digest the matters discussed in the course in spite of a good curriculum. A fair amount of radiation biology and radiological protection should be included in the curriculum. The student should have the opportunity to study, experimentally, both basic nuclear phenomena and applications of nuclear physics to other sciences.

Minimum exercises should cover the following topics:

1. Identification and properties of nuclear radiation
2. Decay scheme
3. Decay laws and statistics
4. Absorption of radiation
5. Physics of detectors including energy selective equipment.

3. To a considerable extent, the training programmes in nuclear topics, from physicists and chemists, on an undergraduate level, follow a similar outline. It might be appropriate and economical to offer some joint courses on this level, particularly in those countries where the number of studies is not too large.

4. UNDERGRADUATE PROGRAMMES:

The establishment of any programme for teaching nuclear physics consonant with modern educational technology needs to consider the following aspects:

a) Prerequisite knowledge in interactive areas

b) General and specific objectives

c) Educational material
   i) texts, bibliography, films, other aids
   ii) necessary facilities
   iii) laboratory work

d) Teaching staff

e) Results evaluation.

4.1.1. Prerequisite knowledge

For the successful initiation of a nuclear physics programme, the students should have a solid background in mathematics and in general physics. The list of textbooks below, indicates the recommended level for entering nuclear physics studies:

a. General physics: Physics for Students of Science and Engineering, by D. Halliday and Resnick (John Wiley, 1962)

b. Calculus: Advanced Calculus, by I. Soholnikoff (McGraw Hill)

c. Elements of Programming: Course M251 (An Algolithmic Approach to Computing) Open University, UK

4.2. General and Specific Objectives

An undergraduate programme in nuclear physics should provide the understanding and the application of knowledge for the topics listed below. The following topics are common to both nuclear physics and nuclear chemistry, although the depth and emphasis might be somewhat different:

- The chemical foundation of atomic theory
- atoms, electrons and radiation
- the nuclear atom
- X-ray and atomic structure
- the quantum theory of radiation
- atomic spectra and atomic structure
- constitution of the nucleus
- isotopes
- natural radioactivity and laws
- artificial radioactivity
- interaction of radiation with matter, (alpha, beta, gamma, neutron and heavy particles)
- radiation detectors
- biological detectors
- biological effects of radiation.

For students of nuclear physics, the list should also include:

- nuclear reactions

- neutron physics, neutron sources
- fission and fusion
- accelerators
- elementary particles

The organization of the above topics in the curriculum can follow different paths. A suitable approach might be to divide the undergraduate curriculum into three parts:

a. Nuclear Physics based on a text such as "Nuclear Physics, by I. Kaplan (Addison-Wesley, 1963) supplemented with some theory, as for example discussed in the publication "Physics of the Nucleus", M.A. Preston (Addison-Wesley, 1965)

b. Nuclear measuring methods presenting knowledge on detectors and associated electronics as found in the book "Radiation detection and measurement", by G.F. Knoll (John Wiley, 1979) and basic information on some atomic, nuclear and surface techniques.

c. Neutron and reactor physics

4.3 Laboratory Work

Below is an extensive list of practical exercises that can be introduced in the undergraduate programme. It is realised that the actual selection of the laboratory experiments will depend on the availability of equipment.

- Ionization chamber, Geiger-Müller and proportional counters, scintillation detectors
- Half-life measurement
- Determination of electronic, atomic and mass absorption coefficient for gamma radiation
- Alpha, beta and gamma spectrometry
- Angular correlation of photon from positron annihilation
- Compton scattering
- dE/dx for alpha particles
- Determination of the growth curve for induced radioactivity
- Energy determination for cosmic muons
- Identification and measurement of charged particles with track solid state detector
- Measurement of thermal neutron flux
- Calibration of a proportional neutron detector

- Measurement of (n, gamma) cross section
- The thermal diffusion length in water
- Fermi age of neutrons in water
- Mean lifetime of thermal neutrons in water
- An approach to criticality for a subcritical pile
- Prompt period of subcritical reactor
- Power measurement for subcritical reactor
- Energy dispersive X-ray fluorescence analysis
- Build-up factor in neutron attenuation in matter
- Measurement of gamma and beta absorbed dose by thermal luminescence.
- Determination of the mass of neutron
- Statistics in radiation measurements

A comprehensive description of laboratory exercises can be found in the book "Experimental Nucleonics, by E. Bleuler and G.J. Goldsmith (Rinehart and Co., Inc., New York 1952). Useful information is collected in "CANBERRA Laboratory Manual" (Canberra Industries, Inc., Meriden, Ct, 1977) and in "ORTEC Application Note AN 34: Experiments in Nuclear Science" (ORTEC Incorporation, 1976).

4.4 Teaching staff:

Teachers must be well educated and trained in the discipline, and closely familiar with the educational material, facilities and evalution of results.They must have knowledge of the specific technical literture, and must be competent in the use of the equipment of the discipline (see also Part 3B, item 3.6).

4.5 Results evaluation:

Evaluation must be made to determine which course objectives have been met, so that improvements can be made in the instructions, and modifications of the course objectives can be introduced where necessary.

5. GRADUATE STUDIES:

5.1.Requirements

Entry requirements for graduate work, and overall requirements for the various degrees will have been specified, in a general sense, by most universities. Nuclear science does not, a priori, require special consideration in this respect. If it differs at all, it is in its interdisciplinary aspects, permitting a broad choice of research areas.

Within the university's overall structure for degree work - which we assume would be appropriate - the detailed requirements would have to be specified for each discipline or programme. Obviously variations would be great, since to train in nuclear engineering is something quite different from that of fundamental nuclear physics.

Graduate level research should be:

a. of high quality,

b. related to the scientific and economical interests and needs of the country,

c. if possible part of a wider international programme or effort,

d. geared in such a way that the methodology of approaching a problem is covered simultaneously with the apprenticeship of a particular technique (graduate studies in the case of general nuclear physics).

The graduate curriculum could cover the following subjects:

i) complements of the subjects not properly treated in the undergraduate curriculum and necessary for graduate courses,

ii) advanced nuclear physics (3 hours per week, one year)
-nuclear forces
-nuclear models
-nuclear reactions
-nuclear spectroscopy
-elementary particles

iii) quantum mechanics (non relativistic and relativistic) and related mathematical methods (2 hours per week, 1 year)

iv) Another course of 1 - 2 hours per week for one year should be offered, covering particular topics on the use of nuclear techniques. This should not be taught permanently, but rather, periodically, depending on the needs. For example, one year could cover the use of one or more techniques in biology or geology. For this course, it is important to carefully select the lecturers because this course will most probably be the one which will influence the choice of research projects. It seems profitable to have, whenever possible, these courses taught by specialists in the field coming from scientific institutions , thus creating the necessary links to other scientific centres.

5.1.2 Research programme:

The research topics that can be introduced at the university as a partial fulfillment of the M.Sc. and Ph.D. requirements are obviously a function of:

- the availability and experience of the staff
- the existing equipment
- the most promising areas for an immediate impact on science and technology in the country and the world.

The formulation of the most versatile techniques and equipment also depend and must reflect the development in the world.

In developing countries, the selection of research programmes requires a high degree of ingenuity due to the fact that adequate results much be obtained with modest investments.

At present, research involving nuclear analytical techniques appears to be the most promising for a fast return. Their use in geological prospection, agriculture, medicine , environmental studies is broad and offers possibilities, both for high quality multidisciplinary research, as well as immediate practical results.

With regard to research programmes, a differentiation must be made between research with "big machines" and other nuclear oriented research using smaller types of equipment. This distinction seems justified because goals, resources, administration are quite different.

5.2 Research with reactors and accelerators:

The universities in developing countries seldom operate large research facilities. Research reactors and accelerators are costly in their installation, as well as in the maintenance. These installations are usually found in nuclear research centres; in such a case, a close cooperation between these centres and the university should be established. The university staff should be permitted, and encouraged to use the expensive research facilities, and the graduate students should find the opportunity to perform their thesis works using such facilities.

For convenience, the research programmes can be classified into fundamental and applied. A reasonable balance between the two should be maintained. It must be realised, however, that it is difficult to produce original and publishable results of fundamental studies (nuclear decay schemes, hyperfine interaction, inner shell ionization cross sections and similar) with modest experimental equipment. In the applied field, the situation is more favourable: by introducing a new technique for the solution of a practical problem, valuable results can frequently be obtained without too much effort.

A condensed list of prominent topics which can be studied with research reactors and accelerators is presented below:

a. Radiation damage induced by neutrons, charged particles or gamma rays. The defects formed on an atomic or microscopic scale can be investigated and related to the macroscopic behaviour of different materials.

b. Neutron scattering (diffraction and inelastic scattering). The determination of magnetic and crystalline structure and the dynamics of solids and liquids offer many open problems.

c. Reactor physics. Determination of neutron fluxes, energy spectra, studies of delayed neutrons, reactor fuel economy, and optimization of reactor parameters are excellent topics for graduate work.

d. Utilization of research reactor for radioisotope production and neutron activation analysis presents many challenges.

e. Reactor safety research.

f. Application of accelerators beams in studies of sputtering, channelling, correlated collision processes, implantation, i.e. an important field where nuclear and solid state physics interact.

g. Charged particle induced nuclear reactions. This field is still wide open; however, relatively good spectrometry equipment, and well stabilized accelerator beams are required.

h. Research reactors and accelerators can be used in neutron cross section data studies.

A particular position among low energy accelerators is taken by neutron generators. At a price of around US$ 100,000. they are within the budget available to many universities. A balanced programme can be established with such a generator, including nuclear reaction studies, fast neutron cross section measurements, neutron thermalization investigations relevant to reactor physics and fast neutron activation analysis.

The degree to which nuclear physicists can contribute to the progress in other fields of science and technology varies considerably from case to case. For example, Table I summarizes the topics where nuclear techniques and nuclear data can be profitably applied and indicates the requirements on the user with respect to the nuclear physics background.

5.3 Other nuclear oriented research

This type of research can be performed on a much smaller scale, and is ideally suited for graduate studies at universities. Often the nuclear part requires some radioisotopes only. The following techniques are well developed now:

a) Mössbauer spectroscopy

b) Nuclear magnetic resonance (NMR), nuclear quadrupole resonance (NQR)

c) Positron annihilation

d) Perturbed angular correlation (PAC)

This list might be expanded by including:

e) Extended x-ray absorption fine structure (EXAFS)

f) Electron spectroscopy for chemical analysis (ESCA)

g) Auger spectroscopy.

TABLE I : AREAS OF APPLICATION OF NUCLEAR DATA AND TECHNIQUES

Applied area	Usage	Main data requirements	Level of knowledge of nuclear physics required by user
Electrical power	Fission reactors	Neutron data, fission data decay data, nuclear structure	High
Design			
Radioactive waste disposal			
Regulation			
Environmental			
Fuel element			
Control i.e. safe-guards.			
Radioisotope batteries		Decay data	Low
Controlled thermal fusion	neutron reactions	Charged-particle reactions	High
Biology and medicine	Diagnostic studies Therapy	Decay data/some reaction data	Medium to low
	Research	Decay data, neutron and charged-particle reactions/ protons, mesons, heavy ions	Medium to low
	Shielding and dosimetry	Absorption data for different types of radiation	Medium
Agriculture	Food preservation	Decay data	Low

Applied area	Usage	Main data requirements	Level of knowledgeledge of nuclear physics required by user
Geology Archaeology Forensic	Elemental analysis	Decay data, neutron capture X-ray fluorescence by means of charged particles	Low to medium
Industrial	Leak detection Gauges/thickness density Controls Fire detection devices Filters Materials treatment Solid-state devices Materials analysis Radiography	Various types noted above depending upon application	Low to medium
Physical sciences	Nuclear physics Astrophysics Solid state Chemistry		Low to high depending on specific area

Some of the above listed techniques require relatively modestly priced equipment, in the order of US$ 30,000. Of course, this depends to a great extent on the sophistication of the applicaton, and must be higher if low or high temperatures or magnetic fields are needed. These techniques have been used in all disciplines of natural science from nuclear physics to medicine.

One might single out Mössbauer spectroscopy because it has the widest range of application, and in addition, it offers an ideal tool in teaching a variety of aspects in science. Particularly in developing countries, valuable results have been obtained often outside the mainstream of the general prevailing interest. In these countries, the special conditions and needs have been taken into account, by concentrating on problems in the fields of mineralogy, geology, environmental research, meteorology, archaeology and biology.

6. Additional considerations

It is well to remember that graduate work can be organized on a small scale and for individual students.A series of formal courses with lectures and well organized practicals may be desirable. However, the required understanding and skills can very well be reached by guided literature studies and individual experimental work. This is certainly more demanding for some of the students, but the same results can be achieved. In fact, the individual student type of graduate programme was the tradition in many European countries until the number of students grew to such an extent that it became both feasible and economical to introduce more rigorously structured programmes. We see no reason why developing countries should postpone local graduate work towards M.Sc. or Ph.D. work because of low student numbers only.

It is important to establish adequate supervision. A graduate programme would have at least one local Ph.D in the fields for which degrees are offered. It would be desirable if, each year, one or two persons from the staff have the opportunity to participate in international events, such as scientific visits, or short training courses in their specific field. Another most effective way to complement supervision is to establish inter-university agreements, either with foreign institutions or with other universities in the country. Attention must also be paid to the relation between the number of staff and students. An equilibrium must be established between these two groups, in order to maintain the excellence of the teaching, training and research work.

In a country having no tradition in nuclear physics both the experimental and theoretical studies should be simultaneously developed. Although to achieve new results in theory is more difficult that in the experiment, there are a few good examples of how nuclear physics was introduced in a country by dealing in the beginning with theory. In any case, it is advisable to organize close cooperation between theorists and experimentalists in the phases of planning the experiments and the evaluation of results. There are a number of experimental observations which need theoretical support: fission process, reactor mechanisms of nuclear reactions induced by neutrons and charged particles, heavy ion reactions, low energy charged particles, reactions relevant for nuclear astrohysics and thermonuclear processes, interpretaton of trends observed in the reaction cross sections, solution of neutron transport equations, unfolding of neutron spectra; interactions of high energy elementary particles.

PART 3B

Radiochemistry - Radiation Chemistry

1. UNDERGRADUATE PROGRAMMES

When the need for a university programme in radiochemistry has been established, it should be introduced first into the undergraduate curriculum. Two approaches can be considered:

a. Introduce nuclear topics into existing chemistry courses.

b. Introduce (develop) a separate course in nuclear chemistry.

c. Consider the suitability of joint courses for chemists and physicists (see Part 3a, 2)

1.1 Method 1: Introduction of nuclear topics in existing nuclear courses

a. Existing courses and appropriate topics.

General chemistry: structure of the atom, radioactivity, fission, fusion.

Analytical chemistry: radioanalytical methods: i.e. isotope dilution; activation analysis; radioimmunoassay (basic aspects).

Organic chemistry: tracers and mechanisms and structure determination, labelled compounds.

Biochemistry/Clinical chemistry: tracers, labelled compounds, radioimmunoassay (applications).

Inorganic chemistry: isotope exchange; structure of compounds.

Physical chemistry: kinetics; first order decay tracer techniques for the evaluation of constants.

b. Implementation. The introduction of nuclear topics in all of the above courses is an ideal situation. In reality, the various professors might not have familiarity with much radiochemistry, and some less usual approaches should be found. For example:

i) the radiochemistry professor can provide guest lectures in various classes.

ii) the radiochemistry professor offers short-courses to acquaint their colleagues with these concepts and laboratory techniques.

1.2 Method 2: Specially designed nuclear chemistry course

The university may decide to include many of the nuclear chemistry concepts and techniques in a single course. This course could become mandatory in the chemistry curriculum.

This course could extend well beyond the chemistry curriculum. In particular, it could serve the needs of the medical profession by providing training for nurses, medical technicians, etc. who use tracers in diagnosis and therapy. Such a course is summarized in Appendix I.

The difference between an introductory nuclear physics course and one in nuclear or radiochemistry is more of viewpoint than of substance. Both courses include topics on the structure of the atom and the nucleus; or radioactive decay and decay laws, on nuclear properties; on interaction with matter. The radiochemistry viewpoint frequently relates to application of tracers to solve problems. The nuclear physics approach is often more theoretical, with a greater emphasis on mathematics and calculation. The resources of the university may dictate that only one introductory nuclear chemistry/physics/biology course be offered. Providing that the teacher of such a course is willing to consider the various backgrounds (and levels of mathematical ability), there is no necessity to provide separate courses for the different types of students. Nuclear science is well suited to an interdisciplinary teaching approach.

2. ESTABLISHMENT OF AN UNDERGRADUATE NUCLEAR CHEMISTRY CURRICULUM

2.1 General considerations:

a. Such an undergraduate nuclear chemistry course would be offered to 3rd or 4th year chemistry/science students.

b. The minimum prerequisites would include: general and analytical chemistry, calculus, physics, with elementary differential equations being very desirable.

c. The lecture concepts and levels are well described in texts such as:

   Nuclear and Radiochemistry: G. Friedlander, J. Kennedy, J.M. Miller (Wiley 1964)

   Introduction to Nuclear Chemistry and Nuclear Physics, B.G. Harvey (Prentice-Hall 1969)

d. The laboratory concepts and level are well described in texts such as:

   Radioisotope Techniques: R.T. Overman and H.M. Clark (McGraw-Hill Book Co., 1960)

   Nuclei and Radiochemistry: G.R. Choppin (WA Benjamin Inc. 1964)

   Principles of Radioisotope Methodology: G.D. Chase and J.L. Rabinowitz (Burgess Publishing Co., 1967)

   Experiments in Nuclear Science: G.D. Chase et. al. (Burgess Publishing Co, 1971)

2.2 Requirements to implement a nuclear chemistry programme

1. Staff

   a) The minimum teaching staff is one person who knows radiochemistry or is willing to learn. The university should recognize this and appoint the person to a full-time chair in radiochemistry.

   b) The minimum support staff is one technician to assist with instruments, both maintenance and repair.

A lecture class in nuclear chemistry or physics can be as large as needed to meet student demands. One person can teach 15 or 150 students.

A laboratory class in radiochemistry or nuclear physics has two factors critically limiting its size:

1. Physical facilities and equipment

2. Safety supervision of persons actually working with radioactive substances.

To elaborate: a class in nuclear physics might be limited because of intrumentation: it is not educationally productive to have more than two or three students working together on one multichannel analyzer. Such a class might be using only sealed sources, which constitute little radiation hazard. In contrast, a radiochemistry experiment might require simple counting euipment only. But the handling of radioactive material by inexperienced students would take very close supervision. Owing to these problems, nuclear science laboratory classes should be designed for no more than 12 students at a time. This requires only 4 to 6 sets of replicate-equipment at the most (or 4 to 6 different sets of equipment used in rotation). Twelve students can be provided with adequate safety supervision.

2.3. Establishing the Radiochemistry laboratory

A. Obviously one begins with the assumption that there exists a building, with laboratories, fume hoods, regulated power and appropriate glassware and supplies.

B. A minimum implementation equipment budget:

   1 dosemeter 1 GM survey meter,
   1 set of NIM units including:
   bin power supply
   timer, ratemeter, scaler
   single channel analyzer
   Detectors: GM, (glass and thin windows)
   NaI scintillation detector

This can be purchased for approximately US$ 5000. (U.S. 1981). Additional requirements for tracer radiochemistry work would include: trays, gloves, planchettes, lead brick, etc. This can be purchased for US$ 2000 (U.S. 1981). Thus a minimum starting budget is less than US$ 10,000 and a minimum annual budget should be 20% of this, or US$ 2000.

3. GRADUATE PROGRAMME

Introduction of tracer techniques into existing chemistry and biology graduate programmes can be done with the minimum equipment described in the Undergraduate Programme.

To develop a graduate radiochemistry or radiation chemistry programme would require an additional laboratory investment.

Texts such as Radiation Chemistry by Allen, or Radiation Chemistry by Sangster and O'Donnel give a picture of this level of instruction.

3.1 Expansion of the Minimum Laboratory

The first step of the expansion of the programme requires:

- Neutrons - available from an isotopic neutron source, or a neutron generator or access to a reactor

- Isotopes - available from an accelerator or a reactor

- Access to an accelerator

3.2 This expansion automatically requires a laboratory which can handle higher levels of radioactivcity. Then a special radiochemistry laboratory must be designed. These design features must include limited access, ventilation, waste disposal. Furthermore, the Radiation Safety Officer now becomes essential to the operation of the programme.

A Radiation Safety Officer who is not a professor can provide valuable support to the educational programme. He provides independent judgement of hazard. The researcher, in his eagerness, is not a wise judge of safety. The Radiation Safety Officer should be added to the University Staff whenever there exists real radiation hazard, for example in work with:

- millicurie levels of activity in laboratory use
- high level radiation source (gamma cell)
- neutron generator
- subcritical assembly
- reactor.

3.3 Equipment expansion must parallel the laboratory development. There must be access to an intense ionizing radiation source such as a gamma cell or equivalent. There must be suitable equipment for radiation chemistry studies (i.e. chemical dosimetry; radiolysis studies). The instrumentation must include:

- additional NIM units
- liquid scintillation counter
- MCA - multichannel analyzers with Ge(Li), Si(Li), intrinsic Ge
- (note: Ge(Li) should not be purchased if liquid N_2 is a problem).
- low background counting system for environmental studies.

3.4 Access to conventional laboratory equipment must be possible. Such instruments as spectrophotometers, chronetographs, nuclear magnetic resonance, infrared spectrometer, mass spectrometer might be available.

3.5 Acquisition and investment should be step by step so that one piece of equipment is purchased and put into operation before another is acquired. A step cost unit is about US$ 10,000. A typical graduate programme investment excluding construction is of the order of US$ 100,000. (U.S. 1981).

3.6 Staff. The staffing is directly a function of the level of sophistication and the number of students involved. One faculty member has a human physical limitation. He can teach two or three courses simultaneously. He can provide adequate supervision to 6 to 12 research students. A typical student/faculty ratio is approximately 18 to 1, for a university as a whole. A support staff ratio of 1 technician and/or secretary to each 4 or 5 professors is reasonable for the university as a whole. Since Nuclear Science requires more close supervision, and more instrumentation than is required in non-science areas, it will require a higher level of support (i.e.: it is a high cost programme both in terms of manpower and in terms of money). A student facility ratio of 12 to 1 for laboratory work; of 6 to 1 for research is reasonable. One instrument technician must be assigned to support the nuclear science programme.

An ideal small staff would be a team of one biologist, one chemist, and one physicist working together to bring nuclear science to the university. They should be support by a Radiation Safety Officer and an instrument technician. They should also have secretarial help.

3.7 Duration of the Programmes. A programme of two years duration should be established and to take a student from the baccalaureate level to a level equivalent to the Master's in the U.S. A programme of three years duration should be established to take a student from the masters level to the level equivalent or the doctorate in the U.S.

3.8 Suitability of graduate programmes. A small country should not undertake such a graduate programme if there is no national need for persons with this level of training.

3.9 A strong recommendation! - Cooperative Efforts. Expansion of educational programmes to the graduate level should be done through the mechanism of regional and/or national and/or international cooperation.

3.10Requirements for participation in graduate programmes.

1. Students should possess background education and/or experience equivalent to a baccalaureate degree in science disciplines such as chemistry, physics, biology, engineering.

2. Faculty to teach in such graduate programmes should have training and experience equivalent to the doctorate level.

4. UNDERGRADUATE RESEARCH PROGRAMME

In addition to the practical laboratory exercises, the students might be involved in some undergraduate research experience on topics related to preparation of radionuclides and labeled compounds, applications of radiotracers in analytical, inorganic, organic, physical and biological chemistry.

5. GRADUATE RESEARCH PROGRAMME

The university must build its research capability in such a way that it will serve the national needs. There should not be a needless duplication of facilities, equipment and programmes. Regional (national or international) cooperation should be encouraged and should be required for major installations.

For equipment suggestions, requirements and costs refer to Section 3, Graduate Programmes.

Starting at the level zero; the first step might be described as competence and confidence building. The topics might involve: rechecking previous work; developing a new measurement and manipulation capability. A few examples:

low level radioactivity counters
environmental measurements
synthesis of labeled compounds
minor/trace element analysis
use of tracers to investigate solid state chemistry.

The aim of this would be to lead to collaborative efforts with others in the same research field.

The second step is that of increasing competence to the level that collaboration with other persons and institutions is possible.

Each collaborator must contribute something indispensible and if possible, unique to overall projects. A few examples:

- unusual set of specimens
- special set of conditions for observation
- researcher's expertise
- pooling of instrumentation.

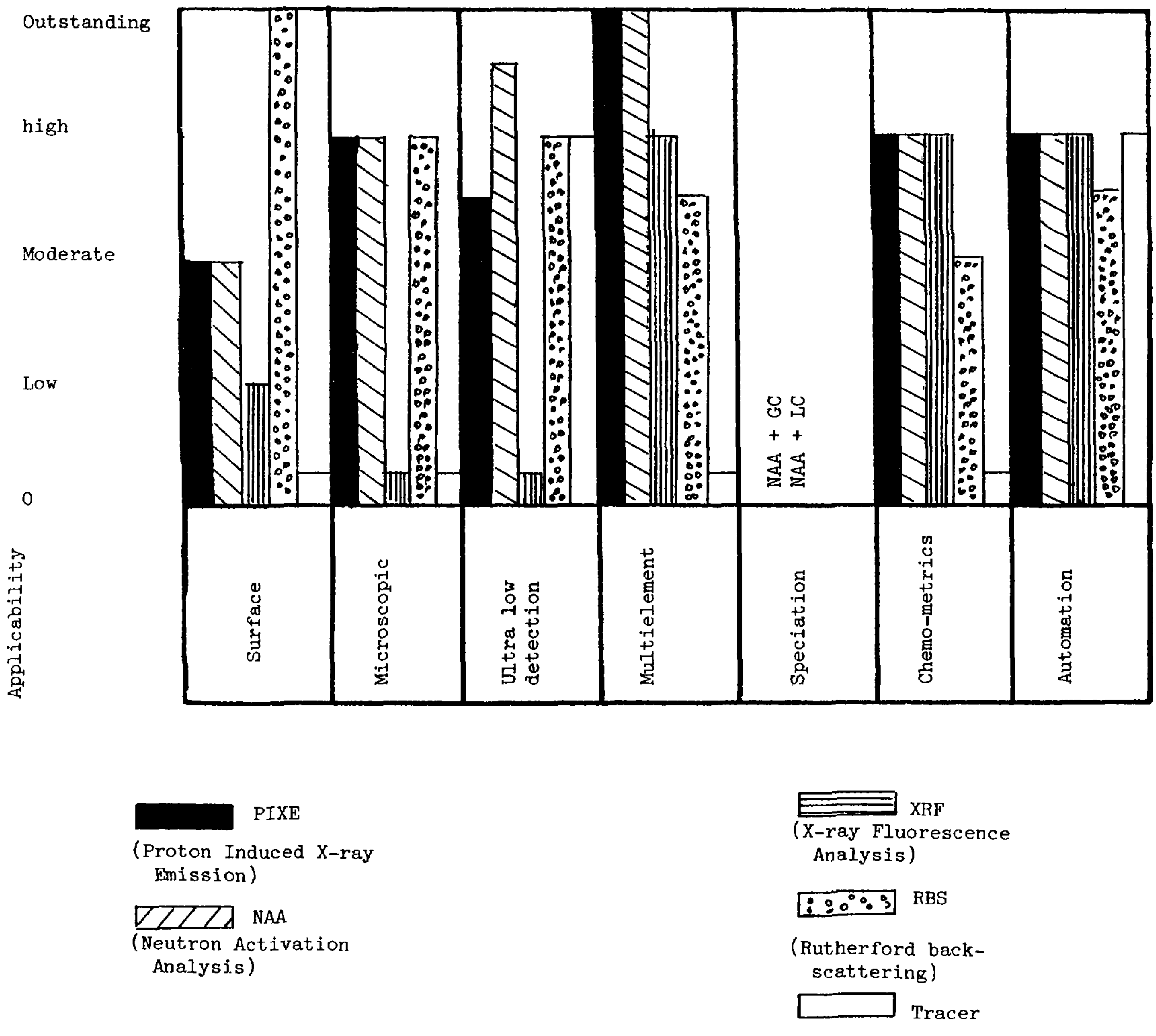
Table 2 illustrates the usefulness of some nuclear techniques in studies of specific properties. Such summarizing presentations are an excellent guide for decision making, at the time when a new method is to be introduced.

The final step is "self-standing" research. This requires facilities and staff, in which researchers must have a clear view of current research trends and know how their expertise can contribute. A few specific examples:

- positronium chemistry for chemical and solid state investigation
- small accelerator projects
- labelling compounds by enzymatic techniques

TABLE 2

Scoreboard



- tracer - coordination chemistry of some of the less familiar elements

- modern radioanalytical techniques as related to the mining industry of the country.

There is a "critical mass" of active research people for a good self-sustaining research programme. This can be just one person with enough time and equipment and support staff. But more frequently good research involves several minds, working together (compare Part 3b, 3.6).

6.SERVICE OFFERED BY UNIVERSITY, COOPERATION

6.1. The university can provide training of persons without consideration of preparation for a university degree. The topics might include:

a) use of radioisotopes for nurses, medical technologists
b) radiation safety training for persons who use X-ray machines (dental, medical, geologists, materials scientists)
c) radiation safety training for persons who use radiography sources (petroleum exploration, thickness gauging, etc.)
d) short courses for persons in industry in the use of specialized equipment (liquid scintillation, X-ray fluorescence, GLC ...etc.).

6.2. The university staff should organize training of teachers to improve and strengthen elementary and high school science teaching (without regard for degree programmes).

a) short courses on new techniques, equipment.
b) continuing education courses.

6.3. Education of general public about things scientific:via radio, press, video, speakers bureaus, etc.

6.4. If major research facilities exist at the university, all potential users should have access to such equipment or services (reactor, irradiation of materials, isotope production by reactors, accelerator computer centre access for data analysis.)

6.5. Cooperation between universities.

a) students at university A could actually enroll in a course, and, earn credits from a special course at university B and have it count as part of the degree at university A.
b) a professor at the university could have access to equipment at university B; the professor at university A could have isotopes produced at university B.
c) theprofessor at university B could teach a course at university A.

6.6. Experts in the community could teach a special course at the university.

6.7. Selection of research projects which are appropriate to societies needs.

6.8. Joint cooperation between local industry and university to select projects of mutual interest. Industry can provide the funding and the university can do the research to solve the industrial problems.

Part 3C:

Electronics

Formal university education and training in electronics for applications in nuclear science is rooted in the fundamentals of modern electronics as this appears in the undergraduate curriculum for electrical/electronics engineers and for students of physics and chemistry. We have divided our consideration into these three areas:

1. Electrical/Electronics Engineering: Students preparing for a baccalaureate degree in electrical/electronics engineering, who might be employed after completion of their undergraduate education in a nuclear science laboratory, should receive training in the following broad areas:

- -Fundamentals of electricity and magnetism.
- -Fundamentals of the physics of atoms, nuclei and solid state.
- -Fundamentals of analog devices and systems.
- -Fundamentals of digital devices and systems.
- -Microprocessors: principles and application
- -Feedback and control systems.
- -Analog system design.
- -Digital System Design including introduction to computer architecture.
- -Interfacing: Digital/Analog, Analog/Digital, Digital/Digital.

It should be noted that the curriculum is not unique for an electrical engineer who might choose to work in a nuclear physics/chemistry laboratory as support engineer for the physicists and/or chemists. Upon graduation he might be employed in other fields which utilize the same fundamental/training of an electronics engineer.

It is possible, by three mechanisms to interest and direct some electronics and engineering students into a career in "nuclear electronics".

1.1 The electronics engineering student enrolls in a nuclear physics laboratory along with undergraduate students of physics in the Department of Physics. Such an arrangement will, in general, work only if prior agreements have been reached between the appropriate faculty in physics and in electrical engineering, to make it possible for the electronics engineering students to "succeed" in a course for which their counterparts in physics have been better prepared. This can, and does work, especially when the electronics engineering students are highly motivated and are academically capable. In this scheme, the electronics engineering students will have the opportunity to study under nuclear physicists and alongside students of physics.

Ideally the course should not only have a strong theoretical base presenting the status and the intriguing challenges of the field, but also enough associated laboratory work to provide a real demonstration of the nuclear physicist's or chemist's research techniques. To capture the engineering student's long term interest both the lure of the quest and the elegance of the questing techniques are important.

1.2. The electronics engineering student is given some lectures, preferably accompanied by relevant demonstration either by competent members of the engineering faculty or by invited nuclear physicists on the subject of electronic application in nuclear physics and/or chemistry. By this mechanism, the presentation can be directed at the engineer. A disadvantage, however, is the absence of some appreciation for what actually goes on in a nuclear physics laboratory. Another disadvantage may be the small number of students involved in such an optional course.

1.3. Electronics engineering students in undergraduate and/or graduate programmes which require a research thesis or independent study should be encouraged to find problems that have direct application to the specific electronics needs of the nuclear physics laboratory programme. In this model, communication between the physicists and the appropriate faculty advisor in the electrical engineering department must exist or can be established to permit the student to identify a research topic. It is important that the faculty advisors work with the student in a feasibility study of the problem to be reasonably certain the the essential raw materials (components, measuring instruments, etc.) are available within the time period for the completion of the thesis or study. An illustrative list of possible thesis topics follows.

1.3.1 Instruments and modules for radiation detectors

a. Design of units that are commercially available, but could be produced locally at less expense.

b. Design of special units needed for experiments, preferably in a way corresponding to accepted standards (NIM, CAMAC).

c. Design of a compact radiation monitoring system including high voltage supply, discriminators, scalers.

1.3.2 Design, construction, testing and calibration of interfaces to connect experiments to digital computers.

a. Design of ADC and DAC units.

b. Designing of interfaces between the computers, or interconnection between data acquisition systems and the computer.

c. Interfaces with output devices.

1.3.3 On-line control of instrumentation

a. Electronics system for spectrometer or diffractometer operation.

b. Alarm system for liquid nitrogen level.

c. Electronic control system for operation of a pneumatic transfer system.

Whether or not any (or all) of these opportunities are available for the electronics engineering student, it is assumed that he will necessarily require extensive "on-the-job training should he choose to work in a nuclear physics/chemistry laboratory. This specialized training will obviously build on his strong undergraduate preparation in the aforementioned subjects, and then focus on the specific electronic devices currently in use in the laboratory and on those which are needed. It is further understood that whenever a highly complex and sophisticated device is to be serviced by this individual (e.g. MCA, mini-computer, etc.) he should, if financially possible, be sent to a special training class given by the manufacturer to fully prepare him for these responsibilities. Where possible, he should be encouraged to undertake graduate work in electronic engineering rélevant to the ever changing need of nuclear experimental techniques.

2. Physics: All students preparing for an undergraduate degree in physics should receive education in fundamental electricity and electronics and in the application of appropriate electronics devices to experiments in physics in general, and nuclear physics in particular.

2.1 The training in electricity and electronics will, in most cases, be less extensive than that given the electronics engineering student. It is not required that the baccalaureate physics graduate (or even those with advanced degrees) be able to service advanced electronics equipment commonly found in the nuclear physics laboratory such as TAC, ADC, DAC, and MCA devices. It should be assumed, however, that he has learned enough basic electronics to understand the fundamental principles of the component devices of which the more complicated systems are built, and that he be capable of (a) using them intelligently and (b) learning their more detailed operating characteristics should he choose to do so. This training in fundamental electricity and electronics should include theoretical and laboratory work in:

- Basic electrical and electronic components (resistors, capacitors, inductors, semiconductor devices; types, characteristics and application).
- AC and DC circuits
- Filters
- Power supplies
- Amplifiers and feedback
- Signal recognition, measurement and description.
- Transducers
- Digital circuits
- Microprocessors
- Measuring systems.

It is understood that, whenever sufficient equipment is available, this instruction should involve the student in laboratory exercises to gain both understanding and skills. A suggested instructional format for teaching these topics could be a one semester course with two hours of lecture and 3 - 4 hours of laboratory work per week.

A list of the equipment and materials needed for laboratory exercises in these topics and the spare parts which should be kept in stock for the laboratory is given in Part 3c, 4.

2.2 Training on the applications of appropriate electronics devices and instrumentation to experiments in nuclear physics should take place in the undergraduate nuclear physics laboratory. In such a laboratory, the instructor selects experiments with several goals in mind: (a) to teach basic properties of nuclei and atoms, (b) to teach how to employ various electronic devices in these nuclear physics experiments, and (c) to teach appropriate analytical techniques for reducing data and for error analysis. In the context of item (b), it is important for the instructor to identify clearly those particular "electronics" skills which the student is to learn in a given laboratory experiment. In these experiments, the student should not be expected to study the inner workings of the instruments being used, but he should be familiar with (e.g. read the specifications sheet for the device) the operating characteristics of the instruments and with the techniques for determining whether these conditions <u>are</u> satisfied (e.g. use an oscilloscope to measure input and output signals.) Some of the basic electronics skills and understandings with which the student should become familiar are:

a. What are the electronic properties of various radiation detectors?

b. What is the purpose and function of the various elements in a system, e.g. preamplifiers linear amplifier, discriminator, delay amplifier, coincidence logic, ADC, TAC, etc.?

c. How does one measure time and amplitude resolution?

d. What is signal-to-noise ratio? Modern ways of noise suppression.

e. What are vacuum metering techniques, and associated electronics?

f. What are the transmission properties of signal cables how are cables matched to signal requirements and how are they prepared and repaired?

g. How to match the input and output impedences?

Valuable information on these topics, together with description of experiments can be found in "Electronics for Scientists and Engeineers", by Robert Simpson (Alyn and Bacon Inc.).

3. <u>Chemistry</u>: Students preparing for a career in nuclear chemistry, radiochemistry or radiation chemistry or in industrial and/or commerical employment in fields related thereto, should acquire training in fundamental electricity and electronics, associated measurement skills, component and system properties. While it may be necessary to adjust the level of instruction and the depth of application for chemistry students, these students should, if feasible, receive the same training as that described for students of physics. It is not assumed that these students will be prepared to undertake significant repair of malfunctioning apparatus, but they should, if possible, be able to use an oscilloscope, for example, to discover which unit in a system is malfunctioning.

The aforementioned educational programmes are regarded as optimal. It is not necessary to have each and every piece of recommended laboratory equipment to begin or to improve the present level of instruction. The implementation of these instructional activities can be done on a gradual basis, improving the laboratory exercises and acquiring additional equipment.

4. Equipment: A list of equipment necessary to equip one working place (to be used simultaneously by 2 - 3 students) in a properly organized electronics teaching laboratory is given below.

1.	Oscilloscope:	Band width 30 MHZ Dual trace switch Sensitivity 5 mV/cm Time base: down to 10 ns/cm Signal delay x-input.
2.	Signal generator:	Repetition rate - 1 MHZ Pulses positive and negative Variable amplitude 0 ... 10V Fixed (10 ns) or variable rise and fall time Pulse duration 100 ns - 1s Output impedance 50 sc
3.	Power Supply:	2 x 0 - 15 V/1A potential free 5V/3A (TTL supply)
4.	Digital Multimeter:	3 1/2 digits Volts: AC, 1000 DC Amperes: AC, DC Resistance
5.	Selected Tools	
6.	Cables	(wires, cables, connectors)
7.	Bread boards	

Items that should be kept in stock to supply the laboratory:

Carbon Resistors:	10 ohm to 10 Mohm, E12 series, 1/4 W
Capacitors:	10 pF - 100 nF (1, 2.2, 4.7, 6.8) 1 /uF - 100 /uF electrolytic
Inductances:	(if needed for filters)
Transformers:	(if needed for power supplies) mains (110 or 220V) to low voltage (5 - 40V)
Diodes:	Si (like 4148) rectifiers, LED's
Transistors:	Si npn and pnp general purpose power transistors, FET-s

Operational amplifiers: General purpose (like /uA 741) some with FET input

Digital IC's HAND,NOR, NMOS, XOR, open collector types flip-flops, monoflops; scallers, multiplexers, adders,

Microprocessor and associated chips: RAM, ROM, PROM, drivers, clocks, parallel I/O, serial I/O, timer, encoder (if a microcomputer set up is planned).

PART 4

Cooperation

To ensure the good operation of a nuclear science department, and its appropriate position in society, the university staff must establish and maintain contacts reaching from interdepartmental cooperation to international.

1. COOPERATION WITHIN THE UNIVERSITY:

One of the characteristic features of nuclear research is its multidisciplinary character. This should be kept in mind when the plans to establish a nuclear science laboratory are drafted. Irrespective of where the laboratory is located (departments of physics or chemistry are most probable candidates), its door must remain open for all possible users. There are some considerations which could assist in creating the "everybody should use it" profile of the nuclear science laboratory:

a. The selection of the technique(s), facilities and equipment to the acquired should be such that the potential for use by different branches of science and technology exists.

b. The different departments of the Faculty of Science (or the School of Engineering) should become involved in the laboratory already in the planning stage. They should be invited to contribute their specific experience, define their demands, and specify their specific requirements.

c. The staff of different departments (physics, chemistry, geology, biology, electrical engineering) should be included in the training scheme which would normally precede the establishment of the laboratory.

d. If an expert is appointed to assist the local staff in the initial stages of the project, the professional and technical personnel from all branches of science and technology present at the university should cooperate with him.

e. Continuous care should be taken that all the possible users of the nuclear science laboratory within the university are kept informed of activities at the laboratory, including experiments completed or in progress and possible new instrumentation, so as to maintain the interest in the nuclear activity laboratory.

2. COOPERATION WITHIN THE COUNTRY:

The nuclear science laboratories can prosper only if they have permanent and intensive bonds with other institutions in the country.

2.1 POPULARIZATION OF NUCLEAR SCIENCE, CREATING INTEREST

Since it is a relatively new branch of science, nuclear science must establish its credibility in society.The university has a public service function. Therefore the university, in accordance with national policy and in some instances at the request of national agencies, can be a source of information to the community about nuclear science.

The staff of the nuclear science laboratory should try to:

a. Utilize the communication media to spread the interest for nuclear science and technology on a popular level, and to present good arguments for application of nuclear science and technology to local problems.

b. Organize lectures at high schools, or invite students to visit the nuclear laboratory, to stir their interest and meet possible good candidates for future studies at the university.

c. Arrange events, such as "nuclear science week", "day of the open door" when everybody can come and inspect the work of the laboratory.

Some possible ways of interaction with the general public and high schools are elaborated below.

2.1.1 General public. Relations between the university and the general public can be developed in many ways. For example:

a. The first and most important bridge must be with the press.

b. A public affairs officer can be established at the university, with the objective to:

   a) write press releases
   b) write short radio news bulletins
   c) organize a speakers bureau.

c. On radio, short (30 second) interesting factual reports about things the university is doing can be introduced.

d. Prepare video film strips.

e. Have a nuclear science booth at a fair. Use the video film strips here.

f. Organize a science fair.

g. Have an Open-House to show the general public any new equipment or new facility.

h. Establish a university-lecture bureau and have speakers available to any general group.

Public information should be as open as possible about the importance of nuclear techniques. It is necessary to mention that in the age of the scientific and technical revolution, the development of a country cannot be realised without basic and applied research. Among fundamental science, nuclear physics plays an important role because it has developed a technical and methodical base which has been directly utilized in other sciences, and in practice.

2.1.2 High Schools

Communication between high schools and the university can be maintained in different ways. For example:

a) University professors can write appropriate high school science books, including laboratory exercises.

b) The university can prepare the high school teachers:

- there can be special nuclear-science institutes or short courses just for the high school teachers,

- many times high school teachers are required to take university classes (to keep up to date and/or for a pay increase); nuclear science classes can be available for this purpose.

c) The university nuclear science professors(in radiochemistry, nuclear physics, nuclear engineering) can go to high schools and give lectures or demonstrations.

d) The universities can establish a "University Relations Office" to continuously interact with high schools.

e) The university can establish a "Speakers-Bureau" with a list of all professors who will speak at any location to any appropriate group on an appropriate topic.

f) University science and engineering students can go to the high schools to give lectures and demonstrations.

g) Sponsor a Career-day when the whole university can welcome the student and tell them of different careers.

h) Sponsor a Science contest - mathematics, physics and/or chemistry high school students can be invited to the university to write an examination. The very best students can be given prizes, books would be an appropriate prize. An organization could donate the prizes, for example, the professional societies of the country or a local Nuclear Agency

2.2TECHNICAL COOPERATION:

On the technical level, the early contacts with the local institutions in industry, agriculture, medicine, mining and energy, should be established and cultivated. This can be accomplished on three levels:

2.2.1. The nuclear laboratory can offer its specific and unique services to those who need them. Examples: analysis for trace elements contents in soil or plants, or determination of the age of archaeological objects.

2.2.2. The potential customers should be invited to join the laboratory to learn and master a specific nuclear technique. If they find it suitable, they should be permitted to use the facilities of the nuclear science laboratory before they can organize their own laboratory.

2.2.3. The staff of the nuclear laboratory can advise on the contemporary technology for applications of nuclear techniques in industrial process control, in medical diagnostics and therapy, use of tracers in agriculture, and radiation technology. If there are other institutions in the country which can also contribute to this report, close cooperation should be aimed for, and unnecessary duplication avoided.

The staff of the nuclear laboratory should watch the developments in the country and should be flexible to accommodate the changing demands for trained manpower. Example: if a number of radiation units for cancer therapy are to be installed in the coming years, the demand for trained medical physicists and dosimetrists can be estimated, and the teaching plan of the university modified to assure the training resulting in the required technical staff.

In many countries, the national research centres have been created. They are characterized by their multidisciplinary approach, and by great concentration of research facilities. The instrumentation in such a centre is frequently of the size and complexity which would be difficult to acquire or maintain at the university. Close cooperation between the nuclear science laboratory and the national nuclear research centres is essential for both partners. For the centre, the university is the source of professional technical staff. For the university, the facilities in the centre offer opportunities to perform or participate in research and teaching which is not feasible in a university laboratory.

3. INTERNATIONAL COOPERATION:

Science cannot prosper in isolation. By continuous and intensive contacts, the scientists must strive to become part of the international community: this is a prerequisite if they intend to stay abreast of developments at home.

3.1 In the early stages of introducing nuclear science into a country, the international contacts are especially important - but also most difficult to establish and maintain.

3.1.1. The local university scientist who receives extensive training abroad, should receive it in carefully selected fields dictated by the needs of the countries rather than by the advancement of his personal career..

3.1.2. Experienced foreign scientists and professors should be invited to visit the university, to assist the local staff in formulating realistic and feasible programmes, to advise on the selection of equipment and to deliver series of lectures as a sample for the future work.

3.1.3. International organizations could be requested to help with advise, through their fellowship and technical assistance schemes.

3.1.4. Bilateral contacts are extremely important. A recommended approach is to find an arrangement with an advanced university abroad, establish a "sister laboratory" contact, and maintain it by exchange of personnel, ideas and equipment. This contact is particularly suitable to solve the notorious "spare parts problem" which, in most cases, does not represent a financial problem, but is, as a rule, the consequence of administrative difficulties.

3.2. At a later stage, when a nuclear laboratory is functioning, the form of the international cooperation will change.

3.2.1. As the basic education is available at home, the training abroad can be limited to advanced graduate studies or to shorter visits intended to familiarize the trainee with a particular method or a specific application.

3.2.2. The visits of foreign scientists can take a more specialized form: a visiting professor will concentrate on discussion of particular methods rather than the presentation of general background information.

3.2.3. Cooperation can also take the form of projects implemented jointly with an advanced laboratory, and of mutual interest to both parties.

3.3. The sabbatical years should be more intensively exploited: there are many scientists in advanced countries who are genuinely interested in assisting their colleagues in developing countries, to the extent that they are willing to spend, at least part of their sabbatical for this purpose, not expecting any large honorariums beyond subsistence allowance.

Similarly, professors from developing countries should spend their sabbatical in a laboratory in an advanced country, carefully selected so that its programme matches the home one. The efficiency of the sabbatical year could be improved if the programme of a visiting professor is prepared in advance and in detail.

3.4. Participation in international meetings is an excellent method to establish personal contacts, and to upgrade and up-date the knowledge. Any possible means should be used to enable the scientists from developing countries to participate in these gatherings.

4. ROLE OF FOREIGN COUNTRIES IN TRAINING AND RESEARCH

For a country starting at point zero, it is necessary to send young scientists abroad to obtain adequate experience in physics, mathematics and modern languages. In a further step, they would continue their studies in those universities at which the scientific level is definitely higher than in the home country, but the research programme and the experimental facilities could be implemented at home without long delay. Permanent connections between these universities and with those having almost the same research and training programme is extremely desirable.

A number of actions can be recommended that would increase the usefulness of training abroad.

4.1 The host country should offer to assist the local authorities in the selection of candidates for education in foreign countries.

4.2 Before starting the programme of study, the fellows should receive a detailed description of the research and training programme of their host institution.

4.3 Many of the scientists who accept foreign students do have some information about scientific resources in developing countries. Each prospective research host should consider and comment upon the suitability of the proposed programme against the background of what he might know about the particular research group or laboratory. Whenever possible, the applicant should submit any supporting documents that may be available.

4.4 In the selection of the host institution, it is in most cases better to find a small but highly regarded school rather than one of the prestigious universities. The small school is likely to suffer the same equipment limitations the students will face when they return home. On the other hand, the prestigious institution is likely to have the latest in equipment; the student never learns how to obtain the desired results with a combination of the minimal devices and lots of ingenuity - a lesson he is sure to need at home.

4.5 Both the institution from the developing country and the institution receiving graduate students should carefully look into the possibility of reducing the time spent abroad. The following approaches might prove satisfactory:

a. The student can perform the experimental part of his work abroad but make all the data evaluation and comparisons at home.

b. Several short visits might turn out to be a more efficient use of (usually scarce) funds than one extended stay abroad.

c. A professor from an advanced country can pay several visits to the university in a developing country, and supervise one or several graduate students.

d. It happens that the graduate students can easily obtain a leave of absence for long term training in a foreign institution. If they try to achieve the same degree at home, they have to carry the full academic load, making it unstimulating to start research at home. The university administration should find ways to allow for reasonable decreasing of teaching duties, for persons working seriously on their higher academic degrees at home.

4.6 It is an important task of the host professor to select the work for a foreign graduate student of such a nature that the acquired experience and knowledge can later be used in the developing country. If necessary (and if possible), the host should modify his own programme, to accommodate the specific needs of his student.

4.7 For senior level scientists it is advisable to visit more advanced laboratories for one or two weeks in order to form some impression of the most recent reesearch programme and modern techniques. In the case of students who intend to become familiar with some methods or techniques, about three months is the minimum time needed. Education abroad should be oriented towards specific problems to the extent that it is possible.

4.8 The training or studying abroad should be of benefit to the student's country and should not contribute to the brain drain. This can be achieved by:

- limiting the length of the stay abraod
- selecting research topics relevant to the home country
- providing the trainee an appropriate job after his return.

APPENDIX I

Course on Radioisotope Techniques

(Held at the Polytechnic School of Milan)

1. The course is held once a year during September and October.

2. It is intended as an introductory course for the application of radioisotope methodology in pure and applied chemistry, including biological and clinical chemistry.

3. In order to attend the course a university degree in chemistry, physics, medicine, biology or engineering is required, exceptionally people with a degree from a technological high school can also be admitted, but they must demonstrate that they have acquired a suitable work experience (for instance during three or four years) in a radiochemical laboratory).

4. During the course, practical work in the laboratory is emphasized, indeed, the course consists of about 25 experiments (each is introduced by one or two hours of theory).

   In order to guarantee a common theoretical background between the attendees, about 30 introductory lessons are given. The detailed programme of the 36th Edition of the course is given below. Minor changes may be introduced in the next session of the Course.

A. Experiments

1. Description and use of a G.M. counter. Use of a programmable table computer.

2. Statistical fluctuation in counting. Poison distribution and its application.

3. Determination of the dead time of the counting equipment.

4. Use of a NaI(Tl) scintillator detector. Energy calibration.

5. Half life determination.

6. Absorption of X and gamma rays.

7. Absorption of beta particles.

8. Self absorption of beta and gamma rays.

9. Backscattering of beta particles and its applications.

10. Application of radioactive tracers in Chemistry: determination of distribution coefficients and application in analytical chemistry.

11. Separation of labelled compounds by solid-liquid chromatography. The "milking technique".

12. Analysis by isotopic dilution.

13. Co-precipitation both as a separation methodology and in relation to the question of the chemical and radiochemical purities.

14. Chemical effects following the nuclear transformation: the Szilard-Chalmers effect and its applications. The Wilzbach method for preparing tritium labelled compounds.

15. Autoradiography and its application to paper chromatography.

16. Use of monitors - radiation shielding.

17. Use of a multichannel analyzer

18. Use of a Ge(Li) detector for gamma rays.

19. Use of an ionization chamber and of a ZnS(Ag) detector.

20. Use of a flow-counter.

21. Preparation of ^{125}I labelled iodoprotein.

22. Use of a liquid scintillator counter for ^{3}H and ^{14}C countings.

23. Radiolysis of an aqueous solution and the question of the storage of radioactive compounds.

24. Radioactivation analysis: sensibility and determination of a calibration curve for quantitative analysis.

B. <u>INTRODUCTORY STAGE</u>

a) <u>Radioactivity</u>

1. The atomic nucleus: the nucleons; dimension of the nuclei, their binding energy. Stable and unstable nuclei.

2. Radioactive decay. Radioactive chains: secular equilibrium.

3. Alpha decay beta decay.

4. The positron (and its fate). Positron and EC decays - gamma emission.

b) <u>Absorption of charged particles and X and radiation in the matter</u>

1. The Bethe formula; particle absorption, the Bragg curve; range-energy curve. Nuclear scattering of alpha particles.

2. Beta particle absorption; Bremsstrahlung; backscattering.

3. & 4 X and gamma ray absorption: the exponential absorption law; photo-electric and Compton effects; pair production.

c) <u>Nuclear reactions</u>

1. Notation for nuclear reactions; formation law of radioactive nuclei under irradiation.

2. Energy balance of nuclear reactions, mechanisms of the nuclear reaction.

3. Principal types of nuclear reactions with particular reference to (n, gamma) and (n, f) reactions.

4. The nuclear reactor; the cyclotron.

C. NUCLEAR DETECTORS

1. Ionization chambers; proportional counter.

2. Geiger-Muller counter.

3. Scintillation counters.

4. Semiconductor detectors.

5. Magnetic spectrometer and other types of nuclear detector (photographic emulsions, etc.)

D. APPLICATION OF RADIOACTIVE NUCLIDES

1-3 Chemical application.

4. Biological application.

5. Availability of radionuclides and labelled compounds. Methods for preparation of labelled substances.

E. HEALTH PRECAUTIONS AND LABORATORY DESIGN

1. Nature of the hazard in handling radioactive material.

2. Dosimetry and monitors.

3. Shielding: material and calculations.

4. Prevention of radioactive contamination in a "tracer" laboratory.

5. Italian radiation protection laws.

6-7. Laboratory design.