
# DEVELOPMENT OF RADIOCHEMISTRY ACTIVITIES IN NEW RESEARCH REACTOR CENTERS

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ABSTRACT

This paper describes the type of work in radiochemistry and chemistry that are liable to be found, and have to be solved, as well as the ones along research lines, in new institution centralising their activities around a research reactor of the swimming pool type.

In some cases, limitation of scientific manpower available imposes a careful choice of problems to be tackled as well as an abandonment of any ambition of covering too many fields at a recently created institution.

As a consequence of the natural evolution of the institution as a whole, in which, probably, three or four main activities are being started, for instance in nuclear physics, reactor physics, radiobiology, besides radiochemistry, the work of the last group, at the beginning has to be of a "service function" rather than of a "research function". This last type of work comes gradually by itself while the service function is being fulfilled and may even arise in order to attend this function in a more rational and definite way.

(*) Presented at the Study Group Meeting on the Utilization of Research Reactors, São Paulo, Brazil, 4 - 8 November, 1963.

In the various fields of work possible to be developed in radiochemistry and chemistry, in institutions having a research reactor, tracer work is one of the most convenient areas to which a new group may start activities, especially by making use of the possibility of using short and medium half-life radioisotopes.

Production and processing of radioisotopes, especially the ones mentioned and for which importation from abroad would not be practical owing to the fact of being short-lived radioisotopes, is another type of activity, this time as a service function that may and should be developed at a very early date, if possible. Adaptation and improvement of existing methods for radioisotopes production, in order to make them suitable to local conditions, may, as a matter of fact, turn out to be a good opportunity for research and for the publication of new methods.

Radiochemical analytical work and classical chemical analysis comes as a third subject that may be started contemporaneously with the other two mentioned. The work may be of a service function, being more appropriate to develop research lines along radiochemical analytical work rather than along classical chemical analysis. By necessity, classical chemical analysis have to be carried out mostly as a service function.

The three main types of possible work to be developed in radiochemistry and in chemistry, as outlined previously, are examined in this paper.

## INTRODUCTION

During the Symposium on Programming and Utilization of Research Reactors, held in Vienna, in October 1961, uses of research reactors and problems connected with the operation of reactors were described and discussed in a broad sense. In the reports presented describing original research, no special

emphasis, in general, was given in connection with the place in which the reactor was in operation. Most of the research paper were presented with own general scientific value on an international point of view, as their support. The final panel discussion, however, followed the general idea of the meeting which was to be oriented towards the needs of new centers and to provide opportunity for exchange of information and experience between old and developing laboratories.

A very good number of papers presented at the Symposium were reports on successful pieces of research carried out, and some outside observer, not familiar with nuclear reactor centers, might even get the impression that reactors, at least for the users, were something that only needed a button pushed for everything to go smooth and easy. Some papers examined objective research programs based on small nuclear reactors as well as the general policy of establishing nuclear research centers. However, only in one of the last discussions of that Symposium, someone suggested that we stop praising our own reactors and that a lot of good information and advice could be given to prospective reactor users and to new reactor centers if some of our reactor troubles were ventilated and discussed at the meeting.

The viewpoint that papers presented at the international meeting were most pertinent to a country of advanced technology has been sponsored by more than one person (see for instance ref. 1, page 2), to which we also agree.

A similar type of meeting took place in December 1962 in Bangkok. Papers and discussions were rather polarized towards developing countries and developing research centers and very objective points of view and suggestions to such developing areas starting nuclear research activities, were exposed. I think this occasion constitutes a good opportunity to quote an opinion expressed during the meeting in Bangkok by a rather well-known

name in the use of reactors in chemical problems, W. Wayne Meinke: "Research and development programs in chemistry as well as chemical service to research and development programs in physics, reactor engineering, agriculture, etc., make sense only if they contribute something to the overall scientific effort of the developing country. The amount of scientific manpower available in such countries is severely limited and cannot be squandered on projects which are of no consequence to the country or the area ..... I believe it is axiomatic that at a reactor center in a developing country even the pure research must have a slight vector towards some overall value to that country. If the research has absolutely no relationship to the welfare of the country in terms of possible training opportunities for future scientists, possible relationship to the country's future plans in the nuclear field, or short term gains in applications, then the group has no business undertaking the research. Indeed the work can probably be done much better with much less effort and expense at existing laboratories in the Western World".(1) One must not misunderstand that we are taking sides in the old theme of "pure research" and "applied research" and in fact we agree with Meinke that "any research program worthy of its name needs a careful balance of pure and applied research in many areas".

Nuclear centers in Brazil are in the position to which much of Meinke's observations are valid. Scientific manpower available is definitely limited and this fact in itself imposes a rather special way of tackling problems. A place like the "Instituto de Energia Atômica", although well equipped, cannot cover the whole spectrum of research possibilities of its equipment. Judicious and careful consideration must be given to the most important scientific and technological areas, in which positive results are liable to be reached, so as not to extenuate and discourage young people decided on continuing their scientific activities in nuclear energy research.

At the "Instituto de Energia Atômica", most of the problems on which the Radiochemistry Division has been engaged were dictated by circunstances imposed as a consequence of the growing of the Institute itself or by outside groups or necessities, such as medical application of radioisotopes. In this way, in about seven years of activities, the same group had to switch from engineering and technological work such as water purification or pilot plant production of uranium salts, to radioisotopes development methods and production on a commercial basis; from biochemical analysis to determination of uranium content of minerals; from chemical tracerwork to the detection of leakage in dams; from fall-out studies and determination of radioactive species in milk to analysis of pesticides by radioactive methods; from activation analysis of uranium and gold minerals and impurities in zirconium, graphite and beryllium, to treatment and disposal of radioactive wastes; from teaching and training activities to consulting in technical application of radioisotopes. The titles of the I.E.A. reports listed in the References, give an idea of the diversification of problems that had to be solved.

Members of the staff of the Radiochemistry Division had, of necessity, to be switched from one job to another and back again, in order to attend the injunctions of the work. The only real specialized group that was definitely necessary to form, was in the area of Radioisotope Chemical Processing, Analytical Chemistry in general, including activation analysis and isotopic dilution analysis, and Uranium Pilot Plant. Treatment, maintenance and analysis of water for the reactor pool was allocated sometimes to the Analytical Chemistry group and sometimes to the Uranium Pilot Plant people.

By the beginning of this year, the staff of the Division of Chemical Engineering started to be assembled. The transference of the engineering work as well as production of fissile material to that Division will free the Radiochemistry Division for

exclusive work along the Radiochemistry line. It is expected that areas such as activation analysis for instance, and other radiochemical areas, which have been developed only in a restricted sense, will be benefited by that transference of responsibilities.

## FUNCTIONS OF A CHEMISTRY DIVISION IN NEW NUCLEAR CENTERS

It is a recognized fact that work done in most new centers is not of enormous interest and importance, most of it being, of necessity, the repetition of work already done, but it is an essential procedure in each new case, and, if published, would serve as a most valuable guide to other groups starting out in the same conditions or situation. This has already been a matter for consideration by Kouts on the Panel Discussion of Programming and Utilization of Research Reactors[2].

If a Radiochemistry Division starts its activities in a nuclear reactor center, at the same time that the reactor is being assembled, that Division is bound to be requested for a lot of work not directly linked to Radiochemistry. If a large staff is already available, some men can be allocated to the various problems which arise by the assembling of the machine. However, this situation of availability of a large staff is not likely to happen in new institutions, especially in developing countries.

Problems that are liable to turn up in a situation like that, and the way they are handled, have already been described elsewhere[3]. Some of them are going to be briefly mentioned in order to add some new information to the subject already presented[3].

## WATER PURIFICATION

The ion-exchangers resins originally placed in the water treatment system of our reactor, are the same up to now, with

practically no loss of efficiency. They have been working for about six years. Conductivity and pH conditions have been easily maintained from $5.0 \times 10^5$ to $10 \times 10^5$ ohm.cm and 6.1 to 6.4 respectively. Regeneration intervals are about the same as the ones mentioned in reference (3), Table 1.

TABLE 1

VOLUME OF WATER TREATED BETWEEN REGENERATIONS (A), AND TOTAL VOLUME OF WATER TREATED IN SIX YEARS OPERATION (B).

| | (A) liters | (B) millions liters |
|---|---|---|
| Softener ..... | 300,000 | 5 |
| Primary mixed-bed (non-radioactive) | 30,000 | 5 |
| Secondary mixed-bed (radioactive).. | 5,000,000 | 165 |

Besides conductivity and pH measurements which have been made since the start of operation of the ion-exchanger equipment, radioactivity of the water is also measured. Small ion-exchangers columns are placed in parallel with the secondary ion-exchanger system, through which water from the pool circulates continuously, and measured after each operation of the reactor in order to detect the possible presence of fission products that might indicate failure of fission elements. Also small columns are placed in a by-pass of the exit from the ion exchangers tanks, in order to detect leakage and saturation of the purifying ion-exchangers resins.

Monitoring of fission products is also being studied by using small columns of silver chloride. These columns are placed

in a by-pass of the heat exchanger and in this way fission products eventually coming from the reactor core would be present in high concentration in the water passing through the silver chloride column. The column retains radioiodine isotopes and also zirconium, niobium, magnesium and manganese. These last two ions are easily eluted from the column by a diluted solution of nitric acid in a one minute operation. Zirconium and niobium radioisotopes are also eluted in a rapid operation with diluted hydrofluoric acid. It seems that only radioiodine isotopes are retained after these fast-radiochemical separation procedures. The column is counted in a well scintillation crystal and presence of peaks of radioiodine fission products $I^{131}$, $I^{132}$, $I^{133}$ and $I^{135}$ are looked for. The method seems to be of reliable application especially if it is taken into account that $Na^{24}$, formed by (n, alfa) reaction in aluminum and responsible for a large part of the radioactivity in the water of the swimming pool reactor, is not retained by the silver chloride column. For the detection of fission products and indication of failed fuel elements, the silver chloride column seems to be highly advantageous over the ion-exchanger columns, since in the ion-exchangers practically all fission products would be collected as well as radioisotopes formed by (n, alfa) or (n,p) reactions.

The column with the silver halide is located in a place in the reactor building where it can be reached during operation of the reactor. In this way a semi-continuous checking of fuel elements' failure is made.

Water condition in this reactor has been very good for the whole time of its operation, indicating that a ceramic tile-lined pool is a good solution for this type of reactor.

## CORROSION PROBLEMS

Previous corrosion problems of fuel elements, identifica-

tion of fission products released in the water, and how these problems were handled, have already been discussed at length[3].

The present set of fuel elements has been in use since April 1959 with no indication of corrosion or failure. These elements have their uranium-aluminum alloy plates riveted with aluminum rivets into the aluminum side plates. No soldering, brazing or soldering fluxes have been applied to these elements. Also an anodised protective treatment has been given to the plates before they were assembled into elements. The elements are placed in an aluminum grid plate and no contact aluminum-stainless steel is made. It is well known that one of the causes of corrosion in aluminum is the contact made by stainless steel and aluminum pieces such as screws, rivets, etc.[4]

Some corrosion on the stainless piping system seems to be taking place. Radioisotopes of manganese ($Mn^{56}$) and of chromium ($Cr^{51}$) have appeared in the water. Chromium might have appeared in the water by dissolution of the chromate coating of new fuel elements; however, the elements have been in the water for a sufficiently long time to dissolve practically all the chromate coating. Besides, the manganese radioisotope presence is explainable only by the dissolution of the steel, since no accidental contamination of the water has occurred. The amount of corrosion products, however, if any, is very small. No problem has arisen as a consequence of this quite normal type of corrosion.

## URANIUM PILOT PLANT

Although the Meeting is specifically held to study the utilization of research reactors, a brief mention will be made of the work the Radiochemistry Division had to carry out in order to make available to other groups, uranium salts of nuclear grade. The object of presenting a summary of this kind of work is

to show the diversity of work that radiochemists or chemists may have to handle in new centers, especially in developing centers. Anyway, most of the exploratory work was made using radioisotopes of impurities in uranium in order to develop purification procedures and the work in itself is a good example of tracer technique work.

Uranium salts had to be supplied to the recently created Nuclear Metallurgy Division in order that they might carry out their projects along the line of production of cermets of $UO_2$ and $U_3O_8$ as well as preliminary studies on reduction of $UF_4$ to metallic uranium[5].

The existent raw material was sodium diuranate obtained as by-product from treatment of monazite sands and, as such, containing rare earths elements and thorium as chief contaminants. The project was tackled by ion-exchanger techniques, since the best experience of the available chemists (only two of them, in fact) was along that line rather than along solvent extraction. Floor space had to be improvised in areas originally reserved for radioisotope production in order that a pilot plant for about 100 to 200 kg of ammonium diuranate could be produced. Deionized water for the Pilot Plant was provided by making a by-pass at the water treatment system for the reactor pool. The process worked out well for that kind of raw material, with decontamination factors for rare earths and thorium from $10^4$ to $10^5$. In fact the final purified material, ammonium diuranate, did entrain sulfate ions as contaminant and although this entrainment could be avoided at the precipitation of ADU, it was decided to eliminate it from the ADU at the time of its calcination, in order to obtain uranium oxide.

The ADU produced has been handled to the Metallurgy Division for reduction to $UO_2$, peletizing and construction of fuel elements for a sub-critical facility, as well as formation of $U_3O_8$

and development of techniques, by that Division, for construction of fuel elements for an Argonauta type reactor to be made, later on, with enriched uranium[5].

## RADIOISOTOPE PRODUCTION

Concerning radioisotopes production by research reactors, the best use that can be made of the machine is in connection with short half-life radioisotopes, for the obvious reasons of difficulty or even impossibility, of importation. For general applications of those radioisotopes as tracers, the internal market can surely be supplied, and demand will meet production possibility. Production of those radioisotopes will not be difficult at all and, practically any radioisotopes requested can be produced.

Medical applications, however, requires radioisotopes whose half-lives can be considered larger than what might be called medium half-life.[4] These are the ones that need some considerations and planning in production in order that they may be produced in harmony with other uses of the reactor.

Production of those radioisotopes in a research reactor has some peculiar characteristics owing to the irregular working periods of the reactor, since that, in order to attend a variety of research projects, the reactor has to work long or short periods of time at high and low power level, continuously or discontinuously. Combination of all these possibilities, or necessities, makes

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(4) In general a "short-lived" isotope is one whose half-life is reckoned in minutes or hours. During the Seminar on the Practical Applications of Short-lived Radioisotopes, held in Vienna in November of 1962, the definition, for the purposes of that Seminar, was extended to isotopes of half-life up to three days, so as to include isotopes that might be imported from abroad but might become cheaper and more readily available as a result of local production.

"production" of radioisotopes, in those reactors, a task that needs careful planning to be carried out.

The first thing that comes to attention is that well established producing methods cannot be directly applied. Methods described in the literature are descriptions of processes developed for radioisotope production reactors working continuously, or at least continuously for five or six days a week with interruptions at week-ends. The amount of material that have to be processed when irradiated for short periods of time, in research reactors, are considerably larger than the ones irradiated for long periods of time in producing reactors. Increase of power level of operation, to compensate for short irradiation periods, cannot be resorted above a certain point since secondaries radiation effects interfere with the chemical processing of irradiated samples.

These problems are not serious for short half-lives radioisotopes produced by (n, gamma) reactions that do not need chemical processing, since a working period of eight hours' operation of the reactor is enough to induce a reasonable activity level on the sample. In some of them even saturation can be attained with eight hours working period of the reactor.

The problems mentioned, had to be faced in connection with some radioisotopes whose production would require chemical processing of the irradiated samples, for instance $I^{131}$, $I^{132}$, $P^{32}$.

## IODINE - 131 PRODUCTION AND DISTRIBUTION

Iodine - 131 is being produced by irradiation of telluric acid and furnished as sodium iodide, carrier free.

Actual and regular production of this radioisotopes started in the second semester of 1961. Prior to that time, starting in 1959, studies and trial production had been made and practically all of the production was used by the Radiobiology Division of this

Instituto. Table II gives an idea of the increased production and use of Iodine-131. Up to the end of 1961 production was in accordance with the possibilities of the Institute as far as number of processing cells available and operation schedule of the reactor is concerned. From 1962 up to now, production has been carried out in accordance with the demand, being larger for the months in which a larger number of requests are made.

TABLE II

NUMBER OF SHIPMENTS AND NUMBER OF MILLICURIES OF $I^{131}$ PRODUCED AND DISTRIBUTED

| Year | Shipments | Millicuries |
|---|---|---|
| 1959 | 20 | 14 |
| 1960 | 77 | 164 |
| 1961 | 346 | 2,930 |
| 1962 | 862 | 13,050 |
| 1963 | 910 (*) | 23,000 |

(*) Value extrapolated to December, this report being written in September,1963

Table III gives the shipments, for 1963, as function of number of millicuries per shipment.

TABLE III

NUMBER OF SHIPMENTS AS FUNCTION OF MILLICURIES PER SHIPMENT (FROM JANUARY TO SEPTEMBER 1963)

| 1 to 5 mc | >5 to 10mc | >10 to 20mc | >20 to 50mc | >50 to 100 mc | > 100 mc |
|---|---|---|---|---|---|
| 63 | 174 | 255 | 118 | 36 | 38 |

Requests are placed directly with the I.E.A. Administration and if they are in order concerning clearance, meaning training of the customer in radioisotope uses and/or medical application, as well as payment, the requests are handled to the Radiochemistry Division for processing and shipment. All requests that are in compliance with those conditions have been, and still are, attended to. Presently, the demand for Iodine-131, calculated from the monthly requests placed at IEA, is about 2 curies per month. This demand can be met up to a maximum of 8 curies monthly with no alteration on present irradiation schedules or processing cells duplication. The maximum can be raised by new irradiation and processing planning.

In general, production of Iodine-131 in radioisotopes production reactors, or reactors running continuously most of the time, is made by irradiation of masses of telluric acid of the order of 200 grams, in thermal neutron fluxes of about $10^{12}$ n/sec. $cm^2$ and irradiation time of about 15 days. In research reactors, in general, the reactor does not run continuously for 15 days, and production conditions have to be planned in accordance. At the IEA, from 100 to 400 grams, depending on the number of requests for that week, are irradiated for two days of eight hours each, with interruption during the night, in a thermal neutron flux of about $10^{13}$ n/sec. $cm^2$. In such a high flux, it often happens that the telluric acid originally in powder form, becomes hard and with a stony appearance very difficult to dissolve which causes difficulties in the processing.

Penteado and Vizeu tried[6] irradiation of telluric acid in solution, and this is being done up to the present. Details of this proceeding are to be presented by the authors at this meeting.

Most of the Iodine-131 production is being used for medical purposes, diagnoses, therapeutics, thyroidean cancer treatment and research. The largest consumer is the "Hospital das Clínicas de

São Paulo" (Public Hospital of the City) in joint collaboration with the Radiobiology Division of the IEA. They receive from one third to half of the whole production. The rest goes to other States Hospitals, private clinics and also to the College of Medicine in Paraguay.

Labelling of organic molecules with $I^{131}$, is being made by the Radiobiology Division. The work of tagging oleic acid, triolein, rose bengal, orthoiodine hypurate of sodium, growth hormone, insulin, iodoantipirin and PVP, will be described in details at this meeting(7).

PHOSPHORUS -32 PRODUCTION

Up to now the demand for phosphorus-32 is not as large as the one for iodine-131.

Phosphorus-32 is produced by irradiation of magnesium sulfate which is much easier to process than elemental sulfur, for the simple reason that the sulfate is directly soluble in water. It is possible, when and if the demand increases, that the classical process of sulfur irradiation will have to be used. From 100 to 200 grams of magnesium sulfate are irradiated for two daily periods of eight hours each, with interruption during the night.

The demand and production have been of 100 to 200 millicuries per month. Production can be raised to 500 or even 800 millicuries per month without any alteration in connection with present irradiation schedules or processing cells.

Most of the phosphorus-32 production has been used by agricultural research work described by Cervellini, Catani and Malavolta at this Meeting(8), and also for medical research at the College of Medicine in São Paulo and Rio de Janeiro. The radioisotope is distributed as phosphoric acid. Table IV gives the production and distribution of Phosphorus-32.

TABLE IV

| Year | Shipments | Millicuries |
|---|---|---|
| 1960 | 12 | 30 |
| 1961 | 49 | 692 |
| 1962 | 124 | 1,385 |
| 1963(*) | 75 (*) | 804 (*) |

(*) Values extrapolated to December, this report being written in September, 1963

As can be seen from Table IV, radiophosphorus is not yet being used regularly. In fact there was a decrease in demand in 1963.

COLLOIDAL GOLD-198

The production method for radiocolloidal gold has been developed this year and the glass equipment designed and built. The processing cell is being constructed and will be seen by the members of the Meeting visiting the Institute.

The colloidal particles produced by this process have already been examined by electron microscopy. Particles are quite uniform in size and have a diameter of 300 angstroms.

Regular production should start at the end of 1963 or the beginning of the coming year. It is expected to have an initial production of 3 curies per week.

IODINE-132

Lately, in São Paulo, interest has been shown for $I^{132}$ for medical research and uses and thus it was decided to start produc-

tion of this radioisotope.

The method is already developed. Uranium oxide is irradiated and processed to recover tellurium radioisotopes, especially $Te^{132}$. This radioisotope is absorbed in alumina which is to be furnished for periodical milking for $I^{132}$. Each $I^{132}$ shipment should be good for a week's milking, allowing for the test of three medical subjects. It is expected to start with a weekly output of about 40 millicuries, and production should start this year.

Glass equipment has already been designed and built and it is in the process of being assembled.

SODIUM-24

$Na^{24}$ is being produced by irradiation of sodium carbonate and dissolution with hydrochloric acid. All the production is distributed for studies of the blood circulatory system. Demand is not very large and processing is carried out only after a request has been placed by the customer. Fourteen shipments of about 2 millicuries each have been made in 1963 (up to September).

CHROMIUM-51

Studies for the production of $Cr^{51}$ should start this year with the collaboration of M. Michel Douis, visiting scientist from Saclay, France.

OTHER RADIOISOTOPES

Production of various other radioisotopes, mostly for tracer work at the Radiochemistry Division of IEA, such as $Eu^{152-154}$, $Nd^{147}$, $Tb^{160}$, $Zr^{95}$, $Hf^{181}$, $La^{140}$, $Y^{90}$, $Sr^{89}$, $Cs^{137}$ (fission

product), $Cd^{115}$, $Cr^{51}$, $Zn^{65}$, $Na^{24}$, is currently made, as well as various natural radioisotopes, i.e. $Pb^{210}$, $Pb^{212}$, $Bi^{210}$, $Bi^{212}$, $Th^{234}$, $Po^{210}$, $Tl^{208}$.

## ACTIVATION AND ISOTOPE DILUTION ANALYSIS

One of the best uses radiochemists can make of a nuclear research reactor is for activation analysis. Amounts of material to be irradiated are usually quite small and, in pool type reactor, possibility of access to irradiating places is practically unlimited, although the best facilities for this purpose are pneumatic rabbits. Most research reactors have this irradiation facility and, besides, portable pneumatic rabbits systems, with plastic piping, are commercially available, or can be locally made.

Equipment necessary for this type of work, besides ordinary scalers and Geigers counters, are single channel analysers, requiring, in general, chemical separations prior to counting or multichannel analysers, which are a "must" for analysis with short half-life radioisotopes and which allow the solution of a good number of problems without chemical separations. Besides, auxiliary equipment for multichannel analysers makes possible the formation of "libraries" of standard gamma spectra for various radioisotopes, registered in magnetic or punched tape, which are particularly useful for the cases in which short half-life radioisotopes are to be analyzed. These "libraries" allow identification of radioisotopes to be analyzed, by comparison to spectra of standards. Auxiliary electronic integrator systems allow calculations of peak areas, and in this way quantitative analysis can be made. The problem of activation analysis in centers provided with nuclear research reactors and/or accelerators is well reviewed by Guinn[9].

Activation analysis problems have been handled at the IEA, although real laboratory facilities for this kind of work were only

available after 1960, in order to attend requests made in connection with some analytical problems proposed to the Division and to which the best, or sometimes exclusive, solutions would be by radioactive methods.

Activation analysis of the pool water and the water in the outlet of the ion-exchanger system, were made for sodium content in order to test efficiency of ion-exchanger removal capacity and to evaluate activity level of the pool caused by sodium remaining in the water and by sodium formed by (n, alpha) reactions in aluminum. Also, uranium was analyzed by activation method in the pool water, as well as in various mineral samples from gold mines which were simultaneously analysed for gold. Samples of locally produced graphite were analyzed for sodium, pure zirconium salts analyzed for their hafnium content, uranium minerals for uranium, niobium and tantalum.

All this work has been carried out by using single channel analyzers with, at the beginning, equipment designed and built by Electronic Division of IEA, and later with commercial models. In July of this year a multichannel analyzer was received, with complete auxiliary equipment, and has already been put in normal operation. A pneumatic rabbit station is being installed next to the counting room in order to allow work with short half-life isotopes. Interest for this type of work has been shown by outsiders including the State Police for criminalistic investigation. Men from the State Police laboratories are being trained in the technique of activation analyzes, at the IEA, and later on the Institute should collaborate when this type of work would be required.

Another line of analytical work, using radioisotopes that can be developed in centers having nuclear reactors, is by isotope dilution which is especially useful for analytical methods in which a quantitative recovery of the product or element to be

analyzed is not possible. If the chemical laboratories are located near the place where the reactor is, activation and isotope dilution analysis can be put on a routine basis including control of production methods at various chemical factories..

Methods of isotope dilution for phosphorus in uranium oxide, at the levels of parts per million, have been developed using $P^{32}$ as labelling material, in order to control quality of uranium produced at the Pilot Plant. Also, along the lines of isotope dilution, a method was developed for total amounts of rare earths element in uranium produced at the Pilot Plant, using $Eu^{152-154}$ for labelling.

In order to attend consultations from industry, isotope dilution method for BHC (hexachlorocyclohexane) was developed and applied in order to check production yield at factories of that pesticide. Payment for this kind of consulting or development work at the IEA, is being made in the form of equipment rather than in specie.

TRACER WORK

Besides activation analysis and isotope dilution, which are methods of work typical of tracers application to analytical problems, chemists associated to nuclear reactors centers can take advantage of the availability of radioisotopes in order to study chemical processes and reactions. Radioactive tracers can be used for studies of mechanism of reactions, kinetics, isotope effects, behaviour of chemical compounds and elements at very low concentrations, diffusion and self-diffusion problems related to structural chemistry, etc. Even in the case of only a medium half-life radioisotope being available for a certain chemical element, this does not constitute any difficulty by itself as far as possibility of getting the radioisotope goes. Weekly shipments and distribution

can be made even to places located hundreds of kilometers far from the reactor but that can be reached by an air-line distribution.

Studies along the line of production methods of materials of nuclear purity, are largely benefited if labelled material is used. Amounts of impurities that have to be eliminated being on a very low concentration level, can be detected and determined in practically all the steps of a purification procedure: additional information can be given in which chemical compound the element whose study is being made, is incorporated, its oxidation stated etc. These informations would be very difficult to obtain if each step of the process and each compound had to be analyzed by ordinary chemical methods or even by optical spectrography.

By using this technique, a good number of problems concerning purification methods for uranium have been studied at the IEA. Rare earths elements and thorium have been studied in connection with their elimination from commercial grade uranium material, from the level of 0.1 to 1% for rare earths and up to 8% for thorium, down to the level of some parts per million after the purification procedures. Radio-autographic techniques were applied in order to locate the position of rare earths and thorium in ion-exchangers columns, using $Eu^{152-154}$ and $Th^{234}$ as labelling radioisotopes. Evolution of those elements along the columns on the steps of elution, washing and so on, could also be followed easily, which would be very difficult to do by other means such as optical spectrography or polarography.

Studies of decontamination factors for elements of high neutron absorption cross sections, on precipitation of uranyl salts with ammonia, as ammonium diurante, were made for rare earths elements and for cadmium, using chelate compounds of those elements in order to improve decontamination. Studies are being developed at the moment by carrying on the precipitation of ammonium diuranate in homogeneous media rather than by using gaseous ammonia.

Work is being developed along the line of determining the mechanism by which the chelate compound of the element from which uranium is to be freed, is entrained by the ammonium diuranate precipitate[36].

Tracer techniques were also applied in order to develop methods for the detection of fission products in milk, by using ion-exchangers and EDTA, avoiding in this way cumbersome methods of milk ashing and precipitations with fuming nitric acid[35].

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An indefinite number of examples of application of radiotracers to chemical problems could be listed. We have quoted only a few examples, listing preferentially some problems we had to solve and for which tracer techniques were the best solution or, sometimes, the only solution.

In fact, this review of the utilization of research reactors in chemistry, is illustrated mostly with our own problems. Some of these problems were not of a radiochemical nature, but rather of technology or even chemical engineering. Although they may not be of "utilization" of reactors, they have to be solved just the same if the reactor is ever to be "utilized". Some of the problems we had to solve are liable to appear to prospective reactors buyers and users, especially in developing countries. One must not forget that, in a way, every country is a developing country in some aspect, and it has even been recognized that the "problems involved in setting up a nuclear reactor center at a U.S. institution not already having one, would also serve as useful examples for developing countries, since they too have similar problems of economics, manpower and so on", in accordance with Rowland[10].

When the time for "utilization" of the reactor by the chemists comes up, and laboratories and equipment are available,

still the choice of problems may not be done with absolute independence. Growth of the institution and activities of new divisions frequently impose the themes for research. However, the solution of the proposed problems may be pushed towards a radiochemical approach. In this way training can be given to new people and their results published in international journals, presented at scientific meetings, or as internal reports. Seven years' experience have taught us that, even when one cannot follow a definite line of research owing to circunstances imposed by the various environmental conditions, by having their results published, our collaborators feel that their efforts have been rewarded.

Now, just to end this review, I think a last subject should be brought to light. It concerns the much talked about subject of "pure" and "applied" research. The words pure and applied research may, by themselves, give rise to a lively discussion.

A lot may be said about the kind of research a developing country should get engaged in: pure or applied. We have ourselves, at the beginning of this review, mentioned the subject, and we sponsored Meinke's viewpoint that, at a reactor center in a developing country, even the pure research project should have a vector towards some overall value to that country. Then we come to something that is almost a dilemma: it seems that applied research in developing countries rarely gets applied. The words are not mine, but they tell the story of a well known scientist who, when visiting an applied scientific research center in a developing country, asked the leader of the best centers: "How many dollars does the country get from every dollar invested here?" The leader answered: "None. We have got the results, but our industry is not ready to accept them"(37).

Now, the situation is really not so drastic. If a research institution carries out an applied research for some private industry and, afterwards, keeps on doing the routine work, they

will never be ready to do the work by themselves. It may be more practical for them to have someone else doing it rather than to equip new laboratories or have to hire a new man. But if the institution solves the problem and do not go as far as to become a laboratory for the consulter's routine determinations, the consulter himself will apply the results, if they really mean any advantage in time, income or quality of product.

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