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An assessment of the present degree of utilization of research-type nuclear reactors in the Philippines, Thailand, Korea, Indonesia, Singapore, Taiwan, Hong Kong, Venezuela, Colombia, Argentina, Brazil, Chile, Mexico; and the various factors either stimulating or inhibiting their optimum utilization. Less-detailed assessments of other related nuclear programs in these countries also are made. The various reactor and related nuclear centers visited varied widely according to size, quality of support, and utilization. Lacking an established tradition of scientific research and development, nuclear progress could be accelerated by continuing effective help and encouragement from developed countries. To really flourish, the nuclear centers will have to be less academic and develop applications that are more closely meshed with overall national plans that attack real, present-day programs. Areas covered in this report are: 1) problems of staffing, 2) degree of reactor utilization, 3) contacts with other groups within the country, 4) contacts with nuclear groups and activities in other countries, 5) practical applications of nuclear methods, and 6) specific needs. In addition, there are summaries of individual countries.

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COMPARATIVE ANALYSIS OF UTILIZATION OF RESEARCH REACTORS IN A NUMBER OF DEVELOPING ASIAN AND LATIN AMERICAN COUNTRIES

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I. Introduction

As indicated by the title of this report, this study was carried out to assess the present degree of utilization of research-type nuclear reactors in a number of developing Asian and Latin American countries — and the various factors that appear to be either stimulating or inhibiting their optimum utilization. In addition, the study included less-detailed assessments of various other related nuclear programs in these countries.

The report is based primarily upon observations made by the author during a number of scientific meetings in which he participated in these geographical areas, and during a number of trips he made to a number of these countries for discussions concerning their degree of reactor utilization (and related subjects). The principal relevant meetings and trips, from which material for this report was gathered, are summarized briefly below, in chronological order:

1 The First Inter-American Conference on Radiochemistry (Montevideo, Uruguay, July 23-26, 1963; sponsored by the Organization of American States).

2. The IAEA Study Group Meeting on Utilization of Research Reactors (São Paulo, Brazil, November 4-8, 1963; sponsored by the International Atomic Energy Agency). During this meeting, and just following it, the author visited the Brazilan Atomic Energy Commission nuclear centers in São Paulo, Belo Horizonte, and Rio de Janeiro.

3. The Seventh Japan Radioisotopes Conference *(Tokyo, Japan, April, 1966). Before or after this conference, the author visited the nuclear facilities of Rikkyo University and of the Musashi Institute of Technology, and the neutron generator production facilities of the Toshiba Company.

4. The U.C.L.A. Conference on Applications of Nuclear Energy in Latin American Development (Los Angeles, California, March 22-28, 1967; sponsored by the University of California at Los Angeles).

5. The International Conference on the Utilization of Research Reactors and Reactor Mathematics and Computation (Mexico City, Mexico, May 2-4, 1967; sponsored by the Mexican Atomic Energy Commission and the American Nuclear Society). After this conference, the author visited the TRIGA reactor

*Meetings and visits in or involving some of the developed countries of Asia (such as Japan) and Latin America were also of value for comparative purposes.

installation of the Mexican Atomic Energy Commission, then under construction.

6. The IAEA Scientific Meeting on Activation Analysis (July 6-8, 1970), and the IAEA Asian Regional Cooperation Meeting (July 9-10, 1970), both held in Bangkok, Thailand; sponsored by the International Atomic Energy Agency. The author represented the U.S. Atomic Energy Commission at these meetings. During and after these meetings, the author visited the nuclear reactor centers in Thailand and Taiwan.
7. Visits to the nuclear centers of New Zealand, Australia, Indonesia, Singapore, Thailand, The Philippines, Taiwan, and Korea (February-March, 1971; trip made for the International Atomic Energy Agency).
8. The IAEA Study Group Meeting on the Utilization of Research Reactors (Santiago, Chile, November 29-December 3, 1971; sponsored by the International Atomic Energy Agency). The author participated in this meeting as a representative of the U.S. Atomic Energy Commission. During the meeting, the author visited the Chilean Atomic Energy Commission's nuclear reactor facility, then under construction.
9. Visits to the nuclear and scientific centers of The Philippines, Thailand, and Korea (August, 1973; trip made for the U.S. Agency for International Development-AID).
10. Visits to the nuclear and scientific centers of Venezuela, Colombia, Argentina, and Brazil (September, 1972; trip made for the U.S. Agency for International Development).
11. Visit to the Mexican Atomic Energy Commission's TRIGA reactor facility (January 2-4, 1973; visit for the International Atomic Energy Agency).
12. A 6-week stay, as an IAEA Visiting Expert, during August-September, 1973, with the Mexican Atomic Energy Commission's TRIGA reactor facility
13. A one-week IAEA Asian Regional Cooperation Meeting, held in Bandung, Indonesia in August, 1975, for the IAEA — followed by short visits to the Singapore Institute of Standards and Industrial Research, and to the Chinese University of Hong Kong.

In addition to discussions held with Asian and Latin American nuclear scientists at the above-mentioned meetings, and during the above-mentioned visits, the author has held many discussions with their nuclear scientists when they visited him at his former laboratories (Shell Development Company and General Atomic) or at his present laboratory (the University of California at Irvine); at various conferences in the United States — particularly, meetings of the American Nuclear Society; at various international conferences — particularly conferences in Vienna, Geneva, Paris, Salzburg, and Amsterdam, sponsored by the International Atomic Energy Agency; and in training courses at the Oak Ridge Associated Universities (formerly, the Oak Ridge Institue of Nuclear Studies). Additional information has been acquired from IAEA Fellows from The Philippines, Thailand, Chile, and Bolivia who have been graduate students of the author at the University of California at Irvine. Also, valuable background information was obtained from discussions with personnel of the U.S. Atomic Energy Commission, the U.S. Agency for International Development, and the International Atomic Energy Agency — and from many country reports supplied by the U.S. Agency for International Development.

II. Overview of Principal Conclusions

From the various types of contacts cited above, the author has reached a number of conclusions regarding the degree and effectiveness of research reactor utilization, and of the utilization of many related nuclear techniques, in a number of developing Asian and Latin American countries. These conclusions, without any references to specific countries, are summarized below. Country-specific background information, upon which these general conclusions are based, are presented in more detail in Section III.

A. General Conclusions

The various reactor and related nuclear centers visited by the author vary widely in such aspects as maintenance; financial support; staff size, quality, and turnover rate; magnitude of reactor utilization; degree of interaction with other governmental and private agencies and interests within the country; long-range planning; adequacy of adjunct equipment; vigor of management; and extent of practical application activities. In these repects the nuclear programs of the various countries range from minimal to good. Most of these countries lack the longer-established and more extensive tradition of scientific and engineering research, development, and application of developed Western countries. Thus, in many cases, their atomic energy commission laboratories represent the outstanding (and in some cases essentially the only) centers of scientific

R and D in their countries. Viewed in this light, even the rather minimal nuclear progress being made in some of these countries is not as bad as one might otherwise think — they are pioneering the introduction of science in their countries, and this takes time. It cannot be done overnight. Many may still be in a phase that may be described as an incubation period. This incubation period can be shortened, and the rate of growth after this incubation (or induction) period can be accelerated, by continuing effective help and encouragement from developed countries. If and when the governments of these countries can be convinced — by nuclear applications of proven economic value — that their nuclear programs are really worthwhile to their countries, funding will improve and their nuclear programs can begin to flourish. A few of these countries are closely approaching this happier state of affairs now, but most are still struggling to make progress with severe limitations of funds for maintenance, operations, purchase of needed auxiliary equipment, and salaries. In many of these countries, poor economic conditions (low per-capita productivity, low per-capita income, low standard of living, inflation, and political instability) — which adversely affect not only their nuclear development, but also all their economic and social development — provide a rather hostile environment for the growth of nuclear science. With such severe and pressing economic problems, nuclear research must still be regarded as somewhat of a luxury, or at least as a very long-range activity, in many of these countries. To really flourish, these nuclear centers must first demonstrate some achievements that are clearly of immediate value to their countries, and they need to develop applications-oriented plans (such as five-year plans) that are closely meshed with overall national plans. They must cease operating so much in a vacuum, and quite so academically. They must interact vigorously with other agencies in their countries, and attack real, present-day problems.

B. Problems of Staffing

In essentially all of these countries there are quite a few really first-class nuclear scientists — most of whom have graduate degrees (generally, Ph.D.'s) from excellent universities in the U.S., Canada, England, France, or Germany. However, the number of such top-notch scientists is quite limited in these countries, and the number of backup personnel, of comparable quality, stature, education, and experience, is often severely lacking. As some of their nuclear-science leaders are promoted into higher government positions, as is now happening frequently, there are in many instances not adequate reserves from which to replace them. In the second echelon, one frequently finds a mix of a few excellent scientists, and larger numbers of good, average, and even poor

scientists. In many of these countries, the salaries paid, particularly to scientists in the second echelon, are extremely poor. This situation has the natural result that, as industrial, academic, or other job opportunities in the country grow, the best people in the second echelon of nuclear scientists are the ones who are preferentially lost. In a number of these countries, the salaries are so low that many or most of their scientists have to hold down one, two, or even three additional jobs, outside the atomic energy commission, in order to support their families adequately. Naturally, this has a most adverse effect on their productivity as nuclear scientists. Only a few of the most dedicated of such scientists can withstand the temptation to take a university position that often pays two or three times as well, or an industrial position that often pays three or four times as well, if the offer of such a position arises. There is thus an extremely large turnover rate of personnel in many of the atomic energy laboratories, with a decided preference for the loss of the most capable members of their staffs — not only amongst the ranks of their chemists, physicists, mathematicians, engineers, medical doctors, geologists, and biologists — but also amongst the ranks of their technicians (particularly electronics technicians) and machinists. There is no question but that, in some of these countries, their nuclear programs will never flourish unless the salaries of their personnel are greatly increased over their present levels. It has been argued by some that this turnover rate is really good for these countries — the atomic energy laboratories serving as a training ground for good scientists, engineers, technicians, etc., who then leave to take good positions in other parts of their country's economic structure. This is undoubtedly true, but it makes it even more difficult for their atomic energy laboratories to make adequate progress on the problems they attack, or to produce significant accomplishments.

C. Degree of Reactor Utilization

In most of these countries (with only a few exceptions), their research reactors are actually operated a fairly large number of hours every week — in some cases even on a 24-hour-per-day basis. Unfortunately, the efficiency of utilization of these reactor hours of operation is often rather low — in some cases amounting to little more than "busy work". The outstanding saving grace in almost every case is the appreciable usage of the reactors for the production of medical radioisotopes. As is discussed in Section F below, this outstanding area of reactor utilization is one that can, and should, continue to grow in the future. In other areas of reactor utilization, such as that of neutron activation analysis (NAA) (also discussed more fully in Section F), the lack of adequate adjunct

counting equipment severely limits the effective use of the reactors for practical NAA applications. In many cases, a perfectly good $500,000 reactor is used very inefficiently for NAA applications studies because of inadequate counting equipment — whereas an investment of only $25,000 (only 5% of the cost of the reactor) could readily triple or quadruple their NAA capabilities.

D. Contacts with Other Groups within the Country

In almost all of the developing countries visited by the author, the extent of useful and operating contacts between their atomic energy commissions and other segments of the government and economy (e.g., with the industrial, agricultural, medical, and educational segments) is extraordinarily small. This is a fundamental weakness, and one that must be remedied if the atomic energy laboratories are to have a significant beneficial impact upon the economies of their countries, and the well-being of their populations. In most cases, it will only be when such useful and vigorous cooperative interactions are developed that the stature of these laboratories will rise, and be recognized by the greater financial support of which they are in such dire need. To progress, the atomic energy laboratories must cease operating as isolated "ivory tower" (and starving) laboratories. They must mix in with all operations within their countries in which nuclear techniques and expertise can be of help. The establishment of such vigorous working relationships with other groups is not easy (it took a long time to accomplish in the U.S.), but it is essential, and it requires a type of leadership that is often lacking in these countries. This, again, is an area in which outside help and guidance could be very productive.

E. Contacts with Nuclear Groups and Activities in Other Countries

Just as many of these atomic energy commissions operate with little interaction with other groups within their countries (as discussed in Section D above), so they also have very few contacts with nuclear groups of other countries — even of nearby and adjoining countries. This lack of contact has at least two serious adverse effects: (1) their personnel miss out on the stimulating effect of discussions of topics of mutual interest with their opposite numbers in other countries, and of the possibilities of utilizing one another's advances in techniques and applications, or even of equipment, and (2) several countries will often engage in separate, quite duplicative, studies of some problems that are really of common interest, and which could be attacked far more effectively in a cooperative, non-duplicative, fashion. There is an obvious solution to

this problem — moderately frequent regional meetings (e.g., meetings of Asian countries, and meetings of Latin American countries) involving the getting together of nuclear personnel of the various countries of the region to discuss in detail problems of mutual interest, to present papers on the results of their studies, and to plan cooperative attacks on problems of mutual interest. The idea of regional cooperative programs, and of periodic regional meetings — in the field of useful nuclear applications — is currently being promoted by the International Atomic Energy Agency in the two regions of the world discussed in this report — Asia and Latin America. These IAEA programs are well thought-out, are already being implemented, deserve strong support from more developed countries, and will undoubtedly be of benefit to the countries concerned — but the financial support available for them is very small.

Such regional contacts are sorely needed, but they are not the only kind of contact with other countries that is needed. In addition to frequent and cooperative mutual-assistance contacts with other developing countries in their region, these countries need more contact with and more help from the more nuclear-advanced countries of Asia and the Pacific, suchas Australia and Japan. They also need more contact with and help from nuclear scientists and the nuclear programs of the leading countries of the Western world — the United States, Canada, England, France, Germany, Belgium, The Netherlands, Italy, and the Scandinavian countries. Possible ways of implementing such healthy and fruitful contacts are stepped-up and continuing programs of visiting experts, sister laboratories, education and training fellowships, international cooperative programs and conferences, planning and advisory groups, donations of smaller auxiliary equipment items, donations of needed books and journals (sorely lacking in many of the nuclear laboratories of these developing countries), and donations of non-classified nuclear reports. Many of such assistance programs exist, but they are generally too small and too spotty.

F. Practical Applications of Nuclear Methods

These countries sorely need practical applications of nuclear methods that can help the economies of their countries and raise the standards of living and health of their people. Although great numbers of such practical applications have been developed and are in regular use in more advanced countries, such as the United States, with few exceptions such practical applications have not grown very much in most of these developing countries. All of them have at least some sort of a nuclear applications program, and all profess that this is an area of their work that deserves a high

priority — but in almost all of them their progress along such lines has been thus far rather minimal or modest. There are many reasons for this general lack of progress (a number of them discussed in the preceding sections of this report), and fortunately there are some encouraging exceptions.

Most potentially useful and practical applications of nuclear techniques center about — in one way or the other — a nuclear reactor. However, in this discussion even non-reactor types of applications should be included, i.e., ones perhaps involving isotopic neutron sources, small accelerators, and radioisotopes best purchased from abroad (e.g., kilocurie gamma-radiation sources, long-lived radiotracers, long-lived radionuclides serving as radiation sources in nuclear gauges, isotopic-sources in x-ray fluorescence instruments, and gamma-radiography units).

1. Production of Medical Radioisotopes

The one outstanding practical application of the research reactors in almost all of these developing countries is the production of medically-useful radioisotopes: ones such as 8.05-day ^{131}I, 6.05-hour ^{99m}Tc (from its 66.7-hour ^{99}Mo parent), 15.0-hour ^{24}Na, and 35.3-hour ^{82}Br. Longer-lived medical isotopes, such as 46.9-day ^{203}Hg (and often even 8.05-day ^{131}I), are usually more economically purchased from abroad, unless a fairly high-flux reactor is available. In most of these countries, the field of nuclear medicine, which uses such radioisotopes largely for diagnostic purposes (and in some cases also for therapeutic purposes), is one of the more aggressive and expanding fields. This field of application has a large potential for further growth — especially if the nuclear reactor laboratories act more vigorously than most of them have thus far in promoting the production, processing, rapid distribution, and medical applications of these radioisotopes. Some of the reactor centers have quite good laboratory facilities for processing, purifying, compounding, testing, sterilizing, and assaying the medical radioisotopes they produce; whereas, at the other extreme, some merely produce the radioisotopes, and leave all of the other operations to either a central medical laboratory or to the various user medical groups (usually hospitals). Most of the medical groups that use radioisotopes for diagnostic purposes have one or a few gamma-ray scanning units, whereas very few of these countries as yet possess even one of the more expensive, but more powerful, Anger cameras. Many of the hospitals in these countries do have kilocurie cobalt-60 sources for cancer radiation therapy. These high-intensity sources are invariably purchased from abroad — usually from the United States, Canada, or England.

2 Production of Non-Medical Radioisotopes

Most of the nuclear reactors in these countries also produce radioisotopes — particularly the short-lived ones (which have advantages for use as tracers, and which, because of their short half lives, are less economical to purchase from abroad) - for various kinds of outside, non-medical, radiotracer studies. In general, however, the extent of the production of such non-medical radiotracers is rather small, compared with their production of medical radioisotopes. The use of radiotracers, to aid in the solution of many industrial, agricultural, and hydrological problems, could undoubtedly be greatly expanded by more vigorous efforts on the part of the various atomic energy commissions. As the experience of the United States in this field testifies to emphatically, one must really get out and "sell" the use of radioisotopes, and actively help new users, if one desires to see their maximum, yet safe, application. It is true, of course, that the rate of growth of such radiotracer applications in these developing countries is also inhibited by their as yet low level, in most cases, of industrial development. Many of their nuclear personnel complain that much of their industry is controlled by foreign companies, and these foreign companies prefer to do their research and development work (often involving the use of radiotracers) in their own central research laboratories instead of in the developing countries. However, even outside the field of basic research and development, there are many applications of radioisotopes as tracers, as sources in nuclear gauges, and as sources in other kinds of instruments that can be made in production operations — applications such as in process control, quality control, safety devices, and trouble-shooting. In this author's opinion, most of the atomic energy commissions in these developing countries should be much more active and agressive than they have been so far in promoting more of such radioisotope applications in industry, mining, agriculture, and hydrology.

3. Neutron Activation Analysis Applications

One of the most promising areas for further development and expansion is that of applications of the neutron activation analysis method. This method of elemental analysis allows one, with a nuclear reactor, to determine quantitatively even extremely low trace levels of most of the elements of the periodic system — in essentially any kind of solid or liquid sample material. When applied in its purely instrumental form (based upon gamma-ray spectrometry), it is a nondestructive method, and can then in many cases also be an extremely rapid method of analysis

Whereas the applications of reactor-based NAA in a great variety of fields (e.g., in fields such as biology, medicine, agriculture, hydrology, industry, environmental pollution, oceanography, geochemistry, archaeology, metallurgy, crime investigation, etc.) are being rapidly expanded and exploited practically in many of the more advanced countries, such as the United State, England, several of the European countries, the USSR, and Japan, most of the developing countries discussed in this report have not made very striking progress in this direction. There are, fortunately, several exceptions — some developing countries that have made, and are increasingly making, some really good practical applications of the NAA method to problems of significance in their particular countries. All of these developing countries that possess a research reactor appear to recognize the great potential value of the NAA method, and all have at least one or a few people working in this field. In most cases,however, the NAA group is too small to form a "critical mass" of personnel — a group of adequate size that they can (1) stimulate one another's thinking, (2) effectively attack a variety of problems simultaneously, (3) work together on larger or more urgent problems, (4) develop various NAA applications specializations — particularly by making operating contacts with other agencies and organizations, and (5) have a stronger voice in the planning and funding of their atomic energy commission's operations. Many of these laboratories or countries have total staffs of one hundred to several hundred people, but only have one or two people working in the field of NAA. This is simply not enough. If, instead, they would set up a group of even five scientists, headed by a very energetic person, this type of work — leading to more effective utilization of their research reactor and to the solution of many problems of importance in the country — would expand and flourish.

Most of the NAA groups are severly lacking in one essential type of adjunct apparatus — a lithium-drifted germanium semiconductor (Ge (Li)) gamma-ray spectrometer. A number of them do not even have really adequate thallium-activated sodium iodide (NaI(Tl)) scintillation gamma-ray spectrometers. The older NaI(Tl) systems are still very useful in NAA work, and are considerably less expensive than the newer, very-high resolution, Ge(Li) systems. A good complete, Ge(Li) system costs in the range of $25 K to $35 K, i.e., two to three times as much as a good, complete, NaI(Tl) system. However, a Ge(Li) system increases the NAA capabilities of a laboratory several-fold, and hence is a worthwhile investment — if

the laboratory has a capable and energetic NAA applications group of at least minimum effective size (~5 persons). A few of the larger reactor establishments in these countries do have NAA groups of the "critical mass" size, and do have one or even two or three good Ge(Li) systems. These are the laboratories that are doing a fair amount of good NAA applications work. Several others are pointing in the right direction, in terms of group size and vigor, and some of these are now trying to obtain funding for a Ge(Li) system. In several instances, where the funding likelihood appears to be low, at least for some time to come, the author has recommended a less expensive interim measure that was used effectively in the author's former NAA laboratory, and in a number of other NAA laboratories. This interim measure consists of purchasing a moderate-sized Ge(Li) detector (with cryostat and preamplifier) and a biased amplifier/pulse stretcher, and then using it with an existing 400-channel or 512-channel pulse-height analyzer. This approach avoids the necessity of purchasing a rather expensive 4096-channel pulse-height analyzer, and its more expensive data readout system. Such an interim-type Ge(Li) spectrometer is of course not as powerful as a full 4096-channel system, but it does provide the same high-resolution capability as the more expensive system, and, for single-element and few-element applications, it is equally good. The 4096-channel system, of course, greatly excels in multi-element studies. The Ge(Li) detector requires the constant availability of liquid nitrogen, but this does not appear to be much of a problem, since all of the reactor locations appear to have some fairly closeby commercial supply of liquid nitrogen, and some have small, but adequate, on-site liquid nitrogen generators. In many instances, the available gamma-ray spectrometry equipment, whether NaI(Tl) or Ge(Li), could be even more effective if, with more complicated samples, a radiochemical group separation procedure were employed prior to spectrometry measurements. In most of these laboratories, radiochemical-separation techniques are not used sufficiently in NAA work, apparently often because of difficulties in obtaining the necessary ion-exchange resins, complexing agents, and special chemicals (such as hydrated antimony pentoxide — "HAP" — an efficient material for sodium removal from activated samples). Some laboratories also complain of the difficulties and long delays encountered in purchasing suitable element standards, standard reference materials, and other essential chemicals.

Whereas a nuclear reactor is by far the most potent and widely useful type of neutron source for NAA work, there are a number of applications in which a small 14MeV neutron generator or an isotopic neutron source can be useful. A few of these developing countries have one or both of these additional types of neutron sources. Almost without exception, these attempts have been disappointing. In this author's opinion, they will continue to be disappointing until such time as the more advanced, smaller, and vastly more stable and dependable high-output sealed-tube type of 14MeV neutron generator is obtained and used; and until milligram amounts of ^{252}Cf are obtained for isotopic-source NAA studies. Those groups that do have 14MeV neutron generators at present almost all have a drift-tube type of machine. These are notorious for their difficulties and large amount of down time (the author speaks from experience, since in his former two laboratories he has had a total of four such drift-tube machines; now, in his present laboratory, he has an excellent sealed-tube machine). The only thoroughly reliable high-output (10^{11} neutron/second 4π output rate) sealed-tube 14MeV neutron generator that is commercially available at present is one made in the United States. At present, milligram and larger amounts of ^{252}Cf appear to be available, for purchase internally and abroad, only from the United States and England.

4. Radiation Treatment of Foods.

In addition to the use of high-intensity radiation sources for cancer therapy and gamma radiography (discussed earlier), a number of these developing countries are greatly interested in, and are doing a fair amount of work on, the possibility of improving the storage life of foodstuffs by radiation treatment. Many of these countries are in tropical zones, and many have rather limited refrigeration facilities — hence radiation preservation of many kinds of especially sensitive and perishable foodstuffs is a subject of greater interest than it is in the United States. In particular, considerable effort is being devoted to studies of the radiation preservation of seafoods and tropical fruit (e.g., bananas, papayas, mangos, etc.), and of the radiation disinfestation of grains (particularly rice). Although the author is no expert in the field of radiation preservation of foods, his visits in several of the laboratories in these countries that are engaged in such studies impressed him favorably. They appear to be doing good work, obtaining quite encouraging results, and attacking problems whose solution could have a real economic impact in their countries. Most

of them are concentrating on relatively mild radiation doses — just sufficient to extend the "shelf life" of such perishable commodities long enough, without refrigeration, to make such processing economically attractive, yet small enough that there is no noticeable impairment of food quality, taste, or odor. The various groups engaged in these studies are sizeable groups — often consisting of 10 to 30 people. (If even half this amount of manpower were devoted to NAA applications studies, their NAA programs could rapidly climb out of the doldrums and become productive). These groups all employ kilocurie and larger cobalt-60 gamma-ray sources. Little attention seems to be given to alternate radiation sources (such as electron accelerators) or to alternate methods of preserving foods (such as refrigeration or chemical fumigation) — from the standpoint of cost. Such cost comparisons should be made, and made very carefully, or else it is possible that they could spend years of effort developing a technically successful process that would not be economically competitive. All of these groups expressed great concern about the United States Food and Drug Administrations' refusal to approve radiation-treated foods within the U.S., at least until long-term feeding tests have established that such treatment does not lead to the formation of significant amounts of carcinogenic or other medically dangerous products.

5. Other Types of Nuclear Studies and Applications.

The other types of nuclear studies, based upon nuclear reactors, in which some of the laboratories in these two regions are engaged, may be grouped together roughly as studies that involve the use of neutron beams. These studies include investigations of neutron radiography, neutron capture, neutron scattering, and neutron diffraction. The last three are studies largely of an academic — rather than applied — nature. In the few laboratories in which studies of these three types are being conducted, a relatively excessive amount of manpower and specialized expensive equipment is being devoted to such studies — in this author's opinion. Some work of this general nature may be justifiable, for the purpose of education and training in neutron techniques, but an undue emphasis on such work would seem to be largely a waste of time. In countries that have such pressing economic problems, and such low standards of living (in most, but not all, of the countries under discussion), it would seem far more sensible to devote their restricted manpower and limited funds to nuclear studies of more immediate practical usefulness to their respective countries. In addition, studies of these types are being made far more readily and far better in

more developed countries with larger (and more experienced) staffs, larger budgets, and much higher neutron fluxes.

The one neutron-beam area of work that does have quite a few applications of significance — neutron radiography — is one in which almost none of the laboratories are working, although a number of them appear to be interested in this field, and several have at least vague plans to commence some work in this field. Not only is this field one that has useful applications, but it also is a field that does not require extremely high source neutron fluxes or complicated and expensive auxiliary equipment. Even a 100-kilowatt reactor, for example, plus one or a few simple beam tubes (horizontal or vertical), a sample holder, X-ray film, sheet gadolinium, and a dark room, is all that is necessary to do excellent neutron radiography work. With the neutron beam intensities available from even a 100-kilowatt reactor, exposures of only the order of minutes are usually needed, so large numbers of specimens of many varieties can be studied in quite reasonable periods of time by even one or a few scientists. Furthermore, this type of work does not interfere with other kinds of studies, using the reactor, that may be carried on simultaneously — work such as radioisotope production, neutron activation analysis, etc.

6. Non-Food Radiation Processing Studies

Two types of radiation-processing studies involving materials other than foodstuffs are being conducted in a number of these countries: (a) irradiation of wood-plastic combinations, and (b) irradiation of cement-plastic combinations. There is much more interest in, and work devoted to, the study of wood-plastic combininations than of cement-plastic combinations, and this emphasis is undoubedly a wise one. Many of these countries possess large supplies of various kinds of soft woods (including bamboo) that are of relatively little economic value for hardwood types of uses, and very small supplies of the more valuable hardwoods. As in the U.S., initial enthusiasm regarding the possibilities of wood-plastic irradiation — leading to the thinking that one might readily convert soft woods into hard woods that could be used economically for home and building construction — soon tapered down. It was thus soon realized that (a) suitable treatment of large timbers was a very difficult problem and (b) even beams that were adequately treated, although much stronger than the original soft wood, were also much denser, and hence the strength per unit weight of such treated wood was not significantly better (and often appreciably poorer) than the original soft wood or of virgin hard wood. Emphasis was thus soon

switched to the possibilities of such plastic-irradiation techniques for the production of specialty types of wood materials or objects, in which surface hardness is more important than overall mechanical strength. In this type of application, some very good results have been obtained. In this author's non-expert opinion, it appears that such processing may soon be economically practical for the production of such things as wood flooring (e.g., parque flooring), table tops, bowling pins, rifle stocks, etc., from soft woods.

In general, wood-plastic irradiation processing consists of impregnating precut or preshaped wood pieces or objects with a suitable monomer, to a suitable depth — by vacuum impregnation, followed by irradiation to a suitable dose and a suitable depth with gamma rays from a many-kilocurie source of gamma rays, such as cobalt-60.

In the case of cement-plastic irradiation, the purpose is generally to improve the salt-water corrosion resistance of solid concrete or cement by incorporating a plastic monomer in its surface layers, and then polymerizing the monomer in situ by exposure to a large dose of gamma radiation. In this type of application, it may be necessary to impregnate, then irradiate, rather large objects (such as cement piling), thus posing some severe mechanical handling and processing problems.

G. Specific Needs

In order to make more effective use of their nuclear reactors — particularly in the area of practical applications of nuclear techniques, and to make greater progress in areas involving the application of nuclear techniques that do not involve their reactors, many or even all of these countries have various pressing needs of various types. These needs can be grouped into two general categories: non-equipment needs, and equipment needs. These two general categories of needs are discussed below.

1. Non-Equipment Needs

To varying degrees, these countries need larger budgets for both capital equipment (discussed in the next section); and for salaries, maintenance, and operations (discussed in this section). The mere availability of larger budgets, although of great significance, is not the only needed ingredient — more efficient utilization of whatever funds are available is generally needed. In this connection, more (heeded) outside advice from more experienced laboratories, and more critical long-range planning would both be very helpful. More thought and planning is generally needed to focus attention on practical problems of particular economic and social importance to the country, that

appear to lend themselves to attack by nuclear methods — followed by project planning and execution by groups of sufficient size to make a significant impact on the problem. The planning needs to take account of economic, as well as scientific, aspects, and it needs input from all other relevant segments of the country's economy, i.e., from non-nuclear segments such as industry (of all types that are important within the country), agriculture, medicine, hydrology, law enforcement, etc.

Also, in every one of these countries — although to quite varying degrees — there is a need for much better salaries for all the personnel. Until these laboratories provide salaries that are competitive with other segments of the country's economy — especially industry and universities — they will continue to suffer from an excessive rate of personnel turnover, poor morale, and inadequate productivity (due to personnel also holding down one or more additional jobs, in order to earn enough money for adequate living). This is a severe need.

Another serious need, and one that is partly related to the salary problem, if for better electronic maintenance. A few of these nuclear laboratories have rather good electronic shop and equipment maintenance facilities, but the majority do not. Nuclear work, of course, relies very heavily upon electronic instrumentation — often quite complicated instrumentation. When a unit such as a multichannel pulse-height analyzer breaks down, it is imperative that, if at possible, it be repaired and made again operational as rapidly as is feasible — preferably within a few hours or at most a few days. The author has observed a number of research and development projects, in a number of these laboratories, that were at a standstill for many months (or even years) due to such equipment breakdowns. Such periods of enforced idleness are disastrous to morale, and severely decrease productivity. Often the problem is an inadequate number of sufficiently expert electronic technicians. Often the problem is the absence of necessary spare parts — with the attendant long delays in obtaining them from overseas (often complicated further by inadequate budgets for spare parts, and by excessively slow purchasing departments — bogged down by red tape, and often apparently incapable or unwilling to give rush priority to the purchase of desperately needed spare parts). Again largely due to low salary scales, competent electronic technicians often leave soon for better-paying positions elsewhere in the country — particularly in industry. More advance stockpiling of critical spare parts (practiced

in some of the laboratories) is of course of great help. In many instances, incoming pieces of equipment and spare parts are inordinately delayed, sometimes for weeks or months, by cumbersome and inefficient Custom's offices. In many cases, better machine shop facilities, and more expert machine shop personnel, would also be of great help.

In many (but not all) of these laboratories, more attention is needed for general physical maintenance. Whereas in most cases the nuclear reactors are maintained quite adequately, the condition of the chemical laboratories, the buildings, the grounds, and the roads is frequently poor. Many show great neglect. A laboratory in a generally rundown condition is certainly deleterious to morale, thus decreasing productivity. Since manpower of a janitorial and physical maintenance type is usually cheap and plentiful in these countries, it is puzzling why more effort is not devoted to maintaining these laboratories in a neat and attractive way. Many of them need cleaning and painting, better lighting, and better care of the grounds and roads — and much cleaner plumbing facilities. With their severely restricted budgets, many of these laboratories apparently feel that such general maintenance is relatively unnecessary. In this author's opinion, this is a mistake.

In most of the laboratories, on the other hand, adequate attention is given to health physics regulations, monitoring, and control — but often other aspects of laboratory safety are not given sufficient attention. This situation, however, does not differ greatly from the practices of many U.S. laboratories (particularly university laboratories) where the general problem of laboratory safety is frequently not given sufficient importance — often until a severe explosion or fire brings about the necessary reforms.

Library facilities in these laboratories cover a wide range: all the way from very poor to very good. Once again, funds are usually the limiting factor, as all of them recognize the need for a continuously updated supply of good reference books, textbooks, technical reports, reprints, and journals in the broad field of the nuclear sciences — as well as the related backup fields of chemistry, geology, metallurgy, mathematics, etc. Any sources of continuing assistance, from abroad, to these libraries would be of great help to them. With increased budgets, of course, many would be able to help themselves. More modern copying equipment (such as Xerox machines) would also make these libraries much more useful to the scientific staff.

Many of these laboratories have concentrated their efforts in a few fields, such as radioisotope production (for medical purposes particularly), neutron activation analysis, and irradiation of foods and wood — plastics combinations. Considering the very limited budgets of many of these laboratories, perhaps such concentration is necessary and even desirable. However, it has led to the considerable neglect of many branches of nuclear science that also could have important useful applications in their countries: fields such as neutron radiography, nuclear gauging, gamma radiography, x-ray fluorescence using radioactive sources, uses of californium-252 sources, uses of 14MeV neutron generators, etc. There is a need, in many of these laboratories, to carefully consider the promise of some of these fields, and then to start working in at least a few of the more promising ones.

2. Equipment Needs.

As was mentioned earlier, many of these laboratories have quite adequate nuclear reactors, but the output of useful work is limited by an inadequate supply of necessary modern adjunct equipment — in particular, more sophisticated equipment such as Ge(Li) detectors, multichannel pulse-height analyzers, fast data readout devices, and small computers. In many instances, at a cost only amounting to 10-20% of the cost of the nuclear reactor itself, the output of useful work of the facility could be doubled, tripled, or even quadrupled.

In general, budgets for such vital adjunct equipment — equipment that would greatly benefit productivity and morale — are exceedingly small. In most cases it is a vicious circle: if nuclear applications of clear economic value to the country could be developed and put into operation, the government would be happy to increase their nuclear budgets, but money is needed first for the equipment that would help them achieve these useful applications. Perhaps one source of supplemental funding that could be helpful, but which has been utilized significantly in only a few of the countries, is that of funding through research and development contracts — contracts with other government agencies and with industrial concerns. Many have samll research contracts with the International Atomic Energy Agency (IAEA), and these contracts are often coupled with small equipment grants, for needed equipment that is relevant to the research contract. These grants are often very helpful, but they are usually quite small — often only a few thousand dollars.

So far as this author could ascertain, the most severe equipment needs in many of these laboratories are for (1) one or two medium-sized Ge(Li) detectors, (2) one

or two 2048-or 4096-channel pulse-height analyzers (with appropriate fast readout devices), and (3) a medium-sized computer. Many could also profit by the availability of additional pieces of smaller, much less expensive, equipment items such as a few more scalers, ratemeters, oscilloscopes, pulse generators, strip-chart recorders, NaI(Tl) scintillation detectors, high-voltage supplies, preamplifiers, linear amplifiers, oscilloscope cameras, automatic analytical balances, a micro balance, centrifuges, vacuum pumps — and increased supplies of reagent chemicals, standards, standard reference materials, ion-exchange resins, chemical glassware, plastic ware, etc. With more of such smaller adjunct equipment and supplies, the productivity of most of these laboratories could be increased quite significantly, the scope of their research and development programs could be expanded — and the availability of backup replacement equipment would decrease the duration of project shutdowns due to equipment failure. This is an area in which international organizations and more highly developed countries could be very helpful — by donating obsolescent (but not obsolete) equipment of these types to these developing countries. Donations of milligram quantitites of californium-252 spontaneous-fission neutron sources would also be of considerable usefulness in several of these countries. Thus far, the availability of 14MeV neutron generators (either purchased or donated) has proven to be a mixed blessing. The laboratories that have such neutron generators almost all have ones of the drift-tube type. These are notorious for their large percentage of down item, and their general unreliability. In most cases, the amount of manpower devoted to maintaining these generators, and trying to carry out useful experiments with them, could have been utilized far more effectively in other pursuits. In this author's experience, the only reliable and productive type of 14MeV neutron generator is the newer, sealed-tube type. Many of the drift-tube machines observed in these countries by the author were sitting idle for long periods of time, while they attempted to repair them or waited for replacement parts to arrive from overseas.

H. Summary and Future Prospects

The nuclear programs and laboratories in most of these countries have a long, painfully slow, road ahead of them — before they became sufficiently productive and useful to their countries to attract the recognition and respect that will result in the sorely needed increased governmental funding. Their present needs are in most cases numerous and serious. They generally need considerably increased budgets (not so much for buildings, but rather for salaries, equipment, supplies, libraries,

and maintenance); more and better short-, medium-, and long-range planning; much more extensive and intimate continuing operating contacts and interactions with other governmental agencies and industrial, agricultural, and medical private companies in their countries; more dynamic leadership; much more attention to practical applications of nuclear techniques; more research and development contracts; more contact with the public; and more contact with similar laboratories in other countries in the same geographical region, and with those in more highly developed countries.

Most of these countries lack a long and well recognized scientific tradition and an adequate supply of native-born and native-educated scientists and engineers. Most are still heavily agricultural countries, only beginning to develop their natural resources and their own industry. Most of them are countries with a low standard of living and a low per-capita productivity. Many of them have severe problems of inflation and political instability. With all of these problems and difficulties, it is little wonder that many of them have thus far made relatively inefficient utilization of their nuclear reactors and their limited adjunct equipment. Many of them operate in excessive isolation from other segments of their country's economy, and from similar laboratories in even nearby countries. Whereas it is easy for persons such as the author to criticize the nuclear activities in many of these countries, and to point out many of their shortcomings, one must also admire the patience and tenacity with which a small group of their leading nuclear scientists (some of them of first-rate caliber) have persevered, in the face of all these obstacles. In most, and hopefully all, of these countries, the author is firmly convinced that these severe obstacles will gradually be overcome, and relatively flourishing and expanding productive nuclear applications programs will develop. Unfortunately, their progress will undoubtedly continue for some time, in most cases, to be painfully slow. With the judicious assistance of international organizations and some of the more highly developed countries, their rate of progress can be very significantly increased.

On a more encouraging note, the nuclear programs in a few of these countries appear to have already progressed beyond this painful induction period, and are now expanding and prospering, to the benefit of their respective countries. In a more practical vein, it should also be noted that these countries will gradually become markets of some consequence for all kinds of nuclear, and related scientific and industrial, equipment — for countries such as the United States.

III. Summaries of Individual Countries

In this section, summaries of the nuclear programs, and especially of the research reactor utilizations, are given for each of the developing countries of Asia and Latin America visited by the author on various occasions. In each case, the nuclear facilities and activities described are those in operation at the time of the author's visit(s). In many cases, these facilities and activities have been expanded somewhat since then.

A. Asian Countries

Relevant to this report, the author has visited many of the nuclear laboratories in The Philippines, Thailand, Korea, Indonesia, Singapore, Taiwan, and Hong Kong. The nuclear programs of each of these countries are summarized below.

1. The Philippines

The author visited nuclear and other organizations in The Philippines during March 1971 and June 1972, in each case for about one week. The organizations visited were the following: (1) The Philippine Atomic Reactor Center (PARC), (2) The Philippine Atomic Energy Commission (PAEC), (3) The Philippine National Science Development Board (NSDB), (4) The Philippine General Hospital, (5) The Philippine Bureau of Mines, (6) The Philippine National Bureau of Investigation, (7) The Philippine Association of Nuclear Medicine, (8) The Philippine Radioisotope Society, (9) the U.S. AID office in Manila, (10) the U.S. Embassy in Manila, and (11) U.N.D.P. headquarters in Manila. During the second visit, it was planned that the author would also visit a number of other organizations, but tremendous floods in the area made travel almost impossible (what travelling that was done was barely feasible even in a 4-wheel drive Jeep). The floods resulted in epidemics of cholera and gastro-enteritis — the author being stricken with the latter.

a. Nuclear Facilities. The principal nuclear facilities in The Philippines consist of a one-megawatt General Electric research reactor (from the U.S. Atoms for Peace Program) and a 22,000-curie cobalt-60 radiation processing source, both located at PARC (in Quezon City, on the outskirts of Manila). The reactor is reasonably well utilized, operating at least 40 hours per week (in two continuous 20-hour isotope production runs), plus shorter runs on demand. It lacks a rotating sample rack and a sufficiently fast pneumatic tube. The principal uses of the reactor are for radioisotope production (particularly medical radioisotopes) and

for neutron activation application studies. The PARC laboratory has a staff of about 200 persons and includes six research departments. These departments, arranged approximately in the order of decreasing size, are the departments of Agricultural Studies, Health Physics, Chemistry, Nuclear Engineering, Biomedical Studies, and Physics. They are supported by an Experimental Services Department and a Reactor Operations Department. The reactor is equipped with two pneumatic transfer tubes and various tubes for longer irradiations. The laboratory is fairly well equipped with auxiliary apparatus, such as an infra-red spectrophotometer, a UV-visible spectrophotometer, a mass spectrometer, an isotopic-source X-ray fluorescence spectrometer, several automatic analytical balances, an atomic absorption spectrophotometer, two gas-liquid chromatographs, and several scalers. However, the laboratory is not adequately equipped with multichannel pulse-height analyzers, having only two 100-channel units (from the IAEA), one 256-channel unit, and one 400-channel unit, all rather old, and used with NaI(Tl) detectors. The 256-channel analyzer is used by the Physics Department, and the 400-channel one is used by the Nuclear Engineering Department (which handles the radioisotope production work), thus leaving only the two 100-channel units for neutron activation analysis (NAA) work. This is a very serious deterrent to their NAA work, as 100 channels are not even adequate for most NaI(Tl) gamma-ray spectrometry work, and would be essentially useless for Ge(Li) gamma-ray spectrometry. The NAA group, which has an ambitious applications program, sorely needs a Ge(Li) system, with either a 2048-or 4096-channel pulse-height analyzer. They have applied to the Technical Assistance Program of the IAEA for such a system. A small liquid-nitrogen machine is already or hand (a regular supply of liquid nitrogen is necessary with a Ge(Li) detector). The Health Physics Department has a PDP-8 small computer, and a large government central computer is also accessible.

b. Nuclear Activities. The neutron activation analysis work at PARC, using the reactor, is reasonably extensive, in spite of the poor nultichannel analyzer situation mentioned above. They are surveying various types of Philippine rocks, minerals, and ores for a number of elements of commercial interest, particularly copper and uranium. This work is partly funded by two IAEA research contracts. For the Philippine Rice and Corn Association, NAA studies of bromine, mercury, and cadmium residues in rice are being conducted. In another study, trace elements possibly related to a coconut disease are being measured. With the Medical School

of the University of The Philippines, trace elements present in kidney stones are being studied. The Biomedical Studies Department is also participating in the World Health Organization/IAEA study of trace elements related to cardiovascular diseases, using NAA techniques. Other NAA studies at PARC include investigations of wear metals in lubricating oils, trace elements in soil, mercury in fish, chromium in diabetes, and selenium in garlic.

In addition to the above NAA studies, the PARC laboratory conducts some agricultrual radiotracer studies, some hot-atom chemistry work, some nuclear engineering training, some neutron-beam research (formerly carried out under a Philippines-India-Korea cooperative program), a fairly extensive program of radioisotope production, and a fair amount of radiation-processing research (food irradiation and wood-plastics irradiation). These studies also are largely or entirely based on the reactor — with the exception of the radiation-processing work, which utilizes their 22,000-curie cobalt-60 gamma-ray source. Although the radioisotope production work is fairly extensive, it could and should be expanded further. At present, they make a few shorter-lived radiotracers for agricultural and hydrological studies; and sodium-24, bromine-82, and gold-198 for medical studies. Nuclear medicine people in The Philippines would like them also to produce technetium-99, iodine-131, and other radioisotopes of medical use, but PARC has thus far not responded to this need.

c. Relationships with Other Philippine Agencies and Organizations. Although the development of effective operating relationships between the PAEC and other agencies and organizations in The Philippines is only in its infancy, a promising start has been made — with some useful results already. Some good long-range organization and planning is evident, and this should, in due time, produce good results. The National Science Development Board (NSDB) of The Philippines is the center of these planning activities. It is an extensive and powerful governmental board, and has jurisdiction over quite a number of governmental agencies and laboratories: the PAEC, the five centers of the National Institute of Science and Technology, the Philippine Inventor's Commission, the Philippine Coconut Research Institute, and the Philippine Textile Research Institute. The NSDB also has close connections with the National Air and Water Pollution Board, the Metals Industries Development Center, and the Philippine Science High School — but these three organizations report directly to President Marcos, rather than to the Chairman of

the NSDB. The other seven agencies and institutes all report to the Chairman of the NSDB, who in turn reports directly to President Marcos. The NSDB has very good top leadership, a total personnel of about 2,000, and a budget of about 61 million pesos. The present Chairman and Vice Chairman of the NSDB are each former Commissioners of the PAEC, which should help to introduce nuclear activities into the operations of the various other agencies and institutes that comprise the NSDB.

The PAEC also has very good top leadership, and has initiated what appears to be good long-range planning. In 1972, the PAEC instituted a much-needed 5-year research and development program, which should produce good results. In addition to operating the PARC laboratory, the PAEC conducts an extensive and vigorous training program. Since 1959, this training program has conducted 83 courses (of 15 different types), training more than 1500 people in various nuclear disciplines. The PAEC appears to have some liaison, not yet very effective, however, with the other parts of the NSDB, and with groups such as the Hydrology Division of the Bureau of Public Works, the National Economic Council, the National Water and Air Pollution Control Commission, the Presidential Economic Staff, the Congressional Economic Planning Office, the Philippine Association of Nuclear Medicine, the Board of Investment, the International Rice Research Institute, the Philippine Fisheries Commission, the National Power Corporation, the National Food and Agricultural Council, the Philippine General Hospital, the Philippine Bureau of Mines, the National Bureau of Investigation, and various private companies. At least, a good start has been made in the PAEC on long-range planning and on cooperation with other organizations.

d. Summary of The Philippines. In this author's opinion, the nuclear program of The Philippines, although still of modest magnitude at present, is moving ahead and shows good promise. In particular, the long-range planning and organization of the National Science Development Board, and the 5-year plan of the Philippine Atomic Energy Commission, should produce good returns in due time. The Philippines share with a number of other developing countries in Asia and Latin America the common problems of a low standard of living, a low per-capita productivity, the lack of a long scientific and engineering tradition, low salaries for government employees, low budgets, political unrest, inflation, etc. However, in spite of all these obstacles, progress is being made in the nuclear field. The top managements of the NSDB and the PAEC both appear to be very good. Throughout the PAEC and PARC there are many good scientists, who show an encouraging enthusiasm about their work.

The Philippines has a wealth of opportunities awaiting the useful application of various nuclear techniques (such as radiotracer methods, neutron activation analysis, nuclear gauging, radiography, radiation processing, etc.). These opportunities exist in abundance in The Philippines in such fields of vital importance to their economy as agriculture, hydrology, minerals exploration and mining, medicine, forestry, fisheries, oil refining, crime investigation, food processing, chemical and other industrial production, etc. PARC is producing medical and other radioisotopes to a significant degree, but this should be expanded further. Their neutron activation analysis applications program is at present small, but viable, and should expand into the host of useful application areas that exist. Their R and D programs on food irradiation (including the radiation disinfestation of grains) and irradiation of wood-plastics combinations are promising and merit expansion. To expand into these promising areas at a reasonable rate, the PAEC needs a steadily growing budget for facilities, small and intermediate items of capital equipment (e.g., one or two good Ge(Li) multichannel gamma-ray spectrometers), salaries, operating expenses, library items, chemicals, and general maintenance expenses. Thought should also be given to the upgrading of their nuclear reactor — to provide appreciably higher neutron fluxes in irradiation positions, and to provide better sample-irradiation facilities. Areas which, in this author's opinion, could be profitably deemphasized are those of neutron scattering and hot-atom chemistry. Closer cooperation with other Philippine agencies and organizations is beginning, is definitely needed, and should accelerate the growth rate of useful nuclear applications. Much more extensive copperation with the nuclear laboratories of other Asian countries (such as Thailand, Taiwan, and Korea) would be very worthwhile. Continuing assistance from such more highly-developed countries as Australia, Japan, Canada, and the United States would also help the Philippine nuclear program greatly. The increasing interest in The Philippines in nuclear power (for the second time, they are at present carefully evaluating the possible role of nuclear power in their future power program) should also be a boost for the overall PAEC program.

2. Thailand

The author's first visit to Thailand was in July 1970, when he represented the U.S. Atomic Energy Commission at a dual IAEA meeting held in Bangkok: a 3-day meeting

on activation analysis work in Asian countries, followed by a 2-day meeting to discuss a proposed IAEA program of regional cooperation in nuclear applications work amongst developing Asian countries. The second visit was a brief one in Bangkok in November 1970, to discuss the extent of the interest of the U.S. Regional Economic Development office there in supporting the IAEA Asian regional cooperation program. In February 1971 the author spent an additional week in Thailand (largely in the area of Bangkok), as part of an extensive trip for the IAEA to help initiate their new Asian regional cooperation program in nuclear applications. The fourth visit, for the U.S. Agency for International Development, was a one-week visit during August 1972. During these various visits to Thailand, the author met with personnel of the following organizations: (1) the Thai Office of Atomic Energy for Peace (OAEP), (2) the Thai National Research Council (NRC), (3) Chulalongkorn University, (4) the Thai Scientific Crime Detection Laboratory, (5) the South East Asia Ministers of Education Organization (SEAMEO), (6) the U.S. Embassy, (7) the U.S. Operations Mission to Thailand (USOM), (8) the U.S. Regional Economic Development office (RED), and (9) the Thai Department of Mineral Resources.

a. Nuclear Facilities. The principal nuclear facilities in Thailand consist of a one-megawatt Curtiss-Wright nuclear reactor (acquired in 1962, under the U.S. Atoms for Peace program), and a 7000-curie cobalt-60 gamma irradiation source, both located in the OAEP laboratory, on the outskirts of Bangkok, near the airport. Except for the applications of medical radioisotopes in the hospitals of Bangkok and Chieng Mai, the nuclear activities of Thailand are concentrated almost entirely in the OAEP laboratory. Auxiliary nuclear and other scientific equipment at the OAEP laboratory includes two old 128-channel pulse-height analyzers, a newer Nuclear Data 512-channel pulse-height analyzer, several 3-inch x 3-inch sodium iodide scintillation detectors, a delayed-neutron counting system, a manual Packard Tri-Carb liquid scintillation counter, a centrifuge, a freeze-drying apparatus, automatic analytical balances, and various scalers, ratemeters, power supplies, and oscilloscopes. The OAEP laboratory is well maintained, has an excellent conference room, and the reactor appears to be moderately well utilized — operating usually from 35 to 40 hours per week, for radioisotope production (largely medical radioisotopes), neutron activation analysis, and some neutron-beam research. The reactor provides thermal-neutron fluxes of 7-8 x 10^{12} n/cm^2-sec in some sample irradiation positions. For sample irradiations, there are four dry vertical tubes and one wet vertical tube

at the edge of the reactor core, and also two pneumatic tubes (ca 2-second transit time, with conventional double containment). In longer irradiations, they have experienced quite a bit of difficulty with rupture of sample containers due to buildup of gas pressure in the containers, due to gamma radiolysis.

One particularly good feature of the OAEP laboratory is their large and excellent electronics department. Organized and headed by a Thai who received additional nuclear electronics training at the Oak Ridge National Laboratory a number of years ago, this department is very active and productive, not only maintaining all of the laboratory's electronic equipment, but also designing and constructing many smaller pieces of nuclear electronic equipment — such as preamplifiers, amplifiers, scalers, ratemeters, timing circuits, printed circuits, neutron moisture gauges, and Geiger-Muller counters, Sample-irradiation polyethylene vials are made locally.

Many other kinds of analytical (but non-nuclear) equipment are available in the Chemistry Department of Chulalongkorn University, also located in Bangkok. Such facilities there include systems for atomic absorption spectrometry, UV-visible-IR spectrophotometry, X-ray fluorescence, X-ray diffraction, and gas chromatography.

The OAEP laboratory badly needed a good Ge(Li) gamma-ray spectrometer, and hence requested assistance from the IAEA in obtaining a medium-sized Ge(Li) detector and a 1024-channel pulse-height analyzer. The requisite liquid nitrogen is commercially available locally, but is somewhat expensive, so they have installed their own (5 liters/hour) liquid-nitrogen system. They also plan to include in their Ge(Li) gamma-ray spectrometry system a PDP-8E computer, an x-y plotter, and a Teltypewriter. They now have a 26 cc coaxial Ge(Li) detector, of good resolution, for the system — as well as a small Si(Li) detector for X-ray spectrometry. The laboratory also has an IAEA- supplied reactor simulator, made in Finland.

b. Nuclear Activities. The nuclear activities of the OAEP laboratory are mainly in the areas of (1) radioisotope production, (2) neutron activation analysis, (3) food irradiation and fruit-fly sterile-male technique studies — using a multi-kilocurie cobalt-60 gamma-ray source, (4) industrial radiography with a 200-kilovolt x-ray unit and various multi-curie isotopic gamma-ray sources (iridium-192, cesium-137, and cobalt-60), and (5) neutron scattering.

The OAEP laboraotry consists of ten Divisions: (1) the Biological Sciences

Division, (2) the Health Physics Division, (3) the Waste Management Division, (4) the Radiation Measurement Division, (5) the Electronic Instruments Division, (6) the Industrial Radiography Division, (7) the Reactor Operations Division, (8) the Isotopes Production Division, (9) the Physics Division, and (10) the Chemistry Division. Three of the Divisions are headed by women.

General cleanliness and health physics control at the OAEP laboratory appear to be quite good. The Waste Management Division is well run, and is branching out into environmental pollution studies. The excellent Electronic Instruments Division has already been discussed above. The principal activity of the Physics Division appears to be in the area of nuetron scattering studies, using reactor beam tubes. The radiography sources used by the Industrial Radiography Division have been mentioned earlier.

In the Waste Management Division, liquid radioactive waste is coagulated, for burial, in an on-site disposal plant. Storage facilities are also available for solid radioactive waste. They are seeking IAEA support to develop a clay process for radioactive waste processing. The Division is also conducting strontium-90 (and other) background measurements in the region of Thailand where installation of a nuclear power plant is planned. Water pollution studies are in the planning stage. Under an IAEA research contract, the Division is carrying out NAA studies of mercury arsenic, and bromine pesticide levels in vegetables and fruits.

In the Biological Sciences Division, in addition to studies of the sterile-male technique for the control of fruit flies, studies are well along on (1) radiation destruction of the eggs and larvae of fruit flies and mosquitoes in fruit, (2) irradiation treatment of onions to postpone sprouting, (3) radiation treatment of various kinds of Thai tropical fruits to extend the shelf-life, (4) irradiation of raw fish to kill salmonella, and (5) radiation preservation of shrimp and fish. They have found that dosages in the range of 2-50 kilorads will kill eggs and larvae in fruit, that irradiation can delay the sprouting of onions by as much as six months, and that doses in the range of 30-100 kilorads will extend the shelf life of tropical fruits for one to two weeks.

The Isotopes Production Division largely concentrates on the production of iodine-131, for eight hospitals in Bangkok and one in Chieng Mai. They irradiate tellurium dioxide in quartz ampoules for four (8-hour) days in the reactor, at thermal-neutron fluxes of $7\text{-}8 \times 10^{12}$, and then separate the iodine-131 activity

produced. At present, they produce about 18 curies of ^{131}I per run. The Division also produces lesser quantities of sodium-24, potassium-42, bromine-82, technetium-99, and colloidal gold-198 — largely used in the hospitals, but also used somewhat in hydrology and agricultural tracer studies and in university teaching. The Division has a hot lab for processing the radioisotopes produced, but does not prepare labelled compounds — leaving this for the hospitals to do themselves. The principal activity of the Chemistry Division is in the area of NAA applications. This work has been hampered by the lack of a good Ge(Li) gamma-ray spectrometry system, and should expand when such a system becomes available. In the interim, before their recent acquisition of their own Ge(Li) detector, they used a Ge(Li) detector borrowed from Chulalongkorn University, but this had to be used with only a 512-channel pulse-height analyzer. Most of their NAA studies thus far have therefore been carried out with sodium iodide scintillation detectors. Their NAA studies to date have included studies of (1) trace elements (sodium, aluminum, manganese, copper, and zinc) in rice and soils, (2) manganese in body fluids, (3) various elements (calcium, magnesium, sodium, phosphorus, zinc, mercury, and selenium) in bladder stones, (4) vanadium, tungsten, and chromium in iron and steel, (5) copper, zinc, and gold in ancient images of Buddha, (6) various inorganic elements in hard and soft woods, (7) various trace elements (sodium, chlorine, copper, manganese, zinc, iodine, and calcium) in forensic human head-hair samples, and (8) barium and antimony in gunshot residues. The crime investigation studies have recently been expanded by the training of three police chemists in forensic NAA work, and by the return to the OAEP laboratory of one radiochemist who spent one year in the author's laboratory at U.C. Irvine, as an IAEA fellow, studying the forensic NAA examination of hair specimens and gunshot residues. A number of the NAA studies being carried out involve post-irradiation radiochemical separations with carriers.

The Thai OAEP presently has a total staff of approximately 160 people, of whom about 60 are professional scientists, and operates on an annual budget that varies from $350,000 to $500,000.

c. Relationships with Other Thai Agencies and Organizations. At present, the Thai OAEP does not appear to have developed sufficient operating relationships with other Thai governmental agencies or private companies. For example, whereas the 140-man Thai National Research Council, with an annual budget of

5.5 million baht (2.5 million of which is given out as research grants) sponsors considerable research in the 350-man Applied Scientific Research Corporation of Thailand (which has an annual budget of 16.5 million baht), no nuclear work is supported. Thailand is still largely an agricultural country, and hence many possibilities exist for making useful applications of nuclear techniques — such as NAA and radiotracer studies — in the fields of soils, hydrology, and agriculture. However, except for the various food-irradiation studies and the NAA studies of trace elements in rice and of pesticide residues in some foodstuffs, the OAEP has not done very much in this important area — and it does not seem to have very much direct operational contact with the appropriate Thai agricultural agencies.

Although still largely agriculture -oriented, the mining and manufacturing segments of the Thai economy are of considerable potential, and are growing steadily. In particular, the last ten years have shown a very significant growth in the Thai production of tin (their largest single ore production), fluorite (second largest), iron (third largest), gypsum, tungsten, manganese, lignite, and various non-metallic minerals. Similarly, during the past ten years, there has been a very large growth in Thailand in the areas of petroleum refining (there are now three oil refineries in Thailand), coal processing, textile manufacturing, production of rubber and rubber products, production of chemicals and chemical products, production of metal products, the production of non-metallic mineral products, and the production of paper and paper products. In spite of this promising growth, interaction between the OAEP and such appropriate Thai agencies as the Ministry of Industry, the Department of Science and Standards, and the Applied Scientific Research Corporation of Thailand — and the application of relevant nuclear techniques to the mining, petroleum refining, and industrial production activities in Thailand — appears to be almost nil.

In order for the OAEP to have a significant and growing beneficial impact upon the overall economy of Thailand, it is clear that the OAEP must broaden its activities, establish good operational contacts with many other segments of the Thai economy, develop medium-and long-range plans on a national scale (not just internally within the OAEP), and exhibit more initiative and aggressiveness. At least one promising sign has been the fairly recent cooperation between the OAEP and the Thai police crime investigation laboratory. Many more such contacts and cooperative programs are needed.

d. Summary of Thailand. The Thai OAEP is of sufficient size, it has quite a few very competent nuclear scientists on its' staff, and it possesses most of the necessary nuclear equipment to mount a fairly extensive, dynamic,and productive program of nuclear applications — one that could have a quite significant and beneficial impact upon the economy of Thailand. However, very little appears to be developing in the OAEP along such needed lines. This deficiency appears to be largely due to an excessive tendency by the OAEP to confine its' efforts within its' own walls; an inadequate effort to seek out useful nuclear applications that could be developed by close cooperation with various other Thai agencies, companies, and organizations; and the absence of medium-or long-range planning to incorporate the activities of the OAEP in a national plan for advancement. Increased contacts with nuclear and nuclear applications groups in nearby developing Asian countries, as well as with such groups in more highly developed countries (such as the U.S. and Japan), would also be very helpful. Of course, some of the difficulties encountered by the OAEP (loss of personnel because of low governmental salaries, long delays in obtaining needed chemicals and spare parts; low capital equipment and operating budgets; lack of some vital pieces of equipment, such as a good Ge(Li) gamma-ray spectrometer, etc.) have obviously hampered the full development of the OAEP. However, in spite of these difficulties, it would appear to the author that a much greater rate of progress would be possible if a more applications-oriented philosophy were adopted — and then pursued with vigor, initiative, and imagination.

3. Korea

The author has visited Korean nuclear and other scientific installations on two occasions, in each case for about one week: in March of 1971 and in August of 1972. The 1971 visit was part of a tour of nuclear installations in six developing Asian countries carried out for the IAEA, and the 1972 visit was part of a somewhat similar tour of nuclear installations in three developing Asian countries carried out for the U.S. AID. During these two visits to Korea, the author visited and held discussions with various members of the staffs of (1) the Korean Atomic Energy Research Institute (AERI), (2) the Radiation Agriculture Research Institute (of the Korean Office of Atomic Energy), (3) the Korea Institute of Science and Technology (KIST) (4) the Korean Radiological Research Institute (medical branch of the Korean Office of Atomic Energy) and (5) the U.S. AID headquarters in Korea. All of these organizations are located in or near Seoul.

a. Nuclear Facilities. The principal nuclear facilities in Korea consist of a non-pulsing 250-kilowatt TRIGA Mark II reactor (acquired from the U.S., under the Atoms for Peace program), and a 2-megawatt TRIGA Mark III reactor (pulsable to 2,000 megawatts) purchased in 1972. Both reactors are located in the AERI laboratories, on the outskirts of Seoul. Both reactors are above-ground pool reactors, equipped with a rotary specimen rack, a pneumatic tube, a thermal column, and several beam ports. Their neutron-beam equipment includes a double-crystal diffractometer, a time-of-flight path, neutron radiography apparatus, and various pieces of equipment for neutron cross-section, neutron-capture gamma-ray, neutron-scattering, and neutron-diffraction experiments. They also have a Toshiba 10^{10} neutrons/second 14MeV neutron generator (a reparations payment from Japan), but this has not yet been put into operation. The Radiation Agriculture Research Institute has a 7,000-curie cobalt-60 gamma-ray source, for radiation-chemistry studies and for the irradiation of wood-plastics and cement-plastics combinations. For the past two years, this source had been augmented by a 20,000-curie cobalt-60 shipboard irradiator, on loan from the Brookhaven National Laboratory. Studies on radiation mutants of grains, particularly rice, are carried out with the cobalt-60 sources. This Institute also has two smaller cobalt-60 units of their own — ones of 100 curies and 200 curies.

The Radiological Research Institute of the Office of Atomic Energy is headquartered in Seoul, and is primarily engaged in work in the field of nuclear medicine. This institute has a staff of slightly more than 100 persons, of whom 13 are M.D.'s and one is a Ph.D. The laboratory is very well equipped, the principal equipment items including a Nuclear-Chicago liquid scintillation counter, a Picker scanner, a Picker Anger camera, a Packard automatic gamma counter, a paper chromatogram scanner, a Picker 100-channel pulse-height analyzer, a whole body counter, a thyroid scanner, a light-scattering system, a gas chromatograph, analytical balances, microscopes, a Beckman DU spectrophotometer, a Sharp low-background beta counter, an animal counter, culture equipment, and three 3000-curie cobalt-60 gamma-ray therapy sources. The clinic part of this Institute handles between 150 and 200 radiology-treatment patients per day. Their equipment is largely of U.S. or Japanese (Aloka) manufacture, and has been mostly purchased from Korean government funds.

Counting (and related) equipment at the AERI laboratories includes sodium iodide scintillation detectors; a few home-made low-resolution Ge(Li) detectors; one each of 100-, 256-, 400-, and 900-channel pulse-height analyzers; a radiopaper-chromatogram scanner; a 5 liter/hour liquid-nitrogen production system; ion chambers

and 2π and 4π windowless flow counters; two liquid scintillation counters for carbon-14 age dating; a delayed-neutron system; and a Sharp low-background beta counter.

The nearby Radiation Agricultural Research Institute also has a sodium iodide/100-channel gamma-ray spectrometer, and a considerable amount of adjunct scientific equipment, e.g., a visible-ultraviolet spectrophotometer, an X-ray diffraction unit, an X-ray fluorescence spectrometer, an atomic absorption apparatus, a gas chromatograph, paper chromatography units, an apparatus for measuring particle. size distributions, a centrifuge, analytical balances, and a number of desk calculators. This laboratory was only completed in 1971, but now has a staff of 112 — 38 of whom are professional scientists. The laboratory also carries out various carbon-14 radiotracer studies, also including measurements by autoradiography. Much of the scientific equipment at this Institute is of Japanese manufacture.

In addition to the two reactors, the most extensive nuclear facilities of the AERI are those connected with their radioisotope-production activities, and those connected with their neutron-beam research. The laboraotry has a fairly extensive radioisotope-production program, in which radioisotopes are not only produced, but also assayed and converted into radiopharmaceutical forms. Their older hot-laboratory processing facilities for this work are now being replaced by a much larger and more modern facility. Their neutron-beam research equipment has been mentioned earlier. It was used considerably in the previous IAEA cooperative program in neutron-beam research, in which Korea, India, and The Philippines participated, and such studies are continuing in the AERI. The AERI has a staff of about 350, of whom some 100 are professional scientists. Its' main divisions are thóse of Isotope Production, Chemistry, Physics, and Electronics.

b. Nuclear Activities. To date, the principal activities of the Korean AERI have been neutron-beam research, radioisotope production, and neutron activation analysis. The main efforts of the Korean Radiation Agriculture Research Institute have been the production of radiation mutants of grains (particularly rice) and studies on irradiated wood-plastics and cement-plastics combinations. The Korean Radiological Research Institute is fairly active in the field of nuclear medicine studies.

At the AERI, a sizeable fraction of their effort appears to be devoted to relatively academic neutron-beam research studies. Their radioisotope production operations are significant, but could be enlarged much further — and probably will be, with the recent acquisition of their second research reactor(the higher-flux 2-megawatt TRIGA

Mark III) and of their new and enlarged nuclear-medicine radioisotope-processing facilities (which include two hot cells, ten semi-hot cells, and a Japanese electric welding unit for sealing high-intensity sources such as iridium-192 sources). Iodine-131 technetium-99, gold-198, and chromium-51 are produced. Thus far, their facilities for, and activities in, the field of NAA applications have been rather modest. Their various NAA applications studies to date (all involving use of their 250-kilowatt TRIGA Mark II reactor) include the following:

(1) thallium in meteorites, rocks, minerals, alloys, and biological samples,

(2) tantalum and niobium in ores,

(3) vanadium, manganese, cobalt, and copper in plant roots,

(4) gold and platinum-group metals in ores,

(5) scandium in monazite ores,

(6) heavy lanthanide (rare-earth) elements in ores,

(7) halogens in organic halogen compounds,

(8) uranium and thorium in minerals,

(9) fourteen trace elements in rice,

(10) various trace elements in human head hair, and

(11) various pesticide-residue elements in rice (under an IAEA research contract).

Although this list might indicate a fairly extensive program in NAA applications, most of these studies have been relatively brief and sporadic studies. They do not appear to yet have a comprehensive, well organized, continuing program in this field. Part of their difficulties has been the lack of good gamma-ray spectrometry equipment, thus requiring the use of more tedious radiochemical separations for many samples that could otherwise be analyzed purely instrumentally, more rapidly, if such better counting equipment were available. They state that they have also done an appreciable amount of NAA service work for outside organizations, but no details were given. They give an NAA training course once a year. Operation of the TRIGA Mark II reactor has been about 2,000 hours per year (4.5 days per week, 8 hours per day).

c. Relationships with Other Korean Agencies and Organizations. As in the case of many other developing Asian countries, the operating contacts between the Korean Office of Atomic Energy (or of its AERI, Radiological Research Institute, and Radiation Agriculture Research Institute divisions) appear to be minimal. This is particularly true of the largest division, the AERI, which seems to operate in a fashion that is largely insulated from other Korean agencies, organizations, and companies. The AERI, of course, does produce radioisotopes for medical and other purposes, and

does some service NAA work, but that appears to be about the extent of their contact with outside groups. Clearly, some kind of determined planning and effort is needed, to bring the facilities, staff, and experience to bear on many problems of the Korean economy where they could be of value. The Radiological Research Institute has more contact with medical groups, since it largely controls the nuclear-medicine activities (centered in their well-equipped laboratory in Seoul),which are largely confined to Seoul. The Radiation Agriculture Research Institute appears to have reasonably good contacts with Korean agriculture, but their wood-plastics and cement-plastics irradiation studies, although technically apparently quite successful, do not appear to have much contact with Korean groups that could advise them on the economics aspects of these processes.

In particular, it seems unfortunate that there is so little contact between the AERI (and also the Radiation Agriculture Research Institute) and the dynamic and impressive Korea Institute of Science and Technology (KIST). The extensive KIST facilities were developed initially with considerable financial support from AID, and the laboratory appears to be quite successful in developing materials and processes of value to the Korean economy At present, KIST has a total staff of about 650 persons, of whom about two thirds are professional scientists and technicians. The laboratory buildings are, of course, quite modern, since KIST is still a very new organization. They are located on some 65 acres of ground. The laboratory has excellent shops, materials testing equipment, and pilot plants — and a very well equipped analytical laboratory. This analytical laboratory has equipment for almost every analytical technique except NAA — namely, Philips Norelco X-ray diffraction and X-ray fluorescence units, a Varian 100-megahertz nuclear magnetic resonance spectrometer, a small mass spectrometer, two Aerograph gas chromatographs (with thermal conductivity and flame ionization detectors and numerous columns), several Cahn electrobalances, an Ainsworth automatic balance, several LECO units for oxygen and carbon determinations, Coleman units for carbon-hydrogen, nitrogen, and carbon-hydrogen-nitrogen determinations, two Beckman infrared spectrometers (one of high resolution), a Jarrall-Ash emission spectrogaph (with photographic film detection), a Perkin-Elmer atomic absorption spectrometer with 40 hollow-cathode lamps, a Sargent polarograph, a Beckman DU spectrophotometer, a Cary-14 spectrophotometer, an electron microscope, an electron microprobe, and a differential thermal analysis unit. The laboratory has a CDC-3600 computer, soon to be replaced by a larger computer. It is surprising that there is no contact between the KIST analytical laboratory and the NAA AERI group. Cooperation between these

two groups could be rewarding. The extensive contacts of KIST with Korean industry, resulting in research contracts, would also be very helpful to the AERI. KIST is a semi-private type of organization, supported largely by research contracts. Salaries there are about twice civil service salaries. Plans are underway, incidentally, to reorganize the AERI along the same lines as KIST. This may be helpful in some respects, but the AERI group will have to be much more aggressive than they have been in the past, if they are to secure enough research contracts to support their operations.

d. Summary of Korea. The problems of the Korean Office of Atomic Energy appear, to the author, to be rather typical of the problems faced by the atomic energy groups in most of the developing Asian countries: inadequate utilization of exisiting nuclear equipment for needed nuclear applications work, lack of some critical adjunct equipment (e.g., good Ge(Li) gamma-ray spectrometry equipment), overemphasis on "pure science" academic studies, lack of meaningful long-rgange planning, inadequate contacts with other groups within the country, and a high personnel turnover rate — due to inadequate salareis, budgets, and exciting programs. In the face of all these difficulties, it is surprising to see Korea purchase a second, more powerful, research reactor — for the same location as the present generally quite adequate, under-utilized reactor. Their research program needs, in this author's opinion, more good planning, more direction toward applied work, and much more interaction with other groups in the country. One area of promise is their expaning production of, and utilization of, medical radioisotpes. The coming into being of Korea's first nuclear power plant — a 600-megawatt U.S. system at Pusan, hopefully will stimulate the activities of their Office of Atomic Energy.

4. Indonesia

The author's first visit to Indonesia was a one-week visit there, for the IAEA, in February of 1971. During tehat period, the author visited two of the principal Indonesian AEC laboratories — one in Djakarta, the other in Bandung, where their nuclear reactor is located. Their third laboratory, one devoted to health physics work (also located in Djakarta) was not visited.

a. Nuclear Facilities. The Djakarta laboratory visited is mainly concerned with radiotracer studies, but was planning to also engage in NAA work soon, when a French (SAMES) 14 MeV neutron generator and an 800-channel pulse-height analyzer, then order, arrived. It was not evident to the author that their NAA plans were as yet very well formulated. In general, the Djakarta laboratory appeared to be in rather poor condition and not very well equpped. Incidentally, the health physics laboratory in Djakarta reportedly had various components, still in pakcing crates, of a Russian 1-megawatt research reactor, obtained a number of years earlier, under the Sukarno

regime. This reactor will probably never be completed, as the fuel, and other essential components, were never supplied by the Russians — after the fall of Sukarno.

The principal Indonesian nuclear laboratory is in Bandung — in the mountains some 120 miles from Djakarta. Here, their nuclear reactor is located. At the time of the author's first visit to Bandung, this reactor was a 250-kilowatt TRIGA Mark II reactor, but this has since been replaced with a 1-megawatt TRIGA core. At that time, they did not seem to have any plans for using, or disposing of the 250-kilowatt core, once the new core was installed. The 250 kW unit was still in operation at the time of the author's first visit, but the rotary specimen rack had been removed for repairs. The reactor is equipped with a conventional pneumatic sample-transfer tube with a transit time of about 3 seconds. At the Bandung laboratory, supporting equipment was quite sparse, including two multichannel pulse-height analyzers (200-and 400-channel units) for NaI(Tl) scintillation spectrometry, a manual room-temperature Packard Tri-Carb liquid scintillation counter, a gas chromatograph, an automatic analytical balance, and a few smaller pieces of equipment. The laboratory was quite lacking in even many very small items of necessary equipment, such as chemical glassware, centrifuges, hot plates, mechanical stirrers, scalers, and single-channel pulse-height analyzers. They had recently purchased a 20 cm^3Ge(Li) detector from Princeton Gamma Tech, in the U.S., but it had been damaged in shipment. When the replacement detector arrived, they planned to obtain a biased amplifier, so that they could use the detector with their 400-channel pulse-height analyzer — until such time as they could obtain a more satisfactory analyzer, e.g., one of 2048 or 4096 channels. Liquid nitrogen is locally available, for cooling the Ge(Li) detector. The Bandung laboraotry also had very limited library facilities, lacking in nuclear science books and journals. The laboratories were sparsely furnished, and in generally poor condition.

One very good part of the Bandung laboratory was the laboratory devoted to the processing, assaying, and packaging of radiopharmaceuticals for distribution to medical groups within Indonesia. This laboratory was quite neat and well run, although small.

b. Nuclear Activities. Except for some radiotracer studies at one of the two laboratories in Djakarta, and health physics work at the other, the main nuclear activities in Indonesia appeared tobe centered at the Bandung laboratory, where their operating TRIGA reactor was located. Here, the principal activities at that time appeared to be radioisotope production (mainly for medical use) and some neutron activation analysis work. The latter appeared to have only included modest studies of trace elements

in petroleum, of nitrogen in food products, and of various elements in alloys, ores, and fertilizers. Their NAA work was minimal, particularly in view of the many potential useful applications of NAA that could be studied, of importance to Indonesia.

c. Relationships with Other Indonesian Agencies and Organizations. So far as the author was able to observe, the Indonesian AEC has virtually no operating contacts with other segments of the Indonesian government and economy. It is particularly surprising that they had not undertaken some joint projects with the government-owned petroleum company, since useful applications of nuclear techniques, such as NAA, radiotracer studies, radiographic measurements, and nuclear gauges, abound in the field of petroleum exploration, production, refining, and petrochemical production. Similarly, it is surprising that they had not undertaken some joint projects with various governmental and private agricultural research groups, inasmuch as the Indonesian economy is decidedly an agricultural one, and there are many possibilities for useful NAA and radiotracer studies in the field of agriculture. The Indonesian AEC could also profit by greatly increased contacts with nuclear groups in nearby Asian countries.

The author's second visit to Indonesia, spent entirely at the Bandung reactor facility, was a one-week visit in early August of 1975. The purpose of this second visit was to participate, for the IAEA, in a meeting of representatives of several participating countries in the IAEA Asian regional cooperative program on nuclear-based methods of analysis. The countries participating were Indonesia, Thailand, and India. The IAEA was represented by a scientific secretary (Japanese) from Vienna, and by the two consultants to this Agency program — Professor Humphry Bowen (England) and the author. This second visit provided only a limited opportunity to tour the Bandung facility, but did provide information on the more recent NAA activities of the Bandung laboratory. The one-megawatt TRIGA reactor is now in quite regular use, their supply of necessary adjunct equipment has increased somewhat since the time of the author's 1971 visit (but they still do not have an operztional Ge(Li) spectrometry system), and their NAA applications program has been appreciably expanded — now including some petroleum studies. Plans are being finalized to install the old 250 kW TRIGA reactor at a new Indonesian AEC laboratory several hundred miles from Bandung, in central Jave. Also, plans are underway to obtain the first nuclear power reactor for Indonesia.

d. Summary of Indonesia. From the author's observations, it would appear that the Indonesian AEC is still in a rather underdeveloped state. It appears to need a more dynamic and applications-oriented program, some good longer-range planning, more financial and other support from the Indonesian government, and greatly increased contact

with other segments of the Indonesian economy. Naturally, many of the problems of the Indonesian AEC (extremely low salaries, leading to personnel leaving or holding down several outside jobs and hence neglecting their AEC work; completely inadequate budgets for all sorts of vital adjunct equipment, library items, training abroad, etc.) are due to the still poor condition of the Indonesian economy, following the near bankruptcy of the country by Sukarno. The country has considerable basic potential, however, and hence, despite its great population density in the principal island (Java), it will undoubtedly steadily recover. Even at this stage, though, the author feels that the Indonesian AEC could have a more productive overall program than it has at present.

5. Singapore

During his extensive IAEA trip to various Asian countries in February-March of 1971, the author also made a brief visit to the limited nuclear facilities of the small city-country of Singapore. Despite its physically very small size, Singapore is a prosperous and dynamic country. Even though it lacks even a small research reactor and has no accelerator facilities (other than a small 14MeV neutron generator), Singapore has a rather good program of radioisotope utilization — centered in the Singapore Institute of Standards and Industrial Research (SISIR). Similarly, their utilization of nuclear medicine techniques, centered in the main Singapore hospital, is fairly extensive. The Department of Physics at the University of Singapore offers students good basic training in most nuclear techniques. The Government Chemistry Department, engaged in activities such as crime investigation, food and drug problems, water quality measurements, Customs problems, etc., was not at that time using any nuclear techniques, but had many potential applications for NAA — if and when it became available with a Singapore research reactor — and was quite interested in the method. The author visited SISIR, the University of Singapore Physics Department, the nuclear medicine section of the main Singapore Hospital, and the Government Chemistry Department during his visit to Singapore.

The SISIR laboratory is fairly well equipped for radiotracer, nuclear gauging, and gamma-radiography studies, but has no facilities for doing NAA work. The Physics Department at the University of Singapore has adequate simple counting equipment, a 100-kilovolt Texas Nuclear Corporation 14MeV neutron generator, and a sodium-iodide single-channel gamma-ray spectrometer. The nuclear equipment in the nuclear medicine section of the main Singapore hospital is more extensive — including three heavily-used 5000-curie gamma-ray cancer-therapy sources (two cobalt-60 ones and one cesium-137 one), a gamma-ray scanner, a Packard Tri-Carb liquid scintillation counter, and various smaller pieces of equipment (e.g., scalers, etc.). The nuclear medicine group

expressed considerable interest in the possibility of acquiring their own research reactor, for the on-site production of medically-useful radioisotopes (currently imported from Australia and India). If they succeeded in obtaining a reactor, they expected to make it available for use also by SISIR, the University of Singapore, and the Government Chemistry Department — all located nearby.

At the time of the author's Singapore visit in February 1971, the head of SISIR did not expect that Singapore would acquire a research reactor for many years to come. However, only some five months later, he visited the author at U.C. Irvine, and informed him that the picture had changed. Due to his government's recent serious interest in obtaining a nuclear power reactor, the need for a research reactor was now increased. He expressed the hope that they would now be able to obtain one relatively soon — to be used for training, radioisotope production, and NAA. The SISIR group works very closely with various private companies and other government agencies.

The author visited Singapore again for a few days in August of 1975, visiting the SISIR again. No major specific changes were noted, except for a very sizeable expansion of SISIR. Singapore's plans for a research reactor and a nuclear power reactor appeared to have been shelved for the present.

6. Taiwan

The author visited Nationalist China (Taiwan) on two occasions, for visits with nuclear groups — once in July of 1970 (immediately after the July 6-10 IAEA regional meeting in Bangkok) and once in March of 1971 (during the extensive February-March Asian trip for the IAEA). Each visit was only for a few days. The nuclear groups visited, on both trips, were (1) the National Tsing Hua University, in Hsinchu, (2) the Union Industrial Research Institute, in Hsinchu, and (3) the Department of Chemistry at the National Taiwan University, in Taipei.

The principal nuclear center in Taiwan is located at the National Tsing Hua University, in Hsinchu — about 60 miles from Taipei. The nuclear center there is based on a 1-megawatt General Electric pool-type reactor (very similar to the GE reactor in The Philippines). This reactor produces many radioisotopes that are used for industrial tracer and nuclear medicine work in Taiwan. The reactor is rather well utilized. The usual operating schedule is as follows: Monday — operation at various power levels for teaching purposes: Tuesday morning through Wednesday evening — 32 hours of continuous 1-megawatt operation for radioisotope production and NAA work; Thursday and Friday — operation for various nuclear engineering

experiments. The reactor is rather well equipped with neutron irradiation positions. These include (1) a 2-second transit-time pneumatic tube, just outside the reactor core, (2) a beam port, also equipped wtih a pneumatic tube; (3) five dry vertical tubes just outside the core and (4) two vertical in-core tubes. Irradiation facility (1) provides a thermal-neutron flux of 2×10^{12} n/cm^2-sec in which samples can be irradiated, in polyethylene containers, for periods of up to 6 hours. Facility (2) provides a thermal-neutron flux of 1×10^{12} n/cm^2-sec, and is used for delayed-neutron NAA work. Facility (3) provides a thermal-neutron flux of 0.5×10^{12} n/cm^2-sec, andisused for the irradiation of samples in aluminum containers, suspended on nylon strings. Facility (4) provides a thermal-neutron flux of 4×10^{12} n/cm^2-sec, and is used for radioisotopes production.

The reactor center regularly or periodically produces the following radioisotopes: sodium-24, potassium-42, bromine-82, molybdenum-99/technetium-99, iodine-131, gold-198, chromium-51, rubidium-86, phosphorus-32, sulfur-35, zinc-65, mercury-203, and copper-64. About 98% of the radioisotope production is for nuclear medicine work at various hospitals in Taiwan, only 2% being used in industrial tracer work and other non-medical radiotracer research work. The U.S. Navy Medical Research Center in Taiwan uses much of the sodium-24, potassium-42, bromine-82, and copper-64 produced at the reactor.

The facilities for NAA work at the reactor center (Institute of Nuclear Sciences) are rather limited, consisting essentially of a Technical Measurements Corporation 100-channel pulse-height analyzer coupled to a 3-inch x 3-inch sodium iodide scintillation detector, and three Ortec single-channel pulse-height analyzers — each coupled to a 2-inch x 2-inch sodium iodide detector. The Physics Department at the University has a good large Ortec Ge(Li) detector, coupled to a 4096-channel pulse-height analyzer, and also has an IBM-1130 (30,000-word memory) computer, but both of these are unfortunately not available to the chemistry NAA group. Similarly unavailable to the NAA group is the gamma-ray spectrometry equipment in the Nuclear Engineering Department of the University: (1) a Taiwan-produced 20 cm^3 Ge(Li) detector, coupled to a Technical Measurements Corporation 400-channel pulse-height analyzer, and (2) a 2-inch x 2-inch sodium iodide detector, coupled to a Technical Measurements Corporation 400-channel pulse-height analyzer. The Taiwan-produced Ge(Li) detectors are made by the Chung Shan Institute of Science and Technology (a government laboratory), but are not yet of very high resolution (~10 keV at 1332 keV). The University has its own liquid-nitrogen facility, capable of producing about 6 liters of liquid nitrogen per hour.

Nuetron activation analysis studies at the National Tsing Hua University have been

comparatively fairly extensive. They include studies of (1) copper, zinc, arsenic, and manganese in body tissues, relative to Wilson's Disease (a joint study with the U.S. Navy Medical Research Center), (2) trace elements (such as copper, zinc,manganese, bromine, and potassium) in rice, citrus leaves, and sugar cane, (3) mercury fungicide residues in rice, (4) mercury levels in tuna, (5) potassium in clay minerals, (6) uranium in copper-uraniferrous quartz ore (by the delayed-neutron method), (7) uranium and thorium in monazite sands (also by the delayed- neutron method), (8) hafnium in zircon, (9) manganese, nickel, copper, cobalt, and iron in aluminum metal, (10) bromine and iodine in sodium glutamate and cassava flour, (11) trace elements in hot-spring waters, and (12) trace elements in old bronzes (museum specimens). They also provide an NAA service for outside users. For their NAA work, they hoped to soon be able to acquire a reasonable Ge(Li) detector and a 1024-channel pulse-height analyzer, which would greatly improve their NAA capabilities. Due to their very limited gamma-ray spectrometry equipment, much of their NAA work thus far has required radiochemical separations. Their work on mercury in rice is conducted in cooperation with the School of Agriculture of the National Taiwan University, and their mercury in tuna work is conducted in cooperation with the government's Food Research Institute.

At the National Taiwan University, considerable training in radiochemistry and radiotracer methods is provided within the Department of Chemistry, but very little NAA work is done. Some NAA work is carried out, activating samples in the reactor at Hsinchu. They were also planning to start up some NAA work with a recently-acquired 14 MeV neutron generator. The Union Industrial Research Institute, located in Hsinchu, has an appreciable program in radiation processing — both of foodstuffs and of wood-plastics combinations — using a 5000-curie cobalt-60 source.

Overall, it appears that the nuclear program in Taiwan is more effective than those in most other developing Asian countries — especially in the areas of radioisotope production and use, and of NAA applications. The nuclear program at the National Tsing Hua Universitys' Institute of Nuclear Science seems to be well organized and active, and they have had the foresight to establish a number of good operating relationships with private companies and other government agencies. No doubt their relative degree of success has been considerably aided by the healthy state of their economy — compared with the economies of most other developing Asian countries. U.S. help has been a large factor in their growth, and it is not clear to the author just how severe the effect on Taiwan will be of the recognition of Mainland China by the United Nations and the

U.S., and of probably declining U.S. assistance. At the time of the author's visits (in 1970 and 1971, i.e., before the United Nations action admitting Red China), Taiwan was still enjoying support from the IAEA, and was embarking upon the purchase of another research reactor, a high-flux materials testing reactor, and a nuclear power reactor. What effect subsequent events has had on these projects is not known to the author.

7. Hong Kong

The author visited the Chinese University of Hong Kong during a 3-day visit to Hong Kong in August of 1975. Nuclear facilities in Hong Kong are quite limited, and are concentrated largely in the Physics Department of the Chinese University of Hong Kong, which has a high-output Kaman Nuclear sealed-tube 14MeV neutron generator. Hong Kong has neither a research reactor nor a nuclear power reactor, although there is some interest in acquiring both sometime in the future. The University does have a fair amount of good counting equipment, including a 400-channel NaI(Tl) gamma-ray spectrometer. By now, a new Ge(Li) multichannel gamma-ray spectrometer, supplied by the IAEA, should have arrived. They plan to then expand their presently small NAA applications program, based upon the neutron generator. To assist them in developing this NAA program, they requested that the IAEA send them a Visiting Expert, highly experienced in NAA, gamma-ray spectrometry, neutron generators, and computer programming, for a 6-month period early in 1976. The IAEA selected one of the author's Ph.D. students, just finishing his Ph.D. in radiochemistry/NAA at U.C. Irvine now. He is an extremely competent and experienced young scientist, and should be of great help to the Chinese University of Hong Kong in expanding their NAA applications program.

B. Latin American Countries

Relevant to this report, the author has visited a number of the nuclear laboratories in Venezuela, Colombia, Argentina, Brazil, Chile, and Mexico, and has participated in a number of Latin American nuclear conferences. The nuclear programs of each of these countries are summariezed below. Not as much time was devoted to visits in these countries as was devoted to visits in the Asian countries (discussed in the previous section of this report), and hence the following Latin American country summaries are not as detailed as those on the Asian countries.

1. Venezuela

The author spent one week in Caracas, Venezuela, during August of 1972 – primarily in visiting, and discussing nuclear applications studies with,personnel of the Instituto Venezolano Investigaciones Cientificas (IVIC). Also, the author had several helpful discussions with the Scientific Attaché in the U.S. Embassy in Caracas. The IVIC laboratories are quite modern, and are located in the mountains, about 10 miles from Caracas (IVIC was founded in 1959). One of the principal facilities at IVIC is their 3-megawatt General Electric research reactor. This reactor experienced a troubled earlier history, being shut down for several years – after its initial period of operation – due to a lack of sufficiently trained personnel. After sending many people abroad for a few years, for further nuclear training, the reactor was started up again in 1965 and has been operated satisfactorily since then.

At the time of the author's visit, the reactor fuel was almost exhausted, and plans were well along to refuel with elements made in Spain. For sample irradiations, the reactor is equipped with five 3-inch diameter vertical tubes just outside the core, and two pneumatic tubes somewhat further outside the core. These provide thermal-neutron fluxes of, respectively, 7×10^{12} and 3×10^{12} n/cm^2-sec. The reactor also includes two thermal columns (which provide a very uniform 10^8 thermal-neutron flux, with a 500/1 cadmium ratio, over a volume of one cubic meter), a storage tank for spent fuel elements, and several beam tubes — one of which was being set up for neutron diffraction work (using a Brookhaven National Laboratory bent-crystal chopper system), one of which was being set up for neutron scattering work, and one of which was almost ready for use in capture gamma-ray studies. A system was nearing completion for uranium measurements via the delayed-neutron method. They plan to install a vertical beam tube soon for neutron radiography work. The reactor is run only on demand, and then for a maximum of 8 hours in any one day. In earlier years, the reactor was used considerably for the production of medical radioisotopes, but this was stopped because of some bad experiences in the use of the radioisotopes by medical people (since their use is not governed by adequate regulations). One small exception is the production of a few medical radioisotopes (potassium-42, sodium-24, and fluorine-18) for the nuclear medicine group in Merida.

Primarily due to the leadership of a German, a Czech, and a Frenchman, the reactor is used a fair amount for NAA studies. These studies include ones on iodine, as related to goiter (about 100 determinations per week for hospitals); ones on uranium, thorium,

iron, manganese, rare earths, vanadium, cobalt, nickel, and aluminum in mineral and ore samples (about 50 samples per month); of chlorine, vanadium, arsenic, iodine, bromine, aluminum, and lead in petroleum and petroleum fractions (about 100 samples per month, for the Venezuelan Petroleum company); and of mercury in fish and algae from Lake Maracaibo (about 15 samples per month). These studies are being made on a routine basis, and on a moderately large scale. In addition, they have conducted a number of less extensive specific NAA studies: of boron levels in silicon; of sulfur in organic compounds; of gold in alloys; of cadmium in salt crystals; and of bromine in biological samples. The group also does some NAA work in connection with studies requested by other groups and private companies, and has conducted one forensic NAA study (of arsenic in hair). They expected to soon be using the delayed-neutron method for determining uranium, and the prompt-gamma method for the analysis of various industrial materials.

Their equipment for NAA studies was limited, but was soon to be considerably augmented. At the time of the author's visit, it included a 3-inch x 3-inch sodium iodide detector and a 40 cm^3 germanium detector (from England), and 400-channel Packard and 1024-channel Nuclear Data multichannel pulse-height analyzers. In addition, the IVIC laboratory had a Hewlett-Packard 4096-channel analyzer, but it was in another department and was not usually available for NAA use. The Activation Analysis Group had recently ordered two Intertechnique (French) 4096-channel analyzers and a Princeton Gamma Tech 100 cm^3 germanium detector. These have presumably arrived by now, and should greatly increase the NAA capabilities of the Group. Spacewise, the NAA Group was rather crowded, but this was soon to be relieved, when a new Chemistry Building, then well along in construction, was completed. The Activation Analysis Group was not to be moved into the new building, but was scheduled to have some additional space in the present (reactor) building that was to be vacated by people moving to the new building. Their new facilities will include eight radiochemical hoods They planned to soon obtain a 5-milligram californium-252 neutron source from France.

Other nuclear equipment at IVIC noted by the author included a manual Packard Tri-Carb liquid scintillation counter, a French automatic NaI(Tl) gamma-ray counting system (with a very large lead shield), a number of double-anode annular Geiger flow counters (made at IVIC), and a paper chromatogram scanner. The large gamma-ray detector was primarily used for determining natural uranium and thorium, and their daughter products, in ore samples. The IVIC laboratory also has a number of major

pieces of non-nuclear equipment, such as four electron microscopes; three gas chromatographs (a Varian Aerograph, a Pye, and a Hewlett-Packard); infrared, ultraviolet, and atomic absorption spectrophotometers; a Hitachi mass spectrometer; 60 and 100 megahertz nuclear magnetic resonance spectrometers; a natural products laboratory; and a catalysis laboratory. The Electronics Department is well equipped, active, and productive. It maintains, repairs, designs, and builds electronic equipment. It makes its' own printed circuits and makes small general purpose computers. The laboratory periodically offers radioisotope training courses, and also now offers M.S. and Ph.D. training in various fields.

The Center of Technological Research part of IVIC consists of five Departments: Metallurgy, Petroleum and Petrochemistry, Mechanical Engineering, Electronic Engineering, and Nuclear Technology. The Nuclear Technology Department in turn consists of three laboratories: Nuclear Geology, Food Irradiation, and Radiochemical and Radioanalytical Chemistry. The Radiochemical and Radioanalytical Chemistry laboratory in turn consists of four Groups: Activation Analysis, Radiochemistry and Gas Chromatography, Wood-Plastics Irradiation, and Health Physics. The Radiochemistry and Gas Chromatography Group does interesting work in the preparation of tritium-labelled compounds (by irradiation of tritiated aqueous solutions of water-soluble organic compounds with cobalt-60 gamma rays), and of chlorine-36 labelled compounds. The Wood-Plastics Irradiation Group utilizes a 7000-curie cobalt-60 gamma ray source to irradiate samples of tropical woods that have been impregnated with monomers such as methylmethacrylate, acrylonitrile, styrene, or mixtures of polyesters. Good results were being obtained. They are studying 24 different combinations (6 Venexuelan soft woods and 4 monomers). They plan to then focus on the three best combinations, and then proceed to pilot plant studies. This work is headed by a Hungarian. They hope to obtain 100,000 curies of cobalt-60 from the U.S. for the pilot plant. The Department of Nuclear Technology has held two neutron activation analysis regional training courses — one sponsored by the IAEA, the other by the OAS.

The IVIC laboratories at the time had a total staff of about 400 persons. IVIC appears to have reasonably close contact with the Consejo Nacional de Investigaciones Cientificas y Technologicas (CONOCIT) – Venezuela's scientific planning organization, and with CODESUR — the Venezuelan government organization in charge of the development of the large and relatively undeveloped and unpopulated Orinoco area,

south and east of the Orinoco River. This area has undeveloped deposits of uranium, thorium, gold, nickel, bauxite, coal, and asbestos. The Activation Analysis Group at IVIC is already analyzing fairly large numbers of samples from CODESUR, for uranium and many other metals of interest (mentioned earlier). Completion of their delayed-neutron apparatus should greatly expedite their uranium assay measurements, since this method, from the author's experience, can process such samples at the rate of one sample per minute, yielding results of excellent precision and accuracy.

IVIC offers Master's degrees and (more recently) Ph.D. degrees, and classifies the senior members of the IVIC research staff who direct the research of graduate students as Professors, Associate Professors, and Assistant Professors. At the time of the author's visit (1972) IVIC had some 90 of its graduate students studying overseas. Of these, 22 were expected to complete their graduate studies and return to Venezuela in 1973. The best of these will be offered positions at IVIC, and the rest will be offered professorships in Venezuela's ten universities. This is part of a program to upgrade the system of higher education in Venezuela, since even the Central University of Venezuela does not give Ph.D. degrees, and very few of the faculty members have Ph.D.'s. There is such a shortage of Ph.D.'s in Venezuela that essentially all Ph.D.'s can obtain positions in IVIC (if scientists or engineers) or the universities. Industrial positions are also readily available for Ph.D.'s. These positions offer somewhat higher salaries (but not much higher), but more routine work. Thus, in Venezuela, IVIC is in a good position to recruit, and keep, good scientists — except for occasional political reorganizations, which have caused a number of good scientists to leave in the past.

All in all, the nuclear activities at IVIC (as well as the overall activities) appear to be in a healthy and growing state — rising from a low period encountered several years ago. Their nuclear work is headed by several very good scientists. However, almost all of these are foreign-born (European) — although some have now become Venezuelan citizens. There is a need to bring in a larger number of competent and well-educated Venezuelan-born scientists, if the IVIC activities are to continue to expand and flourish. IVIC appears to have relatively good operating contacts with other Venezuelan governmental agencies (including particularly the Venezuelan petroleum company and CODESUR. One important area of reactor utilization that appears to be in need of revision and expansion is that of the production of radioisotopes. Their reactor needed refueling (probably accomplished

by now) and an expanded program of usage for various purposes — such as radioisotope production and neutron activation analysis. Equipment-wise, budget-wise, salary-wise, and personnel-wise, IVIC (including its nuclear parts) appears to be much better off than most of the nuclear laboratories in the developing countries of Asia visited by the author. The library and laboratory facilities at IVIC are generally quite good. They do need to participate to a greater extent in Latin American and international conferences on nuclear sciences. For example, of the five major Latin American nuclear conferences attended by the author, cited in Section I of this report (Montevideo 1963, São Paulo 1963, Los Angeles 1967, Mexico City 1967, and Santiago 1971), of a total of 141 papers presented by scientists from Latin American countries, only one paper was presented from Venezuela. On the other hand, they do publish quite extensively in good scientific journals.

2. Colombia

During his August-September 1972 trip to South America for AID, the author spent the first week of September in Bogotá, Colombia, visiting mainly the Instituto de Asuntos Nucleares (IAN), but also COLCIENCIAS(the Colombian Science Policy Organization), the Colombian Cancer Institute, the Colombian Planning Department, the U.S. Embassy, and the U.S. AID office.

The Colombian IAN was formed in 1959, and now (1972) has a total staff of about 90 persons. The IAN houses the only nuclear reactor in Colombia — an above-ground 20-kilowatt Lockheed reactor, and a Kaman Nuclear 14 MeV neutron generator (not yet in operation at that time). At the time of the author's visit, a facility was under construction to house a 10,000-curie cobalt-60 source being supplied by the IAEA for radiation chemistry studies.

Although the IAN laboratories are relatively small, they are modern, well kept, and reasonably well equipped. Their equipment, for example, also includes a delayed-neutron system for uranium determinations, three multichannel pulse-height analyzers (two Nuclear Data 512-channel analyzers and an Intertechnique 400-channel analyzer, the latter a gift from France), various NaI (Tl) detectors, an Olivetti programmable calculator, a Packard Tri-Carb liquid scintillation counter, and two Intertechnique low-background beta counters. In general, all of this equipment appeared to be well used and well maintained.

The IAN is governed by a board consisting of representatives from five Colombian Ministries: War, Health, Mines, Development, and Education. The new director

of IAN (U.S.-educated) was fighting hard to improve both the salary and the budget position of IAN. In the years before his arrival, severe inequalities had developed (e.g., IAN professionals were only receiving salaries of about one half of the salaries received by comparable personnel in the Ministry of Mines, and the seven million peso 1971 budget of IAN had been reduced to only four million pesos for 1972). The IAN consists of four Departments, those of Health Physics, Geological Prospecting, Industrial Applications of Radioisotopes and Radiography, and Agricultrual Applications of Radioisotopes. The Activation Analysis Group, the Radioisotope Production Group, the Carbon-14 and Tritium Age Dating Group, and the Radiopharmacenticals Group are all part of the Department of Industrial Applications of Radioisotopes and Radiography. Studies with the new 10,000-curie cobalt-60 source (when it arrived) were presumably to be carried out by a group in this same Department.

Considering their limited irradiation facilities, the IAN staff appeared to be rather energetically attacking problems of interest and importance. However, also because of their limitations in irradiation (and counting) facilities, progress had been slow, and significant accomplishments had been few. In the field of neutron activation analysis, uranium and thorium measurements in ore samples were being carried out by the delayed-neutron method — the result of efforts by an IAEA expert in NAA from Germany who spent two months with the IAN in 1971. The NAA group was also studying (1) the analysis of geochemical and ore samples for silver, gold, and platinum, (2) the analysis of dental alloys, and (3) the detection of gunshot residues. In general, their NAA work is limited by their rather low reactor neutron flux and their lack of a Ge(Li) gamma-ray spectrometer. Liquid nitrogen is available in Bogotá, so they could maintain a Ge(Li) detector. They have an Olivetti programmable calculator (for simpler calculations), but IAN has no larger computer facilities of its own. A larger computer is available for use by them at the Colombian Computer Institute, but the NAA group, at least, did not appear to be using it as yet. At the time of the author's visit, the 14 MeV neutron generator had not yet been placed in operation — due to lack of adequate shielding. Interest in acquiring such a generator was stimulated by an IAEA expert in NAA from Norway who spent three months at the IAN in 1971. The author urged the IAN to increase the power of their reactor from 20 kilowatts up to its maximum design power level of 80 kilowatts. This power increase would raise the neutron flux by a

factor of four, and yet would cost only about 10,000 dollars (for additional shielding and water circulation). An increase in neutron flux of a factor of 4 would improve NAA sensitivities of detection by a factor of 4 and would also similarly improve the conditions for radioisotope production and neutron beam work — at a very small cost.

Radioisotope production at the IAN is limited severely by the low neutron flux of the reactor. They are able to produce sufficient amounts of bromine-82 for underground-water hydrology radiotracer studies and for pipe blockage locating; and of gold-198 (irradiated as gold foil, then dissolved in aqua regia and converted to the cyanide complex), for use by the Colombian petroleum company as a radiotracer in oil field secondary-recovery operations. Two of these three radioisotopes are rather short-lived, having half lives of 35 hours (^{82}Br) and 2.7 days (^{198}Au), and hence cannot readily be obtained from abroad.

Unfortunately, the low reactor neutron flux does not produce sufficiently high specific activities (curies per gram of element) of medical radioisotopes such as 2.7-day gold-198, 28-day chromium-51, 46-day mercury-203, and 45-day iron-59, so these have to be imported — with considerable loss by decay in the case of gold-198. The principal foreign supplier of medical radioisotopes to Colombia is the Abbott Company, in Chicago. However, the business volume is quite small — only about 4,000 dollars per year. Recognizing the need for locally-produced radiopharmaceuticals — especially those involving radioisotopes of moderately short half life — the IAN Radiopharmaceuticals Group is working hard to develop production techniques that will be effective, in spite of the low neutron flux. They are sensibly concentrating on medically important radioisotopes that are radioactive daughters, and hence can be produced as carrier-free radioisotopes. In such cases, the low neutron flux does not affect the specific activity of the radioisotope produced — it only affects the rate of production of the radioisotope (curies per hour of irradiation). At the time of the author's visit to IAN, the Radiopharmaceuticals Group was concentrating on developing a practical procedure for the production of 100 millicuries of technetium-99m per reactor irradiation, via the irradiation of 500 grams of molybdenum. In a thermal-neutron flux, the molydenum-98 stable isotope, if it capture a neutron, forms 67-hour molybdenum-99. This decays by beta-minus emission to form the desired 6.0-hour technetium-99m. The main problem here, because of the low neutron flux, is that a large amount of molybdenum must be irradiated, and then

chemically processed, to produce even a modest amount of technetium-99m activity. The separated technetium-99m activity must then be rapidly distributed, because of it's short half life. The familiar ^{99}Mo- ^{99m}Tc "cow", widely used in many countries in nuclear medicine work, largely circumvents this half-life difficulty, since the ^{99}Mo parent is much longer-lived than the ^{99m}Tc daughter — but this approach is not very feasible when the ^{99}Mo specific activity is low.

The IAN group is also interested in developing a suitable procedure for producing another medically important radioisotope — 8.1-day iodine-131, the radioactive daughter of 25-minute tellurium-131. Because of the low neutron flux available, again, large amounts of the parent element (in this case, tellurium) must be irradiated and then chemically processed, per amount of radioactive daughter (in this case, ^{131}I) produced. (Due to the shorter half life of the parent, in this case a "cow" system is not available).

The work of the Radiopharmaceuticals Group at the IAN, at the time of the author's visit, was being greatly stimulated by the presence of an IAEA expert on radiopharmaceuticals production from Rumania. In the author's opinion, it would appear that it would be much more economical for Colombia to purchase molybdenum-99 from Venezuela, and then milk it for technetium-99m in Bogotá, than to try to produce it with the low flux of their reactor. Similarly, it would appear to be much more economical to purchase iodine-131 from Venezuela, the U.S., or elsewhere, than to produce it so laboriously in Bogotá. If the reactor power were increased to 80 kilowatts, giving a 4-fold higher neutron flux, the situation for the production of ^{99m}Te and ^{131}I in Bogotá would be significantly improved, but would still be marginal. The Colombian Cancer Institute estimated that it alone could use about 25 millicuries of ^{99m}Tc per day. This Institute also uses about 150 milicuries of ^{131}I per week (costing about one dollar per millicurie, including air transport from the U.S.). They would use more ^{131}I than this, if their budget permitted.

The Nuclear Medicine Group at the Colombian Cancer Institute is not only limited by the unavailability of short-lived medical radioisotopes and their low budget for purchasing longer-lived ones from abroad; but also by their limited equipment. For all of their nuclear medicine work, they have only two radioisotope scanners (one for iodine uptake, and one for renal scanning), and a well-type NaI(Tl) counter.

Perhaps the most active group at the IAN is that involved with radiotracer studies. Some of these radiotracer studies were mentioned earlier — in connection with the

mention of short-lived radioisotopes produced in the Bogotá reactor for industrial and hydrology radiotracer studies. The radiotracer group also utilizes the "total count" method in hydrology studies, employing either bromine-82 or colloidal gold-198. Use of this method was stimulated by the originator of the method, an American who visited the IAN in 1970 as an IAEA expert in radiotracer methods. The radiotracer group, in particular, appears to have fairly close operating contacts with a number of other Colombian governmental institutes, e.g., those involved in the fields of agriculture, mining, hydrology, and medicine. However, even these contacts need to be greatly extended — and those of other groups, such as the Activation Analysis Group, need such contacts even more so.

The Bogotá reactor was operated for 8,820 kilowatt hours during 1971 (equivalent to 441 hours of full-power, e.g., 20-kilowatt, operation). This is a fairly low degree of utilization. A power increase to 80 kilowatts, plus more aggressive applications work and acquisition of a Ge(Li) gamma-ray spectrometer, would probably increase the degree of reactor utilization considerably. Two other (lesser) activities of the IAN, not mentioned earlier, are those of the offering of courses, and of carbon-14 age dating. The IAN gave three short training courses during 1971. Their carbon-14 age dating work was operational at the time of the author's visit, and employed two Intertechnique (French) low-background beta counters (3 counts-per-minute background, large planchets). They also have a Packard Tri-Carb liquid scintillation counter, and planned to start using it soon in their carbon-14 age dating work — counting benzene, made via the acetylene to benzene conversion method. They also were building electrolysis cells for the enrichment of tritium water samples, for tritium age-dating work.

3. Argentina

During his August-September 1972 trip to four Latin American countries for AID, the author made a short visit to the Argentine Atomic Energy Commission in Buenos Aires.

Argentina and Brazil have the two older and most fully developed nuclear programs amongst the Latin American countries, and they were included in the present study to provide a standard of comparison for the other Latin American countries included in the study.

Of the Latin American countries, Argentina was the first to enter significantly into the field of nuclear activites, being the first to acquire a research reactor. Now,

they have two operating research reactors (one built by them), facilities for manfacturin fuel elements, and facilites for the reprocessing of spent fuel elements. Their reactor-based programs include sizeable activities in radioisotope production, production of radiopharmaceuticals, and neutron activation analysis applications. These activities are based on their principal research reactor, a 5-megawatt reactor that is regularly operated continuously for 18 days per month, 24 hours a day. Their NAA facilities are quite up to date, including Packard and Hewlett-Packard 4096-channel analyzers, two Ge(Li) detectors (one of 80 cm^3 volume, from Nuclear Diodes), and a French automatic sample changer.

The author visited the Argentine 5-megawatt reactor, RA-3, in Ezeiza (near the airport, on the outskirts of Buenos Aires), and the Radioisotopes Applications Laboratory at Ezeiza (which includes their neutron activation analysis facilities), but the short duration of the author's visit to Argentina did not allow time to view their other nuclear facilities and activities. The only other discussions were with the Chairman of the Argentine Atomic Energy Commission, with their Director of Research, and with several of their Radioisotopes Applications Laboratory scientists with whom the author was already well acquainted from several previous Latin American conferences. The author also gave a lecture on "Recent Advances in Activation Analysis" at their AEC headquarters (their AEC is called the Comisión Nacional de Energía Atómica, as in most of the Latin American countries, and is abbreviated CNEA).

In spite of the relatively long history of their nuclear activities, the small sample of it viewed by the author gave him the impression of a fairly mature, but not very dynamic program. This situation may have been the result of the unsettled state of political affairs in Argentina at the time (the possible return of Juan Perón to Argentina was being debated at the time).

4. Brazil

During the author's first visit to Brazil, in November of 1963, the author participated in the IAEA Study Group Meeting on Utilization of Research Reactors, held in São Paulo. During the meeting, a visit was made to the principal research reactor in Brazil, a 5-megawatt reactor at the Brazilian AEC's laboratory in São Paulo. Immediately after the meeting, the author visited their two other nuclear laboratories (each also housing a research reactor) — at Belo Horizonte and in Rio de Janeiro, as a guest of the Brazilian government.

The 5-megawatt São Paulo reactor was, and continues to be, the highest-flux reactor in Brazil, the center of their radioisotope production, and the center of their work in neutron activation analysis applications.

The 100-kilowatt TRIGA reactor in Belo Horizonte, at the University of Minas Gerais, at the time had a fairly active NAA applications program concentrated on the analysis of ore samples, since the Province of Minas Gerais is the most highly mineralized province in Brazil.

In 1963, the Rio de Janeiro laboratory of the Brazilian AEC was just in its infancy, and their 10-kilowatt Argonaut training reactor was only under construction — not yet completed.

Some nine years later, in 1972, when the author again visited the São Paulo and Rio de Janeiro laboratories (but not the Belo Horizonte laboratory) of the Brazilian Comissão Nacional de Energia Nuclear (CNEN), considerable growth in these two laboratories was evident — especially, of course, in the Rio de Janeiro laboratory.

Nuclear activities in Brazil may be said to have commenced, officially, in 1953 — when the government created the Radioactive Research Institute. In 1956, the government formed the CNEN and the Atomic Energy Institute. In 1962, the CNEN/Eletrobrás agreement was signed, for construction of Brazil's first nuclear power station (construction of the 600 MWe Angra pressurized water reactor was started in 1971; it is scheduled to go on stream in 1976). CNEN programs in nuclear ore prospecting, fabrication of nuclear fuel elements, and reprocessing of spent fuel have been fairly extensive. In addition to the three research reactors in Brazil, the CNEN also has a 300 keV accelerator for neutron production and a 400 keV Van de Graaff accelerator for neutron production. The CNEN has also given or sponsored a large number of training courses in the various branches of the field of nuclear science. They also have fairly extensive operating programs in nuclear medicine, industrial applications of radioisotopes, agricultural applications of radioisotopes, food irradiation, and fundamental research. Basic scientific equipment available include such kinds of apparatus as a neutron diffractometer, x-ray fluorescence equipment, x-ray diffraction equipment, whole body counters, radioisotope scanners, a nuclear magnetic research spectrometer, and electron microscopes. The three principal CNEN laboratories, each of which possesses a research reactor, are located in São Paulo, Belo Horizonte, and Rio de Janeiro. The reactor facilities and activities of these three laboratories are discussed below.

The São Paulo laboratory is called the Atomic Energy Institute (IAE), and was formed in 1956 in cooperation with the University of São Paulo. As of 1971, the IAE staff totalled 500 persons. It centers about the 5-megawatt pool-type reactor, which was scheduled to be increased later on to 10-megawatt operation. As mentioned earlier, this reactor is the main center in Brazil for radioisotope production (processed in ten hot cells, and delivered at the rate of about 200 shipments per month), production of radiopharmaceuticals, and neutron activation analysis. The reactor was installed in 1957. Their NAA applications program has been a strong one for many years. As of the time of the author's second visit to the São Paulo reactor (in 1972), the NAA group had good sodium iodide and germanium gamma-ray spectrometry and computer equipment in regular operation. São Paulo also is the location of the CNEN's Center for Nuclear Energy in Agriculture (CENA), founded in 1966. It is part of the University of São Paulo. This laboratory carried on extensive agricultural radiotracer studies and studies on plant and seed irradiations.

The CNEN laboratory in Belo Horizonte is called the Radioactive Research Institute (IPR), and was founded at the Federal University of Minas Gerais in 1953. As of 1971, the IPR staff totalled 200 persons. It houses a TRIGA Mark I reactor, first operated at 100 kilowatts, then at 140 kW (and scheduled to be increased to 250 kW). The NAA applications studies with the reactor have been largely concentrated on ore analysis problems.

The Nuclear Engineering Institute (IEN) of the CNEN, founded in 1962, is located on the campus of the Federal University of Rio de Janeiro. It houses a 10-kilowatt Argonaut training reactor, built entirely in Brazil, which went critical in 1965. It also houses a 14 MeV neutron generator and a 750-curie cobalt-60 irradiator. It has a staff of 200. The training activities at the IEN are quite significant. It has a small but good staff of radiochemists interested in NAA and hot-atom chemistry. Their activities, however, are severely limited by the low neutron fluxes available at the IEN.

All in all, the Brazilian CNEN nuclear program is diversified and expanding. It is perhaps the best example of a progressive nuclear program in Latin America.

5. Chile

The author's only visit to Chile was in November-December of 1971, when he participated as a representative of the U.S. AEC in a one-week IAEA conference in Santiago on reactor utilization in Latin American countries. The conference was

held at the new laboratory of the Chilean AEC, on the outskirts of Santiago, which was still under construction. At the conference, a total of 26 papers were presented — including papers from eight Latin American countries: Argentina, Bolivia, Chile, Colombia, Cuba, Ecuador, Mexico, and Uruguay. Oddly, there were no papers from Brazil or Venezuela, and Brazil did not even have any attendees at the conference. Part of the conference was devoted to discussions on the desirability of an IAEA-sponsored program of Latin American cooperation in nuclear applications studies, analogous to the similar IAEA Asian program.

In previous years, the Chilean AEC program had heavily emphasized the field of hot-atom chemistry. At the time of the 1971 conference, their first research reactor, a 5-megawatt reactor of the Herald type (British), was under construction. Plans were being made to expand their research and training activities once the reactor was in full operation. As part of this plan, Chile sent one of their radiochemists to the author's laboratory at U.C. Irvine, under an IAEA fellowship, to learn reactor neutron activation analysis. He was at UCI from late 1973 to late 1974, and then returned to Chile to set up their NAA laboratory. Soon after his return to Chile, their reactor was completed and put into operation. He has now instituted a program of NAA applications, particularly in connection with Chile's extensive minerals production. The reactor provides excellent thermal-neutron fluxes for NAA work. This fact, coupled with their new germanium detector gamma-ray spectrometry and computer equipment and his experience in NAA, should result in a significant program in NAA applications.

6. Mexico

The author's contacts with the Mexican AEC have covered a period of about 13 years. They started early in the 1960's, when Mexico first started discussions with General Atomic regarding their planned purchase of a one-megawatt TRIGA reactor (the author was at that time head of the Activation Analysis Program at General Atomic). During this period, the author lectured on NAA on two occasions before the staff of the Mexican AEC, in Mexico City, and the Mexican AEC sent their principal radiochemist to General Atomic for one and a half years, to study NAA in the author's laboratory. However, completion of the reactor facility at their new laboratory in the mountains outside of Mexico City proceeded very slowly — so much so that when the author was in Mexico City for an international conference in 1967, the reactor was still only partially completed. The author visited the facility at

that time. Although considerable germanium gamma-ray spectrometry equipment was on hand, it was not in use because of the absence still of an operating reactor. About two years later, it was completed and put into operation. The radiochemist who was trained in NAA at General Atomic several years earlier stayed with the Mexican AEC long enough to form an NAA group and get it into operation, using the reactor. Then, discouraged by the time already lost and slow progress, he left to join the research staff of the national petroleum company of Mexico. Fortunately, since he is a very good chemist, he continued to assist the Mexican AEC as a consultant to them on NAA matters.

Despite considerable assistance from the IAEA, particularly in the form of a number of IAEA Visiting Experts, progress on nuclear applications at the Mexican AEC has been rather slow. In the summer of 1973, the author spent six weeks there, as an IAEA Visiting Expert. During this period, he was able to help them step up their NAA applications program considerably, but whether this produced any lasting effect is somewhat debatable. The overall program in nuclear applications of the Mexican AEC seems to lack vigor, sustained planning, and well defined purpose. Considerable personnel turnover is another of their problems. This is not to say that no progress has been made, as the staff has done a significant amount of good work in radioisotope production, hot-atom chemistry, NAA, and nuclear engineering — and has established a number of fledgling contacts with Mexican universities and government agencies. Probably, in due time, however slowly, their nuclear program will grow and expand.

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