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CONFERENCE OF NON-NUCLEAR-WEAPON STATES

CONTRIBUTIONS OF NUCLEAR TECHNOLOGY TO THE ECONOMIC AND SCIENTIFIC ADVANCEMENT OF THE DEVELOPING COUNTRIES*

Report of the Secretary-General

Pursuant to General Assembly resolution 2456 A (XXIII) of 20 December 1968, the Secretary-General has the honour to transmit herewith to the members of the General Assembly the report on the contributions of nuclear technology to the economic and scientific advancement of the developing countries. This report was prepared by a group of experts in accordance with paragraph 8 of the above resolution.

* Item 31 (c) of the provisional agenda.

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LETTER OF TRANSMITTAL

27 June 1969

Dear Mr. Secretary-General,

We have the honour to submit herewith the report of the Group of Experts on Contributions of Nuclear Technology to the Economic and Scientific Advancement of Developing Countries.

We are deeply aware of the importance of the task you called upon us to undertake. We hope that our endeavours will help in strengthening international co-operation in the peaceful uses of nuclear technology and will contribute to the transfer of contemporary scientific and technological achievements to the developing countries.

The Group has reached a consensus on the possible applications of nuclear technology to development and the report reflects the agreed views of all the experts.

We wish to take this opportunity to express our gratitude for the valuable assistance given us by the Secretariat of the United Nations, especially Mr. Vladimir Baum, and the secretariat of the International Atomic Energy Agency.

Yours sincerely,

(Signed) Carlos Graef-Fernández
Chairman of the Group of Experts

(Signed) Pawel Nowacki
Vice-Chairman

(Signed) John S. Fraser
Rapporteur

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Secretary-General
United Nations
New York

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INTRODUCTION

1. The General Assembly adopted resolution 2456 A (XXIII) on 20 December 1968, in which it requested the Secretary-General, in accordance with resolution G of the Conference of Non-Nuclear-Weapon States, held at Geneva from 29 August to 28 September 1968, to appoint a group of experts, chosen on a personal basis, to prepare a full report on all possible contributions of nuclear technology to the economic and scientific advancement of the developing countries; endorsed the recommendation that the Secretary-General should draw the attention of the group of experts to the desirability of taking advantage of the experience of the International Atomic Energy Agency in preparing the report; requested the Secretary-General to transmit the report to the Governments of States Members of the United Nations and members of the specialized agencies and of the International Atomic Energy Agency in time to permit its consideration by the General Assembly at its twenty-fourth session.

2. The Secretary-General of the United Nations appointed the following eighteen persons to form the Group of Experts on Contributions of Nuclear Technology to the Economic and Scientific Advancement of the Developing Countries:

G. Cesoni (Italy); Director, Fiat-Sezione Energia Nucleare

R.B. Duffield (United States of America); Director, Argonne National Laboratory

M.A. El-Guebeily (United Arab Republic); Director-General, United Arab Republic Atomic Energy Establishment

J.S. Fraser (Canada); Senior Scientist, Atomic Energy of Canada Limited

C. Graef-Fernández (Mexico); Director of the Nuclear Centre of Mexico

H.H. Koch (Denmark); Chairman of the Executive Committee of the Danish Atomic Energy Commission

H. de Laboulaye (France); Head, Department of Programmes, Commissariat à l'énergie atomique

I. Malek (Czechoslovakia); Vice-President, Czechoslovak Academy of Sciences

S. Mitsui (Japan); Professor, Faculty of Agriculture, University of Tokyo

P. Nowacki (Poland); Director, Institute of Nuclear Research

M.G. Petrascu (Romania); Chief, Department of Nuclear Physics, Institute of Atomic Physics

J.A.K. Quartey (Ghana); Chairman, Management Committee, Ghana Atomic Energy Commission

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11. In the short term, many of the low-cost applications of nuclear technology presently available could help the process of economic growth in many developing countries. With time, an increasing number of countries will be able to install more sophisticated nuclear facilities including large and costly power plants. A systematic effort should be made to prepare for this by building up the local capabilities. This will depend to a large extent on the further development of effective methods for transferring technology in its broadest sense.

12. The purpose of this report is to indicate the promise that nuclear technology holds for the economic and scientific advancement of the developing countries. It makes no attempt to analyse the specific conditions under which applications could be introduced in various countries. It sets forth the general principles of, and the conditions required for, the effective use of nuclear technology within the framework of national development programmes.

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SUMMARY

A. Transfer of nuclear technology

13. Nuclear and conventional technologies are interdependent and must be related to the specific conditions prevailing in the developing countries. The introduction of nuclear technology into a developing country depends on the state of its scientific and technological infrastructure. An initial requirement is the existence of adequate educational facilities. The training of technicians and skilled workers is crucial. It is recommended that they should be accorded facilities, either individually or as small plant or project groups in which all phases of a particular activity are represented, for training in advanced countries. Nuclear centres can form a valuable link in the transfer of nuclear technology. They should be staffed with an interdisciplinary approach in mind and should co-operate with existing agricultural, medical and other organizations. The medical institutions should be encouraged to train some of their own staff in nuclear techniques. There is a need for more nuclear centres and the existing ones should be made more effective. When a strong cadre of research scientists is available, consideration may be given to a nuclear research reactor.

14. The Group notes that certain atomic energy laboratories in industrially advanced countries are beginning to reduce their work in the field of reactor research and development, and suggests that they be invited to devote a part of their effort towards assisting developing countries.

15. The transfer of nuclear technology requires the transfer of organizational and administrative skills as well as the establishment of safety control institutions. It also has important financial aspects. The Group notes the studies being undertaken currently by various organs of the United Nations on the problem of technology transfer and expects that the question of the transfer of nuclear technology will be included in them.

B. Nuclear minerals

16. At the present time, only uranium is in demand as fuel for nuclear power plants; thorium may become of interest in the future. The rapid growth of nuclear power provides the uranium mining industry, for the first time in its history,

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with a stable and promising commercial market on which reasonably firm plans for exploration and production can be based. The amount of low-cost uranium which should be found and proved before 1980 is of the order of 1 million short tons of U_3O_8.

17. The proved low-cost ore reserves are now approximately 700,000 tons of U_3O_8 over 95 per cent of which are in developed countries. Thus, it may reasonably be expected that a more substantial proportion of the reserves to be located in the future will be found in the developing countries.

18. The average time between the start of an exploration programme and full operation of a new mine may be from six to ten years. Early exploration for uranium is therefore essential if a shortage of uranium in the late 1970s is to be avoided. Since the exploration for and the mining and milling of uranium involve heavy expenses, it is clear that, if the objective is the commercial export of uranium and not just its use in domestic nuclear power plants, consideration will have to be given to the balance between the total expenses in finding, mining and milling the ore and the value of the recoverable uranium.

19. The Group considers that more intensive exploration for uranium is one of the most important ways in which international assistance could be provided to developing countries.

C. Nuclear power

20. There is a direct relationship between electricity consumption and national prosperity. Therefore, increasing the electricity production in the developing countries is imperative if they are ever to approach the present prosperity levels of the industrial countries.

21. Nuclear power is expected to play a growing role in this respect. It has already achieved a commercial break-through in the technically advanced countries and is beginning to be used in a few developing countries that have the necessary minimum demand. Nuclear power has some inherent advantages for a number of the developing countries, but it must satisfy certain economic criteria such as plant size and load factor.

22. In the Group's view, these criteria should be applied flexibly and each case assessed on its individual merits. In particular, the first nuclear plant

in any country may not be able to comply with stringent requirements of competitiveness, but may nevertheless be justifiable if it is the first unit in an economically sound long-term nuclear power programme. Due weight must also be given to the possible indirect industrial and scientific benefits that may result from introducing nuclear technology on a large scale.

23. The number of developing countries that could use nuclear power would be considerably increased if economically competitive medium-sized plants were to be developed. Encouragement should be given to manufacturers to take a greater interest in medium-sized nuclear power plants by further market and technical surveys of the type carried out by IAEA.

24. A developing country embarking on a nuclear power programme should select a proved type of plant and should have or establish the required technological infrastructure for plant operation, maintenance etc. The Group considers that the country should ensure that its own technical staff participates to the maximum extent possible in the selection of nuclear plants as well as in their design and construction.

Desalination

25. The demand for water is increasing more rapidly than the world population. Desalting of sea-water to satisfy this demand has great possibilities. To date, the desalting of water for municipal and industrial uses has been applied on a small scale. It is still very expensive and is only justified where fuel is extremely cheap or where there are no other sources of water. Since very large nuclear reactors produce cheap energy, nuclear energy looks especially attractive for the very large desalting plants that will be necessary to satisfy the water demands of the future.

26. The Group recognizes the advantages that may be gained from the use of large nuclear desalination plants when they can be justified; therefore, the experience of the advanced countries in this field will be of the greatest value to the developing countries. At the same time, it is clear that further research in specialized techniques aimed at reducing the water required for agriculture in arid regions may lead to more effective water usage in these areas.

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27. For the remote future, agro-industrial complexes look promising. These would be very large nuclear-powered plants producing desalted water for agricultural purposes and electricity for power-intensive industries.

D. Radio-isotopes and ionizing radiation

28. The uses of radio-isotopes and ionizing radiation are so many that the Group could only consider the more important ones.

29. Food and agriculture are major fields in which nuclear technology can benefit the developing countries in both the short and long terms. Therefore, all possible aid in this connexion should be extended to them. The utility of nuclear methods is evidenced by the millions of hectares of land on which high-yield radiation-mutant crop varieties are already under cultivation.

30. Isotopes are used to study the uptake of fertilizers by plants as affected by the way in which they are introduced into the soil, their distribution, time of application and chemical composition.

31. Insects can be studied by marking with radio-isotopes. The so-called sterile male technique for the control of insect pests is important since it is specific to predetermined species and minimizes the use of chemical insecticides.

32. Nuclear techniques find numerous applications in medicine and biology. Radio-active materials are used as tracers in medical research as well as in clinical diagnosis and investigation. They are also used as radiation sources in the radiation therapy of cancer and other diseases and in public health applications.

33. In industry, large radiation sources have been installed for various purposes, chiefly for sterilization. The sources utilize gamma radiation and beams of fast electrons. Gamma sources are frequently employed in the radiography of welds and castings, where they have the advantage of small size, portability and independence of power supply.

34. Radio-isotopes have found great application in measuring and controlling physical parameters in industry; instruments for measuring thickness, level, density and moisture-content are only a few examples.

35. Radio-active tracers are used both for laboratory research and for investigations in industrial plants. They have the advantage of being detectable in very low concentrations and even through the walls of pipes or process vessels. Thus, investigations can be made without the expense of shutting down a plant.

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36. Nuclear techniques have also been successfully applied in the search for petroleum, particularly in the exploration of bore holes. Radio-isotope gamma and neutron sources of various kinds, coupled with gamma and neutron detectors capable of operating at depths of several kilometres, are used for bore-hole logging.

37. There is growing need for fresh water for drinking and agricultural purposes; therefore new methods have to be used to locate water sources, especially in arid areas. Radio-isotopes are making a major contribution to the solution of this problem.

E. Nuclear explosions for peaceful purposes

38. The Group notes that while this new branch of technology holds much promise for the future, especially for very large-scale civil engineering works as well as for developing underground mineral resources, or providing storage space for them, it is still at an early stage of development. Many uncertainties must be resolved before it can be put to industrial uses on a wide scale.

39. The Group considers that, in the international field, the first need is to obtain and systematically disseminate more information about the potential of this new technology as well as its technical limitations and costs.

40. Article V of the Treaty on the Non-Proliferation of Nuclear Weapons provides that the "potential benefits from any peaceful applications of nuclear explosions will be made available to the non-nuclear-weapon States Party to the Treaty".[3/]

41. The Group recommends that developments in this technology be kept under constant review by IAEA in co-operation with those United Nations agencies which may be interested in their economic application and their effects upon the environment.

F. International co-operation for promoting peaceful nuclear technology

42. It is probable that the concerted international effort that has already been made to spread the peaceful uses of atomic energy has no parallel in other branches of modern technology. The Group notes the importance of the progress that has already been made to declassify and promote the exchange of information about nuclear science and technology, and it stresses the usefulness of conferences,

3/ Ibid.

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seminars and other meetings of experts which take place within the framework of IAEA. It also takes note of the system for the international exchange of information currently being developed by the International Nuclear Information System of the Agency.

43. Considerable and expanding support will be necessary to foster nuclear technology in developing countries. The Group believes that technical co-operation projects carried out by IAEA will remain the chief source of assistance in introducing nuclear science and technology into many of the developing countries. The Group expresses concern at the difficult financial position of IAEA and feels that there should be a steady increase in the resources available for multilateral technical assistance.

44. For projects of the pilot plant and pre-investment type, the main source of multilateral assistance will probably continue to be UNDP. This assistance is allocated according to the priorities set by the recipient Governments. The Group believes that the Governments of developing countries could re-examine their positions on this matter, taking into consideration the success of projects of this kind already executed in other countries.

45. Major nuclear projects, such as nuclear power plants, require external financing beyond the scope of IAEA and UNDP and special financing arrangements may be necessary in many cases. The Group expresses the hope that international sources of finance, especially IBRD, will review the position taken on the prospects, criteria and conditions for supporting major nuclear projects, bearing in mind the long-term contributions that these could make to the further progress of the developing countries. It also hopes that this financial problem will be given careful and thorough study by the General Assembly and other competent organizations with a view to finding appropriate solutions.

46. The Group notes with satisfaction the high degree of co-ordination between IAEA and other United Nations bodies concerned with the transfer of nuclear technology to developing countries.

I. THE TRANSFER OF NUCLEAR TECHNOLOGY TO DEVELOPING COUNTRIES

A. Introduction

47. The term nuclear technology embraces scientific and technical knowledge, methods and engineering design and "know-how" connected with the nuclear weapons industry, the nuclear power industry, and with all the widespread applications of nuclear phenomena in the community at large.

48. So far as the nuclear power industry is concerned, the stages in the technology are prospecting and mining; extraction of uranium; production of reactor fuel, including isotopic enrichment of uranium; production of special materials for reactors; construction and operation of reactors; reprocessing of reactor fuel and disposal of radio-active wastes. Other non-weapon nuclear technologies concern the applications of radio-isotopes, the uses of radiation and radio-isotopic generators of electricity. Developing countries are likely to utilize nuclear technology on a modest scale initially, with applications of radio-isotopes; but sooner or later they will manifest an interest in the whole range of civil nuclear technology on a time scale determined largely by their rate of approach to an electric grid system partly powered by nuclear plants.

49. Nuclear technology is frequently used in conjunction with other disciplines, as in the following instances:

(a) The agronomist uses nuclear techniques in the development of new cereal mutants or in finding better ways of applying fertilizers;

(b) The entomologist uses them in the study and control of insects;

(c) The doctor uses them in medical research and in the diagnosis and treatment of diseases;

(d) The meteorologist, hydrologist and geologist utilize them in their specialized fields; and

(e) The engineer uses nuclear techniques in the study and control of industrial processes and non-destructive testing and inspection.

But the most notable peaceful application of nuclear technology is the generation of electric power.

50. The utilization of nuclear technology in the developing countries ranges from very slight in some countries to substantial in those which have sophisticated nuclear research centres and even nuclear power programmes.

51. The question of the transfer of technology is a problem of special importance for the developing countries. Their needs range from the creation of local skills and expertise and the acquisition of techniques to the financing of nuclear projects requiring, in certain cases, large amounts of capital.

52. Nuclear and conventional technologies are interdependent and must be related to the specific conditions prevailing in the various developing countries; and although nuclear technology may frequently play an important role, alone or in conjunction with other technologies, it is not a panacea for all existing problems. The introduction of nuclear technology may, however, animate activity in other fields and thus stimulate development processes generally, provided that both nuclear and conventional projects have realistic economic and social aims in accordance with national priorities. Since the introduction of nuclear technology in a developing country depends to a large extent on the state of its scientific and technological infrastructure, it is important to realize not only that each particular application should be examined in relation to the over-all circumstances, but that there should be a substantial effort to develop the infrastructure to the point where the assimilation of nuclear technology becomes relatively easy.

53. Nuclear research and development is currently carried out in the advanced countries as well as in a few developing countries. Such research is expensive. Consequently, it is fortunate that there are many ways in which developing countries can use the results of this research without initially having to undertake this work. The situation with regard to specific practical and local problems, however, is rather different, as the research required can often be more effectively carried out on the spot.

B. <u>General education</u>

54. In some developing countries there are no universities and in certain cases adequate secondary schools are lacking. In others, the number of scientists, engineers, doctors and agriculturalists is inadequate to cope even with day-to-day problems. In each case, it is obvious that the provision of such facilities and

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the recruitment and training of such personnel is the first requirement. It is recommended that full advantage be taken of the UNESCO programme concerned with scientific teaching at school and university levels, and the joint IAEA-UNESCO programme for the introduction of nuclear science into university curricula.

C. Specialized training

55. The sending of individuals to industrially advanced countries for training has long been one of the principal means by which specialized knowledge is transferred from one part of the world to another. If this transfer is to be accelerated, it is vital to expand the facilities for such training, both through bilateral arrangements and through IAEA and the United Nations family of organizations.

56. It must be strongly emphasized, however, that while a supply of graduate and post-graduate specialists is essential, no scientific or technological programme can be effectively carried out without adequate support from technicians and skilled workers; consequently, the training of such personnel is crucial. Besides the provision of local technical schools, it is recommended that additional arrangements be made for specialized training to be given to technicians from developing countries in the institutions of advanced countries. It is also recommended that small plant or project groups, in which all phases of a particular activity are represented, should be accorded facilities for study and training in appropriate laboratories or plants in the advanced countries.

D. Nuclear centres

57. National or regional nuclear centres form an extremely valuable link in the chain along which the transfer of nuclear technology takes place. Clearly, there is a need for many such local centres to be established and for those in existence to be strengthened and made more effective. It is important to recognize that it is not essential for such a centre to have a research reactor. Indeed, consideration should only be given to the establishment of a nuclear research reactor and associated laboratories in a developing country when a strong cadre of research scientists working in universities or other research centres has been built up. Many research reactors in developing countries, and

in some advanced countries, are not being fully employed and running costs are heavy. Where there is an intention to have a nuclear power station operating within ten years, however, a local research reactor is desirable, though not absolutely essential. It provides first-hand experience for reactor physicists, chemists and engineers, and forms a base for the embryo reactor-safety organization. The establishment of a nuclear power reactor would require, in addition to the above-mentioned technological infrastructure, a certain minimum size of electric grid system (see section III below).

58. In many cases, where local nuclear centres will not have a research reactor, they should be provided with the more advanced nuclear equipment not available to other institutions in the country, and should have a staff of well-qualified scientists and technicians. When staffing such centres, it is necessary to bear in mind that the applications of nuclear science usually require an interdisciplinary approach. Full collaboration should be fostered with existing institutions in the country which carry out agricultural or medical research, and they should be encouraged to train some of their own staff in nuclear techniques.

59. National and regional nuclear centres have received advice and support in the past from nuclear laboratories in the advanced countries, usually through the medium of IAEA. Recently there has been a tendency, in a number of large nuclear research centres in the developed countries, to reduce reactor research and development programmes and to diversify their fields of activity. It is suggested that these laboratories might be invited to devote a definite proportion of their effort towards aiding developing countries. Any assistance of this kind should not, however, adversely affect existing forms of aid, which also need further strengthening.

E. Organization and administration

60. The transfer of organizational and administrative skills is as necessary as the transfer of technical knowledge and skills. Failure to take this into consideration can result in wasteful and time-consuming effort in the execution of particular projects. Case studies are required in order to take into account local working conditions and habits.

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F. Health and safety

61. The introduction of nuclear techniques has attendant health hazards which must constantly be kept in mind. The establishment of control institutions is an essential preliminary step and every effort should be made to establish such institutions in developing countries and to train the necessary health and safety personnel.

G. Finance

62. The transfer of technology is, by its very nature, and international co-operative venture which involves financial aspects (see chapter VI below). Care should be taken to ensure that those features necessary for the efficient transfer of technology are adequately covered and that local funds are apportioned so as to derive the maximum over-all benefit from external funds.

H. Studies by United Nations agencies

63. Finally, the studies being undertaken currently by the various organs of the United Nations on the problems of the transfer of technology have been noted and it is expected that the question of the transfer of nuclear technology will be included in this work.

II. NUCLEAR MINERALS

A. Introduction

64. Uranium and thorium ores are the nuclear source materials of primary interest. Presently, however, only uranium is in demand as fuel for the current types of nuclear power plants. Thorium may become of interest, but only in the more distant future if advanced nuclear power stations using this material come into use.

65. In the next decades there will be a substantial and increasing demand for uranium to fuel nuclear power stations. The discovery and development of uranium resources can be of importance for the development of national nuclear power or for the commercial export of uranium. As the time span between the start of a uranium exploration programme and uranium production may be of the order of six to ten years, it is presently opportune to start new exploration so that advantage may be taken of the increased demand in the mid 1970s.

B. Summary of the present world situation

66. The rapidly growing demand for nuclear power is having far-reaching effects on the market for uranium. For the first time in its history, the uranium mining industry may look forward to a stable and promising commercial market upon which reasonably firm plans for exploration and production can be based.

67. In a recent authoritative report[4/] the estimated proven reserves of low-cost ore, outside the centrally planned economies, were placed at 700,000 short tons U_3O_8[5/] with the possible addition of a further 126,000 short tons U_3O_8 from by-product operations.

68. A subsequent authoritative estimate[6/] forecast a consumption of some 90,000 short tons of U_3O_8 per year in 1980 as compared to 16,000 short tons per year today. This means that about 600,000 short tons U_3O_8 will be consumed from 1968 through 1980.

4/ ENEA/IAEA Joint Study Group Report, December 1967.

5/ One short ton of U_3O_8 is equivalent to 0.77 metric ton of contained uranium.

6/ ENEA/IAEA Joint Study Group Report, January 1969.

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69. In addition to the estimated consumption of 600,000 short tons through 1980, it is estimated that an additional eight-year "forward reserve" of 1,100,000 short tons U_3O_8 should be proved by 1980 in order to allow for flexibility and efficiency of operation and to support the post 1980 demand.

70. Present production capacity, which is rated at about 23,500 short tons U_3O_8 per year (38,000 short tons per year with re-activation of shut-down mines), is quite inadequate to meet the annual demand of the late 1970s. New production capacity, much of it based on uranium deposits not yet discovered, will therefore have to be constructed.

71. Although the experts are reasonably confident that such additional uranium resources exist, a considerable amount of work must be done and investment made to locate and prove the required reserves and to build the necessary production capacity.

72. The average time between the start of an exploration programme in a new area and the proving of reserves is between three to five years. After reserves have been proved, the period between the commencement of the design and the full-capacity operation of a new mine and uranium milling plant is also of the order of three to five years, making a total exploration to production lead time of six to ten years. Therefore, the early expansion of exploration is essential if a uranium shortage from the mid-1970s is to be avoided.

73. With regard to the further 1.1 million tons of U_3O_8 required by 1980 as a "forward reserve", technical good practice would permit the expenditure of up to 10 per cent of the estimated content value on exploration and evaluation, with a further investment of the same order of magnitude, or even larger, on mine and mill construction.

74. Currently, over 95 per cent of the proved reserves are in industrially advanced countries. However, countries with presently established reserves by no means exhaust the favourable areas of the world where economic deposits of uranium may be found. Small occurrences of low-cost uranium and considerable reserves of higher-cost uranium are known in many countries and favourable geological conditions exist in many parts of the world where very little mineral exploration work of any kind has been done.

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75. While it is very difficult to generalize about favourable uranium areas, several geological theories have been put forward, according to which favourable areas are to be found in a large part of the world because of the ubiquitous nature of uranium and the multiplicity of its modes of occurrence. Thus, it may be reasonably be expected that a more substantial proportion of the uranium to be located in the future will be found in the developing countries.

C. Economic benefits to developing countries

76. Developing countries could benefit in two ways from the discovery of significant uranium deposits in their territory:

(a) The utilization of national uranium in national nuclear power stations;

(b) The commercial export of uranium.

77. In case (a), if the national uranium is competitive in price, the advantages are clear. If it costs more than the world market price, the developing country will have to weigh the advantages of using a national resource against the higher costs involved. In case (b), the production cost of the product should be sufficiently below the prevailing world price to leave a reasonable profit margin. It should be noted that in the future, purchasers are likely to be interested only in relatively large, long-term and reliable sources of supply.

78. The minimum size of deposit which will be economically exploitable is related to factors such as type of ore, location, transport and labour costs. However, few integrated mining and milling operations are likely to be launched in new areas which do not have a production capacity of at least 200 to 500 short tons of U_3O_8 per year and potential reserves for a period of ten to twenty years. This would suggest that the very minimum target is a deposit with 2,000 tons of U_3O_8 which could be produced at less than $8 per pound of U_3O_8.

D. Uranium exploration and development programmes

79. A survey for uranium ores in a new area, like that for any other mineral, normally involves a series of steps or work phases of increasing complexity and cost, each designed to increase the reliability of reserve estimates and decrease the element of investment risk. The planned expenditure for each phase should never exceed an appropriate small fraction of the possible return and should not be committed until there is substantial positive evidence from the preceding work phase.

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80. The general approach will differ according to the amount and quality of information that already exists about the geology of the country or region concerned. If the region is virtually unexplored from a geological point of view, it may well be desirable to begin with a broad-spectrum survey designed to obtain an over-all picture of the geology and mineral wealth, including uranium.

81. However, if only uranium is being sought - and this is the question with which the Group is concerned - the normal programme would be as follows.

82. As a preliminary step, efforts should be directed to the understanding of the geological environment and of the factors which may govern the existence of uranium ore bodies. This first phase includes the study of the geology and morphology to select the areas which are likely to be the most favourable for the occurrence of uranium. This would usually require preliminary reconnaissance surveying with scintillometers as well as the checking of the radio-activity of the selected portions of the territory with portable field instruments. The duration and the cost of this phase will depend upon the extent of the areas to be searched, the climate, the topography and location of the area with respect to access and living conditions, and the nature of the vegetal cover. The first phase may require from three months to two years. It is far less costly than succeeding steps.

83. The following phase will consist of a more intensive study of the areas which have been selected during the work performed in the preceding phase. It will entail the employment of systematic methods of uranium prospecting, each area being examined more intensively, very often by use of air-borne radiometric surveys and geochemical surveys. This phase requires larger expenditures, especially if air-borne methods are employed.

84. If anomalies are located and if they are believed to be of sufficient interest to warrant it, a third phase can then be embarked upon. It will include examinations of surface indications and preliminary assessments of the ores and their characteristics. The intensity of coverage of a given area is many times greater than in the earlier phases and more accurate instruments are generally required to provide the additional data necessary for a more precise definition of the ore body or bodies. The expenditures for this phase will be correspondingly higher.

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85. Once major anomalies are thus defined, and those that did not warrant further work have been excluded, the final phase may start. The objective is the delineation of the ore body, or at least an initial reserve which would support mining under the prevailing economic conditions. To define reserves it is necessary to determine the dimensions, grades and exact nature of the mineralized parts of the ore body. This requires extensive drilling and trenching, complemented by systematic sampling and analysis, to evaluate the amount of contained uranium. This phase may require, sequentially, separately or jointly, the use of the methods which have already been mentioned. It is the most expensive phase and it may require several years. In certain African countries that have had the help of French experts, the expenditures involved in discovering and evaluating sizable ore bodies (more than 8,000 tons of U_3O_8) has been in the order of $300,000 per year for two years for the first two phases, $600,000 to $800,000 per year for the third phase and $1 million to $2 million per year for the final phase.

86. Thus it is apparent that, if the objective is the commercial export of uranium and not just its utilization in national nuclear power stations, consideration should be given to the proper balance between total expenses in finding the reserves and the estimated recoverable amount of uranium. It is understood that this relationship can vary widely, but as a rough indication it would extend from perhaps 5 per cent to 15 per cent of the total recoverable value.

E. Production of uranium concentrates

87. Because the amount of uranium in an ore is extremely small (0.1 per cent to 0.5 per cent), economic factors require that the concentration process be carried out near the mines. For each ton of concentrate produced, a milling (that is, concentration) plant will consume from 30 to 40 kWh of electric power. Moreover, this operation will require large quantities of water, and fifteen to twenty-five tons of fuel and chemicals per ton of uranium concentrate. Transportation problems in remote locations may therefore be very important.

88. Parallel to the determination of ore reserves, it will be important to develop the best methods of recovering the uranium. This may require the

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adaptation of treatment procedures to the conditions found in developing countries. It may also call for additional research, up to and including pilot plants, directed towards treatment methods that will best suit each particular case, as the local conditions may not necessarily be the same as those in the more industrialized countries.

(i) Capital costs

89. Because of the considerable difference in accessibility, nature, grade and size of uranium deposits, investment costs vary widely from one mining and milling installation to another.

90. For the mills only, United States sources indicate investment costs of the order of $8,000 per short ton of U_3O_8 produced per year for a 200-ton-per-year mill, and of $5,000 per short ton for a 1,000-ton-per-year mill. These estimates probably represent the lower limit of investment costs.

91. As an average for both mines and mills, French experts have quoted an investment cost of some $20,000 to $23,000 per short ton of U_3O_8 produced per year, and similar figures have been published for Canadian and certain United States installations. In an extreme case in a developing area, the cost was as high as $46,000 per short ton of U_3O_8 per year.

(ii) Operating costs

92. It is very difficult to make any general estimate of mining and milling costs. Past experience tends to indicate that mining costs for most deposits in the United States fall within the range of $2 to $4 per pound of U_3O_8 produced and milling costs from $0.75 to $2 per pound of U_3O_8.

93. Under the conditions prevailing in the United States, the most probable ranges of expenditure for discovering, developing (including capital investment) and operating a uranium deposit in the range of 200 to 1,000 short tons of U_3O_8 per year for a ten to twenty-year life would be as follows in terms of dollars per pound of U_3O_8.

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	United States dollars per pound U_3O_8	
	Possible minimum	Possible maximum
Discovery and evaluation	0.40	0.80
Capital investment in mine, mill and other installations	0.40	1.20
Operating mining costs	2.00	4.00
Operating milling and production costs	0.75	2.00
Totals	3.55	8.00

These estimates, which include all items such as overhead and taxation, are very difficult to generalize since the break-down will differ widely from one country and one mining area to another.

94. In regard to the minimum target ore body of about 2,000 tons of contained U_3O_8, a developing country could reasonably expect to have to incur between $1.6 and $3.2 million in exploration and evaluation and between $1.6 and $4.8 million on mine, mill and auxiliary installations.

F. International assistance

95. In the domain of uranium production, many developing countries, irrespective of their technological progress or the size of their industrial base, may be able to benefit from nuclear technology in the near future.

96. Hence, the Group considers that this is one of the most important activities for which international assistance might be sought and should be provided as generously as possible.

97. Such assistance is, in fact, already available internationally for most stages of uranium prospecting and production. As yet, however, it has hardly been sought for the more advanced stages. When it is sought, such assistance should only be given under expert guidance. The various stages are as follows:

(a) Preliminary studies of favourable areas and reconnaissance prospecting;

(b) Aerial surveys;

(c) Ground prospecting;

(d) Evaluation of ore deposits;

(e) Evaluation and selection of mining methods;

(f) Evaluation of ore-processing methods, including a pilot plant if necessary; and

(g) Financing of actual mining and milling installations.

98. The Group also considers that IAEA should take the initiative in convening international symposia and meetings of experts to exchange information and develop recommendations on all aspects of uranium exploration and production.

III. NUCLEAR POWER

A. Introduction

99. The amount of energy that a country consumes is a barometer of its wealth and prosperity. Industrialization in particular depends upon cheap and plentiful energy. The world's energy consumption approximately doubles every fifteen years, but its distribution among countries is as uneven as is the distribution of material goods. Eighty-four countries, accounting for more than one-half of the world's population, consume only 5 per cent of the total energy. As a developing country's per capita production increases, the per capita energy consumption grows even faster. The relationship between electricity consumption and prosperity is even more striking - a doubling of the per capita gross national product requires a threefold increase in the per capita consumption of electricity.

100. It is therefore clearly imperative to increase energy production in the developing countries, particularly electricity production, if they are ever to approach the present levels of per capita production in the industrial countries. For instance, it would require an eightfold increase in the per capita energy consumption of South-East Asia to bring it to the present level of a relatively low-income European country.

101. Energy is used not only for electricity production, but also for motive power and as heat in industrial processes. However, the share of electricity in the total world consumption of energy is rising rapidly; its consumption doubles every ten years (about every eight years in the developing countries as a group), whereas the doubling time for energy as a whole is approximately fifteen years.

102. The chief sources of energy for producing electricity are coal, oil, gas, hydropower, and, in recent times, nuclear fission. Nuclear energy is particularly suitable for producing cheap electricity in large plants. Since this is the energy sector that is growing most rapidly, the over-all long-run trend favours nuclear power.

103. The essential difference between a nuclear power plant and a coal, oil or gas-fuelled plant is that the heat used for raising steam is produced by nuclear fission in a reactor instead of chemical combustion in the furnace of a boiler (see annex II). Since a nuclear steam generator is more complex than a coal or oil-burning boiler, capital costs tend to be higher for nuclear plants. However,

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fuel costs are lower. Generally speaking, the capital costs of nuclear power plants lie between those of fossil-fuelled power plants and hydroelectric plants. The savings in the case of nuclear plants result from lower fuel costs which can typically be half of those for conventional plants. Hence, it pays to operate nuclear plants as continuously as possible (as base load plants) and at the highest possible load so as to produce electricity at the lowest average cost.

104. For all power plants, nuclear or conventional, unit capital costs decrease with increasing size, but this economy of scale is more marked in the case of nuclear plants. Hence, the tendency is towards ever larger nuclear power plants (above 300,000 kWe).

B. Status and growth of the nuclear power industry

105. The first industrial-sized nuclear power plants went into operation in 1956 and 1957. Installed nuclear capacity now stands at approximately 12 million kWe and is expected to increase tenfold by 1975. It will probably pass the 320 million mark by 1980.[7/] Nuclear power has become an accepted component of electric power utilities in many parts of the world. It is beginning to be treated as a "conventional" method of producing electricity and is selected primarily on the basis of economic considerations.

106. To meet the expanding demand for nuclear power stations and their fuel supply, the nuclear energy industry in several advanced countries is growing at a rapid rate. During the next decade, major sectors of the nuclear industry, excluding the centrally planned economies, are expected to grow fivefold; the total annual expenditures will increase from approximately $3 billion in 1970 to over $14 billion in 1980 for nuclear power plants, facilities and materials. Thus, the domestic demand in the advanced countries for well-engineered medium-sized to large power plants[8/] and equipment will result in sources of supply at competitive prices for the developing countries.

7/ These estimates were provided by IAEA.

8/ A large nuclear power plant is considered to be one which will generate more than 300,000 kWe of electrical power. Medium-size power plants are considered to be those ranging from 100,000 kWe to 300,000 kWe.

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107. While nuclear power is growing rapidly in advanced countries, it has had relatively little impact on developing countries. Of the approximate total of 290 nuclear power plants in operation, under construction or firmly planned at the present time, only nine, or less than 2 per cent of the total capacity, are located in five developing countries.

108. In one developing country, nuclear energy has begun to produce electricity. In three others, plants have been ordered, and in four or five others, orders are expected to be placed within the next year or two. Most of the first orders have been placed by countries in fossil fuel deficient areas which have already gone some distance along the path of industrialization.

C. Nuclear power programme in a developing country

109. For developing countries taken as a whole, nuclear power has the following inherent advantages:

(a) Many developing regions are deficient in conventional fossil fuel. This is especially true of South and East Asia, where more than half of the world's population lives. The relatively low fuel costs of nuclear power can represent for such countries significant economies in the cost of imported fuel (and therefore foreign exchange) over the lifetime of a plant. This economy could be larger if indigenous, commercially workable supplies of uranium could be developed, since the cost of uranium accounts for about 20 per cent to 30 per cent of the total fuel costs for a nuclear power plant. As is indicated in section II, it is believed that uranium, in commercially workable deposits, may be found in a broad spread of developing countries.

(b) The relatively small transport and storage costs of nuclear fuel compared with fossil fuel make it possible to locate nuclear power plants in areas where transport costs would rule out fossil-fuelled plants. This offers an opportunity to mitigate inequalities in the development of various regions within large developing countries. Even spent fuel from nuclear reactors, which require heavily shielded containers, is far more economically transported than the equivalent fossil fuel.

(c) In certain cases the adoption of this up-to-date and sophisticated method of power generation can stimulate and produce side benefits in fields such as chemistry, metallurgy and electronics.

(d) The possibility of utilizing a new source of energy can, in some cases, lead to a better bargaining position for the purchase of conventional fuels.

(i) The economic problem

110. Among the problems that face developing countries in introducing nuclear power are those of organization, "know-how" and infrastructure. But, the biggest problem is financial, both because of the economic characteristics of nuclear as compared with conventionally fuelled power plants, as well as the general difficulty that developing countries have in obtaining financing for capital-intensive projects. A 200,000 kWe nuclear power plant would cost between $60 million and $70 million depending on the type of reactor employed.

111. There are two chief factors affecting the choice of size of a nuclear power plant. On the one hand, a desire to reap the benefits of economies of scale and produce electricity at the cheapest cost will favour the largest sized unit. On the other hand, requirements of system stability will limit, on technical grounds, the individual size which can be safely accommodated to approximately 10 per cent of the system capacity.

112. It is apparent from these considerations that a 300,000 kWe unit, for instance, could be accommodated in a system of 2.5 million to 3 million kWe at the time of its commissioning. This is generally considered to be the minimum size of nuclear power plant that is competitive with fossil-fuelled plants at the present time, and then only with fuel costing in the neighbourhood of 35 to 45 cents per million BTU's.[9/]

113. These are broad rules of thumb. If the electricity system is growing rapidly, it may be feasible to add a unit that will account for as much as 20 per cent of the total capacity. The growth rate and the pattern of power-generating capacity should be considered in this context. Also, national technological development policies may override strictly economic considerations, particularly with regard to the first nuclear plant. The decision to install

9/ The competitive fuel cost is determined by the costing assumptions. It is 31 to 46 cents per million BTU's ($12.60 to $18.76 per metric ton of heavy fuel oil) based upon the range of assumptions used by IAEA. It is 45 to 50 cents per million BTU's ($18.40 to $20.40 per metric ton of heavy fuel oil) based upon the assumptions used by IBRD.

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the first such plant should be made with the utmost care by the developing country concerned, weighing the expected scientific and technological benefits against the extra costs. Such a decision could only be justifiable if the plant were to be the first in a planned long-term economically viable nuclear power programme.

114. The point should be cited that in almost all of the advanced countries, the first commercial-sized nuclear power plants were not regarded as "economic" propositions and were not required to satisfy, or even approach, strict economic criteria. The first, and in some cases, the first few plants were seen as ventures into a vital new branch of technology required by the national interest. All the early commercial power plants which are working at present in the advanced countries, where capital is more freely available, were subsidized.

115. Experience has shown that for these and other reasons, any criteria must be flexibly applied, taking into account all the specific factors in each given situation, of which no two will be alike. Each project must be carefully considered both on its merits and as part of the long-term power generation plan of the country concerned.

116. Nevertheless, prima facie economic considerations will make nuclear power plants of the large sizes currently being manufactured interesting to many developing countries only when their over-all energy demands have considerably increased. It is expected that by 1980, another ten developing countries will be in an economic and technical position to install 300,000 kWe plants. In some of these, however, the availability of particularly cheap fossil fuel may continue to make nuclear power relatively less attractive.

117. At the other end of the scale are those countries that have such small or scattered electricity supply systems as to be clearly unable to use 300,000 kWe power plants within the time scales under consideration. Between these two groups, however, are a growing number of developing countries that might be able to use medium-sized nuclear power plants within the next ten to fifteen years, if they become available.

118. In respect of the larger nuclear power reactors now being built in advanced countries, the cost-reducing effects of size and component standardization and of replication in manufacture have hardly had time to make themselves felt. It is

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estimated that the cumulative effect of these factors should lead in the late 1970s to reductions in cost amounting to 15 to 25 per cent from present levels. There is evidence to indicate that standardization and replication would have similar or greater effects in respect of smaller power reactors. It cannot be expected, however, that industry in advanced countries will be prepared to invest heavily in research and development work on medium-sized reactors, including work on those characteristics of importance to developing countries, such as sturdiness, simplified operation and reduced maintenance, until the nuclear manufacturers have a much better picture of the potential markets for such reactors.

119. To encourage these manufacturers to become more interested in the needs of developing countries, IAEA is making a survey of the potential markets for nuclear power plants in the small and intermediate ranges. It has invited potential supplier countries to develop and provide information, through a co-ordinated programme of research agreements, on the technical aspects and the costs of such nuclear power plants.

(ii) Sequence of steps for a nuclear power programme

120. The decision to embark on a nuclear power programme should only be taken by a developing country after making a comprehensive study of its long-term power needs and of the various ways of meeting them. This study should also take into account the prerequisite level of the scientific and technological infrastructure, as well as the indirect beneficial effects that will result from the introduction of the new technology. Thus, for instance, in a developing country in southern Asia, which already has a substantial industrial base, the nuclear programme has led to the establishment of a sizable electronic and nuclear instrumentation industry. The country is now importing very few electronic instruments from abroad and has, in fact, become an exporter. Local industry is participating to a rapidly increasing extent in nuclear power projects. For the first nuclear plant the foreign exchange component was about 60 per cent, for the second it dropped to 40 per cent and for the third it is expected to be only 20 per cent. Nuclear power has stimulated a search for nuclear raw materials and has contributed to the over-all scientific and technological development of the country.

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121. Each developing country will have to ensure that it has the necessary technological infrastructure for the effective operation of a nuclear power plant. Besides specialized national personnel, it must have the basic industrial plants to service the nuclear power station, and to carry out repairs. On the organizational side, it should have the necessary executive body and the basic legislation on nuclear safety and related legal questions. Transport facilities should be adequate for carrying the extra-large and heavy components that may be needed.

122. The developing country that decides to embark on a nuclear power programme should take all possible steps to ensure that its own technical staff participates to the maximum extent possible in the selection of the plant and in its design and construction. Such local participation is essential for the subsequent operation and maintenance of the plant by local personnel and for the future development of the national nuclear power programme. Participation may require an intensive training programme for local technologists.

123. In selecting a nuclear power station, it is advisable to choose a type based upon proved technology rather than an advanced or experimental type. Ideally, the plant should be a duplicate of stations that have been satisfactorily operated for some time in the advanced countries. Because technological advance in nuclear power plant design is rapid, the developing country will have to balance the advantages of incorporating innovations that may be recommended by the manufacturers against the possible effects that such innovations may have on plant performance and availability.

124. Three power-reactor systems are generally regarded as proved and also sufficiently up to date in their economic performances to be interesting to developing countries. These are the "light-water reactor", the "gas-cooled reactor" and the "heavy-water reactor". In choosing among these systems, an important question will be whether to introduce a system that uses natural uranium fuel, or one that uses slightly enriched uranium fuel. Enriched uranium is produced in five countries and exported on a substantial scale at present by one of them. Natural uranium is more widely available and the choice of this fuel may enable a developing country that produces it to use its indigenous supply and become self-sufficient in this respect. In consideration of the fact that the cost of uranium is a small fraction of total nuclear power costs, the use of an

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indigenous supply should be weighed carefully against the consequent economic and technical factors. Among these are that reactors using enriched uranium have lower capital, but somewhat higher fuel costs than those using natural uranium.

125. Developing countries should also examine to what extent it is advisable for them to set up national or regional facilities for fuel fabrication or to participate in regional plants for the reprocessing of irradiated fuel. Information given to the Group has indicated that in view of the large labour component in building and operating the latter facilities, and the much lower labour costs in developing countries, certain selected developing countries that already have extensive industrial experience may be able to undertake fuel reprocessing and to offer these services to other countries at costs competitive with those available from advanced countries.

126. Throughout the operating period of nuclear power stations, a certain amount of liquid and solid radio-active waste materials are produced which must be dealt with to avoid contamination of the area. This problem is even more important in the case of fuel reprocessing plants.

D. Desalination

127. The demand for potable and agricultural water is accelerating throughout the world. Owing exclusively to the increase in population, the demand for water for all purposes will probably double in thirty years. But the water demand is increasing faster than the population of the world because of the rising standard of living in the developing countries. More than one third (37 per cent) of the land-surface of the earth consists of warm, arid regions which belong, to a large extent, to developing countries. In some specific locations of these arid regions, the necessity for water has reached crisis proportions. The common water resources have been exhausted. In some places the wells have been over-exploited and sea-water has invaded the aquifers. Thus, there is a pressing need for the development of new means of providing the required fresh water. Since 40 per cent of the warm arid regions are close to the sea, it seems natural to consider the feasibility of using nuclear energy for converting sea-water into fresh water. In existing desalting plants, the chief source of energy is fossil-fuel; some very small plants use solar energy and one exceedingly small plant (which operates under very special conditions) uses nuclear energy.

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128. To date, the desalting of water for municipal and industrial uses has been undertaken on a rather small scale (up to a few million gallons per day or a few thousand cubic metres per day) at a cost of approximately one dollar per 1,000 US gallons or $0.26 per cubic metre. Even though the cost of desalted water is rather high, there are twenty-five larger plants in operation with a total production of 36 million gallons of fresh water per day (136,000 cubic metres per day). There are thirty-five plants under construction which will produce 109 million gallons of fresh water per day (413,000 cubic metres per day). Desalination of sea-water is the solution where extremely cheap energy is available, as in Kuwait, or in cases where other sources of fresh water do not exist, as in Tijuana, in north-west Mexico. A large nuclear desalination plant with a capacity of 66 million gallons per day (250,000 cubic metres per day) is nearing completion in the USSR.

129. The desalination processes currently being utilized and/or investigated are several different distillation arrangements, reverse osmosis, electrodialysis and freezing. The very number of the lines of investigation implies the great interest in this field and the vigorous development that is currently under way.

130. For the very large plants necessary to satisfy the water demands of the future, large quantities of low-cost energy will be required. For such projects, nuclear energy may be economically attractive since economies of scale particularly favour very large reactors. A nuclear power plant has the further advantages that it is essentially insensitive to location and does not normally contribute to atmospheric pollution.

131. When considering nuclear energy for desalting purposes, there are two possibilities. Either the nuclear plant can be used for the single purpose of producing fresh water, or it can be used for the dual purpose of producing water and electric power. Since such plants do not yet exist, their performance cannot be judged. The dual-purpose plant is attractive in theory since, from a thermodynamic standpoint, effective use can be made of the available low-grade heat. By combining the two processes in one plant, a larger nuclear reactor can be used, resulting in a lower-unit capital investment. A disadvantage of dual-purpose plants for many developing countries is the lack of markets for large quantities of electric power.

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132. The Group recognizes the advantages that may be gained from the use of large-scale nuclear desalination plants when they can be justified. Therefore, the experience of the advanced countries in this field will be of the greatest value to the developing countries. At the same time, it is clear that further research in specialized techniques aimed at reducing the water required for agriculture in arid regions may lead to more effective water usage in these areas.

133. Growing interest is being shown in nuclear agro-industrial complexes as possibilities for the more remote future. These would incorporate very large nuclear power plants that would produce electric power at perhaps half of today's cost, produce desalted water for agriculture and simultaneously supply the energy and water needs of large energy-intensive industries, such as fertilizer production. A joint study is being carried out by the Oak Ridge National Laboratory in the United States and IAEA on the potentialities of these conceptual nuclear agro-industrial complexes which may become important future factors for the economic progress of developing countries.

134. To assess the economic feasibility of these complexes, pilot plants will have to be built and projections made of the steps required to complete full-scale projects. In view of this, the Group feels that it would be premature for it to express any firm views on nuclear agro-industrial complexes.

IV. RADIO-ISOTOPES AND IONIZING RADIATION

A. Introduction

135. The uses of radio-isotopes and ionizing radiation are so numerous that only the ones important for the developing countries will be considered in this report.

B. Food and agriculture

(i) General

136. Food is one of the major concerns of all mankind and has engaged the attention of governments, economists and scientists throughout the world. In several heavily populated regions, food needs are already far in excess of the indigenous production and the situation is steadily deteriorating with the impact of the population explosion.

137. Fortunately, technological progress in food and agriculture has been swift during the past few years. Advances in crop production have been so rapid that they may already be considered to constitute a significant break-through.

138. This break-through has come primarily as a result of scientific progress in a variety of agricultural disciplines, such as plant breeding, soil fertility, moisture management, plant physiology, crop protection and mechanization. As production levels have increased, scientific techniques used to sustain these levels have become more sophisticated.

139. It is not sufficient to produce food containing only the required number of calories; attention must also be paid to its composition, particularly to its protein content and quality.

140. The virtue of nuclear techniques is that, for a variety of problems, they can offer solutions which either cannot be obtained by other means or which can be obtained more quickly, more efficiently or more economically thereby. Nuclear methods have already contributed significantly to the scientific as well as the economic development of agriculture in both the developed and developing countries. This is evidenced by the millions of hectares of land on which high-yield radiation-mutant crop varieties are already under cultivation, by improved fertilizer and water management practices as a result of isotopic studies with

fertilizers, and by soil moisture studies with neutron moisture metres. It should be stressed, however, that nuclear techniques can and should be used as one among the various tools of the food and agricultural researcher.

(ii) Radio-active and stable isotopes

141. Techniques involving the use of radio-active isotopes for all purposes should be applied by well-trained personnel and must be accompanied by measures against unnecessary exposure.

142. Isotopes are used to study the uptake of fertilizers by plants as affected by the way in which they are introduced into the soil, their distribution, time of application and chemical composition. This work is of special significance to developing countries where fertilizers, when used, form a major item in farm expenditure.[10/]

143. As crop production levels increase through the application of the macronutrients (nitrogen, phosphorous, and potassium), a number of micronutrients, essential to plant growth but not normally present in commercial fertilizers, will become important. Isotope and radiation techniques are particularly suited to studies of such trace constituents. In many instances these techniques constitute a valuable way to detect and to follow the movement of these important micronutrients.

144. It is expected that the importance of isotope techniques in plant physiology will increase as more production stress is put on crop plants. As grain yields are multiplied, the density of plants in the field becomes such that photosynthesis is limited mainly to the topmost parts, including flower parts and lawns. Further studies are therefore required to investigate the photosynthesis mechanisms of these plant parts to determine the relative efficiency in carbohydrate, protein, and oil production, the transport of photosynthetic products, and the movement of water and mineral ions. The absorptive capacity of roots and their patterns of growth also need studies in order to aid the soil scientist in determining the optimum growth conditions for the high-yielding varieties. And the determination of the optimum growth conditions essential for achieving the high yields of the new crop varieties cannot be made without an appreciable increase in our knowledge in soil chemistry and soil fertility.

10/ Experiments in Thailand using radio-active phosphorous-32 and stable nitrogen-15 isotopes have led to new methods of plant culture and fertilizer application which require one-half of the previous amount of nitrogenous fertilizer.

145. One of the applications of nuclear techniques in insect and pest control is the use of radio-isotopes to mark insects or other pests. With relatively simple equipment, an insect marked with a radio-isotope can easily be distinguished and used in field studies of ecology. Data from these studies are useful for developing effective control methods.

146. The increasing use of pesticides for the protection of food and feed crops in the field could result in harmful residues in foodstuffs which might affect human health and cause serious damage to the environment. The quantities of residues which can constitute a health hazard can be so small as to be difficult to detect by classical chemical means. The use of nuclear techniques, such as radio-isotope labelling and neutron-induced activation of the samples taken for the investigation not only offer quick and useful methods of analysis, but sometimes the most effective means of detection.

147. Improvements in animal nutrition have been made through a better understanding of nutritional requirements, including the role of minerals and micronutrients in general metabolism and in the production of meat, milk, eggs and wool. Such studies involve the use of advanced and accurate chemical methods where the use of isotopic tracers has already played a significant role. This has resulted in the improvement of diets and patterns of feeding. Similarly, deficiency diseases have been detected and studied through the use of isotopes.

148. Isotopes could make a much greater contribution in the field of marine biology than has been the case to date. This applies both to ocean fisheries as well as to inland fisheries and fish culture.

(iii) Ionizing radiation

149. Ionizing radiation is used for breeding new crop varieties, sterilizing insects, producing parasite vaccine, and opens some new possibilities for the disinfestation and preservation of foods. Recently, a number of superior crop varieties were developed by the use of irradiation of seeds or growing plants. Several of these varieties are now extensively grown throughout the world.

150. The need for induced mutations in plant breeding is twofold: one is that a plant character sought in modern agriculture may not be found in existing populations of the crop in question; the other is that even if the desired

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character can be found, it may be too time-consuming, and sometimes impossible, to transfer it and incorporate it into an acceptable variety. An example of this application was found when the first high-yielding Mexican wheat variety was introduced in India. Its grain colour was changed from red to amber (a grain colour preferred by Indian consumers) by a radiation-induced mutation. It took only three and a half years from irradiation until the amber-coloured mutant was on the market. The new variety retained all the high-performance features of the Mexican wheat; only the colour was changed. In Japan, the highest-yielding rice variety was produced by irradiating a high-yielding local variety and selecting shorter plants with a high response to fertilizers. A radiation-induced mutant of rice plant has been found to contain twice as much protein as the parent variety and to mature sixty days earlier. The time required to fix desirable characteristics in mutations so that they are propagated to succeeding generations without change can be reduced by using radiation to induce the mutations.

151. Under conditions of high crop production, problems of water tension in the soil and plant become more important. The efficient use of water is the key to profitable crop production. The use of neutron moisture metres for continuous soil moisture determination and the use of isotopic tracers to study the movement of water in the soil and plant can be expected to increase and will be of assistance in establishing efficient methods of water conservation in arid areas.

152. The increase in the use of agricultural chemicals and the hazards resulting therefrom call for measures to find alternative approaches to insect and pest control. One of the more interesting alternatives to pesticides is to make use of the natural mating instincts of insects to achieve efficient control. This is known as the sterile male technique and it depends upon the releasing of vast numbers of radiation-sterilized male insects into an infected area. The sterilized insects become part of the indigenous population, and in the case of some species, compete with the fertile insects for mating partners, thus reducing the number of fertile matings taking place in the infected area. The next generation of insects will thus be considerably reduced in number. Repeated releases of sterile male insects in overwhelming numbers in isolated areas can result in effective suppression of the particular insect in the treated area. There are no chemical residues and other insect species and wildlife are not harmed.

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153. Although this method is new and must be worked out separately for each insect species, there are already some practical cases of success. Further research and experience are necessary to determine the full potential of this promising technique.

154. It was possible to prepare an effective vaccine against some parasitic animal diseases caused by helminths by irradiation of the larvae.

155. Some types of food can be made stable for long-term storage by high doses of radiation, but this procedure may have some undesirable effects in altering their characteristics. Relatively low doses, which do not cause changes, have been shown to increase effectively the shelf life of certain food products. It is also possible to eliminate certain pathogens from food, such as Salmonellae, and to disinfest effectively grain or to inhibit the sprouting of stored potatoes with low doses of radiation.

156. Considerable scientific evidence is available in regard to the safety of irradiated food for human consumption; no method of food preservation has been subjected to such intensive tests for wholesomeness. Although no fully commercial irradiation process is yet being applied to food, several foods, such as potatoes, wheat and wheat products, have already been cleared for human consumption after treatment with the prescribed doses of irradiation. Intensive research into the wholesomeness aspects of other types of irradiated food will hopefully lead to their acceptance.

157. Studies of the economic aspects of food irradiation have also been undertaken. They have already shown that for certain types of food and food products, preservation by irradiation may economically compete with other techniques and present certain advantages. It is expected that legislation respecting the irradiation of foods and their distribution will be enacted in several countries to facilitate their movement in international commerce.

(iv) Problems of introducing nuclear techniques and actions needed

158. Many obstacles to the rapid introduction of nuclear technology in the field of food and agriculture exist in developing countries. They include:

(a) An insufficient number of suitably trained personnel in agricultural experimental stations and universities;

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(b) The lack of specialized laboratories and advanced equipment; and

(c) The lack of powerful irradiation units and the considerable amounts of isotopically-labelled compounds required, such as fertilizers.

If agricultural activation analysis or tracer techniques are required, co-operation between agricultural research institutions and nuclear research institutions will be essential.

159. The Group feels that food and agriculture are major fields in which nuclear technology can benefit the developing countries in both the short and long terms and that all possible aid in this connexion should therefore be extended to them.

C. Medicine and biology

(i) General

160. Nuclear techniques find numerous applications in medicine and biology. Radio-active materials are used as tracers in medical research as well as in clinical diagnosis and investigations. They are also used as radiation sources in the radiation therapy of cancer and other diseases and in public health applications.

(ii) Applications in medicine

161. One of the biggest health problems to be overcome in the developing countries relates to the control and eventual eradication of the great endemic diseases - malaria, filariasis, schistomiasis, as well as to nutritional disorders such as protein, iron and vitamin deficiencies.

162. In the majority of the developing countries, the resources at present available to the health services as regards medical personnel and hospital facilities are altogether inadequate. Thus, priority often has to be given to the establishment of an effective basic medical service and the application of public health measures for the control of diseases and disorders in the population as a whole, rather than to the clinical diagnosis and treatment of diseases in individuals.

163. In spite of the fact that the use of nuclear techniques in medicine and biology is not decisive, they help to speed up developments in the very important

fields of health and nutrition. However, this does not dispense with other means of investigation. Also, nuclear techniques cannot be introduced routinely in the general medical practice, as they require expensive equipment which can be utilized only by fully trained specialists, including medical doctors and medical physicists. Furthermore, specially trained radiology and electronics technicians are needed to service the equipment. The necessity cannot be overstressed of having well-trained personnel working on a full-time basis in order to avoid serious misuses of these techniques. It is therefore necessary to keep the right balance between the development of nuclear and the other techniques used in clinical medicine.

(a) Medical research

164. Radio-active tracers have been widely used in medical research, biochemistry, endocrinology, haematology, immunology and the study of nutrition.

165. The establishment of effective public health measures for the control of endemic diseases and nutritional disorders must be based on an understanding of their aetiology and pathology. Techniques are required for their clinical diagnosis and for the evaluation of the responses of individual patients to treatment and the response of the population as a whole to control measures.

166. Nuclear techniques have already made, and will continue to make, significant contributions to research in these matters. The Group feels that the establishment of facilities for the use of radio-isotopes in medical research, especially in connexion with the study of the endemic diseases and malnutrition (protein deficiency), deserves a definite and perhaps high level of priority in the developing countries.

(b) Clinical use

167. Techniques in nuclear medicine fall into three main categories. In the first category are scintigraphic techniques for the depiction of various organs or tissues of the body and for the location of tumours, cysts, abscesses and other lesions. These techniques depend upon the incorporation of radio-activity within the organ or tissue under investigation. The second category comprises techniques

for the investigation of the functional state of various organs of the body. These techniques involve observations on the uptake, turnover and excretion of labelled substances by the body. In the third category are various techniques for the measurement of biologically active substances in samples of blood, urine or other specimens.

168. The rapid growth of activities connected with nuclear medicine in recent years in the advanced countries may be taken to indicate that such activities will, in the course of time, undergo a similar expansion in the developing countries.

169. Although these techniques are not essential for the establishment of appropriate treatments as they can rarely give information which could not be otherwise available, they can be valuable aids for the work of physicians once the necessary facilities have been set up in these countries, at least in large medical establishments of the university type.

(c) Radiation therapy of cancer

170. The use of radio-active materials as sources of ionizing radiation for radiation therapy has increased very rapidly during the last two decades. There are now more than 2,000 cobalt-60 teletherapy units in existence. Such machines are considerably more convenient and economical to operate than X-ray generators, because of their simpler maintenance needs. They are thus particularly suitable for use in the developing countries.

171. For intracavitary and interstitial brachytherapy, the classically used radium sources may easily be replaced by cobalt-60 or cesium-137 sources. So long, therefore, as radiation therapy remains an important line of attack in this domain, there will be an increasing demand for radiotherapy facilities.

(iii) The problems of introducing nuclear techniques in medicine and biology

172. The main obstacle to the rapid introduction of nuclear techniques in medicine in most developing countries is, without question, the lack of suitably trained personnel, both of university and technician levels. More than in any other branch of medical science, nuclear medicine depends on complex equipment and advanced chemical, physical and mathematical techniques.

173. Second only to the professional problem is the provision and maintenance of equipment. And this is partly a personnel problem also. As techniques have advanced, the electronic equipment used in nuclear applications in medicine and biology has become progressively more elaborate and expensive. Its maintenance can be undertaken only by skilled electronics technicians having appropriate means at their disposal for testing and repair.

174. The supply of radio-active materials also poses problems in many developing countries. Furthermore, attempts to introduce nuclear techniques in medicine and biology in the developing countries are often impeded by administrative difficulties. The available facilities may not be fully utilized because of duplication of responsibility or poor liaison between different local authorities. This is especially so between those responsible for nuclear matters and those responsible for health services.

175. The Group is of the opinion that it would be useful to organize, where possible, laboratories and centres with sufficiently advanced equipment and training capacity to cover the needs of isotope research work in the fields of medicine and biology and eventually also in food and agriculture.

(iv) Action needed to overcome these problems

176. The first essential action for the introduction of nuclear medical techniques in any developing country should be an assessment of their applicability in relation to the prevailing state of development. In making this assessment, particular attention should be given to the availability of personnel. Emphasis should thus be placed on national or regional training programmes in the developing countries.

D. Industry

177. Practically all industrial processes in which ionizing radiation might conceivably be used, apart from the applications mentioned in section D (iii) below, involve either a chemical change or a biological effect.

178. Two main sources of ionizing radiation are used, namely, gamma radiation from radio-active isotopes and beams of fast electrons. In order to effect a desired

change in bulk material by means of radiation, the degree of penetration obtained by gamma rays is essential. In certain cases, where deep penetration is not required, irradiation by electron beams can be used.

(i) Irradiation with gamma rays

179. For the treatment of bulky materials, the more highly penetrating gamma radiation from radio-active isotopes is necessary. Nuclear reactors produce, as a result of the fission process, radio-active fission products which are separated from uranium and plutonium when the spent fuel is reprocessed. Radio-isotopes are also produced by irradiation of various materials in a reactor.

180. Radiation processing plants have been built in several countries chiefly for the sterilization of disposable medical equipment. The materials to be irradiated are moved around the source in containers in a special conveyor so as to be uniformly irradiated to the correct dose. Irradiation has advantages over heat as a means of sterilization in that the items can be packed and sealed beforehand since the plastic packaging materials, which would be damaged by heating, can be safely exposed to radiation.

181. It has not been easy to find economically attractive uses for ionizing radiation in the chemical process industry because the same or equivalent effects can usually be produced more cheaply by purely chemical means. Various radiation polymerization and other radiation chemical processes have been operated on pilot or small production scales. The formation of surface coatings on textile fibres by graft polymerization and the production of straight-chain biodegradable detergents are examples. One process which shows considerable commercial promise is the production of wood-plastic or other fibre-plastic composites. Wood is impregnated with a liquid vinyl monomer, which is polymerized within the wood by exposure to radiation. Although polymerization can also be brought about in this case by chemical means, difficulties are encountered at the heating stage; thus irradiation may prove to be the better method. The wood-plastic composite has greatly improved properties as compared with the original wood and is now being produced commercially, but not yet on a really large scale. Its use in developing countries will depend upon the creation of a market for this high-priced material.

182. The radiation processing industry is clearly still in its infancy. World potential for production of massive radiation sources is, however, increasing rapidly, giving promise of reduced costs in the future.

(ii) Irradiation with electron beams

183. Electron accelerators are "machine-type" sources whose radiation output characteristics can be designed for specific radiation-chemistry processes. Provision may also be made for varying these characteristics over a wide range for multi-purpose use. In a number of cases, accelerators have some advantages over radio-isotopes as radiation sources. For example, they make it possible to regulate the radiation energy in a continuous manner, to shape the dose field and to obtain very high energy-absorption rates in the irradiated object. In recent years, electron accelerators have come to be much more widely used in radiation processes, and they are continuing to gain in popularity.

184. Electron accelerators are used for irradiating polyethylene cable insulation and various polyethylene products in order to increase the heat resistance of this material. They are used for radiation hardening of polymer coatings, to speed the process and increase the strength of the coating, and in radiation vulcanization of some types of rubber having special properties pertinent to tropical conditions. Accelerators are also used to create polymer chains in polymer films and fabrics in order to give them bactericidal and moisture-resistant properties. Electron accelerators are also very useful for the sterilization of medical equipment and bone tissue.

(iii) Instruments utilizing radio-isotopes

185. The commonest industrial application of radio-isotopes is in instruments for measuring thickness, density, level of liquids and solids, and for analysis. They are also finding increased use as light sources.

186. One of the most important advantages of a radio-isotope instrument is its ability to make measurements on an object without having to touch it; a further advantage is that nuclear radiations can penetrate substantial thicknesses of materials. These qualities allow measurements to be made on hot or easily marred surfaces, on rapidly moving materials or on the contents of closed vessels or

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pipes, where physical or chemical conditions may be unfavourable for other techniques. Radio-isotope sources are robust and self-contained; they operate independently of external power supplies and, as the signal from the detector is electrical, the instrument can easily be linked to electrical, pneumatic or hydraulic control systems.

187. The thickness of paper, and indeed of sheet made from any kind of material, can be controlled by means of radio-isotope thickness gauges. The degree of attenuation of beta radiation passing through the sheet from a source on one side is measured by a detector on the other, and any departure from the norm generates an electrical signal which causes a compensating adjustment to be made to the production machinery. Gauges working on similar principles are used for controlling density or for determining levels in vessels of all kinds. Radio-isotope sources of X-rays can be incorporated in analytical instruments to excite the characteristic X-ray fluorescent spectrum of a particular element; thus the quantity present can be determined from the intensity of the fluorescent radiation by reference to a standard sample. Portable instruments of this type are used for the determination of metals in geological samples in the field or in mines. Fixed instruments can be used for process control in ore extraction plants.

(iv) Gamma radiography

188. Radio-isotope gamma-ray sources are employed in some circumstances as an alternative to X-ray generators in the radiography of welds and castings. Such sources have the advantage of small size, portability, lower cost and independence of power supply. They are thus particularly useful, not only in the steel industry, but also in other fields in remote areas. As technicians can be trained in a few months and the minimum equipment purchased for a few thousand dollars, this has been one of the first radio-isotope techniques adopted by developing countries. Considerable savings have been reported from the use of gamma radiography.

(v) Radio-active tracers

189. Radio-active tracers are used both for laboratory research and for investigations in industrial plants. They have the advantage of being detectable in very low concentrations and even through the walls of pipes or process vessels. Thus, investigations can be made without the expense of shutting down a plant. The equipment required is simple, easy to maintain and relatively inexpensive. The fundamentals of radio-active tracer techniques can be learned in a fairly short time. In some instances, naturally occurring radio-active isotopes have been used.

190. Full-scale plant tracer investigations have the biggest impact and these include studies of material transport, determination of volumes and optimum mixing times, leak detection, dispersion of effluent and tests of equipment function.

191. Even a simple experiment, such as measuring the time required to achieve a desired degree of mixing, can result in large savings if, as is generally the case, it is found that the time can be reduced. Quick detection with radio-active tracers of faults in industrial plants, such as a blockage or a material short-circuit, can result in savings of tens of thousands of dollars when a shut-down is averted or reduced in duration. The improvements in chemical processes and the decrease in time in such things as analysis and wear testing are among the more important benefits.

192. In some developing countries, teams of radio-isotope specialists offer a service to a large number of industries on demand. When the volume of such work justifies it, particular industries employ their own staff.

(vi) Radio-isotopes power generators

193. Industry clearly offers many outstanding opportunities for the profitable use of radio-isotopes. One entirely new application, which has considerable promise for the future, depends on the use of large amounts of particular radio-isotopes as heat sources for very small thermo-electric generators. These are known as isotopic electric-power generators and they are noted for their simplicity of structure, dependability and long life. They can supply power to various kinds of apparatus for several months or even years without needing to be serviced.

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194. The power capacity of isotopic generators is tens of kilowatt-hours per kilogramme with a lifetime of up to ten years. By comparison, the best storage batteries have capacities in the order of 200 to 300 watt-hours and electro-chemical generators have capacities of 150 to 200 watt-hours per kilogramme with much shorter lives. Isotopic electric-power generators are reliable in operation for long periods of time and their efficiency is virtually unaffected by climatic conditions.

195. Isotopic electric generators are relatively costly sources of power in terms of power output, but they have special advantages for remote or inaccessible localities. They have potential applications as compact and reliable sources of power for coastal navigational lights, airport beacons, remote radio communications units and submarine cable repeaters.

196. The use of nuclear techniques in industry is now so widespread that it is no longer practical to convene meetings dealing generally with the subject. Meetings devoted to specific industries have been held by IAEA and these will continue. Research contracts will be used to foster the development of new techniques and to adapt existing techniques to the particular conditions in developing countries. Considerable effort will be made to ensure that nuclear techniques are integrated with conventional methods so that they will be used only when they offer the most convenient and practical solutions.

(vii) Some examples of tracer techniques in industry

197. The following are some applications of importance in various basic industries, which are among the first to be developed in a country undergoing industrialization.

(a) Cement industry

i. Testing of a homogenizing mixer for raw materials in a cement factory;

ii. Testing of the working of some parts of the processing apparatus in a cement factory;

iii. Measuring the residence time of materials in a raw cement grinding mill.

The extension of this type of testing to other problems of mixing, residence time and transfer of materials in any other industrial plant is straight forward.

198. The average cost of such applications is about $2,000 to $3,000 each, but could be much lower if the tests were carried out as part of a continuing programme with trained personnel working under the supervision of a specialized expert from an outside organization.

(b) Fertilizer industry

199. Radiometric determination of potassium in fertilizers can be carried out by measuring the natural radio-activity of potassium. This type of measurement can be used to regulate continuous production mixers for a fixed, preselected percentage of potassium in the final product. Such an instrument or system, depending on the purpose and capacity, may cost about $1,000 to $5,000.

(c) Textile industry

200. The textile industry is often one of the first to be promoted in developing countries. There are many possibilities for the application of radio-active tracer techniques in this field. For example:

(a) Testing of uniform mixing of various types of wool fibres, by labelling the wool fibres by radio-active tracers;

(b) Testing of the distribution of oils, starch and other adhesives on yarns;

(c) Study of the distribution of wool fibres during formation of the yarn.

A cost of $1,000 to $2,000 may be anticipated for experimental work of this type.

E. Hydrology and geology

(i) Applications in hydrology

201. The increasing need for fresh water for drinking and domestic use, for irrigation and for industry is now a serious problem in various parts of the world, regardless of the degree of technological development. Science and technology can do much to help overcome limitations to the exploitation and use of water and to assure better economic development.

202. The most common water problems are:

(a) Locating sufficient quantities of exploitable water;

(b) Distributing water when and where it is needed; and

(c) Ensuring that the quality of the water is always suitable for the intended use.

203. Locating sufficient water for domestic, agricultural and industrial uses is commonly a difficult problem in arid and semi-arid lands, especially in high plateau areas. Normally in such regions the streams flow for short periods only after heavy rains. Underground water sources can be exploited only by deep drilling and pumping, which require power and make development expensive.

204. In the developing countries, it is timely to study potential water-supply contamination now in order to learn how to prevent it. Adequate hydrologic and hydrogeologic knowledge of the framework of a water-supply system are essential in order to make constructive recommendations about beneficial water-quality controls and to limit pollution.

205. The rate of flow of a water course is one of the basic parametres in hydrology. Because of the high sensitivity of detection, radio-isotopes, particularly tritium, are more practical than standard chemical tracers for measuring large flows.

206. The radio-isotopes tritium and carbon-14 were introduced into the atmosphere as a result of nuclear weapon trials and the concentration of tritium in rainfall increased after 1954 to a maximum value in 1963. It is possible, by radio-activity measurements, to distinguish between water which has recently been exposed to the atmosphere and older water, so that information can be obtained on the age and structure of aquifers and on the rates of inflow of new water.

207. The determination of sediment movement and transport in harbours, estuaries and coastal waters is a major problem in hydrology and hydraulic engineering. Harbour dredging, which is not always economic, must be compared with building new, deeper water harbours to accommodate today's deeper-draft vessels. A glance at the globe will reveal that most of the world's coastlines are in the developing countries where ports are needed to foster economic growth. Nuclear techniques can assist in providing the hydrologic knowledge needed to help solve the problems in connexion with the construction of these ports.

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208. Leakage from reservoirs and canals can cause large losses of water and structural instability. Radio-isotopes are useful in tracing water movement by injecting them at one point and recording the arrival times and concentration changes at other points. Also, nucleonic gauges can measure the water equivalent of snow cover, a knowledge of which is necessary for forecasting snowmelt runoff.

(ii) Applications in geology

209. Nuclear methods have been used extensively in prospecting for uranium and thorium (see section II).

210. The dating of minerals and rocks by nuclear methods is now an established branch of geology and has led to results of the utmost importance concerning the history and evolution of the earth. Nuclear techniques have also been successfully applied in the search for petroleum, particularly in the exploration of bore holes. Radio-isotope gamma and neutron sources of various kinds, coupled with gamma and neutron detectors capable of operating at depths of several kilometres, are used for bore hole logging. Such methods are specially valuable where measurements have to be made through steel casing and they yield information on density, porosity, water content, stratigraphical corrolations and location of oil-brine interfaces.

211. The radio-isotope X-ray fluorescence analyser is available as a portable prospecting device and is already proving to be of considerable value to the field geologist and in the mine.

V. NUCLEAR EXPLOSIONS FOR PEACEFUL PURPOSES

A. Introduction

212. One of the most spectacular future applications of nuclear energy lies in the potential use of nuclear explosions for peaceful purposes. The applications of nuclear explosions for peaceful purposes may be broadly divided into two categories: deep or contained explosions for the recovery or better utilization of natural resources; and relatively shallow or cratering explosions for earth and rock removal.

213. This application of nuclear energy differs from the applications discussed in the preceding chapters in that the accumulated experience is less extensive than that which currently exists for such fields as nuclear power. Research in this field has been limited to only a few countries, in particular the United States and the USSR. Although more research and development work remain to be done, it is expected that economically attractive applications of nuclear explosions will be developed.

214. The principal areas in which the necessary research and development are being carried out are (a) improvements in peaceful nuclear explosion technology; (b) the safety aspects of nuclear explosions; and (c) the peaceful utilization of nuclear explosions.

B. Underground engineering or contained explosions

215. Contained explosions appear particularly promising for:

(a) Recovery of oil from oil shale;

(b) Stimulation of gas and oil reservoirs;

(c) Recovery of oil from tar sands or bituminous sandstones;

(d) Creation of underground caverns for gas storage;

(e) Fracturing of ore bodies for the recovery of the mineral values by *in situ* leaching or block-caving; and

(f) Utilization of coal beds.

216. Contained explosions may therefore make resources available that could not otherwise be utilized. However, more research and development are needed on both the explosions themselves and on the recovery processes that would subsequently be employed.

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C. Excavation or cratering explosions

217. The potential of nuclear excavation, simply stated, is that it makes possible certain large-scale earth-moving and rock-moving projects such as the building of harbours and isthmian canals, the deepening and/or widening of channels, rerouting of rivers, creation of water reservoirs, removal of overburden for open-pit mining, and opening or cutting mountain passes.

218. Nuclear excavation, therefore, may give man the opportunity to construct harbours and canals where he was unable to before - or to divert water resources so they may better serve his needs. Accordingly, the true economic advantages of this technology may well be more in the opportunities that it offers than in the actual cost of any particular project.

219. As in the area of contained explosions, more research and development are needed in the case of nuclear cratering.

D. Safety aspects of nuclear explosions

220. The principal safety considerations in the utilization of nuclear explosions are those related to the potential ground motion and to the radio-activity problems arising from them.

221. When a nuclear explosion occurs beneath the surface of the earth, large amounts of energy are almost instanteneously released causing the material of the explosive device and the rock material in the immediate vicinity of it to be vaporized. The high pressure which occurs within the vaporized material causes a shock wave to spread outward. This shock wave is sufficiently intense initially to vaporize the material through which it propagates. However, the energy per unit of area at the surface of the shock wave diminishes as it spreads outward and eventually vaporization at the shock front ceases. The rock just beyond the vaporized area is melted by the shock front. For some distance beyond this radius of vaporization and melting, the shock front causes fracturing and permanent deformation of the rock. Ultimately, the shock wave energy becomes too small to cause these inelastic effects and the energy then propagates outward as an elastic wave.

222. In principle, parameters such as the size of the explosion cavity, the mass of rock melt, the size of crater produced, the extent of rock fracturing and

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the amplitude of airwaves and of seismic waves can be predicted with good accuracy. More experiments are needed, however, using higher yields in different media.

223. A significant question which has to be answered in connexion with the underground engineering applications is the degree to which the products recovered by, or stored in, the caverns will be contaminated by radio-activity. For example, in gas stimulation projects, tritium now appears to be the radio-active nuclide of possible concern, while in oil shale or copper recovery, other radio-active nuclides may be serious from a product acceptability standpoint. Experiments will provide the data required to identify the possible extent of this problem and to suggest possible ways to minimize or eliminate it.

224. One method of reducing the radio-activity in the product may lie in the design of special explosives to reduce or eliminate those radionuclides which pose a problem for a particular product. If an explosion is not completely contained, the gases in the cavity formed by the explosion continue to expand and ultimately break through the fractured material above and reach the atmosphere. Continuing research is require to minimize the introduction of radio-activity into the atmosphere and aquifers. In excavation and cratering explosions, the principal safety problem is the contamination of bodies of water and the atmosphere. Proposed earth-moving and rock-moving projects in particular will have to be examined very carefully to be certain that the potentially dangerous effects on the environment are within acceptable limits.

E. Assessment of present status of technology

225. A number of cratering tests have been made by the United States and some information is available from them. The United States has also conducted an experiment (Gasbuggy) to study the stimulation of gas reservoirs by deep explosions. The preliminary data that have been released so far are encouraging. Further explosions are planned by the United States to investigate their use in the recovery of oil from shale and copper from low-grade ore bodies.

226. Both technologies, however, are still in the relatively early research and development stage. More data on, and a better understanding of, the basic explosion phenomenology and the explosion's radiation, seismic and accoustic effects are needed.

227. The Group notes that both the USSR and the United States are actively pursuing research on the technology of nuclear explosion for peaceful purposes to bring it to a practical level.

F. Conclusions

228. The Group is well aware that the main potential benefits deriving from nuclear explosions for peaceful purposes are that they may make presently inaccessible resources economically exploitable, and that they may make some otherwise impossible civil engineering projects economically feasible. Their economic advantages therefore appear obvious.

229. The Group believes that while the technology will be developed through further research and experiments, the benefits of this new technology may not necessarily accrue in the immediate future to the developing countries. It is expected, however, that by the end of the 1970s contained explosions and nuclear cratering may become practical.

230. The Group considers that in the international field the first need is to obtain and to disseminate systematically more information about the potential of the new technology as well as its technical limitations and costs. The Group notes that IAEA is making a start in this direction. It considers that IAEA should keep in close contact with those United Nations organizations that are also interested in the economic, scientific and safety aspects of this technology, for example, transport, energy and health.

231. Article V of the Treaty on the Non-Proliferation of Nuclear Weapons provides that the potential benefits from peaceful applications of nuclear explosions will be made available to the non-nuclear weapons States Party to the Treaty. Both the United States and the USSR have indicated that they would be prepared to supply peaceful nuclear explosion services when the technology permits. The Group recommends, therefore, that developments in this technology be kept under constant review by IAEA in co-operation with those United Nations agencies which may be interested in their economic application and their effects upon the environment.

VI. INTERNATIONAL CO-OPERATION IN PROMOTING PEACEFUL NUCLEAR TECHNOLOGY

A. Introduction

232. It is only by international co-operation that the door to the nuclear future has been opened to developing countries and, indeed, to many technically advanced countries. The concerted international effort that has already been made to spread the peaceful uses of atomic energy probably has no parallel in other branches of modern technology. Among the landmarks have been the three large United Nations international conferences on the peaceful uses of atomic energy held in 1955, 1958 and 1964; the setting up of the International Atomic Energy Agency in 1956; and, at about the same time, the establishment of regional nuclear-energy bodies, such as the Inter-American Nuclear Energy Commission, the European Nuclear Energy Agency and the European Atomic Energy Community. International co-operation in the nuclear field also takes place within the framework of the Council of Mutual Economic Co-operation and the Joint Institute for Nuclear Research at Dubna, the USSR. Other examples of international co-operation are the Centre d'études de récherche nucléaire at Geneva and the Regional Radio-isotope Training Centre for the Arab Countries in Cairo, the United Arab Republic. There have also been large bilateral programmes of co-operation which have helped to set up forty-one research reactors in developing countries and have provided training for several thousand scientists and technicians and have aided the financing of nuclear power projects in the amount of several hundred million dollars.

233. Nuclear technology has only recently begun to contribute to the economic progress of the developed as well as the developing countries. To quicken the pace of their development, a broad and systematic effort to assist the exchange of information has taken place. Each year many articles are published on nuclear science and its peaceful applications. The effort being made to spread this information may be partly gauged by the thousands of scientists and technicians who have taken part in the three main United Nations meetings and the many IAEA scientific meetings that have been held since 1958. A fourth United Nations conference on the peaceful uses of atomic energy is scheduled for 1971.

B. Technical assistance

234. The transfer of nuclear science and technology presents special economic and financing problems (see chapter I). Major projects are capital intensive. Even minor ones often require sophisticated scientific equipment and supplies, and thus may entail a larger "hardware" component than is normal in similar aid programmes in other fields.

(i) Bilateral programmes

235. Bilateral programmes of assistance played a major role in the late 1950s and early 1960s in introducing nuclear technology in developing countries. Today, bilateral projects consist chiefly of pre-investment studies for nuclear power or desalination carried out by consultants (or experts from a donor country) and paid for (or partly paid for) under foreign aid programmes. In view of the tapering off of bilateral aid from certain sources, developing countries have had to turn increasingly to international organizations in order to launch new programmes as well as to maintain the momentum of those started with bilateral help.

236. Several Governments have found it useful to associate IAEA with such studies or to ask the Agency to review consultants' reports. The Group considers that, before there is any major commitment of capital, such impartial evaluation by an international organization can be important and recommends that the developing countries avail themselves of such services.

(ii) Multilateral programmes

(a) International Atomic Energy Agency

237. The Agency draws upon three sources for its technical assistance: its "regular" programme financed by voluntary contributions to its "General Fund"; gifts by Governments which are administered by IAEA, for example, equipment, cost-free fellowships, and cost-free services of experts; and UNDP (Technical Assistance) that is, the technical assistance component of UNDP.

238. Since 1958, some $38 million worth of technical assistance has been given by, or channelled through, IAEA from these three sources. More than 3,000 scientists have been trained under IAEA fellowships and a further 1,300 in IAEA

training centres. More than 1,000 experts have been sent into the field, while equipment to the value of $5 million has been provided.

239. The aggregate programme from these three sources is valued currently at about $4 million a year, approximately one third of which is provided by each source.

240. Of the three sources, the most crucial is the first, namely, the Agency's "regular" programme. This is used flexibly as "seed money" to identify and initiate projects and to prepare the way for the larger and longer-lasting projects on which UNDP is increasingly concentrating its resources.

241. The Agency's "regular" programme depends entirely upon voluntary contributions by Governments to a target set each year by the General Conference. The value of the programme has remained static in monetary terms at about $1.3 million a year since 1962; thus, its real value has been steadily eroded by inflation.

242. The Group notes that to mitigate certain of the problems arising from the erosion of its "regular" technical assistance programme, the Agency is making greater use of its technical staff in field assignments. While this is clearly a limited solution, the Group considers that it deserves encouragement. The Group also recommends that IAEA make such financial adjustments as are necessary to ensure that all of the voluntary contributions it receives are devoted to technical assistance and not to other activities of less interest to developing countries. Of considerable importance with respect to international co-operation in the peaceful uses of nuclear technology in developing countries are conferences, seminars, symposia and panels of experts which take place within the framework of IAEA.

243. The Group notes that the Agency's research contract programme, while not regarded as technical assistance in the strict sense, does give useful support to applied research in developing countries (about two thirds of the research contract funds are spent on research contracts with laboratories in developing countries). This programme, which is <u>not</u> dependent upon voluntary contributions, has also remained financially static at a level of approximately $900,000 per year for some years. The Group recommends that the resources available for this programme should be devoted to the greatest possible extent to helping nuclear

science institutes in developing countries and that these resources should be augmented. Well equipped facilities in certain technically advanced countries are now able to do more research for developing countries and to absorb a growing number of trainees from those countries. The Group considers that IAEA should take this into account in carrying out its training programmes and also in awarding research contracts. In cases where these contracts are given to institutes in advanced countries, their award might be linked with the acceptance by the institute of a scientific trainee from a developing country.

(b) United Nations Development Programme

244. The financial resources of UNDP are based on government pledges and allocated, in principle, according to priorities set by recipient countries. In the past, UNDP's activities were divided into two major sectors - Technical Assistance and Special Fund. Only about 2 per cent (approximately $1 million annually) of the UNDP (Technical Assistance) component is currently devoted to applications of nuclear technology.

245. UNDP (Special Fund) projects normally involve a team of expatriate experts and some equipment financed from UNDP funds, as well as sizable contributions from the recipient country, mainly in kind. An average Special Fund project may be of the order of $1 million, and the recipient country's contribution is usually about the same. The duration of such projects may vary from one to five years.

246. The IAEA has been the executing agency for only five Special Fund projects to date, although the Governing Council each year approves more than 100 new projects. As in the case of UNDP (Technical Assistance), it is the Government of the developing country itself that establishes, in its requests to UNDP, the priorities for Special Fund projects.

247. The projects executed by the Agency have nearly all been pioneer applications of nuclear technology in developing countries and they have had to overcome the technical difficulties that beset any pioneer enterprise. They have included a study of the feasibility nuclear power in the Philippines, the establishment of two centres for applying nuclear techniques in agricultural research (in Yugoslavia and India), and the first large-scale field experiment

(in Central America) in the use of the sterile male technique for the control of a particularly destructive insect pest, the Mediterranean fruit fly.

248. The experience gained in these first ventures has been particularly valuable, not only for the countries concerned, but also for other developing countries. It will certainly be easier to replicate these types of projects elsewhere.

(c) Co-operation within the United Nations system

249. Nuclear techniques can often be usefully employed to carry out a specialized part of much larger non-nuclear projects. For instance, nuclear techniques are useful tools for certain hydrological studies in water resources development projects. They are also used in exploration for non-nuclear minerals.

250. To deal with this type of situation, the United Nations, and several agencies, including FAO, WHO and UNESCO have made, or are making, sub-contractual arrangements with IAEA under which the Agency carries out the nuclear part of the project, often using its headquarters staff and laboratory facilities for this purpose. The Group considers that this is an effective way of avoiding duplication and recommends that such arrangements be made on a wider scale.

251. In general, the Group notes that a high degree of co-ordination has been achieved between IAEA and the other agencies concerned with the transfer of nuclear technology to developing countries. Besides the Joint FAO/IAEA Division, the Group notes that IAEA and WHO have a permanent technical liaison at each other's headquarters, that the IAEA and UNESCO have a joint programme for nuclear science teaching, that a similar training programme is being developed with the ILO and that IAEA and WMO have been co-operating for several years in hydrological and meteorological surveys. The Group notes the co-operation already established between IAEA and UNESCO in introducing nuclear science teaching in schools and universities in the ECAFE area and feels that this effort should be extended and expanded in other areas. Finally, the Group feels that in conducting energy surveys and evaluating the markets in anticipation of nuclear power programmes, co-operation between the United Nations and IAEA has proved valuable and should be strengthened.

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C. Capital investment

252. The implementation of the various projects mentioned in this report requires expenditures which vary widely in magnitude. Projects using small quantities of radio-isotopes would require funds not exceeding tens of thousands of dollars; a large project using large radiation sources would cost in the neighbourhood of a million dollars; the exploration and proving of economically exploitable uranium ore deposits might involve the expenditure of a few million dollars; mining and milling investment costs would be of the order of ten million dollars for a capacity of 500 short tons of U_3O_8 per year; construction of a nuclear power station of 200,000 kWe would cost more than $60 million; and the construction of fuel cycle plants, excluding enrichment, for a large nuclear power programme of approximately 10,000,000 kWe would require a sum of similar magnitude.

(i) Bilateral sources

253. The power reactor projects carried out (or being carried out) in developing countries have been financed bilaterally under favourable terms. The two power plants in Tarapur, India have been financed by a "soft" loan from the United States Agency for International Development at 3/4 per cent interest, with a forty-year repayment period. The plant in Rajasthan, India has been financed by a 6 per cent loan from Canada and the Kanupp plant in Pakistan has also been financed by Canada, partly by a grant and partly by a loan at 6 per cent interest. The power plant in Atucha, Argentina has been financed by a loan at 6 per cent interest with a twenty-five-year repayment period and five years of grace.

(ii) Multilateral sources

254. Within the United Nations system, the International Bank for Reconstruction and Development/International Development Association complex is the only source of capital funds.

255. The IBRD applies normal banking criteria to any application for a loan. These criteria are not designed to take account of the indirect benefits that are likely to result from the introduction of nuclear technology in a developing

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country that has sufficient industrial and technical infrastructure in other respects. The IBRD has made it clear, however, that no change in its criteria can be expected. In other words, IBRD will examine a request for a loan for a nuclear project strictly in the light of whether it represents the most economic means of obtaining the required increment of electric generating capacity.

256. The Inter-American Development Bank, the African Development Bank and the Asian Development Bank may also be potential sources of finances for nuclear power projects.

257. The Statute of IAEA provides that it may help any Member State to make arrangements to secure the necessary financing from outside sources, but that it must not assume any financial responsibility for the project. The Agency can thus help developing countries to prepare and present information on proposed projects to the financing institutions. Its familiarity with fuelling also enables the Agency to play a role in making arrangements for financing this important cost component of any nuclear power project. But it is clear that IAEA's role in helping developing countries to secure the necessary capital is limited.

D. Conclusions

258. The utilization of nuclear technology within a reasonable period of time by the developing countries will require considerable funds. These requirements will, of course, vary according to the projects planned.

259. For projects in the smallest range, the main source of finance is, and will be, the technical assistance programme of IAEA. This will, therefore, be the chief and perhaps only source of financial aid in connexion with nuclear technology for many developing countries for some years to come. The Group has already noted the difficult financial position of IAEA's programme and wishes to express again its concern. At a time when the interest of developing countries in nuclear technology is obviously growing, the Group considers that there should be a steady increase in the resources available for multilateral technical assistance in the nuclear field, especially through the Agency.

260. With regard to those projects of a pre-investment or pilot plant tyoe in the middle range of cost, the chief multilateral source of finance is, and will

probably continue to be, UNDP. It is for Governments to set the priorities in their national requests for UNDP assistance. The Group, nevertheless, suggests that Governments of developing countries should review this matter to ascertain whether they wish to give higher priority to nuclear projects, especially of the kinds already successfully executed in other countries.

261. Major nuclear projects such as power plants, however, require financing far beyond the reach and scope of IAEA and UNDP. Such projects are likely to have foreign exchange requirements beyond the present capacity of most developing countries; thus, special capital financing arrangements will be necessary in many cases.

262. In view of the dimensions of the financial problem, the Group expresses the hope that international sources of finance, especially IBRD, will review the positions taken so far on the prospects, criteria and conditions for financing major nuclear installations, bearing in mind not only the immediate benefits from initial projects, but also the long-term contributions that such projects could make to developing countries. The Group hopes that this problem of finance will be given careful and thorough study by the United Nations General Assembly, and other competent organizations, in order to find appropriate solutions.

ANNEX I

GLOSSARY OF TERMS AND ABBREVIATIONS

Activation — The process of inducing radio-activity.

Aetiology — The study of the causes of disease.

AGR — Advanced gas-cooled reactor.

Alpha particle — The nucleus of a helium atom.

Beta particle — The electron emitted in radio-active decay.

Brachytherapy — A form of treatment by radiation in which the source of radiation is close to the treated area. It includes intra-cavitary treatment, in which the source is within the internal cavities of the body; interstitial, in which the source is within the tissues; and surface therapy, in which the source is outside the body, but close to it.

BTU — British thermal unit.

BWR — Boiling water reactor.

CANDU — Canadian deuterium-uranium reactor.

Chain reaction — A reaction in which one or more products are capable of producing the same reaction.

Deuterium — A heavy isotope of hydrogen.

Ecology — The study of living organisms, modes of life and relations to surroundings.

Endocrinology — The study of the functions of glands, the secretions of which pass directly into the bloodstream.

Enrichment — The alteration of the natural mixture of isotopes to increase the concentration of one or more of them.

Fission — The division of the heavy nucleus of an element (e.g. uranium) into two lighter nuclei or elements.

Fission products — The new elements formed when the nucleus of a heavy element is fissioned or split. They are usually highly radio-active.

Fossil fuel — Coal, oil or gas.

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Gamma ray — An electromagnetic radiation emitted in radio-active decay.

Haematology — The branch of biology concerned with the blood and blood-forming tissues.

Heavy water — Water in which the hydrogen is replaced by deuterium.

Helminths — Intestinal worms.

HTR — High-temperature gas-cooled reactor.

IAEA — International Atomic Energy Agency.

IBRD — International Bank for Reconstruction and Development.

Immunology — The branch of biology concerned with immunity; a form of resistance to pathogenic agents to which the species is usually susceptible.

Ionization — The processes of dissociation of neutral molecules into electrically-charged constituents - ions.

Isotope — A form of an element having a particular number of constituent neutrons and protons in its nucleus.

Kinetic energy — Energy of motion.

kWe — Kilowatts of electrical power.

LWR — Light-water reactor.

Magnetometer — A device for measuring the earth's magnetic field.

Megawatt — One million watts or one thousand kilowatts.

Morphology — The external structure of rock forms or topographical features.

Mutant — A new genetic form.

Neutron — A sub-atomic particle with no electric charge.

Nuclear power — Electric power generated by a nuclear power plant (or station).

Nuclear power plant (or station) — A thermo-electric generating station in which a nuclear reactor is the source of heat.

Nuclear power reactor — A nuclear reactor, the heat from which is used for generating electricity in a thermo-electric generating plant (or station).

Nuclear steam generator — A nuclear power reactor plus heat exchanges (sometimes called steam-raising units) and pumps or fans for circulating the primary coolant through the reactor core and the heat exchangers.

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Nucleus (of atom) The central core containing neutrons and protons.

Pathology The study of the functional and structural changes causing, or caused by, diseases.

Photosynthesia The process by which light energy is used in plants to build up complex substances from carbon dioxide and water.

Proton A sub-atomic particle with an electric charge.

PWR Pressurized water reactor.

Radio-active The description of an isotope which spontaneously decays into a different nucleus with the emission of sub-atomic particles and/or gamma rays.

Radio-isotope Synonymous with radionuclide.

Radiometric Measurement of radio-activity.

Radionuclide A nuclear species that is radio-active.

Scintigraphic Method of recording gamma activity distribution.

Scintillometer A device for detecting gamma radiation.

Teletherapy A form of treatment in which the source is away from the body.

Tracer A radio-active or stable nuclear species used to identify chemical components in biolcgical or chemical systems.

U_3O_8 The oxide form into which uranium is usually milled.

ANNEX II

NUCLEAR POWER REACTORS

1. The nuclear reactor which provides the heat energy for steam generation is a device in which the process of nuclear fission can be initiated, sustained and controlled. In such a reactor, usually called a power or nuclear power reactor, nuclear fission occurs when the nuclei of uranium or plutonium atoms are struck by sub-atomic particles called neutrons. The heavy atom splits into two lighter atoms, called fission products, which recoil with enormous kinetic energy. This energetic splitting, or fission, of the nucleus of the atom is accompanied by the release of a few neutrons. If, on the average, at least one of these neutrons strikes another heavy nucleus and causes a fission, the necessary conditions to sustain a chain reaction exist.

2. The energy with which the fission fragments fly apart is very rapidly converted to heat energy as the fragments strike the surrounding materials. Some of the neutrons released from the nucleus strike materials which absorb them unproductively, but some strike other fissionable nuclei; it is this fraction that serves to maintain the chain reaction.

3. Thus, the essential characteristic of fuel for a nuclear reactor is that it contain some fissionable material or material that undergoes nuclear fission when struck by neutrons. The only naturally available fissionable material is uranium-235, an isotope or form of uranium constituting about 0.7 per cent of the element as found in nature. Almost all of the rest of natural uranium is uranium-238. When neutrons strike uranium-238, a "synthetic" fissionable material (plutonium-239) is formed; for this reason, uranium-238 is called a fertile material.

4. It is possible to achieve a self-sustaining fission reaction with the natural mixture of uranium-235 and uranium-238. But the use of natural uranium as a reactor fuel imposes severe limitations on reactor design and operation. To circumvent these limitations, enriched fuel is often used. By this is meant fuel containing a higher concentration of fissionable uranium-235 atoms than that in natural uranium. Enriched fuel can be obtained by putting natural

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uranium through an isotope separation process which removes some of the uranium-238 from the natural mixture, thereby increasing the relative amount of uranium-235. It can also be obtained by adding a synthetic fissionable substance (for example, plutonium-239) to natural uranium.

5. Solid uranium metal, fabricated into rods and sealed into containers, was (and is) used in reactors, of early design, but the fuel which will probably be used in most of the small to medium-size reactors likely to be developed in the future is one of the oxides of uranium. Uranium oxide fuel is generally formed into small cylindrical pellets and packed into long thin tubes to form fuel elements. The walls of the tubes or cans, sometimes called cladding, serve to lock in the radio-active fission products which are formed as the fuel undergoes fission. The fuel elements containing the oxide fuel are assembled into bundles or fuel assemblies for insertion into the reactor. The fuel assemblies are disposed in the reactor parallel to one another and set in a carefully designed geometric pattern.

6. The "geometry" of the fuel is important from a reactor physics standpoint; a certain distribution of fuel within the reactor core is required for the system to function efficiently.

7. The reason for this is that each fission of an atom of uranium-235 produces (on the average) only 2.5 neutrons. Some of these will be lost by useless absorption in the materials of which the core is constructed leaving only about two neutrons available from each fission. If the chain reaction is to be maintained, one of these must strike an atom of uranium-235 or plutonium-239 and cause another fission. But in natural uranium there are 140 atoms of uranium-238 for every atom of uranium-235. The statistical probability therefore is that most of the neutrons will strike atoms of uranium-238 and will not cause further fissions so that the chain reaction will die out. To maintain the chain reaction, the probability of neutrons causing further fissions must be increased. This is done by reducing their velocity and, in many reactors by using enriched fuel. Neutrons travelling at slow speeds are less likely to be absorbed by atoms of uranium-238 and more likely to cause fission of atoms of uranium-235. The velocity is reduced by letting the neutrons

collide with the molecules of a moderator which surrounds the fuel elements. When the energy of the neutrons is reduced to that of the molecules in the moderator, the neutrons are said to be in thermal equilibrium with the moderator. It is for this reason that reactors which rely on a moderator to maintain the chain reaction are called "thermal reactors". The elements which are most effective as moderators are the light elements. Those which have been most generally used are hydrogen, carbon in the form of graphit, and an isotope of hydrogen known as heavy hydrogen or deuterium. When hydrogen or heavy hydrogen are employed as moderators, it is customary to use them in combination with oxygen, that is, as ordinary water or heavy water.

8. A coolant is used to remove the heat generated by fission from the core of the reactor so that it can be utilized to generate, in turn, steam, mechanical energy and electricity. The coolant should be a good conductor and absorber of heat, but not an absorber of too many neutrons. Reactors moderated by light water generally also use light water as the coolant. Most reactors moderated with graphite use a gas coolant, such as carbon dioxide or helium. Reactors using heavy water as a moderator generally use either light or heavy water as the coolant.

9. In all reactors the control of the rate at which fission occurs, and thus the heat output, is obtained by regulating the "population" of free neutrons in the core. This is most commonly done by movable rods incorporating a material, such as boron or cadmium, which has a high propensity to absorb neutrons. When inserted into the core, they absorb neutrons and reduce the number that are available to cause further fissions. Withdrawal of the rods, called control rods has the opposite effect. Full insertion of the rods shuts down the reactor.

10. Provision must be made in a reactor for introducing and removing the fuel elements. The measure of burn-up (the energy production per unit of weight of the fuel during exposure in the reactor) is usually expressed in terms of thermal Megawatt (1,000 kilowatts) days per metric ton or kilogram of fuel (MWd/ton or kg). Burn-up is limited by dimensional instabilities of the fuel elements which dictate replacement before structural damage occurs.

11. Upon removal from a reactor, irradicated fuel elements must first be moved to a shielded storage vault or pool at the site. They are left there for weeks or months to cool; that is, to allow some of the radio-activity to die down. Fuel assemblies removed from reactors always contain some unburned uranium and plutonium which should be reclaimed. The procedure by which the nuclear fuel is reclaimed is called reprocessing. Reprocessing is a complex chemical operation performed at specialized plants to which used fuel is shipped in heavy shielded containers. Most of the operations in reprocessing have to be performed by remote control because, in spite of the cooling periods, substantial radio-activity remains. The chemical reprocessing consists mainly of removing the cladding, separating the fission products and radio-active poisons through a sequence of wet chemical processes and finally separating the unburned uranium and plutonium, both of which can be used in new fuel elements. The safe handling of the highly radio-active fission products during the reprocessing operations has been satisfactorily solved.

Types of nuclear power reactor

12. Several power reactor systems have been developed to a stage where they can now be considered for application in developing countries. These include light water reactors (LWR), heavy water reactors (HWR) and gas-cooled graphite-moderated reactors.

13. Light water reactors (so-called because they use light or ordinary water as the moderator) include the boiling water (BWR) and pressurized water (PWR) types. Both use enriched uranium fuel and have been developed principally in the United States and the USSR. At present, thirty prototype and commercial LWR's totalling 6,250,000 kWe are in operation, or will commence operation in 1969, in eleven countries. Another 107 units are under construction or firmly planned.

14. Heavy water reactors (which use heavy water as the moderator) have six or more variants using natural or enriched uranium, pressure tubes or pressure vessels, and different coolants, such as light water, heavy water, gas or organic liquids. At present, five prototype HWR's totalling 362,000 kWe are in operation in four countries. None is scheduled to commence operation in 1969. Another twenty-one units are being modified or are under construction or firmly planned.

15. Gas-cooled reactors include the carbon dioxide cooled, graphite-moderated natural uranium reactors developed in the United Kingdom and France. Advanced gas-cooled reactors (AGR) and high-temperature gas-cooled reactors (HTR) using enriched uranium fuel, are under development. At present, thirty-five prototype and commercial power reactors of the first type totalling 7,062,000 kWe are in operation or will commence operation in 1969, in four countries. In addition, one AGR and two HTR's totalling 88,000 kWe are in operation in three countries. Another fifteen units are under construction or firmly planned.[a/]

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a/ Power reactor data obtained from the following sources: NUCLEAR ENGINEERING, Vol. 13, No. 142, March 1968, pp. 202-214; NUCLEAR INDUSTRY, Vol. 16, No. 6, June 1969, pp. 16 and 17; Ontario Hydro Special Report on Nuclear Power, June 1969; and "Small and Medium Power Reactors", Summary Report of an Internal Working Group, IAEA, 20 March 1969.

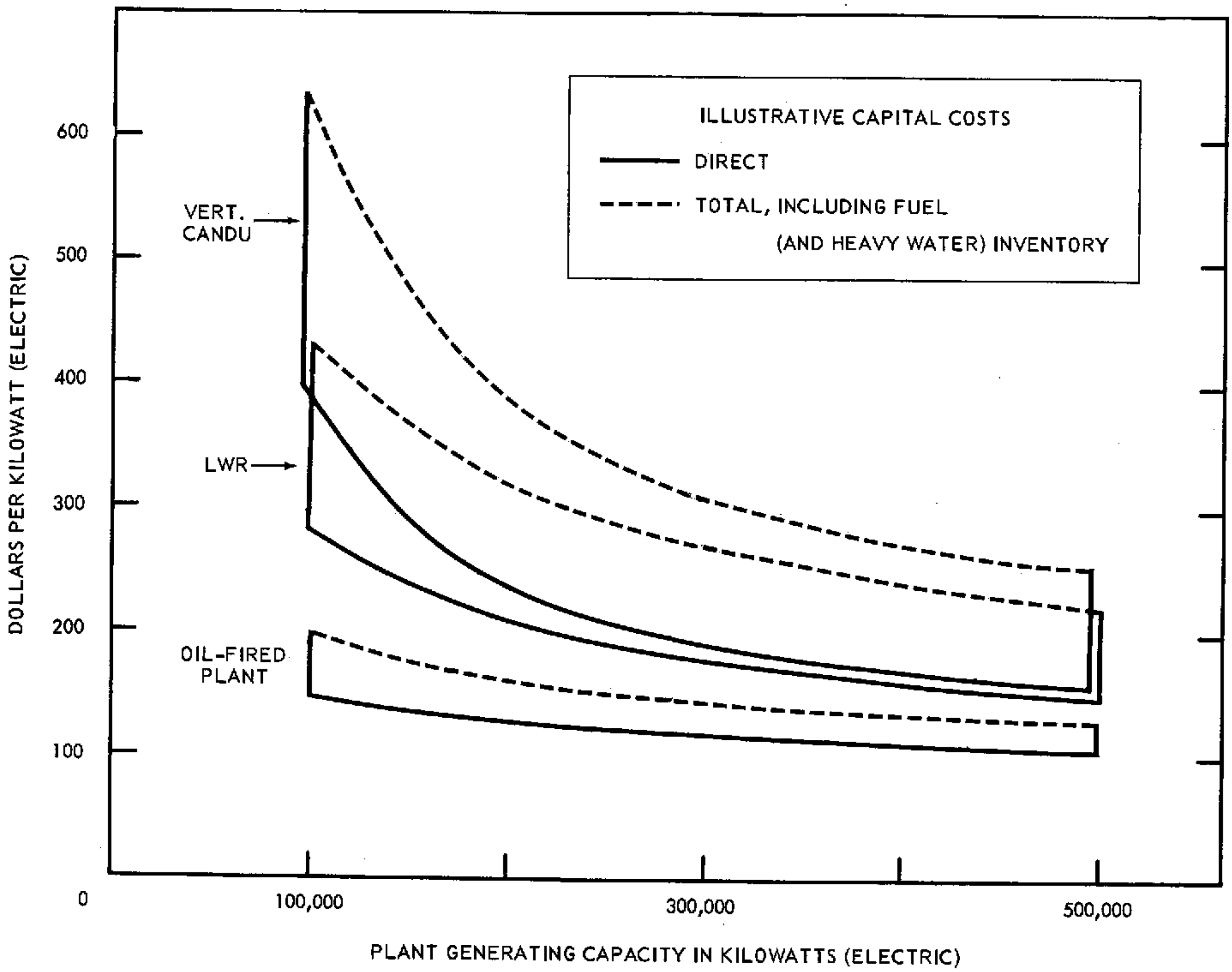
ANNEX III

COMPETITIVE STATUS OF NUCLEAR AND FOSSIL-FUELLED POWER PLANTS

The following graphs give illustrative capital costs, generating costs and break-even fuel prices for a range of medium-size reactors from 100,000 to 500,000 kWe. These graphs are based on information provided by IAEA.

Figure 1

Illustrative capital costs for the Canadian Deuterium-Uranium, light water reactor and oil-fired plants



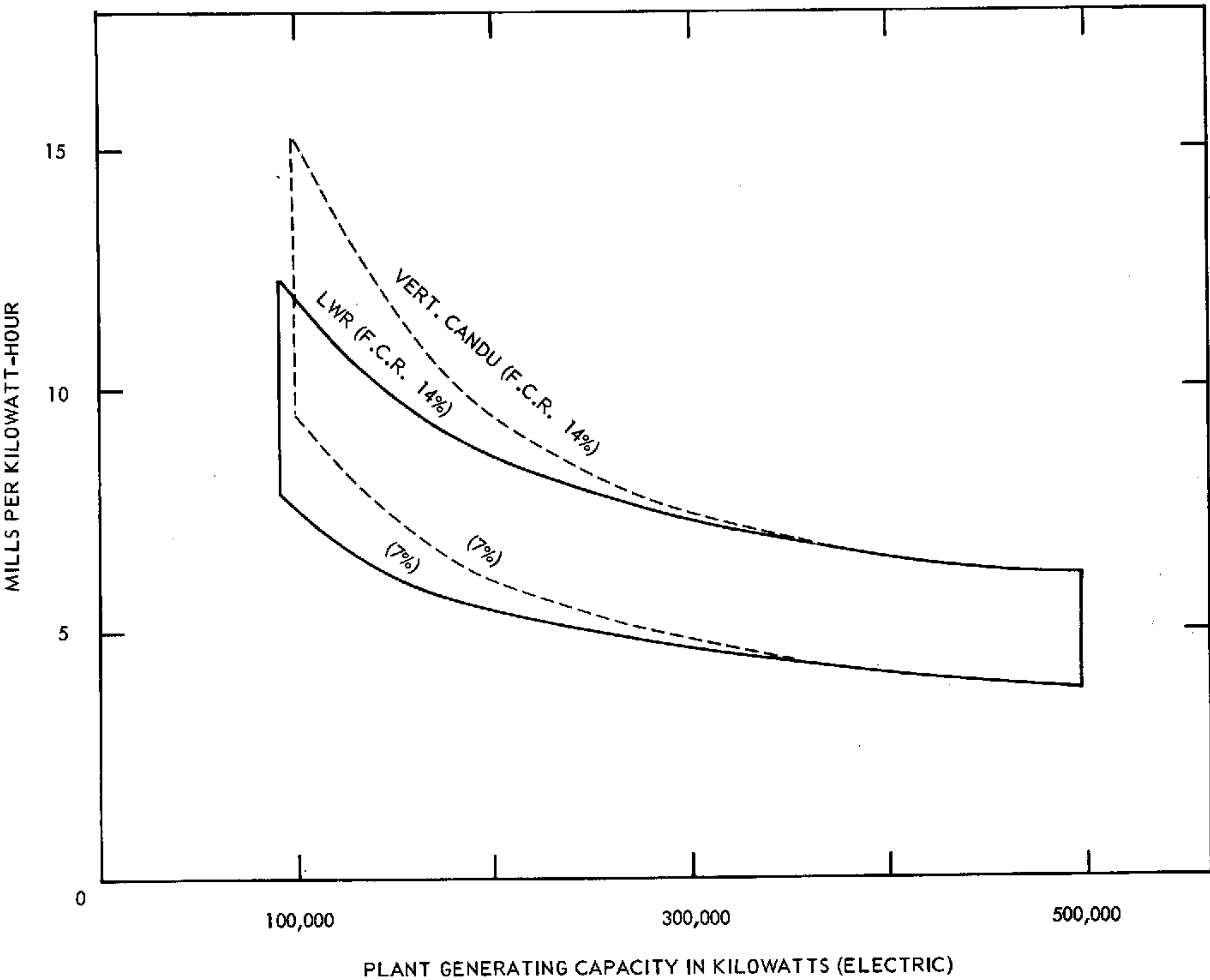
Source: IAEA.

CANDU = Canadian Deuterium-Uranium

LWR = Light water reactor

Figure 2

Illustrative generating costs for fixed charge rates of 7 and 14 per cent

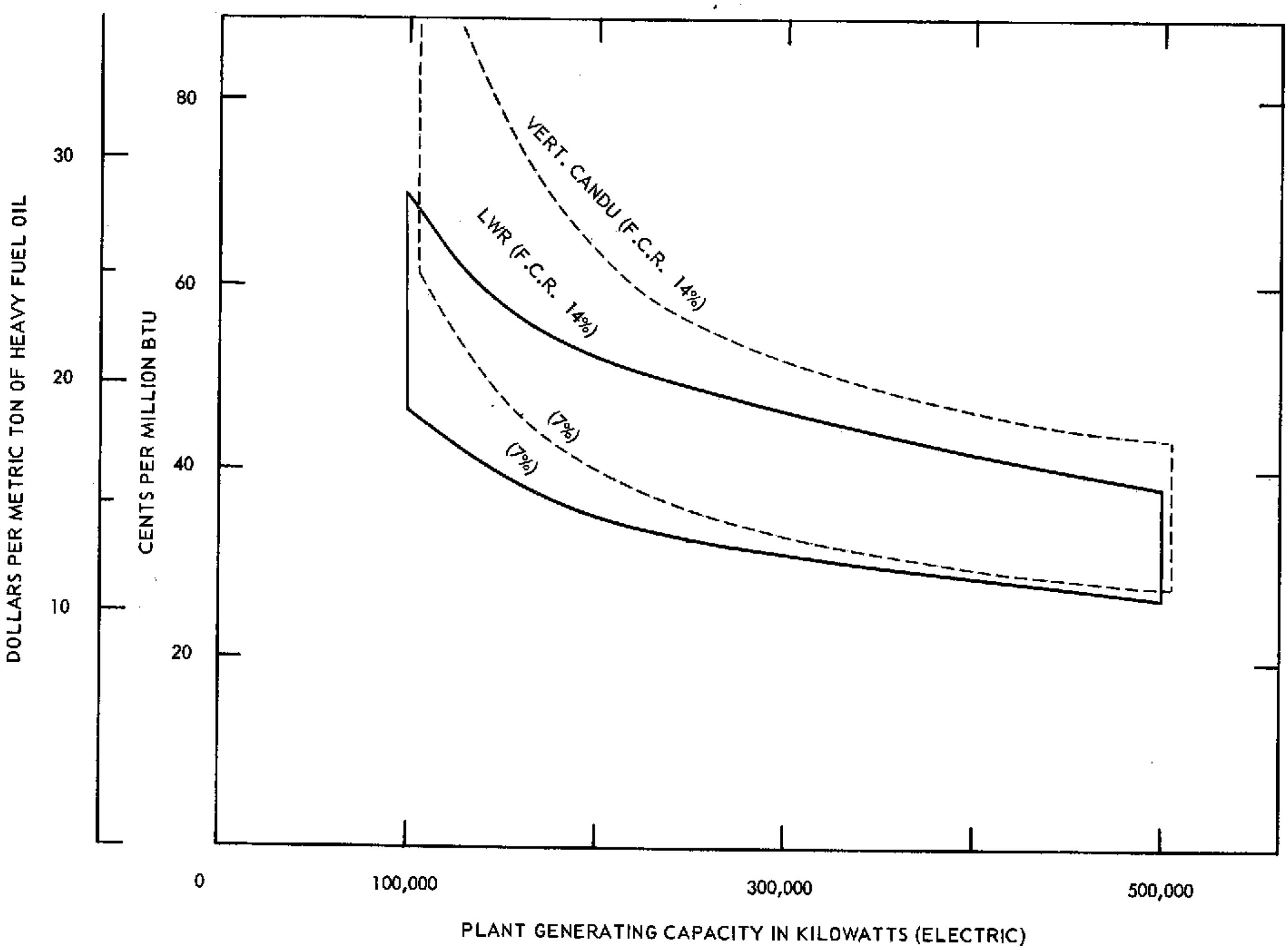


Source: IAEA.

F.C.R. = Fixed charge rates

Figure 3

Illustrative "break-even" fuel oil prices for fixed charge rates of 7 and 14 per cent



Source: IAEA.