GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 65-33

ATOMIC ENERGY DEVELOPMENTS AND FUTURE URANIUM REQUIREMENTS AS ENVISAGED AT THE THIRD INTERNATIONAL UNITED NATIONS CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY, GENEVA, SEPTEMBER 1964

S. M. Roscoe

Price, 35 cents

1965

GEOLOGICAL SURVEY

OF CANADA

PAPER 65-33

ATOMIC ENERGY DEVELOPMENTS AND FUTURE URANIUM REQUIREMENTS AS ENVISAGED AT THE THIRD INTERNATIONAL UNITED NATIONS CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY, GENEVA, SEPTEMBER 1964

S. M. Roscoe

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

Available by mail from the Queen's Printer, Ottawa,
from Geological Survey of Canada,
601 Booth St., Ottawa,
and at the following Canadian Government bookshops:

OTTAWA
Daly Building, corner Mackenzie and Rideau

TORONTO
Mackenzie Building, 36 Adelaide St. East

MONTREAL
Æterna-Vie Building, 1182 St. Catherine St. West

or through your bookseller

A deposit copy of this publication is also available
for reference in public libraries across Canada

Price 35 cents **Cat. No. M44-65/**33

Price subject to change without notice

ROGER DUHAMEL, F.R.S.C.
Queen's Printer and Controller of Stationery
Ottawa, Canada
1965

CONTENTS

	Page
Introduction	1
Nuclear power reactors	1
Nuclear fuel systems	1
Reactor types	2
Graphite moderated reactors	3
Light water moderated reactors	3
Heavy water moderated reactors	4
Fast reactors	5
Direct conversion (MHD)	6
Controlled fusion	6
Nuclear heat for industrial and domestic use and for sea water desalinization	6
Miscellaneous applications of atomic energy	8
Transport	8
Compact power plants	8
Uses of isotopes and radiation sources	8
Nuclear explosives	9
Raw materials other than fuels	9
Isotope separation	10
Uranium enrichment plants	10
Heavy water plants	10
Safety, health hazards	11
Factors favouring increased use of nuclear power	12
Future uranium requirements	13
Exploration requirements	16

ABSTRACT

Expansion of demand for uranium to fuel new thermal power plants is expected not only to restore a rapid rate of extraction of Canada's large known uranium ore reserves within ten years but to present opportunities to exploit deposits as yet not discovered or deposits considered below ore grade at current uranium price levels.

ATOMIC ENERGY DEVELOPMENTS AND FUTURE URANIUM REQUIREMENTS AS ENVISAGED AT THE THIRD INTERNATIONAL UNITED NATIONS CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY, GENEVA, SEPTEMBER 1964

INTRODUCTION

It is generally appreciated that Canada, with an advanced nuclear technology, and uranium and thorium resources larger than those of any other country, should eventually profit greatly from future expansions in the use of atomic energy for the generation of electrical power in many countries. The extent of these advantages may depend to some degree on the ability of persons associated with the Canadian mining industry to follow and understand the significance of nuclear developments that are likely to take place during the next five years — a period that will precede important increases in uranium consumption. Recent projections of uranium requirements suggest that we should concern ourselves less with the question of dates when idle Canadian uranium mines may be reopened and more with the problems of how we are going to find new deposits that will be required at a date that may be only a few years later than the initial resurgence of demand. It is important that potential customers be persuaded that they can have confidence in our ability to discover and deliver ever increasing supplies of uranium at reasonable prices.

This report has arisen out of the writer's attendance at the Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, August 31 to September 9, 1964, and his collaboration with J.W. Griffith on a paper on Canadian resources of uranium and thorium presented at that conference. This is not a comprehensive review of the conference itself, however, or of individual papers presented there. Such reviews may be found in the October issue of Euronuclear and other trade publications and papers will be published in forthcoming proceedings of the conference.

The writer is indebted to J.W. Griffith of the Mineral Resources Division, Department of Mines and Technical Surveys, for advice in preparation of this report.

NUCLEAR POWER REACTORS

Nuclear fuel systems

Fuel systems other than those used in most reactors today are possible and will become more economically feasible in the future due to increased scale and lower costs of fuel reprocessing and perhaps to rising prices of uranium.

The isotope uranium-235 is the only naturally-occurring fissile material but it is possible to artificially produce other fissile isotopes, plutonium-239 and uranium-233, by bombarding uranium -238 and thorium-232 respectively with neutrons. Fuels used in most present reactors consist of either uranium enriched in uranium-235 by means of expensive isotopic fractionation or natural uranium with its inherent ratio of 1 atom uranium-235 to 138 atoms uranium-238. During heat-producing fission some of the uranium-238 atoms capture neutrons and are thereby converted to plutonium. In present thermal reactors the total of uranium-235 plus plutonium-239 decreases during burn-up and eventually the spent fuel is removed from the reactor. Some plutonium as well as uranium depleted in its original uranium-235 content can be recovered chemically from the spent fuel and the reprocessed fuel may be re-cycled in the reactor to obtain some additional burn-up but ultimately the bulk of the uranium-238 content of the original fuel charge must be set aside unless extraneous seed material is added to the system. Large stocks of depleted non-fissile uranium thus accumulate from both reactor operations and isotope separation plant operations.

Fast breeder reactors offer a means of ultimately utilizing depleted uranium. Such reactors using plutonium and uranium-238 can produce plutonium faster than it is consumed. This would lead to a drastic reduction in future fuel requirements.

A fuel system using thorium with either uranium-235 or plutonium-239 as a seed results in the production of the fissionable isotope uranium-233 which can be chemically separated and itself used as a seed with thorium or with uranium-238. The thorium-232 — uranium-233 cycle is most interesting as it will breed in thermal reactors. Thorium, abundant in placers, conglomeratic, pegmatitic and other deposits and about 4 times more abundant than uranium in rocks, may therefore eventually become a major raw material for nuclear power.

Reactor types

The main types of power reactors now considered economically competitive are graphite moderated reactors, heavy water moderated reactors, and light water reactors.

Graphite moderated reactors

The U.K. has led in the introduction of nuclear power generation. By 1969 they will have eleven gas cooled, graphite moderated, natural uranium-fuelled nuclear plants with an aggregate capacity of about 5,000 MWe (5 million kilowatts of electric power), more than one tenth of their present total installed generating capacity. They had been planning another 5,000 MWe for the period 1970 to 1975 using the same type of reactor (MAGNOX) but are now considering other types.* France too has concentrated on graphite moderated reactors in her large nuclear power program and by 1968 will have about 1,400 MWe of installed capacity. Power costs of about 6 mills are anticipated for the later units. Italy, Japan and Russia are also building or operating large power reactors of this type as well as other types. The future of graphite moderated reactors evidently depends on current efforts to develop high temperature, gas cooled types with greater thermal efficiency. A U.S. paper at the conference claimed that a 1,000 MWe reactor of this type could produce power at 3 mills. Such claims were considered premature as a 40 MWe prototype is only now under construction.

Light water moderated reactors

Reactors using light water both as moderator and coolant are economically attractive because of their compactness, simplicity in design and operation, and low capital costs. In smaller sized plants this should give them advantages over other types of nuclear plants. They require a source of enriched fuels and access to fuel reprocessing facilities, however, and present plants have to be shut down for refuelling operations. The U.S. have concentrated on development of boiling water and pressurized water reactors using enriched uranium fuel and have a capacity of nearly 1,000 MWe in 5 boiling water reactors and 3 pressurized water reactors. Operating costs have been high but the next generation of power reactors which will contribute another 3,500 MW of nuclear capacity by 1968, will include 500 MW boiling water plants expected to be competitive with conventional fuel-fired plants at the same sites. Estimates of 4 mill power for the Oyster Bay plant in New Jersey have attracted widespread interest. Large water reactors are planned, under construction or already operating in France, India, Italy, Japan, Netherlands, Belgium, West Germany, East Germany, Spain and Russia as well as in the U.S. It is interesting that one large U.S. pressurized water plant (Indian Point) was initially fuelled with thorium seeded with uranium-235 although it has been converted to operate on slightly enriched uranium.

---

*A decision was announced in May 1965 to proceed with construction of advanced gas cooled power reactors in the U.K.

Heavy water moderated reactors

Heavy water moderated reactors have some inherent advantages as the use of heavy water, theoretically the best moderator, leads to superior neutron economy, low fuel inventory, good burn-up, and high power output per unit of fuel burned. These advantages are particularly important where natural uranium is used as the fuel. Heavy water is expensive, however, so inventory and make-up costs are significant cost items. Moreover, tritium, a highly noxious material, forms and accumulates in the heavy water presenting technical difficulties and expenses not encountered with light water. Present heavy water reactor plants are relatively large and entail higher capital costs than water reactor plants of equivalent power output. They are most competitive, therefore, with the latter plants (as well as with coal-fired plants) in situations where very large generating stations are required and where capital financing charges are low.

Canada's A.E.C.L. has concentrated on heavy water moderated reactors and has developed the CANDU power reactor which uses heavy water in pressure tubes as coolant as well as outside the tubes as moderator and features on-load refuelling and a once through fuel cycle using natural uranium in the form of UO_2. CANDU plants of about 200 MW capacity are being built at Douglas Point, Ontario, in India and planned in Pakistan (132 MW). The Indian parliament recently approved plans for a second 200 MW CANDU plant. A 1,000 MW twin reactor station is to be built near Toronto and is expected to generate power there at a 4 mill cost competitive with coal-fired plants in this area where coal costs are relatively low. This plant to be completed in 1970 will be designed to accept additional units permitting expansion to 4,000 MW. Its status can be realized if we consider that the only larger or comparable sized plant now in sight is a 1,180 MW British gas cooled, graphite moderated station scheduled to come into operation in 1969. The latter plant with anticipated power costs in the 6 to 8 mill range is believed to be the last MAGNOX station that will be built in Britain. Sweden, which has also concentrated on heavy water reactors, is building a 140 MW pressurized heavy water reactor. Norway, France, West Germany, Switzerland, U.K., and the U.S.A. are all building or operating smaller experimental or prototype reactors, most of which are significantly different from CANDU. It is now generally acknowledged that heavy water moderated reactors will have a very important place in future developments and that Canada is well in the lead in this field.

Fast reactors

Most atomic energy authorities are convinced that fast breeder reactors should be developed as soon as possible if we are to make most effective use of our nuclear fuel resources and thereby prevent a significant, if not crippling, rise in the cost of power perhaps as early as the turn of the century. We must bear in mind that many of them may be predisposed to arrive at this conclusion because of their inability to correctly interpret the true significance of our ore reserve figures, because great quantities of depleted uranium and considerable plutonium will rapidly accumulate due to power developments in addition to the quantities that have already accumulated in the U.S. due to their military program, and because the formidable technological difficulties in developing efficient, safe, fast breeder reactors present an irresistible challenge.

The fast breeder reactor must operate at a very high intensity with a large concentrated charge of highly enriched uranium (ideally, uranium-238 plus plutonium-239) and with no moderator. The most serious difficulties involve the large quantities of heat that must be transferred rapidly; molten sodium is the most popular of coolants now under consideration. Experimental fast reactors have been brought into operation in the U.S.A., U.K. and Russia. Others are planned in these countries and in France, West Germany, and Switzerland. Russia appears to have made particularly substantial progress as they are jumping from a 5 MWth (5,000 kilowatts thermal energy) test reactor to a 1,000 MWth reactor.

Prototype fast breeder power reactors to be brought into operation during the next few years may lead to the operation of power stations using such reactors beginning in the period 1975 to 1980. Economic factors that would encourage or discourage large scale introduction of such plants are difficult to evaluate. They would ultimately (after a time lag of several decades) lead to total raw fuel requirements and costs lower than those that would prevail without breeders. Paradoxically, however, their initial effect would be to increase these requirements and thus contribute to upward pressure on the price of natural uranium. This is because they require very large inventories of uranium compared to thermal reactors with equivalent power output. On the other hand, it is hoped that their introduction would also tend to lower total power costs by increasing the refund value of plutonium that can be recovered from fuels burned in the thermal reactors.

Some authorities, in France and West Germany in particular, consider that there will be a need for a generation of near-breeder, thermal converter reactors before fast breeder, power reactors are economically feasible. Later, when breeders are introduced, each of them could supply adequate plutonium to keep several of these near-breeders in operation. The most efficient converter would almost certainly be a heavy water reactor not unlike CANDU. Such converters could also use the thorium-232 — uranium-233 cycle, in fact they themselves could breed in this cycle. A few experts, Canada's W.B. Lewis the most vociferous among them, consider that fast breeder reactors will not be essential in the foreseeable future. These authorities believe that utilization of thorium holds great promise for extending supplies of nuclear fuels.

DIRECT CONVERSION (MHD)

The possibility of magnetohydrodynamic (or MHD) power-generation in large scale power stations using coal, oil, gas, or nuclear fuel is currently under study in many countries and could conceivably be realized in 10 to 20 years. In this process, thermal energy is converted directly to electrical energy by passing hot, electrically-conducting gas through a stiong magnetic field. The ionized gas, in effect, substitutes for the rotors of a conventional generator. It is believed that MHD could raise efficiencies to 60 per cent from present limits of 40 per cent. The gas must be extemely hot. The British are developing a high temperature gas cooled reactor and have let it be known that they consider one of its attractive features is its potential capability to team up with MHD. Fast breeder reactors would also be particularly suitable in this application. It might also be possible to use reactors that operate at lower temperatures.

CONTROLLED FUSION

Problems of achieving a controlled fusion reaction have been found to be much greater than researchers had previously thought they would be, according to Sir William Penney, Chairman of the conference session on Controlled Fusion. He expressed confidence in eventual success but stated that it was not possible at present — "to demonstrate scientifically that ultimate sucess must come". His estimate of world spending on fusion research was $100 million per year, one tenth of which was being spent in the U.K. L.A. Artsimovich (USSR) stated "... the problem of making energy from the synthesis of matter will be a burden for our grandsons, not our sons. But we cannot sit here and twiddle our thumbs until the problem grabs us by the throat". Russia was the only country that emphasized fusion research in their nuclear exhibit.

NUCLEAR HEAT FOR INDUSTRIAL AND DOMESTIC USE AND FOR SEA WATER DESALINIZATION

Significant economies can be effected by combining electricity generation and heat production in nuclear plants. Markets for consumer heat may thus become factors in siting of nuclear power plants and may contribute to their increased use. A Swedish heavy water reactor has produced 10 MW of electric power and 55 MW of heat for a Stockholm suburb 2½ miles away. Many industrial processes require large amounts of heat. Russians (P/319)* see small (25 to 50 MW) combined power and central heat stations justified in remote areas where costs of transporting conventional fuel is high. The utilization of heat as well as power produced in large central nuclear stations would effect much greater savings in fossil fuel consumption than would nuclear power generation alone. They believe that organic fuels should be conserved as much as possible for chemical purposes.

Sea water distillation plants will need very large quantities of low temperature heat which may be supplied more cheaply by nuclear power stations than by fossil fuel burners provided that there is also a demand for large blocks of electrical power in the same areas. Israel plans a dual purpose plant to desalt 80-160 million gallons of water per day and generate about 150 MW of power. A similar sized plant is under study for southern California. Russia is planning to use heat from the 1,000 MWth fast breeder now under construction in the Caspian Sea area to desalinate water as well as produce 350 MW of electrical power. The U.A.R. and Tunisia hope to build plants to desalinate about 5 million gallons per day. Various estimates of costs of water from such plants have ranged from 40 to 80 cents per 1,000 U.S. gallons. Such costs are acceptable for industrial and domestic water but costs for pumped irrigation water in the U.S. are not over 15 cents per thousand gallons.

According to James T. Ramey, U.S. Atomic Energy Commissioner, each of the main reactor types would be equally suitable for plants up to 1,000 MW equivalent but heavy water reactors of the CANDU type might have an economic edge in larger plants. Unit costs of both water and power drop rapidly with increases in size. It has been estimated that a mammoth plant could desalinate 1.9 billion gallons per day at a cost of about a half million dollars per day, or 23 cents per 1,000 gallons, together with about 5,800 MW of by-product electricity at a cost of a quarter of a million dollars per day, or 1.8 mills per kWh. This fresh water output of 1.9 billion gallons per day, or about 3,500 cu. ft. per sec. is equivalent to the flow of a fair size river, the Bow River at Calgary for example. Warnings against over optimism regarding desalination were sounded at the Geneva meeting. Before we talk too much about making the deserts of the world bloom, we should consider the number of existing areas that could absorb the huge block units of water and power which must be produced to attain acceptably low costs.

---

*Refers to numerical designation of U.N. Conference papers.

MISCELLANEOUS APPLICATIONS OF ATOMIC ENERGY

Transport

Performance of nuclear powered submarines, surface naval vessels, the Soviet icebreaker, Lenin, and the U.S. demonstration merchant ship, Savannah, have been impressive but the application of nuclear power to commercial shipping has lagged. The only civilian nuclear powered ship under construction at present is Germany's 'Otto Hahn', scheduled to be operational in 1967. The Russians are going to build two more icebreakers but have indicated that they are not working on any merchantmen at present. The Japanese are planning an atomic-powered hydrographic vessel. The Netherlands are developing a ship propulsion reactor, NERO. The Belgians and British are working jointly on the 'Vulcain' reactor for both marine and stationary installations. The Americans have developed several compact marine reactors (apart from naval reactors) but have not announced any plans to put these in ships.

Russia's V.S. Emelyanov in his opening address as President of the Conference expressed a belief that nuclear powered aircraft will someday be developed. Nuclear and isotopic propulsion systems for space craft are under development in the U.S.

Compact power plants

Thermoelectric and thermionic conversion (like MHD described above) are means of obtaining electric current from heat without mechanical apparatus. They offer advantages in reliability as well as compactness. Small units using radioisotopes as heat sources have been in operation for years in automatic weather stations, buoys and other navigation devices and in satellites. Larger converters using nuclear reactors as heat sources are under development. The U.S. 'SNAP' 500 watt unit designed to power communication satellites is to be tested in space in 1965. The Russians have had their 'Romashka' in operation for several months.

Uses of isotopes and radiation sources

Benefits derived from the ever increasing use of isotopes and other radiation sources in medicine, agriculture, in industry, and in all branches of science may outweigh all other benefits and all costs attributable to the development of nuclear technology. New applications and advances in radioactivity measurement techniques and in the production of isotopes were reported at the Geneva Conference. Uses of radioactive isotopes as tracers in hydrological and geological investigations were reviewed in one paper (P/875) but nothing new was described. The use of neutron activation to determine 14 trace elements in Greek lakes was described in another paper (P/854).

In addition to well known uses of radioactivity for detection purposes, for sterilization, and for the inducement of mutations, an exciting new field of chemonuclear industrial applications is developing rapidly. Applications include the production of non-permanent detergents, semiconductors and superior plastic and other synthetic products derived through radiation-induced polymerization. Radiation can also increase the efficiency of catalysts in chemical reactions such as nitrogen fixation. Of special interest to Canadian forest industries is the development of Novawood, a wood-plastic blend said to have the appearance and workability of natural wood and the durable finish of a plastic. The radiation sources for most of these industrial applications will be isotopes, like Cobalt-60, or radiation machines but we may see chemonuclear reactors installed in some industrial plants.

If important markets could be found for non-fissile isotopes produced in nuclear fuels during their burn-up in power reactors, the sale of such isotopes would contribute to a lowering of fuel costs and thus of total nuclear power costs. No such markets are in sight at present, however, and it is questionable if the expanding use of isotopes and radiation will contribute significantly to increases in uranium consumption.

Nuclear explosives

The U.S. Operation Plowshare was reported on during the conference but nothing new was disclosed. Study of the feasibility of blasting a new 'Panama' canal using nuclear devices has been a major objective of this program. It has been estimated that costs could be cut in this manner to as little as one third that obtainable using conventional construction methods. It was disclosed at the conference that the UAR had approached the UK with a request for assistance in blasting a canal from the Mediterranean to the Qatara depression. Evaporation in the depression would maintain a head of 200 feet with a flow adequate to operate a 300 MW hydro power generating station, according to the press report.

RAW MATERIALS OTHER THAN FUELS

Requirements for materials with unusual properties as fuel cladding, control rods, and structural purposes in reactors will add significantly to present limited markets for a number of elements, among them zirconium, beryllium, niobium and perhaps hafnium, indium and lanthanum.

Economic geologists and mineral economists, among others, will therefore be watching nuclear developments with these needs as well as uranium and thorium requirements in mind.

ISOTOPE SEPARATION

Uranium enrichment plants

All of the enriched uranium used to date in reactors has been produced in plants built for military purposes. Enrichment is still a security sensitive area and little information on this subject was given at the conference. There is a great deal of interest currently in centrifugal separation of uranium isotopes and lack of new information on this subject was a particular disappointment. A French paper (P/89) indicated that centrifugation, in so far as the art is known by them, would not reduce separation costs or permit small scale operations. France has recently started up a gaseous diffusion plant for the production of uranium-235 or enriched uranium. The paper indicated that nuclear energy programs involving annual increases of more than 4,000 MWe of enriched uranium reactor capacity would be required to absorb the output of the smallest economic diffusion plant. Evidently most countries wishing to use enriched uranium reactors must depend on others for their fuel supplies. The Germans, who have been active in laboratory scale research on centrifuging and other isotope separation techniques, see no need for an enrichment plant, either built on their own or in cooperation with others, for at least ten years. Presumably isotope separation plants will become less important and strategic when large amounts of artificial fissile isotopes become available through the operation of chemical reprocessing plants in many countries that will have large nuclear programs.

Heavy water plants

Most of the heavy water used in reactors throughout the world has come from two U.S. hydrogen sulphide dual temperature plants; one of these has been dismantled, the other has been operated at 1/3 of capacity since 1958. Deuterium of Canada is building a 200 ton per year plant of this type near Glace Bay, N.S. The contract price with AECL for production of 1,000 tons of heavy water by 1970 is one third less than 1962 prices and subsequent increased production (400 tons) will result in further price decreases. India has a small heavy water plant but is planning another to supply 200 tons per year needed in her nuclear program. It is interesting that both the Indian and Canadian plants will take advantage of cheap local coal for their heat requirements. France is said to be planning a plant to recover deuterium as a by-product of a synthetic ammonia plant.

SAFETY, HEALTH HAZARDS

Reactor safety record has been excellent. Possibilities of accidents are slight and such accidents do not present significant threats of an unusually hazardous nature such as exposure of persons outside of the plant area to dangerous radiation. Lessons have been learned from reactor accidents, and the staging of mock accidents will further improve safety precautions and practices.

Most accidents in the nuclear industry have occurred in chemical treatment facilities. For example, a fatal accident occurred in a U.S. chemical plant in July 1964 when a worker poured a concentrated solution containing enriched uranium from a 'safe geometry' flask into a different shaped container thereby inadvertently creating criticality (a concentration of fissile atoms sufficient to sustain a fission chain reaction). This was the second accident of this type in the U.S.

It is important for the nuclear industry to gain the public's confidence that their operations are no more dangerous than other industrial operations. Many nuclear power stations will have to be located near major population centres. The safety aspect has been one line of attack brought to bear upon nuclear power by coal interests in the U.S. (their other main attack has been against government support and alleged subsidies of nuclear power developments). Spokesmen for commercial nuclear interests have counterattacked with statements that more radioactive material is dispersed from the stack of a coal-fired power station than from a nuclear one, that in the U.S. alone 19,000 deaths per year are due to coal smoke, and that hundreds of coal industry workers are killed every year (287 in 1962).

Safe disposal of radioactive wastes is apparently not going to be as great a problem technically or economically as was earlier feared. It has been estimated that costs of waste management should be less than one per cent of total power costs. The disposition of wastes should be considered primarily as a matter of storage rather than of dispersion of acceptably low concentrations of radioelements into the environment. Temporary storage permits wastes to lose a large part of their initial radioactivity which is due mainly to short-lived radioisotopes. Controlled permanent storage of waste concentrates containing long-lived radioisotopes can be facilitated by fusing them with melted rocks into glass blocks. Some rocks may be superior to others for this purpose. Nepheline syenite was used in early experiments at Chalk River. Some low-level wastes can be disposed of (or stored under less rigidly controlled conditions) by making use of the capacity of soils, silts, clays, minerals and rocks to retain micro amounts of strontium, cesium and other radioisotopes. Pyroclastic rocks containing the zeolite, mordenite, formed during devitrification show high retention, according to a Czechoslovakian study.

Biologists and others are studying maximum permissible exposures of humans to radiation and possible long term effects on the human environment that might accrue as a result of future large scale use of atomic energy if appropriate precautions are not taken. A Russian team reported to the conference that any small radiation dose produces a certain quantity of additional mutations and that radionuclides produced by nuclear explosions are certain to produce genetic effects. A German study (P/541) cited evidence that krypton-85 may have accumulated in the atmosphere due to reactor operations as well as from nuclear explosions. A Russian paper reported that rates of exchange between ocean depths and the surface were high enough to cast doubts about the wisdom of deep-sea disposal.

Dr. Sigvard Eklund, Director General of the International Atomic Energy Agency, stressed the importance and urgency of establishing international agreements and regulations with respect to transport of nuclear materials and disposal of radioactive wastes. Appropriate precedents may become harder to establish as power reactors become commonplace in many countries, with an attendant tendency, perhaps, for the influence of scientists to become overwhelmed by other influences.

FACTORS FAVOURING INCREASED USE OF NUCLEAR POWER

Most of the known reserves of coal, oil and gas are located within relatively limited areas of the world. Undeveloped hydro resources are small in comparison with total power requirements. A major part of the world's population is concentrated in areas where the people are at a distinct economic and geopolitical disadvantage with respect to sharing in the utilization of these known energy resources and resources likely to be discovered. Even within developed countries with large energy resources there are considerable variations in costs of power due to costs of transporting conventional fuels and transmitting power. Nuclear power offers a means of redressing these imbalances, as the costs of extracting, processing and transporting the relatively small amounts of nuclear fuel required are small compared to analogous fuel costs for conventional power plants.

Capital costs and operating costs of nuclear power plants have been reduced remarkably during the past few years. It has been estimated that nuclear power plants could compete favourably with conventional fuel-fired plants in 60 per cent of the U.S.A. This competitive position, however, will not be conclusively demonstrated until about 1970 when projected, large, low cost plants go into operation. Due to their low fuel costs, nuclear power plants benefit more from increased size than conventional fuel-fired stations. Expansions of power grids and power requirements result in increasing opportunities to integrate large, central, base load, nuclear stations into the systems. The integration of these stations into a power network, with conventional plants and hydro stations supplying the peak loads, will decrease the cost of power in the system as a whole.

Nuclear power could help many countries deficient in energy resources to increase their power production without worsening their balance of payments and foreign currency positions. If it is necessary to import uranium, the cost of doing so is very small compared to the cost of importing the quantities of fossil fuel that would have an equivalent energy content. Savings would be achieved even if the nuclear fuel were imported in the form of fabricated fuel elements.

A developing nation may be anxious to build its first nuclear power station, partly for prestige purposes, but more importantly because it considers that this will open a door to a sophisticated technology. As suggested above, most underdeveloped countries have more to gain by the introduction of nuclear power than developed countries. Lack of means to finance the construction of nuclear power stations, however, will seriously limit their ability to increase their power production, in the same way as this lack of capital inhibits their general industrial growth and capacity to utilize large blocks of power.

FUTURE URANIUM REQUIREMENTS

The quantities of uranium required up to 1970 can be predicted fairly closely because nuclear power plants that will be coming into production prior to then must now be under construction or in an advanced state of planning. Beyond 1970, requirements must be based on a number of assumptions: (1) rate of increase of all types of installed generating capacity; (2) the share of nuclear power in new generating capacity; (3) the inventory requirements and burn-up of uranium per unit of nuclear power generated. The second factor listed involves much greater uncertainties than either of the others. In a U.S. paper, Faulkner and McVey (P/256) estimated that about 0.5 ton U_3O_8 per megawatt year of installed nuclear generating capacity will be needed in 1970 but that this will be reduced to about 0.3 ton per megawatt year by 1980. They assume that water reactors using slightly enriched uranium will be the dominant type. If heavy water, natural uranium reactors are more widely used than they suppose, the uranium consumption per megawatt year would be less than that indicated by their figures. If fast breeder reactors are introduced in large numbers, say in 1980, this would increase slightly the uranium consumption per megawatt year for a period extending to beyond the turn of the century.

Countries with major nuclear programs will have sizeable stocks of nuclear materials on hand in 1971 when consumption is expected to catch up with production amounting to about 14,000 tons annually as indicated by present contracts. Faulkner and McVey (P/256) consider that the equivalent of about 100,000 tons of uranium produced prior to 1971 may be available for nuclear power plants and that stocks of enriched uranium may be adequate to meet requirements of plants using this type of fuel "for several years beyond 1970". Cumulative requirements for nuclear fuel will surpass 100,000 tons in 1973 or 1974 and 200,000 tons by 1976 or 1978. By the mid seventies, then, we shall have to be mining U_3O_8 at a rate about equal to the rate of consumption, regardless of releases of fissionable materials from stockpiles during the period 1970 to 1975.

Between 27,000 and 38,000 tons of U_3O_8 will be required in reactors in 1976 according to the Faulkner and McVey predictions used herein; presumably this would have to be mined in 1975, if not before. It would require several years to build up production from a level of about 14,000 tons to a 1975 level of around 35,000 tons so if increases in production are delayed until after 1971, they will have to be made very rapidly.

United States producers will likely be favoured during the initial increase in market outlook because a large part of the market will be in the U.S. and the U.S. will be selling enriched uranium to other consumer countries. South Africa will also have an initial advantage because of its production of uranium as a by-product of gold mining. Australia, France and other countries can produce or increase their production of low cost uranium. Some consumer countries that are as much interested in a domestic supply as in a cheap supply of uranium will doubtless have some success in exploration by the early seventies. Canada's main opportunity to enter the market at this early stage would lie in her ability to contract with European consumers interested in establishing assured long term supplies of low cost uranium. On this basis, it is conceivable that some increase of Canadian production, over that now scheduled, might be realized before the end of this decade.*

The initial increase in production would be effected by the reopening of mines that have fully written-off plants and can produce U_3O_8 at prices around $5 per lb. Production from Eldorado's Beaverlodge mine and perhaps three large Elliot Lake mines should be needed by 1974. Higher uranium prices would be required before all of those previous operators that have some ore reserves left could reopen. With existing plants, production could possibly approach 30,000 tons (10,000 in Canada) although this rate could not long be maintained. As stated above, U.S. estimates (P/256) suggest that annual requirements may exceed 30,000 tons by 1975. Further projections suggest that annual requirements may reach 47,000 to 62,000 tons by 1980. If these estimates are correct, existing mines and plants will

---

*In early 1965 Denison Mines Limited announced that negotiations were being conducted for a long term contract for sale of a large quantity of its uranium to France.

be unable to satisfy requirements after 1975. At higher uranium price levels, capacities of some existing plants could perhaps be increased and some new plants could be installed to mine ore reserves that cannot be mined from existing plants. There are certain important limitations, however, on the rate at which the known large reserves can be mined. These are discussed below.

Known ore reserves are expected to total about 474,000 tons (P/256) in 1971. Nearly 3/4 of these reserves will be in conglomeratic deposits in Canada's Elliot Lake area and in South Africa. This proportion will rise during the late seventies unless important deposits are discovered to replace U.S. reserves that will be depleted during this period. If requirements were to be met entirely from known deposits, production of conglomeratic ore would have to be increased to about 40,000 tons by the end of the seventies. This would be roughly equivalent to peak Free World production in 1959 at which time the conglomeratic deposits contributed about 40 per cent of the total. It is questionable that production from known conglomeratic deposits could be raised to 20,000 tons per year let alone to 40,000 tons per year. South African uranium production is tied to her gold production and probably could not be greatly expanded. Production from known ore in the Elliot Lake area exceeded 10,000 tons per year between 1957 and 1960 but several mines exhausted or substantially depleted their ore reserves at that time and others would exhaust theirs after a few years of renewed operations. Only a few mines can draw on substantial reserves. With an aggregate productive capacity of 5 to 6 thousand tons of U_3O_8 per year, these do not have abnormally long lives compared to numerous great metal mines* that have operated for many decades. Production from these mines, therefore, may not be substantially increased.

After 1976, it probably will no longer be possible to satisfy rapidly growing uranium requirements through increases in the rate of exploitation of known ore deposits. Production increases in the late seventies must come largely from deposits not yet discovered or from material not at present considered ore — that is, not exploitable under present technology at U_3O_8 prices under $10. Major tonnages of material in this category could be exploited in the Elliot Lake area and elsewhere in Canada and in other countries, if production costs were sufficiently reduced, or if the price of U_3O_8 rises above $10 per pound.

---

*Most metal mines characteristically report reserves that are much smaller than tonnages that will ultimately be mined. It is important to understand that this is not the case with Elliot Lake mines. The extent of the bedded conglomeratic ores was outlined during exploration work and it is unlikely that these mines can extend their lives by finding new ore as they mine known ore. The reserve estimates are as likely to have been slightly too great as too small.

Deposits still unknown may begin to augment production as early as 1975 as favourable market prospects will surely have generated intensive exploration by the early seventies. When the rate of discovery of new ore mineable in the $5-$10 per pound uranium price range is exceeded by the rapidly rising consumption rate, it will be necessary to begin to draw on material that we now consider as potential ore in the $10-$20 per pound uranium price range. It is far too early, of course, to speculate on when this might happen, but it is worth while considering possible effects of rising uranium prices on Canada's position as the principal exporter of uranium.

A rise in the price of uranium from present levels of around $5 to $10, $15 or perhaps even $20 per pound would not result in important changes in the competitive position of nuclear power but fears that the price might rapidly rise still higher and doubts about the ability of the mining industry to produce increasingly large quantities of uranium — even at high prices — could inhibit nuclear power developments and hence delay anticipated market expansion. In answer to such fears, it has been suggested that uranium could be extracted from extensive geological formations, such as phosphatic strata, shales and granites, and from sea water, at costs (ranging as low as $20 per pound) that would not cripple nuclear power. Many countries, otherwise dependent on foreign suppliers (notably Canada), would be able to develop their own large extraction industries along these lines.

EXPLORATION REQUIREMENTS

Discoveries of new uranium deposits are needed in the early seventies to assure supplies for reactors that we hope will be planned at that time for initial operation in the late seventies. Most of the ore in the great deposits near Elliot Lake was outlined by holes a few hundred to a few thousand feet apart drilled during a three year period and this ore was brought into production three to four years after the start of this drilling. Reconnaissance exploration holes drilled several miles apart, however, could not have failed to find these deposits. If more deposits like them are present in Huronian rocks, they will be found cheaply and rapidly and could be brought into production within five years of the start of intensive exploration. There is no other area, however, where there are possibilities of rapid success from renewed exploration. Unless we are going to stake our hopes entirely on the Huronian conglomeratic deposits, exploration for uranium should be resumed before the end of this decade as urged by W.M. Gilchrist, president of Eldorado Mining and Refining Ltd.

New starts on nuclear power projects during the next few years will lead us to more refined prognostications of future uranium markets. It is doubtful if major, expensive exploration projects will be launched until these markets show demonstratable evidence of firmness. It should not be necessary however to wait until then before sharpening up the tools of exploration. Thought should be given now to the selection of target areas. Areas containing pegmatites and alkalic rocks should obviously be assessed, as should sedimentary sequences likely to contain carboniferous shales, phosphorites, red beds and placers. All of our known uranium ore deposits are within areas that contain an abundance of relatively radioactive rocks, which in many cases do not show obvious relationships to the individual deposits themselves.

It is important to develop more sophisticated radiation detection instruments so that radioactive provinces discovered during previous exploration activity, and others not yet discovered, may be outlined rapidly and cheaply. Gamma ray spectrometers, capable of distinguishing between potassium, thorium, and uranium radiation and detecting and measuring small quantities of these elements in rocks, would be particularly useful if they could be developed in forms suitable for ground, airborne, and diamond drill-hole applications in Canadian conditions. Such an instrument has great potential as an aid to geological mapping, correlation, and search for various types of deposits that may be associated with rocks that have abnormal potassium contents, as well as for uranium and thorium exploration.