atomic specialists towards the solution of this most important problem - the conversion of salt water into fresh water.

It is essential to channel all the energy stored up in military stockpiles in the shape of nuclear weapons into the construction of powerful atomic reactors which will produce cheap power and also desalinate water. The construction of large desalination plants is a rational method of using atomic energy.

In the light of the magnificent prospects before us in the field of atomic science and of the complexity of the problems which that science has to solve, it is essential for scientists to collaborate and to unite their forces. During the past six years, there have been many events in scientific life that have made for the development and strengthening of scientific ties.

The International Atomic Energy Agency has begun to expand its activities. It has convened a series of important scientific meetings at which many atomic problems have been discussed in detail. Conferences, symposia, seminars, and summer schools have been organized for the consideration and discussion of many questions relating to the use of radioactive isotopes and radiation, controlled nuclear fusion, the disposal of radioactive waste, etc.

All this has greatly strengthened scientific ties. The long interval between the Second and Third International Conferences has been filled with intensive activity in world scientific circles working on the problems of atomic energy. But all the conferences, meetings and symposia held during the past six years cannot replace international conferences convened by the United Nations, because the latter provide particularly striking and convincing evidence of the importance of diverting atomic energy from the path leading to war into the path of peace and progress.

THE THIRD CONFERENCE - A SUMMING-UP

Dr. Glen T. Seaborg, Leader of the US Delegation to the Third Geneva Conference, at a special evening lecture summed up the results of the ten-day meeting which, he said, brought us to the borders of the age of nuclear power and might be called the Conference of Fulfillment.

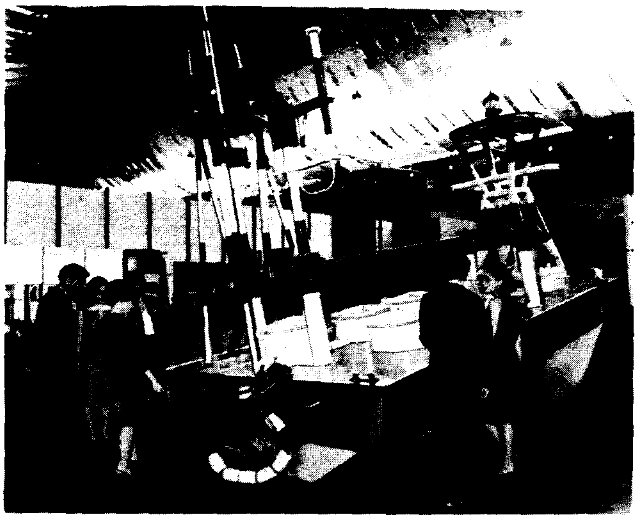
Perhaps the most impressive indication of progress, he said, was the growth in world installed nuclear capacity - from only 5 MW(e) in 1955 to 185 MW(e) in 1958. Today in 1964 there was almost 5000 MW(e). One could see that, by 1970, the total world nuclear power capacity would be about 25 000 MW(e) and by 1980 this would have increased to 150 000 or 200 000 MW(e).

The following is a slightly condensed version of his statement of the technical progress reported to the Conference.

"Many of the delegates to this Conference view nuclear power in three phases. The first is that phase reached in the past year or so - the coming of age of the three types of presently economic reactors: the graphite moderated, gas cooled reactor; the heavy water moderated, heavy water cooled reactor; and the light water moderated, light water cooled reactor.

The second phase of nuclear power is the improved or advanced converter reactors, including near breeders. These reactors run a gamut of types - including heavy water moderated, graphite moderated, light water moderated and even types using a variable moderation of heavy water and light water. This phase of nuclear power development promises to bring greater fuel utilization, preparation of fuel for breeders at a faster rate and potentially even lower cost power than today's reactor. It must be recognized, however, that continued improvement of the present reactor types will probably keep them economically competitive during most of this time.

The third and somewhat concurrent phase of nuclear progress is the development of breeder reactors. This Conference has heard considerable discussion of fast breeder reactors using the plutonium and uranium-238 fuel cycle. Perhaps less discussion than they merit has been given to thermal breeders fueled on the thorium and uranium-233 fuel cycle. In either case these breeder reactors promise to extend by an order of magnitude and more the fuel utilization of our uranium and thorium resources since they will produce more fissionable material than they consume. In essence they are our key to unlocking the energy stored in the non-fissionable but extremely abundant isotopes - uranium-238 and thorium-232.



Exhibition at the Palais des Expositions, Geneva. A floating atomic weather station in the US exhibit, designed to transmit reports. Power is provided by a Snap-7 nuclear generator (US AEC photo)

One Goal, Many Approaches

Not all delegates agree that these three phases can be arranged in a progression from the presently economic reactors to improved converters capable of even greater economies to a somewhat concurrent pursuit of a longer term programme on breeder reactors. Some delegates feel there is no need for the intermediate converter phase and that nuclear power development programmes of the respective countries should proceed directly to the breeder reactor phase. But the uncertainties still associated with the long term economic outlook of breeder reactors would seem to provide a strong rationale for the concurrent and more immediate development of improved converters for many countries. Conversely there are some delegates who feel that no appreciable effort should be expended on breeders at this time since the present reactor types and improved converters could provide abundant power for many decades to come. If, as reported to the Conference by the UK, it will be possible to produce uranium from sea-water at prices not higher than $20/lb of uranium oxide this view may be considerably strengthened.

Clearly, the Conference shows that the aim of all of the nations is to achieve abundant economic nuclear power. We are approaching this goal in different ways, and it appears fortunate that alternative explorations are being made. It seems likely that the nuclear power base for some time to come will consist of a number of different systems paralleling each other in time. We are not likely to find a sharp cut-off point at which one type of reactor will cease to be useful. Moreover, it is unlikely that any advanced system - converter or breeder - will be widely adopted if it does not become economical. In my opinion we will never see breeders in wide use, for example, if the technology is not advanced to the economically competitive stage. One in fact can see circumstances in which breeders could only become economic if the price of fuel is driven up high enough.

The proceedings here show that the focus of competitive nuclear power today is on large size plants, 500 megawatts of electrical output each. Plans for even larger plants of 1000 electrical megawatts each are just quietly assumed. When we look toward the reactors for desalination of sea-water, we consider plant sizes as large as 2000 electrical megawatts. But the other end of the spectrum also requires attention. Not all countries can use power in these large blocks. Hopefully, one of the outcomes of the large-scale development of nuclear power will be the advent of economic power reactors in the smaller sizes more suited to many of the developing countries. Nuclear reactors below the 500 megawatt size are already showing economic benefits in certain of these countries.

Economics of Nuclear Power

Let me turn now to details, first by following the central thread in my general remarks; that is, the economics of nuclear power. The cost of power from any generating station, nuclear or conventional, is governed by four main factors: construction costs, operating cost, fixed or carrying charge rate, and system characteristics which determine the plant capacity factor. Except for the fixed charge rate, these subjects have been extensively discussed in various sessions of the Conference. It is perhaps unfortunate that more consideration was not given to fixed charges, since apparently much of the controversy over the relative merits of various reactor systems stems from differences in this fixed charge rate. In fact some efforts toward international standardization of the bases for computing reactor economies would probably have been welcomed.

Technical and economic factors have restricted the number of reactor types that are well enough developed to be candidates at present for immediate large-scale power programmes. The reported prospective construction costs for the three predominant reactor types in the world today are only about one-half the costs of the first large reactors.

Construction costs range from $140 to $280 per kilowatt. Running costs range from 1.3 to 2.8 mills per kilowatt hour. I have not attempted to combine construction and operating costs to arrive at total power costs due to the difference in fixed charge rates between countries. The significant fact is that those systems which tend to have high capital costs

A Press conference was held at the conclusion of each session of the conference (UN photo)

tend to have low running costs. Those countries which have concentrated on the development of those reactors with low fuel costs have low fixed charge rates which tend to offset their higher capital costs. In fact, the lower carrying charges were one of the main reasons which made these lines of reactor development attractive. It speaks well for these reactor technologies that they have been able to become more competitive with other fuels in their own countries in spite of increases in some elements of the fixed charges such as the interest rate increase noted

The Geneva exhibition: part of the USSR display (UN photo)

by both Dr. Lewis and Sir William Penney. This has been very severe in the case of the UK programme, where the rate of earnings used for economic assessment of reactor costs has risen from 4% in 1955 to $7\frac{1}{2}$% at present.

All of these reactor types still have considerable potential for economic improvement through increased unit size, through multiple unit stations, through large-scale production by replication of designs, and through steady engineering improvements of the type that have substantially reduced the cost of conventional stations over the years. The reported improvements by the United Kingdom in their initial 5000 MW(e) national power programme based on the magnox reactors are illustrative of this.

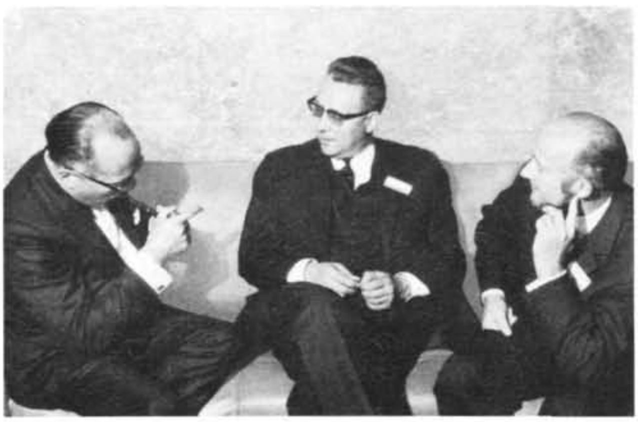
Scope For Improvement

Experience has also demonstrated that many power reactors can operate safely at power levels considerably higher than their initial design ratings, thus substantially reducing unit costs. The Yankee reactor has had its power level increased from 110 MW(e) initially to 175 MW(e). Reactors now in the design and construction stage still have this "stretch capability". For example, the Oyster Creek plant has a minimum capability of 515 MW(e) but if the expected power density is achieved in the core, 640 MW(e) is possible. Russian experience with the first 210 megawatt unit at Norovoronezh has made it possible to increase the capacity of the second unit, which is a modernized version of the first, to 365 megawatts or more. As experience accumulates, new plants will increasingly be rated initially closer to their ultimate capacity.

The reports have further indicated that there remains the possibility of substantial reductions in fuel cycle costs. The reductions to be achieved between the costs we have experienced up to now and future costs may be much greater than the 50% by which we have already reduced capital costs, although the amount of reduction will vary with reactor type. Fuel fabrication costs will be greatly reduced as we go on to develop improved fabrication techniques and increase the scale of the fabrication industry. Illustrative of this is the United Kingdom experience in fabricating almost two million magnox elements. The French reports on scaling up their fabrication efforts are also noteworthy. Increases in irradiation levels, which reduce fuel cycle costs, are also in prospect for all types of reactor fuels. Again the recent increase of the guaranteed irradiation level of the magnox fuel from 3000 to 4000 megawatt-days per ton is clear evidence of these achievements. Other components of operation, maintenance and fuel cycle costs such as the reprocessing of spent fuels also have potential for cost reduction.

As far as the fuel itself is concerned, possibilities for further savings have also been reported.

Natural uranium prices are currently well below the cost of the uranium used in the early cores of existing reactors. The widely quoted $6/lb figure is probably only an upper limit at present. Over a period of years this will help the economics of reactors fueled with both natural uranium and enriched uranium. Utilization of increased percentages of the uranium material mined, as conversion ratios increase, will also tend to reduce costs. However, certain of these potential reductions in fuel cycle costs may require some concomitant increase in capital costs just as the choice of natural uranium fueled reactors necessitates higher capital costs to start.



Corridor conference in the Palais des Nations. Mr. M.S. Halter, Mr. J. Goens and Mr. J. Bouquiaux of Belgium (UN photo)

Perhaps the most encouraging economic evidence of all lies in the projections of nuclear power growth given to this Conference. It appears quite certain that nuclear energy will play an increasing role in meeting the electrical power needs of many countries. The role of nuclear power will vary from country to country depending upon the extent and costs of their conventional resources. In this respect, the relative economics of nuclear power will be most important. The managers of the electric utility systems in all countries seem to insist, quite naturally, on economic competitiveness before they will engage in large-scale nuclear power programmes.

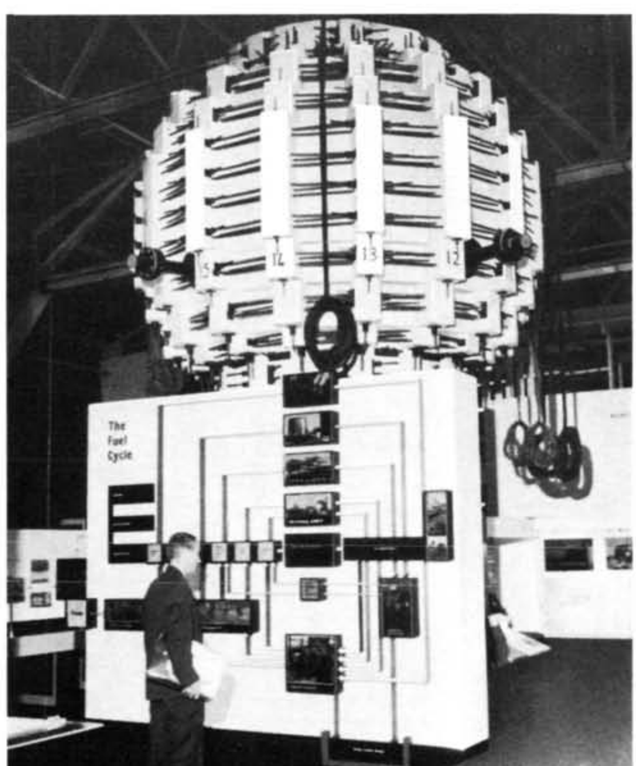
Future of Nuclear Power

The present economic types of power reactors, as developed to date, represent only a first step. Many reports on forthcoming converter reactors promise substantial improvements in economics and fuel utilization. While opinions may differ on the paths to pursue for the future, there is substantial agreement that we must develop improved converters to obtain these greater efficiencies. In looking toward ultimate future needs, there is almost general agreement as to the need to develop breeder reactors although some nations, like Canada, support the opinion that breeder reactors may not be required for many years in the future, if at all. The general consensus, however, is evidenced by the programme plans reported upon by the UK, USSR, France, Germany and the US.

A variety of forthcoming converter reactor types is presently under study and development in many parts of the world. Some of the potential advantages of these reactors include such properties as high conversion ratios, high specific power with resultant lower fuel inventory, high temperature and high thermal efficiency, larger single unit capacity, more efficient use of natural uranium, thorium and plutonium, and a potential contribution toward ultimate breeding systems. In some cases these converter concepts are based on design variations and extensions and combinations of the technology of the proven reactor types. In other cases, they represent innovations in technology.

As an example, heavy water moderated reactors represent a class of reactors which has good long range as well as short range potential. Reported at the Conference were extensions of the heavy water moderated technology to designs which are under study and development, incorporating such coolants as gas, organic compounds, water and steam. The or-

The Geneva exhibition:-UK panel on the fuel cycle, and above it, model of the pre-stressed concrete pressure vessel for the Wylfa nuclear power station (UN photo)



ganic cooled, heavy water concept, being developed under the ORGEL project by Euratom, the OCDRE project in Canada, the DON project in Spain and the recently planned programme in the US in connection with desalting appear to offer considerable promise, as do the French and Czechoslovakian programmes using gas cooling with a heavy water moderator and the UK work with steam cooling. It is clear from the scope of organic work planned that many countries have now mastered the handling of organics as coolants in reactors, by establishing and maintaining satisfactory purity standards in the cooling system.

Other examples of the evolution of advanced converter reactors from the present types of large power reactors are the spectral shift reactor design (employing a variable mixture of light and heavy water), the Swedish designs for pressurized and boiling heavy water reactors, the seed and blanket pressurized water concept and nuclear superheating. The experience in Sweden in achieving a very low heavy water leakage rate is very encouraging. The work in superheating appears to be particularly advanced in the USSR with the operation of the Beloyarsk power station.

Fast Reactors

Advanced reactor versions of graphite moderated gas cooled reactors are also being developed leading to high temperature, improved fuel cycle and higher conversion ratio performance. The AGR and Dragon projects in the UK (the latter a broad multi-nation effort) and the HTGR in the US represent principal efforts in this direction.

We find substantial development effort is also being directed toward sodium cooled reactors. The development of the sodium cooled graphite moderated reactor in the US has as its prime objective an economic, high temperature large power reactor system; in addition it is also contributing a significant amount of sodium technology which is applicable to the sodium cooled fast reactor systems. It is noteworthy that the Hallam Nuclear Power Facility in the United States, a reactor of this type, is the largest sodium cooled reactor in operation today. As a part of its over-all reactor programme, Germany is developing the KNK reactor project which will use a sodium cooled and zirconium hydride moderated reactor. The USSR programme also indicates substantial development of sodium components.

The reports reflect that emphasis on fast reactors has increased spectacularly in many countries during recent years. Germany, the UK, US and USSR all have announced or reaffirmed their intentions to proceed with relatively large prototype reactors, of several hundred megawatts electric capacity. We have heard reports from the USSR and the UK on their operating experience with fast reactors, the BR-5 and Dounreay plants, respectively. The integrated power of Dounreay has reached a total of 9080 MWd and its total electric power production is over 36 million kWh. Dounreay has been successfully demonstrated at full power and its continued use as a fuel test facility should contribute significantly to the UK's fast reactor programme.

It has been reported that the EBR II at the US National Reactor Testing Station is now producing power and it is anticipated that this reactor, as well as the Enrico Fermi plant, will produce valuable information on fuels, components performance and systems reliability. In France, the Rapsodie fast reactor is being constructed, which will give important data on physics behaviour, including the kinetics of fast reactor cores. The programme in Germany is progressing rapidly with an intensive evaluation being made of the various coolants and systems which may be applied in fast reactor technology.

There has been major emphasis on the eventual use of the plutonium and uranium-238 cycle to use effectively these materials by taking advantage of the high breeding ratios which appear feasible with this cycle. Both metallic and ceramic fuels are being evaluated for achieving high efficiency and low cost performance. This has led to the development of strong programmes directed toward evaluation of the neutronics and of inherent safety of such fast reactor fuel systems.

High Safety Standards

On the fuel evaluation side, a series of experimental fuel assemblies are being irradiated in the UK Dounreay reactor. Fuel material also has been irradiated to some 6 per cent burn-up in the USSR's BR-5. There are firm plans to carry out sample and fuel sub-assembly irradiations in the very near future in Rapsodie, Fermi, EBR II and in the fast flux loop in Belgium's BR-5. Further, the United States is building a fast test reactor, FARET, in which valuable physics measurements will be made and in which small cores can be tested at high power densities and to high burn-ups. The USSR also announced plans for their 60 MW(e) reactor, BR-60, in which they hope to demonstrate fuel burn-ups in excess of 10 per cent.

On the safety studies side, Doppler and sodium void coefficient measurements for fast reactor systems are under theoretical and experimental investigation in several countries. The session papers and discussions indicate general agreement on Doppler coefficient contributions to reactor kinetics and safety - it will be negative, large and reliable. Experimental work is being carried on in the critical facilities: ZEBRA, VERA and QUAGGA in the United Kingdom, ZPR-III and ZPR-VI in the United States, BFS in the USSR and FR-0 in Sweden. A number of facilities are planned for operation within the next five years; namely, MASURKA in France, SNEAK in Germany, and ZPPR in the United States. Another planned fast reactor project is the Southwest Experimental Fast Oxide Reactor, SEFOR, which is being undertaken in an international partnership of Euratom, the Federal Republic of Germany, Southwest Atomic Energy Associates (a group of American utilities), General Electric Company and the USAEC. SEFOR will be used to measure Doppler and sodium temperature coefficients on mixed plutonium-uranium oxide cores under transient conditions.

Although the main effort in breeder reactor development is in the direction of sodium cooled fast reactors, the reports here reflect that other fast reactor systems are being studied which would use other coolants such as gas and steam. A paper by the Swiss delegation describing a fast gas cooled system and a paper on the evaluation of different coolant systems in Germany were presented.

Work in several countries which may lead to thermal breeder reactors also was presented, utilizing the thorium and uranium-233 fuel cycle. Three of the reactor concepts described which offer the potential of utilizing the important energy reserves now locked in thorium, and eventually of breeding, are the high temperature gas-graphite system, the heavy water system, and the seed and blanket pressurized light water system. The potential advantages of fluid fuel reactors, such as the slurry oxide or molten salt systems, for thermal breeding also should be noted.

Nuclear Fuel Cycle

Let me turn to the manufacture of nuclear fuel, one of the most important technologies of nuclear power, where we find steady improvement through a diversity of approaches. These improvements have accounted for a slow, steady gain in fuel performance over the years, with operating temperatures becoming higher and an increase in the heat output of each unit of fuel throughout.

While the number of separate reactor concepts being pursued has narrowed somewhat in recent years, there are still many options as to the fuel cycle. Uranium metals are being used in low exposure natural uranium systems. For water cooled reactors the presently favoured and most thoroughly proven fuel material is uranium oxide. The results reported to this Conference indicate that this fuel will continue to be favoured in these reactors because it can sustain high irradiation exposures. A number of papers suggest that carbide fuels appear quite promising for non-water reactors. Other compounds such as nitride, sulphide, silicide, etc. have been reported upon.

Stainless steel and zirconium alloys continue to be prominent cladding materials, although fuel designers continue to be concerned about high temperature embrittlement under irradiation. Magnesium alloys have been serving well in low temperature gas cooled systems. For future applications ceramic fuel particles coated with carbon offer a good fuel for high temperature gas cooled reactors.

Remote handling manipulators in the exhibit of the Federal Republic of Germany attract interest at the exhibition (UN photo)

In Canada, typical fuels are natural uranium oxide clad in zirconium with fuel exposures estimated at 10 MWd/kgU. In France, the fuel is natural uranium metal with magnesium alloy cladding with fuel exposures around $3\frac{1}{2}$ MWd/kgU. In the USSR, the light water reactors use enriched uranium oxide clad in stainless steel alloys and will produce greater than 20 MWd/kgU. At the present in the UK "adjusted" natural uranium metal is clad in magnesium alloy and produces 4 to 5 MWd/kgU. In the US the fuel is largely uranium oxide clad in stainless steel or zircaloy with exposure expectations of 16 to 25 MWd/kgU.

A number of fluid fuel concepts such as molten salt, molten plutonium and aqueous slurries are also being studied and developed. These concepts offer the promise of significant reductions in fuel cycle economics, but they pose formidable problems that are still to be solved.

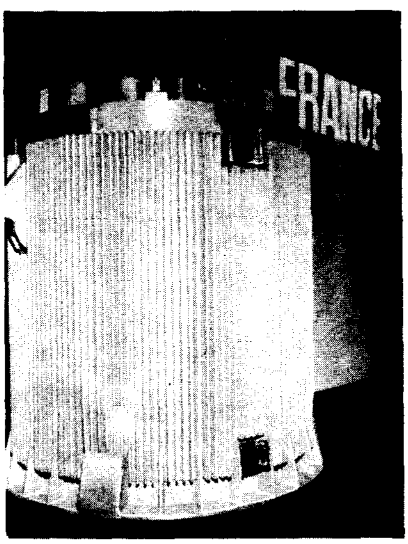
In view of the excellent progress experienced in developing long endurance fuel and reducing the costs of the various unit operations required to support the fuel cycle, it now appears that the economic optimum fuel exposure for converter type reactors will be in the same neighbourhood as a reasonable integrity lifetime of the fuels.

There have been several reports on the final phase of the fuel cycle - spent fuel reprocessing where there are a number of competing methods. At present the aqueous solvent extraction process is the accepted means for recovery of nuclear fuels. Other recovery processes such as pyrometallurgical and pyrochemical reprocessing however are advancing rapidly. In the end, the types of fuels that need to be processed will largely determine the most economic fuel recovery process.

As reported, the economic recycle of the bred fuels - plutonium and uranium-233 - can now be clearly foreseen. Within a few more years, plutonium recycle should be demonstrated in large commercial power reactors and it will be an important step in assuring the economics of the complete fuel cycle. Similarly, recycle of uranium-233 will follow a few years later.

Nuclear Safety and Waste Management

From the reports given at this Conference it would appear that throughout the world a general safety philosophy is developing for these nuclear reactor systems. The approach appears to be based largely on two related but separated and conservative paths. First, to prevent accidents, the reactor is generally designed conservatively, taking into account the kinetic or neutronic behaviour of the system, the characteristics of the materials used in its construction, and the incorporation of redundant instrumentation and control systems made as fail-safe as possible. In addition, reactor operators are carefully trained and detailed plant operating procedures are carefully followed. Secondly, most power reactors are equipped with a variety of engineered safeguards and emergency systems to minimize the consequences of an accident. For example, in some countries it is common practice to enclose the entire reactor system in a containment structure built to withstand considerable pressure and with a high degree of leak-tightness.



Shipping flask for fuel elements for the reactor Pégase, at French display (UN photo)

To support these policies, extensive nuclear safety research development and test programmes are conducted in almost all countries supporting reactor programmes. I believe we can be quite confident that these investigations, which cover a broad spectrum of subjects from reactor kinetics to fission product behaviour and materials research and in which a rather wide variety of scientific and technical disciplines are involved, will continue to contribute to nuclear energy's generally excellent safety record and will keep pace with the requirements of the industry as it develops.

The concern for nuclear safety does not cease with the continued safe operation of nuclear reactors. Their radioactive wastes must also be disposed of safely. Significant advances during the past years have been made and reported on here by Czechoslovakia, France, India and the US in the handling of radioactive waste products from nuclear energy operations, including power reactor installations. There has been a strong impetus throughout the world for vigorous waste management research and development programmes directed at further reduction in the quantities of radioactive materials being discharged to the environment.

As indicated in reports by France and the US, the strict management and disposal of radioactive waste at nuclear power stations are not limiting the development of large-scale and widespread nuclear power generation, and it may be noted also that during the past years, these waste handling operations have not resulted in any abnormal release of radioactivity to the environment. Radioactivity concentrations in power reactor plant effluents, with no environmental dilution, have been in the low range of 1-3% of the internationally accepted radiation protection standards.

The disposal of certain types of solid and liquid low-level waste effluents to the ground has proven to be safe and acceptable in many countries including Canada, the US and the USSR. The growth of land burial or storage sites, with the resulting economies, have essentially eliminated ocean disposal as an important waste management operation in many nations of the world with available land area.

More than 15 years' experience in the UK, the US and the USSR with the improving methods of handling highly radioactive liquid waste from fuel reprocessing by storage in special underground tanks has shown such storage to be a safe and practical interim measure. The long term usefulness of this method is limited, however, by the long effective life of the waste (hundreds of years) and the comparatively short life of storage tanks, estimated at several decades. Accordingly, a number of countries are developing means to convert high-level liquid waste to stable solids.

After high level liquids are converted to solids, there still exists a requirement for permanent storage of these solid wastes. Man-made structures may not be adequate to last for the hundreds of years that must pass before the wastes become relatively harmless; underground salt formations appear to offer an attractive alternate site for solids and concentrated liquid wastes because of their unique geological characteristics. Salt formations are dry, impermeable, have good structural strength and thermal conductivity and are not associated with usable ground water sources, and they exist in many parts of the world. Future developmental work in several countries along this path will be watched with interest.

With continued attention to this area of nuclear safety and waste management, I firmly believe that we can achieve the potential benefits of nuclear power and at the same time protect - or even improve - our general standards of public health and safety. The increasing use of nuclear power may indeed help to lessen atmospheric pollution, largely a result of the widespread use of fossil fuels.

Advances in Energy Conversion

The progress reported to this Conference in the area of energy conversion techniques, nuclear thermo-electric and thermionic conversion and magneto hydrodynamics, is opening new vistas for power generation.

The conversion of the heat of nuclear fission directly into electrical energy by means of the thermionic emission of electrons has been demonstrated a practical concept in the short time since the last Conference. The potential of this concept is perhaps best indicated by the extent of the effort, reported at this Conference, under way in the United Kingdom, the USSR, France and the US. Out-of-pile tests of converters with both uranium carbide and refractory metal emitters have shown lifetimes of thousands of hours. In-pile tests with both uranium carbide and uranium oxide fueled converters have operated for several hundreds of hours. Naturally the potential of these devices has stimulated materials development. As the technology of refractory metals is advanced to allow higher temperatures in reactors, the efficiency of the thermionic concept increases to the point where there is more and more incentive to overcome the many remaining problems.

The generation of electric power using magneto hydrodynamics techniques is being pursued in a number of laboratories. Here again the high temperatures of the plasmas required pose serious materials problems although the use of an inert working fluid would reduce the severity of the materials problem. The closed cycle converter operated in conjunction with a high temperature gas cooled nuclear reactor appears attractive. Proposals have been reported upon in this connection for reactors operating in the temperature range of 1800-2200°C.

Generation of electric energy by the direct thermo-electric conversion of the decay heat of radioisotopes has become an established technology since the last Conference. The technology is now being demonstrated not only in space but also in a number of terrestrial applications including weather stations, navigation buoys and lighthouses. A US barge-mounted weather station powered by a 60 watt strontium-90 generator is operating in the Gulf of Mexico. The Soviet Union reports the successful operation of an automatic weather station in the middle part of their country powered by a 5 watt cerium-144 fueled generator.

The direct thermo-electric conversion of the fission heat of a nuclear reactor has been demonstrated. The efforts in the Soviet Union which culminated in "Romashka" are of great interest. This uranium dicarbide (UC_2) fueled fast reactor, coupled to silicon-germanium thermocouples, has been operating at about 1800°C and generating power at a level of several hundred watts since the middle of August.

Protective clothing displayed on Sweden's stand at the exhibition (UN photo)

The United States hopes to demonstrate in the spring of 1965, with a developmental orbital flight of SNAP 10A, a 500 watt reactor unit also employing thermo-electric power conversion. This uranium-235 fueled and zirconium-hydride moderated reactor with liquid metal coolant will weigh less than 1000 pounds, including pay-load shielding. These reactor units in larger sizes will permit future communication satellites to broadcast simultaneously several channels of television directly to individual homes.

It seems clear that these reactor concepts, SNAP and Romashka, while receiving their impetus from the needs for space power, will find equally important roles as compact, reliable terrestrial power sources.

Other Applications

We have heard reports of the US studies for combination power and desalting application, and the studies by Israel and Tunisia. The USSR and France have presented interesting data on reactors for process applications such as in desalting situations. We are encouraged by these reports and expect that one or more combination nuclear power and desalting installations producing millions of gallons per day of fresh water will be constructed and in operation within the next four to eight years.

The studies that have been undertaken to date indicate that combination nuclear installations in the next few decades will be able to produce fresh water and electric power at costs which may be attractive for many municipal and industrial needs throughout the world. The water from these combination plants may even find economic potential for selected agricultural use when compared with other alternatives in specific situations.

Another immediate application of nuclear reactors is to supply power and heat in remote locations. We have heard a Soviet Union report on the 750 kW(e) ARBUS organic cooled and moderated package plant. This plant, which began operation in the summer of 1963, uses a carbon steel primary loop and pumps and auxiliaries available from the oil industry for lower cost, and consists of 19 packages each weighing not more than 20 tons. Soviet scientists have also described the 1500 kW(e) TES-3, a pressurized water plant arranged on four large, tracked vehicles. US scientists described their portable pressurized water reactors, using compact cores of uranium oxide-stainless steel cermet fuel, together with details of operating experience at several sites in the US, the Arctic, and the Antarctic. The success of these plants which generate up to 2000 kW(e) in addition to a substantial quantity of space heat provides the technology which is applicable to any small nuclear power plant for remote installations, be it for mining, a scientific mission or for other needs.

The hopeful outlook for the maritime application of nuclear power expressed in the 1958 Conference can now be supported by successful operating experience with two nuclear powered vessels. The icebreaker Lenin, during its nearly five years of operation, has demonstrated the advantages of nuclear power for this important service. The N. S. Savannah is now completing its second European voyage and is also meeting its expectations.

Two countries, West Germany and Japan, already have firm projects for construction of their first nuclear powered ships. Others are carrying on development in preparation for future projects, and the Soviet Union announced during the Conference that it expects to build two new nuclear icebreakers, with the first one coming into operation in 1971.

The US Plowshare programme for developing peaceful uses of nuclear explosives has received considerable attention. Despite the fact that this programme is in an early stage of development and many data are needed before useful projects can be undertaken, the potential for use of nuclear explosives in excavation, mining, recovery of gas and oil and as a research tool appears promising. Significant suggestions for methods of international collaboration and participation have been proposed by delegates from a number of nations. It is hoped that through such international support and cooperation nuclear weapon technology can be converted into a valuable research and engineering tool for the benefit of all mankind.

Research and Hig Flux Reactors

Conference papers suggest that the uses of newer research reactors fall plainly into three main kinds of activity. First, there is the continuing examination of radiation effects on materials for the construction, moderation and fueling of reactors. Second is the more fundamental and better controlled kind of physical research made possible by reactors designed to meet more specific research needs. A good example of this is the work reported on pulsed reactors. The third area is the production of radioisotopes for medical therapy, for tracer uses and now for the production of relatively large quantities of transplutonium elements, in both the US and the USSR.

My personal bias is evident when I say that the prospect of performing basic and exploratory research on gram quantities of californium isotopes, hundreds of milligrams of berkelium, milligrams of einsteinium and up to a milligram of fermium produced in these reactors is one of the most exciting to which we have been exposed in decades.

The shift from all-purpose to specialized research reactors is most clear when one considers the construction of high flux reactors for either materials testing or isotope production. In operation or shortly to be in operation are the HFIR, HFBR and ATR in the US, the MP, MPR and SM-2 in the USSR, and the PEGASE in France.

This desire for higher neutron fluxes has stimulated technological developments of an order of magnitude, or more in some cases, beyond the conditions existing in present power reactors, thus paving the way for further improvements in power reactors. Such major advances include the development of fuel elements and cores to operate at very high power densities and heat fluxes.

We have also learned how to specially tailor the flux in experimental areas, and through past experience have come to appreciate the need to coordinate carefully the design and construction of the reactor with our research needs. The new knowledge has resulted in such notable experimental facilities as fuel element testing loops in the USSR MR reactor and the French PEGASE reactor, the high temperature gas cooled loop in the UK Pluto reactor, the liquid hydrogen cold sink in the French high flux beam reactor and the liquid hydrogen moderator chamber in the British DIDO reactor.

Radioisotopes

It is clear that the technology associated with isotopes now permeates every scientific and engineering field. It is indeed one outgrowth of the atomic age that can be employed by all countries regardless of size or state of technological advancement.

In my judgment, an outstanding technical accomplishment of the past few years - as represented by papers presented here - has been the effort to produce, separate and purify radioisotopes in quantities sufficient to permit consideration of their use as sources of thermal and radiation power. Several countries have reported major progress in this area. Another area of outstanding achievement has been the use of radioisotopes in medicine to alleviate man's suffering; this is the domain of what I have called "The Humane Atom".

From the scientific viewpoint, the widespread establishment of neutron activation analysis as a standard technique for measurement of trace quantities of almost every element in the periodic table represents a contribution of immeasurable value to medicine, agriculture and the physical sciences. In fact, its application has been extended even to law enforcement.

Ionizing radiation - whether the source be radioisotopes, machines or reactors - is finding a place in the processing of organic chemicals, plastic and other materials, in sterilization of medical supplies and in the preservation of foods.

Controlled Thermonuclear Reactions

The disclosure of previously classified research on controlled thermonuclear reactions was one of the main features of the 1958 Conference. That year and its aftermath was an age of innocence for this intriguing field of research - a field of research which could lead to the extraction of an inexhaustible supply of energy from the oceans. The papers presented here show that we have learned a great deal in the intervening years. Plasma physicists now know well the hard scientific and engineering realities of suspending, squeezing and holding in space gases with temperatures of the order of those found in the stars. They have learned that the prospects for an easy engineering short-cut to controlled fusion are not bright. They have demonstrated, to the satisfaction of themselves and the nuclear community, that controlled fusion is one of the most difficult scientific and engineering problems ever encountered.

The early optimism followed by the sobering experience of the last six years should not, however, blind us to the truly significant progress that has been made. An important and exciting new area of fundamental science in plasma physics has grown up. I shall mention three of the many evidences of the maturing of plasma physics. One is the increasing sophistication of the field, represented in part by the development of a new language which is getting beyond the comprehension of the rest of us in the nuclear field. The second is sheer size - the general increase in the number of scientists in controlled fusion research, the increased investment in scientific facilities by governments and the expanding literature. The number of scientific papers per year on plasma physics has increased about 45 per cent since 1959, as have the number of workers in the field. A rough count indicates that work is now going on with 10 major experimental devices in the USSR, 14 in the UK and Western Europe, 4 in Japan and Australia, and 10 in the US.

The most important indicator of growth, however, lies in the scientific results of these years, contained in papers presented here. Whereas in 1958 plasma scientists were only on the verge of producing fusion reactions with thermal neutrons truly attributable to the reaction, a number of laboratories today regularly produce plasma with ion energies exceeding the so-called minimum ignition temperature.

A usable controlled fusion reaction would require nuclear reactions of adequate duration, temperature and density of plasma. Today one machine may best approach the production of the required temperature, another the required duration of nuclear reactions and another the desirable density of plasma, but no one machine is capable of meeting all three requirements. The aim now - and it is a long-range one - is to achieve reactions combining all of these factors satisfactorily in a single machine.

An important foundation of knowledge has been erected on the most important problems of controlled fusion, namely plasma stability. The pioneering work of Ioffe in the Soviet Union on the confinement of plasma in a region where the pressure of the magnetic field is at a minimum, the so-called Minimum-B confinement, is to be admired. It is also encouraging to learn of the many new experiments under way to measure the limits of plasma stability under varying conditions, such as the NTSE in the UK, DECA in France, and the DC-2 in the US.

There is a growing ability to predict plasma behaviour. Numerous good checks between experiment and theory have been achieved - for example, in the Phoenix experiments in the UK, and in the Levritron and ALICE experiments in the US. Such agreements did not exist in any laboratory results in 1958, and these are a strong indication of the growing maturity of plasma science.

We cannot be absolutely sure that controlled thermonuclear power can be developed, although the general feeling at the Conference is that this will be accomplished at some time - perhaps before the end of the century. Certainly the benefit - essentially unlimited power for the earth's population - is one we cannot overlook."

THE NEW BOARD OF GOVERNORS

Mr. H.M. Tohamy (UAR), Vice-Chairman

Miss Blanche Margaret Meagher (Canada), Chairman of the Board, 1964-65

Mr. W.O. Billig (Poland), Vice-Chairman

Miss Blanche Margaret Meagher was elected chairman of the IAEA Board of Governors for 1964-65, after the new Board had been constituted at the Eighth Session of the General Conference in September. Since 1962 Miss Meagher has been Canadian Ambassador to Austria, and Canadian Governor of the Agency. Miss Meagher joined the Canadian Department of External Affairs in 1942, and has held a number of foreign diplomatic appointments; she has also served on Canadian delegations to the UN Educational, Scientific and Cultural Organization, the International Telecommunication Union, the Economic and Social Council of UN and the UN Disarmament Sub-Committee.

The Vice-Chairmen of the Board are Mr. Wilhelm Billig (Poland) and Mr. Hassan M. Tohamy (UAR). Mr. Billig is Chairman of the State Council for Atomic Energy, and High Commissioner for Peaceful Uses of Atomic Energy. Mr. Tohamy is Ambassador to Austria, and Resident Representative to the Agency.

Of the twelve elected members of the Board, five were chosen by the General Conference in 1964 for two years, viz. Argentina, Chile, Netherlands, Thailand and the United Arab Republic. Seven were elected in 1963: Afghanistan, China, Congo (Leopoldville), Morocco, Romania, Switzerland and Uruguay. The remaining thirteen members have been designated by the Board: Australia, Belgium, Brazil, Canada, Finland, France, India, Japan, Poland, South Africa, USSR, United Kingdom and United States.