including about 140 from outside the United Kingdom. In more recent years similar organizations have been formed in many other parts of the world, notably in Australia, Canada, the Netherlands, Scandinavia, and the USA. The Agency has close and cordial relations with many of these associations, as well as with numerous individual medical physicists. An International Organization for Medical Physics, linking the various national associations, was inaugurated at the beginning of this year.

NEW MATERIALS IN NUCLEAR TECHNOLOGY

A major objective of current research in nuclear technology is to develop reactor materials that can withstand the effects of high temperature and intense radiations. The efficiency of a nuclear power station - more specifically, the efficiency of utilizing the heat for the production of electricity - is partly dependent on the temperature at which the reactor can be operated, but the working temperature cannot be increased to the point at which the fuel elements will fail.

This has led to a search for non-metallic forms of nuclear fuel, because in general these have a higher melting point than metallic fuels. Oxides of uranium, of course, have been used as reactor fuel from the earliest days of nuclear technology, but considerable work is still being done to improve the production and fabrication of oxide fuels so that they may be able to stand up to the progressively exacting conditions to which they may be subjected in a reactor. Simultaneously, work is being carried on to develop other forms of non-metallic fuel, such as carbides, nitrides and silicides, as well as new materials for use as reactor components other than fuel.

The IAEA Director General, Dr. Sigvard Eklund (middle), addressing the opening session of the Prague conference. Others on the podium, left to right: Mr. Joseph C. Delaney (IAEA); Mr. Witold Lisowski (IAEA); Dr. Karel Petrzelka, Resident Representative of the CSR to IAEA; Dr. Jan Neumann, Chairman of the CSR Atomic Energy Commission; Dr. Jaroslav Kozesnik, Vice-President of the CSR Academy of Sciences; Dr. Adolf Svoboda, Mayor of Prague; Dr. Čestmir Simane (IAEA); and Mr. Alexander Pushkov (IAEA)

A conference on New Nuclear Materials Technology, held in Prague last July by the International Atomic Energy Agency, showed that this work is likely to improve considerably the performance of nuclear power stations and thus contribute to a reduction in power costs. Hopeful references to this possibility were made both by the Agency's Director General, Dr. Sigvard Eklund, in his opening address to the conference, and by Dr. Cestmir Simane, Director of the Agency's Division of Technical Supplies, in a speech at the closing session.

Dr. Eklund said that recent experience with nuclear power stations had shown that the working temperatures, burn-ups, load factors and lifetimes of the plants were greater than anticipated and this had given rise to cautious optimism about the future of nuclear power. In the established reactor types, however, temperature limitations of the fuels or of the cladding materials imposed a limitation on operating temperatures and net plant efficiencies. For example, in Magnox cladding (as in the natural uranium power reactors operating in Britain) the steam temperature was limited to 400°C, and the net plant efficiency in both Magnox reactors and the light water reactors fuelled by enriched uranium was about 30 per cent. Uranium oxide fuel with stainless steel cladding, on the other hand, would permit steam temperatures of about 480°C. With uranium carbide fuel dispersed in graphite one could attain a steam temperature of 540°C, which would give a net station efficiency of about 35 per cent.

Another advantage of non-metallic fuels, Dr. Eklund said, was the possibility of achieving higher fuel burn-ups, due to their stability under temperature and radiation effects. This would permit better utilization of fuel and less frequent refuelling. All this, said Dr. Eklund, indicated that non-metallic fuel elements could contribute significantly to the economic competitiveness of nuclear power.

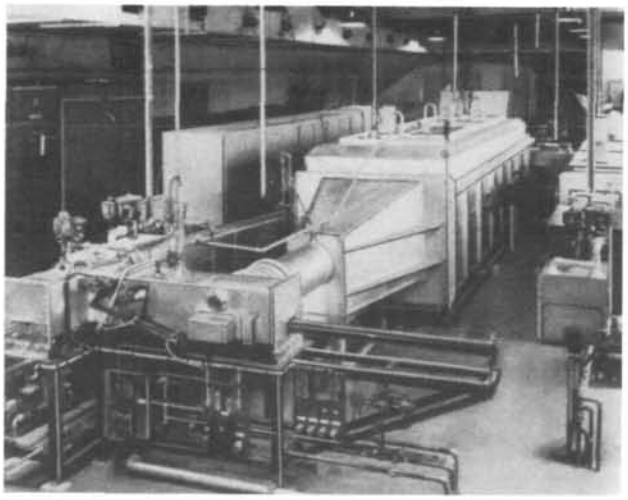
Dr. Simane pointed out at the end of the conference that although the scope of the conference covered all new materials used in nuclear technology, the discussions had been mainly concerned with the development of new forms of reactor fuel. Oxides of uranium, he recalled, had long been in use, but it was clear that their full potential had not yet been realized. Various problems had been encountered (for example, the low thermal conductivity of uranium oxides at high temperatures), but as the discussions showed, a number of promising approaches were being made to solve these problems. Largely because of the conductivity problems associated with oxides, more and more attention was being paid to the development of carbide fuels, and a number of interesting papers had been presented at the conference on the production and fabrication of uranium carbides as reactor fuel. Dr. Simane said he had no doubt that work on these lines would make it possible to operate reactors at higher temperatures than at present.

The conference, which lasted five days and was divided into nine sessions, discussed the technology of both producing and fabricating non-metallic fuels. It also heard reports on the experience so far gained with such fuels - either from reactor operation or from preliminary tests. Further, there was some discussion on the use of new materials as reactor components other than fuel.

Oxide Fuels

Much of the discussion on oxide fuels centred on methods of preparing uranium dioxide and its fabrication as reactor fuel, because the behaviour of the fuel is largely dependent on the past history of the material and the processes applied to fabricate it as fuel elements. Among the main processes involved are (1) reduction of the oxygen content of the uranium extracted from ore deposits so as to form the oxide with the lowest oxygen content, viz. uranium dioxide (UO_2), and (2) "sintering" or densifying of the dioxide powder in order to make it extremely compact in the form of either pellets or small grains tightly held together. The sintering is often done by the application of heat and pressure.

A few papers were presented on methods of preparing uranium dioxide. Among them, a paper by three Czechoslovak scientists (G. Landspersky and others) described the phase transformations in the manufacture of uranium dioxide from ammonium diuranate. Another, by D. Kolar and two other Yugoslav scientists, was on the conversion of uranium hexafluoride (UF_6) to uranium dioxide; in the work described, a complex ammonium uranium fluoride was prepared by the reduction of uranium hexafluoride with ammonia in the gaseous phase at a temperature of 40°C, and the product was retained in electrical precipitators and converted into uranium dioxide by reaction with water vapour and hydrogen.

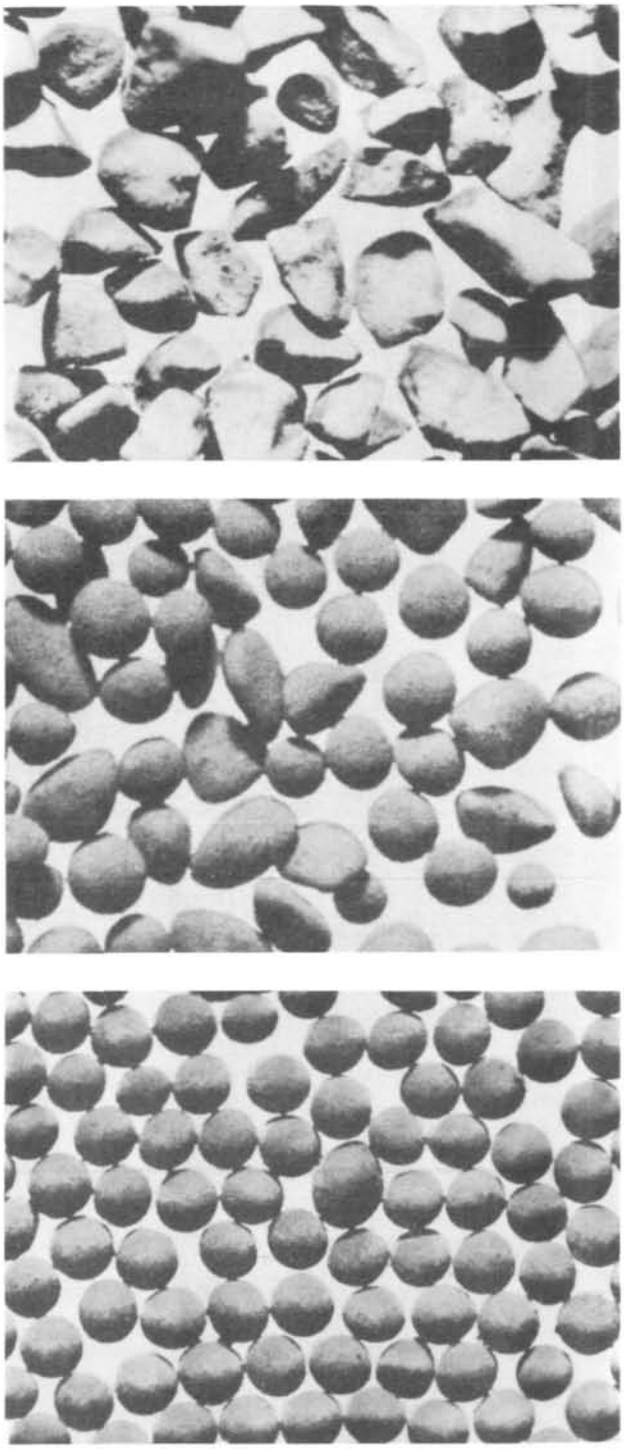


General view of a furnace for industrial sintering of uranium oxide. (Picture reproduced from paper by R. Hauser and A. Porneuf)

Uranium dioxide suitable for sintering is produced in France at various industrial plants by the reduction of trioxide obtained by the calcination of a precipitated ammonium uranate. The different types of equipment as well as the precipitating, filtration, calcination and reduction processes used in this work were described in a paper by M. Delange (France). Two other French scientists (R. Delmas and J. Holder) gave a paper on the preparation of sinterable uranium dioxide for the fabrication of the fuel elements for EL-4, the heavy water moderated, gas-cooled, enriched uranium power reactor now under construction in France.

Sintering techniques were discussed in a number of papers. A continuous furnace for industrial sintering of uranium oxide was described by R. Hauser and A. Porneuf (France). The main features of this furnace are automatic operation, rigorous control of presintering and sintering atmospheres, flexibility of temperature regulation, and high output (5 tons of uranium oxide per month). It can operate continuously up to 1700°C, and the sintering atmosphere is provided by cracked ammonia or pure hydrogen.

A process for producing small sintered spheres of uranium dioxide by forming the spheres in a die and pressing them by a special method was described in a paper from Italy (C. Bondesan and others), and another Italian paper (E. Brutto and others) discussed thermal shock tests on such spheres. In a paper on



These three photographs, taken from the paper by H. Lloyd, show the progressive rounding of uranium dioxide granules by gyration. The picture on top shows the granules before being subjected to the gyration process, the one in the middle was taken after four hours' gyration and the one at bottom after nine hours' gyration

the thermal behaviour of uranium oxide fuel elements, H. Andriessen and J. M. Leblanc (Belgium) explained that the heating power that can be extracted from a fuel element is limited, for one thing, by the thermal conductivity of the element and, for another, by the maximum temperature permitted at the centre of the element. They reported experimental work aimed at (a) determining the variation with temperature in the effective thermal conductivity of uranium oxide fuel elements densified by various methods (vibration, shaping, etc.) and (b) assessing the extent to which structural changes in the material (sintering, grain coarsening, melting, etc.) affected the thermal conductivity.

Several other papers were given on the thermal conductivity of uranium oxide fuels, and R. Caillat and others (France) presented a report on in-pile measurements of the thermal conductivity of uranium oxide in the French reactor EL-3.

Reviewing some of the recent developments in uranium dioxide technology, J. A. L. Robertson (Canada) pointed out that uranium-dioxide fuelled power reactors had been operating on a routine basis for several years, and good performance of this form of fuel was now taken for granted. The aim of current technological research was no longer to demonstrate feasibility but to reduce fuelling costs by bringing down the cost of fabricating the fuel and improving its performance. Referring to three factors which would limit the performance, namely temperature distribution, fission product release, and sheath strain due to thermal expansion of the fuel, Mr. Robertson noted that significant advances had recently taken place in the understanding of all these three phenomena.

As regards temperature distribution, Mr. Robertson referred to a recent discovery that a particular single crystal of uranium dioxide had a very high thermal conductivity at elevated temperatures (instead of the conductivity falling off with an increase in temperature). Further investigations at Chalk River, Canada, had helped to explain the factors on which this enhanced conductivity depended. Similar progress had also been made in the understanding of the other two factors: release of fission product gases from the fuel and distensions of fuel element sheaths as a result of thermal expansion of the fuel. Mr. Robertson said that the in-reactor measurements which were now possible would determine whether any potential economic advantage lay in novel forms of fuel. Meanwhile, continuing development of sintered uranium dioxide in the simple rod geometry would provide stiff competition.

One important technological approach which is now being tried in several countries is to have a combination of ceramic (non-metallic) and metallic materials. The products, called cermets, consist of non-metallic particles dispersed in a metallic matrix. One main idea behind this approach is to overcome the problem of the low conductivity of uranium oxides at high temperatures, the metallic matrix providing a good conductor.

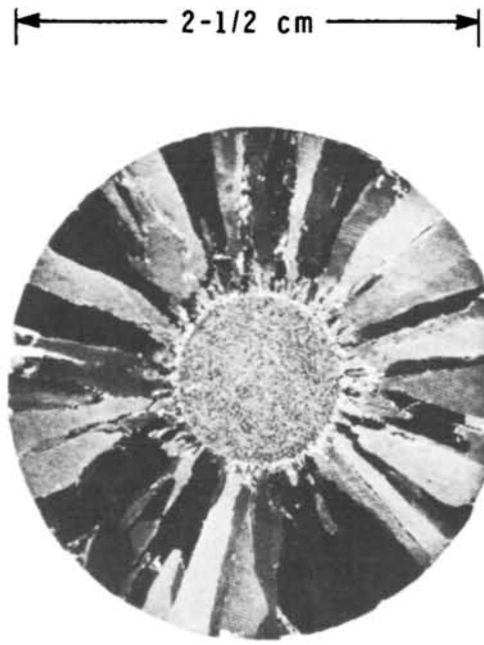
Various cermet fuels have already undergone considerable development, and uranium dioxide dispersed in stainless steel plates has been successfully used in several American reactors. Discussing this form of fuel element, H. Lloyd (UK) stated that in most cases the uranium dioxide content of the fuel in plate form had been relatively small, and he reported on experiments to explore the feasibility of fabricating cermets with a higher content of uranium dioxide. The results, he said, had been encouraging and had shown that UO_2-stainless steel cermet plates containing 30 to 50 vol. % UO_2 could be fabricated.

Another paper from the United Kingdom (J. Williams) discussed dispersed oxide fuels based on plutonium dioxide, uranium dioxide and thorium dioxide as the fissile and fertile phases and oxides of beryllium, aluminium and magnesium as matrix materials. The author reviewed the potential usefulness of these cermets as high temperature reactor fuels in terms of fuel integrity and fabrication. He also pointed out that a variety of techniques were available for the preparation of the fissile/fertile particles, for their coating and for their incorporation into high density matrices.

Certain processes in uranium dioxide dispersed in a matrix were discussed in a paper by six Soviet scientists (S. T. Konobsevsky and others). It gave some data on the effect of high burn-up on the structure and spacing of the uranium dioxide lattice and the interaction of the uranium dioxide with aluminium during irradiation. Another Soviet paper (V. E. Ivanov and others) described certain features of uranium-based cermet alloys.

Another approach - to have fuel elements composed of a thoria core and a uranium oxide ring - was discussed in a paper by two French scientists (J. Doumerc and R. Hauser). They pointed out that it is the high temperatures within nuclear fuels with a uranium oxide pellet base and the resulting abrupt heat gradients that impose practical limits on their use. They described a study aimed at investigating the power gains that might be expected by concentrating the fissionable material, the source of heat, at the periphery of the fuel. The fertile material forming the central part plays only a minor role in the production of power, and that too only at the end; besides, it can tolerate slightly higher maximum temperatures than the fissionable material.

A paper by five American scientists (G. E. Benedict and others) gave an account of the work done at Hanford Laboratories in the USA on techniques of producing reactor fuel oxides possessing unique properties. They stated that by the use of molten chloride salt solutions as reaction media it had been found possible to produce crystalline uranium and plutonium dioxides and solid solutions of various oxide mixtures at relatively low temperatures. Exploratory work had indicated that these techniques might also be useful in the preparation of other non-metallic fuel materials.



Cross-section of a uranium dioxide cylinder. (Picture reproduced from paper by G.E.Benedict and others)

Carbides and Other Materials

As indicated before, carbide fuels appear very promising, especially for use in fast reactors. Several papers were given at the conference on the production of uranium and plutonium carbides and their fabrication as fuel elements.

Uranium carbides can be prepared by the carbon reduction (i. e. reduction of oxygen by reaction with carbon) of uranium dioxide. The oxidizing tendency of uranium dioxide presents a difficulty, but according to a paper by G. H. B. Lovell (South Africa), the problem can be solved by using stable urano-uranic oxide (U_3O_8) in place of uranium dioxide. Mr. Lovell discussed two methods for preparing the carbide from the stable oxide of uranium (U_3O_8), and stated that satisfactory samples of uranium monocarbide and uranium dicarbide, as well as cermets of uranium monocarbide and uranium metal, had been prepared by these methods.

Reporting on studies on uranium carbide at Spain's Junta de Energia Nuclear, H. Bergua and A. Fornes in a paper stated that uranium carbide is produced from uranium metal in small quantities and from uranium dioxide in large quantities. In the metallic process, uranium is first reduced to finely divided powder, which is then mixed with graphite powder, pressed into pellets and either sintered or fed directly into an arc melting furnace. For preparation from uranium dioxide, the oxygen content of the dioxide is reduced by reaction with carbon.

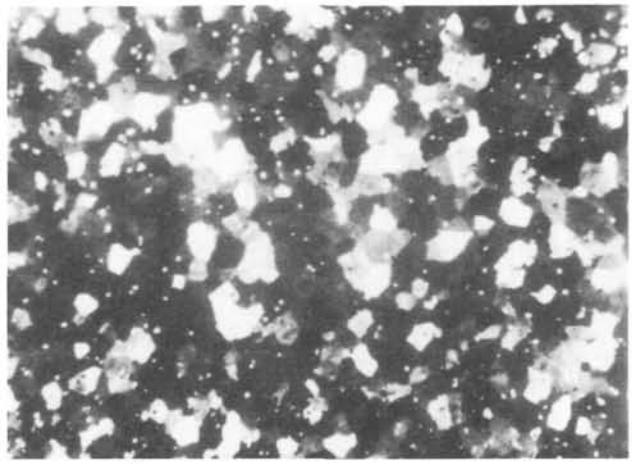
J. Vangeel (Belgium) described methods of stabilizing uranium monocarbide and producing single-phase carbide, and discussed how the melting of uranium carbides in the presence of oxygen and nitrogen yields a single-phase uranium carbonitride.

Discussing the sintering behaviour of carbide powders, L. E. Russel (UK) said that oxidation of the fine powders has an inhibiting effect on sintering; he reported experimental work which has thrown some light on the mechanism of this inhibition. In another paper, he discussed some aspects of the structure and properties of uranium carbide and plutonium carbide alloys. Yet another paper on this subject from the United Kingdom (R. Ainsley and others) reported studies on the preparation of carbides by the direct reduction of oxides with carbon in vacuo over a temperature range of 1300 - 1800°C. The carbides produced, it was reported, had been sintered to high densities in various gas atmospheres and in vacuo.

A paper on radiation damage in uranium carbide, by B. G. Childs and J. C. Ruckman (UK), gave the results of research into the irradiation behaviour of cast uranium carbide following that reported at last year's IAEA symposium on radiation damage in solids and reactor materials.

The possibility of using uranium carbide as reactor fuel has led to the development of various processes for densifying it. A paper by A. Porneuf and R. Hauser (France) described the research, design and industrial development concerning a process for the fabrication of uranium carbide bars by arc melting and casting.

R. Liebmann and two other authors from the Federal Republic of Germany presented an account of the development of non-metallic fuel elements for the high temperature gas-cooled reactor of the Brown-Boveri/Krupp Reaktorbau GmbH. Two fuel element concepts were considered and developed. In the first, the fuel insert consists of a mixture of uranium dicarbide and graphite, and in the second, the insert is a solid solution of uranium monocarbide and zirconium monocarbide. Data on fission product release from the fuel inserts were given in another paper.



The microstructure of a hot-compressed solid solution of zirconium carbide and uranium carbide. (Picture reproduced from a paper by R.B. Kotelneekov and others)

Papers were also given on certain other materials that can be used in nuclear technology. Several of these papers dealt with beryllium which can be used both as moderator and as neutron reflector in a reactor. Fabrication of beryllium oxide powders was the subject of a paper by J. S. O'Neill and D. T. Livey (UK), and a paper by three French authors (R. Beauge and others) discussed the effects of neutron irradiation on the physical properties and mechanical characteristics of beryllium oxide bricks used as neutron reflectors.

According to a paper by six Soviet authors (V. E. Ivanov and others), magnesium cermets and magnesium-beryllium alloys have many potential uses in nuclear technology, thanks to their great stability under the effects of high temperatures. The paper gave some results of work on the development of the cermets and the super heat-resistant alloys produced by powder metallurgical methods.