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MONTHLY INFORMATION BULLETIN OF
THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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Public Relations Branch
U.K.A.E.A.
11 Charles II Street
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Cambridge radio telescope inaugurated

Another giant "eye" for observing the remoter areas of the universe has been opened with the inauguration of the new 5-km telescope at the Mullard Radio Astronomy Observatory of the Cavendish Laboratory on 17th October, 1972. The inauguration ceremony, carried out by Sir Alan Hodgkin, President of the Royal Society, was attended by a large number of national and overseas press.

The U.K.A.E.A., as agents for the Science Research Council, arranged contracts with all parties concerned with the design, manufacture, setting out and construction of the telescope which was built with a grant of £2.1 million from the S.R.C.

In addition to their role as project managers, the Engineering Division of the Authority produced detailed designs for the foundations and civil engineering works and for the complete control and power cabling systems. They also supervised the construction and were closely involved in the accurate location and alignment of the aerials.

It was a fundamental requirement that the intersection point of the polar and declination axes of each of the eight aerials, about which the reflectors are steerable, should lie on a straight line. The reference points which define the vertical projection of this line onto the earth's surface were established by the Ordnance Survey who also found its astronomical co-ordinates to one second of arc.

In order to satisfy the requirement that the aerials should remain on the straight line the Authority's design of the foundations had to achieve as high a degree of stability as possible. The geological conditions were unfavourable: a layer of alluvium one to three metres thick on top of gault clay with a high water content. A total of 120 in-situ concrete friction piles each 0.9 metres diameter were used and taken 7.5m to 9m into the gault clay depending on their loadings.

At the fixed aerial positions, the piles are arranged in groups of three, and support the feet of the tubular steel tripods which in turn support the reflectors. They are similarly arranged at the observation positions along the track but here the piles support bearing pads which locate the moveable aerials when observing.

Authority staff worked with the Ordance

Survey and the National Physical Laboratory to develop techniques which established reference points along the 5km of track to a remarkably high degree of accuracy.

Authority staff also extended these reference points to provide other points to define the polar and local vertical planes at each of the fixed aerials and specific observation positions. This entailed a knowledge of the variation in the local vertical at each of these locations—in the north-south and east-west planes.

Authority surveyors accurately located appropriate points over which survey instruments could be positioned to locate the polar axis of each aerial and evolved a technique for setting up the optical axis of the auto-collimating theodolite reading to 0.2 seconds arc on the polar axis at each specific location on which aerials were erected. This technique was further developed to record the characteristics of each aerial reflector when set at different declinations and hour angles.

They were assisted in some aspects of this survey work by surveyors from the Ordnance Survey and Engineering Surveys Ltd.

The work also included designing the high voltage electrical power system to supply the eight aerials spaced out over a distance of 5 kilometres along the array. This 11,000 volt system was laid underground as were other high voltage cables to replace nearby area board overhead lines which would have interfered with the radio reception.

A scheme was produced for the laying and jointing of approximately 55 miles of low loss radio type co-axial cable including path compensating loops in the ground and cut to very precise lengths to provide a most carefully balanced connection between all the aerials, and the control room, for the reception of the radio signals.

As a central control computer is used to control all movement of the aerial array, a network of multi-core cables was necessary to enable the precise position of each aerial to be signalled back to the control room, and the computer to send out the necessary star tracking instruction to the aerial drive motors. The cable systems were complicated by having to provide 32 plug-in positions along the track to enable the four moveable aerials to change position as required by the observatory.

IN PARLIAMENT

Desalination

18th October, 1972

MR. FARR asked the Secretary of State for the Environment by what date he expects that the first full-scale plant for the desalination of salt water will be operating in Great Britain.

Mr. Peter Walker: In the light of the latest information, it seems unlikely that desalination will make any substantial contribution to water resources in the immediate future, although there may be some desalting applications and also some contribution to purification of river water and processing of effluent. I am anxious to examine any developments in this sphere and if viable to give them every encouragement.

Mr. Farr: Is my right hon. Friend aware that there is a projected shortage of water in the South-East by the 1980s and that the construction of reservoirs is becoming more difficult for geographic and environmental reasons? Will he tell the House what happened to the Ipswich desalination plant which was temporarily postponed a year or so ago and of which we have heard no more?

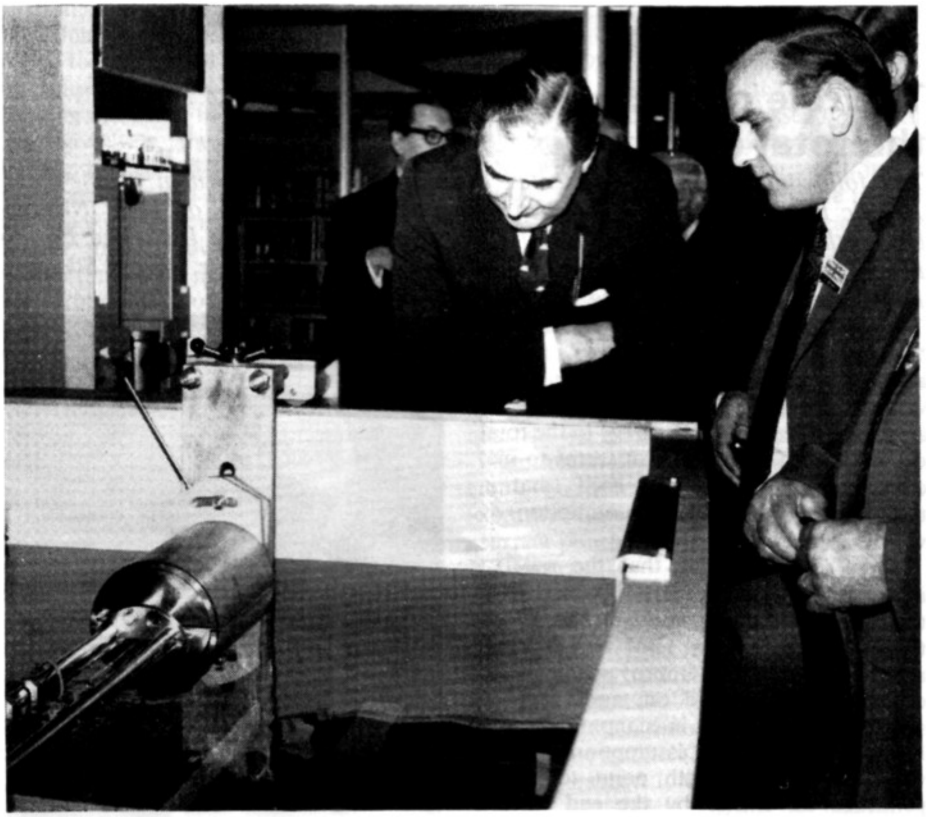
Mr. Walker: The Government offered to pay the majority of the money required for that project, but the private sector involved was unwilling in the end to put in any money whatsoever. As a result, our judgment was that it was right to obtain from them the technical information they had available, which may be of use at a later stage, and to try to obtain some European collaboration in this sphere.

Nuclear enterprises

23rd October, 1972

MR. SKEET asked the Secretary of State for Trade and Industry whether it is Government policy to approach development in the nuclear field by integrated European companies or through national companies linked with European and other firms under licensing agreements.

Mr. Emery: The statement made by my right hon. Friend to the House on 8th August made it clear that the proposed new nuclear design and construction company should be capable of playing its part in international, and especially European collaboration in the development and exploitation of nuclear reactors, to



Mr. Peter Emery, Parliamentary Under Secretary to the Department of Trade and Industry, visited the Authority's stand at Nuclex and is seen listening to Mr. Stewart Swinden, Sales and Service Engineer, Reactor Group, describing the equipment used in the Reactor Plant Inspection Service. The equipment, which was demonstrated in the sort of underwater environment in which it has to operate during the inspection of light water reactors, attracted considerable attention. The RPIS has already announced two contracts for this work in Europe—in Holland and Belgium.

which the Government attach much importance. The precise forms of collaboration will depend on the circumstances in each case.

25th October, 1972

MR. SKEET asked the Secretary of State for Trade and Industry if he will list the multi-national European links which the United Kingdom Atomic Energy Authority, British nuclear companies and contractors have negotiated in recent years and the role each such enterprise was designed to perform.

Mr. Emery: The U.K.A.E.A. has not in recent years negotiated the setting up of any new enterprises with organisations in other European countries. However, it has well established and good working arrangements with its European counterparts for the exchange of research and development information. In particular, the Authority has been a signatory to agreements covering the O.E.C.D. DRAGON (H.T.R.) project since 1959.

British Nuclear Fuels Limited, in which the U.K.A.E.A. is at present sole shareholder, has in recent years associated in three multi-national companies, CENTEC GmbH, URENCO Ltd.—both formed pursuant to the intergovernmental agreement of 4th April, 1970, on collaboration in the development and exploitation of the gas centrifuge process—and United Reprocessors GmbH. The role each of these enterprises is designed to perform is set out in the Annual Report of BNFL.

The Radiochemical Centre Limited, also at present wholly owned by the U.K.A.E.A. has formed a subsidiary company, Amersham Buchler GmbH, in con-

(*continued on page 221*)

The role of nuclear energy in the total energy mix

The following paper was presented by Sir John Hill, Chairman of the U.K. Atomic Energy Authority and British Nuclear Fuels Limited, on 13th November to the 1972 International Conference of the U.S. Atomic Industrial Forum held in Washington, in association with the American Nuclear Energy Society's International Winter Meeting.

The general theme of today's session is "Nuclear energy and the quality of life" and it is in that context therefore that I would like to put before you some thoughts about the role of nuclear energy in the total energy mix. This involves, it seems to me, consideration of the total itself (that is to-day, total world energy consumption) as well as of the mix.

Some idealists argue that the way to improve the quality of life is to renounce technology and all its works and to return to primitive simplicity. But realists must accept, I suggest, that improvements in the quality of life depend on, and must be sustained by, increases in economic output. Even quite modest assumptions about world economic growth point to a dependence on energy by the end of the century which can, in my opinion, be met sensibly only by major recourse to nuclear energy. I do not think anyone who has studied the figures for the growth in consumption of fossil fuels and considered the best estimates of world reserves would seriously challenge this assertion. It must however be said that the position of gas, where reserves are relatively small, oil, where reserves are substantially larger, and coal, with its enormous reserves, present very different timescales. I mention timescales here because any paper dealing with the role of nuclear power is inevitably going to rely heavily upon predictions of long-term changes. It is my experience that this type of prediction usually gets the general pattern right but is frequently fallible, or even inaccurate when it comes to timescale.

To show that I approach these subtle problems of prediction with due care and scepticism, perhaps I could start off by describing how some predictions of energy consumption in the U.K. went quite seriously wrong and, with the brilliance that always accompanies the clarity of hindsight, explain what went wrong. I should add that the present quite severe difficulties facing the nuclear industry and the heavy electrical industry in the U.K. is in substantial part attributable to this situation.

Sir John Hill

Let me go back to pre-1952 when the average house in Britain was heated by burning raw coal in an open fireplace. Such a fire was pleasant to sit beside and quite inexpensive. It had the disadvantage that, in many cases, the rest of the house was pretty cold and it was the principal cause of fogs and air pollution.

In the winter of 1952 London experienced a period of strong atmospheric inversion which resulted in one of the worst smogs that the capital has experienced. Subsequently statistics showed that several thousand people with respiratory ailments died prematurely as a result of this severe pollution. Rightly, the environmental lobby, as it has now become, pressed for legislation to prevent a recurrence, and in

1956 the first of the clean air Acts of Parliament was passed. This made it illegal to emit smoke in designated areas of our cities and effectively prohibited the burning of coal in these areas.

Progressively the British householder gave up his beloved but inefficient and dirty open coal fire and switched to electricity, manufactured town gas and, in the larger houses, to oil. Town gas was not cheap, at that time being manufactured largely by the carbonisation of coal and there was a big movement to electrical heating. The growth in electricity demand increased from 7 per cent per annum, which had been the average growth rate for a very long time, to 8 per cent, 9 per cent, 10 per cent and above in the period up to 1962.

By the time this trend was clearly discernible amongst the normal scatter of statistics the Electricity Boards were seriously short of the plant and, with the demand going up rapidly, the ordering rate was stepped up from about 2,000 MW per annum to 6,000 MW per annum to overcome the backlog and meet the rising demand. However, other changes were also taking place on a slightly different timescale. The gas industry was undergoing a double technical revolution in no less than five years. The first was the gasification of light oils which substantially reduced the cost of production of town gas. The second was the discovery of substantial quantities of natural gas in the North Sea which could be produced on a heat basis much more cheaply than coal.

The economic balance between gas and electricity was changed substantially and there was a massive swing to the use of gas —to the detriment of all the other fuels including electricity. By 1965 the Electricity Boards found themselves in the position of having a great deal of plant on order and under construction, an overloaded heavy electrical industry and the lowest growth rate they have ever experienced. Since that time gas has greatly expanded its share of the energy market; electricity growth has been low by historical standards and the Electricity Boards have been re-trimming their networks which has inevitably meant a very low rate of ordering of new stations, including nuclear stations.

I have given this bit of local history—local to the U.K. I mean—not as any criticism of the planners because their job is almost impossibly difficult, but simply to illustrate the difficulties in planning. Could they reasonably have predicted the freak smog in 1952, the new processes for gasification of light oil, or the presence of natural gas under the North Sea?

In the long term these factors will all appear as bumps on the curve. But, in the shorter term, these bumps can lure us into predictions and decisions which can upset our calculations for almost a generation.

Having illustrated one of the many problems in the long-term planning and, by implication the reservations that must be applied to its conclusions, I think we will all agree that it is nevertheless essential. This is particularly so in capital intensive industries such as ours where the time from inception to completion of a project is so long. But how do we do this planning to an accuracy that will at least guide us to the current policies for the development of our industry?

First, if we consider total world energy consumption it is clear that it has not followed a straight logarithmic line. Until the middle of the last century world energy consumption was almost static, but then the spread of industrialisation contributed to a fivefold rise by 1900 (3½ per cent per annum) when it reached 1,000 million tons of coal a year, other fuels playing no significant part. The rate of growth in consumption was thereafter much lower, it taking forty years for consumption to double again (2 per cent per annum), but in more recent times the rate of growth has risen to 5 per cent per annum with oil and natural gas consumption growing at 8 per cent per annum.

These changes in growth rate in the past have probably resulted—at least in part—from the very inefficient use of fuel in the early days and the relatively efficient use in recent years. The effect of the two World Wars has, however, also been significant and if we are forecasting on the basis of the experience of the last twenty years we must accept that we are assuming a level of world political and social stability similar to that which has characterised this period. I have no idea if this is a valid assumption for the period up to the year 2000, but it is very difficult to do effective planning on any other basis. Assumptions about the growth of population are also very relevant.

We are all generally aware of the relationship of energy consumption per capita as a function of gross national product per capita and a linear relationship is often assumed for simplicity. We have studied this relationship rather carefully as it is of considerable importance, if not in predicting absolute growth rates at least in being able to cross-check one set of assumptions against another.

Let us consider a primitive society where the bulk of the gross national product derives from hunting or primitive fishing, i.e. non energy consuming industries. In such a society the introduction of an additional energy consuming industrial unit will make a bigger proportional increase in energy consumption than in gross national product. In a highly developed high energy consuming country, on the other hand, the introduction of a new energy consuming industry will result in a proportional increase of total power consumption much closer to the proportional increase in gross national product. If one plots on a logarithmic scale the energy consumption per capita and the gross national product per capita for the range of countries at different times, the changes fit remarkably well into a simple pattern. The relationship for each country seems to be following a predetermined course.

Well, how does this help us? It enables estimates to be made of total useful energy consumption by extrapolating gross national product. As a statistic this may be more reliable than extrapolation of the consumption of individual fuels particularly at a time when the fuel mix might be changing quite rapidly. It is at the least another technique that might assist in the difficult job of planning. We have applied these extrapolations to a variety of countries and the results are in good agreement with the estimates of energy consumption made by the United Nations secretariat in their paper to the Geneva Conference on the Peaceful Uses of Atomic Energy last year. In the case of the U.K., they suggest figures somewhat above those being used in many planning exercises carried out at the present time.

On the world scene we can expect total energy requirements to multiply by about four times by the year 2000 and we can also expect that by that same date some half of the world's energy demand will be in the form of electricity. So now we come to the question of the mix—and especially of the part that nuclear power will play in that mix.

There is no question that there are ample reserves of fossil fuel in the world to meet these demands. The world reserves of coal are enormous, as indicated by the estimate that by the year 2000 we shall only have consumed 2 per cent of the world reserves. But this is not the problem we are facing. What is happening is that we are consuming the most accessible and most convenient fuels (gas and oil) fastest and, what is more, we are depleting most rapidly those reserves which are most conveniently situated geographically, economically and politically. But this is nothing new. The situation is really not very different from that we experienced in England 200 years ago when the convenient forests were becoming depleted and coal had to be mined to keep us warm in the winter.

Western Europe is not well endowed with fossil fuels. The coal is difficult to extract and the recent discoveries of gas and oil in the North Sea, although substantial, are small in relation to Europe's total energy requirement. Without nuclear power Europe will continue to be very largely dependent upon imported hydrocarbon fuels and with a mounting balance of payments and political dependency problems.

In the United States coal reserves are very large, but there are clear signs that domestic production of natural gas and oil will have to be limited soon if reserves are not to be depleted too quickly.

In Japan reserves of indigenous fuel are small and the country is, to a very great extent, dependent upon imported energy mostly in the form of oil.

In countries where the operation of large nuclear plants is a practicable proposition there will be both economic and political pressures to construct nuclear capacity. The economic forces will be generated in attempting to avoid the use of less convenient fuels or having to transport fuels over long distances. The political pressures will be to seek to limit the ever growing dependence of most industrial countries on imported oil and to reduce the cost of large energy imports.

But turning now to reserves of uranium, we should appreciate that, at least as far as current designs of reactor are concerned, the position in the nuclear field is not dissimilar to that of fossil fuels. Uranium consumption in the world at the present time is small and most of what is being produced is going into stocks and work in progress. The amount actually being burnt at the present time is trivial. As with fossil fuels, man exploits first the richest and most accessible reserves and statements of recoverable reserves frequently mean uranium that can be recovered for less than \$10/lb U_3O_8. At this price of uranium, big nuclear reactors can generate heat at a price below that of fossil fuels except in areas particularly favourable to them.

But the world reserves of 'low cost' uranium, i.e. \$10/lb. as used in the present designs of nuclear power stations are small by comparison with the reserves of fossil fuels and even substantial additional discoveries which we must assume will be made will not invalidate this statement. A major shift in the world production of electricity to nuclear stations of existing designs would, at some time in the future, increase the price of uranium to a point where the economic balance was restored. The time taken to reach this situation would, of course, depend upon the rate of installation of nuclear plants and the rate of discovery of new uranium deposits.

We can say then that the present designs of reactor have already had a major impact on electricity generating pattern throughout the developed countries. They will, I am sure, very soon be proved a boon to the environment. They have added a new and important fuel to the list of energy sources, but present designs of nuclear station cannot claim to have transformed the world energy position.

The key factor which differentiates the nuclear power situation from the conventional power situation is nuclear power's potential. The transformation of the world energy picture by nuclear power depends upon the next generation of reactors—particularly the fast reactors. Prototype fast reactors are now under construction in several countries and the first of these should start operation next year. These reactors can improve the utilisation of uranium by about forty times by comparison with today's nuclear stations. This high utilisation means not only that our known reserves will deliver forty times more energy but, more important for the longer term, will enable the vast reserves of very low grade uranium to be utilised without significantly increasing the overall cost of electricity. Uranium is a quite abundant element in the earth's crust but its compounds are relatively soluble in water and it has become very widely distributed. However, with the high utilisation possible in the fast reactor even the extraction of uranium from sea water would be quite economic if no lower cost sources were available. Fast reactors will also be able to burn thorium which is abundant in many parts of the world.

The production of useful power from controlled fusion is another long-term possibility. The technology is, however, very difficult—much more difficult than fission and so far nobody really knows how to do it on any practical basis. That does not say, however, that it cannot be done or that it will not be economic when the time comes.

But now let us consider what nuclear power can do for world energy supplies and then, perhaps more important, what it is likely to do. It would be quite possible to build nuclear stations in greater numbers than we are now doing. Uranium mines could be opened quite quickly and more enrichment plants could be built. Fast reactors are reaching the point when the first large commercial stations are being planned. It would be quite possible to build these stations in addition to, or in place of, existing nuclear designs. Small reactors could be built for remote areas. We have the ability to go nuclear very fast if we choose to do so. We could reserve our supplies of natural gas and oil for uses where nuclear power is not suitable. We could conserve our supplies of low cost uranium by going to fast reactors.

But what will in fact happen? All the world agrees that it would be a bad thing for the whale to become extinct. The only thing they cannot agree on is to stop killing it. But to be fair, attempts are now being made to preserve the whale and the efforts are now meeting with some success although they have come very late. Nearly everybody would now agree that to burn pure methane to generate electricity is a waste this world will come to regret. But again the issue is slowly coming to be recognised and many suppliers of natural gas have recently regretted signing long-term supply contracts only a few years ago.

Nuclear reactors of the present generation are capable of burning usefully no more than about 2 per cent of the uranium they consume. Nuclear fuel will therefore be used most inefficiently, as coal was used inefficiently in our factories 100 years ago. But this will not trouble anybody in industry provided he can see assured supplies at a reasonable price for ten years ahead or until he retires, whichever is the longer. Anyway, when it comes to uranium supplies so many people have cried wolf for so long that few people in industry will worry until the price really starts to go up very substantially.

But perhaps in nuclear power we should take a slightly longer view. From early planning to operation of a nuclear plant can be eight years and we hope to get 30 or 35 years useful life from the plant, i.e. we expect it still to require uranium in 40 years' time. We should keep a serious eye on uranium reserves and predicted consumption twenty years ahead. In a long timescale industry, we have got to do our best at long-term planning.

Against the argument for very rapid introduction of nuclear power on conservationist grounds must be set the real danger of becoming too dependent on new technologies before their long-term reliability and acceptability is demonstrated.

So what do I think will happen? First, nuclear power will continue to expand rapidly as it picks up the base load and will then increase more slowly on a proportionate basis as it has to operate at lower load factors. Existing types of reactor will continue to be built for a considerable time in spite of their poor uranium utilisation because of the investment in their manufacture and the experience and confidence that will have built up in operation. The fast reactor will, in due course, take over the job of providing base load electrical power because of its low fuel cost and freedom from inflation in the uranium market. The speed at which it is introduced will be determined more by the rate of build-up of confidence in the system than minor differences in economics. The large-scale use of nuclear power will be spearheaded by the biggest industrialised countries where there is a large electrical demand and a strong manufacturing industry. The rate of installation will be strongly influenced by the economic balance between nuclear and fossil fuels.

Finally, we must keep as our goal the supply of the major part of the world's energy requirement without burning fossil fuels. This requires the continued development of nuclear reactors—certainly the fast reactor for electricity generation, perhaps the high temperature reactor for process heat, and possibly the fusion reactor for the next century.

Hazards from laser radiation

The application of lasers to many diverse fields of technology has already resulted in a multitude of benefits, ranging from medical treatments to space communications, but like other innovations, they have attendant dangers.

In particular, lasers can cause surface burning of skin and, if they enter the eye, blind spots due to destruction of the tissue of the retina. Other potential risks not yet fully evaluated include possible genetic damage and malignant, i.e. cancer-producing transformations in the human body.

To provide a comprehensive source of information as to the risks attendant on the use of lasers and the safeguards which may be employed to prevent them, the British Standards Institution has published BS 4803 : 1972 *Guide on the protection of personnel against hazards from laser radiation*, which is based upon an earlier publication by the (then) Ministry of Technology.

The standard is a substantial 38 (A4) page document which deals with every aspect of the problem including analysis of the factors which determine the risk, such as the frequency and power of lasers, the design of the apparatus generating them, and the permissible level of radiation in the human body. Details are given of the precautions and procedures which should be observed, and of the medical supervision of personnel which should be carried out.

Who uses lasers?

Current applications of lasers for research or production operations include: communications, geological measurements, welding, medical treatment of malignant growths, aerial weapons guidance and production of three dimensional holograms.

Price, including postage, £1.90 (plus 20p for orders under £2.00). From BSI Sales Branch, 101 Pentonville Road, London, N1 9ND.

Void formation experiments

With the advent of the fast reactor, certain components will be subjected to fast neutron doses far in excess of those hitherto achieved. Even at this early stage of development it is well established that, after prolonged irradiation at temperatures about 0·4 of the absolute melting temperature stainless steel components undergo density changes resulting from radiation-induced porosity. This porosity has been identified as resulting from the formation and growth of small voids a few hundred Ångstroms in diameter within the material[1]. The voids are thought to nucleate as small gas bubbles from either the helium which is formed continuously by transmutation during the irradiation or from dissolved gas already present in the material. The bubbles grow into voids by the condensation of irradiation-produced vacancies. Vacancies and interstitials are produced in equal numbers during irradiation but the net flux of vacancies to voids is thought to occur because dislocations in the metal have a slight preferential attraction for interstitials.

The elastic scattering cross-section for charged particle collisions is, in general, several orders of magnitude higher than that for neutron-atom collisions. For this reason the damage build-up which takes years in a reactor can, in principle, be simulated within hours in a particle accelerator. The limitation is that, whereas

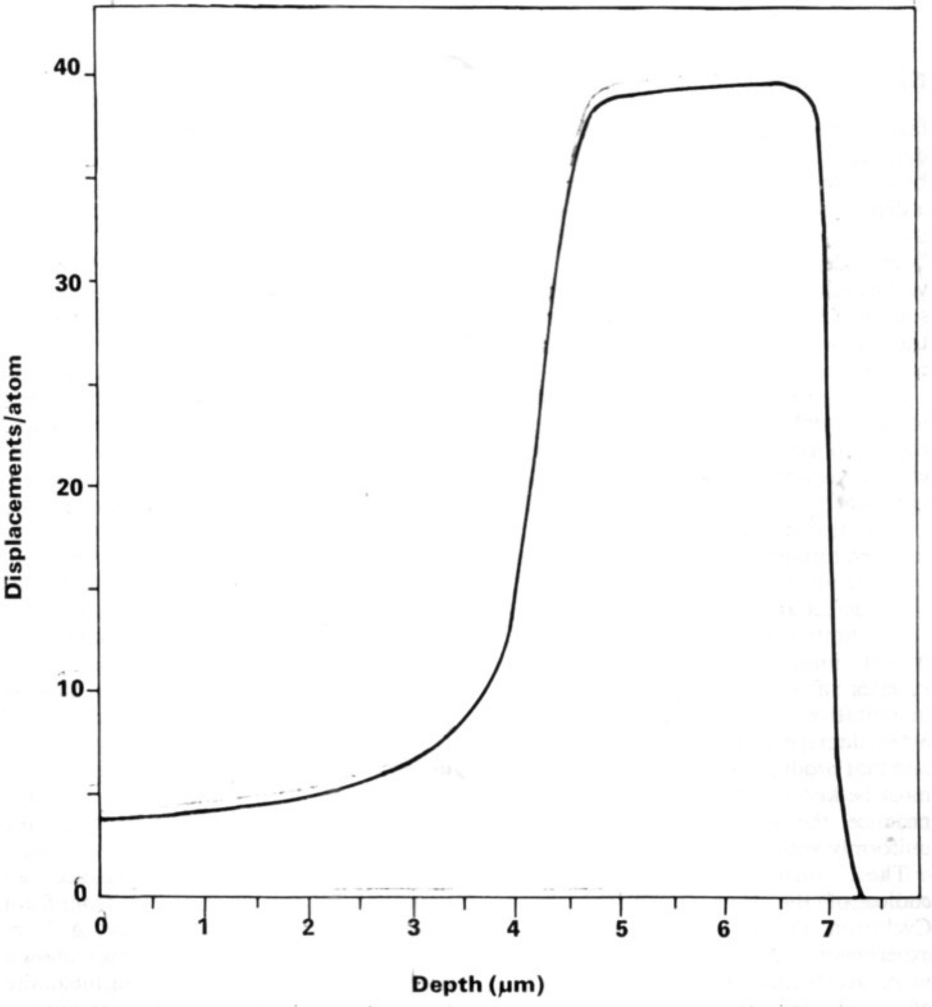


Fig. 1. *Damage density in displacements/atom as a function of depth or a 20MeV C^{++} irradiation of nickel or metal of similar density.*

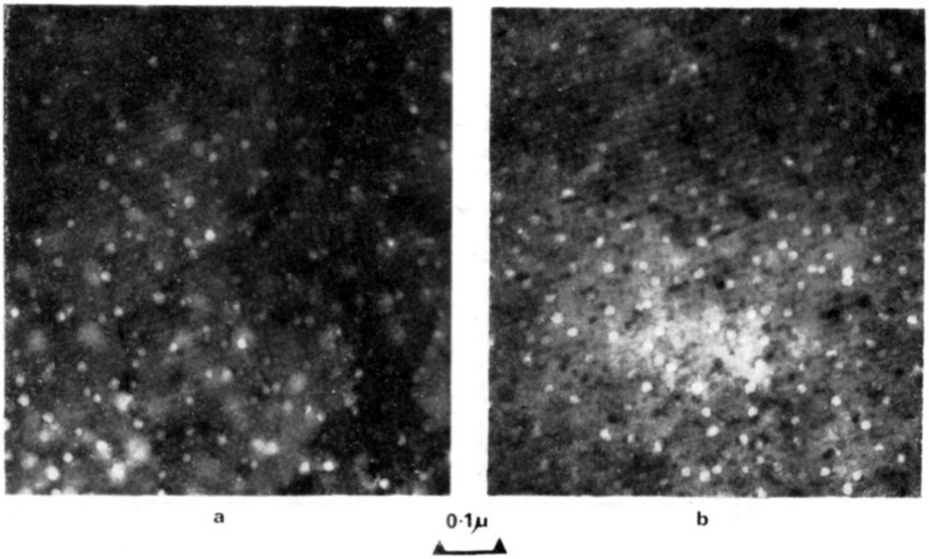


Fig. 2. *Comparison of voids produced in nickel by neutron and ion irradiation* (*a*) *DFR* (*b*) *VEC*.

fast neutrons produce uniform radiation damage throughout a large specimen, ion bombardment can only result in damage to a depth roughly equal to the ion's range in the solid, which is relatively small. Ion bombarded solids can thus only be investigated for void formation by techniques suitable for small volumes and, in practice, transmission electron microscopy is used in most cases.

Although it is a relatively simple matter to form voids during ion bombardment at the appropriate temperature, several special conditions must be stipulated for a useful quantitative simulation of the neutron case. In the first place, the radiation damage must be formed effectively in bulk material away from surfaces which influence the point defect and dislocation content of the solid; both these quantities are of paramount importance in determining the kinetics of void growth[2]. Secondly, the quantitative comparison between the radiation damage produced by fast neutrons and that produced by the ion bombardment must be known. Thirdly, it is desirable to produce the ion bombardment damage uniformly within a given volume.

These considerations have led to the choice of the Harwell Variable Energy Cyclotron (V.E.C.) for void formation experiments. A comparison of this with other accelerators from the point of view of void formation has been made previously[3]. Until recently the bombarding species in the experiments has been 20 MeV C^{++} ions. From examination of specimens extracted at different depths below the bombarded surface of nickel foils it has been possible to calibrate the damage density versus depth profile for the C^{++} irradiations[3]. The basis of the calibration is a comparison between the volume fraction of voids formed at different depths for different irradiation doses. At all doses, the damage density in the early stage of the C^{++} track can be calculated since here the elastic collisions are in the regime of the Rutherford scattering cross-section. Fig. 1 shows the damage density in displacements/atom as a function of depth for a 20 MeV C^{++} irradiation of nickel (or metal of similar density). In this case the foils have been mounted on a "rocking target holder". This apparatus rocks the foils in a controlled manner during irradiation to widen the damage peak of the C^{++} ions[4]. The control function was devised from the previously determined calibration curve for normal incidence irradiation during which 40 displacements/atom would be created at the peak by 3×10^{17} ions/cm^2. As the figure shows, the rocking holder produces an almost uniform damage density from 5 μm down to 7 μm below the surface. A 2 μm uniform depth of damage has been chosen as the best compromise between the desire to obtain uniform damage and the restriction of irradiation times in the cyclotron. More

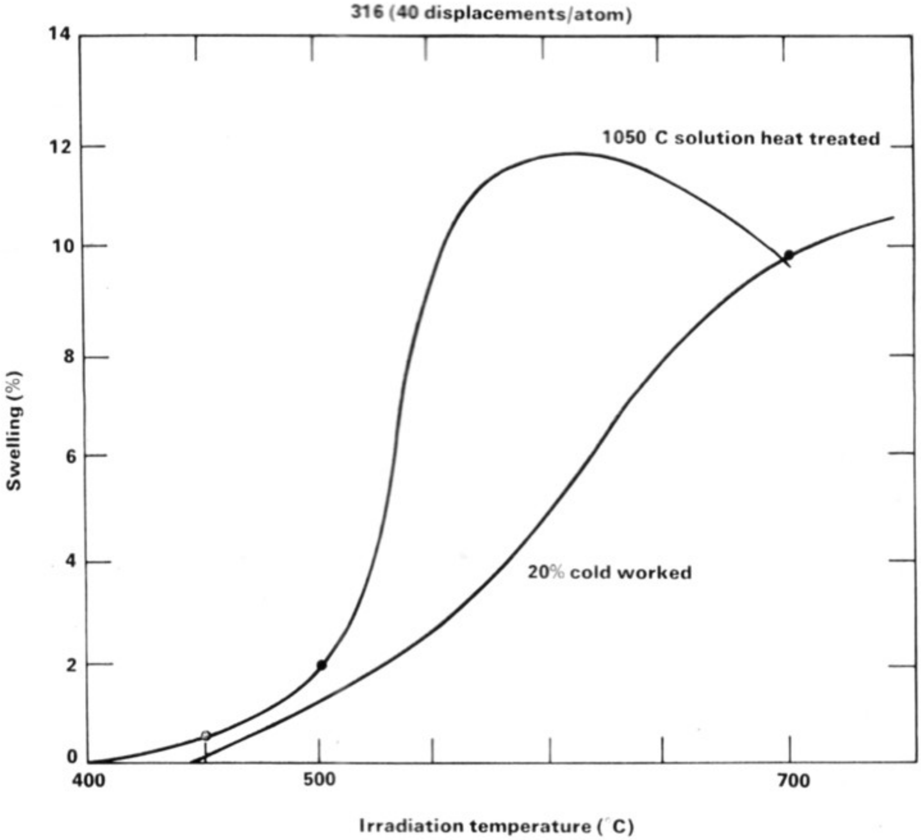


Fig. 3. *Temperature dependence of swelling in 316 steel.*

recently, irradiations have been performed with 48 MeV Ni^{6+} ions. In this case one has the advantages of damage produced quickly and away from the surface, and in addition the introduction of impurities such as carbon is avoided. In order to simulate the helium production by (n, a) reactions in the reactor, helium is uniformly implanted prior to irradiation to a concentration of 10^{-5}.

In order to relate the results of V.E.C. irradiations to the reactor case the damage density for a particular fast neutron spectrum must be known. Calculations have now been made for the spectra in the Dounreay Fast Reactor[5]. Fig. 2 shows voids in two nickel specimens, one (a) irradiated in D.F.R. and the other, (b), in the V.E.C. with 20 MeV C^{++} ions. The ion bombardment was arranged to produce the same number of displaced atoms as that calculated to have accumulated during the reactor irradiation. The similarity in the void populations and particularly the values of swelling is readily apparent. In direct comparisons of V.E.C. and reactor irradiations, the increased dose rate (about 1,000 times) of the V.E.C. must be considered. In general this larger dose rate increases the temperature of maximum void growth by about 100°C[2]. In the case of nickel the swelling versus temperature curve shows a flat region of about 150°C over which maximum swelling occurs. This is not the case in stainless steel as indicated in Fig. 3 which shows results of 20 MeV C^{++} irradiations of solution treated and 20 per cent cold-worked 316 stainless steel over the temperature range 400-700°C. The increased swelling resistance of 20 per cent cold-worked steel is also indicated in Fig. 3. The effect of cold-worked on swelling in stainless steel has been described previously[6,7].

Void swelling as a function of dose in pure nickel, solution treated 316 stainless steel and Nimonic PE16 is shown in Fig. 4. The results were obtained from

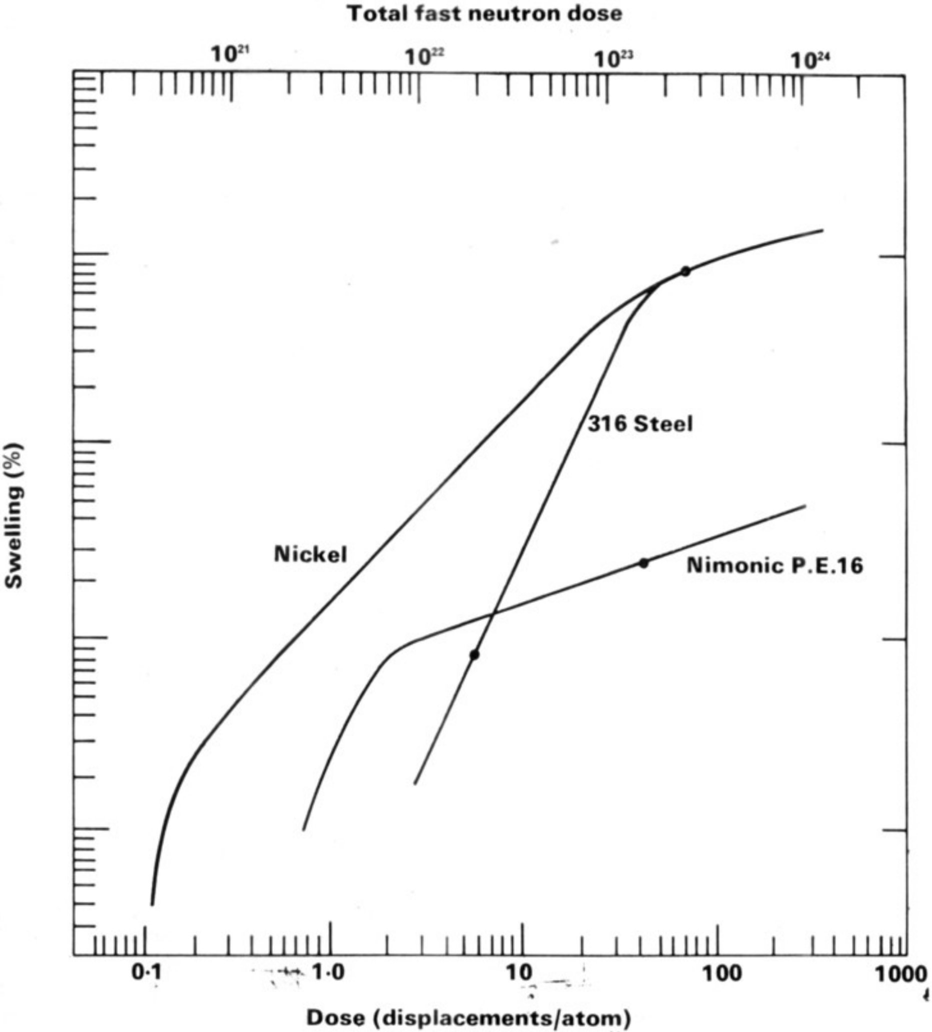


Fig. 4. *Dose dependence of void swelling in nickel, 316 steel and Nimonic PE16 irradiated at 525°C with 20MeV carbon ions in the VEC.*

V.E.C. irradiation at 525°C of foils containing 10^{-5}He with 20 MeV C^{++}ions. Consistent with reactor data, voids in nickel were first observed after relatively low radiation damage doses, about 0.1 displacements/atom. Over most of the dose range, swelling in nickel varied as a linear function of dose up to 6 per cent at 40 displacements/atom. The swelling rate then fell to give 15 per cent swelling at 350d/atom 316 stainless steel showed marked differences in swelling behaviour from nickel, as indicated in Fig. 4. No voids were visible in specimens irradiated to less than 2 displacements/atom. Above this dose the swelling increased approximately as $(\text{dose})^2$ up to about 40 displacements/atom. Above this dose, where the swelling was about 5 per cent, the swelling rate decreased and as shown in Fig. 4 the swelling curve merged with that for nickel to give about 15 per cent swelling after 380d/atom. The swelling behaviour of Nimonic PE16 is different from nickel and stainless steel. Voids were first seen in C^{++} irradiated specimens after about 2d/atom at a swelling of about 0.1 per cent. Included in Fig. 4 is a result from a 4 MeV proton irradiation which gave 0.01 per cent swelling after 0.75d/atom. Above 2d/atom the swelling increased slowly (approximately as $(\text{dose})^{1.3}$) to reach about 0.5 per cent after 300d/atom. These results are for PE16 which was solution treated and aged to give γ precipitates (Ni_3 (Ti, Al)) about 100Å in diameter.

Although swelling is manifest as voids it is, of course, physically caused by the equivalent interstitial content in the metal. This is present as radiation-produced dislocation loops, lines and networks in addition to those interstitials which reach the free surface. Current theories of void growth[2] show that the dislocation concentration is one of the chief parameters which determine the kinetics of void growth. The experimental determination of dislocation content is thus important in testing the predictions of theoretical models. As stated earlier, in experiments aimed at simulating fast-neutron-induced voidage it is necessary to produce the damage sufficiently far away from surfaces for the dislocation and point defect concentrations to be unaltered by the proximity of the surfaces. In all three face centred cubic metals studied, the first appearance of voids was accompanied by the first appearance of small (<50Å) dislocation loops, some of which could be positively identified as faulted interstitial loops lying on [111] planes. In nickel the loops soon unfaulted as the dose increased and grew to form a network which increased to maximum density of about 5×10^{10} cm/cm³ at about 40d/atom. Above this dose, where large voids were produced by coalescence, the dislocation density decreased. In steel the dislocation density increased sharply to reach 10^{11} cm/cm³ at 10d/atom, then levelled off to reach 2×10^{11} at 350d/atom but did not decrease as in nickel. In PE16 the dislocation density again increased sharply and was greater than 10^{11} cm/cm³ at all doses above 2d/atom.

The interpretation of the swelling behaviour of nickel and stainless steel with respect to the observed dislocation densities and current theories of void growth have been given elsewhere[2,8,9]. Two possible causes of the suppression of void growth in PE16 have been given. First, the coherent interface around the γ' precipitates promotes recombination by constraining point defects to move in the interface without loss of identity. Secondly, the radiation-produced dislocation array quickly becomes very dense, being locked by the precipitates, and greatly enhances recombination.

For further information contact: Dr. R. S. Nelson, A.E.R.E. Harwell, Didcot, Berks.

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A.E.A. Reports available

The titles below are a selection of the reports published during the past two months and available through H.M.S.O.

AEEW-M 1123
A New Model for the Dynamics of Steam Drums. By A. Hopkinson, March, 1972. 7pp. HMSO. £0.50. SBN 85182 008 5.

AEEW-R 806
FADDEEV: A Fortran Code for the Calculation of the Frequency Response Matrix of Multiple-Input, Multiple-Output Dynamic Systems. By D. H. Owens. June, 1972. 31pp. HMSO. £0.50. SBN 85182 009 3.

AERE-R 6591
The Recovery of Gamma-Irradiated Salmonellae from Horsemeat using Liquid Culture Media. By T. S. Kennedy and B. E. Winsley. August, 1972. 18pp. HMSO. £0.50. SBN 7058 0192 6.

AERE-R 7146
A Multi-Channel Analysis Package for use in the Damusc System. By O. M. Jarvis. 1972. 23pp. HMSO. £0.50. SBN 7058 0142 X.

AERE-R 7155
An Experimental Capacitance Liquid Film Thickness Monitor. Operating Instructions and Circuit Details. By D. N. Benn. September, 1972. 33pp. HMSO. £1.00. SBN 7058 0222 1.

AERE-R 7200
The Pyrogenic Activity of Bacteria Dried onto Glass or Plastic Surfaces and Sterilised by Heat or Gamma-Radiation. By B. E. Winsley. 1972. 9pp. HMSO. £0.50. SBN 7058 0162 4.

Reactor fuel safety studies

An important part of the endorsement of any fuel system is a demonstration of its safety under both normal and abnormal reactor operating conditions. Endorsement for normal operating conditions is obtained as part of the normal irradiation programme for fuel element development. However, the study of pin behaviour under abnormal operating conditions and the study of certain pin defects under normal operating conditions is more difficult.

Considerable experience has been gained at Harwell in the simulation of fuel safety problems using both computer and analogue models.

Computer models

Two-and three-dimensional heat transfer programs are used at Harwell for the prediction of pin component temperatures under transient and steady state conditions. The programs will accept cylindrical or rectangular geometry and, with the IBM 370/165 computer, complex models can be built up if required. A variable dimension facility has been built into the two-dimensional program, so that the model size is restricted only to the space available in the computer (eg the maximum model size, represented by the number of mesh lines in each co-ordinate direction, might be 40 (radial) × 100 (axial) or 80 (radial) × 50 (axial) since the product of the number of radial and axial grid lines is the limiting factor).

The models may include internal coolant channels and gas gaps, and the programs will take account of conduction, convection, heat transfer to internal or external coolants, and of radiation. Physical properties of fifteen standard materials are stored with the program; if any of these is used, it need not be defined by the user, who, however, has the option of writing in any or all of the physical properties for his model. The properties may be defined as quadratic or linear functions of temperature, or as constants. Heat transfer coefficients and flows of coolants may be specified by the user as time dependent, or as constant. Internal heat generation rates may also be time dependent or constant.

A typical application for the program is the simulation of a reactor transient on a fuel pin. Here the rate of rise and fall of reactor power will determine the time dependent heat generation rates in the pin, and the temperature history in the pin may be followed through a series of temperature maps produced as output at times specified by the program user.

Steady state problems may also be solved by the programs, since the alternating direction method used in the solution of the transient equations is an efficient method of arriving at steady state solutions. A typical application is the prediction of sample temperatures in an in-pile experiment. Here the model is likely to be more complex than the fuel pin transient model. Experimental results have given confidence that the predictions will be good provided that the model realistically describes the actual case.

Analogue models

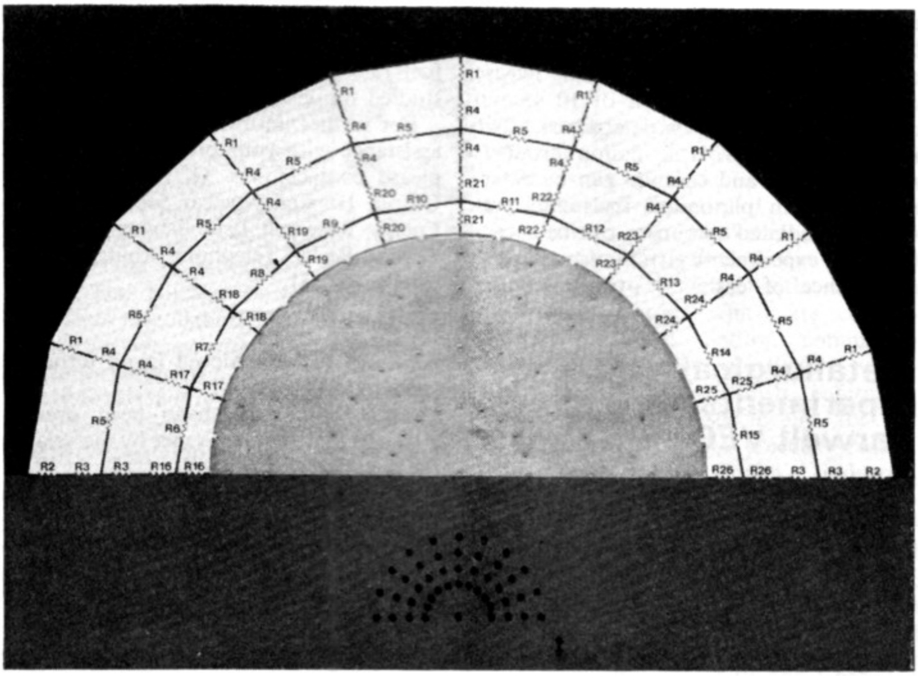
An alternative method of exploring heat transfer problems is by the use of analogue models. This technique has the advantage of being applicable to non-symmetrical or complicated shapes. It uses the equivalence of thermal with electrical conduction so that thermal conductivity, heat flow and temperature can be simulated by electrical conductivity, current and voltage respectively, ie:

Actual	*Electrical analogue*
Temperature difference (T)	Voltage difference (E)
Heat flow (Q)	Current (I)
Thermal resistance $\frac{d}{kA}$	Electrical resistance (R)

where d = effective heat transfer length
A = effective heat transfer area
k = thermal conductivity

Equation: $Q = \frac{kAT}{d}$ Equation: $I = \frac{E}{R}$

Models are constructed, usually many times full size, using either banks of discrete resistors and conducting paper (Teledeltos) for two-dimensional models, or liquid electrolyte for three-dimensional models. The conducting paper or liquid electrolyte is used to represent the most awkward geometry of the section considered, the 'end effects' being represented by resistor networks. Currents are applied at suitable points in the electrical network to represent heat flows. By measuring the voltage differences between chosen



points the temperature differences can be obtained.

Direct current is used except when electrolytes are employed. Alternating current at frequencies of 400-1000 Hz is then used to avoid electrode position and polarisation effects. The accuracy obtained is about ±5 per cent and good agreement is obtained between the predicted temperatures and those measured in practice.

Example

A two-dimensional analogue was used to investigate the effect of bond voids in a sodium bonded fuel element. The fuel pellet was represented by a central semicircle of Teledeltos paper assuming uniform conductivity over this area. The gas between the fuel and the clad was represented by an array of resistors, some corresponding to sodium and others to poorly conducting gas in the void as shown in the photograph. The low resistance value R_{Na} of the resistors simulating the high thermal conductivity sodium is obtained from the equation:

$$R_{Na} = \frac{d}{kA}$$

where d = effective path length
k = thermal conductivity
A = effective path area

The heat transfer in the gas void is mainly due to radiation; the resistor values R_v are obtained from the equation:

$$R_V = \frac{M(T_H - T_C)}{A\,\Sigma(T_{H}{}^{4} - T_{C}{}^{4})}$$

where M = Model constant
A = effective area
Σ = emmissivity
$T_H{}^4$ = temperature of fuel surface
T_C = temperature of clad inner

A large number of electrical contact points are provided throughout the model so that, by measuring the voltage differences between the points, a temperature map is easily obtained.

In-pile studies

In addition to out-of-pile model simulation, some direct in-pile experiments are being carried out in support of theoretical predictions. Rigs have been designed and are being used for testing bond defect conditions in sodium bonded carbide elements. A knowledge of the release of fission products from reactor fuel materials over a wide range of conditions is essential to reactor safety calculations, and specialised small scale techniques have been developed at A.E.R.E., Harwell using the DIDO materials testing reactor. Small specimens can be irradiated under accurately measured conditions which simulate normal operation or fault conditions in a fast or thermal system. Measurements can be made up to 2,000°C and the release of gaseous fission products of 10 second or more half life can be determined. The release of other volatile fission products such as iodine and caesium can be determined. Both plutonium fuels and previously irradiated specimens can be accepted. The experiments give the temperature dependence of emission over the entire temperature range encountered in operating fuel elements. Effects of burn-up, fuel rating and gaseous environment are studied similarly.

For further information on this work or assistance with your problems in this field please contact: Mr. O. S. Plail, Project Officer, Harwell Nuclear Services, Atomic Energy Research Establishment, Harwell, Didcot, Berks. Telephone Abingdon 4141, extension 4051.

Metallurgical experiments on the Harwell VEC

The wide variety of ions available from the Harwell Variable Energy Cyclotron (VEC) makes it a powerful tool for research into the irradiation behaviour of nuclear reactor materials.

The two main types of experiment performed with ions having energies between 1 and 10 MeV per nucleon are:

1 Simulation of the build-up of nuclear reaction products.

2 Production of displacement damage in a crystal lattice.

A technique for changing quickly from one beam to another, e.g. 8 MeV helium to 24 MeV carbon ions, has been perfected for experiments combining both types of study. Either fast neutron or recoiling fission fragment damage can be simulated by careful selection of mass and energy of the accelerated particle.

A significant volume of material is normally required for electron microscopy or the testing of mechanical properties. Within this volume it is necessary to have uniformity of implanted ions or radiation damage. Area uniformity is achieved with the VEC by the use of deflecting coils fitted to the flight tubes. Depth uniformity can be produced by movement of an aluminium wedge within the beam to modulate its energy. In an alternative method the target oscillates about an axis perpendicular to the beam.

Equipment has also been developed to irradiate materials at closely controlled temperatures. This can be combined with the oscillating target to ensure volume uniformity of damage. A special chamber and pumping apparatus enables high temperatures to be achieved in an ultra-high vacuum.

These techniques have been used to simulate the conditions met by materials in the core of a fast reactor.

Material irradiations carried out on accelerators at Harwell are supported by computer programs for calculating ion penetration depths and the intensity of damage along the track of a particle. Other programs calculate the laws of movement for the energy modulating wedge and oscillating target.

Over the past four years beams of carbon, nickel and chromium ions have been extensively used to form voids in many materials. The great advantage of using heavy ions for these experiments lies in the speed with which results are achieved.

The damage density created during many years' irradiation within a reactor can be simulated in a few hours. It therefore provides a valuable complementary technique to fast neutron irradiation testing and may be used to indicate likely behaviour under fast reactor conditions. An important additional advantage is that very little radioactivity is produced in the material so that normal handling in an open laboratory is possible. Electron microscopy is usually used for the study of target material and special techniques have been developed to prepare samples from accurately known depths in the material. Examination techniques have been perfected to enable quantitative data on irradiation defects to be obtained.

The experiments are backed by theoretical work which allows estimates to be made of damage rate effects, swelling rates and the role played by cold work and irradiation temperature.

Enquiries to Mr. J. H. Worth, Atomic Energy Research Establishment Harwell, Didcot, Berks.

IN PARLIAMENT

(continued from page 207)

nection with the German firm Buchler & Company, to market its products in West Germany.

As regards the two design and construction companies, British Nuclear Design and Construction has a licence arrangement with Brown Boveri (Mannheim) for the promotion of the A.G.R. system; The Nuclear Power Group has agreements to collaborate on thermal and fast reactor systems with various European companies including:

Kraftwerk Union AG. Federal Republic of Germany.
Agip Nucleare SpA. Italy.
Belgonucléaire SA. Belgium.
Interatom GmbH. Federal Republic of Germany.
NV Neeratom. Netherlands.

T.N.P.G. is also one of four European companies, shareholders in Inter-Nuclear, a company incorporated in Belgium to exploit the H.T.R. commercially; and is a member of the Gas Breeder Reactor Association, an association of organisations which supports a team of engineers in Brussels to carry out feasibility and economic studies on the gas-cooled breeder reactor.

Also, in the private sector, there are a large number of manufacturers in the United Kingdom of the specialised equipment and materials for nuclear power stations, many with overseas affiliates. The question of European links which these companies may have formed is a matter for the individual firms.

Nuclear Installations Inspectorate

25th October, 1972

MR. HAROLD WALKER asked the Secretary of State for Trade and Industry what are the minimum qualifications required of candidates for admission into the Nuclear Installations Inspectorate; what is the current salary scale for such inspectors; and what are the present numbers.

Mr. Emery: Candidates for appointment as Inspectors of Nuclear Installations are normally required to possess a first or second class honours degree, or equivalent, in science or engineering or to be corporate members of an appropriate professional institution.

The current national salary scale for inspectors is £2,910-£3,760 and the total professional staff of the Inspectorate is 66.

Fast breeder development

26th October, 1972

MR. SKEET asked the Secretary of State for Trade and Industry if he will detail the British and European enterprises formed for the development of fast breeder reactor systems and the countries in Western Europe which are contemplating prototype and/or commercial reactors of this type before 1980.

Mr. Emery: No British enterprises have been formed specifically for the development of fast breeder reactor systems. Present British industrial organisations concerned with the supply of thermal reactors and their fuel are closely involved with the U.K.A.E.A. in fast breeder development work. However, the possibility of arranging collaboration for fast reactor development and exploitation between the appropriate organisations in this country and those in Europe is currently under active consideration.

In Europe, I understand that fast reactor development is also being pursued through existing national and industrial organisations. These have in some cases formed international associations for development work or to share costs of construction and benefits from operating experience.

B.N.E.S conference

The British Nuclear Energy Society, in association with The Institution of Mechanical Engineers, will be holding an international conference on "Boiler dynamics and control in nuclear power stations" from 22nd to 23rd March, 1973. Further information is available from The Secretariat, British Nuclear Energy Society, 1-7 Great George Street, London, SW1P 3AA. Telephone 01-930 7444.

Radiological protection

The Society for Radiological Protection is organising a meeting on "Partial Body Exposure—The Response of Bone and Lung", in London, on 9th January, 1973. Further information is available from Professor J. H. Martin, Department of Medical Biophysics, The University, Dundee, DD1 4HN, Scotland.

Uranium prospecting

A "Uranium Prospecting Handbook" describing the latest methods of uranium prospecting and their use in different environments has been published by the Institution of Mining and Metallurgy.

It is based on the proceedings of a N.A.T.O.-sponsored Advanced Study Institute on Methods of Prospecting for Uranium Minerals, directed by Dr. Michael Davis, Technical Adviser at the U.K.A.E.A. London Office, and Dr. S. H. U. Bowie, Chief Geochemist of the Institute of Geological Sciences.

Both Dr. Davis and Dr. Bowie, and the third Editor, Mr. Dennis Ostle, Head of the Radiogeology and Rare Minerals Unit, I.G.S. have been intimately concerned with managing the joint U.K.A.E.A.-I.G.S. programme on new uranium prospecting instruments and methods, and the U.K. Uranium Reconnaissance Survey, carried out over the preceding five years.

The papers which constitute the main body of the handbook are by an international group of authors, each of whom is an expert in his particular field, from Australia, Canada, Denmark, France, Italy, the U.K. and the U.S.A. A record of discussion among participants and a number of "case histories" are also included.

Although uranium supply presently exceeds demand, this situation cannot persist for long in the face of large and growing nuclear power programmes. Increased demand will require the discovery of large new uranium reserves. The period from exploration to exploitation of an ore discovery takes the best part of ten years and the appearance of the handbook is therefore expected to attract wide international attention.

Courses at Harwell

THE following courses are due to be held by the Education Centre, A.E.R.E., Harwell, Didcot, Berks. Further information and enrolment forms can be obtained on application. The fees shown are exclusive of accommodation.

Radiological Protection

5th to 9th February, 1973

Lectures, demonstrations and practical work designed to give some experience in the safe handling of radioisotopes. While it is assumed that students are normally graduates in science or engineering, or hold equivalent qualifications, such qualifications are not considered essential to attendance. It is intended to be of use to 'competent persons' since it contains information about safety precautions when using X-rays, industrial uses of radioisotopes, instrumentation and the regulations applicable to the use of ionising radiations. Fee: £60.

Testing and Inspection of Plastics

13th and 14th February, 1973

For inspectors and engineers who require a knowledge of process and acceptability testing and inspection of plastic and reinforced plastic components.

Experience gained in UKAEA workshops and industrial plants is described by lecturers with specialist knowledge of the subjects, which include: processing of thermoplastics and rubbers, testing of thermoplastics and rubbers; non-destructive testing methods, destructive testing methods, quality control and inspection of fibre composites and the running of a plastics control laboratory. Fee: £24.

Low Temperature Technology

19th to 22nd February, 1973

For designers, operators and experimentalists concerned with equipment working at temperatures below about 150°K—referring particularly to the safe and efficient use of liquid nitrogen, hydrogen and helium.

Topics covered include: Properties of refrigerants and materials, thermometry; design techniques; practical aspects; commercial equipment and specific applications. Fee: £48.

Design of Pressure Vessels

27th February to 1st March, 1973

For drawing office staff and others in a research and development environment concerned with the detailed design of pressurised equipment, mainly in the range covered by existing codes of practice.

Experience gained in Harwell design offices is used in the lectures which cover materials, welding, pressure relief devices, flanges and sealing, inspection and testing and the use of aids to calculation. Internal and external pressure is considered. Fee: £36.

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