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A REVIEW OF FAST REACTOR PROGRESS IN THE UK

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During the last year the fast reactor programme in the UK has gone well with the construction of the PFR playing a dominant part. The reactor is now nearing completion and it is hoped to maintain the date for full power operation of 1973.

During the year the two Design & Construction Companies and the CEGB have been playing an increasingly large part in the programme. TNPG is responsible, under contract to the Authority, for the completion of the construction of the PFR. TNPG, and to a lesser extent BNDC, are undertaking design work for the larger 1300 MW(E) Commercial Fast Reactors, again under contract to the Authority. This ensures continuity of design work until the contract for the first CFR is let by the Central Electricity Generating Board. In the meantime the CEGB is increasing its participation in CFR design considerations and have completed the first stage of their studies of the problems of introducing sodium cooled fast reactors in their system by adopting a plan leading up to starting construction of a 'lead' CFR during 1974. The plan identified the key issues to be endorsed at various stages and calls for regular review and updating to match developments in the overall situation and the exigencies of a new reactor system. The studies were extended to identifying in depth the development requirements of the CFR reference design against the timescales and objectives of the plan.

On the 1 April the Authority's Trading Fund activities were transferred to British Nuclear Fuels Ltd and the Radiochemical Centre Ltd.

BNFL will be concerned with fuel production for British power reactors and also with export business in fuels and fuel services. It will operate the enrichment plant at Capenhurst, the uranium fuel plant at Springfields, the plutonium fuel and reprocessing plants at Windscale and the magnox reactors at Calder Hall and Chapelcross.

During the year complete core sub assemblies have been produced by the PFR fuel manufacturing line at Windscale. This plant will be used to provide fuel for the PFR and the first CFR. Experience gained in its design and operation has enabled improved estimates of the cost of manufacturing fast reactor fuel to be obtained.

PROTOTYPE FAST REACTOR

The construction phase is now nearing completion. Virtually all the civil work except for some work on the irradiated fuel examination caves is finished. The electrically driven boiler feed pump is at present being tested and the turbine is due to be commissioned in a few months time using an auxiliary boiler capable of producing 33,000 Kg/hr of steam at 3.5 MN/m^2 and 340°C. The 275 KV line running 100 miles south from Dounreay is now complete.

The reactor roof was supported on a temporary frame about 15 metres above its final position above the reactor vault. The leak jacket, the reactor tank, the reactor jacket and the diagrid support structure are all in their appropriate positions beneath the roof. The reactor tank is supported temporarily by straps from the leak jacket. The leak jacket is floated in water in the concrete vault and can be raised or lowered by altering the water level. The diagrid support structure which supports many of the internal parts of the reactor is supported from the temporary frame. The various internal parts of the reactor including the diagrid and reactor insulation have been assembled while the main components were in this position. By raising and lowering the four main components in turn, the welds connecting them can now be made in sequence.

At the end of April the roof was lowered on to the diagrid support structure and the first weld started.

The future programme envisages the water test starting in about one year from now, sodium filling in the summer of 1972 and power at the end of that year.

COMMERCIAL FAST REACTOR

The design study of a 1250 MW(E) fast reactor power station has continued during the year. Alternative designs for various parts of the system have been studied. Particular attention has been paid to the type of steam generator to be used, the optimum layout of the station, the design of pumps and intermediate heat exchangers, and to the refuelling system. The refuelling system is most important because of the large numbers of sub-assemblies to be handled and the high cost of outage time with these large reactors. Refuelling periods ranging from once every six weeks to once a year are possible, though in the UK generating system the shorter refuelling periods are apparently more favourable.

DOUNREAY FAST REACTOR

The Dounreay Fast Reactor has operated according to plan during the year. Four irradiation periods have been completed, including the one which had been started just at the time of last year's report. The reactor has continued to operate with a full load of experiments both in support of UK programmes and for sponsors in various overseas countries. About two weeks unscheduled shut-down time was lost by a minor NaK fire, arising from a small leak in a secondary heat exchanger circuit. Most of the overhaul and modification referred to in last year's report has been completed and the benefits are already being obtained. For example the longest period ever of operation at full power, without any interruption or power reduction was achieved recently.

It is expected to load the first of the new experimental fuel rigs (mini sub-assemblies) mentioned in last year's report, for the next irradiation period. As a result of design and development work during the year it will soon be possible to use full length fuel pins in the centre sub-assembly (typically containing 77 pins) as well as in the mini sub-assembly.

To date 339 million KW hours of electricity have been generated, most of which has been fed into the public electricity supply.

FUEL AND CLADDING

Work has continued during the past year on a number of variants to the reference oxide fuel parameters chosen for the PFR design, covering such items as clad material, fuel density, can thickness and pin design detail. From the data obtained, it is clear that the dimensional changes which will occur at a given temperature and burn-up are a function of the cladding material, and differences are seen here between different austenitic stainless steels. Fuel density has been varied over the range approximately 70% to 95% of theoretical and again significant differences in pin behaviour are observed over this range of densities.

During the year a number of DFR sub-assemblies in the burn-up range above 5% have been withdrawn from the reactor, dismantled for detailed mensuration, and rebuilt and returned to the reactor. This enables a much more accurate assessment to be made of the way dimensional changes proceed with burn-up than can be obtained from measuring different sub-assemblies. The intention is to take sub-assemblies up into the region where pin failures will occur, both to examine the consequences of pin failure on other pins, and also to get guidance on the burn-up at initiation of failures and the development of failure rates in sub-assemblies. The DFR irradiations continue to include explorations of carbide concepts in an attempt to exploit the potential of carbide fuel. Occasional evidence has been seen of the effects of minor gas entrainment in the coolant, which can lead to pin failure in adverse circumstances. These occasional events have in fact added to the confidence that genuine pin failure by ductility exhaustion in the clad will be of no great consequence in reactor operation.

A substantial effort on the design and experimental side has been deployed during the year examining the consequences of void formation in cladding and structural materials. The design studies have included the examination of both free standing and constrained cores. Programmes have continued on DFR material to characterise swelling as a function of neutron dose, temperature and material. The rate of accumulation of neutron dose is necessarily limited by the DFR peak flux which is significantly lower than in a commercial reactor. The studies which have been carried out show that there is a significant difference in the performance of alternative austenitic steels, and between stainless steel and the nickel base alloy PE16. In addition to the DFR irradiations a substantial amount of experimental work has been carried out on the Harwell accelerators, especially on the Variable Energy Cyclotron (VEC). In these accelerators the same number of displacements as will occur in a year in a commercial fast reactor can be induced in a day. This enables doses higher than have been reached in fast reactor irradiations to be covered. The information arising from this work has been reported in detail at the BNES Reading Conference. The important features arising from the accelerator studies are the indication that swelling at higher doses proceeds at a power which is less than linear with dose, and that the swelling in the nickel base material PE16 is noticeably small. It is the UK opinion that the combined data from the DFR irradiations and the VEC show promise that the rather difficult design problem indicated from extrapolations with dose to the power 1.5 or 2, will not in fact materialise.

In support of these studies improved estimates have been made of damage rates throughout the DFR, PFR and CFR reactors. In addition the hydrogen and helium generation rates in the steel of these reactors have been determined from a survey of the (n p) and (n, α) reactions.

Both for fuel pin performance and for the behaviour of constrained sub-assemblies, data are required on the behaviour of materials under stress while in a neutron flux. Work has been proceeding for some years at Dounreay on this topic using stressed springs. This work is continuing.

Work is proceeding satisfactorily on the manufacture of fuel for PFR. This comprises not only the standard reference oxide fuel, but also a substantial programme of experimental variants from which an optimisation of the reference fuel will be undertaken for the use of oxide in commercial fast reactors. A complimentary programme on cladding and structural materials is in the advanced stages of planning.

REACTOR ENGINEERING DEVELOPMENT

Preparations are continuing for the water commissioning experiments which will be carried out in PFR. During these experiments the extent of gas entrainment in the primary circuit will be determined using direct viewing, remote viewing and quantitative measurements of gas content.

At the same time measurements will be made of the vibration of selected groups of core sub-assemblies using accelerometers. Sophisticated vibration analysis techniques will be used to show the extent of random and coherent vibrations. Vibration of the other major components in the reactor will be measured using strain gauges.

Experiments using a four times full scale model and water as the working fluid have been carried out to investigate the effect of plugging 24 central channels in a 91 pin sub-assembly. The experiments showed evidence of standing waves and considerable turbulence downstream of the blockage. Measurement of the degree of mixing showed the effect was equivalent to a steady flow in the blocked region of $\sim$10% of the flow rate for an unblocked assembly. From these measurements it can be concluded that boiling downstream of such a blockage is unlikely to take place.

Certain of the thermal hydraulic problems of the PFR have been analysed in detail. The distribution of hotspots in the fuel sub-assembly, the most effective method of combining the different contributions, and the best strategy for setting the gags are topics which also have relevance to CFR. The cooling of the shield rods of PFR and the flow patterns which are established in the sodium have been studied to ensure that the temperature of the shield rods stay within satisfactory limits. A computer programme was written to analyse the flow pattern and allow for flow parallel and transverse to the rods.

Experiments are continuing to determine the acoustic signature of boiling, both in water and sodium and for detecting this signature against a background of noise emanating from mechanical equipment, possible cavitation etc. During PFR commissioning measurements will be made of the background noise, and also of the noise transmission properties of the circuit.

A joint experiment is being mounted with CENG Grenoble to investigate sodium boiling in a single heated channel.

An automatic plugging meter for use in primary circuits is now fully developed. In this plugging meter the sodium is cooled via a secondary NaK circuit before heat is rejected to atmosphere so that any possibility of leakage of activity from the primary circuit is eliminated. Attention is being paid to methods of predicting the flexural vibrations of the primary tank resulting from vibrations induced in the sodium pool. A mathematical theory for the coupling between the sodium and the tank has now been developed and predictions of the acoustic vibrations of the tank have been made, which are in good agreement with experimental measurements made using water filled model tanks.

The Super Noah test of the simulated failure of the bottom end of a water tube in a PFR steam generator took place on Friday 22 January. It tested the effect on adjacent tubes and the efficiency of the reaction product effluent system. Analysis of instrument readings shows that the test reaction proceeded satisfactorily. The cyclone separator worked well and the oxide fumes ejected from the stack could hardly be seen.

PHYSICS

An attempt is being made to rationalise the development of calculational codes and methods by adopting the use of standard interfaces, so that commonly required edits can be used on a variety of codes. Good progress has been made in the development of TIGAR which is a three dimensional diffusion calculation using a mesh of triangular prisms. Many detailed improvements have led to fast operation and comparisons with other codes have been very favourable. Segmentation of the code enables a full core to be represented in three dimensions but execution of such a case is fairly time consuming. A recent extension allows a coarser mesh to be used by adopting hexagonal prisms. A wider range of edit facilities is currently being developed.

Studies on the use of U235 in fast reactors have progressed to the stage where detailed physics assessments are complete for fuel cycles based on complete replacement of Pu239 by U235 and for mixed systems in which low enrichment uranium supplements the plutonium. Economic studies and the potential requirements for these schemes as means of overcoming any plutonium shortage are still in progress.

Recent work in support of the design of the 1200 MW(E) CFR has included a study of cores with two, three and four enrichment zones. There seems little overall incentive to have more than three zones. A parameter study has been made of radial breeders to help optimise the design. Computer codes for representing the behaviour of sub-assemblies with grid-spaced or wire wrapped pins are being developed for use in hot spot analysis of sub-assembly behaviour.

The parametric survey programme, FROVE, is being continually improved to make the methods embodied in it as accurate as possible consistent with reasonable speed. Results from FROVE are used to provide input data for the economic survey code DISCOUNT, which enables the cost benefits for a complete reactor programme to be evaluated for alternative courses of action.

EXPERIMENTAL PHYSICS

The Zebra assembly 8 experimental programme on simple lattices with unit K-infinity was completed in June 1970. Since then measurements have been made on two simple plutonium fuelled critical assemblies, Zebra assemblies 9 and 10. Seven test zones with unit K-infinity were built in the Zebra 8 series together with one test zone (8G) which had a composition and leakage typical of a zone in a fast power reactor. The seventh unit K-infinity test zone (8H) was composed of enriched uranium and natural uranium plates (together with a small proportion of structural steel). This test zone is similar to ones built in the USA (ZPR 9/25) and in Japan (FCA IV/1) and would be suitable as a standard assembly for the international comparison of measurement techniques. The critical masses of both assembly 9 and assembly 10 were about 300 KG Pu239. Assembly 9 contained about 50% by volume of stainless steel and in assembly 10 the steel was replaced by extra uranium oxide and graphite. The measurements made in assemblies 9 and 10 included fission rate distributions from which values of the buckling have been derived.

Measurements of fission ratios using solid state track recorders scanned automatically using the Zebra quantimet equipment have achieved accuracies comparable with those obtained using the standard activation foil technique and the results obtained using the two techniques are consistent. A large cylindrical proportional counter for measuring spectra in an extracted beam is being developed to try to extend the range of spectrum measurements using this technique up to about 5 MeV. Improved electronic systems are being developed to enable higher counting rates (resulting from the presence of a high proportion of Pu240) to be used with the in-pile proportional counters. The Li6 solid state detector has been calibrated using mono-energetic neutrons from the Harwell Van de Graaf machines.

The cross section adjustment studies have been extended to make adjustments in ten energy groups and to take account of measurements of bucklings and small sample reactivity perturbations. Predicted correction factors to be applied to reactor design calculations have been extended to include distributed properties such as internal and external breeding gain and the accuracies of the corrected values are also estimated in the scheme.

The analysis of the reaction rate ratios and small sample reactivity perturbation measurements made in the plate and pin cell versions of Zebra 8G has shown that the calculation methods treat the two geometries consistently and account for sample size effects correctly. For the canning and structural materials of primary importance these size effects are small.

SAFETY

Safety studies have continued to play an important part in the development programme. The introduction of the CFR into the CEGB network will involve not only the CEGB itself but the Nuclear Installation Inspectorate so that many new people are now studying methods of ensuring the safe operation of fast reactors in the UK. Although the main safety features have been identified, much detailed work in support of the safety case remains to be completed. Much of this work is concerned with postulated sub-assembly incidents in which local blockages are supposed to escalate to blockage of the whole sub-assembly with consequent sodium boiling and ejection from the sub-assembly.

Work on sodium boiling is directed towards two main areas. The first of these is determination of the amplitude and frequency spectrum of the noise of local boiling in aid of the development of boiling noise detectors. A comprehensive series of tests planned in PFR were referred to earlier. During the water tests a variety of sources and detectors will be placed in various parts of the reactor to investigate transmission and detection of noise. A second series of tests, more limited due to the difficulty of operating in sodium, will continue after the reactor has been sodium filled and will be used to qualify differences in behaviour between water and sodium. Both studies include the use of a small boiler which will be placed in the core to provide a noise source.

The second main aim of the boiling work is a study of the spread of boiling in sub-assemblies due to small blockages. Work in a water rig with partial blockages and the work in sodium being carried on in collaboration with the French in the CFNa sodium rig at Grenoble were mentioned in an earlier section. Theoretical analysis of channel blockage situations have shown that the previously used 'marching' techniques are limited in their scope and alternative 'elliptic' methods are being considered. General dynamical behaviour has been examined with analogue computer models and for longer term studies including boiling and parallel channel effects the water reactor programme Splash is being modified to incorporate sodium coolant.

Studies of 'Spert' type thermal interactions range from theoretical studies of the interface behaviour of impacting liquids to experimental techniques. These experimental techniques use aluminium or lead and water to simulate molten UO_2 and sodium, techniques for performing similar experiments using UO_2 and sodium are being developed.

In order to determine the effect of any such interactions on the reactor structure special slow burning gas producing charges have been developed and some preliminary firings have already taken place.

Studies of whole core meltdown accidents are mainly theoretical in nature. Further effort has been devoted to estimating likely reactivity ramps resulting from accident situations and the calculation of energy releases from the resultant excursions. Some experimental work has been done on the effects of firing special 'gas-free' charges under sodium in order to study the effects of fuel coolant interactions resulting from a nuclear excursion in a fast reactor core. Results to date have shown little indication of any 'Spert' type interaction - but this may be due to the presence of a small amount of residual gas in the charge which it has not been possible to eliminate.

Work on instruments for detection of incidents at an early stage in their development continues.

The possibility of detecting sodium boiling from observation of changes in the neutron flux has been assessed. For a reactor of 1200 MW output the reactivity worth of the effect is found to be too small to be useful as a reliable basis for boiling detection.