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INTERNATIONAL ATOMIC ENERGY AGENCY

INTERNATIONAL WORKING GROUP ON FAST REACTORS

SECOND ANNUAL MEETING

VIENNA, 18 - 20 MARCH 1969

SUMMARY REPORT

1. INTRODUCTION

The second annual meeting of the IWGFR was held in Vienna from 18 - 20 March 1969. The meeting was attended by the members of the Group from France, Federal Republic of Germany, Japan, UK, USA and USSR, observers from Czechoslovakia and Poland, and a representative from ENEA. The list of participants is attached to the Summary Report (Attachment 1).

The meeting was presided over by Mr. Vautrey (France).

The general considerations of the meeting were on national programmes on fast reactors and future activities of the IWGFR. The agenda of the meeting is found in Attachment 2.

2. APPRAISAL OF THE IWGFR'S ACTIVITIES

The scientific secretary summarised the activities of the IWGFR from the period of the first meeting. There will be three conferences on fast reactors until March 1970:

- International Conference on Fast Reactor Irradiation Testing in Thurso, UK, from 14 - 17 April 1969.
- International Conference on the Physics of Fast Reactor Operation and Design in London, UK, from 24 - 26 June 1969.
- The IAEA Symposium on Progress in Sodium Cooled Fast Reactor Engineering in Monaco from 23 - 27 March 1970.

The dates for the last two conferences have been changed as compared to the dates which were discussed at the Group's last meeting. Monaco was chosen to host the Agency's Symposium as we feel that France will be able to make it possible to arrange a technical visit to Cadarache for those interested participants of

March, 1969

REVIEW OF FAST REACTOR PROGRESS IN THE U.K.

1968 - 1969

by R.D. Smith

INTRODUCTION

During the last year construction of the PFR has made good progress. The reactor tank is in place and all the buildings are essentially complete, though there have unfortunately been some welding difficulties in the construction of the reactor roof which will lead to some delay in the completion of the reactor.

Design studies for subsequent fast reactors have been extended to include 600 MW(E) reactors as well as the larger 1300 MW(E) units studied previously.

The Dounreay Fast Reactor has been brought back into operation after successful repair of the leak in one of the primary coolant pipes and our fuel irradiation programme is now going ahead rapidly.

PHYSICS

A series of plutonium fuelled test zones has been built into Zebra. The composition of each zone was adjusted so that the k-inf was near to unity. The P.C.T.R. technique in which removal of central lattice cells is required to give near zero reactivity change, has been used to test that the required condition for k-inf was met. In these test zones, particular attention has been given to keeping the number of regions in a lattice cell small so that the heterogeneity can be calculated by rigorous methods. The important capture and fission events have been measured in the appropriate plates using foil techniques, and particular attention has been given to reducing systematic errors wherever possible and to checking measurements with alternative techniques. For example, solid state track recorders have been used to check on fission rates normally measured from fission product γ activity in foils. The foils are calibrated in a separate experiment in a dummy fission chamber. Great importance is attached to accurate measurement of the U.238 (n, γ) reaction. An absolute technique is now being used to measure U.238 capture events using Am-243 to calibrate the coincidence counter; this is an alternative to the previous Zebra technique in which a thermal neutron calibration is used. Good agreement between the two methods has been achieved.

In the assemblies studied the neutron spectrum has been measured using time of flight techniques, proportional counter measurements and Li-6 solid state spectrometers. The proportional counter measurements have been extended down to energies of 3 Kev using pulse rise time discrimination. Most data has however come from measurements using the 14 MeV pulsed electron linear accelerator. This accelerator has a beam of 200 ma and gives a yield of 5×10^{14} neutrons/sec. in the pulse from a water cooled uranium-molybdenum target. There is a 200 metre flight tube and Li.6 and Boron scintillator detectors are used. Results obtained so far have been encouraging. The main difficulty has been in the accurate determination of the variation of sensitivity with energy of the detectors used.

All these results are being used to test current differential nuclear data, and, coupled with existing integral data, are being used to adjust the data, within the errors, to provide the best fit to all the measurements.

The F.D.4. data set has been brought into general use during the year and comparisons between calculated and experimental values have been made for a large number of assemblies. In general the higher values of plutonium alpha reported last year have been confirmed, but a review of the present position will be made at the specialist meeting in June this year.

Detailed analysis of the Zebra PFR mock-up experiment has continued and resulted in revised predictions of physics parameters for the P.F.R., together with better estimates of the uncertainties in these predictions.

FUEL

The fuel irradiation programme so far completed has successfully endorsed the referehce design mixed PuO_2 - UO_2 fuel element up to a maximum burn-up of 7½%. Based on this reference design of fuel element a new fabrication plant was developed and the construction of this plant is now well advanced. Sections of the plant will be handed over for trials during this year and manufacture of the first charge for P.F.R. will commence in 1970.

The continuing irradiation programme in D.F.R. includes a number of important variations on the reference fuel. These include the use of differing cladding materials, can thicknesses and fuel densities, but owing to the interruption of the programme by the leak it will be some time before these experiments have completed the full cycle irradiation cooling and examination.

At the present time the reactor is on run 62 which started on February 6th and is due to be completed on April 2nd. The reactor contains a total of 59 experiments in the core and 41 in the blanket. Of these 9 are for overseas countries including one central subassembly. These irradiations cover topics of interest both to fast reactors and to thermal reactors, for which the high damage rate obtainable in D.F.R. is of major importance.

MATERIALS IN SODIUM CIRCUITS

Owing to the prolonged shutdown of D.F.R. little progress has been made on the effect of fast neutron irradiation on the physical and mechanical properties of fuel cladding materials. Further work has been performed on the phenomenon of void formation using a Heavy Ion Accelerator. Voids have been produced in type 316 stainless steel which had previously been irradiated at 20°C with He+ ions of various energies so as to produce a reasonably uniform distribution of implanted helium atoms to a depth of some 3000 A at an average concentration of between 10^{-5} and 10^{-6}. Subsequent irradiation in the temperature range 450-600°C with 100 kev protons, carbon ions or iron ions in the Harwell 150 kev Heavy Ion Accelerator produced voids in the helium implanted steel. After all cases of bombardment with carbon or iron ions and in most cases after proton bombardment, cavitation was only observed when the steel had previously been implanted with helium. The work indicates that the presence of helium or hydrogen is necessary before void formation will occur in type 316 steel. It is thought that the voids result from the growth of helium bubble nuclei under conditions of vacancy supersaturation in an irradiation environment.

Further information has been obtained on the effect of fast neutron irradiation on the creep-rupture properties of type 316 stainless steel tubes. D.F.R. irradiation produced a loss of rupture ductility, but in general no significant change in creep strength to biaxial tests of solution-treated material at 650°C. Cold worked tubes suffered loss of creep strength at 550°. Irradiation of solution-treated tubes at 650°C in D.M.T.R. caused a considerable loss of high temperature ductility and a significant reduction in cree rate both during and after irradiation.

It is believed that an irradiation-induced carbide precipitation process is responsible for the increase in creep strength.

Further work on the compatibility of circuit materials in sodium has confirmed previously published data. It is clear that the mass transfer of stainless steel in oxygen-containing sodium is very complex and involves a number of processes, some of which may interact upon each other. Mass transfer rates in isothermal loops do not differ widely from those observed at the highest temperature in more complex non-isothermal loops. Therefore, clearly, the most important factor is the oxygen level in the circuit. Preliminary work on vanadium alloys shows that low oxygen contents are required in the sodium in order to avoid high corrosion rates. The work indicates that alloys with high Ti, Zr and Al contents are unlikely to be satisfactory in sodium unless the sodium has been hot trapped to remove oxygen.

DOUNREAY FAST REACTOR

At this time last year the leak in the primary vessel of the D.F.R. had been located and preparations for its repair started. A two metres long section of 10 cm diameter pipe within the neutron shield was replaced and welded in place using a specially developed internal welding machine. The welding parameters had previously been determined on a full scale mock up where a large number of welds were done under conditions similar to those in the vault. All the remaining welds were made using standard orbital welding equipment. During the whole operation the argon atmosphere in the reactor vessel was maintained, so that many operations had to be done in glove boxes. Expandable plugs were used to seal the repair section wherever possible. Some trouble was experienced when joining some of the hot trap pipes due to NaK contamination of the welds. This was overcome by using tightly fitting plugs of solid sodium that were easily dispersed after the weld was complete by warming the outside of the tube. In addition to replacing the faulty section of pipe in the affected primary circuit the small pipes from the other seven hot trap circuits were blanked off. A total of 148 welds was completed within the vault of which 22 were on the primary circuit itself and the rest on the leak jacket.

After pressure and leak tests the reactor was recommissioned on June 19th 1968. Initially the oxide content of the core remained high at about twice the normal operating level of 15 ppm. After a period of power operation, purification of the NaK and tests of corrosion of the driver charge cladding, the liquid metal condition was satisfactory for loading experimental rigs.

The reactor returned to normal operation in September and operated satisfactorily. Shortly after full power was reached analysis of the argon blanket gas showed unambiguous presence of radon. The only source of radon in the reactor was from the radium tracer inserts in some of the experimental pins in the reactor. The suspect experiments were removed and failures were located in two of them. Each of the failures was at the upper end of a pin (coolant inlet end) and was typical of failure due to local gas bubble blanketing of the heat transfer surface probably due to gas entrainment. A check of selected highly rated experiments indicated that no other failures had occurred.

Acoustic measurements of the 24 individual primary coolant circuits showed that two circuits transported gas bubbles into the reactor when the primary elctro-magnetic pumps were being brought to full flow. It was found that in these two circuits, which are different to the remainder in that they do not contain expansion tanks, gas entrainment occurs when the NaK rises past an outlet pipe in the purification traps as flow is increased. An operating technique to flood these outlet pipes continuously while the primary flow was being raised was evolved. Acoustic measurements taken throughout a full operating cycle showed that gas entrainment from the two circuits had been cured. This has been confirmed by the successful irradiation of a full range of experiments including a subassembly.

At the beginning of December when the reactor was shut down to recharge fuel and change experiments, the top rotating shields stuck due to NaK entering the mercury gas seals. The resultant alloy was dissolved by prolonged purging of the seals with clean mercury. The next run commenced in February and the reactor has operated normally since that date.

PROTOTYPE FAST REACTOR

Work on the major buildings has proceeded to plan so that the Reactor and Decontamination Hall, Steam Generator Building, the Turbine Hall and Electrical Annexe are now weather tight. The Sea Water Pump House is complete and the installation of equipment has commenced. The N.S.H.E.B. have commenced the preparation of the transformer and switchgear site and erection of the first ten miles of 275 kv transmission line is completed.

Whilst the civil engineering work was being carried out on site, contracts were placed with British industry for all the major engineering sections of the reactor and steam generation plant. The concrete reactor vault, 12 m. diameter 15 m deep, is complete and the steel leak jacket, fabricated on site, has been inserted into the vault. The primary tank which will contain the whole of the primary circuit of the reactor is complete except for a small amount of final welding.

The components of the core support structure are now being assembled at D.E.R.E. into a single unit ready for insertion into the primary tank. Fabrication of the reactor jacket which separates the hot and cold sodium pools is proceeding to programme.

Difficulties arose in the fabrication of the biological shield roof which is a complex fabricated steel structure forming the top closure of the reactor from which are suspended the heat exchangers, pumps and reactor core. The examination of completed welds by ultransonic techniques indicated 'pull out' in the plate material underlying the weld. The principal cause of the 'pull out' is the presence of laminar weaknesses in the plate material, which escaped detection during comprehensive non-destructive testing methods employed in the inspection of the plate since at that stage they had not opened up. The defective welds are being treated by chipping out the metal in the faulty areas and refilling with weld metal.

Tests on the components of the fuel handling machine have now been completed. The various bearings, universal joint and ball, nut and screw mechanisms have all proved satisfactory and a minimum maintenance-free life of five years is predicted for the in-pile operation of the fuel-handling machine. The manufacture of the actual fuel handling system for the reactor is almost completed and this is being subjected to trials at the manufacturers prior to delivery to site. In the Reactor Engineering Laboratory at Risley a saddle coil flow meter has been calibrated against a British Standard Venturi using the mechanical pump rig over a range of sodium flows from 1,200 to 6,500 gallons per minute. The flow was measured by the Venturi to an accuracy of better than $\pm$ 2% and the flow as calculated from the saddle coil measurements was within the experimental error of the Venturi over the complete flow range. Mechanical performance tests on a prototype control rod have commenced. A complete control rod and actuating mechanism have been fitted into a 30 ft. high x 30 in. dia. vessel filled with sodium. The test programme includes a comprehensive series of mechanical tests at sodium temperatures up to 600°C.

The core support grid is on final machining and will soon be set up at the manufacturers works for tests with a complete dummy core. Satisfactory progress is being maintained on the manufacture of the rotating shield for the reactor and manufacture of the sodium pumps is in progress.

On the steam generation plant considerable development work has been carried out on tube to tube plate welding for both intermediate heat exchangers and boiler units to meet the very high standard of integrity which has been set for these welds. All the main components have now been manufactured for the heat exchangers and by using the tube to tube plate welding techniques developed, final assembly should proceed satisfactorily. The manufacure of the boiler circulating pumps, which are among the largest glandless pumps manufactured to date in the U.K., is on schedule, the first pump being under test at present.

The problems encountered in the manufacture of the roof have resulted in the completion of construction data for the reactor being delayed. The construction programme is at present being reassessed and a new completion date for the reactor will be announces shortly.

COMMERCIAL FAST REACTORS

Work has continued on the designs for future civil fast reactor power stations with reactors of about 625 MW(E) as well s the 1250 MW(E) reactors previously studied. Particular attention has been paid to methods of handling short cooled fuel and to safety problems especially containment systems.

Economic studies of the development of the U.K. generating system have confirmed the advantages of introducing fast reactors in the U.K. at the earliest possible date, even though fuel costs for the early fast reactors will be higher than the later stations due to the small throughput of the fuel fabrication and reprocessing plants. In consequence the choice of a date for the building of the first commercial station depends on a complex interaction of technical and economic considerations. As noted last year it would be possible for a large commercial fast reactor to be on power in 1976.

R.D.S.
March 1969.

Discussion of the Presentation by Dr. Smith

Engelmann: Is there any large report on the PFR mock-up experiments available yet?

Smith: The answer is no. These results are in several small reports. Some of the results will be reported at the London conference.

Engelmann: You mentioned you have done spectrum measurements. I wonder whether there are new results at Zebra with a good agreement of measurements made by different techniques.

Smith: I really try to avoid answering this question because we have not finished sorting this out yet. There are discrepancies between the techniques and between the techniques and calculation. Certainly some results would appear at the London conference. It seems that the time of flight results in particular forecast a larger number of low energy neutrons than we had suspected. I would rather not say it as a definite conclusion, because this depends on an energy calibration of the detectors and this is a rather difficult thing to do accurately.

Wensch: I wonder whether components for PFR will be fabricated and tested to meet the codes.

Smith: Certainly such components as piping and vessels will meet the normal codes. I do not know whether the codes embrace every aspect, for example steam generators, but I believe the majority meet standard codes.

Schuster: Is there any work under way on carbide fuels?

Smith: We are irradiating carbide fuels in the DFR. This fuel will not be used for the first charge of the PFR. We regard this as an advanced fuel. Early tests tended to show that it will not readily go to higher burn ups as an oxide fuel.

Schuster: You said nothing about materials behaviour in sodium: about the displacement, the distortion and some other events in the high fast neutron flux. Are there any experiments in this respect?

Smith: During the last year most of our attention was to these swelling phenomena. We consider this effect as probably the most important.

Schuster: Can you give us some estimate about the delay in construction of PFR?

Smith: Because of troubles with the roof, the reactors cannot now be completed before the end of 1971. If we can manage to keep to this date, it would mean that the reactor is on power by the end of 1972, which means of delay of twelve months.

Schuster: You said that a possible date for a commercial fast reactor to be in operation in your country was 1976. You cannot start the construction of such a reactor without first having some experience with the PFR.

Smith: If we have to wait for experience of the PFR, it turns out that CFR should be postponed to about 1980. The 1976 date is based on the assumption that we would be prepared to start construction of a CFR before we had experience with the PFR. But this depends on many decisions - Government decisions, the view of C.E.G.B., and so on.

Wensch: Do you have some cost estimates for the construction of the PFR?

Smith: I don't have such information with me. There are cost estimates in existence, but I do not know whether these figures were released.

Boxer: You mentioned that design studies for subsequent fast reactors have been extended to include 600 and 1300 MW units. I wonder if you are able to comment upon the impact and of reoptimisation on these designs when the new plutonium alpha date are introduced.

Smith: We said at the Karlsruhe conference that the effect of new data compared with the old is to reduce the breeding gain by about 0.1. The effect on an optimisation of a reactor design is not perhaps quite as great as one would have thought, since in any event one tended to design a reactor so that it had the highest breeding gain that one could attain. The highest breeding gain you can get is a little lower than you would have thought. The things you do in order to get the higher breeding gain - high fuel fraction, good design, low parasitic capture - are the same with new data as they are with old. The only thing that this may do in your analysis is to shift your optimum slightly towards things which give you high breeding gain.

Engelmann: We have calculated the loss in breeding gain due to the higher plutonium-239 alpha values. The higher Pu alpha values seemed in the beginning to reduce the breeding ratio by 0.08 to 0.1 for soft spectrum fast reactors and in the order of 0.06 to 0.08 for harder sodium-cooled reactors; the recalculation of the new infinite plutonium composition in fact reactors changes this reduction and it tends to reduce the loss in breeding gain. So our calculations show that taking into account only the plutonium alpha change, the reduction in breeding gain seems to be for sodium-cooled fast reactors in the order of 0.04 rather than in the order of 0.1.

Spinrad: We have done fairly popular exercises at the Agency in trying to guess what the price and value of plutonium might be in future decades. The estimate at the moment shows a rather steadily and constantly rising cost of plutonium alpha value. I think that this feature will do a lot to negate the plutonium alpha business because the higher value of plutonium inevitably forces you to squeeze a little more out of breeding gain and to go to higher power densities in order to have a relatively inexpensive fuel cycle. The net result I suspect is going to be a spectrohardening of most fast reactor designs to where rather lower energy troubles with plutonium alpha are no longer so important. We are trying to predict things that are likely to be in the 1980's.

Smith: I do not think we are in great disagreement with Dr. Engelmann. I did say the total 0.1 took into account the other cross section changes which have tended to occur over the last year, and in particular the 238 capture cross sections come down and the steel cross sections seem to show signs of going up. These three together give the result which obviously gives us a hardness of the spectrum, but it is of the order of 0.08 to 0.1. You get some of this back again if you perhaps have a plutonium of degraded composition with a lot of plutonium-240. By and large I think we still find that the breeding gains are about 0.1 lower than they were 1.5 years ago.

Simmons: A question concerning a break in the pipe at Dounreay. Did you notice any effects of surface cracking or other types of indication of thermal stresses?

Smith: No, the whole of the inside pipe-work was almost like new. There was very little evidence of a surface attack of any sort.

Simmons: If I remember correctly the design of your pool system, you have an open duct from the reactor proper to the heat exchanger. This permits the underside of the roof of the reactor vessel to see the high temperature of the sodium. Having now done a design of that system and going to another system, would you reconsider that design arrangement?

Smith: Yes, we are looking at arrangements which do keep the surface of the pool at a more cool and more constant temperature. I do not think we feel that this is a problem which would cause us too much worry. In the CFR studies some of the designs do not have these hot surfaces.