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NEA Coordinating Group on Gas-Cooled Fast Reactor Development
Annual Progress Report of the Federal Republic of Germany 1975

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Abstract

The paper gives a short summary of the work performed in the Federal Republic of Germany for the Gas Cooled Fast Reactor in the frame of the NEA-OECD Collaborative Programme on GCFR's. The work has been performed at the two German Nuclear Centers at Karlsruhe and Jülich. In the field of fuel element development, heat transfer experiments have been performed to improve the thermal performance of the artificial roughness on the fuel element pin surfaces, and preparations for a large irradiation experiment in the reactor BR2 are under way. In the field of design and safety studies the work was concentrated on the development of a computer code to investigate the dynamic behaviour of a GCFR with a steam turbine, on investigations of the cooling of the core melt caused by a core melt-down accident, on neutron streaming effect studies, and on calculations of the energe release by hypothetical scram rod ejection accident.

NEA Koordinierungsgruppe für die Entwicklung Gasgekühlter Schneller Brüter
Jahresbericht der Bundesrepublik Deutschland 1975

Zusammenfassung

Der Bericht faßt die Arbeiten kurz zusammen, die in der Bundesrepublik Deutschland auf dem Gebiete des gasgekühlten Schnellen Brutreaktors im Rahmen des NEA-OECD Programms für die Zusammenarbeit am GSB ausgeführt wurden. Mit den Arbeiten wurden die beiden deutschen Kernforschungszentren Karlsruhe und Jülich befaßt. Auf dem Gebiete der Brennelemente wurden Experimente zur Verbesserung der Wärmeübertragungsfähigkeit ("thermal performance") der künstlichen Rauhigkeit auf der Brennelementoberfläche sowie Vorbereitungen für ein großes Bestrahlungsexperiment am Reaktor BR2 durchgeführt. Auf den Gebieten des Reaktorentwurfs und der Sicherheitsstudien wurde die Arbeit auf die Entwicklung eines Rechenprogramms zur Analyse des dynamischen Verhaltens des GSB mit Dampfturbine, auf die Untersuchung der Kühlung der Kernschmelze nach einem Unfall mit Niederschmelzen des Reaktorkernes, auf Effekte anisotroper Neutronendiffusion und auf Rechnungen der Energiefreisetzung während eines hypothetischen Abschaltstabauswurfes konzentriert.

1. Fuel Element Development

1.1. Heat Transfer Experiments

1.1.1. Heat Transfer Experiments with Rough Surfaces

The experiments to measure the heat transfer and friction coefficients of rough surfaces are generally made with a single rough heated rod contained in a smooth concentric tube (annulus), while the GCFR fuel elements are made up of a large number of parallel pins in a regular array. A new method has been developed by means of which it is possible, better than with previous available methods, to transform the annulus experimental data to geometries typical of the fuel elements of a GCFR. Ten rough rods with different rectangular ribs have been isothermally investigated, each in four different outer smooth tubes, and heat transfer experiments have been performed for two of those rods, each in two different outer smooth tubes. These experimental data and data from the literature transformed with the present method allowed to establish the effect of the five determining parameters (Reynolds number based on the roughness height and the gas properties evaluated at the wall temperature, ratio of the roughness height to the length of the velocity or temperature profile, ratio of the wall temperature to the gas temperature, ratio of the pitch to the height of the roughness ribs, ratio of the height to the width of the ribs) on the turbulent flow velocity and temperature profiles. The thus obtained correlations were applied to a geometry typical for a GCFR fuel element, and it was shown that the thermal performance (= St^3/f) of a roughness with two dimensional rectangular ribs can be up to 2.3 times as much better than that of a smooth surface /1/. Literature surways of various two dimensional roughness have been performed /2/ /3/ /4/ /5/ /6/.

Furthermore two rods with different three dimensional roughnesses have been investigated with isothermal tests and tests heat transfer. Here the effect of the ratio of the roughness height to the length of the velocity profile has not yet been completely established. However preliminary data show already a considerable improvement of the thermal performance in respect of the values obtained for the two dimensional roughnesses mentioned above /7/ /8/.

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1.1.2. Development of a Computer Programme for Rough Clusters

The computer programme SAGAPO, which calculates the friction and heat transfer coefficients of smooth and rough rod clusters by integration of the logarithmic velocity and temperature profiles obtained in the annulus experiments (s. 1.1.1.) and can account for grid spacers, diversion cross flow and turbulent mixing, was applied to evaluate the heat transfer experiments with the 12 rough rod bundle used to calibrate the BR2 irradiation experiment (s. 1.1.3.). The agreement between measured and calculated values was excellent /9/ /1o/.

1.1.3. Experiments with Rod Clusters

The measurements of pressure drop and temperature distribution (224 thermocouples) in a bundle of 19 rods with smooth and rough surfaces performed in the Helium Loop (max. helium pressure 5o bar) for a Reynolds number range of $1.4 \times 1o^3$ to $1.1 \times 1o^5$ have been documented /11/ /12/.

5o isothermal and 1o1 heat transfer tests were performed in the Helium loop with the 12 rough rod BR2 calibration bundle. The maximum linear rating was 46o W/cm and the measured maximum wall temperature was 79o°C. The temperature of the corner and wall rods were up to 12o°C higher than the temperatures of the inner rods /1o/ /13/. The pressure drop due to the spacers was rather high, therefore a second series of tests was repeated with slightly modified spacers, which did not produce a noticeable improvement on the previous ones. A third series of tests with a larger shroud for the bundle and spacers with smooth edges produced temperatures up to 1oo°C lower in the wall and corner rods than the in the central subchannels, and considerably reduced pressure drop due to the spacers.

1.1.4. Effect of Spacers on Temperature Distribution on Rough Rods

Temperature distribution measurements in the spacer region with smooth and rough rods and various spacers have been documented and general correlations obtained /14/ /15/ /16/ /17/.

1.2. Material Tests

1.2.1. Fuel Coolant Compatibility

Out of pile tests have been performed with clad and bare pellets of UO_{2-x} and $(U_{o.8}\ Ce_{o.2})O_{2-x}$ in flowing helium with 1ooo and 1oo vpm of H_2 and H_2O respectively. The construction of an apparatus for duration tests with H_2 and H_2O impurity content less than 1o vpm has been started. The experiments and theoretical considerations showed that swelling does not occur for $H_2/H_2O \geq 1:1$ and/or PuO_2 content greater than 2o Mol %. The attack to the 1.4988 steel cladding material is not enhanced if $H_2/H_2O \geq 1o:1$. The fuel oxidation process for a cladding crack of 3o µm width is slow.

1.2.2. Corrosion Experiments in Helium at a Known Level of Impurities

Out of pile duration tests have been performed with helium with the following impurities: 2.7 vpm of H_2O and 127 vpm of H_2. The helium pressure was 1.5 bar and the temperature 8oo^{o}C /18/ /19/. The results of the experiments are given below for the three steels 1.497o (15Cr-15Ni-Ti-stabilized), 1.4981 (16Cr-16Ni-Nb-stabilized), 1.4988 (16Cr-13Ni-Nb-stabilized).

Reaction time /h/	Weight increase /mg/dm^2/		
	1.497o	1.4981	1.4988
5oo	28	7	5.5
1ooo	44	12	1o
25oo	67	16	16

1.3. BR2-Irradiation /2o - 27/

The start up of the KFA-GCFR-He-Loop-Mol-"vented fuel"-twelve bundle-performance-test is envisaged for the middle of 1976. In the spring of 1975 the Belgium CEN has joined this project officially as a partner.

The development of the GCFR-test-fuel-element was successfully brought to an end in 1975 by KWU (Erlangen). The construction work on the GCFR-test-fuel-elements for Mol is going on and the elements will be delivered in time.
GfK-Karlsruhe has performed for this experiment in 1975 successful out of pile calibration experiments where an electrically heated twelf pin GCFR test bundle with nominal full bundle and pin power was used. These experiments are necessary for the final lay out of the shroud-tube for the inpile-test-bundle.
At KFA in Jülich a GCFR-test-bundle-dummy-fuel-element was tested in an 15oo h run in an out of pile loop at isothermal conditions of 35o $^{\circ}$C, He-pressure of 6o bar and a He-throughput of o,2 kg/s. The tested fuel-element-bundle behaved according to the design-calculations. For this test one of the three original He-blowers which are now installed at Mol has been used and tested. This was also the case for the electrical power supply, control devices and a part of the instrumentation which will be used at Mol.
After the 15oo h test-run the GCFR-fuel-element-dummy was disassembled and the different parts went through thorough examinations; not even an appearance of a failure could be detected.
In 1975 almost the greatest part of the "He-Loop-Mol" with its various mechanical electrical and safety-correlated sections has been tested and installed at the reactor-site at Mol.
Measurements at the zero-power-reactor BR02 and reactor-physics-calculations have shown, that the envisaged linear heat rating of the test pins of 5oo W/cm for the GCFR-experiment at Mol can probably be realised without rising the present nominal power of the BR2.
KWU has received 1975 from KFA-Jülich an order to go on with the design- and construction-work for a full size demonstration and prototype GCFR-fuel-element-bundle.

2. Design and Safety Studies

2.1. Karlsruhe-KWU Study

The work on the design and safety of the GCFR in collaboration between the Karlsruhe Nuclear Center and the firm KWU has been continued in 1974 /28/ /29/ /3o/ /31/. In the frame of the agreement KWU performed various studies on non-hypothetical and hypothetical accidents /32/ and on the design of the fuel element for a 1ooo MWe GCFR /33/.

The Karlsruhe work in the frame of the KWU collaborative programme can be divided in the following activities.

2.1.1. Development of a Computer Code to Investigate the Dynamic Behaviour of a GCFR with a Steam Turbine

The code PHAETON2 has been successfully tested for the extreme case of natural convection with flow reversal. The results agree well with experimental data from the literature. The code takes into account of transient heat transfer /34/. For the calculations for the 1ooo MWe KWU design a model was used with two parallel coolant circuits, one representing the damaged primary loop and the other the seven undamaged loops. The core is represented by four pins in four different reactor regions (3 in the core, 1 in the blanket). Calculations for the coolant pressure loss accident show that previous calculations performed by KWU and GAC with less sophisticated codes are pessimistic.

2.1.2. Cooling of the Core-Melt Caused by a Core Melt-Down Accident

Various liquids have been considered as possible emergency coolants for a core melt. In particular lead, $ZnCl_2$ and water have been investigated. Thus the compatibility and possible reactions of liquid lead with the various components of the core melt was studied. With water as emergency-coolant it can be shown, that in a GCFR no formation of oxy-hydrogen gas is possible, due to the presence of helium and water steam, which act as a dilution medium /35/ /36/ /37/.

2.1.3. Neutron Streaming Effects

The precision and the reliability of the computer code to calculate the neutron streaming effects was improved through the automatic insertion of results from the newly available one dimensional multigroup programme MANDI.

2.1.4. Energy Release Calculations by Hypothetical Accidents: Scram Rod Ejection

The joint calculations GfK-KWU of the energy release, pressures and fuel displacements in case of a hypothetical rod ejection accident have been continued. Various sensitivity studies have shown that power, reactivity ramp and average temperature have small effect and the reactivity itself a great effect on the energy release, which for fresh fuel is in the region of 21ooo MJ. The gas fission products reduce this figure quite considerably /38/ /39/.

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