SUMMARY REPORT

Introduction

The Research Coordination Meeting was held at O-arai Engineering Center, PNC, Japan, from 26-28 September 1994. Meeting participants came from France, India, Japan and the Russian Federation. The objective of the meeting was to discuss and review data and to validate LMFR structural codes. On behalf of the Power Reactor and Nuclear Fuel Development Corporation (PNC), Dr. Nakamoto who is the Director of the Advanced Technology Division, OEC, PNC welcomed the participants. He gave a brief outline of the nature of work on fast reactors being performed at the PNC and wished the participants success in their deliberations.

The meeting was opened by Mr. A. Rinejski of IAEA. He gave a brief account of development work worldwide on fast reactor commercialization. He stressed the importance of the detailed core analyses to ensuring reactor safety in the event of earthquakes. The meeting was chaired by Mr. Morishita of PNC, Japan.

Discussion of calculation results, conclusions

Analysis performed by Japanese organizations: Four Japanese organizations, Power Reactor and Nuclear Fuel Development Corporation (PNC), Mitsubishi Atomic Power Industries Inc., Toshiba Corporation and Hitachi Corporation are involved in the Coordinated Research Programme (CRP).

Mr. Morishita (PNC) presented his analysis of French Rapsodie core mock-up in air experimental data. The calculations were made by a general purpose non-linear finite element code FINAS, with a nineteen element model (central row). The seismic response analysis with the single row model gave fairly close agreement with those measured in the experiment. He concluded that, based on the comparison of analysis results with experimental data, the presented analysis gives good results with reasonable accuracy for practical purposes.

Mr. Itoh (Mitsubshi) presented analysis results of problems of the one row test in air and of the three dimensional test in water. He pointed out that the measured displacement is well reproduced by the computer code FINDS which Mitsubishi has developed. He also pointed out that the predicted displacements of the neutronic shield elements are smaller than measured for reasons not yet understood. More efforts to check both analysis and measured data was suggested.

Mr. Horiuchi (Hitachi) reported the results of his calculation on the mock-up Rapsodie experiments using the SAFA code. Calculations were made for the experiments "in air" and in water with a single row model. For the in air experiment, the calculation without inclusion of impact energy dissipation gave close agreement for displacement except at the end, where the maximum displacement was relatively large. Calculations that included the energy dissipation produced results without this discrepancy. Mr. Horiuchi stressed the importance of the energy dissipation caused by impacts.

Mr. Kobayashi (Toshiba) presented results of Rapsodie and PEC tests. The calculations agreed reasonably with the experimental data. But more work is needed to study the effects in an asymmetric configuration which is more representative of the actual designs.

The impact forces were smaller in the corner-to-corner acceleration than in flat-to-flat. In air, the calculated displacement time histories of the top of the elements agreed well with the experimental data. Preliminary calculations have been made with the single row model for the test in water. More work is needed to evaluate the effects of fluid before starting the multiple row analysis.

Analysis performed by Russia: Mr. Silaev presented results of his calculations using the DINARA code. Based on a comparison of results with experimental data in terms of distribution of maximum of displacement collision forces and acceleration at the top level, analysis of the single row model gives good results.

Analysis performed by IGCAR, Kalpakkam and by BARC, Bombay: Mr. Ravi pointed out that the difference in displacement between theory and experiment is about 10% for the in air calculation and about 20% in water calculation. The results show very good matching with the results of the other participants. The strain values at top load pads (TLP) and at the foot of the subassembly compare well within 20%. As for the data, the comparison of the top displacement history for fuel subassemblies is good. For the neutron shielding subassemblies, (N/S) there was some difference which was also observed by other participants in their analysis results with respect to the BARC, Bombay, results. Mr. Ravi said that there is a reasonably good match between the experimental and the calculated values of displacements. The maximum difference is 33% for the maximum values. The computed accelerations were however an order of magnitude higher. Regarding the Fourier spectra of the displacement response for the row model, there is a clear peak at 3.5Hz which is the first natural frequency of the fuel subassemblies (F/S) whereas such clear peaks were absent in the Fourier spectra corresponding to the cluster model. Mr. Ravi pointed out that in the BARC calculation which employed a model superposition technique, a rather large time step of 0.25ms was giving reasonably good displacement response, in comparison to the much smaller time steps employed in the time integration calculations which is of the order of 0.01ms.

CEC (France) activities: Mr. Fontaine presented the first calculations performed on the single row layout and the hexagonal cluster of the Monju core. All the calculations were performed in air. After a brief presentation of the geometrical data, Mr. Fontaine described the vibration characteristics of the assemblies calculated with up-dated data. A non-linear analysis of the eigenvalues was then presented. The eigenfrequency of the fuel assembly (3.6Hz) is reached for displacements greater than 20mm. Since the computer code CASTEM 2000 uses a modal combination method, the stiffness of neglected modes was calculated and taken into account in the determination of shock stiffness. No damping was considered during the impacts. Concerning the seismic input, several levels were applied and the results (displacements and impacts forces) were compared to the experimental data. The agreement with the test results are rather good with respect to displacements. The impact forces at upper pad level were comparable to the tests in the case of the single row layout but the agreement is not so good for the hexagonal cluster. A possible explanation is that only maximum values were compared, and that the calculation were performed with theoretical acceleration. The second phase of the presentation concerned the Rapsodie mock-up. The calculations were performed in air and in water with a single row layout of assemblies. As explained in the previous presentation, the shock stiffness takes into account the neglected modes of assemblies. The values of damping used were the same for all the modes, with different values when it concerns F/S or N/S, in air or in water calculations. A presentation of a non-linear analysis of the eigenvalues of fuel assemblies was made. The linear value of frequency is reached for a displacement greater than 15mm. Concerning the in air results, the same profile of displacement between calculations and test was observed. The profile of impact forces at pad level presented its maximum between the F/S and N/S. Concerning the in water calculation, the fluid-structure effects were introduced through added masses (diagonal terms of the added mass matrix), and coupling with the vessel (non diagonal terms). A value of participation factor was tuned to around 0.9. With this participation factor, good agreement is obtained on the displacements. This shows that the fluid-structure interaction effects have to be accurately taken into account.

Analysis performed by ENEA (Italy[1]): The Italian paper reported a numerical study which was performed by ENEA to fully assess the fluid-structure interaction (FSI) model applicable to the seismic analysis of restrained Liquid Metal Fast Reactor (LMFR) cores. The study was based on the results of French shake table tests of the Rapsodie mock-up and was performed using both the one-dimensional (1D) code CORALIE and the two-dimensional (2D) code CLASH. The first goal was to check the adequacy of the model based on the results of shake table tests of groups of 7 and 19 PEC core elements. The second goal was to improve this model to account for the effects of reduced thickness of the liquid layer surrounding the core. Both goals were achieved, in spite of some uncertainties related to the core geometry and element constraint conditions. In fact, the results of the study showed that: (1) The two-concentric shell FSI model which had been developed for the PEC vessel-core coupling on the basis of experiments on groups of PEC core elements in full scale, is also applicable to other LMFR core geometries (at least when these cores are restrained), provided that the effects of the relatively thin liquid layer present between core and tank are correctly taken into account (the tank-core distance was quite large in the cited experiments on PEC core element groups), (2) To account for these effects, reference must be made, in the correction factor, to the radius of the circular section which has the same area as the core cross-section, (3) The analysis performed based on the single core diameter is not adequate for cores like the Rapsodie mock-up (interactions with the adjacent element rows are important, probably more than 2D effects). This may be attributed to the fact that the fuel and neutron shield elements of this mock-up are characterized by quite different first natural frequency values, (4) Shock stiffness (k_{sh}) have a great effect on the results. Satisfactory agreement between calculation and measurements has been obtained using very high k_{sh}-values, which were consistent with the assumption of simultaneous shocks on more than two wrapper tube faces and that of no effect of the modes neglected in the dynamic analysis (these assumptions were justified by the results of previous studies), and (5) The nominal values of some parameters used for the dynamic analysis appear incorrect. This is especially the case of constraint conditions of the neutron shield elements, which do not behave as encastres at high excitation. Also the gaps at the top between these elements seemed overestimated. However, these uncertainties have not hindered full achievement of the purposes of this study.

Conclusions

A wide range of topics regarding seismic behaviour of LMFR cores was discussed. At present, it is very difficult to perform an analysis of the whole core, given the present limitations in computer power in some countries, but detailed core analyses are very important with respect to ensuring reactor safety in the event of earthquakes. It was agreed that the central row seismic analysis gives conservative displacement and shock force. The

[1] The representative from Italy could not attend the meeting but he had sent his paper to all participants in advance. After discussion the meeting participants proposed to include his paper in the report.

effect of fuel pins on the natural vibration frequency of the wrapper, which has so far been neglected, might be given a more closer look. This may become all the more important in the context of irradiated sub-assemblies, in which the pins touch the wrapper tube due to swelling. In the context of poor matching of displacement responses for the neutron shield elements between the experiment and the calculations, for the Rapsodie data, the need to look into the boundary condition details of the neutron shielding elements was stressed.