

NUCLEAR ENERGY AGENCY COMMITTEE  
ON REACTOR PHYSICS

**SUMMARY RECORD  
OF THE TWENTY-FOURTH MEETING**  
(TECHNICAL SESSIONS)

WINFRITH, U.K.  
14th-18th September 1981

Compiled by  
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Atomic Energy Establishment Winfrith

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## TECHNICAL SESSIONS

Following an established practice, for each topic a Committee member was assigned to prepare a draft summary, and these summaries were reviewed before the closing of the meeting.

Technical papers are referred to by their number. A complete list of all the papers presented at the meeting is given in Annex 2.

## 1. New Topics

### 1.1 Pin/Plate Heterogeneity Calculation and Comparison with Experiment

Rapporteur: G. Campbell

Paper A-447 from the UK draws attention to the importance of being able to extrapolate from plate-type lattices used widely in zero power experiments to the pin-geometry of power reactors. The use of pin-fuelled minicalandria to investigate this extrapolation has shown unexpected discrepancies in the reactivity of mixed oxide pin fuel relative to that of plate cells containing metallic plutonium, the pin fuel being less reactive than expected.

To investigate these heterogeneity effects in clean geometry, comparisons are being made in Zebra of the relative properties of cores built entirely with plates and almost entirely with pin fuel. The reactivity difference has been found to be dependent upon position of the cells in the core, indicating deficiencies in cell-leakage calculations as well as  $k_{\infty}$  and the need to make whole-reactor calculations to investigate the effects. A small region of mixed oxide plate cells is also included in the experiments as a less extreme variant of the plate cell.

The Zebra cores are offered for international benchmark calculations of pin/plate heterogeneity effects.

Paper A-450 reviews the French position on heterogeneity effects in MASURCA lattices in which use is made of cylindrical fuel rodlets and square diluent rodlets. Plate cells also feature in the RACINE programme.

A two-dimensional treatment of the heterogeneity effect in the MASURCA core pin cells is required for the most accurate predictions, and results in a predicted increase in  $k^*$  (production/absorption) of about 0.25 %

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compared with a 1D treatment. Studies of blanket region heterogeneity in MASURCA pin cells have shown that to calculate the U-238 capture rate in sodium relative to UO<sub>2</sub> a smaller buckling is needed as the high-energy core leakage is under-estimated by the simplified model used. It is recognized that further validation of pin/plate heterogeneity effects are now required to supplement earlier ERMINE experiments which were confined to U-235 fuel cells with graphite diluent. The effects of streaming on heterogeneity are currently being studied theoretically, and emphasis should be placed on these effects in experimental pin/plate heterogeneity investigations.

Paper A-452 from Japan reports calculations on infinite arrays of one and two-dimensional plate cells with emphasis on the resonance shielding and spatial fine structure. The two-dimensional treatment increases the k-inf value by about 0.4 % which is less than the experimental discrepancy reported. In paper A-451, also from Japan, sodium voiding of FCA plate and pin cells is analysed, choosing a diffusion coefficient to take account of streaming effects between voided and non-voided cells. Whilst good agreement with experiment is found for plate cells, pin-cell voiding is overestimated.

The US paper, A-453, extends the earlier Monte-Carlo validation of plate cell lattices to voided pin-cells. Good agreement is found with the SDX pin geometry cell homogenization treatment for voided cells.

Discrepancies between the ZPPR-7B pin lattice results and the preliminary pin lattice results for ZPPR-11 (where the internal solid UO<sub>2</sub> blanket of ZPPR-7 has been replaced with UO<sub>2</sub> blanket pins) were also reported. The US opinion was that plate streaming effects have not yet been experimentally validated.

In general discussion, the Committee agreed that the UK proposal to base a benchmark calculation on the Zebra pin/plate heterogeneity experiments would be valuable in contributing to the resolution of present pin/plate discrepancies. The UK agreed to detail the benchmark proposal and circulate it to members. US, French, German and Japanese interest in participating was expressed. The proposal should include calculation of the Zebra mixed PuO<sub>2</sub>/UO<sub>2</sub> plates as an intermediate step between the Pu metal plates and the mixed pin cells.

## 1.2 Progress towards Achieving 3D Transport Solutions for Reactor Calculations

Rapporteur: T. Inoue

On this topic six papers, A-454, 459, 456, 457, 458 and L-250, were presented and discussed. A few additional comments were given on work described in the national progress reports. These were concerned with the need for 3D transport codes and the requirements for code exchange.

Paper A-454 describes a space and angle finite element method and paper A-459 describes a finite element/spherical harmonics method. Both of these approaches are used for obtaining exact reference solutions. Paper A-454 describes a multilateral prism-shaped reactor system divided into a number of prism-shaped and box-shaped elements. Six mutually perpendicular directions are defined in the angular domain to take account of anisotropy in the angular flux. The solution is obtained by applying Galerkin's method using vacuum and/or reflective boundary conditions. Paper A-459 describes a finite difference formulation using an iterative procedure and also describes a finite element solution in XYZ and XY geometry, both formulations being combined with a spherical harmonics angular representation. Good agreement with an exact calculation has been obtained for an XY test problem in both formulations. The method operates in many geometrical options and is not dependent on the number of energy groups. For the finite element formulation the running time is about a factor of five greater than that for the finite difference formulation.

Paper A-456 describes the status of 3D transport analyses in the US. Practical analyses have relied on Monte Carlo methods (VIM, MORSE, MCNP, TRIPOLI). The 3D transport code THRETRAN-1 has been applied to FFTF analyses but running times are long. The development of 3D transport codes concentrates on synthetic diffusion and nodal approaches.

Papers A-457 and 458 are concerned with more recent solution methods such as perturbation and synthetic approaches. Paper A-457 describes a perturbation method for computing reactivity (eigenvalue) changes. The method can be applied to safety-related  $S_N$  computations and also to  $S_N$  computations of many other types. It is very efficient. The computations are remarkably accurate, even though running times are only about a fifth to ~~a tenth of those~~ required for full-scale  $S_{32}$  calculations. The paper also compares a linear synthetic computation with diffusion calculations. The linear method appears somewhat more reliable than the non-linear method. Paper A-458 uses the multichannel synthesis method based on the transport codes APOLLO and DOT3.5 to compute 3D power distributions in complicated geometries. The method blends 2D-XY solutions with 2D-RZ solutions. Discrepancies observed between calculated values and those measured in CABRI are discussed. Further work to improve the multichannel method is in progress.

The final paper, L-250, compares calculations using the three-dimensional discrete ordinates transport code ENSEMBLE with measurements of streaming through a twice-bent cylindrical duct in water. The ratios of calculated-to-experimental reaction rates range from 0.48 to 1.76 for all types of reactions. It is shown that ENSEMBLE can predict the attenuation through the duct better than the conventional two-dimensional treatment.

Additional comments were made on work described in the national progress reports of Germany, UK, France and Japan.

The Committee noted that 3D transport codes are needed for several applications such as global shielding analysis, burnup analysis of heterogeneous cores, power distributions, etc. The Committee also discussed standardization testing and interface requirements which might assist the exchange of such large codes.

The Committee agreed that discussions on the state of the art in this area should continue. The possibility of sponsoring an international specialists' meeting on 3D transport solutions for reactor calculations will be discussed at the next NEACRP meeting.

### 1.3 Beta and Gamma Decay-Heat Measurements for Fast and Thermal Reactors, particularly for Pu-239

Rapporteur: F. Maienschein

Akiyama, Furuta and An of the University of Tokyo (A-462) have measured beta and gamma-ray spectra following fission of U-235 and Pu-239 by fast neutrons. Integration of these data gives energy release rates with uncertainties of  $\sim 5\%$  which agree well with data for thermal fission and with the summation calculations using the Japanese Nuclear Data File (JNDC). Earlier UK measurements of beta-ray energy release are consistent with this measurement.

The JNDC was shown in a paper by Yoshida of NAIG and Nakasima of Hosei University (L-253) to improve remarkably the agreement between experimental results and summation calculations as compared with the use of ENDF/B-IV and other data files. This improvement resulted from the use of an approximate theory of beta decay to provide estimates of average beta and gamma-ray energies for high Q-value nuclides, which have short half lives. Evidently, decay schemes derived from measurements tend to underestimate the gamma-ray emission.

Baumung, K uchle and W urz of Karlsruhe (A-463) have made calorimetric measurements of the energy release from fission products from U-235 which agree within better than 3% with the ANS standard for times between 15 s and 4000 s. A Moxon-Rae detector was also used to determine separately the gamma-ray contribution.

A note by Dickens of ORNL (A-464) compared 4 measurements of total decay heat from fission products of Pu-239 and U-235 (Maienschein also cited an unpublished gamma-ray spectral measurement at LANL which agrees with that made at ORNL). For short decay times the data tend to be discrepant considering the estimated uncertainties. Dickens' note judges that the differences are probably not due to normalization. The general tendency in the US is to use the ANS standard which quotes uncertainties of about 5% for decay heat power for long irradiations of Pu-239. ENDF/B-V gives poor predictions for the separate components of decay heat for Pu-239 at short times after fission due to the problem with high-Q nuclides. The

data file thus requires revision, which is planned, but these effects are judged to be sufficiently small for long irradiations that they do not invalidate the uncertainty estimates in the ANS standard. Dickens' note provides data for Pu-241 and refers to new fission-product yield data for Pu-239.

A paper by James of Winfrith (A-465) takes the view that the various discrepancies among measurements and summation calculations must be taken into account to increase the uncertainty for Pu-239 decay heat to 10 % for 1 $\sigma$ . For U-235 the uncertainty is estimated to be 5 - 7 %. Calculations based upon the UK data file fall below most experimental results for Pu-239. Considering ratios of Pu-239/U-235 decay heat for long irradiations James concludes that, although the LANL and ORNL measurements separately differ by 8 %, the ratios are in close agreement. However, the measured ratios differ systematically from the ratio of the summation calculations by about 8 %, and it is difficult to see how this discrepancy could be explained by deficiencies in the summation calculations. Sensitivity analysis is being investigated to help identify possible sources of error.

From the discussion, it appeared that different analyses of the same experimental data sets have led to numerically different results. Further study of the papers presented and direct communication among the investigators will be necessary to remove these ambiguities. Any positive results of further discussions should be communicated to Committee members before the next meeting in order to facilitate the discussion there.

On another aspect of decay heat, a paper by Costa, Crouzet and Josso of Cadarache (A-466) gave data for the overall delayed-heat measured and calculated for Phenix subassemblies. In work to date, agreement has been obtained to within 20 % with the predictions being conservatively high. Predictions for Superphenix were also made with the new code PROTEE and the results compared with the ANS standard. All of the decay-heat calculations include, in addition to fission products, decay of U-239 and Np-239, alpha particles from heavy nuclides, and activation in steel and sodium. Furthermore, uncertainty estimates are provided for all of these components.

#### 1.4 Techniques for Sub-Criticality Reactivity Monitoring in Out-of-Pile Configurations

Rapporteur: J. Bouchard

Subcriticality monitoring in the out-of-pile fuel cycle was a new topic discussed by the Committee. The development of new techniques in this field has two main objectives:

- To reduce the large safety margins usually adopted in the design of transport flasks and reprocessing plants. (For criticality studies it is currently assumed that all fuel is fresh and has the maximum possible enrichment.)
- To satisfy the need for a criticality control device in some particular apparatus of the reprocessing plant.

Paper L-254 from France reported on a recent experimental programme undertaken at the La Hague reprocessing plant using the gamma spectrometry technique to check the burn-up and cooling time of PWR fuels. This work was primarily directed towards criticality applications, but other potential applications, for instance relating to fissile input inventory and safeguards, were also considered. The applications justified simultaneous measurements by the gamma spectrometry and the neutron counting techniques. On the basis of a sensitivity study the authors have defined a procedure which guarantees non-criticality, even if the historical data used in the analysis of the experimental results contain some errors. The expected accuracies, confirmed by the results obtained on nearly 60 subassemblies, were better than 10 % on burn-up and cooling time. For future developments, aimed at other applications, the target accuracy will be 1 % on the Pu content.

A neutron measurement technique developed at Karlsruhe was briefly described in paper A-463. Using a strong Cf-252 source the authors measured the multiplication factor of a fuel element which can then be related to the reactivity of the fuel in the dissolver. They have checked the relationship for PWR fuels and work is in progress for BWR fuels.

Paper A-467 mentioned two methods currently under development in the US. The pulsed neutron technique used at Pacific Northwest Laboratory (PNL) is well suited for reactivities above 0.9, but some measurements have also been made for lower reactivity values. The method has been improved to allow applications to small process vessels as well as to large fuel arrays. The second development concerns the neutron noise technique using a Cf-252 source. Tests are in progress to investigate the lower limit of measurement of this promising technique. In the discussion it was mentioned that some work based on the neutron transmission technique is performed at the National Bureau of Standards (NBS).

The Committee noted two parallel developments of subcriticality monitoring techniques:

- fully independent measurements of the reactivity,
- fuel identification tests and burn-up measurements, the reactivity then being deduced from the knowledge of the physical behaviour of the spent fuel.

Work is in progress in both directions, justified by the various applications and required accuracies.

Two papers dealing with isotope correlation techniques were also discussed. Paper A-468 reported the work on post-irradiation analysis and theoretical prediction of isotopic ratios performed at Karlsruhe. Except for some minor actinides the agreement between calculation and experiment for the usual isotopic correlations was satisfactory, the deviations being of the same order as in interlaboratory comparisons.

Theoretical studies performed at Argonne were reported in paper A-469. These aimed at confirming the applicability of isotopic correlation techniques to safeguards on LWR and LMFBR fuel cycles with emphasis on the latter. The results indicated a good sensitivity of the various isotope correlation functions to different parameters, including the initial composition of the fuel. The possibility of counting neutron yields from the fuel was also investigated, and it was concluded that this technique can be recommended as a primary technique for safeguards applications.

Work in the field of isotope correlation techniques is also carried out at JRC Ispra and in France.

The Committee had already reviewed this topic at its 22nd meeting (Paris 1979). The various studies which are in progress in several countries show how different applications in the out-of-pile fuel cycle can benefit from the reactor physics knowledge on spent fuel. The topic will be retained for further discussion at the next NEACRP meeting.

#### 1.5 Progress on Intercomparison of Reaction Rate Measurements in Fast Reactors

Rapporteur: L.G. Le Sage

Only one paper (A-470) from the US was presented on this topic. In this paper ANL reported on a 3-phase program of reaction rate intercomparisons with emphasis on U-238 comparison. Special portable counting equipment was developed at ANL-Idaho to accomplish the intercomparison. The initial intercomparison was with ANL-Illinois and the agreement was very good. The second comparison was with AEE Winfrith. Although final results are not available, the preliminary values for U-238 capture appear to agree to

within 1 or 2 percent. The third intercomparison experiment was a comparison of U-238 capture rates measured by both activation and mass spectrometry. These results are not yet available.

Results of intercomparison measurements for U-238 capture and fission, U-235 fission and Pu-239 fission among Winfrith, Karlsruhe and CEN-Mol were also reported. This appeared in the UK national report. Agreements to within just over 1 % were observed for these measurements. It was also observed that the radial variations in U-238 capture across the plates were taken into consideration in cell-averaging, only at Winfrith.

#### 1.6 Delayed Neutron Data and Reactivity Scales, Beta(eff) Data

Rapporteur: L.G. Le Sage

Papers from Japan (A-472), France (A-471) and the US (A-473) were presented, and attention was called to a paper by Fischer on the same subject previously published in Nuclear Science and Engineering (Vol. 62, p. 105, 1977).

The impact of the basic delayed neutron data on the calculated  $\beta_{\text{eff}}$  for FBR's was evaluated in the Japanese paper. It was observed that the calculated  $\beta_{\text{eff}}$  is sensitive to both the basic nuclear data and the delayed neutron spectrum. This sensitivity is greater in large, soft spectrum FBR's.  $\beta_{\text{eff}}$  values for the ZPPR-9 critical assembly were calculated using four different data sets. These sets and the respective  $\beta_{\text{eff}}$ 's relative to the ANL ENDF/B-V result (in brackets) were Tomlinson (1.06), Tuttle (1.05) and Cox (1.03). The delayed neutron spectra were also considered and it was noted that the spectrum of Eccleston and Woodruff was very soft relative to three other delayed spectra measurements.

The present status of delayed neutron data accuracy was summarized in the French paper. It was concluded that the uncertainty of the delayed neutron yield is about 6 % for PWRs and 8 % for FBR's. This leads to an estimated uncertainty in calculated  $\beta_{\text{eff}}$  values for reactors of about 10 %. Additional integral measurements are planned to reduce this uncertainty to approximately 5 %.

Results of integral  $\beta_{\text{eff}}$  measurements in nine critical assemblies were reported in the US (ANL) paper. This included 6 plutonium assemblies and 3 uranium assemblies. Measurement techniques included both noise and Cf-252 source methods. The noise technique is inherently about twice as accurate as the Cf-252 technique. Although there is some scatter in the results, the measured values are typically about 5 % above the values calculated using ENDF/B-V data. There was no clear bias between the values for uranium and plutonium cores or between values measured by the two experimental techniques.

The Fischer paper reported measurements of  $\beta_{\text{eff}}$  in critical assemblies. It was concluded that the measurements supported the Tuttle delayed neutron data evaluation, and were 5 - 8 % above the Keepin data.

In the discussion that followed the presentation of the papers, it was pointed out that in some cases, out-of-date delayed neutron data is being used for LWRs. It was also observed that all discussions have concerned the total  $\beta_{\text{eff}}$  while errors in the individual decay groups could be important in some areas. Further, differences in the calculated U-238 to Pu-239 fission ratio can have a significant impact on  $\beta_{\text{eff}}$  for an assembly. ANL (Le Sage) agreed to consider preparation of a benchmark problem addressing the reactivity scale and the central worth problem and report to the next meeting of the Committee.

## 2. Topics Carried over from Previous Meetings

### 2.1 Pressurized Transient Studies, Collapsing the Transient Equations to a 1-D or Point Model Form, Prediction of Moderator Temperature and Reactivity Coefficients

Rapporteur: J.R. Askew

Paper A-474 reported validation studies on the RETRAN code against the loss of feedwater ATWS experiment LOFT L6-5. Generally good agreement was obtained but a number of detailed modelling problems, especially in representing the steam generators, were identified, and some limitations in the knowledge of the experimental conditions discussed. Tests of the code IQSBOX against BWR plant startup data were reported in the Federal Republic of Germany activities report (p. 13), showing that the strong feedbacks associated with this type of reactor were satisfactorily modelled. Theoretical studies related to plutonium recycling were also presented.

Noting the difficulty of obtaining definitive validation comparisons the Committee agreed that any conclusion on the state of the art in this area should await the outcome of the proposed benchmarks on PWR and BWR plant data.

Papers A-475, 476 and 477 discussed theoretical studies of the problems of reducing kinetics models to one-dimensional and point forms. In particular the difficulty of producing the required feedback was emphasized. A way of doing this was demonstrated to work satisfactorily for both moderator and fuel temperature effects when compared with both static and kinetic calculations, giving accuracy of better than 10 % in the reactivity coefficients. Paper A-478 treated a similar problem related to asymmetric rod drop in a PWR. Again, care was needed to match the three-dimensional results with a point model, the reactivity result lying between

those obtained condensing with the initial and final power distributions but closer to the latter case. Differences of 30 % were possible between different models.

It was concluded that great care was needed in using condensed representations of core kinetics, and that some form of three-dimensional comparison was needed to justify such models. There was good evidence, however, that static comparisons were adequate for this purpose.

## 2.2 Utilization of Information from Operating Reactors, Evidence of Capabilities for Predicting Pin Power Distributions and Doppler Coefficients

Rapporteur: H. Küsters

In papers A-479, 480 and 481 Doppler and temperature coefficients for a French PWR, the FBR Phenix and the AGR at Hinkley Point are discussed.

On the basis of a mathematical model of the flux behaviour in a PWR after a rod drop experiment, the following reactor parameters were deduced: reactivity change, heat transfer coefficients, reactivity coefficients (Doppler and moderator) and residual power. In preliminary experiments on a French 900 MWe PWR the Doppler coefficient could be measured to an accuracy of about 10 %. In the discussion it was pointed out that corrections for the expansion of structural material were negligible for the experiments performed. The accuracy of the method will be improved by:

- precisely measuring the total power of the core,
- determining the moderator coefficient from a reactivity balance,
- performing experiments for low values of the moderator coefficient.

In a first series of measurements of the isothermal Doppler coefficient in the prototype fast reactor Phenix large corrections had to be applied due to the relatively high power level (leading to deviations from an isothermal distribution) and control rod calibration effects. The more recent measurements were performed very carefully at 400 °C, the core being isothermal and the power high enough to ensure reliable measurements with neutron chambers. To compensate the reactivity gain resulting from lowering the sodium temperature from 400 °C to 250 °C, only one control rod was moved. This was calibrated for the control rod configuration as used in the experiment. The uncertainty of the experiment was estimated to be 10 - 15 % at the 2 $\sigma$  level. Theoretical predictions based on Carnaval IV, giving results with a 20 % uncertainty, agree fairly well with the measured values.

At CEA it is planned to reduce the present uncertainty level in theoretical predictions to 10 - 15 % by repeating Doppler measurements with samples in critical assemblies. There is no urgent requirement for these measurements from the safety point of view. Many Doppler experiments have been performed in the US, the UK, Germany and Japan but no further measurements are planned.

In the UK, the fuel temperature coefficient of reactivity for the Hinkley Point AGR was measured during transients induced by control rod bank movements from one steady position to another. Reactivity changes were determined by inverse kinetics analysis. The fuel temperature coefficient was obtained from the slope of a plot of core reactivity against fuel temperature. The uncertainty was reported to be  $\pm 10$  % at the 1 $\sigma$  level both for high and low power levels. Theory and measurement agree fairly well within the experimental uncertainty. No need is seen to further improve the accuracy.

Papers A-482 and 483 deal with measured and calculated pin power distributions in the 50 MWe Dodewaard BWR (Netherlands) and the plutonium-fuelled heavy water FUGEN reactor (Japan).

For the BWR plant, the difference between measurement and calculation for the cases without control blades is 3 %, which is also the uncertainty of the experimental results. In cases with control blades the difference is about 7 %. Difficulties were observed for fuel rods adjacent to an instrumentation tube.

In the FUGEN reactor, the theoretical neutron flux distribution has been compared with distributions obtained by in-core monitoring during power operation from the initial core to the second refuelled core. Calculations were performed with a two-group 3D coarse-mesh method (one mesh point per assembly) and a one-group 3D coarse-mesh treatment. The two-group results agree satisfactorily with experiment and the one-group calculations show small differences only.

From the papers and discussions in this session it can be concluded that, for the considered cases, experimental and theoretical determinations of the Doppler coefficient (PWR, FBR and AGR) as well as of pin power distributions (BWR and HWR) agree satisfactorily.

### 2.3 Heterogeneous Cores, New Physics-Related Information

Rapporteur: M. Salvatores

Papers were presented dealing with current experimental programmes of fast heterogeneous configurations at several laboratories (UK, US and CEA-CNEN-DEBENE). The US paper (A-487) reported the recent ZPPR-11 experiments. The six phases of this programme covered different aspects of the physics of heterogeneous cores, with particular emphasis on sodium

void experiments. The calculation/experiment (C/E) comparisons presented related to criticality, reaction rate distributions, control rod worths (with interaction factors up to 50 %) and preliminary results on sodium void. The tendencies reported are very similar to those observed in the corresponding homogeneous core programmes, except perhaps for a larger radial tilt in the C/E distribution of the reaction rates. Except for the tilt, this type of general conclusion has also been reached in the analysis of the BIZET experiments presented in the UK paper (A-488). As far as methods are concerned, the good performance of diffusion theory was generally agreed, even if a more extended use of transport theory was necessary to eliminate discrepancies in C/E, in particular for threshold reaction rates (e.g. U-238 fission). Transport theory is also necessary for fine analysis of sodium void experiments. On the other hand, simple methods were used by different laboratories to produce fertile region cross-sections, and these simplified methods seem to perform well in comparison with more elaborate approaches. In the UK paper it was indicated that a strong sensitivity to small asymmetric perturbations is observed experimentally in the flux distribution. This type of effect was also illustrated in detail in the French paper on the RACINE programme (A-485), where cell asymmetries affected in a significant way the reaction rate distributions, in particular the fission rate of U-238. Both the UK and the French papers stressed the ability to predict these effects with standard diffusion methods. In the latter paper experimental verifications were presented.

Paper A-486 by CEA and DEBENE illustrated the experimental control rod programme for the heterogeneous configuration of RACINE, intended to study strong interaction effects (up to a factor of approximately 2) and the related "rod-stuck" problem.

Paper A-484 from Japan dealt with the safety aspects of large heterogeneous LMFBR's, indicating that detailed studies are in progress using the SAS3D code to investigate the potential safety advantages of heterogeneous cores. Finally, paper A-489 from ANL illustrated a theoretical method to express flux tilt effects in terms of eigenvalue separation with potential applications to large homogeneous and heterogeneous LMFBR core studies.

In summary, the papers of this section did not directly address the issue concerning the merit of the heterogeneous core concept. The concept is considered an interesting option for the future and, in the case of CRBR, has already been adopted as a solution for the first core. Regarding physical aspects, the recent experimental programmes indicate a growing understanding of the basic phenomena, even if some problems concerning modelling, transport corrections, etc. remain to be solved. The large, heterogeneous core configuration experiments planned at ZPPR and the continuing RACINE programme should help to resolve these problems and reduce the present uncertainties to those of the standard homogeneous cores.

## 2.4 Miscellaneous

A US paper from Argonne (A-490) summarizes some recent work on intra-cell adjoint flux distributions aimed at improving sample worth predictions. For most fissile samples the calculated corrections tend to reduce the "central worth discrepancy". Worth correction factors for U-235 in the range 0.91 to 0.98 have been calculated for ZPR-6/7 as well as several other assemblies.

## ● National Programmes

The national activities reports were summarized and discussed at the meeting. The full reports are consolidated in the document NEACRP-L-255.

## 4. Benchmarks

### 4.1 LMFBR Burn-up Benchmark

● The majority of analyses have been submitted, although the Committee extended to 31st October the deadline for receipt of outstanding contributions. Dr. Salvatores will issue a draft review document by the end of 1981 and will organize a specialists' meeting on the topic in April 1982 in Cadarache, France. This time schedule will allow the conclusions for the benchmark to be reported at the next NEACRP meeting.

### 4.2 Multi-Dimensional Kinetics Benchmark

Committee members confirmed their continued interest in this benchmark exercise. Dr. Küsters explained the further difficulties which he had experienced in trying to obtain suitable experimental data from operating reactors. The Committee decided to subdivide the benchmark into separate BWR and PWR exercises. Dr. Skardhamar was invited to co-ordinate the BWR benchmark, and Dr. Hemmig was asked to investigate whether Dr. Loewenstein from EPRI could co-ordinate the PWR exercise. Should this prove difficult, Dr. Küsters proposed that EPRI should issue the PWR benchmark specifications and Kraftwerk Union should be invited to organize a specialists' meeting.

#### 4.3 Noise Analysis Benchmark in Connection with SMORN III

A computational benchmark is being conducted in conjunction with the Specialists' Meeting on Reactor Noise - SMORN III, which will take place in Tokyo from 26th to 30th October 1981. Participants have received three types of noise data, one artificially generated and two recorded on different reactors. These will be analyzed to a given specification with the methods available. Fifteen contributions have already been received and a complete review of all solutions will be presented at SMORN-III. It is planned that the exercise will continue into a second phase with analysis of a physical benchmark. Further details are given in the document NEACRP-A-455.

#### 4.4 CSNI Transport Flask Criticality Calculations

The results of the analyses of the comparison calculations for five series of configurations were summarized by Dr. Whitesides. The first three problems are based on critical experiments, while problem number four consists of a detailed model of a transport container with unknown  $k_{eff}$ . For the first three problems the different calculational methods and data sets gave consistent results which agreed well with the experiments. However, considerable inconsistency was observed for the "blind" problem number four. The discrepancies could be resolved at a second stage of the exercise by carefully defining a fifth benchmark problem. A final report on the work will be produced at the meeting of the CSNI sub-group on transport container criticality in January 1982.

Several proposals for the extension of the benchmark are being considered. The NEACRP members were invited to influence any future activities in this field by contacting directly the respective national CSNI sub-group members.

#### 4.5 Interactive Effects of Gadolinium Poisoned Pins in BWRs

Poisoned fuel pins have been introduced into BWRs in order to enhance fuel performance, and there is a requirement to verify that calculational methods can adequately handle such geometries. Dr. Wydler introduced a benchmark for which three solutions already existed (cf. NEACRP-A-460). The Committee adopted the specification as a NEACRP benchmark activity and invited members to submit additional analyses.

## 5. General

### 5.1 Highlights of Recent Meetings of Interest to NEACRP

- NEACRP Specialists' Meeting on Nuclear Data and Benchmarks for Reactor Shielding, 27th to 29th October 1980, Paris.

Proceedings of the meeting were distributed in early 1981. A brief summary was presented to the Committee by Dr. Rief. Recent developments in uncertainty analysis for practical shields and in the adjustment of multigroup data sets need to be validated. To this end, a new programme of shielding benchmark exercises has been initiated. The results of the intercomparisons will be reviewed at a working group meeting in July 1982 and a report will be prepared for the next meeting of NEACRP.

- IAEA/ENS Meeting on Advances in Mathematical Methods for the Solution of Nuclear Engineering Problems, 27th to 29th April 1981, Munich.

A brief report was presented by Dr. Askew. The Committee noted that the introduction of parallel computer systems was likely to have a significant influence on future methods for solving nuclear engineering problems.

### 5.2 Specialists' Meetings Planned or Proposed

- Specialists' Meeting on In-Core Measurements in Operating Reactors, 1982.

Committee members reported developments in in-core instrumentation in several countries and concluded that it would be appropriate to hold a specialists' meeting on this subject towards the end of 1982. The Committee will invite the Halden Project, which is active in the field, to take the lead in the organization of the meeting, in cosponsorship with NEACRP, and possibly IAEA.

- Sixth International Conference on Radiation Shielding, Spring 1983, Tokyo.

A preliminary information sheet (NEACRP-A-491) was presented by Dr. Hirota. The meeting will continue the cycle of major international conferences on shielding. The Committee discussed the proposed scope of the meeting and concluded that emphasis should be placed on topics related to physics, and that the agenda should not encompass chemistry, detailed instrumentation and health physics. The Committee agreed to assist in the organization of the meeting and Dr. Rief was nominated to represent NEACRP on the international organizing committee. A review of the Shielding Benchmark Exercises will be presented at the meeting.

- International Conference on Nuclear Data for Science and Technology, 6th to 10th September 1982, Antwerp.

The meeting is intended to continue the cycle of conferences on nuclear data which have been successively held in the UK, USA and USSR. NEACRP is represented in the organization of the meeting by Dr. Campbell (UK) and Dr. Bouchard (France).

### 5.3 NEACRP Book on the Status of Fast Reactor Physics

Four chapters have been received by the editor, Dr. Richmond, and the two outstanding chapters will be available within six weeks. However, as there are disparities in the dates when the various contributions were written and there is some overlap in their scope, the Committee decided to publish the document as a collection of independent articles under the title "A Review of Topics in Fast Reactor Physics". The chapters will be circulated to Committee members for brief comment and the Secretariat will schedule publication for early 1982.

(Since it did not prove possible to complete the outstanding chapters within the agreed period of time, the Chairman decided to cancel the project and invited the authors to publish their chapters independently, if they had not already done so.)

ANNEX 1

## LIST OF PARTICIPANTS

Delegates

For Canada	Dr. P.M. Garvey	
For Japan	Dr. J. Hirota	
	Mr. T. Inoue	
For the USA	Dr. P. Hemmig	
	Dr. L.G. Le Sage	
	Dr. F. Maienschein	
For the countries of the European Communities and the European Commission acting together	Dr. J. Bouchard	(France) <u>Vice-Chairman</u>
	Dr. M. Salvatores	(France)
	Dr. H. Küsters	(F.R. of Germany)
	Dr. R. Martinelli	(Italy)
	Dr. J. Askew	(United Kingdom) <u>Chairman</u>
	Dr. G. Campbell	(United Kingdom)
	Mr. H. Rief	(CEC)
	Dr. M. Bustraan	(Netherlands)
For the other European countries of OECD	Mr. T. Skardhamar	(Norway)
	Prof. G. Velarde	(Spain)
	Dr. P. Wydler	(Switzerland) <u>Scientific Secretary</u>
Nuclear Energy Agency	Mr. J. Rosén	
	Dr. D.M. Johnson	<u>Secretary</u>

Observers

All sessions	Mr. J.L. Rowlands	(NEANDC)
	Dr. A.T.D. Butland	(United Kingdom)
Session on Benchmarks	Dr. E. Whitesides	(USA)

Apologies for absence were received from Dr. McCulloch (Australia). Following an established rotation, Mr. Skardhamar (Norway) also represented Denmark, Finland and Sweden and Dr. Bustraan (Netherlands) also represented Belgium.

ANNEX 2

## NEACRP DOCUMENTS PRESENTED AT THE 24TH MEETING

"L" Documents

- |       |                                                                                                                                                                                      |                                                          |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|
| L-250 | Application of a Three-Dimensional Discrete Ordinates Transport Code to Shielding Design and Analysis                                                                                | H. Yokobori,<br>T. Nishimura,<br>K. Tada                 |
| L-251 | The Danish Solution of the NRF Benchmark Problem 1980; Control Rod Ejection in a PWR                                                                                                 | A.M. Hvidtfeldt Lar-<br>sen, E. Nonbøl,<br>B. Thorlaksen |
| L-252 | An International Intercomparison of Results for the Reactivity Effect of Steam Ingress into the Core of a Gas-Cooled Fast Reactor KfK 3143 (April 1981)                              | E. Kiefhaber,<br>J. Braun                                |
| L-253 | Decay Heat Calculations Based on Theoretical Estimation of Average Beta and Gamma Energies Released from Short-Lived Fission Products J. Nucl. Sci. Technol., <u>18</u> , 393 (1981) | T. Yoshida,<br>R. Nakasima                               |
| L-254 | Non-Destructive Testing of Burn-ups and Cooling Times on PWR Spent Fuels                                                                                                             | P. Marimbeau,<br>J. Pinel                                |
| L-255 | Reactor Physics Activity in NEA Member Countries                                                                                                                                     |                                                          |
|       | Australia                                                                                                                                                                            | Japan                                                    |
|       | Austria                                                                                                                                                                              | Netherlands                                              |
|       | Belgium                                                                                                                                                                              | Norway                                                   |
|       | Canada                                                                                                                                                                               | Spain                                                    |
|       | Denmark                                                                                                                                                                              | Sweden                                                   |
|       | Finland                                                                                                                                                                              | Switzerland                                              |
|       | France                                                                                                                                                                               | United Kingdom                                           |
|       | F.R. of Germany                                                                                                                                                                      | United States                                            |
|       | Italy                                                                                                                                                                                | JRC Ispra                                                |

"A" Documents

- A-446 NEA Data Bank Activity Report,  
September 1981
- A-447 Proposed International Comparison Cal-  
culations of Fast Reactor Critical Assem-  
blies in Pin and Plate Geometry J.L. Rowlands,  
J.M. Stevenson
- A-448 High Priority Nuclear Data Measurement Re-  
quirements J.L. Rowlands
- A-449 Summary Record of the 22nd NEANDC Meeting  
held in Aix-en-Provence, France, 6th-10th  
April 1981
- A-450 Heterogeneity Effects in MASURCA Rodlet  
Cells M. Salvatores,  
G. Rimpault, R. Soule
- A-451 Sodium Void Reactivity Worths in Plate and  
Pin Cell Assemblies T. Takeda, K. Tanimoto,  
K. Shirakata
- A-452 On the Geometric Modelling Effects for the  
Pin/Plate Heterogeneity Calculation Y. Ishiguro,  
K. Tsuchihashi
- A-453 Validation Results for the SDX Cell Homo-  
genization Code for Pin Geometry R.D. McKnight
- A-454 Space and Angle Finite Element Method for  
Solving Three-Dimensional Multi-Group Neu-  
tron Transport Problems T. Fujimura,  
M. Matsumura,  
Y. Nakahara
- A-455 Reactor Noise Analysis Benchmark Exercise  
in Connection with SMORN-III J. Hirota,  
Y. Shinohara
- A-456 Status of 3D Transport Calculations for  
Reactors J.W. Lewellen
- A-457 Perturbation Methods for Cutting Costs of  
Transport Calculations E.M. Gelbard
- A-458 TRACASYN: A 3D Power Distribution Evaluation  
Using a Multichannel Synthesis Method from  
the Results of 2D Transport Calculations J. Porta
- A-459 The Solution of the Multigroup Neutron Trans-  
port Equation Using Spherical Harmonics J.K. Fletcher
- A-460 Specifications for a LWR Benchmark Problem  
with Adjacent Poisoned Fuel Rods C. Maeder, P. Wydler

- |       |                                                                                                                                                      |                                                   |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| A-461 | ANL Calculations of the NEACRP LMFBR Depletion Benchmark Problem                                                                                     | J.R. Liaw,<br>H. Henryson II                      |
| A-462 | Measurements of Fission Products Decay Heat for Fast Neutron Fissions                                                                                | M. Akiyama,<br>K. Furuta, S. An                   |
| A-463 | Decay Heat Measurements and Criticality Control of Irradiated LWR-Fuel Elements                                                                      | K. Baumung,<br>M. Kühle, H. Würz                  |
| A-464 | Beta and Gamma Decay-Heat Measurements for Fast and Thermal Reactors, Particularly for Pu-239                                                        | J.K. Dickens                                      |
| A-465 | Fission Product Decay Heat from U235 and Pu239 - A Brief Survey of the Experimental and Theoretical Data                                             | M.F. James                                        |
| A-466 | Decay Heat in Fast Power Reactors: Objectives, Qualifying the Computer Code                                                                          | L. Costa, J. Crouzet,<br>F. Josso                 |
| A-467 | Out-of-Pile Subcriticality Monitoring                                                                                                                | J.W. Lewellen                                     |
| A-468 | The Qualification of Nuclear Data and Methods for Post-Irradiation Analysis and Application of Isotopic Correlation Techniques to Nuclear Safeguards | U. Fischer, H. Küsters,<br>M. Marzo, H.W. Wiese   |
| A-469 | Nuclear Material Safeguards Surveillance and Accountancy by Isotope Correlation Techniques                                                           | P.J. Persiani,<br>J.A. Goleb, T.K. Kroc           |
| A-470 | Recent Developments in $^{238}\text{U}$ Capture Measurements                                                                                         | D.W. Maddison,<br>J.M. Gasidlo,<br>S.G. Carpenter |
| A-471 | Delayed Neutron Data                                                                                                                                 | C. Golinelli                                      |
| A-472 | An Analytical Study on Uncertainties of Reactivity Scale ( $\beta_{\text{eff}}$ ) of Large LMFBR Cores                                               | H. Nakamura, T. Aoki                              |
| A-473 | The Reactivity Scale for Fast Spectrum Criticals                                                                                                     | E.F. Bennett                                      |
| A-474 | RETRAN Validation: Analysis of the LOFT L6-5 Experiment                                                                                              | C. Olding, P.A. Lambert                           |
| A-475 | The SPLOSH/SMASH Averaging Problem                                                                                                                   | J.R. Askew                                        |
| A-476 | A Preliminary Study of a Method of Spatial Averaging for SPLOSH                                                                                      | R.E. Mott                                         |

- A-477 Further Aspects of the Spatial Averaging Problem R.E. Mott
- A-478 Transient Effect on Reactivity in Reactor Point Kinetics Calculation H. Fujimoto, T. Hakata
- A-479 Measurement of Doppler and Heat Transfer Coefficients in PWR C. Cervoni
- A-480 Measurements and Calculations of the Fuel Temperature Coefficient of Reactivity for Hinkley Point 'B' AGR A.R.R. Telford
- A-481 Measurements of the Doppler Effect at Phenix J.C. Gauthier, M. Vanier, J.C. Cabrillat
- A-482 Measured and Calculated Pin Power Distributions in the Dodewaard BWR W.J. Oosterkamp, F.J. v.d. Kaa
- A-483 Refuelling Analysis of Pu-Fuelled HWR-FUGEN H. Kato, S. Ohteru, T. Haga, H. Kamikawa
- A-484 A Study on the Safety and Physics Aspects of Large Heterogeneous LMFBR's K. Aoki, Y. Moriki, K. Miyagi, T. Inoue
- A-485 Effects of Cell Asymmetry on the Performance of a Large Heterogeneous Critical Assembly W. Scholtyssek, G. Humbert, M. Martini, G. Norvez
- A-486 Control Rod Experiments in RACINE A. Stanculescu, G. Humbert
- A-487 Recent Developments in Heterogeneous Core Critical Experiments in the US C.L. Beck, H.F. McFarlane
- A-488 Progress in the UK Analysis of the BIZET Heterogeneous Fast Reactor Assemblies J.M. Stevenson
- A-489 On the Relationship between Local Flux Tilt and Eigenvalue Separation During Delayed Critical Transients in a Fast Reactor B.S. Yarlagadda
- A-490 The Effects of Intra-Cell Adjoint Flux Heterogeneity on FOP Reactivity Calculations K.S. Smith
- A-491 Sixth International Conference on Radiation Shielding Japanese Preparatory Committee