Nuclear Energy Agency
of the
Organisation for Economic Co-operation and Development

International Atomic Energy Agency

SPECIALISTS' MEETING ON SENSITIVITY STUDIES AND SHIELDING BENCHMARKS

OECD Headquarters, 7th-10th October 1975

SUMMARY REPORT PREPARED FOR THE NEACRP

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The Proceedings will be published by the NEA in the Spring of 1976 including all the papers tabled at the meeting and the complete versions of the State-of-the-Art reports as presented by members of the Editorial Panel.

January 1976

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INTRODUCTION

1 The Paris meeting on Sensitivity Studies and Shielding Benchmarks was the third in the series of meetings initiated by the EACRP in June 1973 with the aim of co-ordinating work on the assessment of data for shielding calculations, and exchanging results of integral benchmark experiments. It was envisaged that the experimental and theoretical programmes reviewed at these meetings would lead, ultimately, to a revised data request list covering the broader area of shield design for fast and thermal reactors which includes energy-deposition calculations for in-core gamma heating and breeder/diagrid damage studies.

2 The specific objectives of the Paris meeting were to define the co-ordinated programmes of work which would be required to establish an International Request List of Nuclear Data for Shield Design; to review the progress which had been made with the benchmark experimental programme initiated at the first meeting held at Ispra in April 1973; and, in the light of the experience gained, to identify the respective roles of differential and integral measurements in meeting new data requirements.

3 The current reactor data request lists do not adequately reflect the needs of shield designers and this can be attributed to three main factors. In the first place, it is difficult to arrive at a generally agreed statement of design criteria since the target accuracies are more closely related to specific design issues than those of reactor physics, and are primarily matters of individual commercial judgement. Secondly, the importance attributed to the accuracy of basic nuclear data is strongly dependent on the type of method employed for shield design. Most commercial reactor shielding has been carried out using well-proven combinations of codes embodying simplified calculational models with data-sets based on old cross-section libraries. The effects of data errors in such methods are often obscured by the inherent physical approximations. Their extension to handle new situations has more readily been accomplished by modifying the models or by changing the correction factors quoted for design applications using mock-up experiments, rather than by seeking improvements in the accuracy of the basic data files. Finally, although more rigorous transport methods have been employed in design calculations for many years, there have until recently been no satisfactory techniques available for investigating the sensitivity of such methods in deep penetration calculations to uncertainties in the basic cross-section data.

4 With the increasing emphasis on the use of transport codes for shielding calculations in both performance assessment and commercial design work - principally discrete-ordinate (S_n) and Monte Carlo methods - it has been clear for some time that uncertainties in the basic nuclear data have been influencing design issues. Two significant developments have emerged during the last few years, however, which now make the proper assessment of shielding data requirements a feasible proposition, namely:

(i) the availability of one-dimensional perturbation codes for data-sensitivity studies in deep penetration calculations with adjoint and/or correlated-tracking Monte Carlo for multi-dimensional problems;

and (ii) the realisation of techniques for quantifying the error assignments on spectrum measurements made in integral benchmark experiments covering a wide spatial/energy range.

For a given range of shielding problems it now appears feasible to establish which data are controlling the prediction of design parameters, and whether the corresponding target accuracies can be met within the quoted uncertainties on these data in the evaluated files. At the same time, sensitivity analysis can be utilised to design an integral benchmark experiment in which the scope and precision of spectrum measurements is adequate, at least, to check the error assignments of the evaluations and, possibly, to indicate the origin, sense and magnitude of the significant errors.

5 An international meeting in Vienna supported by the IAEA to review the differential nuclear data for shielding was proposed as long ago as April 1972, but this was subsequently postponed until the necessary groundwork could be completed which would enable the accuracy requirements to be properly established. It was argued at the Paris meeting, however, that the time is now ripe for a co-ordinated programme of data assessment studies to be initiated and that the preliminary findings, taken in conjunction with results of integral benchmark experiments, could enable a more realistic data request list to be drawn up by about the Autumn of 1976. With this aim in view, the methodology of sensitivity analysis was examined and a co-ordinated programme of further work was drawn up in order to establish the calculational tools required for this exercise; participants outlined the types of shield which they proposed to analyse, covering a wide range of fast and thermal reactor types; and a firm recommendation was made to the IAEA and NEA that the Vienna meeting should be held in October 1976. Whilst the main purpose of this meeting was to identify the data requirements and revise the request list, it would also provide a convenient opportunity to review progress in the co-ordinated programme of benchmark experiments. A list of specific objectives was accordingly drawn up and it was agreed that the title should be:

"Specialist Meeting on Differential and Integral Data Requirements for Shielding Calculations"

STATE-OF-THE-ART REVIEW

6 In order to draw up a co-ordinated programme of work required to establish an International Data Request List for Shielding at the proposed Vienna meeting, it was first necessary to establish those calculational capabilities which were available in the participating laboratories. Secondly, with the aim of arriving by that time at a definitive statement of the roles of differential and integral measurements in meeting these requests, considerable attention was given to the rapidly improving technology of 'penetration benchmarks' which stemmed largely from the initiatives taken originally at the Ispra meeting.

7 A total of 19 papers was tabled at the meeting which was attended by 30 participants from 9 NEA countries, EURATOM, and Jugoslavia, together with representatives of the two sponsoring organisations.

8 The outstanding feature of these presentations was the major progress which had been made by all organisations in both the theoretical and experimental areas since the Ispra meeting. In particular, all laboratories had implemented the recommended ANISN/SWANLAKE route for sensitivity analysis, the EURLIB multigroup data set had been launched, multidimensional sensitivity problems were being tackled in several laboratories and a concerted attempt was already being made on the application of these various techniques to determine data requirements for practical problems.

9 A comparable degree of progress had been made with integral benchmark experiments and the development of both analytical and measuring techniques. A notable feature of this recent work was the use of sensitivity analysis for the design of benchmark experiments with sensitivity profiles matched to those obtained in practical design situations. It was already clear that neutron benchmark penetration experiments would ultimately achieve the standards of precision needed to enable a large proportion of the requirements to be omitted from the revised Request List for shielding.

10 Considerable interest was expressed in the new ENDF/BIV error files and the associated processing modules in MINX. It was agreed that a request should be made to the NEA/CPL to implement both MC2-2 and MINX as soon as possible, recognising that there were some hardware limitations to be overcome in order to accommodate the latter on the Ispra computer.

Methodology of Sensitivity Analysis (Dr E M Oblow)

11 Dr Oblow said that the widespread use of the ANISN-SWANLAKE codes indicated that the methods had been well tested and that the results were readily accepted and easily communicated. Since ANISN-SWANLAKE was readily available it could be adopted as a standard for any collaborative work which might be agreed upon. Other one-dimensional sensitivity codes were discussed, but it was clear that the basic methodology used in them was the same as that employed in ANISN-SWANLAKE. These other codes might serve as an independent check on results obtained in any collaborative programme.

12 Developments in two-dimensional discrete-ordinates sensitivity methodology using DOT and VIP at ORNL and a pseudo-two-dimensional method using one-dimensional codes with fictitious absorption to represent leakage at Winfrith were reported. These developments opened up the area of sensitivity analysis of practical shield design problems and integral experiments. The methods were not, however, well documented and this fact, in addition to possible difficulties in using DOT, might slow efforts in this area outside of ORNL. Correlated-sampling Monte Carlo remained the only potential method for handling three-dimensional data sensitivity analysis problems exactly with transport theory. Despite the fact that only one paper was presented on this method (Appendix 1, para. 3), the approach was a well established perturbation technique which should be applied more extensively to cross-section problems. It was surprising that no papers had been tabled on multidimensional diffusion theory sensitivity methodology which existed in the European reactor physics community and could be readily applied to some shielding problems.

13 Several important limitations of the basic discrete-ordinates sensitivity analysis were brought out in discussions. First, the inherent restriction of linear perturbation expressions to small changes in data existed, and care should be exercised in interpreting effects of large changes in deep penetration problems. Second, errors in fluxes and adjoints were reflected to second order in the sensitivity profile, but care should be exercised in checking models by using the non-adjointness property of S_n equations to get good agreement between forward and adjoint results before a sensitivity study was begun. Agreement to higher order accuracy than the effects being studied should be achieved in these comparisons.

14 The more widespread application of the methodology appeared to be the generation of one-dimensional sensitivity profiles for shield design and experimental analysis. Such results were reported in most papers. This use of sensitivity information was mostly directed at understanding the transport process

and the relative importance of basic cross-section data in specific energy ranges. This work was extensive, commendable, and formed the much needed basis for a collaborative effort.

15 Perturbation applications of sensitivity analysis were less widely discussed even though this also was an important application of the methodology. Papers did reflect predictive applications for group boundary selection and cross-section adjustment methodology. This passed up the strong applicability of predictive methods for understanding the effects of differences in the data files used in shielding analysis, an important area of concern in a collaborative programme based on testing several different multigroup data files.

16 Uncertainty analysis applications appeared in papers from the U.S. and probably would be one of the more important development and application items for the future in terms of determining cross-section data needs. Work in this area was currently hampered by the unavailability of ENDF/B error file data outside of the U.S. and even within the U.S. As these files became more available and the formats and processing of such data became better understood, this technique should lead to more quantitative assessments of target cross-section data accuracy requirements. The general uncertainty analysis methodology with emphasis on inclusion of relevant integral experiment results was not discussed in enough detail to judge how best to use integral measurement information. In particular, the relationship between uncertainty estimation and cross-section adjustment methodology was strong in the ORNL approach which lead one to believe that European efforts in adjustment should play a large role in developments in this area.

17 The conclusion which could be drawn from the methodology standpoint was that important data requests could be identified for a wide range of shielding problems only in a qualitative or semi-quantitative sense. This capability lay in the ability to analyse sensitivity profiles representative of generic shield design and couple this information with some knowledge of the state of accuracy of the base data file. Despite the cautious manner in which this conclusion was stated, it represented a large step forward in drawing up a meaningful data request list. More quantitative assessments would have to await future developments in the area of uncertainty analysis and availability of ENDF/B-IV and ENDF/B-V error file data.

18 Despite the availability of an adequate base methodology, three other factors were crucial for meeting the goals stated. First, a significant number of benchmark experiments and generic shield design problems would have to be agreed and analysed with sensitivity methods to generate a library of relevant sensitivity profiles. Second, target accuracies in responses of interest for the design of generic reactor systems would have to be put forth with some degree of thought. Third, an assessment of important discrepancies arising in relevant integral measurements in addition to the assessment of cross-section uncertainty information would have to be made. Such information would be used to assess the current status of the data files in meeting target design accuracies. Finally, it could be concluded that significant progress had been made in applying sensitivity codes. The methodology was at least keeping pace with and, in some cases, leading the way to future applications which had a direct bearing on the solution of practical shield design problems and assessment of cross-section data needs.

Sensitivity Studies on Practical Shield Designs (Mr A F Avery)

19 Mr Avery suggested that the question which eventually had to be answered was "What further measurements of differential cross-sections were needed for shield design?". The reply, which had to be given in terms of isotope, reaction

and required accuracy, depended upon the answers to two subsidiary questions. Firstly, "Were the available data satisfactory?" and if not then, secondly, "Were further differential measurements the best way of remedying the deficiencies?". The latter question would perhaps be answered in the discussions of what could be learned from benchmark experiments, and he went on to review briefly the way in which the adequacy of current data was assessed.

20 The first requirement was to set a target accuracy for the response of interest in the practical design. The paper by Herrenberger et al summarised the target accuracies suggested by technical personnel connected with shielding for such responses as heating, displacements, activation, biological dose and instrumentation output. These ranged generally from the order of ± 20% for displacements and heating to factors of two for external dose, although the latter could be required much more accurately when it provided unwanted background at a research facility for example. Similarly, the papers by Gerstl et al and Avery et al quoted target accuracies of ± 50% for dose-rates and ± 20% for displacement-rates without attempting to justify them. It was important that the target accuracies be given careful consideration to ensure that they were consistent with the accuracy with which the responses could be used and, moreover, that they were justified by the cost penalties. The latter were very much dependent upon the particular reactor design under consideration, but it was important to give as much information as possible without prejudicing the commercial aspects.

21 The next step towards formulating data requests was to ensure that the errors from other sources would not introduce major uncertainties. The method of calculation and the representation of the shield should be sufficiently accurate to create pressure for improvement in cross-section data as a way of achieving the target accuracy. The accuracy of method and model could usually be judged by comparisons between the predictions of different approaches or by comparisons with experiment. The uncertainty in a response due to cross-sections could be estimated by the use of sensitivity calculations, together with the evaluators' assessments of the errors associated with the data. The papers of Gerstl et al, Avery et al and Oblow all described this approach using perturbation methods to obtain the sensitivities of various responses to changes in cross-section data in practical shield designs. Important findings of this work were the need to examine partial cross-sections and to take account of the correlations between them. This was demonstrated in the American results by the use of covariance matrices to enable the effects of changes in cross-sections to be combined in a realistic way. The availability of error data and covariance matrices in ENDF/B-IV together with the computer codes for processing them, marked a significant step forward. In the work of Gerstl et al and of Avery et al it had been shown that in most cases acceptance of the evaluators' assessments of the accuracy led to an uncertainty due to data which still enabled the target accuracy to be met. In these instances there was thus no need for improvement in data. It would still be important, however, to check the evaluators' assessments of the accuracies of differential data by comparing predictions and measurements in benchmark experiments.

22 In one case examined in his own paper, Mr Avery said that the uncertainty of the predicted response due to estimated errors in the cross-section data was not sufficient to meet the target accuracy. In this instance an improvement in cross-sections for one material over a restricted energy range had been proposed as a way of meeting the accuracy requirement. There were very many ways of improving the cross-sections, all of which would produce the target accuracy and the choice of suitable guide-lines or constraints to enable a decision to be made was essentially subjective. Oblow described an approach in which the "cost" of improving a cross-section was included and the "best" combination of data improvement found by minimising this cost. No practical examples are given applying this approach. One could envisage the subjective

nature of target accuracies being removed if, instead, the effect of uncertainties in the practical design were also expressed as a cost function and a minimum of the costs of measurements and the cost penalties in design were then sought. The benefits of such an approach, however, would not be restricted to the shielding of a single reactor, and it would not be feasible to contemplate including cost penalties for data uncertainties in all of their possible applications. In deciding which cross-section data should be attacked, however, it would be useful to have sensitivity profiles available for the practical situations so that data which would enable several target accuracies to be met could be examined first.

23 Thus, in order to be able to consider data requirements at the proposed Vienna meeting in 1976, it would be necessary to assess the adequacy of the available data. The papers which had been presented illustrated how this could be achieved. In detail, the requirements were:

(a) Assessments of target accuracies for specific reactor types

These should be based upon practical calculations using the designer's own in-house data sets rather than idealised situations so that the uncertainties arising from other causes and the cost penalties could be included in their justification.

(b) Sensitivity calculations for practical response functions

The uncertainty due to cross-section errors could then be derived by weighting them with the sensitivities and combining them using the covariance matrices when available. Even when the full analysis with covariances was not possible it would be useful to look at the limits implied by straightforward combinations of errors as described, for example, by Gerstl et al.

(c) Checks of evaluators' assessments of the errors

The analysis proposed in (b) above was based upon the evaluators' estimates of the accuracies of differential cross-sections. Benchmark experiments would be needed to check these assessments and perhaps to modify them as was done with, for example, the Oak Ridge code FIREBIRD in the FORSS system described by Oblow.

(d) Identification of data requirements

The results of the steps (a), (b) and (c) outlined above would be to indicate those situations in which the data needed to be improved. These could then be translated into specific data requirements if some system of constraints, as discussed by Avery et al and Oblow, was imposed.

The Analysis of Benchmark Experiments (Mr A K McCracken)

24 Mr McCracken said that in the papers which had been presented at the meeting, three broad approaches to the analysis of experiments could be discerned. Those by Bouteau and his collaborators described an attempt to produce a simple, cheap method of calculation - a 'formulaire' - which would accurately describe the propagation of neutrons in a variety of iron/sodium mixtures of relevance to the French reactor programme; adjustment of the method to achieve agreement with measurement was envisaged. The objective of this work was essentially short-term - the building of an adequately shielded reactor of a certain type. This approach

succeeded admirably in its limited purpose but it threw little light on the adequacy of basic data or on the methods of calculation applied in configurations differing from that of the measurements. The papers of Gerstl and Avery, like those of Bouteau, were concerned with problems of interest to designers. Unlike Bouteau, however, they had applied sensitivity analysis in conjunction with unsimplified transport calculations to investigate the effects of basic data uncertainties on the prediction of specified reaction-rates. This type of analysis, at present unsupported by experiment, had been covered by Mr Avery's summary.

25 A single-material benchmark experiment made no specific concessions to the problems of a designer apart from the choice of a material, say iron, which is in widespread use in reactors. The outcome of such an experiment would be confidence (or lack of it) in the ability of a method of calculation with its associated data to predict measurements over a wide energy range, and over a depth of penetration greater than any likely to be met with in practice. If the experiment was analysed with a transport calculation in conjunction with a perturbation code inferences could be drawn about the state of the basic data used in the calculation. In reconciling calculation with experiment realistic estimates of errors in the measurements were required. If these comprised a set of unfolded flux spectra it was possible to estimate the stochastic error on the fluxes due to causes like counting statistics. In certain circumstances, for example in the highly structural spectra found in iron, it was important to take account of systematic errors induced by the energy calibration of the instruments - these might well be larger than the stochastic errors. In order to check that individual workers could usefully compare results it had been suggested by Dr Butler that the unfolding of a standard spectrum like ^{252}Cf might be used as a test of the ability to ascribe realistic errors to a measuring technique. Having established confidence in the measurements they could be utilised in the adjoint source used in sensitivity calculations. Mr McCracken drew attention to a suggestion in the paper by Mr Grimstone and himself that an ideal source for use with SWANLAKE was

$$H_j^+ = \frac{\phi_j - \Upsilon_j}{\sigma^2(\Upsilon_j)}$$

where ϕ_j and Υ_j were respectively components of the calculation and unfolded flux spectrum. This led directly to a sensitivity profile equal to the rate of change of total goodness-of-fit between measurement and calculation with data cross-section. Having established this differential it was merely a matter of tactics to minimise

$$\sum \frac{(\phi_j - \Upsilon_j)^2}{\sigma^2(\Upsilon_j)} + \sum \frac{(\delta x_i)^2}{\sigma^2(x_i)}$$

by the choice of the δx_i to find the optimum data adjustments. In this procedure it was possible to draw a useful conclusion about the validity of the accuracy estimates on the cross-sections and the fluxes by comparing the weighted sums of squares of the residual deviations with the expected value which was given by:-

$$\left\langle \sum \frac{(\phi_j - \Upsilon_j)^2}{\sigma^2(\Upsilon_j)} + \sum \frac{(\delta x_i)^2}{\sigma^2(x_i)} \right\rangle = N_\phi$$

where N_ϕ was the number of components of the measured spectrum.

These error assessments and adjusted group cross-sections, with their associated correlations, for a transport calculation and the goodness-of-fit achieved when these adjusted cross-sections were applied to the prediction of the measurements, appeared to be the main immediate products of a single-material benchmark experiment.

26 It was generally accepted that it was not practicable to think in terms of altering basic data files on the basis of a single experiment - what was obtained could serve as a guide to evaluators, to be taken in conjunction with all other evidence.

27 The problem had been posed of arriving at a concensus of findings from the various experiments in iron being undertaken by participants at this meeting. Clearly, the use of common methods of calculation, data sets and method of analysis was important so that all calculators were at least making the same mistakes. Equally clearly, all experiments had to guarantee the integrity of our measurements by some exercise such as that suggested earlier in this summary. It seemed desirable that all experiments should be analysed by a single group (in addition to such analyses as individual teams might wish to make of their experiments). This central group could either try to construct a single equivalent benchmark experiment, a concept which had been the subject of some discussion, or it could analyse each experiment separately to present a weighted concensus conclusion - it was not immediately obvious that there is any difference between these approaches.

28 A further question which had not been answered during the discussion was the number and type of measurements required to carry out a good benchmark experiment. The issue of activation detectors versus spectrometers had arisen several times. Protagonists of the former emphasised their simplicity and reliability, and it was claimed that ample experimental evidence could be obtained with a suitable range of such detectors; those employing spectrometers argued that they were exploiting a device which was equivalent to a very large number of activation detectors. This problem could only be resolved by using both methods in a single experiment and analysing the results separately. The collaborative measurements in iron would provide an opportunity for this to be done; a reasonable speculation would be that while spectrometers gave more total information activation detectors might be more cost effective in terms of information achieved per unit of skilled effort involved.

The Role of Integral and Differential Measurements in Improving Nuclear Data for Shielding (Professor U Farinelli)

29. Professor Farinelli said that the issue of cross-section adjustment had been a very controversial one for a number of years in reactor physics; it seemed less likely, however, that it would split the shielding community. There was an important area of overlap which had emerged between the "adjusters" and the "non-adjusters" which might lead towards a common approach to the use of integral results; the diversity that would remain being due to actual differences of the particular situations and of the reactor development programmes.

30 Having completed the forward and adjoint calculations with in-house and the common EURLIB data sets there were two courses open. In the one case - "the classical U.S. approach" the benchmark experiment was seen as a test of the differential data. It was then necessary to evaluate sensitivity of the integral results to uncertainties in the nuclear data and to split accordingly the difference

between predicted and observed results among the different contributions taking into account the correlation of errors. The results served to identify areas of discrepancy between integral and differential data and of possible shortcomings in the latter. This information was fed back to the evaluators for consideration. This might lead to a re-evaluation or a new request in the WRENDA list. In this context, many participants had stressed the importance of having reliable assessments for errors and their correlations; the information available in ENDF/B-IV was still scarce but it was expected that considerably more would become available in the new year.

31 In the other extreme integral results were used to adjust the multi-group cross-sections within their quoted error bars so bringing the predictions into much closer agreement with experiment. For this purpose the same calculational tools were required, namely: a sensitivity analysis of integral results to fine group data; an evaluation of the uncertainties in the differential data (with the associated error correlations); and a criterion to subdivide the uncertainty among the different cross-sections and energy ranges. In practice there were some indications that the practical outcomes were very similar, particularly in the case of those ENDF evaluations where some account had been taken of integral information.

32 There were several levels at which the adjustment procedure could be applied. The one which was closest to the differential data was the so-called Consistent Approach of Gandini et al by which only corrections of cross-sections having physical meaning were applied such as changing level-density parameters within assumed uncertainties. The next possibility was the standard UK approach of generating adjusted fine-group libraries which were kept quite separate from the differential files. Composition-dependent cross-sections were then generated from this library for each application and it was updated when either new evaluated differential information was obtained or when a substantial body of new integral results became available. A further simplification adopted in the "formulaire" developed at Cadarache was to adjust few-group cross-section sets which were applicable only to a limited range of compositions or to a particular type of design. In this approach several different problem-dependent cross-sections could be used and the problem of cross-section condensation was by-passed.

33 During the discussion, Mr Avery had referred to the Adjusted Diffusion Coefficient method developed in the UK. This was essentially a tool for extrapolation from or interpolation between Monte Carlo or more rigorous calculations. The adjustments made to the diffusion coefficient were specifically intended to take up the deficiencies of diffusion theory rather than basic data and the method should be recognised as one of parameter adjustment as opposed to data adjustment. As such it did not fall within the scope of the meeting but it should be remembered that most of the existing water reactors had, of necessity, been developed with procedures which in some cases were even more empirical. Consideration of the timescales determined by reactor projects might therefore determine the ultimate course to be adopted in the "differential versus integral" controversy.

Experience with the Group Cross Section Library EURLIB and Updating to ENDF/B-IV (Dr G Hehn)

34 Dr Hehn said that for reactor shielding applications, the collection of evaluated cross-sections in the ENDF/B library was the most complete one. This library was the natural choice for reference cross-sections in shielding calculations. Since the data processing codes in use had different capabilities, unacceptable differences could occur in producing group data from point data. In addition to the basic point cross-sections, some standard multigroup libraries were therefore

needed. For the common field of core physics and shielding, the CSWG group structure of 239 neutron groups had been proposed, of which the 100 group EURLIB library was a sub-set specifically processed for shielding. The wide acceptance of this library for the interpretation of benchmarks in the NEA programme represented an important step forward in the standardisation of data which was an essential ingredient of fruitful collaboration.

35 The various interpretations of different benchmark experiments with the EURLIB library provided the best check of cross-section data. It had already been shown that resonance weighting was important for iron and for reactor steels. Some of the deficiencies in the iron cross-sections could be avoided by using ENDF/B-IV. Dr Hehn then went on to summarise the present status of the EURLIB library and the proposed changes in updating to ENDF/B-IV as follows:-

(1) Nuclides included

Since various materials had to be considered in the iron and sodium integral experiments with converters and fast reactors, the following nuclides were included in EURLIB-2:

H, C, O, Na, Al, Cr, Mn, Fe, Ni, Si, Ca, Cn, U-35, U-38

There were also requests for: B, N, Mg, Zr, Ba, Pb, Pu-39, and special weighted stainless steel.

(2) Number of neutron groups

The present 100 group structure of the multigroup library seemed to be a good compromise. The extension to 240 groups as proposed by the CESWG to embrace corephysics requirements was not practical for shielding calculations. Problem-dependent condensed versions were available comprising 33 groups and 15 groups respectively for deep penetration calculations with DOT and MORSE.

(3) Scattering moments

The present P_3 truncation was judged to be sufficient for most applications. The inclusion of gamma data and some special requirements for extension to the P_5 approximation were currently being considered.

(4) Weighting

Generally, the weighting was $1/E$ for $E \leq 0.82$ MeV
and χ/E for $E > 0.82$ MeV

For iron and stainless steel narrow resonance weighting was used.

(5) The thermal group

Normally a water-moderated Maxwellian spectrum was used for averaging the cross-sections. For thick slabs of iron, stainless steel and sodium the hardened spectrum of the special nuclides was applied.

(6) Application for diffusion calculations

In EURLIB-3 σ_{tr} would be included for diffusion theory calculations.

(7) Extension to a coupled neutron and gamma library

For the biological dose and heating calculations, initially in fast reactors and LWR's, the addition of 20 gamma-ray groups was planned in EURLIB-3. The coupled neutron and gamma multigroup library with 120 groups could be condensed into two few-group structures for each reactor type, thus:

(a) (30n + 10γ) for one-dimensional design calculations;

and (b) (15n + 5γ) for two-dimensional design calculations.

(8) Additional group-response data

The inclusion of kerma factors, dose factors, displacement cross-sections, averaged over different spectra, was needed for the common benchmarks.

(9) Detector cross-sections

Group data for threshold detectors and resonance detectors were available and could be included in the EURLIB library.

(10) Timescales for EURLIB-3

The target dates for updating the EURLIB library were as follows:

Coupled multigroup library (100n + 20γ) from ENDF/B-IV - April 1976
Condensed PWR and LMFBR libraries - May 1976

The Interaction Between Reactor Physics and Shielding Calculations (M. J Barré)

36 M. Barré began by remarking that the emergence of this question at the Panel meeting indicated a trend which had been evident during the past few years in the relationship between the two disciplines of reactor physics and shielding, which had a great deal in common but which had, in the past, been allowed to develop along separate lines.

37 Dealing first with data and methods, M. Barre pointed out that neutron propagation in different shield materials was very sensitive to the total cross-sections, a phenomenon which was not directly apparent in core problems. The classical methods of reactor physics normally used the diffusion approximation with adjustment of the diffusion parameters, although total cross-sections for iron, stainless steel and sodium had to be determined through neutron propagation experiments. In both cases, however, neutron calculations were sensitive to inelastic scattering cross-sections and elastic scattering cross-sections.

38 The development of transport methods in 1D or 2D, which had been accomplished for shielding, was also important for particular core situations. These methods were used for correcting the diffusion models in those problems exhibiting strong heterogeneities such as control rods, for example.

39 All the data concerning production, fission, absorption, on the other hand, were deduced from core balance calculations which were very sensitive to these reactions. For materials like Fe, Cr, Ni and stainless steel, the basic information came from reactor physics, even in the case of degraded spectra like those present in shields (example: RB2/TV programme at Bologna on structural materials). In the case of inelastic slowing-down, the iron cross-sections

played a significant role but they were of secondary importance compared with U-238; nevertheless a comparison with results obtained from shielding experiments was very useful. In the case of elastic scattering, oxygen played an important role in the core and it was also important in shielding. The sensitivity of parameters on elastic cross-sections of other elements was of less importance Particular studies on neutron spectra had permitted the adjustment of the elastic cross-section of Na.

40 There were several developments of measuring techniques which had been motivated initially for core physics studies but could be used for shielding applications. Examples where improvements made in techniques for one discipline had been of benefit in the other have included:

- absolute measurements of reaction-rates of activation detectors or fission chambers;

- relative measurements of reaction-rates for the same techniques;

- spectra measurements using proton recoil counters;

- gamma heating (use of TLD detectors).

41 Probably the most important issue concerning reactor physics in relation to shielding was the derivation of starting fluxes for penetration calculations from the spectra predicted in the reactor lattice. The latter were obtained from the "formulaires" which were adjusted to calculate correctly the core parameters. This problem of the interface between core and shield studies was tackled, at the CEA, through the shielding "formulaire". As far as neutron propagation was concerned, the "core formulaire" yielded the neutron source in intensity and spectrum, at the core-shield boundary. The only difficulty stemmed from the necessity to make allowance for the anisotropy of this source in the penetration calculation - the anisotropy did not figure prominently in the core calculations. This difficulty could be overcome by a systematic parametric study of the anisotropy effects which were not strongly dependent on the media of interest.

42 In core physics, the approach followed for some years in many countries in order to answer project questions could be summarised in the following way:

- definition of needs and precision desired;

- sensitivity studies for defining the causes of errors;

- design of integral experiments which were sensitive to these uncertainties;

- adjustment of "formulaires" (approximation of methods and data) on the basis of integral data;

- transposition to design by means of correction factors for calculated values and uncertainties.

This philosophy was directly applicable to shielding problems. The very object of this meeting and the different papers presented indicated that this philosophy was currently being adopted by many countries. This harmonisation of approach between studies of the core and the shield was most constructive and it appeared to have gained impetus since the Paris Conference in 1972.

Common Interests Identified by Fission and Fusion Applications (Mr S W Gerstl)

43 Mr Gerstl said that the number of papers tabled at the meeting dealing with fusion nucleonics applications of sensitivity analysis did not adequately reflect the level of effort directed towards fusion reactor shielding. Nevertheless, a number of important points had been identified in the discussion of the topics of common interest to fission and fusion reactor shielding problems.

44 Firstly, the cross-section sensitivity profiles in CTR applications usually peaked at 14 MeV and fell off rapidly towards the lower energies. In the recent CRBR sensitivity analyses, as well as in the early FFTF studies, relatively high sensitivities were also found in the MeV region when very deep penetrations were considered. A similar phenomenon had been identified in the water reactor shielding problem studied by Mr Avery. These findings clearly established a common interest in the high energy cross-sections extending down to the region of 3 MeV where unacceptable uncertainties had already been identified in several key materials.

45 Secondly, there was a common emphasis on heating problems involving coupled n-γ data sets and the accuracy assessments for capture gamma-ray spectra. Capture by epithermal and fast neutrons was an important problem in both cases.

46 Finally, there was a common interest in the new error files and the associated processing codes for ENDF/B-IV data. Considerable progress had been made in this area for CTR shielding applications which could benefit designers of shields for fission reactors.

47 Great importance was attached to the assessment of data sets and the identification of any new requirements for differential measurements. Benchmark shielding experiments were now being performed for fusion reactor studies and a similar approach was being adopted for the utilisation of the results. Design sensitivity analyses on generic classes of problem had been performed in the U.S. Such studies provided valuable guidance for designers in estimating the possible effects of design changes on the nuclear performance parameters of interest.

48 With regard to the forthcoming meeting in Vienna, Mr Gerstl expressed the hope that fusion reactor shielding could be included, and he drew the attention of participants to a preliminary list of requirements already drawn up in the U.S., namely:-

USNDC-CTR-1 entitled "Status and Critical Reviews" by D Steiner.

OBJECTIVES OF THE VIENNA MEETING, OCTOBER 1976

49 Having established the technical feasibility of producing a Revised Data Request List based on quantitative analyses working from specified target accuracies, participants agreed on the following statement of objectives for the Vienna meeting:-

(i) to review the overall needs for basic data as indicated by the sensitivity studies on typical shielding problems;

(ii) to ascertain whether these requirements were met by existing evaluations of differential data;

(iii) to decide whether adjustment of the existing differential data utilising integral benchmark information would suffice to meet these requirements in practice;

(iv) if not, to compile an international request list of the outstanding items, specifying if possible whether new differential measurements or new evaluations of existing measurements would be required;

(v) to review the methodology for sensitivity analysis in complicated geometric situations and to initiate further studies of practical generic designs which illustrate this aspect of the problem;

(vi) to review progress with the continuing programme of benchmark experiments and the intercomparison of results;

(vii) to affirm the communication links with the evaluators and measurers via the existing committee structure for the amendments and modifications which would subsequently be made to the preliminary request list.

50 It was agreed that, in view of the specific purposes of this meeting, it should be restricted in size to between 30 and 50 participants made up again largely from the shielding specialists and authors of the sensitivity codes. It would also be important to have some representatives from the differential-data measurement and evaluation fields to advise on the status of existing information and the possible implications of any new requests for differential measurements which might emerge from this exercise.

CO-ORDINATED PROGRAMME OF SENSITIVITY STUDIES

51 With these objectives in view, the meeting went on to consider in detail the work which would be required to achieve a consensus request list, recognising that on the short timescale laid down (which had been largely determined by the NEACRP's assessment of various national project requirements), it would be essential to share out the work between different laboratories and that the resulting list would only deal with the main structural materials. Subsequent revisions would be required to encompass the full range of materials encountered in practical shield design.

Sensitivity Benchmarks

52 Great importance was attached by all participants to the assignment of realistic target accuracies firmly rooted in the various reactor project shielding studies currently underway. Moreover, it was recognised that whilst the standard calculational route of ANISN/SWANLAKE should be used, the sensitivity studies would necessarily have to be conducted with the individual data-sets employed for these project calculations. This, in turn, led to the proposal for theoretical sensitivity benchmarks which could be used to identify significant differences in the data requirements established by the use of different data sets and/or cross-section libraries.

53 The attention of the meeting was drawn by M. Barré to the existing NEACRP proposal for a 1D fast reactor core/breeder benchmark to compare various reactor physics and safety calculational methods. It was agreed that the fast reactor shielding sensitivity benchmark should be based on this model, extending it out through a typical sodium/iron configuration. M. Barré (CEA Cadarache) undertook to provide the additional specification for this idealised 1D shield by Christmas 1975.

54 In the water reactor field, a typical PWR shield configuration was proposed which should be specified in a two-dimensional model together with a one-dimensional representation. Dr Hehn (IKE Stuttgart) undertook to draw up these specifications, choosing if possible a geometry which could be set up for measurement in the EURACOS II fission-plate facility. This problem would

be available to analyse directly by the Oak Ridge VIP code or by the correlated tracking Monte Carlo method. Comparison with the standard 1D method of analysis with SWANLAKE would, at the same time, indicate the influence of geometric approximations on sensitivities derived for this class of problem.

55 As a further check on the influence of geometric modelling in 1D for sensitivity calculations, Dr Rief (EURATOM) undertook to apply his Monte Carlo code to a typical axial shield of a pressure-tube reactor, to be specified by Mr Avery (UKAEA Winfrith). This would also serve to extend the scope of the water reactor sensitivity studies to include heavy water configurations. Dr Whittier (AECL Canada) expressed a wish to be associated with the specification of the typical pressure-tube reactor problem.

Assessment of Data Requirements for Practical Design

56 In addition to performing calculations for the sensitivity benchmarks, participants were invited to speculate on the scope of their contributions to the assessment of data requirements for practical designs which would form the basis of the revised International Request List for shielding. The following proposals were tabled:-

Fast Reactor Shields:	US (Oak Ridge) UK Japan (Tokyo University and JAERI) France EURATOM (axial shield streaming in collaboration with Oak Ridge)
PWR Shields:	France FRG
Pressure Tube Reactors:	UK Canada (AECL) EURATOM (axial shield streaming in collaboration with Winfrith)
Fusion Reactors and Experiments:*	US (Los Alamos) CNEN UK

57 It was recognised that this list could only be regarded as provisional, since several participants drew attention to the fact that there were a number of organisations - particularly in the light water field - who might wish to contribute to these practical data requirement studies when they received advance details of the programme in the NEACRP report.

COLLABORATIVE PROGRAMME OF SHIELDING BENCHMARKS

Review of Progress

58 Dr Nicks said that considerable progress had been made with the collaborative iron benchmark experiment originally proposed at the Ispra meeting in April 1974. He had been asked to collate the results of this experiment and undertake the intercomparison exercise. Although it was not yet clear precisely how this should be done there were good prospects for completing a preliminary analysis in time for the Vienna meeting.

*Subject to confirmation by the NEACRP that fusion reactors are included in the programme.

59 In order to facilitate this work he urged participants to ensure that a report on the experimental results was prepared in the standard format which had been agreed at the Winfrith meeting in April 1975. There were now at least ten experiments in pure iron (or mild steel) in progress but, in view of the significant differences in the source spectra, geometry and detector characteristics it was essential to have the information clearly presented in a manner which facilitated the intercomparison.

60 Dr Oblow had suggested that the format should be extended to include 1D sensitivity profiles for the various integral detectors used in the experiments. It would also be desirable to present the results of forward ANISN/DOT calculations using EURLIB-I in order to make full use of such results in the standard benchmark report. It was agreed that whilst this was a desirable extension to the agreed format, it should not be allowed to delay publication of the measurements.

61 Dr Nicks said that the status of the NEA benchmark experiments in progress on the various irradiation facilities reported at the meeting would be summarised in the form of a table for inclusion in the report to the NEACRP (Table 1).

Future Programme

62 TAPIRO: Professor Farinelli reported that the final results from the sodium slab experiment would include a wide range of activation rate distributions, absolute measurements of the reaction-rates, and the flux spectrum at the copper-sodium interface. Differential neutron spectrometers would be used with unfolding methods such as SPECTRA and SAND II. Thereafter the systematic analysis of these measurements was planned.

63 YAYOI: Professor An reported that the analysis of the measurements made using the gun source was being continued in order to find a calculational procedure which could improve the representation of the experimental assembly. Moreover, measurements with thick iron slabs would be continued; sodium measurements were also envisaged.

64 ASPIS: Mr McCracken said that the experiments were almost complete; some complementary measurements to examine the effect of a water filter between the source and the iron block were in progress. The analysis of the experimental results was continuing.

65 EURACOS II: Dr Nicks said the irradiation facility was being installed at the TRIGA reactor of the University of Pavia; it was planned to perform activation profiles and neutron spectra measurements with proportional counters and an organic scintillator.

66 Point Cf and DT Sources: Dr Koban said that measurements of 14 MeV neutron leakage spectra from lithium spheres were underway at Karlsruhe, and Professor An said that the JAERI measurements of the neutron leakage spectrum from iron were being repeated because of bad statistics and neglect of the time lag correction in the sphere.

67 TSF: Dr Oblow said that a configuration made up of an iron spectrum modifier followed by a 15 ft thick sodium block and an outer slab of pure iron had been measured in the past; the preliminary findings of these measurements had been presented to the 4th International Shielding Conference at Paris in 1972. Similar experiments had recently been repeated by using the TSF source directly without a collimator and including a region of steel between the sodium and the outer iron slab; analysis was still underway.

68 PROTEUS: Dr Herrenberger confirmed that it was proposed to make neutron spectrum measurements along the axial shield of the fast critical facility PROTEUS in the near future.

SUMMARY AND CONCLUSIONS

69 In general, it was accepted that the meeting had achieved the objectives laid down by the NEACRP, namely to:-

(i) agree on the use of a standard route (ANISN/SWANLAKE) for the calculation of data sensitivities;

(ii) initiate at least two independent assessments of the methods available for calculating data sensitivity in multidimensional problems in order to arrive at a clear statement of the influence of geometric effects on data requirements determined from 1D calculations;

(iii) to agree on a joint programme of sensitivity calculations on a range of practical shield configurations with the aim of eliciting contributions to furnish the basis for a new international request list from the various participating laboratories for the Vienna meeting in 1976.

Participants recognised that the programme of work drawn up for this meeting was ambitious, particularly since they had thought it necessary to establish two sensitivity benchmarks in order to identify any significant differences in requirements derived from practical design calculations performed with various in-house data sets. Nevertheless, it was hoped that the essential basis of the new request list would emerge from the Vienna meeting with definitive statements, at least, about the prime materials of concern for neutron calculations namely: iron, sodium, water, D_2O, graphite, etc, and those giving rise to the important sources of gamma-ray production in practical designs.

70 A strong recommendation was made to the NEACRP about the importance of CTR shielding which was already posing design issues in relation to the shielding of major fusion reactor experiments, apart from longterm basic work. The large area of overlap between the data requirements for fusion and fission reactor shielding was emphasised and it was clear that the same (or very similar) techniques were being developed for transport calculations of radiation penetration and sensitivity analysis.

71 It was agreed that the EURATOM team were best suited to the task of distributing the problem data for the sensitivity benchmarks and of collating the results of the experimental programme. No firm proposals for intercomparing the results had emerged, however, apart from reconciling the overall conclusions drawn about the accuracy of specific data libraries.

72 The wide acceptance of the EURLIB library had been apparent at the meeting and Dr Hehn had agreed to produce two more versions including gamma production data and updating to ENDF/B-IV.

73 Multigroup data processing was still posing major problems for most laboratories and it was clear that some organisations outside (and some inside) the US would not be able to utilise the new error files until the MINX capabilities were more generally available. In view of the considerable interest expressed in these developments by participants from the NEA laboratories, a request was made that the CPL at Ispra should implement

MINX as soon as possible. Several requests had been made for the RADAK unfolding code and Mr McCracken agreed to make arrangements for it to be issued through the CPL in the Spring of 1976.

TABLE 1

Status of Experiments in NEA Shielding Benchmark Programme

Facility	Source Geometry and Strength	Shield Configuration and Material	Experimental Results	Availability of Results	Analysis of Experimental Results
HARMONIE (Cadarache)	Cylinder, 3 KW	Iron-sodium laminated configuration; pure iron block; pure sodium block	Activation rates, neutron spectra by proton recoil counters	In progress, results will be available at the beginning of 1977	"Formulaire 0" under development
TAPIRO (Casaccia)	Cylinder, 5-10 KW	Sodium block, 1 x 1 x 1 m	Activation detectors	In progress	
YAYOI (University of Tokyo)	Cylinder; 2 KW reactor operated in a gun mode	Iron slabs with thicknesses up to 20 cm	Neutron spectra by proportional counters and organic scintillator	Ready for distribution	ANISN/CYGUS (1D Monte Carlo) and MORSE calculations
ASPIS (Winfrith)	Disk; 7 Watts	Iron block, 2 x 2 x 1.5 m Light Water Tank 2 x 2 x 1 m	Activation rates, gas-filled proportional counters; organic scintillator, resonance foils	Fe measurements distributed in standard format	ANISN, DOT, McNID (Monte Carlo) calculations In progress
TRIGA converter (Casaccia)	Disk; a few Watts	Iron block, 1 x 1 x 1 m	Activation detectors; fission chambers	Distributed in standard format	ANISN, DOT-3
EURACOS II (University of Pavia - EURATOM)	Disk; 30-300 Watts	Iron block, 1.5 x 1.5 x 1.5 m (under construction)		Irradiation facility is being constructed	
Cf 252 (Karlsruhe)	Point; 7.10^7 u/sec	Iron spheres; up to 40 cm diameter	Neutron spectra by proton recoil and He semi-conductor spectrometers	Ready for distribution	ANISN: Stuttgart and Japan DTK: Karlsruhe

(continued on next page)

TABLE 1 (continued)

Facility	Source Geometry and Strength	Shield Configuration and Material	Experimental Results	Availability of Results	Analysis of Experimental Results
Cf 252 (JAERI)	Point; Cf fission	Iron sphere; 50 cm diameter	Neutron spectra by organic scintillator	In progress	Monte Carlo calculations under way
Accelerator (Karlsruhe)	Point; 14 MeV 10^9 n/sec	Iron cylinder placed adjacent to the target	Neutron spectra	In progress	2D transport calculations envisaged
Accelerator (JAERI)	Point; 14 MeV	Iron sphere; 50 cm diameter	Neutron spectra by time-of-flight and NE213 liquid scintillator	In progress	
TSF (Oak Ridge)	Sphere; 10 KW reactor operated as a gun source	Pure iron and steel configuration Steel spectrum modifier and 4.5 m thick cylinder of sodium	Neutron spectra with large NE213 cell and proton recoil spectrometers	Available; results published by Maerker and Muckenthaler	Finished
	Sphere; 10 KW Reactor operated in core-source mode	Steel-sodium configuration of gun source experiment repeated with core source	Neutron spectra with large NE213 cell and proton recoil spectrometers	In progress	

APPENDIX A

Summary of Presentations

The Sensitivity Analysi Development and Applications Programme at ORNL
(E Oblow, USA)

1 A review was given of the Oak Ridge sensitivity analysis work to date and future trends. The FORSS sensitivity code system is discussed with application to the use of evaluated error files. An important advance is VIP - the two-dimensional analogue of SWANLAKE.

Transport Calculation of the Generalised Importance Function of Sensitivity Studies (M Salvatores, Italy)

2 This paper was concerned with some features of the transport methods, and their use in mixed fissionable-structural media (interfaces between blanket and shields, benchmark facilities with converters, or actual core systems).

An Attempt to Calculate Sensitivities in 3-D Geometries by Monte Carlo Techniques
(H Rief, EURATOM)

3 The development of a Monte Carlo method for calculating sensitivities in three dimensions was described. The method is based on the "once-more-collided" point estimator procedure with correlated sampling, and incorporates a region-dependent "expected leakage estimator" to improve sampling in deep penetration problems.

Integral Experiments on the Penetration of Neutrons in Steel/Sodium Shields
(F Bouteau, France)

4 Experimental studies on HARMONIE of neutron propagation in iron/sodium mixtures, whose composition varies from pure sodium to pure iron, were described and some results given. The purpose of these experiments is to test the "formulaire" described in the companion theoretical paper (para 10 below).

Neutron Leakage Spectra from Iron Spheres with a 242 Cf Source at the Centre
(H Werle, FRG)

5 Spectra of neutrons leaking through Fe spheres of diameters up to 40 cm from a ^{252}Cf source were measured in the energy region 0.06 MeV to 8 MeV with proton recoil proportional counters and a ^{3}He semiconductor spectrometer. The measurements are in broad agreement with transport calculations using the KEDAK file though small adjustments to the inelastic scattering cross-section above 1 MeV are indicated.

Iron Shielding Benchmark Experiments at YAYOI (S An, Japan)

6 The YAYOI experiments included the measurement at various angles with proton-recoil and NE213 spectrometers of spectra between 10 KeV and 15 MeV leaking through slabs of iron up to 20 cm thick. A comparison was shown with calculations using ANISN and the Monte Carlo codes MORSE and CYGNUS; ENDF/B3 and ENDF/B4 data files were used.

The Winfrith Benchmark Experiment in Iron - Experimental Results
(A Packwood, UK)

7 The first benchmark to be carried out in the ASPIS fission-plate facility on the NESTOR reactor at Winfrith was described. The standard format laid down for the presentation of benchmark results was used. Measurements of the spectrum were made with gas-filled proportional counters and NE213 scintillators over the range 5 KeV to 5 MeV at penetrations up to 100 cm of pure iron (mild steel).

Progress Report on Benchmark Experiments (U Farinelli, Italy)

8 Progress with measurements made in Fe using the enriched converter, and in sodium using the TAPIRO reactor was reviewed. The following aspects have been examined:-

(i) effect of resonance treatment in collapsing cross-sections;

(ii) determination of the transverse buckling by comparing 1-D and 2-D results;

(iii) effect of order of scattering expansion.

Some investigation of activation detector cross-sections were also carried out by comparing reaction-rate measurements in the core and reflector of TAPIRO using the well known Category 1 detectors as standards.

Calculations for Iron Benchmark Experiments with Cf and 14 MeV Neutron Sources
(G Hehn, FRG)

9 A status report was given of calculations of spectra leaking through spheres with Cf and 14 MeV source neutrons. EURLIB data sets based on ENDF/B3 and ENDF/B4 were used. A preliminary conclusion was that the latter provided better agreement with experiment at energies above 1 MeV but less good agreement in the KeV region, suggesting that the scalar inelastic cross-section in ENDF/B4 is well known but that the differential cross-section is inadequate.

Calculational Models for the Treatment of Neutron Penetration in Sodium/Iron Regions for the Shielding of Fast Reactors (A Khairallah et al, France)

10 A simplified calculational model was described, based on ANISN, for the description of neutron penetration in fast reactor shields. Considerable economy of running time at the expense of an acceptable reduction in accuracy was achieved by relaxing the energy and angular mesh criteria adopted for reference calculations. Adjustment of the method to give consistency with integral measurements was proposed.

Preliminary Analysis of the Winfrith Iron Benchmark Experiment (A K McCracken, UK)

11 Sensitivity analysis has been applied to the experiment reported separately in benchmark format (paragraph 15). A modified sensitivity function, which monitors the change in agreement between calculation and experiment was used. Preliminary cross-section perturbations were described. Agreement between calculation and experiment is generally good up to 50 cms penetration but for deeper penetrations significant underestimates of the flux above 1 MeV were observed.

Preliminary Studies of Neutron Benchmarks Experiments for 1D Transport Calculations Through an Iron Sphere (Y Furuta, Japan)

12 An experimental study has been carried out of the problems of using spectra leaking through iron spheres as a method of validating 1D discrete-ordinate transport calculations. Both D-T and fission spectrum source neutrons were used and spectra were measured by time-of-flight to an NE213 detector. Problems to be overcome before this experiment has the status of a benchmark are:-

(i) poor counting statistics;

(ii) a correction to the time spectrum for the time of neutron migration in the shell.

Multigroup Cross-Section Adjustment by Linear Regression (W Mathes, EURATOM)

13 A method of adjusting data was proposed which has a least squares procedure modified by the repeated application of statistical tests - important groups being identified by a "stepwise regression" method. The results of some theoretical tests of the method were shown.

Sensitivity and Uncertainty Analyses for Iron Cross-Sections (S Miyasaka, Japan)

14 Sensitivity studies were carried out and applied to NE213 measurements made behind 10 cm and 20 cm of iron in the YAYOI benchmark experiment (para. 6). A survey was made of the effect of calculated results of using either the evaporation model or the optical model to determine the inelastic scattering energy transfer matrix; this demonstrated that the sensitivity of group cross-sections is closely related to the method of processing basic cross-sections.

Application of Sensitivity Theory to Energy Group Structure Definition (V Herrenberger, Switzerland)

15 The application of sensitivity theory to group condensation for penetration calculations was considered. Approximations made during a condensation procedure were discussed and a relationship is established between the acceptable error of a calculation and the errors introduced by various approximations.

Consideration of the Philosophy of Design Margins (V Herrenberger, Switzerland)

16 This paper presented the findings of a questionnaire to which seventeen replies were received from experts in Central European countries on the problem of defining target accuracies. Three broad classifications were presented: (i) Power Reactors; (ii) research and test reactors; (iii) irradiation facilities. It was suggested that this represented the first step in a continuing process of identifying and updating mean target accuracies for the guidance of shielding experts.

Target Accuracies and Sensitivity Studies in the Assessment of Data (A F Avery, UK)

17 Sensitivity calculations were described relating the accuracy of data requirements to target accuracies specified by designers for various quantities in three practical shields. The importance of partial cross-sections and the need for evaluators to assign accuracies to data in the libraries were both underlined as a result of these studies.

The Application of Sensitivity Analyses to Nuclear Data Assessment (S A W Gerstl, USA)

18 A computational method was described to determine cross-section requirements with particular reference to the Tokamak Fusion Test Reactor. Cross-section uncertainties and calculated sensitivities were used with perturbation theory to determine variances of nuclear design parameters of interest.