NEACRP-L-121

THE NEA/EURATOM RESTRICTED MEETING OF SPECIALISTS ON SHIELDING BENCHMARK EXPERIMENTS HELD AT AEE, WINFRITH, APRIL 1975

Summary Report Prepared for the NEACRP Meeting
to be held at Bologna, 9-13th June, 1975

by

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May 1975

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LIST OF PARTICIPANTS

Dr J Butler	(Chairman)	UKAEA, AEE Winfrith
Dr J Royen		NEA
Dr R Nicks		EURATOM, Ispra
Dr G Perlini		" "
M. P Caumette		CEA, Cadarache
Dr G Hehn		University of Stuttgart
Dr J Koban		Kraftwerk Union
Prof. U Farinelli		CNEN
Dr M Martini		CNEN
Prof. T Hyodo		Kyoto University
Dr R Richmond		EIR Wurenlingen
Mr A K McCracken		UKAEA, AEE Winfrith
Mr M J Grimstone		" " "
Dr T D Beynon		University of Birmingham

In addition to the participants, the following observers were present:-

Mr J A Dennis	National Radiological Protection Board, Harwell
Mr S D Lympany	Imperial College, University of London
Mr A F Avery	UKAEA, AEE Winfrith
Dr P C Miller	" " "
Mr A Packwood	" " "
Mr A D Knipe	" " "

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INTRODUCTION

1 In April 1974 a restricted meeting of specialists on shielding benchmark experiments was held at Ispra to examine current work and future plans in the field of penetration experiments with a view to the co-ordination of programmes and the exchange of results. The laboratories represented agreed to undertake a benchmark experiment on neutron penetration in pure iron and/or sodium using a common set of activation detectors, with agreed cross-sections, and common methods of calculation employing a standard cross-section data set for iron to be supplied by Dr Hehn of the University of Stuttgart and Dr Nicks of EURATOM, Ispra. A full report of this meeting is given in NEACRP-L-1 and a summary report in ESIS Newsletter No 10 (July 1974).

2 The meeting held at AEE Winfrith in April 1975 was intended to provide a forum for those taking part in this exercise to discuss their progress to date and to exchange information on their experiences with calculations using the agreed data set, and to discuss such relevant experimental topics as the intercalibration of detectors, unfolding, and the intercomparison of results from individual laboratories.

3 It was agreed that specific papers would not be formally tabled at this meeting, with the exception of one from Mr A K McCracken on proposals for the intercomparison of benchmark results from different laboratories which was prepared in response to an action accepted at the Ispra (April 1974) meeting, and is included as an appendix to this report. Participants did, however, circulate notes and graphs to provide background information, or as a basis for discussion.

PROGRESS WITH MEASUREMENTS AND CALCULATIONS

4 Dr Nicks described measurements made in the EURACOS I facility to study neutron streaming in a sodium coolant duct which simulated conditions in the German SNR reactor. Measurements with resonance sandwich detectors made in sodium behind a spectrum modifier of iron and aluminium showed satisfactory agreement with calculations performed by the DOT III/DOMINO/MORSE combination of programmes, and this method of calculation was deemed suitable for the interpretation of future experiments in fission-plate facilities. Dr Perlini also distributed a note describing "The EURACOS II Facility" with a power of 300 W which was being set up in the thermal column of the LENA reactor of Pavia University.

5 Prof. Farinelli said that measurements at the TAPIRO reactor were now being made in sodium, the study of iron would follow later in the year - the methodology was, however, the same for both materials. The first objective of the EURLIB calculations was to establish the starting conditions at the reflector shield interface. The possibility of inserting a U-235 converter between the reflector and the shield sample was being considered to enrich the source flux components in the 0.5-1 MeV energy range.

6 Prof. Hyodo distributed "Iron Shielding Benchmark Experiments at 'YAYOI'". Preliminary transmission measurements using gun source geometry had been made through 15 cm of Fe. The emergent radiation had been viewed both with and without a collimator by detectors which included NE213 scintillators and proportional counters. Preliminary calculations had been carried out using ANISN, PALLAS and the Monte Carlo code SYGNUS and compared with spectra unfolded by FERDOR.

7 Dr Beynon described work on the Birmingham University accelerator producing an approximate fission spectrum at the centre of an iron block with a Maxwellian

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temperature corresponding to 0.9 MeV. Measurements had been made with gas-filled proportional counters in access holes and spectra had been unfolded with SPEC-4. Difficulty had been found in reconciling the unfolded energies of the resonance and antiresonance in Fe with the energies measured by transmission measurements at Harwell, possibly attributable to data on the ionising properties of tritons. The experiment had been analysed using ANISN with ENDF 3 data - ENDF 4 data was now being used - with SWANLAKE for sensitivity studies. Supplementary measurements were being made with a slowing down time spectrometer on a pulsed cyclotron.

8 Mr McCracken outlined recent progress in the UK Fe benchmark experiment which was described in more detail in the distributed notes "Progress with Measurements and Calculations in the UK Iron Benchmark Experiment" and "A Multi-Detector Multi-Position Unfolding with RADAK". An extensive series of measurements with threshold detectors and hydrogen filled proportional counters had been carried out, and a 3 ml NE213 scintillator had recently been calibrated at Harwell. Measurements with this instrument and with resonance sandwich foil detectors were expected to complete the planned experimental programme in June. All measurements made to date had been incorporated in a single unfolding in RADAK - this involved simultaneous processing with a single response matrix of 28 proportional counter and 6 threshold detector outputs. Difficulties had also been experienced with the energy-scale calibration of proton recoil counters and with their response to thermal neutron backgrounds in the vicinity of moderating materials.

9 M. Caumette said that measurements had been made and reported with sulphur, rhodium, manganese and gold to a depth of 1 m along the axis of a mild steel column in HARMONIE and also in a shield consisting of steel tubes filled with, and surrounded by, sodium. Volume fractions of iron studied were 30%, 50% and 70%. A pure sodium experiment had been conducted two years ago. The general principle applied was to separate as far as possible source problems and problems of propagation - the source at the entry to the test shields was measured in detail. Calculations had been performed using ANISN with a reduced number of groups.

<u>Discussion Summary</u>

10 It was generally agreed that the ANISN/DOT/DOMINO/MORSE combination was potentially a powerful tool for the analysis of benchmark experiments but difficulties had been experienced in several laboratories with the point flux estimator in MORSE which had produced negative components of the flux, and large statistical fluctuations at dose-points embedded within the body of the shield. The former effect was attributable to the Legendre scattering expansion and could be overcome for gamma-rays by using the Klein-Nishina formula. In the case of neutrons, isotropic scattering could be assumed for calculating the low energy flux. The statistical fluctuations observed within the shield were attributable to scattering events occurring close to the dose-point; it was noted that various alternative forms of this estimator had been proposed in the literature, and further work to implement these concepts in the codes used for the benchmark exercise would be desirable.

11 An albedo routine had been established in the version of MORSE used at Ispra and the amended code package (MORSE E) would be made available to the NEA/CPL in 6 months time.

12 Several participants reported difficulties with the use of NE213 including: unsatisfactory gamma discrimination at Birmingham and Winfrith; perturbation

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of the line shapes due to competing reactions at 14 MeV in the Harwell NRPB laboratory and some unresolved questions about the effects of streaming in the access holes on PROTEUS at Wurenlingen.

13 It was reported from Winfrith that attempts were being made to adjust detector cross-sections using the RADAK code but it was clear that the iron benchmark alone did not offer a sufficiently wide range of spectra to reveal discrepancies in the shapes near the important region of the threshold.

14 In contrast to the situation in reactor physics, the shape of the fission spectrum above 8 MeV is important for shield penetration calculations. It was recognised that disagreements in the shape which were revealed at the recent Harwell meeting on inelastic scattering data should be taken into account in the interpretation of conclusions drawn from benchmark experiments about the adequacy of high-energy cross-section data. This problem underlines the complementary roles of accelerator and reactor-source benchmark experiments which are both required to examine the full energy range of cross-section data of significance in shielding calculations.

THEORETICAL WORK AND ANALYSIS OF RESULTS

15 Dr Hehn said that the ENDFB/3 library was the basis of the EURLIB set. Thermal cross-sections were calculated using the program FLANGE II. Resonances could be treated in 1000 groups by ENDREB II and ETORSY and condensed to the required structure. The procedure agreed with Ispra for the benchmark exercise for materials other than iron was to use SUPERTOG III assuming a $1/E$ spectrum up to 0.8 MeV and a U-235 fission spectrum above this energy. For iron the narrow resonance approximation was used - 11000 point values of the total cross-section were taken from ENDFB/3 and cross-sections were weighted with $(\sigma_T E)^{-1}$ over all energies to give 99 groups. Gamma-ray production data was calculated in 100 groups - to be condensed to 20 - using LAPHAN. Pure gamma-ray interactions for Compton scattering, photoelectric effect and pair production were dealt with by the SMUG code. Heat deposition from gamma-rays was calculated by MACK and from recoils by DICE. The 99 group cross-sections were condensed at Ispra via one-dimensional transport calculations to a 33-group and a 15-group structure. When the ENDFB/4 data was used changes would be found in cross-sections above 800 KeV.

16 Mr Grimstone reported calculations that had been carried out using both EURLIB and UK data. The problem studied was a simplified one-dimensional version of the UK iron benchmark experiment with a fission source preceded by graphite and followed by iron. A McNID Monte Carlo calculation using UK DFN-906 was performed as a reference. Separate 37 group, P_5S_8 ANISN calculations using the same basic data, but given E^{-1} and $(\sigma_T E)^{-1}$ weightings, were carried out and showed that E^{-1} weighting was grossly inadequate. The EURLIB data was used in a 99 group ANISN calculation and the mean spectrum in the iron was used as the weighting spectrum to produce cross-sections condensed into 15 and 33 groups. ANISN calculations were performed in these group schemes and satisfactory agreement was found with the 99 group scheme - it was concluded that DOT calculations could therefore safely be performed in 15 groups.

17 Dr Nicks said that at Ispra one-dimensional plane geometry calculations had been carried out for a converter embedded between a thermal column and an iron block using ANISN and the EURLIB data. Spectral equilibrium was noted at energies below 25 KeV. The effect of the spatial mesh had been studied and results were found to be very sensitive to this. The influence of neighbouring materials had also been studied and after 93 cm of iron the flux below 25 KeV was reduced

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by a factor two if the thermal column were removed. Comparison had been made with measurements on the CASACCIA converter facility and agreement was generally satisfactory except for the Mn(n, γ) reaction-rate - this was probably due to the presence of Mn in the iron. Calculations with a Mn concentration of 0.8% had reduced the flux below 25 KeV by a factor two - this could be attributed to Mn resonance structure near 25 KeV.

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18 It was generally agreed that although conversion programmes such as MISSIONARY were available, close inspection of the results by experienced evaluators was required to guarantee the integrity of the conversion process.

19 The ANISN-SWANLAKE combination had been used at Stuttgart to study radiation damage in the sodium tank of the SNR. This appeared to be the first example of the application of sensitivity analysis to a practical shielding problem in the European field.

20 A modified version of SWANLAKE had been developed at Birmingham to allow perturbation of scattering matrices in addition to the total cross-sections which are perturbed in the NEA/CPL version.

21 The Winfrith Group were examining the feasibility of calculating the sensitivity of a fictitious detector which monitored the "quality" of a calculation with respect to measurements made at all energies and all depths of penetration. This method had the advantage that adjustments were indicated to data which would lead to a Maximum Likelihood agreement between experiment and calculation.

22 A two-dimensional anisotropic diffusion perturbation code was being developed at CASACCIA based on an existing diffusion code. Considerable interest was expressed in the possible use of diffusion theory in various forms for sensitivity analysis. It was argued that the method could be made sufficiently accurate by various semi-empirical corrections and that great savings in computing time could thereby be achieved.

23 The role of spectrum filters or modifiers located between the primary source and the test material in a conventional benchmark experiment was discussed at some length; it was recognised that great care was needed in establishing the the starting spectrum used in the penetration calculations since the detector responses within the shield might be disproportionately sensitive to the cross-sections of the filter materials.

INTERCOMPARISON BETWEEN LABORATORIES AND UTILISATION OF RESULTS

24 Dr Butler said that at the Ispra Meeting he and Mr McCracken had accepted an action to consider methods whereby results from different laboratories might be compared. The note RP&SG/TN/14 had accordingly been prepared and he would invite Mr McCracken to present this before proceeding to a general discussion on the utilisation of the results of benchmark experiments.

25 Mr McCracken said that the ratio of calculated and experimental reaction-rate ($C/_E$) could be expressed in terms of the calculated flux, the detector cross-sections used, and the previously determined counter efficiency, together with the errors on these quantities. The note showed that if measurements were made in the same material in another laboratory which also used the same method of calculation, and the same cross-section data, the individual $^C/_E$ ratios could be used to reveal differences in absolute calibration of the detectors provided

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these ratios were taken in a region in which two conditions are satisifed:

(i) the spectrum has the same shape;

(ii) the sensitivity profiles are the same.

The proposal was to search for such conditions and, if they could be found, to adjust all calibrations for each detector studied against whichever is considered the best.

26 The effects of lateral leakage could be treated by using fictitious absorption cross-sections in a one-dimensional calculation, the validity of this artifice having been established by comparison between ANISN and DOT.

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27 It was agreed that whilst this approach might be useful for comparing some experiments such as fission plate studies, for example, there could be difficulties in satisfying these conditions with measurements made under disparate source conditions.

28 Some participants felt that since the procedure was tantamount to an inter-calibration of detectors in an iron-block spectrum, this could be accomplished more readily, either by exchanging detectors between laboratories, or calibrating them in each laboratory against a fission spectrum from a Cf252 source of known strength.

29 The Chairman pointed out that the objective of the proposed intercomparison procedure was to identify systematic errors between results from different laboratories which might not be due solely to detector calibration. It was clear, however, that the timescale envisaged for this exercise at the Ispra meeting was too optimistic; it could therefore be taken up again at the Paris Meeting and, in the meantime, he invited participants to consider the proposals in more detail and put forward any alternative ideas.

FUTURE PROGRAMME OF WORK ON BENCHMARKS

30 Professor Farinelli said that the sodium experiment of TAPIRO would be completed in July 1975 and the iron benchmark would then be started. It was hoped to have some preliminary results from this experiment by September. Dr Nicks expected EURACOS II to be working in October and to have some results by the Spring of 1976; Dr Richmond reported that measurements in PROTEUS would begin towards the end of 1975. Professor Hyodo said that the measurements in iron at YAYOI would continue until July and that, provided a licence was obtained, experiments would begin with sodium at the end of 1975. M. Caumette said that the sodium experiment on HARMONIE would be completed in June when a further iron penetration experiment would be carried out. Mr McCracken reported that measurements in ASPIS would be completed by June and that analysis of results to date was proceeding.

FUTURE MEETINGS

31 Dr Royen reported that the meeting entitled "Specialist Meeting on Sensitivity Studies and Shielding Benchmarks" sponsored jointly by the NEA and the IAEA would be held at the NEA Headquarters in Paris from 7th to 10th October 1975. An agenda had been proposed by Dr Butler and this would be circulated before the next NEACRP meeting on 9-13th June. The meeting would be restricted to 50-60 participants.

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32 Plans for a subsequent meeting, in 1976, on Data Requirements for Shielding, had been discussed formally with the IAEA - both the Reactor Physics and Nuclear Data Sections had been approached. A preliminary announcement of the technical programme would be made jointly by the IAEA and NEA when the formal arrangements for co-sponsorship had been agreed.

SUMMARY AND CONCLUSIONS

33 In his closing remarks the Chairman said that whilst substantial progress had been made since the programme had been launched at Ispra in April 1974, the timescales envisaged at that meeting had been too optimistic. It should, however, still be possible by the time of the Paris Meeting to establish for single-material benchmarks the methodology which would be used to identify the respective roles of differential measurement and integral penetration experiments allied with re-evaluation. It might still not be clear precisely how multi-material and "engineering" benchmarks with more complicated geometries should be interpreted; and one of the important topics at that meeting would be the respective roles of perturbation methods, adjoint Monte Carlo, and correlated-tracking Monte Carlo for the sensitivity analysis of such experiments.

34 Sensitivity calculations were being utilised in two distinct roles. In the first place they were being used to determine which cross-section data were important for typical design situations - an application which requires a multi-dimensional capability - with a variety of different reaction-rates to be considered including heat-deposition, damage, activation and biological dose. Secondly, the same analytical tools were being used to design an integral experiment sensitive to those cross-sections which had been found important in practical designs.

35 With regard to the execution of these experiments, difficulties were still being - and would continue to be - experienced with neutron and gamma detectors. There were instrumentation problems concerned with thermal neutron and gamma-ray backgrounds, and the intercalibration of spectrometers in overlapping regions. On the analysis side, there was an urgent need to compare the unfolding codes used for proportional counter and NE213 scintillators in order to clarify the issues concerning the effect of smoothing functions, response matrix determinations and the assignment of errors.

36 In common with reactor physics, there appeared to be two schools of thought on how the results of benchmark experiments should be used when errors in the group cross-section data were indicated. An appeal could be made to the evaluators in an attempt to identify the underlying deficiencies in the basic nuclear data leading to a revision of the files; alternatively, an adjusted group set could be obtained which gave best agreement with the experiment.

37 Finally, it had not yet been possible to agree on a procedure for the inter-comparison of results from different laboratories, principally because the programme had not reached a stage where results from several different experiments could be furnished in the agreed standard format. Nevertheless, the importance of adopting some measures to eradicate systematic errors between different laboratories was agreed by all participants.

NEACRP "L" Distribution

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APPENDIX TO NEACRP-L-12

THE INTERCOMPARISON OF BENCHMARK RESULTS FROM DIFFERENT LABORATORIES

In an experiment carried out in a single laboratory a common practice is to take the ratio of an experimentally determined reaction-rate E to that given by calculation, C. The quantity C/E plotted as a function of penetration distance gives a useful picture of the consistency between calculation and measurement. It is interesting to enquire into the conditions under which similar experiments carried out in separate laboratories can be compared by inspection of the respective curves of C/E. This note outlines one possible approach to the problem.

Let T be the true value of any reaction-rate
C be the calculated value, and
E be the measured value

Assume that C is the result of a properly-performed transport calculation so that the errors in it are caused predominantly by uncertainties in basic data $\delta \underline{x}$ (giving rise to uncertainties in flux prediction $\delta \underline{\psi}$) and in $\delta \underline{\sigma}$, the detector activation cross-sections.

Then $C = \sum_j \psi_j \sigma_j$ and $\delta C = \sum_j \delta \psi_j \sigma_j + \sum_j \psi_j \delta \sigma_j$

We can write $E = \epsilon M$

where M is a measured count-rate and
ϵ is a previously-determined counter efficiency.

Errors on M due to finite counting times can often be kept rather small so that the main uncertainty in the determination of E is caused by a systematic error $\delta \epsilon$.

$$\text{Thus, } T = C + \sum_j \delta \psi_j \sigma_j + \sum_j \psi_j \delta \sigma_j = M(\epsilon + \delta \epsilon)$$

$$\therefore \frac{\epsilon M}{C} = \frac{E}{C} = \left[1 + \frac{\sum \delta \psi_j \sigma_j}{\sum \psi_j \sigma_j} + \frac{\sum \psi_j \delta \sigma_j}{\sum \psi_j \sigma_j} \right] \Bigg/ \left(1 + \frac{\delta \epsilon}{\epsilon} \right)$$

Using the definition of sensitivity given by Bartine (1) et al

ie $U_x = \dfrac{\delta C}{C} \Big/ \dfrac{\delta x}{x}$ the second term in the numerator can be replaced

by $\sum_x U_x \dfrac{\delta x}{x}$ giving

$$\frac{E}{C} = \left[1 + \sum_x U_x \frac{\delta x}{x} + \frac{\sum_j \psi_j \delta \sigma_j}{\sum_j \psi_j \sigma_j} \right] \Bigg/ \left(1 + \frac{\delta \epsilon}{\epsilon} \right) \qquad (1)$$

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Suppose now that measurements in the same material are made in another laboratory where the same method of calculation and the same data-set $\underline{x}$ and detector cross-sections $\underline{\sigma}$ are used. This worker will find:-

$$\left(\frac{E}{C}\right)' = \left[1 + \sum_x U'_x \frac{\delta x}{x} + \frac{\sum \psi'_j \delta \sigma_j}{\sum \psi'_j \sigma_j}\right] \Bigg/ \left(1 + \frac{\delta \epsilon'}{\epsilon'}\right) \qquad (2)$$

If $\underline{\psi} = k\,\underline{\psi}'$ where k is constant, ie if the predicted spectral shapes are the same, then the third term in the numerators of equations (1) and (2) is the same. If further $\underline{U}' = \underline{U}$, the second terms are also equal, and we can write

$$\frac{\left(\frac{C}{E}\right)}{\left(\frac{C}{E}\right)'} = \frac{\left(1 + \frac{\delta \epsilon}{\epsilon}\right)}{\left(1 + \frac{\delta \epsilon'}{\epsilon'}\right)}$$

and differences in absolute calibration of the detectors are revealed. It would then be possible for several workers to agree on a particular calibration as the best available and to adjust their own to agree with this. The essential steps in such an exercise would thus be:

(i) Measurement and calculation in different facilities with the same material, using the same code and data-set $\underline{x}$ and the same detector group cross-sections $\underline{\sigma}$.

(ii) Calculation at several depths of penetration of both the spectrum $\underline{\psi}$ and the detector sensitivities $\underline{U}$.

(iii) A search for regions with common spectral shapes and absolute sensitivities, and, if these can be found

(iv) An agreement to converge on a given calibration for each detector studied.

It is not immediately obvious that these conditions can be satisified but if they can a useful intercalibration of detectors, without the need to exchange samples, may be possible.

Reference 1: Neutron Cross-Section Sensitivity Analysis - ORNL-TM-3944 by D E Bartine et al

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17 April 1975

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