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MASTER

SHIELDING BENCHMARK EXPERIMENTS

Report of a Joint NEA/EURATOM
Specialist Meeting held at Ispra, April 1974

by

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and
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INTRODUCTION

1 The meeting had been arranged at the request of the European-American Committee on Reactor Physics (EACRP) which had reviewed the subject of integral (benchmark) shielding experiments at their 16th annual meeting held in June 1973. The already well-established US programme of Shield Data Testing under the auspices of the Cross-Section Evaluation Working Group (CSEWG) had been discussed at this meeting, and papers were also tabled from Japan and several European establishments indicating that a considerable amount of work was being undertaken in these countries on integral experiments in support of both energy-deposition and radiation penetration studies. Several new source facilities were being utilised for these experiments; there was a marked trend away from conventional activation detectors; the shielding community were adapting some of the methods used for neutron spectroscopy in zero-energy reactors and developing new techniques to overcome the special problems of deep penetration measurements.

2 It was timely, therefore, to call a meeting of specialists to examine in detail the current work and future plans in this field with a view to co-ordinating these programmes and, ultimately, exchanging results. The EACRP accordingly recommended that such a meeting be held to consider first, the work in the European and Japanese communities, and that note should be taken of the format used for reporting integral shielding experiments in the USA*. If this could be adopted, with suitable modifications as required, it would greatly facilitate the subsequent exchange of benchmark information with the CSEWG as envisaged by the EACRP.

3 The terms of reference of the meeting had been broadened to include energy-deposition and radiation penetration studies - as opposed to the conventional shielding field. Energy-deposition studies include the calculation of heating by neutrons and gamma-rays in the core and breeders of fast reactors, in addition to the reflector and shield regions which are normally the province of the shield designer. Atomic-displacements also come into this category, although the interpretation of a predicted atomic displacement-rate in terms of observable radiation effects was specifically excluded.

DEFINITION OF A BENCHMARK EXPERIMENT

4 Whilst it was recognised that the definition of a shielding benchmark experiment was a difficult task, which was further complicated by the inclusion of energy-deposition studies in reactor cores, general agreement was expressed on the importance of identifying those experiments which would be accepted as benchmarks for testing combinations of data and methods, as opposed to those which were specifically designed to measure cross-sections directly. Dr LaBauve said that this question of nomenclature had led to difficulties in the US programme. Integral experiments which, for example, might be strongly data-orientated and which had been used for evaluation purposes had already been given a certain weight; they should not therefore be subsequently used as benchmarks except, perhaps, for tests of consistency or checks of the accuracy of data-processing routines.

5 It was generally agreed that the term "integral" was misleading: most shielding experiments now included the measurement of a differential energy spectrum and, when such measurements were carried out with an effectively monoenergetic source (such as the 14 MeV D-T reaction for example) then the

*This format is illustrated in STD-7 (by R E Maerker) which was distributed to EACRP members prior to the 16th (June 1973) meeting.

only distinction between a differential cross-section measurement and a benchmark experiment lay in the size of the sample. In the former case, the sample dimensions were reduced to the limit determined by the signal-to-background ratio, when the correction for multiple scattering would be small; whereas in the latter case, the sample dimensions were increased to make lateral leakage a small correction and the penetration depth adequate to achieve the required cross-section sensitivity. Penetration (or migration) then, was a key word for a benchmark, not only in conventional shielding experiments but also in core/breeder energy-deposition studies where photon migration between regions of markedly different source strength give rise to the heating problems which are important in practical designs.

6 The requirements for source definition in a benchmark experiment were discussed in some detail. It was clear that the high precision associated with Linac experiments in the US. and to a lesser extent with the beam source on the Oak Ridge TSF, could not be achieved with degraded fission sources from the pool-reactor cores which had previously been used in many European shielding experiments. For this reason, Dr. Nicks said, both the UK and EURATOM teams had rejected much of their early work on shield mock-ups in compiling lists of benchmark experiments. It was agreed that a fission converter-plate was a cleaner system but Monte Carlo calculations had been necessary for the interpretation of the EURACOS experiments because of the influence of the thermal-column graphite and lead shields behind the plate and the closed-circuit cooling containment. This configuration had to be included in the theoretical interpretation of each experiment. The absolute fission-rate could be accurately mapped throughout the converter plate but if filter regions were introduced to modify the spectrum incident on the experimental shield, then these should again be included in the calculations for all experiments and the cross-sections would need to be exhaustively studied in the preliminary source measurements. Alternatively, if the energy spectrum and angular distribution of the flux emerging from the outer surface of the filter region was measured, then these data would completely define the source at this starting position for a subsequent penetration calculation in the shield.

7 In the case of the fast reactors, HARMONIE, TAPIRO and YAYOI, Prof. Farinelli suggested that the treatment of the core source would not pose a serious problem if one of the criteria for a benchmark put forward in the UK paper was adopted, namely that the errors involved in the representation of the source (and the shield geometry) should be small compared with the accuracy of the measurement at the given position in the shield. Thus, for the interpretation of measurements close to the reflector, a detailed two-dimensional analysis of the core flux distributions would be required; calculations of this type had been accomplished on TAPIRO and HARMONIE using the discrete-ordinate code DOT. At greater distances from the core, a one-dimensional treatment would suffice. Dr Devillers said that in the case of measurements made in iron, graphite and sodium on HARMONIE, it had been possible to use the ANISN code in spherical geometry at penetration distances beyond the so-called adaptation block (located between the reflector and experimental shield) without introducing significant errors.

8 Prof. An said that similar experiments were planned for the YAYOI reactor at Tokyo utilising one of the intermediate or fast neutron column facilities with the reactor operated in a lead reflector. Some neutron transmission measurements in steel had already been carried out using a collimated beam from the reactor in the manner of the Oak Ridge TSF benchmark facility. This approach greatly simplified the treatment of the source: it was unnecessary to represent the core flux distributions and control rods, etc, in the calculation because the

emergent spectrum from the collimator could be measured directly with a spectrometer located on the centre line.

9 Dr Casini pointed out that different types of experimental facility would exhibit different data sensitivities, and that no single establishment had access to all types of facility. One advantage of a collaborative programme of benchmark experiments would be that information from one type of experiment could be used to supplement measurements from another. In order to achieve this objective it would be important to establish common standard for benchmark experiments, and the meeting accordingly agreed on the following definition:-

> "A benchmark is a penetration or (migration) experiment in which the uncertainties involved with theoretical treatment of the source and the geometry of the system are small compared with errors in the measurements at a given penetration distance in the shield."

This definition was able to accommodate neutron experiments carried out with fast and thermal source reactors (using either the core-source of beam-source modes), fission-converter plates and Linac facilities. It was not inconsistent with the requirements of "in-pile" gamma dosimetry experiments and, moreover, it left the evaluators in no doubt as to the proper role of the experiment, which was the testing of calculational methods incorporating sets of cross-sections processed in point-wise or in multigroup form from a particular choice of evaluated data file.

10 At the same time it was noted that there was another quite separate category of "Laboratory Benchmark Experiments" which were designed to test and intercalibrate detectors and spectrometers. An example of this was afforded by the iron block experiment used to test Thermoluminescent Detectors at Winfrith and at Oak Ridge. (Reference 3 in Appendix B to this report).

REVIEW OF PUBLISHED RESULTS OF BENCHMARK EXPERIMENTS, CURRENT WORK AND FUTURE PLANS

11 A list of the papers which were presented at the meeting describing benchmark activities in six European countries, Japan and the USA is given in Appendix A.

(a) "Facilities for Shielding Benchmark Experiments at CNEN Casaccia" by U Farinelli and M Martini

12 Prof. Farinelli presented the paper from CNEN Casaccia where the main facility is the TAPIRO fast source reactor which has a maximum power of 5 KW with a small uranium metal core surrounded by a copper reflector. It differs from other fast source reactors based originally on the AFSR at Idaho Falls in two respects, namely: the use of a helium cooling system, which may permit future operation up to 10 KW; and the choice of copper as the reflector material. In the context of benchmark shielding experiments this material has an important effect in that it produces a leakage spectrum (similar to that of a dilute fast reactor) which will be significantly different from those of HARMONIE and YAYOI. The second benchmark facility at Casaccia is an enriched uranium converter-plate with a power of some 45 Watts situated on a TRIGA reactor which also incorporates a fission-spectrum standard irradiation facility.

13 Neutron attenuation studies with activation detectors have been carried out in an iron block using the fission converter-plate. Similar experiments in a large sodium block are in progress in the horizontal facility on TAPIRO and a mock-up experiment of the lower internal shield and diagrid region of the PEC reactor is under construction.

(b) "Neutron Propagation in the Steel Column of the Source Reactor HARMONIE" by C Devillers and Y Oceries

14 Dr Devillers presented the paper from the CEA describing the characteristics of the fast source reactor HARMONIE which has a small enriched uranium core with a maximum power of 2 KW surrounded by a blanket of depleted uranium and a reflector of stainless steel. On one side of this reflector there is an iron (mild steel) column and on the opposite side there is a graphite thermal column.

15 Attenuation measurements have been made with sulphur, rhodium, manganese and gold detectors in both columns and the spectrum has been measured at four positions in the iron column using proton recoil counters. The maximum penetration depth studied was about 160 cm from the core centre. Calculations in this facility have been accomplished with the ANISN code but the results are very sensitive to the choice of data library and group scheme. Checks have been made with the two-dimensional DOT code to check the validity of the spherical approximation used with ANISN.

(c) "Review of Published Results, Current Work and Future Plans of Benchmark Shielding Experiments in Japan" by S An et al

16 Professor An presented the paper from Japan which includes a review of published shielding experiments. The gamma-ray studies include back-scattering and dose build-up factor measurements with radioactive sources, and neutron attenuation measurements in slab shields and in ducts have been made in the JRR-4 pool reactor. Time-of-flight measurements in shells composed of practical shield materials have been undertaken on the KUR linear accelerator at Kyoto University.

17 An extensive programme of benchmark shielding experiments is planned for the fast source reactor YAYOI installed at Tokyo University. This reactor is basically similar to HARMONIE with a blanket of depleted uranium but the reflector is made of lead and the core can be moved horizontally to operate at five separate stations, including a beam hole, fast, intermediate and thermal neutron columns and a special "bare reactor" facility.

18 Some neutron transmission measurements in iron have already been made in collimated beam geometry using a large NE 213 scintillator, the pulse height distribution being unfolded with FERDOR. Preliminary calculations have been made with the discrete-ordinate code PALLAS. Again, several data sets have been used based on ENDF/B, the ABBN and KEDAK libraries. It is proposed to install a Linac for future work using the reactor as a fast neutron booster source.

(d) "Measurement of Radiation Penetration in the Iron Shield of a Gas-Cooled Fast Reactor Lattice" by R Richmond

19 Dr Richmond described the proposed programme of measurements in the axial blanket and iron shield of the gas-cooled fast reactor lattice in the coupled fast-thermal reactor PROTEUS. Fission rates, U-238 capture rates and proton-recoil counter spectra will be measured in the central lattice with mixed plutonium-uranium oxide fuel, the upper axial blanket composed of depleted uranium oxide and the axial shield which comprises a mild steel slab. Provision is made to replace the latter by a rodded steel region thereby extending the same core/blanket heterogeneity up through the shield.

(e) "The UK Programme of DATAM Experiments on Energy-Deposition and Radiation Penetration" by J Butler, M D Carter, A K McCracken and A Packwood

20 Mr McCracken presented the UK paper which describes the underlying philosophy of the Winfrith DATAM programme of benchmark experiments including the question of target accuracies, the methods of data processing and the role of data (or parameter) adjustment. The DATAM experiments are a special type of benchmark which provide tests of DATa And Methods: they comply with the definition in paragraph 9 above with the additional requirement that the measurements must be capable of interpretation directly with approximate design codes working in their normal mode. The programme is accordingly strongly methods-orientated and the paper outlines the two-option scheme of survey (kernel/albedo/diffusion) and Monte Carlo codes.

21 The early UK work on LIDO is reviewed in this paper and some experiments are identified which measure up to DATAM standards using the core as a source and also fission converter-plate sources. The shielding work was terminated on LIDO in July 1972 and subsequent measurements have been concentrated on the ASPIS converter-plate facility on NESTOR at Winfrith with supporting studies on ZEBRA and other zero-energy reactors. A feature of the present ASPIS fission-plate which is composed of natural uranium is its low power (approximately 7 Watts) for which thin (5 mm) gaps on either side are sufficient to permit convection air cooling. The geometry is very simple and the plate is effectively embedded within the experimental shield. Feasibility studies have been carried out with proton recoil counters and a small (3 ml) NE 213 scintillator in a mild steel shield with a thickness of about 1000 mm. The results have been used to check the two-dimensional removal-diffusion code SCORE4 and the Monte Carlo code McNID incorporating the DICE 360 system which processes data from UKNDL. Proposals for future DATAM experiments involving duct systems and more complicated 3D geometries are included in the paper.

(f) "The Application of Shielding Benchmark Experiments to the Testing of Nuclear Data, Calculational Methods, and Procedures" by R J LaBauve, D R Harris, D W Muir, P B Hemmig

22 Dr LaBauve presented the paper on the US programme which recognises two categories of benchmarks: namely integral experiments and reference calculations. The former are orientated towards nuclear data testing or checking on specific features of a calculation or code. Reference calculations, on the other hand, are used to verify that the physics of a calculation is correct or that it is properly coded. At present, the emphasis in the benchmark programme is on the preparation of ENDF/B4 which will be particularly applicable to shielding problems in that it contains neutron-induced photon production cross-sections for 37 nuclides, decay data for 825 fission products and complete revaluations of photon interaction cross-sections for 87 elements.

23 Benchmark experiments have all been allocated SDT (Shield Data Testing) numbers and are divided into two categories: single-material or multi-material. Examples of the former are the Oak Ridge broomstick checks on total cross-sections, the Lawrence-Livermore Laboratory pulsed sphere experiments, and the third-generation time-of-flight experiments in which scattered neutrons and secondary photon spectra are measured on the high power linac at Intelcom. Rad. Tech. Several multi-material experiments are being considered for selection as CSEWG benchmarks including a mock-up of the FFTF performed on the ZPPR, and some clean engineering mock-ups on the Oak Ridge TSF relating to the design of the FFTF stored-fuel facility and control-rod streaming channels.

24 Several new integral experiments are being planned, but the distinction between data-testing and methods-testing is rarely clear cut. In planning new data-testing experiments one or, at the most, only a few materials would be used. In methods-testing benchmarks only materials with well-known cross-sections would be employed with relatively simple source and shield configurations in line with the definition in paragraph 9 above. Planned experiments concerned with the FBR programme are aimed at neutron deep penetration, secondary-gamma production, gamma-ray heating, pin-streaming, duct streaming and cavity migration.

(g) "Sensitivity Studies and Integral Benchmark Experiments" by G Hehn (FRG)

25 Dr Hehn explained that this paper was concerned primarily with the philosophy of benchmarks. Starting from integral quantities such as gamma-ray heating, atomic-displacements or biological dose, the first step was to determine their sensitivity to the data and geometry of the design environment. With forward calculations, the influence of a few different data sets could be examined but the problem should properly be studied using adjoint calculations within the framework of perturbation theory. Using the ANISN/SWANLAKE approach, sensitivity profiles had been calculated for radiation damage and heating in the wall of a PWR pressure vessel and for the biological dose outside the primary shield. The next stage of the exercise was to examine the sensitivity profiles of various published benchmark experiments to identify those with similar characteristics which could therefore serve as checks of the multigroup set used in ANISN. Consideration was also being given to the sensitivity profiles in two-dimensional cases but in the PWR situation they were not expected to differ greatly from those calculated for one-dimensional geometries.

(h) EURATOM Shielding Experiments

26 Dr Nicks gave a verbal presentation, illustrated with slides, of the EURATOM work with the EURACOS fission converter-plate facility which had been operated on the ISPRA-1 reactor and was now closed down. He agreed with Mr McCracken of the UK that a fission-plate afforded a very simple system for the theoretical interpretation of benchmarks. An important feature of EURACOS had been its high source strength (1300 Watts power) of 10^{14} neutrons per sec. with a fast flux of 10^{10} n/cm.sec. at the front of the experimental shield. Closed circuit forced air-cooling had been used, and the converter plate contained within its cooling box had a diameter of 80 cm. As mentioned previously (paragraph 6) this configuration necessitated a two-dimensional Monte Carlo treatment of the source region for each experiment.

27 The first benchmark experiment on neutron propagation in laminated iron-water shields had already been published in the Special Issue No 1 of the ESIS Newsletter. Dr Nicks suggested that this might provide the basis of a suitable format for reporting neutron benchmark experiments (Appendix B-4). A more complicated experiment had been studied in support of the SNR design involving a sodium-filled duct with bends passing through shield walls of graphite, steel and concrete. These measurements had been made with activation detectors and a special study of the epithermal spectrum had been carried out with resonance sandwich foils. Experiments on secondary gamma production in steel had been started on EURACOS, but it was now intended to transfer this facility to the TRIGA reactor at the University of Pavia. The power would be reduced to about 700 Watts but this would not adversely affect the programme if more reliance were placed on high-efficiency neutron spectrometers instead of activation techniques.

PROPOSALS FOR A COLLABORATIVE BENCHMARK PROGRAMME

28 Opening the discussion on the possibility of establishing a co-ordinated programme leading ultimately to the exchange and intercomparison of results with the CSEWG Shield Data Testing experiments, the Chairman suggested that:-

(i) At least one single-material experiment should be carried out on all the different facilities - iron and graphite were the obvious contenders and both were of interest to fast breeder and high temperature reactor projects.

(ii) A basic list of activation detectors should be drawn up for use in these experiments in addition to any spectrum measurements which might be made. Special consideration should be given to the response cross-section data.

(iii) In each case the initial theoretical interpretation of the penetration measurements in this common material should be undertaken with the same code(s) and data sets; comparison of the various measurements with the predictions of this standard calculation (with appropriate corrections for geometry and leakage) would reveal differences between the data sensitivities which would be largely attributable to differences between the spectra incident on the experimental shields. These findings would also be a valuable aid in the detection of any systematic error trends.

Choice of a Standard Material

29 The proposal that each laboratory should study, first, the same material met with general approval. Dr Devillers suggested that iron should be chosen as the standard material in preference to graphite; both materials had been studied in the HARMONIE columns but difficulties had been experienced with thermal neutron backgrounds in proton-recoil counter measurements in graphite. Mr McCracken supported this view, similar problems had been encountered with graphite in the ASPIS facility at Winfrith, and the counters were being modified to eliminate their sensitivity to thermal neutrons. Moreover, the resonances in iron posed a useful test of the counter resolution before tackling more complicated experiments.

30 Professor Farinelli said that an integral experiment in iron slabs had been carried out with the TRIGA converter-plate at Casaccia but he would rather wait until the detector cross-section data had been improved before regarding this experiment as a benchmark. He was prepared to establish the iron block benchmark in the horizontal facility on TAPIRO where it would be irradiated directly by the leakage spectrum of the copper reflector. In order to examine the effect of the spectrum shape a fission converter-plate could be interposed since the reflector leakage spectrum was sufficiently soft to furnish an adequate fission source strength.

31 Professor An drew attention to the collimated beam source experiments in iron which had been started on YAYOI; it was proposed to extend this work to cover a penetration range between 30 and 80 cm. To date, the measurements had been restricted to the fast neutron ($\sim$1 MeV) region. Dr Nakamura said that attenuation measurements through iron had been made with 14 MeV and 3 MeV "point" sources generated on a Cockroft-Walton accelerator. Calculations with Monte Carlo were in progress.

32 Dr Nicks confirmed that the iron block experiment started originally on EURACOS would be set up again when the fission plate was re-established at Pavia University. He proposed to use the novel spectrometer devised by Professor Pinelli. This had been the subject of a special presentation during the meeting and the prototype had been published in Nuclear Instruments & Methods.⨍

33 Dr Herrenberger, on behalf of Dr Richmond, who had had to leave the meeting early, recalled that iron was to be studied in both slab and rodded form on the axial shield of PROTEUS.

Activation Detectors and Spectrometers

34 It was generally recognised that activation methods had always figured prominently in European and Japanese experiments and there was clearly a continued interest in them for the future programme, although such techniques would be supplemented - and in some cases perhaps supplanted-by spectrum measurements using principally NE 213 scintillators and proton-recoil counters. The question of cross-section data and intercalibration of activation detectors had been considered at the Consultants Meeting on Nuclear Data for Reactor Neutron Dosimetry held at Vienna in September 1973 under the auspices of the IAEA Nuclear Data Section. This meeting had been attended by Prof. Farinelli who was also Chairman of the EURATOM Working Group on Reactor Dosimetry. Dr Butler said that the detector requirements for shielding were significantly different from those for in-pile dosimetry. He therefore invited Professor Farinelli to chair a small working group of experts to advise the meeting on the position with regard to the choice and calibration of detectors, and the question of response cross-section data. Their report is summarised below in paragraphs 39 et seq.

35 With regard to the choice of a common code and data set for the initial interpretation, it was generally agreed that the ANISN/DOT/MORSE combination should be used since it had been implemented at all the laboratories concerned. This would facilitate the early application of sensitivity calculations utilising the SWANLAKE code (in conjunction with ANISN) which was now available from the NEA Computer Programme Library.

36 Dr Hehn and Dr Nicks undertook to provide a P_3 data set for mild steel using the processing code SUPERTOG based on the ENDF/B3 file for iron. It was agreed that this set should have $\sim 10^2$ groups and that the group boundaries should be chosen to coincide with some of those in the 270 group set proposed by Dr LaBauve* as a possible standard set for CSEWG benchmark calculations. This would enable condensations to be made for subsequent comparisons at a later stage in the programme.

37 The main problems envisaged in generating this initial multigroup set were the effects of small differences in the composition of different mild steel samples and the treatment of the weighting function for resonances in iron. Professor Farinelli said that the Casaccia and Cadarche samples had almost identical compositions (ie 99% iron with traces of manganese, carbon, etc) and the only impurity which mattered was the 0.8% of manganese. It was agreed that a typical composition should be assumed for generating the data set with less than 1% of

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*Report of the CSEWG entitled: "Specification of a Generally Useful Multigroup Structure for Neutron Transport" by C R Weisbin and R J LaBauve

⨍ Nuc. Inst. Meth. 82 (1970) 106-108

impurities but this restriction should be noted by all users. The weighting function in iron would be calculated using the "narrow resonance approximation" which gives a slowing down spectrum of $\frac{1}{E\Sigma_t}$. This spectrum weighting had been tested by Goldstein and had been shown to be adequate for shielding calculations. Dr Hehn said that the modification of the spectrum after penetrations in excess of 80 cm would probably necessitate a fine group calculation, say 1000 groups, in order to devise a weighting flux. However, for the first benchmark comparison it was considered that the $\frac{1}{E\Sigma_t}$ weighting would be satisfactory. This would enable the cross-section set to be derived readily with SUPERTOG in about three months.

38 Concern was expressed by several participants about the effect of systematic errors which might not be adequately revealed by the comparisons between predictions with the standard data set and experimental results from the various facilities. In the case of the three fission plate measurements which had been proposed, namely: ASPIS (Winfrith), the TAPIRO LHF (Large Horizontal Facility) and the EURACOS converter ultimately to be operated on the TRIGA reactor at Pavia, the data sensitivities should be identical. Under these conditions, the Chairman suggested that it might be possible to undertake a specific exercise to identify systematic errors. Consideration was accordingly given to the following procedure:

(i) calculate the spectrum and/or detector reaction rates along the penetration axis of the shield making appropriate corrections for leakage, etc, with DOT/MORSE;

(ii) plot the axial distribution of C/E ratio, ie the ratio of the calculated reaction-rate or group flux to the measured value;

(iii) calculate the same reaction-rate and/or group flux distribution for an idealised infinite-plane fission source embedded in an infinite medium composed of the experimental material;

(iv) predict from the C/E results of (ii) the corresponding values in the idealised shield of the quantities measured in the experiment.

If there were no significant sources of systematic error then all three sets of results would be on the same curve (within the quoted statistical accuracy). Doubts were expressed as to whether this would be a useful procedure for the other facilities which had different sensitivity profiles arising mainly from differences in the incident spectrum. Mr McCracken pointed out that it was proposed to modify the spectrum in the ASPIS facility by interposing a simulated uranium oxide breeder region at the front of the shield. In this way it should be possible to reproduce the leakage spectrum of HARMONIE and YAYOI. Consideration was also being given at Winfrith to an experimental comparison between beam-source geometry and large converter-plate geometry. The preliminary findings of this exercise would be made known to the participating laboratories as soon as they become available.

REPORT OF THE WORKING GROUP ON ACTIVATION DETECTOR CROSS-SECTIONS

39 Professor Farinelli reported the findings of the Working Group, comprising Dr Nicks, Mr McCracken and Dr Devillers, which were summarised in a table reproduced here as Appendix C. This had been compiled in three categories:

firstly, those detectors which were of general use in all aspects of shielding work including measurements on zero-energy reactors and on power reactors, during commissioning and normal operation. The choice was a compromise between the conflicting requirements of energy-coverage, sensitivity and half-life. The second category contained resonance and sandwich detectors, there was a significant gap between manganese and tungsten (from 337 down to 18 eV) which might be filled by lanthanum, but there were reservations about this reaction because of handling difficulties which put it in the third category. This last category contained the detectors which were of special use in fast reactors (including uranium fission foils) where there is negligible thermal flux and a low epithermal contribution below 100 eV.

40 With regard to the cross-sections, it was not practicable to make reference to a single evaluation because the Working Group had agreed not to recommend data which apparently gave rise to discrepancies exceeding 10% in the well-known integral experiments. For the threshold reactions, those marked with a cross should be available from CCDN on tape.

41 Finally, Professor Farinelli drew attention to those reactions marked with an asterisk. These had been selected by the IAEA Consultants Meeting (paragraph 34 above) for their Category I list of Reactions. The differential data for these are known with a high accuracy; new evaluations could be expected but a strong recommendation had been made that these cross-sections should not be "adjusted" on the basis of integral experiments. A second category of other reactions useful for reactor dosimetry had been compiled and it was specifically intended that their cross-sections should be adjusted with reference to measurements in a set of 9 benchmark spectra. It was proposed to rely on calculations of these spectra which would be checked against reaction-rate measurements made with Category I detectors.

42 Mr McCracken drew attention to his proposal in the UK paper for adjusting the cross-sections of certain shielding detectors in the ASPIS facility beginning with rhodium which had, at present, a large uncertainty. The main difference between these proposals was that adjustments in ASPIS would be carried out in spectra measured with proton-recoil counters and NE 213 scintillators, and that a series of typical shielding spectra would be set up by means of filter slabs.

43 Mr McCracken and Professor Farinelli agreed jointly to undertake the task of selecting the appropriate cross-section data for Category I detectors in Appendix C, which had been recommended for use in the iron benchmark exercise, and producing group-averaged values appropriate to the 10^2 group scheme chosen by Dr Hehn and Dr Nicks for the initial round of calculations.

FORMAT FOR PRESENTATION OF RESULTS

44 Whilst the meeting recognised that the question of the format for reporting results was of paramount importance in any benchmark programme, comparatively little time was spent in discussing the details because satisfaction was generally expressed with Dr Nicks' ESIS format used for the EURACOS iron-water benchmark (Appendix B-4). Mr McCracken and Dr Devillers, however, stressed the importance of including the spatial distribution of the fission-rate throughout the source region expressed in absolute units. This amendment would be particularly important in the case of fast source reactors used in the core-source mode. (The fission distribution in any blanket region should be similarly specified.) Alternatively, if this information was not available then sufficient data should be supplied to enable the sources to be calculated with a 2D or 3D code.

Dr Hehn also suggested that the chemical composition of each medium in the shield should be specified in adequate detail to evaluate the cross-section data.

45 With regard to the format of SDT 7 which had been recommended by the EACRP, the meeting felt that this was orientated towards the requirements for cross-section measurements or strongly data-orientated benchmarks. Dr LaBauve said that consideration was being given by Straker and Harris to the possibility of changing this format and he would draw their attention to the ESIS report and the comments made at the meeting.

SUPPLEMENTARY EXPERIMENTAL PAPERS

The following three papers were tabled at the meeting:

(a) "A Benchmark Experiment to Test Activation Detector Cross-Sections on the TAPIRO Reactor" by M D Belli et al

46 The proposals of the Consultants Meeting on Nuclear Data for Reactor Neutron Dosimetry held in Vienna by the Nuclear Data Section of the IAEA are summarised in paragraph 1 of the paper. Preliminary experimental results are given from TAPIRO comparing measurements and predictions using two-dimensional DOT calculations in the P_o, S_8 approximation for Category I reactions and a selection of Category II reactions. Significant discrepancies, attributable to shortcomings in the calculation, were observed in the reflector. A programme of further work is outlined.

(b) "A Gamma-Ray Energy Deposition Benchmark Experiment" by A D Knipe

47 This report briefly discusses the relationship between the energy deposition rate measured in a ^{7}LiF thermoluminescent detector (TLD) and that of a surrounding medium - the so-called cavity correction factor of dosimetry. An algorithm, based on Monte Carlo, for the calculation of cavity corrections is outlined. Predictions of this algorithm are compared with measurements of TLD absorbed dose in an iron block benchmark experiment using ^{60}Co as a source of gamma-rays.

(c) "The RADAK Unfolding Code" by A K McCracken

48 The paper describes RADAK which finds Maximum Likelihood Solutions (MLS) consistent with the output of any combination of detectors, together with a full correlation analysis of the errors of the solution. An example, taken from the ASPIS benchmark feasibility study in iron, is shown of the simultaneous unfolding of nine detector outputs. The adjustment of detector response, implied in a MLS is stressed and some exploratory work on the refinement of both detector absolute calibration and cross-section shape is discussed.

FUTURE MEETINGS

49 The Chairman drew attention to the last item on the agenda which was concerned with proposals for an NEA/IAEA meeting to be held on the "Methodology of Sensitivity Studies and Benchmarks" which had originally been planned for 1974. This meeting had to some extent been overtaken by events: it would not now be feasible to hold it during the present year, and he was not clear whether the financial provision made by the sponsoring Organisation would allow postponement to 1975. Dr Lesca, however, stated that discussions had taken place between NEA and the IAEA and provision was made in the NEA budget for a meeting on shielding topics in 1975.

50 Dr Butler said that he would work on the assumption that a meeting would take place and he invited comments and suggestions for detailed topics on the agenda. Dr LaBauve thought that it would be very useful if there was a follow-up from the present meeting, particularly since ENDF/B4 (which included error assignment) would be available and presumably the second round of iron calculations would have been completed on at least some of the experiments. Professor Farinelli agreed with these views and suggested that the meeting would be more effective if it were restricted to discussing iron benchmarks. This would obviously include papers on sensitivity studies. He also pointed out that the use of Monte Carlo for adjoint calculations and sensitivity studies would be discussed at the Argonne Meeting scheduled for July 1974.

51 Dr Hehn and Dr Nicks felt that the term "methodology" should be dropped from the title of the meeting, thereby changing the emphasis a little towards applications since there were relatively few different methods likely to be available by mid-1975 to study shielding data sensitivity. Most groups would be using either SWANLAKE, adjoint Monte Carlo or correlated sampling Monte Carlo.

52 Summarising the position, the Chairman said that the consensus of opinion was clear: the meeting should be held in the Spring/Summer of 1975 with the title "Sensitivity Studies and Benchmarks". This obviously did not exclude papers on methodology. It would be appropriate at that time to review the position on the iron benchmark, although he noted that according to the time-scale quoted for some of the experiments not yet started it would not be practicable to have a full review of the programme. Professor Farinelli suggested that perhaps a further meeting of those participating in the iron benchmark programme should be held within the next two years to discuss detailed technical progress. He was also concerned that there had been little opportunity to discuss the problem of TLD, gamma-ray dosimetry in iron and fast reactor environments.

53 Dr Butler said that these points would be noted by the EACRP. He also would like to draw their attention to the fact that target accuracies had not, in his opinion, been adequately discussed. There had been a noticeable lack of comment on this question at the Paris Shielding Conference in September 1972. Perhaps this was a reflection of the design issues affected and the commercial judgements involved in assessing design margins. The relation between benchmark accuracies and designers' target accuracies was not straightforward and would perhaps be clarified when more results of sensitivity analyses on generic designs became available during the next two or three years.

APPENDIX A

Benchmark Programmes

1 "Facilities for Shielding Benchmark Experiments at CNEN Casaccia" by U Farinelli and M Martini

2 "Neutron Propagation in the Steel Column of the Source Reactor HARMONIE" by C Devillers and Y Oceries

3 "Sensitivity Studies and Integral Benchmark Experiments" by G Hehn

4 "The Application of Shielding Benchmark Experiments to the Testing of Nuclear Data, Calculational Methods, and Procedures" by R J LaBauve, D R Harris, D W Muir, and P B Hemmig

5 "The UK Programme of DATAM Experiments on Energy-Deposition and Radiation Penetration" by J Butler, M D Carter, A K McCracken and A Packwood

6 "Measurement of Radiation Penetration in the Iron Shield of a Gas-Cooled Fast Reactor Lattice" by R Richmond

7 "Compilation of Integral Shielding Experiments" by R Nicks and G Perlini

APPENDIX B

Experimental Techniques

1 "A Benchmark Experiment to Test Activation Detector Cross Sections on the TAPIRO Reactor" by M D Belli, U Farinelli and M Martini

2 "The RADAK Unfolding Code" by A K McCracken

3 "A Gamma-Ray Energy Deposition Benchmark Experiment" by A D Knipe

4 "ESIS Exp 1: Neutron Propagation in Laminated Iron-Water Shields" Special Issue No 1. ESIS Newsletter R Nicks and G Perlini

APPENDIX C

List of Activation Reactions and Cross Sections Suggested for Use in Benchmark Shielding Experiments

Reaction	Type	Energy Response	Reference for cross section	Remarks
1 GENERAL USE				
^{27}Al(n,α)^{24}Na	Thresh.	6.4 ÷ 11.9 MeV	(1)+*	Included for relatively high threshold; use may be limited by available intensity
^{32}S(n,p)^{32}P	Thresh.	2.5 ÷ 7.5 MeV	(2)+	
^{58}Ni(n,p)^{58}Co	Thresh.	2.1 ÷ 7 MeV	(3)+*	
^{115}In(n,n')^{115}In^{m}	Thresh.	1.2 ÷ 5.8 MeV	(1)+*	
^{103}Rh(n,n')^{103}Rh^{m}	Thresh.	$<$ 0.5 MeV	(3)+	Low threshold; energy response in a fission spectrum is not meaningful
^{55}Mn(n,γ)^{56}Mn	Therm. + Res.	E_r = 337 eV	(4) *	High energy data are probably unsatisfactory
^{197}Au(n,γ)^{198}Au	Therm. + Res.	E_r = 4.9 eV	(1) *	
2 RESONANCE AND SANDWICH DETECTORS				
^{23}Na(n,γ)^{24}Na		2850 eV	(5)	Of special interest for fast reactor applications
^{63}Cu(n,γ)^{64}Cu		580 eV	(5)	
^{55}Mn(n,γ)^{56}Mn		337 eV	(4)	Also suggested for general use
^{186}W(n,γ)^{187}W		~18 eV	(5)	
^{197}Au(n,γ)^{198}Au		4.9 eV	(1)	Also suggested for general use
^{115}In(n,γ)^{116}In		1.4 eV	(5)	
3 SPECIAL USE				
^{235}U(n,f)		.19 ÷ 5.1 MeV	(4) *	Very useful for fast reactor experiments; cross section very well known
^{59}Co(n,γ)^{60}Co	Therm. + Res.	$E_r \simeq$ 130 eV	(1)	Thermal neutron and sandwich measurement; applicability limited by intensity
^{164}Dy(n,γ)^{165}Dy	Therm.		(6)	For thermal neutron measurements
^{27}Al(n,p)^{27}Mg	Thresh.	3.5 ÷ 9.3 MeV	(4)+	Experimental set-up must be compatible with short half-life
^{54}Fe(n,p)^{54}Mn	Thresh.	2.3 ÷ 7.8 MeV	(6)+	Enriched detector should be available
^{56}Fe(n,p)^{56}Mn	Thresh.	5.5 ÷ 11 MeV	(6)+	Enriched detector should be available
^{139}La(n,γ)^{140}La	Therm. + Res.	E_r = 72.4 eV	(5)	Useful for completing set of sandwich detectors where difficult manipulation is acceptable

+ Data available from NEA-CCDN, Saclay

* IAEA Category I Reactions

NOTE: Nuclear data other than cross sections should be taken from (7).

APPENDIX C (continued)

References

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"Evaluated Reference Cross Section Library"
BNWL 1312, Battelle North West Laboratory (1970)

(2) H Liskien and A Paulsen
"Compilation of Cross Sections for Some Neutron Induced Threshold Reactions"
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(3) A Fabry and J C Scheepers
EANDC(E)127 "U" (1970)

(4) ENDF/B-III, Evaluated Neutron Data Files, Version 3 (1972)

(5) T J Conolly and F de Kruyf
"An Analysis of 24 Isotopes for Use in Multiple Foil (Sandwich) Measurements"
KFK 718, EUR 3716e, Karsruhe (1968)

(6) W L Zijp
"Compilation of Evaluated Cross Section Data Used in Fast Neutron Metrology"
RCN-73-083, Reactor Centre Nederland, Petten

(7) W L Zijp
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