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INTERNATIONAL NUCLEAR DATA COMMITTEE

# ANALYSIS OF THE REAL-84 INTERCOMPARISON EXERCISE

SUMMARY OF THE SPECIALISTS' MEETING
ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND HELD IN JACKSON HOLE, USA, 27-29 MAY 1987

October 1987

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

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The IAEA Specialists' Meeting on Analysis of the Results of the REAL-84 Intercomparison Exercise was held in Jackson Hole, Wyoming, USA, 27-29 May.

The aims of the meeting were:

- discussion of the final report on the REAL-84 exercise,
- formulation of conclusions and recommendations from REAL-84 for the presentation at the ASTM-EURATOM Conference on Reactor Dosimetry,
- formulation of the REAL-84 follow-up (REAL-88) programme, and distribution of actions among the project participants,
- review of the nuclear data base for radiation damage predictions.

The final report on the REAL-84 exercise was prepared by Drs. H. Nolthenius, W. Zijp (Petten) and Drs. E. Zsolnay, E. Szondi (Budapest). During the meeting it was critically analyzed and corrected. It will be published as an ECN-report. The recommendations of the IAEA Consultant's Meeting (Budapest, September 1986, see below) were also checked (see INDC(NDS)-190/G+F+R).

## Conclusions

In accordance with the conclusions of the IAEA Consultant's Meeting on the Assessment of the Results of the REAL-84 Exercise in Budapest, September 8-10, 1986, it was noted that the interlaboratory spread of the integral results was larger than expected. One of the main reasons may be traced to inconsistencies in the input data sets, leading participants to add or change input information. In particular, the input spectra were not well-defined at low and high neutron energies and discrepancies were noted for some reactions such as $^{47}Ti(n,p)^{47}Sc$, $^{59}Co(n,\gamma)^{60}Co$, $^{115}In(n,\gamma)^{116m}In$, and $^{58}Ni(n,2n)^{57}Ni$. It was thus agreed that revised data sets are needed.

A new exercise, REAL-88, should be initiated to remove these inconsistencies in the data in order to produce a reference data set.

As a first step, a few laboratories will review the input data and produce revised data sets. These data will then be adjusted by participating laboratories and the results will be reviewed to determine if there are remaining inconsistencies requiring further analysis. Once satisfactory agreement has been achieved, the IAEA will then distribute these data upon request. Although it is recognized that the information is not complete for many of these input data sets, especially concerning the covariance information, they can be used as a benchmark for testing spectral adjustment codes and procedures.

## Recommendations

1) It is requested that the IAEA organize and support the REAL-88 exercise. The Nuclear Data Section should convene a Consultant's Meeting in the Spring of 1988 to review the results of the exercise and formulate future plans.

2) In the REAL-88 exercise neutron cross sections and their uncertainties will be taken from the existing IRDF-85 data file. However, it is recommended that the IRDF file be revised to include new data, especially the reactions

$^{47}Ti(n,p)^{47}Sc$, $^{93}Nb(n,n')^{93m}Nb$,
$^{54}Fe(n,\alpha)^{51}Cr$, $^{45}Sc(n,2n)^{44m}Sc$,
$^{59}Co(n,p)^{59}Fe$, $^{93}Nb(n,\gamma)^{94}Nb$,
$^{93}Nb(n,2n)^{92m}Nb$, $^{197}Au(n,2n)^{196}Au$,
and $^{238}U(n,2n)^{237}U$.

The $^{115}In(n,\gamma)^{116m}In$ reaction should also be revised to include production of the short-lived (55min) isomer.

3) Inconsistencies were noted in the uncertainty and covariance files in IRDF-85 for many reactions. In particular the $^{197}Au(n,\gamma)$, $^{46}Ti(n,\gamma)$, $^{47}Ti(n,p)$, $^{48}Ti(n,p)$, $^{58}Fe(n,\gamma)$, $^{63}Cu(n,\gamma)$, and $^{237}Np(n,f)$ uncertainties should be reexamined since these reactions are widely used for spectral adjustment. The IAEA should include this in the WRENDA request list.

4) The IAEA should make available a number of computer codes, such as LINEAR, RECENT, GROUPIE, SIGMAI, UNC32/33 and FITOCO, for distribution along with the REAL-88 benchmarks spectral data sets since these codes are particularly useful for spectral adjustment.

5) Further work is needed to develop and test procedures for neutron self-shielding and cover reactions and for the conversion of group cross sections and their uncertainties. The IAEA could support these efforts by granting a research contract or a fellowship.

Actions

1) Participants at this meeting have agreed to revise the input data sets for REAL-88, as follows:
F. Stallmann (ANO,PSI,PS2); M. Matzke (U35); L. Greenwood (RTN,TAN, CFRMF).

2) H. Nolthenius (ENC, Petten), E. Zsolnay and E. Szondi (BEE, Budapest) will evaluate the results of the REAL-88 exercise.

3) V. Goulo (IAEA) will communicate to the participants of the REAL-84 exercise NDS' plans for the REAL-88 exercise and circulate a report of this meeting. The IAEA will circulate data tapes for the REAL-88 exercise and make the results available to interested parties.

Timetable for REAL-88

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|---|---|
| Sept. 1, 1987 – | Revised input data sets sent to Petten |
| Nov. 1, 1987 – | Revised REAL-88 data tape circulated by IAEA |
| Feb. 1, 1988 – | Participants return results of the REAL-88 exercise to Petten |
| Spring 1988 – | IAEA Consultant's Meeting on REAL-88 |
| July 1989 – | IAEA AGM on Status and Requirements of ND for RD and related safety aspects in connection with the 7th ASTM-EURATOM Symposium on Reactor Dosimetry, Strassburg, France. |

LIST OF PARTICIPANTS

| | |
|---|---|
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# ADJUSTMENT OF THE REAL-84 EXERCISES WITH THE LSL-M2 ADJUSTMENT PROCEDURE*

F. W. Stallmann

## INTRODUCTION

In the REAL-84[1] exercise, spectrum and dosimetry information was provided in order to test the consistency and adequacy of a number of different adjustment procedures. The examples were typical of those encountered in practice and covered a wide variety of neutron environments and related dosimetry experiments. The fact that these examples were taken from actual, not sanitized, data confronted the participants with the typical difficulties encountered in the application of adjustment procedures and thus provided a test not only for the comparison of different mathematical schemes but also for the skill of the investigator to judge correctly and to overcome typical problems in the evaluation of dosimetry experiments. It has been pointed out before that an adjustment procedure is not a "black box" to be applied without thinking. Less generally recognized is the fact that adjustment is not primarily a method to obtain "best" values for, say, fluences or fluence-related values but to check for consistency between calculated fluences and dosimetry or between different dosimetry measurements and, if such consistency is established, to reduce uncertainties due to the combined information, and if not, to exercise judgement to pinpoint the offending sources of inconsistencies and to either correct or to remove them. Thus an adjustment method should not only be mathematically correct but also provide the means to correctly identify the sources of inconsistencies. The author did not participate in the exercise proper - although he provided some input - but has run all parts of it with the LSL-M2[2] adjustment procedure. This paper gives some of the findings and difficulties encountered and suggestions for their solution. Its main purpose is not to go into competition with the other participants but to point out how adjustment methods can be used to detect inconsistencies and what can be done about them. One major result of this investigation is the reassessment of the cross-section files that accompany the LSL program package.

## PROCEDURES

The LSL-M2 method is a logarithmic least-squares procedure that adjusts calculated multigroup fluences and dosimetry measurements to obtain consistency and to minimize the sum of squares of the adjustments relative to the assigned uncertainties. Input must be provided for calculated fluences, reaction rates, and group cross sections together with variances and covariances for these data. In addition, values of the response functions for the damage parameters must be given in the same energy group structure as the fluences. All uncertainties are given in relative terms, i.e., as absolute values of the logarithm of the data. More than one spectrum can be processed at a time in order to exploit the correlations of fluences calculated for different points of the same reactor environment and to extrapolate to points not covered by dosimetry. Scaling can be chosen as an option resulting in a scaling factor for the adjusted fluences that minimizes the adjustments of both calculated and measured reaction rates in the least-squares sense. The main output provides adjusted group fluences and reaction rates together with the percentage of adjustment and the chi-square/degrees of freedom as a measure for the consistency of the data. Also provided are the values of damage parameters such as fluence for $E > 1.0$ MeV or dpa for any arbitrary response function with uncertainties given in form of standard

*Paper to be presented at the IAEA Specialists' Meeting, Jackson Hole, Wyoming, May 27-29, 1987.

deviations and correlations. The auxiliary output gives a record of the input data and some processed data, in particular the C/E values for the reaction rates and the uncertainties for the calculated reaction rates separated into fluence and cross-section contributions. These data are useful to pinpoint the sources of inconsistencies and to find possible remedies.

RESULTS OF THE REAL-84 ANALYSIS

1. General Considerations. The REAL-84 input data provided directly the reaction rates with standard deviations and correlations and also the group fluences with the same form of uncertainties. Cross-section data and uncertainties were provided in the form of the IRDF cross-section file and some auxiliary data and processing codes. For the LSL-M2 program package, an auxiliary code is included that determines group cross-section values and their uncertainties from a file that was compiled from the information in the IRDF[3] file. None of the processing codes provided with REAL-84 were used. Scaling of the fluences was necessary for all but one example, although in some cases the original data had been arbitrarily pre-scaled. Only fluence for E > 1.0 MeV, E > 0.1 MeV, and dpa for iron (ASTM) was calculated, primarily for lack of time and also because the other damage parameters are not likely to shed more light on the findings that in our case were primarily concerned with inconsistencies. No problems arose if only these parameters were considered; the values and uncertainties obtained with LSL-M2 agree well with those of other participants,[4] regardless whether the input data were consistent or not. Most of the problems encountered concerned the non-threshold detectors, as will be shown later, and these do not influence the results in the high-energy region. Most of the difficulties could be traced to problems in the cross-section input file.

2. The ANO Spectrum. No problems were encountered in this example. All dosimetry is from threshold sensors that are well established. This problem was run both in the scaled and the unscaled version with practically the same results. It was originally perceived for adjustment in unscaled form. The chi-square/n values are 0.4 for the scaled and 0.3 for the unscaled version. This is less than the expected value of 1.0 which indicates that the input uncertainties are probably too high. However, since this leads to conservative estimates, there are no serious implications connected with this type of inconsistencies.

3. The PS1 and PS2 Spectra. These problems were originally run by the author[5] in the multiple spectrum version of LSL-M2 and no inconsistencies were detected at that time. It was, therefore, quite surprising that both cases showed large chi-square values when run again with the REAL-84 input, even after some errors in the input had been eliminated. A closer analysis showed that in the original run the dosimetry cross-section file of ENDF/B-IV was used as provided by B. Magurno and this file had very large uncertainties assigned to resonance region of the $^{59}$Co(n,γ) and $^{45}$Sc(n,γ) reactions. The author had also increased the cross section uncertainties of the $^{58}$Fe(n,γ) reaction in the thermal region because of the known problems of this reaction in many integral measurements. This eliminated all the inconsistencies for the low-energy region; no effort was spent to refine the results for this region since the main interest for this experiment was the determination of damages associated with high-energy neutrons. This and some of the other examples in the REAL-84 exercise suggest that the uncertainties given for these reactions by the IRDF file are unrealistically low. A discussion and re-evaluation is given by F. Schmittroth[6] in his dosimetry cross-section file and the author changed the values in the IRDF file in accordance to Schmittroth's suggestions. This reduced the chi-square values for the PS1 example to a value of 0.98 that is near ideal. It should be noted that the $^{238}$U fission reaction was eliminated due to competing Pu production. The PS2 example needed a further modification by increasing the uncertainties

for fluences below 10 keV. This is quite reasonable since all fluence values below 100 keV were not directly calculated but extrapolated using a one-dimensional preliminary calculation. None of these changes influence significantly the high-energy region that is important for radiation damage. These modification reduced the values of chi-square from 3.5 to 0.7.

In the PSI example, all dosimeters had been covered with gadolinium so that no information for the thermal energy region was given. No attempt was made to account precisely for the attenuation through gadolinium; instead, cross-section values for the thermal (first) energy group were set to zero. This is accurate enough considering the other uncertainties for this region, e.g., the temperature for the thermal equilibrium with thermal neutrons.

4. The CFR Spectrum. In this example, major inconsistencies were found leading to a chi-square value of 13.9. They were traced to two dosimeters, $^{59}Co(n,\gamma)$ and $^{115}In(n,\gamma)$. Elimination of the two lead to the quite acceptable value of 1.1. It was found later[4] that the cross-section values for $^{115}In(n, )$ in the IRDF were too low by a factor 0.797 which is consistent with the adjustment required for this dosimeter. No reasons for discrepancy in the cobalt dosimeter are known. It should be noted that the data in the original paper were already normalized to be consistent without scaling.

5. The RTN Spectrum. As in the previous example, two dosimeters were found to be completely inconsistent with the rest, namely $^{197}Au(n,\gamma)$ and $^{47}Ti(n,p)$. The former needs a correction for self-shielding, but this requires more information about the foil geometry. The latter is unexplained and exceeds by far (a factor of 3.5) the large uncertainties of its cross-section values. Elimination of the two dosimeters leads to the near ideal value of 0.94 for chi-square.

6. The TAN Spectrum. No significant inconsistencies were detected. The chi-square value was 1.3 which is slightly large and probably due to correlations that are assumed for the reaction rate measurements. The adjustments for the dosimetry are all small and appear to be uncorrelated.

7. The U35 Spectrum. Two dosimeters are found to be inconsistent with the rest, namely $^{58}Ni(n,2n)$ and $^{115}In(n,\gamma)$ leading to a chi-square value of 2.9. As stated before, the indium cross-section file is in error and the necessary adjustment is consistent with the bias factor. The response of the nickel detector is at the extreme high end of the spectrum which is a very small fraction of the total fluence; the actual measuring uncertainty may, therefore, be underestimated, or, as suggested, the given group structure not fine enough to represent the nickel response accurately. It is interesting to note that fairly large adjustments in both fluences and other dosimetry measurements disappear once the two offending dosimeters are eliminated.

## SUMMARY AND CONCLUSIONS

The foregoing discussion shows that adjustment methods, judiciously applied, are quite valuable to pinpoint and eliminate possible errors in dosimetry, fluence, and cross-section data. The dosimetry cross-section file that was compiled in connection with the LSL-M2 program package has been revised on the basis of the experiences with the REAL-84 exercise. Almost all revisions concern $(n,\gamma)$ reactions whose main responses are in the thermal and - with suitable covers - epithermal energy region. The cross sections for the high-energy region which is of primary interest in reactor pressure vessel surveillance are well established and none of the inconsistencies found in the REAL-84 exercise affected significantly this region.

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