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From: M. Lammer and H.D. Lemmel

Subject: Fission Yield Data

Highlights of the Conclusions and Recommendations from the IAEA Specialists' Meeting on Fission Yield Evaluation, Studsvik, Sweden, 11, 14 and 15 September 1987, and Proposal for an IAEA Coordinated Research Programme.

A slightly modified version was distributed as INDC/P(87)-24.

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1. TOPICS DISCUSSED AT THE MEETING

The topics discussed during the meeting were:

- International cooperation between evaluators and with other groups performing special evaluation tasks and measurements of deficient fission yield data.
- The proposal for an IAEA Coordinated Research Programme (CRP).
- Communication with measurers.
- Formats for the exchange and dissemination of experimental and evaluated fission yields.
- Definitions of fission yields.
- Identification of deficient (unmeasured, discrepant) data needed for application and for obtaining complete yield sets for the most important fissioning systems.
- Further improvements of models for the fission process and for fission yield distributions.
- Treatment of errors in evaluations; introduction of correlations and covariances.
- Standard sets of fission yields.
- Energy dependence of fission yields.

No papers were presented at the meeting by participants; instead, a Working Paper was prepared by M. Lammer with contributions from the main evaluators of fission yields, T.R. England (LANL, USA), M.F. James (Winfrith, UK) and Wang Dao (Beijing, China), which served as Agenda for discussions during the meeting's sessions.

2. CONCLUSIONS AND RECOMMENDATIONS

2.1. The role of a CRP

R1 It was strongly recommended that an IAEA CRP should be held with the title: "Fission Yields, Data and Evaluation".
A CRP would enable closer and more effective cooperation between evaluators and with other groups working in the field of fission yields. The official status of the CRP should help raise funds for evaluation work and measurements needed. In particular, it should ensure the continuation of the fission yield evaluation effort in the UK and USA after the completion of JEF-2 and ENDF/B-VI in 1988.

R2 Therefore the CRP should be initiated early in 1988; the actual programme should start according to the budgetary plans of the IAEA, but not later than beginning of 1989.

A1 Action on M. Lammer: in consultation with IAEA officials to initiate the CRP within the time schedule given above.

R3 Participants support the recommendation from previous meetings that fission yield evaluation should continue independently at different places to reflect different approaches. A comparison of evaluations enables the disclosure of possible mistakes and deficiences which may be due to the rather complex correlations involved in fission yield evaluation.

R4 Therefore, the CRP should not aim at the publication of a single recommended set of fission yields. However, it should produce a
R5 recommended set of yields used as standards in fission yield measurements.

Presently ongoing evaluation efforts are:

T.R. England, B.F. Rider (USA): 50 fissioning systems*) for ENDF/B-VI.
M.F. James, D.R. Weaver (UK): 15 fissioning systems, for JEF-2; to be extended later.
Wang Dao (China): 10 fissioning systems for CENDL; to be extended later.
A.C. Wahl (USA): 6 fissioning systems and indpendent yields.

The fission yields contained in the French (CEA) and Japanese (JENDL) files have been adopted from other sources.

Within the frame of a CRP, these groups of evaluators could identify and discuss gaps in data, discrepant and/or erroneous measurements, and recommend further work to be done. However, in view of the limited manpower available to these groups, they cannot perform a number of special evaluation tasks (as discussed below) requested by users and needed for an optimum evaluation.

R6 Therefore the meeting participants recommend, that apart from the evaluating groups, also measurers should participate in the CRP, who are prepared to perform the recommended measurements and special evaluations.

2.2. Exchange of data

R7 The EXFOR format was recommended to be accepted as the format for the compilation and exchange of experimental data, to be used in future by all evaluators.

However, as the EXFOR data base is still not complete, a special effort to remove this deficiency should start as soon as possible after this meeting in cooperation with the 4 Neutron Data Centres:

USA National Nuclear Data Centre (NNDC), BNL, USA
NEA Data Bank (NEA-DB), Saclay, France
IAEA Nuclear Data Section (NDS), Vienna Austria
USSR Nuclear Data Centre (CJD), Obninsk, USSR

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*) Fissioning system = a fissioning nucleus together with a given neutron energy (e.g.: U235 thermal fission).

A2 Action on the 4 Neutron Data Centres: a completeness cross-check should be made between CINDA, EXFOR and the evaluators' files of experimental data. All data missing in EXFOR should be compiled. NNDC has a computer program for the automatic conversion of experimental data compiled by B.F. Rider into EXFOR.

A3 Action on V. McLane (NNDC): to convert all those of Rider's data into the EXFOR format which ar not in the EXFOR file, and distribute them to the responsible Data Centres. In a joint effort with evaluators, the Data Centres will complete these converted EXFOR entries with information taken from the original literature, as the workload of the groups involved permits.

R8 For the sake of the cooperation between evaluators and for a comparison of data bases, the Neutron Data Centres should consider to agree on a common computation format.

A4 Action on evaluators: to study the basic EXFOR and computation formats for futher improvements.

R9 The ENDF format should be used for the exchange and dissemination of evaluated data, in particular ENDF-VI, as soon as it will be ready.

2.3. Special recommendations concerning EXFOR

R10 It was recommended that EXFOR be advertised at meetings, in publications, etc. dealing (among other things) with fission yield data.

R11 Reviews and corrections of experimental results performed by evaluators should be included in the respective EXFOR entries with appropriate comments and flagging.
It was recognized that jounal editors generally do not accept too lengthy publications containing all details on data and error analysis.

R12 It was therefore recommended that such details be published in laboratory reports and/or, in particular, be provided by measurers for compilation into EXFOR.

R13 With all this detailed information, EXFOR entries were recommended to be recognized as publications, which can be quoted as references.

2.4. Communication with measurers

Most likely, participants in the CRP will not be in a position to perform all measurements recommended by the CRP. This meeting recommends several means of communication with measurers.

R14 Fission yields, which will be recommended to be measured, should be maintained and updated by NDS on a computer file. A newsletter listing these requirements together with indications of the application fields for which the data are needed, could be issued by the NDS on behalf of the CRP.

R15 The same list should be published in every issue of the report series "Progress in Fission Product Nuclear Data (FPND)".

R16 In addition, WRENDA and national request lists should be used to publish the required measurements, although the long intervals between publications do not promise a timely response to the requests.

R17 The assistance of INDC members and liaison officers should be sought to establish contacts with groups prepared to measure the required fission yields.

A5 Action on M. Lammer: to present this proposal to the INDC and, if agreed, to act as a link between INDC and CRP.

2.5. Definitions of fission yield

The commonly used definitions of fission yields, were accepted at the meeting and will be published in the summary report of the meeting. As highlights, 2 definitions are reproduced here which were not uniquely used in the past:

> The total chain yield is defined as the sum of cumulative yields of the stable end products of a chain. This term may be used for all cumulative yields which have practically the same value as the chain yield in the strict definition. A total chain yield may differ from the sum of independent yields of the same chain due to delayed neutron emission. This definition has been chosen to avoid confusion as it has generally been used in publications of experiments, whereas the term "chain yields" meaning the "sum of independent yields" was used only by evaluators and for some fractional yield determinations.
>
> An "absolute fission yield measurement" requires the determination of the number of fissions as well as the number of nuclides or the absolute activities of fission products. All yield determinations based on assumptions or literature values for other fission yields should be regarded as relative.

2.6. Model calculation and independent yields

Mass and charge distributions predicted by theoretical models for the fission process are not sufficient for applied purposes. However, participants of the meeting recognized the importance of fission theory for evaluation and hoped that future developments would help in the understanding and improvement of semiempirical models.

The behaviour of semiempirical model parameters near symmetric fission (distribution width, charge displacement) is still uncertain. Further studies are also needed for the variation of the Gaussian width parameter σ with fissioning system. Even for the most thoroughly studied system, U235 thermal fission, only about 1/5 of all independent yields are measured. Therefore,

R18 further measurements of independent yields and charge distributions, particularly in the symmetric region are needed. Many more measurements for U235 thermal fission should be done, but the extension to other fissioning systems would also be highly desir-

R19 able. It should be a task for the CRP to study and compare the Z_p and A'_p models regarding their prediction capability.

R20 For a better understanding of the fission process and to enable the further development of predicting models, the odd-even effect and isomeric yields should be studied in detail by measurers and evaluators. In particular, predicted isomeric yield ratios are unreliable, and measurements are needed.

2.7. Fission yield measurements

Deficient chain yield data (i.e.: no measurements, discrepancies) were identified for 15 fissioning systems during the meeting and will be presented in the first list of required measurements. Other fissioning systems will be studied by CRP participants.

Measurements of independent yields including those of very short lived fission products have been recommended (3.6.) for model calculations. They are important for the prediction of decay heat via summation calculations.

R21 Special care should be taken by measurers and evaluators to take into account isomeric yields, branching fractions and delayed neutron emission in independent yield measurements. Measurers are
R22 requested to publish sufficient details on the method used and how these data were used in the analysis.

Ternary fission yields are requested by reactor designers primarily for Tritium, but also for He4, both for thermal neutron fission and as a function of neutron energy. In evaluations, ternary fission yields enter the calculations of physical constraints on the sums of mass and charge yields.

R23 Further measurements of ternary fission yields are needed:
- for thermal neutron fission;
- as a function of neutron energy;
- versus binary fragment mass.

Statement of concern
Meeting participants are aware of the danger that radiochemistry institutes and the associated facilities like OSTIS, HAIWATHA and others are being closed down. They are worried about this development, since it will seriously reduce the possibilities for measurement of fission yields.

2.8. Fission yield evaluation

Fission yield evaluations should concentrate on fissioning systems required for nuclear energy and related applications. However, evaluation of existing measurements for other fissioning systems should continue since they are helpful for studies of systematics and fundamental fission theory.

Detailed studies of discrepant fission yield data, as well as checking and possible correction of experimental data in general, are beyond the possibilities of present evaluators, but could be a special task for participants of the CRP. The results should be included in EXFOR entries.

For many years there has been an outstanding difference of approach between UK and US evaluators towards the minimum uncertainty that should be assigned to any type of measurement. This problem was discussed at the meeting with the recommendation
R24 that the limits should be reviewed during the CRP in the light of modern techniques. However, it was not agreed that evaluators should use the same limits in the future, as such differences constitute part of the independent evaluation methods.

R25 It is desirable for evaluators to introduce correlations and to set up variance-covariance matrices for fission yields. The assistance of experts in measurement techniques is needed to work out correlations with typical coefficients for different methods. The collection of correlations and development of programs for covariance matrices would be a special task for the CRP, possibly within a fellowship.

2.9. Energy dependence of fission yields

For many years the evaluation of the dependence of fission yields on fast neutron spectra with varying mean energy has been requested for reactor applications. This task has never been accomplished by evaluators due to the lack of manpower, and should therefore be part of the CRP; in particular, the following two considerations should be addressed:

- to define the most suitable energy dependent spectrum parameter;
- to find a representation of the energy dependence of yields in evaluations to compare spectrum dependent yields with fission yields from monoenergetic neutrons.

3. SUMMARY OF THE CRP

The overall goals of the CRP would be:

- To ensure the continuity in fission yield evaluation;
- To establish a network for future cooperation to share the workload connected with evaluations, and for communication with measurers;
- To produce complete, consistent yield sets for fissioning systems important for applications, which are derived from experimental results and reliable model calculations.

The main tasks for the CRP would be:

- To cooperate in the compilation of yield data into EXFOR, and in the improvement of the EXFOR (and computation) format and coding rules.
- To review presently available yield data and semiempirical models and to recommend measurements needed.
- To further develop models to achieve more reliable predictions.
- To improve the whole evaluation process from the compilation of experimental data to the final least squares fitting procedure using all suitable physical constraints and correlations.
- To define special tasks to be performed by designated CRP participants or, possibly, by research fellows.
- To review the results of special tasks and the overall progress of the effort, and to recommend further steps to be taken.

The special tasks to be performed by one or more participants in the CRP are:

- to perform measurements of some of the yield data recommended by CRP participants;
- evaluation of fission yields used as standards.
- evaluation of isotopic and isobaric independent yields;
- study of isomeric yields, influence of delayed neutron emission;
- detailed studies of discrepant data;
- checking and correction of experimental results;
- development of methods and computer programs for the introduction of correlations and covariance matrices in the evaluation process;
- evaluation of the energy dependence of fission yields;

The following groups were proposed at the meeting for participation in the CRP:

Evaluations:
T.R. England, B.F. Rider (LANL), USA
M.F. James (AEE Winfrith), D.R. Weaver (U. Birmingham), UK
Wang Dao, Zhang Dongming (Beijing), China
A.C. Wahl (Washington U.), USA

Measurements and special tasks:
H.-O. Denschlag (U. Mainz), FRG
J.K. Dickens (ORNL), USA
G. Rudstam (Studsvik), Sweden

A group from Radiochemistry Division, BARC, India, which was not represented at the meeting but has been performing many fission yield measurements in recent years and at present.