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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

IAEA Research Coordination Meeting

X- AND GAMMA-RAY STANDARDS FOR DETECTOR EFFICIENCY CALIBRATION

Braunschweig, Federal Republic of Germany
31 May - 2 June 1989

SUMMARY REPORT

P. Christmas
Division of Radiation Science and Acoustics
National Physical Laboratory
Teddington, Middlesex, U.K.

A.L. Nichols
Chemistry Division, Winfrith Technology Centre
Dorchester, Dorset, U.K.

H.D. Lemmel
IAEA Nuclear Data Section
Vienna, Austria

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SUMMARY

The final official meeting of the IAEA Coordinated Research Programme on the Measurement and Evaluation of X- and Gamma-ray Standards for Detector Efficiency Calibration was held in Braunschweig from 31 May to 2 June 1989. Work undertaken by the participants was reviewed in detail, and actions were agreed to resolve specific issues and problems. Initial steps were also made to establish a format and procedure for the preparation by mid-1990 of an IAEA Technical Reports Series booklet; the measurements and recommended data will be listed, and a IAEA data file established for issue to all interested organisations.

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CONTENTS

LIST OF ABBREVIATIONS

BIPM:	Bureau International des Poids et Mesures, Paris, France
CBNM:	Central Bureau of Nuclear Measurements, CEC, Geel, Belgium
CRP:	Coordinated Research Programme of the IAEA
GS:	Document series of the CRP on Gamma-ray Standards for Detector Efficiencey Calibration
IAEA:	International Atomic Energy Agency, Vienna, Austria
ICRM:	International Committee for Radionuclide Metrology
ICRM Symposium:	International Symposium on Nuclear Decay Data, PTB Braunschweig, FRG, 6 to 8 June 1989
INEL:	Idaho National Engineering Laboratory, Idaho Falls, USA
KRI:	Khlopin Radium Institute, Leningrad, USSR
LMRI:	Laboratoire de Metrologie des Rayonnements Ionisants, Gif-sur-Yvette, France
NBS:	National Bureau of Standards, Washington D.C., USA
NDS:	IAEA Nuclear Data Section, Vienna, Austria
NIST:	National Institute for Standards and Technology, Washington D.C., USA (formerly NBS)
NPL:	National Physical Laboratory, Teddington, UK
OMH:	National Office of Measures, Budapest, Hungary
PTB:	Physikalisch-Technische Bundesanstalt, Braunschweig, FRG
WTC:	Winfrith Technology Centre, Dorchester, UK

1 INTRODUCTION

An internationally coordinated research programme (CRP) was established by the IAEA Nuclear Data Section in April 1986 to produce an evaluated file on nuclear data for the efficiency calibration of semi-conductor photon detectors. A list of preliminary radionuclides was prepared at an initial meeting in Grenoble (1), and the data were reviewed by the CRP participants in Rome (2). This meeting at PTB, Braunschweig, FRG, constituted the final meeting of the CRP to monitor relevant data measurement programmes, define future evaluation efforts to complete their work, and initiate the preparation of a suitable IAEA Technical Reports Series document for publication in 1990. The list of participants and observers is given in Appendix A and the meeting agenda in Appendix B. A comprehensive list of actions arising from the meeting can be found in Appendix C.

2 PROGRESS REPORTS

A significant number of progress reports had been distributed before the meeting as GS documents, and they were used as the basis of assessing future needs and actions. These reports are listed in Appendix D and are available on request from H Lemmel (IAEA).

2.1 Half-lives

2.1.1 Measurements

(a) NIST

Schima (NIST) summarised the status of the half-life measurements in terms of an on-going programme of work for Na-22, Mn-54, Co-57, Cd-109, I-125, Cs-137 and Eu-152. He noted that NIST would not be measuring the half-life of Co-56. Schima agreed to issue a summary paper to Lemmel (IAEA) on all the relevant measurements for distribution as a GS paper.

(b) NPL

Christmas (NPL) described the various half-life studies underway, including Mn-54, Co-56, Co-57, Co-58, Zn-65 and Se-75. These measurements would continue for some time beyond the completion of the CRP. Data had been reported for I-125 (ICRM Symposium at Braunschweig) and Eu-152 and Eu-154 (GS/8); no measurements were planned to determine the half-life of Na-24. Christmas agreed to issue a summary paper to Lemmel (IAEA) describing the status of all the NPL studies.

(c) PTB

Debertin (PTB) noted that half-life measurements had been completed and

reported for Co-56 and I-125 (GS/38). The remaining on-going studies will not be completed in time for inclusion in the CRP report (Fe-55, Ba-133 and Eu-155).

(d) CBNM

Bambynek (CBNM) described I-125 half-life measurements; these will not be completed in time for inclusion in the CRP report.

2.1.2 Evaluations

The tabulations prepared by Woods and Munster (GS/37 and NPL Report Rs(EXT)95) were briefly reviewed by the CRP. Further measurements have been undertaken to determine the half-life of I-125, including the studies of Woods and Lucas (ICRM Symposium at Braunschweig). The current data file is listed in Table 1. It was noted that Eu-155 would be included in the half-life evaluation because it is widely used as an emission-rate secondary standard, although P_x and P_γ data will not be assessed, and that Sn-113 would be accepted as a calibration standard. Christmas (NPL) and Debertin (PTB) agreed to evaluate half-life data for Th-228 (excluding daughters), Np-239 (as Am-243 daughter) and Am-241.

2.2 X- and Gamma-ray Emission Probabilities

2.2.1 Measurements

(a) NIST

Schima (NIST) reported that the Se-75 gamma-ray emission probabilities had been measured and the data submitted to Jedlovszky (OMH) for evaluation as an ICRM exercise. The emission probability measurements for Eu-154 had been published in NBS Special Publication 626, and Yoshizawa (Hiroshima University) undertook to incorporate this reference in his evaluation. Schima noted that the decay data for Sb-125 would not be available for inclusion in the CRP report.

(b) NPL

Measurements of the gamma-ray emission probabilities for Zn-65 would not be completed in sufficient time for inclusion in the CRP evaluation.

(c) OMH

Barta (OMH) and co-workers have completed measurements of the gamma-ray emission probability for Cr-51; a draft report was in the process of preparation with a

provisional value of 0.09860(90) for the 320 keV transition. Experimental studies of Se-75 will be reported at the ICRM Symposium, Braunschweig, and Ba-133 measurements had been reported in GS/33. Emission probability studies of Co-57 had been discontinued, and will not be completed within the framework of the CRP.

(d) PTB

Debertin (PTB) noted that measurements of the gamma-ray emission probabilities for Zn-65 and Y-88 would be reported by Schötzig at the ICRM Symposium, Braunschweig. PTB data were also available for Se-75 (ICRM intercomparison by Jedlovszky (OMH)) and Cd-109 (BIPM exercise). Measurements of the decay data for Co-57, I-125 and Am-241 would not be available within the timescale of the CRP.

(e) INEL

Helmer (INEL) reported that gamma-ray emission probabilities for Sb-125 and Eu-154 have been measured and the data reported in an INEL laboratory report. A paper has been accepted for publication in Applied Radiation and Isotopes, and a preprint will be made available to the relevant evaluators.

2.2.2 Evaluations

The CRP evaluations for x- and gamma-ray emission probabilities were reviewed in considerable detail. The contents of the current data files are listed in Tables 2 and 3. Many of these decay parameters need to be re-evaluated on the basis of new measurements and the agreed resolution of specific problems. These re-evaluations are noted in Appendix C.

The x-ray emission probabilities were all reported in GS/45 (Bambynek (CBNM)) on the basis of a well-defined evaluation procedure, while the problems identified with the equivalent gamma-ray emission probabilties are listed below:

(1) Na-22 (Schima): GS/44

An independent Soviet evaluation (Chechev) implied a very small uncertainty (0.99940(4)) for the 127.5 keV gamma-ray transition. Any evaluation of this decay parameter is based on the derivation of the internal conversion coefficients.

(2) Na-24 (Schima): GS/44

Weak beta branches determined by balancing the high-energy gamma transitions.

(3) Sc-46 (Yoshizawa)

Yoshizawa (Hiroshima University) agreed to provide Lemmel (IAEA) with an updated evaluation of the gamma-ray emission probabilities for Sc-46.

(4) Cr-51 (Nichols): GS/27

Nichols (WTC) will modify the tables associated with the E_γ evaluation, and agreed to incorporate the OMH measurement of P_γ in the evaluation.

(5) Mn-54 (Yoshizawa)

Yoshizawa (Hiroshima University) agreed to provide Lemmel (IAEA) with an updated evaluation of the gamma-ray emission probabilities for Mn-54.

(6) Fe-55 (Bambynek)

Only x-ray emission probabilties will be evaluated for Fe-55.

(7) Co-56 (Yoshizawa): GS/42

Yoshizawa (Hiroshima University) agreed to produce suitable footnotes for the tabulations in GS/42 so that an independent text was not required.

(8) Co-57 (Barta): GS/24

Barta (OMH) reported problems in the evaluation of P_γ for the 14.4 keV gamma-ray; both Coursol (LMRI) and Debertin (PTB) agreed to provide additional data from their laboratories. No equivalent difficulties had been experienced with the 122 and 136 keV transitions.

(9) Co-58 (Barta): GS/24

No problems.

(10) Co-60 (Schima): GS/44

No problems.

(11) Zn-65 (Nichols): GS/27

Nichols (WTC) agreed to re-evaluate the gamma-ray emission probabilities for Zn-65 since new measurements have been reported by PTB (ICRM Symposium, Braunschweig). NPL is also studying this nuclide, and Christmas undertook to provide information on the status of this work.

(12) Se-75 (Nichols): GS/13

The ICRM intercomparison by Jedlovszky (OMH) involves recent data from the various national standards laboratories. Earlier data need to be

combined with this study, and Nichols (WTC) agreed to undertake this task. Barta (OMH) will provide Nichols with a final version of the OMH evaluation as soon as possible.

(13) Sr-85 (Yoshizawa): GS/42

Yoshizawa (Hiroshima University) agreed to produce suitable footnotes for the tabulations in GS/42, and check the data against the latest Wapstra mass tables.

(14) Y-88 (Coursol): GS/46

Various modifications were requested in GS/46 (eg Schötzig's data replace the measurements of Debertin, express emission probabilities as fractions, correct misprints).

(15) Nb-93m (Bambynek)

Only x-ray emission probabilities need to be evaluated for Nb-93m.

(16) Nb-94 (Helmer): GS/28

No problems, apart from the need to generate suitable tables.

(17) Nb-95 (Helmer): GS/29

Experimental measurements and theory do not agree. Schima (NIST) will study the Antoneva et al paper, 1974, and discuss the difficulties with Helmer. Suitable tabulations need to be generated when this problem has been addressed.

(18) Cd-109 (Coursol): GS/47

Coursol (LMRI) agreed to re-evaluate the decay data for Cd-109, with all measurements included. Chechev (KRI) will send all available Soviet data and experimental details to Coursol (LMRI) and Bambynek (CBNM).

(19) In-111 (Yoshizawa): GS/42

No problems, other than development of suitable footnotes.

(20) Sn-113 (Helmer)

The x- and gamma-ray emission probabilities for Sn-113 will be evaluated by Bambynek (CBNM) and Helmer (INEL) respectively.

(21) Sb-125 (Coursol): GS/48

No problems.

(22) I-125 (Coursol): GS/15

PTB measurements require assessment by Debertin, and these data will be communicated to Coursol (LMRI). It was also noted that a BIPM intercomparison had taken place and that new data might be available in time for the CRP evaluation.

(23) Cs-134 (Yoshizawa): GS/42

The data require re-evaluation with all measurements included, and the gamma-ray emission probabilities should be evaluated as relative values. In combining data, mean values should be obtained for P_γ^{rel}, and the appropriate normalisation factor evaluated (ie. Tables 4.1 and 4.4 could then be combined) to derive absolute emission probabilities.

(24) Cs-137 (Coursol): GS/34

No problems.

(25) Ba-133 (Barta/Jedlovszky): GS/24

Barta (OMH) agreed to re-evaluate the decay data for Ba-133, including all available experimental measurements.

(26) Ce-139 (Coursol): GS/49

The single gamma-ray emission probability has been derived from the evaluated internal conversion coefficients. This fact needs to be noted in the text of the IAEA Technical Reports Series document.

(27) Eu-152 (Helmer): GS/43

A total of 35 data sets have been evaluated including the measurements undertaken as an ICRM intercomparison exercise. All values have been re-assessed and extensive tabulations produced; these tables require simplification, and the participants agreed that χ^2 and weighting factors should be removed from the final format. It was also agreed that the final recommended x-ray emission probabilities should not include the low values for the EC-branch to Gd-152.

(28) Eu-154 (Yoshizawa): GS/42

Both Helmer (INEL) and Schima (NIST) have produced new measurements for Eu-154; thus, a re-evaluation is required by Yoshizawa (Hiroshima University). X-ray emission probabilities also require evaluation by Bambynek (CBNM).

(29) Au-198 (Nichols): GS/27

No problems, apart from adjustments in the format of the tables.

(30) Hg-203 (Helmer): GS/30

No problems.

(31) Bi-207 (Yoshizawa): GS/42

Measurements were urgently requested to be undertaken by INEL, NIST and PTB in support of Yoshizawa's rejection of publications prior to 1970. The final evaluation of emission probabilities for Bi-207 will be delayed until these experimental studies have been undertaken and reported.

(32) Th-228 and daughters (Coursol): GS/34

No problems; both Th-228 and daughter gamma-ray emissions were selected for listing as recommended data.

(33) Am-241 (Bambynek)

Bambynek (CBNM) agreed to re-evaluate the gamma-ray emission probabilities for Am-241 on the basis of the accepted CRP procedure.

(34) Am-243/Np-239 (Nichols)

Data require evaluation.

3 HIGH-ENERGY GAMMA RAYS

A summary paper had been drafted by Helmer (GS/40), and all written comments were returned to the author. Helmer (INEL) agreed to redraft this document for inclusion as a section in the IAEA Technical Reports Series of the CRP.

4 CRP FOLLOW-UP ACTIVITIES

The IAEA-CRP on the Measurement and Evaluation of X- and Gamma-ray Standards for Detector Efficiency Calibration will conclude the current work programme with the preparation of the specified data library and the publication of a comprehensive report within the IAEA Technical Reports Series (3). Discussions ensued on the most appropriate methods of achieving publicity for this standards file, and maintaining a high-quality data base.

It was agreed that strong efforts should be made to generate a simple format in which to present the recommended data for detector efficiency calibration. The IAEA Technical Reports Series booklet was only viewed as an appropriate source document from which to prepare a more basic set of data for issue to a wider set of potential users (eg. manufacturers and suppliers of sources and environmental-monitoring laboratories). The recommended data should also be provided on floppy disc for use with suitable spectral analysis packages. It was also agreed

that the coordinator of the Non-neutron Nuclear Data Working Group of the ICRM (Nichols (WTC)) should review recently published data on an annual basis and report his findings to the ICRM (eg. via the ICRM newsletter) and to the IAEA Nuclear Data Section. An annual status report could be issued in this form on the progress made to improve x- and gamma-ray data for detector efficiency calibration; furthermore, the situation should be reviewed more formally at an IAEA-sponsored meeting of CRP members approximately 4 years after the CRP had prepared and published the final report. The following recommendations were agreed by the CRP participants on the basis of the wide-ranging discussions:

(1) The CRP urged that the recommended x- and gamma-ray data for detector efficiency calibrations be produced in an abbreviated and intelligible format for issue to manufacturers and suppliers of standard sources and other relevant organisations, as well as to other data compilers and evaluators.

(2) The CRP recommends annual monitoring of relevant data and data needs by the coordinator of the ICRM Non-neutron Nuclear Data Working Group. A brief report should be issued to the ICRM (for inclusion in the ICRM newsletter) and IAEA-NDS every 12 months by the coordinator.

(3) An IAEA-sponsored meeting should be held approximately 4 years after the CRP has completed its current work, so that progress can be assessed on a multinational basis and the resulting data re-evaluated. This would permit changes to be made in the standards data file at a controlled and specified time.

5 SOVIET DECAY DATA STUDIES

Chechev (KRI) described relevant studies undertaken in the USSR to measure and evaluate the decay data for specific radionuclides.

5.1 Measurements

Work has been undertaken at KRI in conjunction with UVVVR, Czechoslovakia, to measure specific x- and gamma-ray emission probabilities of:

Fe-55, Se-75, Cd-109, Sn-119m, Te-125m,
Ba-133, Sm-145 and Tm-170.

These studies have involved a wide range of measuring systems, including $4\pi\beta$-γ(X), $4\pi\beta$, calorimetry, Ge(Li) and Si(Li) equipment at KRI, and $4\pi\gamma$(NaI), $4\pi\beta$-γ(X), Ge, Ge(Li) and Si(Li) detectors at UVVVR.

5.2 Evaluations

Soviet evaluators have followed the guidelines of their own recommended procedures (similar to the philosophy adopted by the IAEA-CRP on Transactinium Nuclide Decay Data). Thus, σ_{min} should not be less than the minimum measured value, and

$$\frac{\Delta T_{1/2}}{T_{1/2}} \geq 0.05\% \text{ for } T_{1/2} > 100 \text{ years}$$

and $$\frac{\Delta P_{x,\gamma}}{P_{x,\gamma}} \geq 0.5\%$$

Decay data have been evaluated for:

Na-22, Ti-44, Mn-54, Fe-55, Co-56, Co-57, Co-60, Zn-65, Se-75, Y-88, Cd-109, Ag-110m, Sn-113, Ba-133, Cs-137, Ce-139, Eu-152, Ta-182, Ir-192, Hg-203, Bi-207 and Am-241.

6 FINAL CRP REPORT

The participants agreed that the format adopted for the IAEA Technical Report Series No 261 (Decay Data of the Transactinium Nuclides) showed be used as a basis of discussion (3). This document consists of three sections:

(a) Part 1, Assessment and Status of Requirements,

(b) Part 2, Data Measured and Evaluated by the CRP,

(c) Part 3, Data Recommended by the CRP (Computer Listing).

A draft paper was distributed by Nichols (WTC) that will be presented to the ICRM Symposium at Braunschweig. All participants commented in detail on the precise wording in this summary report of the IAEA-CRP. It was also viewed as appropriate to use a modified version of this paper as Part 1 of the IAEA Technical Reports Series. This section could also be expanded to include more detailed descriptions of the evaluation of the x-ray emission probabilities and high-energy gamma-rays obtained via nuclear reactions (see Section 3).

The tabulations in Part 2 will be ordered by nuclide and will include:

I
- (a) half-life, recommended value,
- (b) evaluator (and origin),
- (c) CRP measurements (if any),
- (d) list of data evaluated plus abbreviated references.

II
- (a) emission probabilities of selected x- and gamma-rays as fractions (not percentages),
- (b) evaluator (and origin),
- (c) recommended values,
- (d) CRP measurements (if any),
- (e) comparison list of data evaluated,
- (f) internal conversion coefficients (if used),
- (g) x-ray data assessed.

III List of all recommended data in abbreviated format with references (see IAEA Technical Report Series No 261).

The above format was discussed in considerable detail and many specific questions were raised; however, it was agreed to use this approach, and adopt the method of using tables and footnotes to detail and explain the evaluation procedures. Precise (and real) difficulties will only be experienced when attempts are made by the evaluators to initiate this format.

Part 3 will be produced by Lemmel (IAEA) with a modified introductory section.

The following deadlines were agreed for the production of the report:

(a) outstanding CRP measurements to evaluators and Lemmel by 1 September 1989,
(b) CRP evaluations to Lemmel by 6 October 1989,
(c) draft report to be circulated to participants by 20 December 1989,
(d) comments on draft report to Lemmel by 2 February 1990,
(e) final agreed manuscript to IAEA editors by 30 March 1990.

7 CONCLUSIONS

The final meeting of the IAEA-CRP on the Measurement and Evaluation of X- and Gamma-ray Standards for Detector Efficiency Calibration was held at PTB, Braunschweig from 31 May to 2 June 1989. Efforts continue to produce an acceptable set of recommended decay data, and a significant number of measurements and evaluations have been undertaken to achieve the defined goal. This work is now approaching a critical stage when all participants need to dedicate considerable efforts to finish their studies and complete a significant number of the desired evaluations. All results will be forwarded to Lemmel (IAEA-NDS) as they become available for incorporation into the final report and the standards data file. Hopefully, these efforts will come to a successful conclusion by 6 October 1989.

Parts 1 and 2 of the CRP report will be prepared and edited by the participants to produce a suitable draft version of the IAEA Technical Reports Series. The various parts of the document will be collated by Lemmel and issued for comment when appropriate. It is intended to publish the final report in 1990.

REFERENCES

1. A. Lorenz, Gamma-ray Standards for Detector Calibration, Summary Report of a Consultants' Meeting Held at the Centre d'Etudes Nucléaires de Grenoble, France, 30-31 May 1985, INDC(NDS)-171/GE, 1985.
2. P. Christmas, A. L. Nichols and A. Lorenz, Gamma-ray Standards for Detector Calibration, Summary Report of a Research Coordination Meeting Held in Rome, Italy, 11-13 June 1987, INDC(NDS)-196/GE, 1987.
3. IAEA Technical Reports Series No 261, Decay Data of the Transactinium Nuclides, IAEA Vienna, 1986.

Note: Data are preliminary and subject to revision

Table 1

Half-lives of Radionuclides Used for Detector Calibration

Nuclide	Decay Mode	Half-life (days) Value	Uncertainty	Exponent	Reference
11-Na-022	EC	950.8	± 0.9		CH8701
11-Na-024	β^-	0.62356	± 0.00017		CH8701
21-Sc-046	β^-	83.79	± 0.04		CH8701
24-Cr-051	EC	27.706	± 0.007		CH8701
25-Mn-054	EC	312.3	± 0.4		CH8701
26-Fe-055	EC	999	± 8		CH8701
27-Co-056	EC	77.35	± 0.23		CH8701
27-Co-057	EC	271.79	± 0.09		CH8701
27-Co-058	EC	70.86	± 0.07		CH8701
27-Co-060	β^-	1925.5	± 0.5		CH8701
30-Zn-065	EC	244.26	± 0.26		CH8701
34-Se-075	EC	119.64	± 0.24		CH8701
38-Sr-085	EC	64.849	± 0.004		CH8701
39-Y -088	EC	106.630	± 0.025		CH8701
41-Nb-093m	IT	5.89	± 0.05	E+03	CH8701
41-Nb-094	β^-	7.3	± 0.9	E+06	CH8701
41-Nb-095	β^-	34.975	± 0.007		CH8701
48-Cd-109	EC	462.6	± 0.7		CH8701
49-In-111	EC	2.8047	± 0.0005		CH8701
50-Sn-113	EC	115.09	± 0.04		CH8701
51-Sb-125	β^-	1007.7	± 0.6		CH8701
53-I -125	EC	59.402	± 0.014		CH8701
55-Cs-134	β^-	754.28	± 0.22		CH8701
55-Cs-137	β^-	1.105	± 0.004	E+04	CH8701
56-Ba-133	EC	3862	± 15		CH8701
58-Ce-139	EC	137.640	± 0.023		CH8701
63-Eu-152	EC	4933	± 11		CH8701
63-Eu-154	β^-	3136.8	± 2.9		CH8701
63-Eu-155	β^-	1.77	± 0.05	E+03	CH8701
79-Au-198	β^-	2.6943	± 0.0008		CH8701
80-Hg-203	β^-	46.595	± 0.013		CH8701
83-Bi-207	EC	1.16	± 0.07	E+04	CH8701
90-Th-228	α	698.7	± 0.7		IAEA86
93-Np-239	β^-	2.355	± 0.004		IAEA86
95-Am-241	α	1.580	± 0.002	E+05	IAEA86
95-Am-243	α	2.690	± 0.008	E+06	CH8701

References

CH8701 (GS/037) Christmas, P., Debertin, K., Woods, M.J.
Half-life Data for Calibration Nuclides:
Formulation and Application of Evaluated Criteria
Private Communication (1987). Report RS 11/2/07

IAEA86 Lorenz, A. (Ed)
Decay Data of the Transactinium Nuclides
IAEA Technical Report No. 261 (1986)

Note: Data are preliminary and subject to revision

Table 2

X-Ray Standards: Energies and Emission Probabilities

Nuclide	Trans	Energy (keV)	Probability	Reference
24-Cr-051	VKa	4.95	0.201(6)	BA8401
24-Cr-051	VKb	5.43	0.027(1)	BA8401
25-Mn-054	CrKa	5.41	0.226(4)	BA8401
25-Mn-054	CrKb	5.95	0.030(1)	BA8401
26-Fe-055	to be evaluated			
27-Co-057	FeKa	6.40	0.510(2)	BA8401
27-Co-057	FeKb	7.06	0.069(3)	BA8401
27-Co-058	FeKa	6.40	0.235(4)	BA8401
27-Co-058	FeKb	7.06	0.032(1)	BA8401
30-Zn-065	CuKa	8.04	0.341(6)	BA8401
30-Zn-065	CuKb	8.91	0.046(1)	BA8401
34-Se-075	AsKa	10.53	0.489(30)	BA8401
34-Se-075	AsKb	11.72	0.076(6)	BA8401
38-Sr-085	RbKa	13.38	0.500(8)	BA8401
38-Sr-085	RbKb	14.98	0.087(8)	BA8401
39-Y -088	SrKa	14.14	0.513(8)	BA8401
39-Y -088	SrKb	15.86	0.092(2)	BA8401
41-Nb-093m	to be evaluated			
48-Cd-109	AgKa	22.10	0.821(18)	BA8401
48-Cd-109	AgKb	25.01	0.173(7)	BA8401
49-In-111	CdKa	23.11	0.684(20)	BA8401
49-In-111	CdKb	26.18	0.145(6)	BA8401
50-Sn-113	to be evaluated			
53-I -125	TeKa	27.38	0.134(30)	BA8401
53-I -125	TeKb	31.12	0.250(8)	BA8401
55-Cs-137	BaKa	32.06	0.0566(18)	BA8401
55-Cs-137	BaKb	36.8	0.0134(4)	BA8401
56-Ba-133	CsKa	30.85	0.980(16)	BA8401
56-Ba-133	CsKb	35.4	0.23(5)	BA8401
58-Ce-139	LaKa	33.30	0.639(17)	BA8401
58-Ce-139	LaKb	37.98	0.153(5)	BA8401
63-Eu-152	SmKa	39.91	0.591(12)	BA8401
63-Eu-152	GdKa	42.75	0.00648(22)	BA8401
63-Eu-152	SmKb	45.9	0.149(3)	BA8401
63-Eu-152	GdKb	49.3	0.00176(18)	BA8401
63-Eu-154	to be evaluated			
79-Au-198	to be evaluated			

Note: Data are preliminary and subject to revision

Table 2 (Continued)

X-Ray Standards: Energies and Emission Probabilities

Nuclide	Trans	Energy (keV)	Probability	Reference
80-Hg-203	T1Ka2	70.83	0.038(20	BA8401
80-Hg-203	T1Ka1	72.87	0.064(2)	BA8401
80-Hg-203	T1Kb1	82.5	0.022(1)	BA8401
80-Hg-203	T1Kb2	84.9	0.0063(3)	BA8401
83-Bi-207	PbL1	9.18	0.0051(6)	BA8401
83-Bi-207	PbLa	10.45	0.0958(15)	BA8401
83-Bi-207	PbLb	12.5	0.196(22)	BA8401
83-Bi-207	PbLg	13.7	0.045(6)	BA8401
83-Bi-207	PbKa2	72.80	0.226(12)	BA8401
83-Bi-207	PbKa1	74.97	0.382(20)	BA8401
83-Bi-207	PbKb1	84.9	0.130(10)	BA8401
83-Bi-207	PbKb2	87.3	0.039(3)	BA8401
95-Am-241	NpL1	11.9	0.86(3)	BA8401
95-Am-241	NpLa	13.9	0.133(4)	BA8401
95-Am-241	NpLb	17.8	0.194(6)	BA8401
95-Am-241	NpLg	20.8	0.049(2)	BA8401

Reference

BA8401 (GS/016) Bambynek, W.
Emission Probabilities of Selected X-Rays for Radionuclides Used as Detector Calibration Standards
Internal CBNM Report GE/R/RN/18/84 (November 1984)

Table 3

Gamma Ray Standards: Energies and Emission Probabilities

Nuclide	Energy (keV)	Emission Probability
11-Na-022	1274.542(7)	0.99937(14)
11-Na-024	1368.633(6)	0.999936(15)
11-Na-024	2754.030(14)	0.99855(5)
21-Sc-046	889.277(3)	0.999836(16)
21-Sc-046	1120.545(4)	0.999871(12)
24-Cr-051	320.084(1)	0.0986(7)
25-Mn-054	834.843(6)	0.999746(25)

Note: Data are preliminary and subject to revision

Table 3 (Continued)

Gamma Ray Standards: Energies and Emission Probabilities

Nuclide	Energy (keV)	Emission Probability
27-Co-056	846.764(6)	0.99933(7)
27-Co-056	1037.844(4)	0.1413(5)
27-Co-056	1175.099(8)	0.02239(11)
27-Co-056	1238.287(6)	0.6607(19)
27-Co-056	1360.206(6)	0.04256(15)
27-Co-056	1771.350(15)	0.1549(5)
27-Co-056	2015.179(11)	0.03029(13)
27-Co-056	2034.759(11)	0.07771(27)
27-Co-056	2598.460(10)	0.1696(6)
27-Co-056	3201.954(14)	0.0313(9)
27-Co-056	3253.417(14)	0.0762(24)
27-Co-056	3272.998(14)	0.0178(6)
27-Co-056	3451.154(13)	0.0093(4)
27-Co-056	3548.18(12)	0.00178(9)
27-Co-057	14.4119(4)	0.0960(8)
27-Co-057	122.0612(15)	0.8560(17)
27-Co-047	136.4730(15)	0.1068(8)
27-Co-058	810-775(9)	0.9945(1)
27-Co-060	1173.238(4)	0.99857(22)
27-Co-060	1332.502(5)	0.99983(6)
30-Zn-065	1115.546(4)	0.5071(33)
34-Se-075	96.7344(10)	0.0342(6)
34-Se-075	121.1171(14)	0.171(3)
34-Se-075	136.0008(6)	0.582(8)
34-Se-075	264.6580(17)	0.585(5)
34-Se-075	279.5431(22)	0.2484(23)
34-Se-075	400.6593(13)	0.1140(25)
38-Sr-085	514.009(12)	0.1140(25)
39-Y -088	898.042(4)	0.941(5)
39-Y -088	1836.063(13)	0.9936(5)
41-Nb-094	702.645(6)	0.9979(5)
41-Nb-094	871.119(4)	0.9986(5)
41-Nb-095	765.807(6)	0.9981(3)
48-Cd-109	88.0341(11)	0.0365(6)
49-In-111	171.28(3)	0.9078(10)
49-In-111	245.35(4)	0.9416(6)

Note: Data are preliminary and subject to revision

Table 3 (Continued)

Gamma Ray Standards: Energies and Emission Probabilities

Nuclide	Energy (keV)	Emission Probability
50-Sn-113	391 to be evaluated	
51-Sb-125	176.334(11)	0.069(1)
51-Sb-125	380.435(20)	0.0151(2)
51-Sb-125	427.889(15)	0.294(3)
51-Sb-125	463.383(15)	0.1042(10)
51-Sb-125	600.557(18)	0.178(2)
51-Sb-125	606.641(19)	0.0500(7)
51-Sb-125	635.895(20)	0.113(10)
53-I -125	35.4919(5)	0.0667(5)
55-Cs-134	563.23(2)	0.0836(3)
55-Cs-134	569.32(2)	0.1539(6)
55-Cs-134	604.69(2)	0.9763(6)
55-Cs-134	795.84(1)	0.854(3)
55-Cs-134	801.93(2)	0.0869(3)
55-Cs-134	1167.92(2)	0.01792(7)
55-Cs-134	1365.16(2)	0.03016(11)
55-Cs-137	661.660(3)	0.851(2)
56-Ba-133	79.623(10)	0.0263(8)
56-Ba-133	80.998(5)	0.3411(28)
56-Ba-133	276.398(1)	0.07147(30)
56-Ba-133	302.853(1)	0.1830(6)
56-Ba-133	356.017(2)	0.6194(14)
56-Ba-133	383.851(3)	0.08905(29)
58-Ce-139	165.857(6)	0.7999(10)
63-Eu-152	121.7824(4)	0.2837(13)
63-Eu-152	244.6989(10)	0.0753(4)
63-Eu-152	344.2811(19)	0.2657(11)
63-Eu-152	411.126(3)	0.02238(10)
63-Eu-152	443.965(4)	0.03125(14)
63-Eu-152	586.273(9)	0.0460(6)
63-Eu-152	778.903(6)	0.1297(6)
63-Eu-152	867.390(6)	0.04214(25)
63-Eu-152	964.055(4)	0.1463(6)
63-Eu-152	1085.842(4)	0.1013(5)
63-Eu-152	1089.767(14)	0.01731(9)
63-Eu-152	1112.087(6)	0.1354(6)
63-Eu-152	1212.9700(13)	0.01412(8)
63-Eu-152	1299.152(9)	0.01626(11)
63-Eu-152	1408.022(4)	0.2085(9)

Note: Data are preliminary and subject to revision

Table 3 (Continued)

Gamma Ray Standards: Energies and Emission Probabilities

Nuclide		Energy (keV)	Emission Probability
63-Eu-154		123.071(11)	0.407(7)
64-Eu-154		247.930(1)	0.0698(10)
63-Eu-154		591.762(5)	0.0495(6)
63-Eu-154		723.305(5)	0.201(2)
63-Eu-154		756	0.0455
63-Eu-154		873.190(5)	0.122(2)
63-Eu-154		996.262(6)	0.1050(13)
63-Eu-154		1004.725(7)	0.182(2)
63-Eu-154		1274.436(6)	0.350(4)
63-Eu-154		1493.6	0.00717(10)
63-Eu-154		1596.5	0.01816(22)
79-Au-198		411.8044(11)	0.9557(47)
80-Hg-203		279.1967(12)	0.8148(8)
83-Bi-207		569.702(2)	0.9774(3)
83-Bi-207		1063.662(4)	0.741(2)
83-Bi-207		1770.237(10)	0.0687(3)
90-Th-228		84.373(3)	0.0122(3)
90-Th-228	*	238.63	0.435(4)
90-Th-228	*	241.0(1)	0.0405(4)
90-Th-228	*	277.35(6)	0.0640(6)
90-Th-228	*	300.09	0.0325(4)
90-Th-228	*	510.80(8)‡	0.228(3)
90-Th-228	*	583.191(2)	0.851(6)
90-Th-228	*	727.330(9)	0.0664(9)
90-Th-228	*	860.37(8)	0.1252(12)
90-Th-228	*	1620.735(10)	0.0149(6)
90-Th-228	*	2614.6	0.3588(6)
93-Np-239		106	0.272(4)
93-Np-239		228	0.1127(18)
93-Np-239		227	0.1438(21)
95-Am-241		26.34	0.024(1)
95-Am-241		59.537(1)	0.359(4)
95-Am-243		43.53(15)	0.0593(13)
95-Am-243		74.67(15)	0.682(14)

* Indicates daughter in equilibrium with parent radionuclide
‡ Need to add footnote involving annihilation radiation (e^+e^-)

APPENDIX A

IAEA Research Coordination Meeting on

GAMMA-RAY STANDARDS FOR DETECTOR EFFICIENCY CALIBRATION

31 May - 2 June, 1989
Physikalisch-Technische Bundesanstalt (PTB)
Braunschweig, FRG

List of Participants

Dr. W. Bambynek	CEC-JRC Bureau Central de Mesures Nucléaires Steenweg naar Retie B-2440 Geel, Belgium Tel (014) 571 211 Telex 33 589 EURAT B Fax (014) 584 273
Dr. T. Barta	National Office of Measures (OMH) 126 - PF. 19 H-1531 Budapest, Hungary Telex 224856 omh h Tel 567-722 Ext 152 and 261
Dr. P. Christmas	Division of Radiological Science and Acoustics National Physical Laboratory Teddington, Middlesex TW011 OLW United Kingdom Telex 262344 Fax 01-943-2155 Tel 01-977-3222
Dr. N. Coursol	LMRI Centre d'Etudes Nucléaires de Saclay B.P. No. 2 F-91190 Gif-sur-Yvette, France Tel 33(1) 6908 5288 Fax 6908 2619 Telex ENERG 604641F MRI+
Dr. K. Debertin	Physikalisch Technische Bundesanstalt Abteilung 6 Bundesallee 100 D-3300 Braunschweig, FRG Tel (0531) 592-6300 Fax (0531) 592-4006 Telex 952 822 ptb d

Dr. R. G. Helmer	Idaho National Engineering Lab. EG&G Idaho Inc. P.O. Box 1625 Idaho Falls, Idaho 83415 USA Fax 208/526-2814
Dr. A. L. Nichols (Chairman)	Chemistry Division Building A50 Winfrith Technology Centre Dorchester Dorset DT2 8DH United Kingdom Tel (305) 251888 Ext 3194 Fax 305 251140
Dr. F. J. Schima	National Institute for Standards and Technology (NIST) Gaithersburg, Maryland 20899 USA
Dr. Y. Yoshizawa	Faculty of Science Hiroshima University 1-1-89 Higashi-Senda-Cho Hiroshima-Shi 730 Japan Telefax 82-244-4528
Dr. H. D. Lemmel (Scientific Secretary)	IAEA, Nuclear Data Section P.O. Box 100 A-1400 Vienna, Austria Tel Vienna 0043-222-2360-1717

Observers

Dr. K. Chechev	Khlopin Radium Institute, Rentgen 1, 197022 - Leningrad USSR Tel 244-09-03 247-57-37
Dr. H. Miyahara	Nagoya University Department of Nuclear Energy Furo-Cho, Chikusa-Ku 464-01 Nagoya, Japan
Dr D Santry	National Research Council Division Physics M-35 Ottawa Canada K1A OR6

APPENDIX B

Research Coordination Meeting

Gamma-Ray Standards for Detector Efficiency Calibrations

31 May - 2 June 1989, (09.00 - 17.30), PTB Braunschweig, FRG

Agenda

1. Introductory Items
2. Progress Reports from CRP Participants
   - Discussion of the status of individual recommended data sets
   - Assignments of final work and deadlines
3. Follow-up activities
   - publicity
   - general international knowledge and acceptance of CRP data?
4. Soviet decay data studies
5. Formulation and drafting of final report

APPENDIX C

ACTIONS

Bambynek (CBNM)

1. Convert tables to CRP format, in particular convert percent values to fractions, and give footnotes justifying the values used in calculations.

2. Check whether input numbers agree with CRP values, and update the input numbers when new CRP values appear (keep contact with Lemmel about new CRP values).

3. Evaluate P_x and ICC for Nb-93m, and submit Coursey data to Lemmel for issue as GS paper.

4. Possibly include Soviet data for which Chechev is asked to send references.

5. Omit weak x-rays from table of recommended data (eg. in case of ^{152}Eu) but keep all in a sub-table.

6. Where applicable, eg. Eu-154, add in a footnote that x-rays are so weak that they can be ignored.

7. Evaluate x-rays for ^{198}Au.

8. Re-evaluate P_γ and P_x for Am-241.

Barta (OMH)

1. Send Cr-51 paper to Nichols, and to Lemmel for GS distribution.

2. Re-evaluate Co-57 (GS/24) after receipt of new experimental data from Coursol and Debertin - thereafter it must be decided whether this nuclide is usable for calibration purposes or not.

3. On the basis of his conference paper and the ICRM intercomparison, finalise ^{75}Se P_γ. This was previously done by Nichols (GS/13), and new experimental values from Jedlovszky's paper must be included.

4. Re-evaluate P_γ of ^{133}Ba (GS/24), including <u>all</u> experimental data; experimental data can be rejected only if some deficiency has been identified.

Chechev (KRI)

1. Send references for experimental data on ^{109}Cd P_γ and P_x (even in Russian) to Mme Coursol and Bambynek.

2. Send all experimental x-ray data (plus references) to Bambynek.

Christmas (NPL)

1. Contact Alberger at Brookhaven on half-life of Co-56.

2. Report on status of NPL half-life measurements.

3. Report new NPL results on ^{65}Zn P_γ and send it to Nichols for updating his evaluation, and to Lemmel for GS distribution.

Coursol (LMRI)

1. Send her report on Co-57 P_γ measurement to Barta for updating his evaluation, and to Lemmel for GS distribution.

2. In GS/46 on ^{88}Y Schötzig's value replaces Debertin's value despite the increased uncertainty; convert % to fraction; remove misprints in energies.

3. In GS/47 on ^{109}Cd expand Table 2 to include all experimental data; possibly to include Soviet data for which Chechev is asked to send references.

4. Update her evaluation of P_γ for I-125 in GS/15 with the new PTB value to be provided by Debertin.

5. Include in Th-228 decay data evaluation the daughter-product decay data, including footnote on half-lives of daughters.

Debertin (PTB)

1. Re-evaluate half-lives of Th-228, Np-239 and Am-241.

2. Reasoning required for inclusion of Eu-155 (only half-life included).

3. Finalise the PTB experiment for ^{57}Co P_γ and send the report to Barta for updating his evaluation, also to Lemmel for GS distribution.

4. Submit a report on the new PTB value for ^{65}Zn P_γ to Nichols for updating his evaluation, and to Lemmel for GS distribution (presented at ICRM symposium).

5. Reassess the PTB measurements of P_γ for I-125 and send the report to Coursol for updating of her evaluation GS/15, and to Lemmel for GS distribution.

6. Write up the PTB data (February 1988) on P_γ for Bi-207 and send it to Yoshizawa for updating the evaluation, and to Lemmel for GS distribution.

Helmer (INEL)

1. Send paper on Sb-125 and Eu-154 to Lemmel for GS distribution.

2. Contact Schima about ^{95}Nb and discuss higher energy β spectrum.

3. Evaluate P_γ for Sn-113.

4. Extract from GS/43 (Eu-152) a shorter version to be included in the CRP book; this will involve a multi-page table with many footnotes.

5. Provide Yoshizawa with new INEL data on Eu-154 (action fulfilled at the meeting).

6. Provide Yoshizawa with new INEL data on Bi-207 for updating the evaluation.

7. Re-write a draft section on "High Energy Lines from Reactions".

8. Check all E_γ values after evaluations completed ie. during draft stage of CRP report.

Nichols (WTC)

1. Re-evaluate P_γ for ^{51}Cr with CRP-OMH data included.

2. ^{65}Zn GS/27: omit Table 1 (energies) and incorporate the new values from PTB and NPL (compare actions on Debertin, Christmas).

3. Re-evaluate P_γ for ^{75}Se including ICRM-OMH data comparison.

4. Update GS/27 P_γ data on ^{198}Au.

5. Evaluate P_γ for ^{243}Am and ^{239}Np.

Schima (NIST)

1. Send a summary paper on NIST half-lives to Lemmel for distribution as GS document (except for Co-56 which will only be ready by September).

2. In paper GS/44 on ^{60}Co add more footnotes to show how the recommended values were obtained. The evaluation of energies should be omitted.

3. Contact Helmer about ^{95}Nb.

4. Provide Yoshizawa with the new NIST data on Eu-154.

5. Check whether there are new NIST data on Bi-207 and send data to Yoshizawa for updating his evaluation.

Yoshizawa (Hiroshima University)

1. The "private communication" for Eu-154 in the evaluation report to be changed to NBS Special Publication 626.

2. Send evaluation on Sc-46 and Mn-54 P_γ to Lemmel for GS distribution.

3. Add footnotes to the tables of GS/42 so that the tables are selfexplanatory and the current text can be omitted.

4. Improve table formats in GS/42 for ^{85}Sr etc.

5. For Eu-154 (GS/42, pages 29 and 30) add data from INEL (handed over by Helmer at the meeting) and from NIST (to be supplied by Schima); then update decay scheme although not all gammas will be included in this list of recommended values.

6. For Bi-207 (GS/42, page 38) add data from PTB, INEL, perhaps also NIST, as soon as these have been received; this should solve the problem that no single experiment should carry more than 50% of the weight; re-evaluate.

Lemmel (IAEA)

1. Distribute GS papers when received.

2. Inform Bambynek when a paper contains data relevant to x-rays evaluation.

3. Prepare the recommended values in suitable form on a floppy diskette.

4. Prepare draft IAEA Technical Reports Series document for issue to CRP participants by 20 December 1989.

5. Draft an address list for advertising the CRP standards and circulate this initial list to the group for further additions (include, among others, manufacturers and suppliers of standards).

Appendix D

List of GS- Papers

No.	Author(s)	Date	Title
GS/1	R.G. Helmer		Preliminary Evaluation of P_γ Values from the Decay of ^{152}Eu
GS/2	A.L. Nichols	Dec 85	Cr-51 - Gamma-Ray Emission Probabilities
GS/3	T. Barta		Report on gamma photon emission probabilities ($P_{\gamma i}$) of ^{57}Co, ^{58}Co and ^{133}Ba based on data from the literature
GS/4	K. Debertin	Jan 86	Evaluation of half lives
GS/5	R. Vaninbroukx		^{241}Am
GS/6	R. Vaninbroukx		^{243}Am
GS/7	M.J. Woods	Mar 86	Evaluation of half-lives
GS/8	M.J. Woods and S.E.M. Lucas		The Half-Lives of ^{152}Eu and ^{154}Eu
GS/9	A. Robert	Aug 77	Standard 6.13 MeV gamma-ray Source
GS/10	R. Jedlovszky	Dec 86	Progress Report April 1, 1986 to December 10, 1986
GS/11	C. van der Leun	Feb 86	Investigation of Light Nuclei by Particle Capture and Resonant Absorption
GS/12	R. Jedlovszky	May 86	Plan of ^{75}Se Action
GS/13	A.L. Nichols	Mar 87	X-and Gamma-ray Standards for Detector Calibration: Evaluation of Specific Decay Data
GS/14	P. Christmas	Mar 87	Half-Life Data for Calibration Nuclides: Formulation and Application of Evaluation Criteria
GS/15	N. Coursol	Apr 87	Progress Report: Evaluation of $E\gamma/P\gamma$ of Y88, I125, Sb125 and Cs137
GS/16	W. Bambynek	Nov 84	Emission Probabilities of Selected X Rays for Radionuclides used as Detector Calibration Standards
GS/17	Y. Yoshizawa		Evaluation of Gamma-ray Emission Probabilities for Co56, Sr85, In111, Cs124 and Eu154
GS/18	W. Bambynek	Jun 87	Progress Report
GS/19	R. Jedlovsky	May 87	Progress Report II
GS/20	B. Denecke	May 87	Measurement of the 59.5 keV Gamma-ray Emission Probability in the Decay of Am241 with a 4 π-CsI(Tl)-Sandwich Spectrometer

No.	Author(s)	Date	Title
GS/21	R. Jedlovsky	May 87	Report for the CRP Meeting
GS/22	N. Coursol	Jun 87	IAEA CRP on Gamma-ray Standards for Detector Efficiency Calibration
GS/23	F.J. Schima	Jul 87	IAEA CRP on Gamma-Ray Standards for Detector Efficiency Calibration - Progress Report from the NBS for the June 11-13 meeting
GS/24	T. Barta et al		Revised evaluation of the gamma photon emission probabilities (P) of Co57, Co58 and Ba133, based on data of the literature and on experience of the IAEA CRP expert's meeting on 13-15 June 1987, Rome
GS/25	R. Jedlovsky	Nov 87	Progress Report III covering time period 1 April - 30 November 1987
GS/26	W. Bambynek	Jan 88	Tables for Internal Conversion Coefficients
GS/27	A.L. Nichols	Mar 88	X- and Gamma-Ray Standards for Detector Calibration: Re-Evaluation of Specific Decay Data
GS/28	R.G. Helmer		Decay of Nb94
GS/29	R.G. Helmer		Decay of Nb95
GS/30	R.G. Helmer		Hg203
GS/31	W. Bambynek	Mar 88	Gamma-Ray Standards for Detector Efficiency Calibration Progress Report 1987
GS/32	R. Jedlovszky	87	Measurement of Gamma Proton Emission Probabilities of Se75
GS/33	R. Jedlovszky	88	Measurement of 76.6 keV Gamma Photon Emission Probability of Ba133
GS/34	N. Coursol	88	Progress Report - Evaluation of E_γ/P_γ of ^{93m}Nb, ^{228}Th and ^{137}Cs
GS/35	D.D. Hoppes	Jul 88	Nuclear Data for X- or Gamma-Ray Spectrometer Efficiency Calibrations
GS/36	C. Ballaux	86	Measurement of the Gamma-Ray Emission Rate of ^{109}Cd with a Well-type NaI(Tl) Detector
GS/37	P. Christmas	Dec 87	Half-life Data for Calibration Nuclides: Formulation and Application of Evaluation Criteria
GS/38	H. Schrader		The Half-Lives of Co56 and I125
GS/39	J.L. Campbell		State-of-the-Art Efficiency Determination for A Si(Li) X-Ray Detector in the 3-40 keV Energy Range

No.	Author(s)	Date	Title
GS/40	R.G. Helmer		Detector Efficiency Calibrations at High Energies
GS/41	R.G. Helmer	Oct 88	Current Activities in Radionuclide Metrology at INEL
GS/42	Y. Yoshizawa		Evaluation of Gamma-Ray Emission Probabilities for Co56, Sr85, In111, Cs134, Eu154 and Bi207
GS/43	R.G. Helmer		Decay of Eu-152
GS/44	F.J. Schima	May 89	Evaluation of Gamm-Ray Emission Probabilities for Na22, Na24 and Co60
GS/45	W. Bambynek	May 89	Pre-evaluation of emission probabilities of selected x-rays for radionuclides used as detector-calibration standards (GE/R/RN/05/89)
GS/46	N. Coursol	May 89	Y-88 evaluated (draft, may be revised)
GS/47	N. Coursol	May 89	Cd-109 evaluated
GS/48	N. Coursol	May 89	SB-125 evaluated
GS/49	N. Coursol	May 89	Ce-139 evaluated
GS/50	Y. Yoshizawa et al	Apr 85 (distr. July 89)	Evaluation of gamma-ray intensities of 41 calibration standards
GS/51	F.E. Chukreev, V.A. Vukolov	May 89	The intensity of gamma radiation in the decay of barium-133
GS/52	V.P. Chechev	May 89	Soviet works on measurement, evaluation and standardization of decay data of the radionuclides used for x- and gamma-ray detector calibration