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Gamma-Spectroscopic Measurements of the ^{235}U Isotope Abundance in a UF_6 Sample (Performed in the Framework of the REIMEP-86 Interlaboratory Exercise)

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Abstract

This report describes the measurement of the $^{235}U/U$ isotope abundance in a certified UF_6 sample by means of gamma spectrometry. The work was performed in the framework of the REIMEP-86 interlaboratory exercise. The $^{235}U/U$ abundance value obtained from the measurements presented in this report was 3.5005 ± 0.0031 % $^{235}U/U$ which compares very well to the certified value of 3.5001 ± 0.0010 % $^{235}U/U$. The report describes in detail the experimental set-up, the data evaluation and the error analysis. Some hints are given to improve the precision and to reduce the measurement time in future experiments of this type.

Gammaspektroskopische Bestimmung der ^{235}U Isotopenanreicherung in einer UF_6 Probe (durchgeführt im Rahmen des Interlaboratoriumsprogramms REIMEP-86)

Zusammenfassung

Der vorliegende Bericht beschreibt die gammaspektroskopische Bestimmung der $^{235}U/U$ Isotopenanreicherung an einer genau spezifizierten UF_6 Probe. Die Messungen wurden im Rahmen des Interlaboratoriumsprogramms REIMEP-86 durchgeführt. Die in diesem Bericht beschriebene ^{235}U Anreicherungsmessung ergab 3,5005 ± 0,0031 % $^{235}U/U$, was in guter Übereinstimmung zum spezifizierten Wert von 3,5001 ± 0,0010 % $^{235}U/U$ steht. Der Meßaufbau, die Datenauswertung und die Fehleranalyse werden detailliert beschrieben. Es werden ferner einige Hinweise gegeben, wie bei künftigen Messungen dieser Art die Genauigkeit verbessert und die Meßzeit verkürzt werden kann.

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INTRODUCTION

The purpose of the Regular European Interlaboratory Measurement Evalutation Program (REIMEP) is, like other programs of similar type, to demonstrate the interlaboratory spread of measurement results and to allow the participants to compare their results to a certified value and to the results of other laboratories. Extending previous programmes the present REIMEP-86 UF_6 exercise was not restricted to a particular measurement technique but includes for the first time both mass spectrometry and gamma-ray spectrometry as representatives for destructive (DA) and non-destructive (NDA) analysis techniques, respectively. In case of the gamma-spectrometric assay the comparison to the well established and routinely used mass spectrometry provides the chance to demonstrate the potential of this NDA technique and to recognize the limitations for its application.

Highly accurate determinations of the ^{235}U abundance by means of gamma-ray spectrometry are only possible when the measurements are performed relative to carefully characterized reference materials. Such internationally certified Reference Material for NDA ^{235}U - abundance measurements is available since 1985 as EC-NRM-171/NBS SRM-969 from CBNM, Geel, and from NBS, Washington. The measurements of the unknown REIMEP-86 UF_6 sample presented in this paper have been performed relative to this Reference Material.

The REIMEP-86 UF_6 sample was shipped in a well characterized monel can containing about 80 g UF_6 as a solid sample. The areal density of the UF_6 material provided more than 99.9% of the characteritic 185 keV gamma radiation perpendicular to the sample surface as compared to an infinitely thick sample. If a suitable collimator is used, the observed 185 keV gamma radiation originating from the decay of ^{235}U atoms serves as a direct measure for the ^{235}U abundance of the sample material in such a quasi-infinite-thickness geometry. However, corrections have to be applied for the different matrix composition of the reference material and the unknown UF_6 sample, respectively (U_3O_8 versus UF_6), for the different gamma attenuation in the container walls, and for counting losses due to pile-up and dead-time effects in the counting electronics.

In order to evaluate the accuracy limits of the gamma-spectrometric ^{235}U - abundance measurement technique and to identify possible, so far unknown sources of systematic errors, all measurement parameters affecting the assay accuracy have been examined very carefully. The measurements and the data evaluation are described in detail in the present paper.

1. EXPERIMENTAL SET-UP

This chapter describes the sample - collimator - detector geometry and the counting electronics used for the measurements presented in this paper. The former aspect is of particular importance for the applicability of the "enrichment - meter" principle.

1.1. Counting geometry

The "enrichment - meter" principle used for the gamma-spectrometric determination of the ^{235}U abundance in the present paper is based on the assumption that the unknown sample to be assayed is quasi-infinitely thick, i.e., that the surface-radiation intensity of the characteristic 185 keV gamma rays is almost the same as obtained from a really infinite sample of identical sample material (see ref. /1/).

Of course, in case of a limited sample size the quasi-infinite-sample condition can only be defined with respect to a collimator that limits the solid angle through which the sample surface is seen from the detector. In turn, for a given collimator the sample size required for quasi-infinite-thickness geometry depends on the density and the chemical composition of the sample material, and on the distance between sample and collimator. In order to simplify this complex multiparameter relation, the considerations in ref. /1/ have been restricted to cylindrical shapes of sample and collimator, respectively, and to a fixed distance of 3 mm between collimator entrance plane and sample surface (not container surface). Further, the quasi-infinite-sample condition has been defined in terms of a minimum areal density providing 99.9% of the characteristic gamma-ray intensity expected from a really infinite sample in direction perpendicular to the sample surface. The minimum areal density for UF_6 is given by (see eq. 3.3c in ref /1/ and Appendix F in this paper) :

$$\rho^{area}_{min}(UF_6) = \frac{6.908}{\mu(UF_6)} = 6.68\, g\, cm^{-2} \tag{1.1}$$

where μ denotes the mass attenuation coefficient. The value of 8.2 g cm^{-2} specified for the areal density of the REIMEP-86 UF_6 sample is clearly above the required minimum value. The problem remains to find a suitable collimator for quasi-infinite-sample geometry.

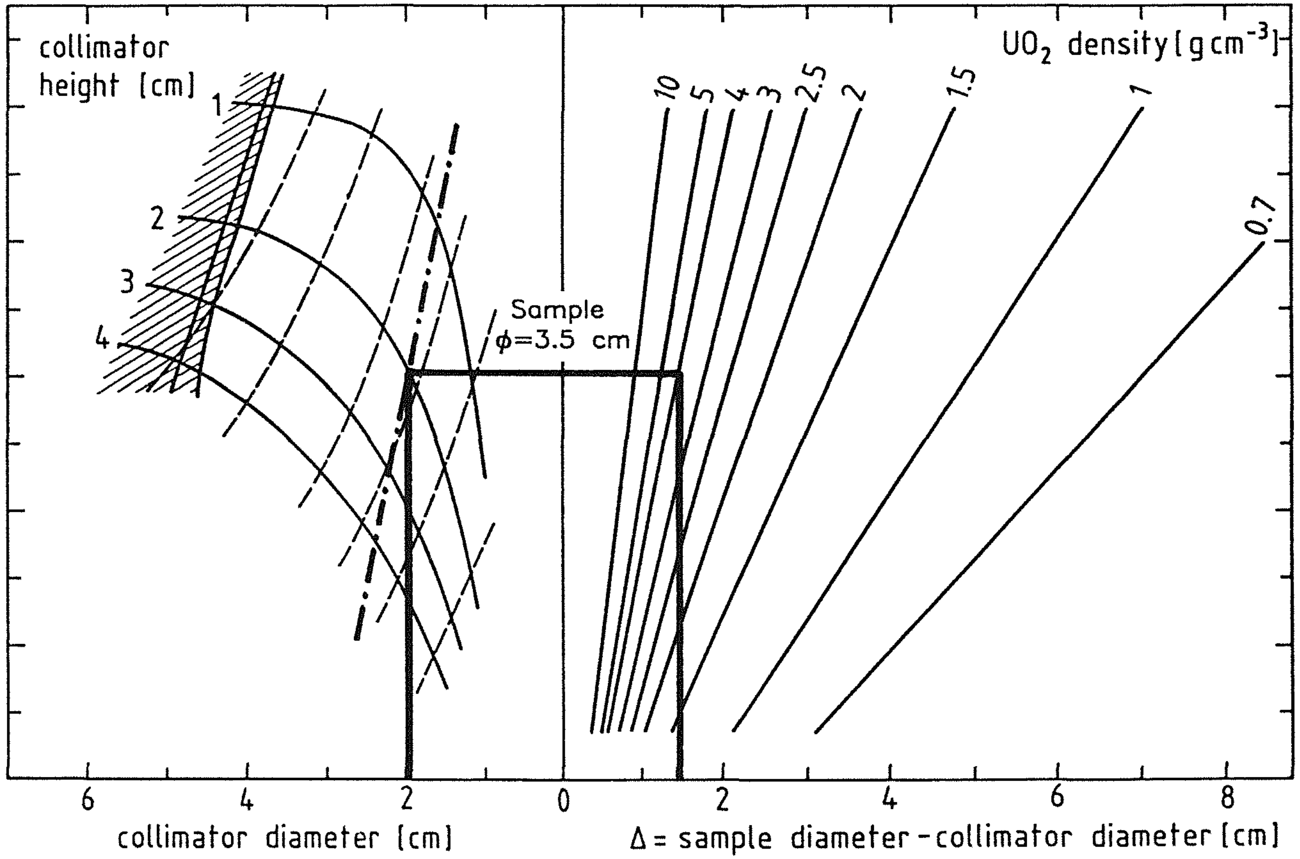

Fig. 1 *Relation between collimator dimensions, sample size and minimum sample density for UO_2. Dashed lines in the left hand part indicate collimator geometries with equal gamma counting rate. Collimator geometries in the shaded region do not fulfill the "quasi-infinite" thickness condition for the Reference Samples EC-NRM-171/NBS-SRM-969.*

Observing the restrictions mentioned above the relation between required collimator diameter, collimator height, sample diameter and sample density is displayed in fig. 1. The left hand part of fig. 1 combines the characteristics of the collimator : The collimator diameters are given on the abscissa, the collimator heights are shown as parameters of the set of curves. Dashed lines indicate collimator geometries that exhibit equal 185 keV gamma counting rates. The right hand part of fig. 1 presents the sample characteristics given as differences between sample diameter and collimator diameter (always > 0), with the minimum sample-density values shown as parameters of the set of straight lines. Both parts of the figure are connected by a common arbitrary scale.

Fig. 1 is a more general presentation of the relation between sample size and collimator as compared to fig. 3.7 in ref. /1/ where this relation is given only for a fixed sample diameter of 7 cm. Note, that in contrast to the latter figure the density values given here refer to UO_2 instead of U_3O_8. In order to utilize fig. 1 also for uranium compounds other than UO_2 one has to use an effective, UO_2 equivalent density instead of the true compound density $\rho\,(x)$:

$$\rho_{eff} = \frac{\mu\,(x)}{\mu(UO)_2}\,\rho\,(x) \qquad (1.2)$$

where μ denotes the corresponding mass attenuation coefficients. Taking the μ values from Table C2 in Appendix F, and using a density of 5.2 g cm^{-3} for the REIMEP-86 UF_6 sample we arrive in this case at an effective sample density of

$$\rho_{eff}\,(REIMEP\;UF_6) = 4.10\,g\;cm^{-3} > 4\,g\,cm^{-3}$$

Thus the dashed-dotted line drawn in parallel to the 4 g cm^{-3} – line in fig. 1 at a distance of 3.5 cm (corresponding to the sample diameter) shows the maximum permissable collimator configurations for the REIMEP -86 sample. Of course, any collimator parameters below this line will also satisfy the quasi-infinite-thickness condition at the expense of a lower counting rate. However, any collimator configuration above this line will violate this condition.

For the measurements presented in this paper we have used a collimator with 2 cm diameter and 2 cm height. It can be deduced from fig. 1 that this collimator - sample configuration does fulfill the quasi-infinite-thickness condition for 3.5 cm-diameter samples. It should be noted that the data presented in fig. 1 have been calculated for 3 mm distance between sample and collimator, and for 2 mm aluminium absorber between sample and collimator. In the present measurements the sample-collimator distance is slightly larger (4 mm instead of 3 mm). However, this effect is compensated by the higher photon attenuation in the additional 2 mm thick monel layer causing a stronger forward peaking of the gamma-ray flux entering the collimator, and by a safety margin used for the effective sample density (4.0 g cm^{-3} instead of 4.1 g cm^{-3}).

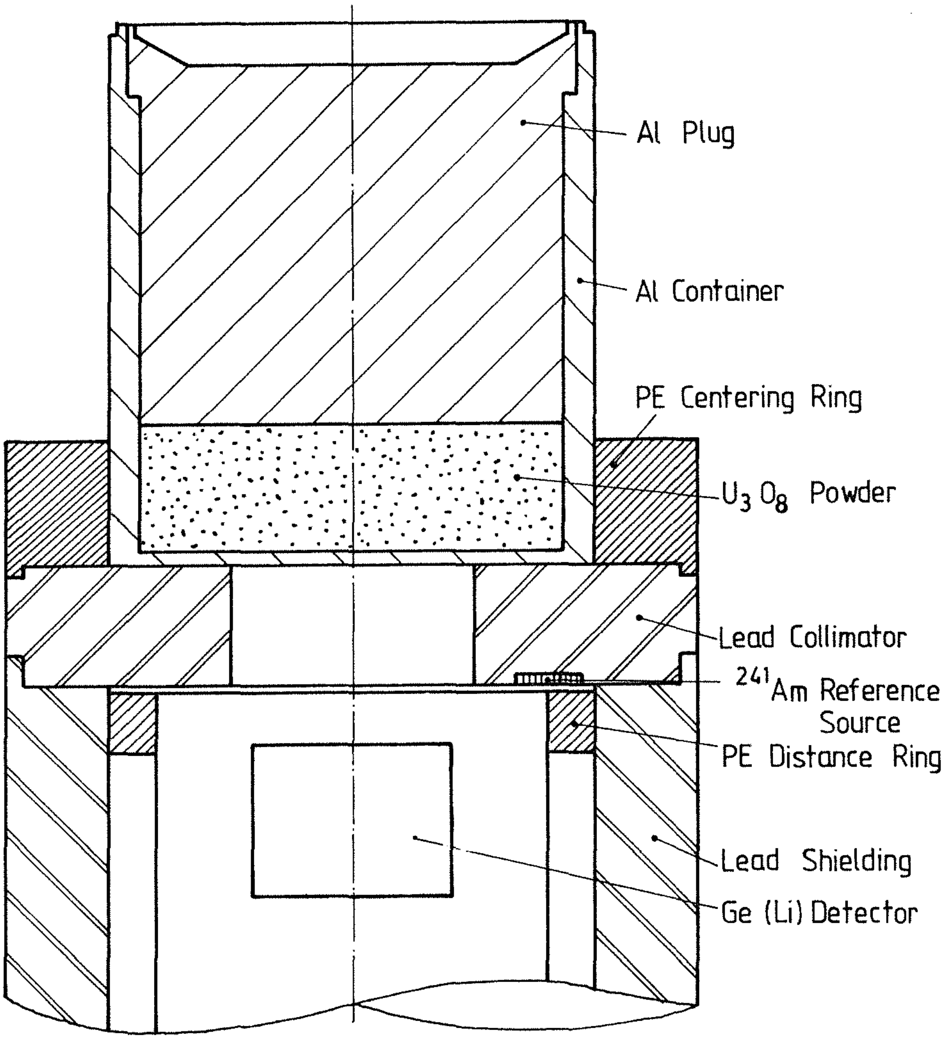

Fig. 2 Schematic view of the sample - collimator - detector arrangement

Fig. 2 shows schematically the sample - collimator - detector - arrangement used for the measurements. The lead shielding has been rigidly fixed to the flange of the detector cap in order to prevent variations of the distance between collimator and detector. Also the ^{241}Am source has been fixed to the collimator by means of screws to provide a geometrically stable reference gamma source. Not shown in fig. 2 are the calibration disks that are positioned between sample container and collimator. The calibration samples with 2 mm aluminium bottom have been measured with the 2 mm monel calibration disk, the UF_6 sample with 2 mm monel bottom has been measured with the 2 mm aluminium calibration disk, so that in all measurements the gamma rays had to penetrate always 2 mm monel and 2 mm aluminum before entering the collimator. In fig. 2 the counting arrangement is given for the case of the calibration samples, in case of the UF_6 sample, exhibiting a smaller diameter, a tighter polyethelene centering ring has been used.

1.2 Counting electronics

A schematic view of the counting electronics ranging from the detector to the multichannel analyzer is given in fig. 3. A medium size Ge(Li) is used for the detection of the gamma rays penetrating the collimator. Through a preamplifier with resistive feedback the signal is transfered to a main amplifier providing semi-gaussian shaped output pulses. These pulses are analyzed in a Wilkinson-type ADC running with 80 MHz. The analyzed pulse heights corresponding to the energies of the gamma rays registered in the detector are stored and evaluated in a computer-controlled multichannel analyzer (MCA). The gamma spectra have been stored to magnetic disk for later evaluation.

A digital spectum stabilizer has been added to the system in order to improve the reliability of the measurements. The gamma peak at 59 keV originating from the ^{241}Am reference gamma source attached to the collimator (see fig. 2), and the 185 keV gamma peak from the decay of ^{235}U, present in all samples assayed, have been used as reference peaks for the digital stabilizer. In addition, pulser signals from a high-precision pulse generator with adjustable rise- and fall-time are fed into the preamplifier and are treated by the pulse-processing chain in the same manner as signals originating from gamma events in the detector. The signals from the electronic pulser may serve as an indicator for the stability of the system and may be used for second-order corrections as demonstrated in Chapter 3 of this manual.

It is of special importance to carefully supervise the frequency of the almost periodic pulser. Therefore the number of pulser events during measurement time as well as the real measurement time must be recorded in order to arrive at the true mean pulser rate during assay time. This has been achieved here by feeding the digital trigger output of the pulser (having a fixed amplitude of 4.5 V) to a second ADC running in parallel with the spectrum ADC. This results in a background-free spectrum with a single peak corresponding to the 4.5 V of the

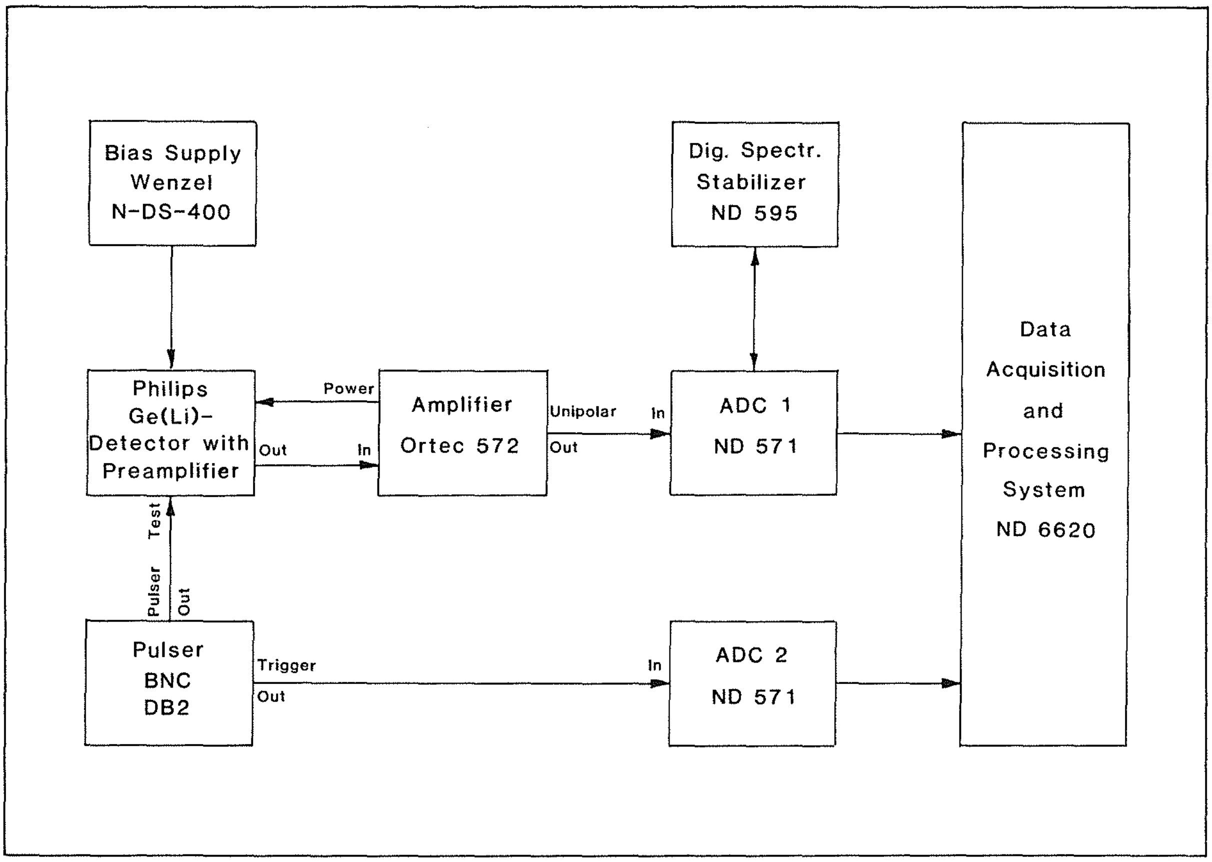

Fig. 3 Schematic view of the counting electronics used

input signal. Note that no pulse pile-up is possible in this particular case of a periodic pulser. The integrated number of pulser events and the real counting time have been printed out but have not been recorded to magnetic disk. From both values the mean pulse rate is evaluated and is used for pile-up and dead-time corrections relative to the pulser. Since the printer failed during measurements #35 to #40 no correction of this type could be done in these cases.

The multichannel analyzer was always operated in live-time mode, i.e., the MCA timer is gated off in its high-frequency part whenever the MCA is busy with analyzing and storing of an event. Thus the preset live time is simply the sum of time intervalls during which the system is not busy. The real measurement time is the sum of the preset live time plus the system-busy time. Note that no pile-up rejection circuit was implemented in the pulse-processing chain since the total counting rate of less than 1 kcps in all cases looked comparatively low.

Table 1 displays the type, the manufacturer, the settings and the main characteristics of all electronic components used in the measurements.

TABLE 1 COUNTING ELECTRONICS USED.
CHARACTERISTICS AND SETTINGS.

DEVICE	MANUFACTURER/TYPE	PARAMETERS / REMARKS
DETECTOR	PHILIPS APY41SQ/N	GE(LI) SINGLE OPEN-ENDED COAX ACTIVE VOLUME = 18 CCM ACTIVE DIAMETER = 3.1 CM DEPLETION LAYER = 1.2 - 1.4 CM WINDOW = 0.5 MM AL CAP-DET DISTANCE = 8 MM
PREAMPLIFIER	PHILIPS 56019	RESISTIVE FEED-BACK
HV SUPPLY	WENZEL N-DS-400	POT. = 5.6 (+ 2250 V)
AMPLIFIER	ORTEC 572	COARSE GAIN = 100 FINE GAIN = 10.01 SHAPING TIME = 1 MICROSECOND BLR = AUTO DELAY = ON NEGATIVE INPUT UNIPOLAR OUTPUT
ADC 1 (SPECTRUM)	NUCLEAR DATA 571	GROUP = 4K CONVERSION = 4K LLD = 0.04 ULD = 10.00 ZERO = 1.45 DIG. OFFSET = OFF
DIGITAL SPECTR. STABILIZER	NUCLEAR DATA 595	ZERO (59 KEV): CENTER CHN = 480 WINDOW = 6 RATE = 2 GAIN (185 KEV): CENTER CHN = 1820 WINDOW = 6 RATE = 2
PULSER	BNC DB2	FREQUENCY = 140 HZ MODE = REP RANGE = 1V NORMALIZE = 0.0 AMPLITUDE = 9.725 RISE TIME = 0.2 MICROSECONDS FALL TIME = 1000 MICROSECONDS REFERENCE = INT ATTENUATION = X2 / X10
ADC2 (PULSER DIG.)	NUCLEAR DATA 571	GROUP = 512 CONVERSION = 2K LLD = 0.20 ULD = 9.80 DIG. OFFSET = OFF
MULTICHANNEL ANALYZER	NUCLEAR DATA 6600	LIVE-TIME MODE

2. THICKNESS CORRECTION FOR CONTAINER WINDOWS

Basically the enrichment-meter principle relies on the absolute determination of the characteristic gamma-counting rate emitted by a quasi-infinite sample into a fixed solid angle. In practice the 185 keV gamma counting rate of the unknown sample is measured relative to the corresponding counting rates observed from well specified calibration samples. Since in NDA applications the gamma radiation is always measured through the container wall it becomes clear that the attenuation of the gamma rays in the wall will directly affect the observable 185 keV gamma counting rate and thus the assay result. It is therefore required that the container windows through which the gamma radiation is measured are identical for the calibration samples and for the unknown sample as well, or that appropriate corrections are applied that account for different gamma attenuation in the container walls.

In our case the container materials of the UF_6 sample and of the reference samples are quite different - 2 mm monel and 2 mm aluminium, respectively - resulting in about 20% differing gamma attenuation. In order to keep the required attenuation correction small, we have measured the reference samples with an additional monel absorber and, vice versa, the UF_6 sample with an additional aluminium absorber, thus providing nearly identical windows for all measurements, namely about 2 mm monel plus 2 mm aluminium.

For high-precision measurements the effect of the still remaining wall-thickness differences has to be examined in more detail. Using the correction factors given in the REIMEP-86 data sheet:

- 3.4 % per 1 mm aluminium and
-13 % per 1 mm monel,

we arrive at an estimate for the accuracy of the wall-thickness determination required to keep this contribution to the relative error of the enrichment assay below our target value of ± 0.05% :

± 0.015 mm for aluminium and
± 0.004 mm for monel.

The window-thickness data specified in the Dimensional Control Sheet in case of the Reference Samples, and in the REIMEP-86 Data Sheet in case of the UF_6 sample (for both see Appendix E) are well within the above tolerance limits.

TABLE 2 CONTAINER-BOTTOM THICKNESS MEASUREMENTS. ULTRASONIC MEASUREMENTS (US) RELATIVE TO 1.9950 MM AL AND TO 2.0000 MONEL DISKS, MICROMETER MEASUREMENTS (MS).

A) SCHEMATIC VIEW OF MEASUREMENT POINTS AT CONTAINER BOTTOM

```
            CONTAINER LABEL

               * 1/21 *
          *                 *
       *                       *
    8/28                      2/22
               * 9/29 *
   *        *            *         *
  *       16/36        10/30        *

 *       *                  *        *
                  17
7/27   15/35   20 37 18   11/31    3/23
 !       !        19        !        !
 *       *                  *        *
 !       !                  !        !
 !*      !14/34        12/32!       *!
 ! *     !  *            *  !      * !
 !       !     * 13/33 *    !        !
 !  6/26 !                  !  4/24  !
 !     * !                  !  *     !
 !       !*                *!        !
 !       !     * 5/25 *     !        !
 !       !                  !        !
 !       !<----- 1 CM ----->!        !
 !                                   !
 !<------------- 2 CM -------------->!
```

B) MEASUREMENT RESULTS

MEAS. POINT	#194 US (MM)	#295 US (MM)	#446 US (MM)	UF6 US (MM)	AL DISK MS (MM)	MONEL DISK MS (MM)
# 1	1.984	1.976	1.985		1.995	2.000
# 2	1.991	1.982	1.984		1.993	1.999
# 3	1.982	1.981	1.984		1.995	2.000
# 4	1.987	1.981	1.984		1.995	2.000
# 5	1.981	1.982	1.983		1.995	2.000
# 6	1.986	1.979	1.981		1.995	2.000
# 7	1.981	1.979	1.979		1.995	1.999
# 8	1.986	1.979	1.978		1.995	2.000
# 9	1.983	1.988	1.990		1.995	2.000
#10	1.979	1.989	1.990			
#11	1.980	1.992	1.984		1.995	1.999
#12	1.980	1.990	1.992			
#13	1.985	1.992	1.985		1.995	1.999
#14	1.982	1.991	1.988			
#15	1.985	1.991	1.989		1.995	1.999
#16	1.989	1.992	1.992			
#17	1.993	1.992	1.992	2.004		
#18	1.992	1.992	1.991	2.003		
#19	1.993	1.992	1.991	2.002		
#20	1.995	1.990	1.991	2.003		
#21	1.989	1.977	1.982			
#22	1.987	1.982	1.983			
#23	1.987	1.986	1.984			
#24	1.987	1.979	1.981			
#25	1.980	1.985	1.981			
#26	1.979	1.977	1.981			
#27	1.983	1.978	1.979			
#28	1.989	1.980	1.978			
#29	1.982	1.989	1.987			
#30	1.979	1.992	1.981			
#31	1.981	1.989	1.986			
#32	1.982	1.987	1.985			
#33	1.980	1.991	1.985			
#34	1.985	1.987	1.988			
#35	1.984	1.990	1.984			
#36	1.978	1.983	1.983			
#37	1.993	1.985	1.990	2.004	1.995	2.001
MEAN	1.985	1.986	1.985	2.003	1.995	2.000
RMS ERR	0.005	0.005	0.004	0.001		
ZEISS PRECISION PASSAMETER MEASUREMENTS ALONG FOUR DIAGONALS					1.9950 0.0005	2.0000 0.0005

These wall-thickness values along with the stated uncertainties are summarized in the upper part of Table 3. Note that we have used a very narrow collimator of 2 cm diameter only. Therefore only the thickness values in the central region of the counting window have been used in case of the Reference Samples, the mean value of which is labeled X5 in the Dimensional Sheets.

Facing the extremely low tolerance limits for the thickness of the counting windows we have decided to validate the stated values by own measurements. For the thickness measurements we have used an ultrasonic thickness gauge, in case of the calibration disks additional measurements have been performed using a micrometer and a high precision Zeiss Passameter. The corresponding precisions obtained at the 1 σ level are:

± 0.001 mm for the ultrasonic thickness gauge,
± 0.001 mm for the micrometer, and
± 0.0005 mm for the Zeiss Passameter.

The calibrations of the ultrasonic thickness gauge have been made relative to the thickness of the corresponding calibration disk determined from the Passameter measurement.

The results of our measurements are displayed in Table 2. The upper part of the table shows schematically the position of the measurement points relative to the container label imprinted on each Reference Sample. The mean values and the RMS errors are given at the bottom of the table. Note that the RMS error presents a conversative error estimate because it does not account for real inhomogeneities in the window thickness of the Reference cans that are clearly observed within the precision limits of the ultrasonic thickness gauge. For the thickness values of the calibration disks we have used the more accurate data from the Passameter measurements.

The final results of our thickness measurements and the associated errors are shown in Table 3 along with the corresponding values from the Dimensional Control Sheets of the EC-NRM-171-008 Reference material and of the REIMEP-86 UF_6 sample, respectively. Comparing both data sets one recognizes a small disagreement for the thickness of the aluminium calibration disk and for the monel bottom of the UF_6 container, that is outside the stated 1 σ errors. We have therefore performed the data evaluation described in the following chapters for both sets of thickness values independently. Table 4 shows the corresponding

TABLE 3 THICKNESS OF SAMPLE CONTAINER BOTTOMS AND CALIBRATION DISKS

MATERIAL	THICKNESS (MM) +- RMS ERROR (MM)	DEVIATION FROM REFERENCE (MICRON)
A) THICKNESS FROM CERTIFICATE EC-NRM-171-008 (X5) AND FROM UF6 REIMEP-86 DIMENSION SHEET APP. 6		
FOR U3O8 MEASUREMENTS:		
MONEL DISK	2.000 +- 0.001	0 +- 1 (REF.)
AL BOTTOM #446	1.983 +- 0.005	- 17 +- 5
AL BOTTOM #295	1.988 +- 0.002	- 12 +- 2
AL BOTTOM #194	1.983 +- 0.007	- 17 +- 7
FOR UF6 MEASUREMENTS:		
AL DISK	2.000 +- 0.003	0 +- 3 (REF.)
MONEL BOTTOM UF6	2.000 +- 0.001	0 +- 1
B) THICKNESS FROM ULTRASONIC AND MICROMETER MEASUREMENTS PERFORMED AT KFK		
FOR U3O8 MEASUREMENTS:		
MONEL DISK	2.0000 +- 0.0005	0 +- 0.5 (REF.)
AL BOTTOM #446	1.985 +- 0.004	- 10 +- 4
AL BOTTOM #295	1.986 +- 0.005	- 9 +- 5
AL BOTTOM #194	1.985 +- 0.005	- 10 +- 5
FOR UF6 MEASUREMENTS:		
AL DISK	1.9950 +- 0.0005	0 +- 0.5 (REF.)
MONEL BOTTOM UF6	2.003 +- 0.001	+ 3 +- 1

correction factors used to compensate for different attenuation of the 185 keV gamma rays in both cases.

It can be seen from Table 4 that the corrections required are comparatively small ($\simeq$ 0.05%). We have therefore neglected any second order correlations like the collimator - dependent effective mean pass length of the gamma rays through the container wall that adds another correction of $<$ 0.005% to these correction factors (see ref. /1/ Appendix A.3). Also the uncertainties of the linear attenuation coefficients given have been neglected.

TABLE 4 CORRECTION FOR ATTENUATION OF 185 KEV GAMMAS IN CONTAINER BOTTOMS AND CALIBRATION DISKS.

ATTENUATION OF 185 KEV GAMMA RAYS (REIMEP-86 APP. 7/APP. NDA-1):

- 3.4 % PER MM ALUMINIUM USED
- 13 % PER MM MONEL USED

SAMPLE PLUS DISK	CORRECTION I DIMENSIONS FROM CERTIFICATE AND REIMEP-86 APPENDIX 6	CORRECTION II DIMENSIONS FROM ULTRASONIC MEASUREMENTS AT KFK
# 446 + MONEL	0.99942 +- 0.00021	0.99966 +- 0.00015
# 295 + MONEL	0.99959 +- 0.00015	0.99969 +- 0.00018
# 194 + MONEL	0.99942 +- 0.00027	0.99966 +- 0.00018
UF6 + AL	1.00000 +- 0.00017	1.00039 +- 0.00013

A special problem that we faced in our ultrasonic thickness measurements should be mentioned: Whereas the ultrasonic measurements of the aluminium layers created no problems we observed that the measured thickness values of the UF_6 monel bottom slightly increased (by a few micron) from the center of the counting window towards the outer diameter. A similar effect was observed also with the ultrasonic measurements of the calibration disk though the passameter measurements assure a thickness homogeneity of better than ± 0.0005 mm. So far we have no explanation for this effect. Thus we have restricted our measurements to the central region of the counting window in case of the UF_6 monel bottom as can be seen from Table 3. Doing so we arrive at a window thickness of 2.003 ± 0.001 mm for the UF_6 monel bottom, a value that is clearly outside the specification of 2.000 ± 0.001 mm given in the REIMEP data sheet. Nevertheless we have used the former value for the attenuation data set II shown in Table 4 that is the basis of our finally reported $^{235}U/U$ abundance value

For the case that our ultrasonic thickness determination of the monel is erroneous, and an equal thickness of both the UF_6 monel bottom and the monel calibration disk can be assured by other means, then our reported ^{235}U % enrichment value has to be lowered by 0.0014, i.e, instead of

3.5005 ± 0.0031 % $^{235}U/U$ abundance, as reported,

we would get then

3.4991 ± 0.0031 % $^{235}U/U$ abundance.

3. DATA EVALUATION

This chapter describes the evaluation of the 185 keV counting rate from the peak counts observed in the measured MCA spectra and from the measurement live time. It also comprises corrections for pulse losses due to dead-time and pile-up effects. Finally the calibration procedure is summarized.

3.1 Evaluation of net-peak counts

Standard procedures have been used for the evaluation of net peak areas from the measured spectrum. A complete program listing and a thorough description of the input parameter is given in ref. /2/. Here we summarize the salient points only.

All relevant measurement parameters are written to an analysis file on magnetic disk prior to the start of the actual measurements. The informations required for data analysis are always taken from this file. The content of the file is given in fig. 4. It comprises the number of peaks to be analysed and their characteristics like energy, position in the MCA spectrum, background windows on the low- and high-energy side of the respective peak, the type of background subtraction to be applied, and the information whether the peak shall be used for

```
ANALYSIS FILE :  ELMT.A2



1) NUMBER OF INTEGRATIONS :                                              5
2) NORMALIZATION TO REFERENCE PEAK IN REGION :                           1
      LIVE TIME OF THE REF. MEASUREMENT (SEC) :                     30000.
      COUNTS IN REFERENCE PEAK :                                  4153728.
      ERROR OF REFERENCE PEAK (COUNTS) :                             1952.
3) INTEGRATION WIDTH IN FWHM(KEV) BELOW AND ABOVE
                              THE PEAK POSITION :                     2.20

4) ROI   ENGY     POS        BGL (CH) BGR          STEP/LINE   CAL   PULS

    1    59.54    479    376    397    498    506      S        Y      N
    2   143.77   1374   1306   1327   1419   1428      S        Y      N
    3   163.37   1582   1535   1555   1603   1619      S        Y      N
    4   185.72   1819   1745   1767   1843   1857      S        Y      N
    5   266.00   2672   2626   2650   2696   2714      L        N      Y



LAST UPDATE :    11 FEB 1987 11:35:08 AM
NEW UPDATE  :    16 FEB 1987  3:21:53 PM
```

Fig. 4 Content of analysis file

evaluation of the FWHM as a function of energy, and wether it is a pulser peak or not. Moreover the analysis file also contains the indicator for a reference peak that may be used for normalization purposes. We didn't make use of this option for reasons that will be discussed in the next section.

Another important parameter is defined in the analysis file: the integration width in units of FWHM. This integration window determines the limits for the channel-content summation after subtraction of an appropriate background. It should be noted that, in contrast to the background windows, this window is not fixed, but its position and width is derived from the peak centroid and the FWHM fitted individually for each actually measured spectrum and for the respective peak. Integration is performed in fractions of channels by linear interpolation. We have selected a width of 2.2. FWHM units for the peak-summation window according to the recommendation given in ref. /1/. This setting provides a good signal-to-background ratio with an acceptable susceptibility to peak-parameter variations. The window is placed symetrically to the peak centroid and comprises about 99% of the total peak area in case of a purely gaussian peak shape.

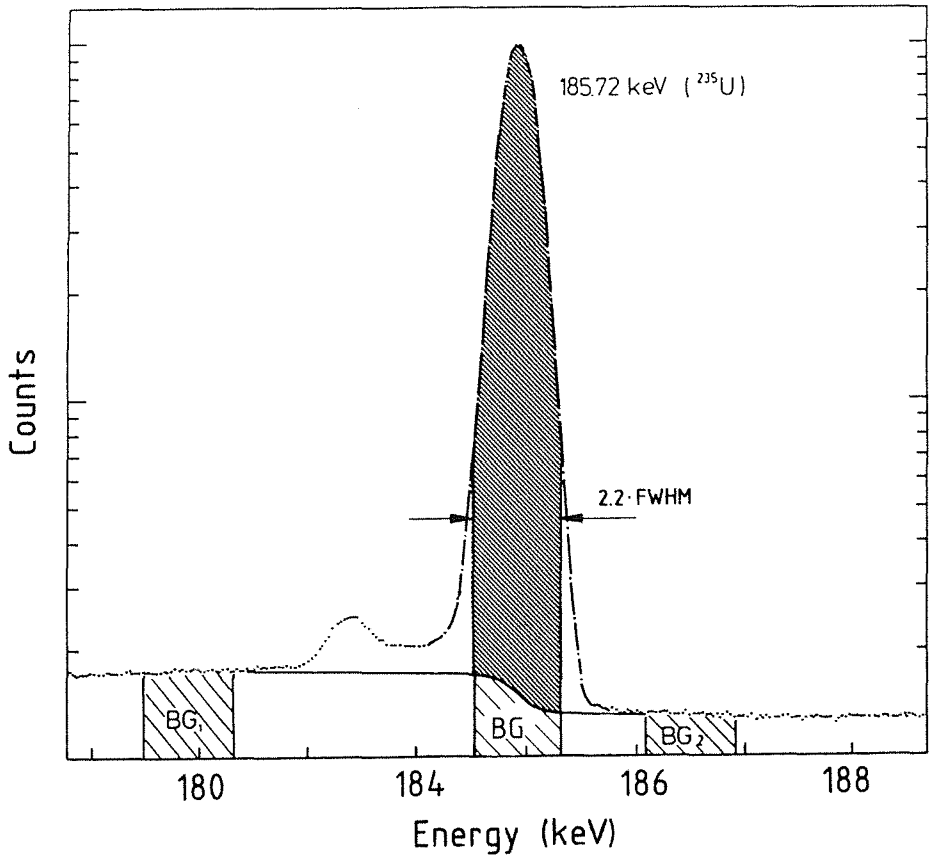

Fig. 5 Window settings for the 185 keV peak

A typical example for the setting of the peak- and background windows, for the step-like background subtracted and for the evaluated net-peak area is shown in fig. 5 for the spectral region around the 185 keV peak originating from decay of ^{235}U used here for the determination of the $^{235}U/U$ abundance.

```
                                                              16 FEB 1987   3:24:06 PM

      SAMPLE :   295-008


     FILE/                     ACQUIRE                 ELAPSED LIVE   ELAPSED REAL
    ELEMENT                     START                   TIME (SEC)     TIME (SEC)

  MESS   .U29B1         31/ 1/1987    15: 9:58            30000.         30711.


  SLOPE (EV/CH)         :   94.169
  OFFSET (KEV)          :   14.423
  COUNTRATE (CPS)       :     756.

  LINEAR REGRESSION (FWHM)

        FIT COEFF. :                           A0 =    0.4808003E 00
                                               A1 =    0.1921846E-02
        CORR.COEFF. :                        R**2 =    0.9874887E 00

 ROI    BACKGROUND WINDOWS        STEP    ENERGY    POSITION        FWHM         FWTM  FWFM
            (CHANNEL)             /LINE    (KEV)   (CHANNEL)        (EV)         (EV)  (EV)

  1   376    397    498    506      S      59.54     479.13    776.     774.   1451. 3064.
  2  1306   1327   1419   1428      L     143.77    1373.74    872.     872.   1556. 2072.
  3  1535   1555   1603   1619      S     163.37    1581.74    885.     894.   1615. 2052.
  4  1745   1767   1843   1857      S     185.72    1819.05    925.     917.   1677. 2215.
  5  2626   2650   2696   2714      L     266.00    2669.87             998.


                    ENERGY       AREA          ERROR
                    (KEV)      (COUNTS)    (COUNTS)    (%)

                     59.54    4051802.       2050.    0.05
                    143.77      92286.        415.    0.45
                    163.37      56469.        362.    0.64
                    185.72     799172.        935.    0.12
                    266.00    4217088.       2066.    0.05
```

Fig. 6 Typical print-out from the evaluation program

A short description of the flow of the data evaluation program is summarized below:

1) Linear energy calibration using the two gamma peaks with lowest and highest gamma energy in the analysis file as reference peaks.

2) Subtraction of a smoothed step-like function as a background approximation below the peak of interest (see ref. /3/). The boundary conditions for this step function are taken from the adjacent background windows.

3) Determination of peak centroids for the peaks of interest using a gaussian fit to five channels around the peak maximum.

4) Determination of the energy resolution of selected gamma peaks in the spectrum (FWHM, FWTM FWFM = Full Width at Half-, Tenth-, Fiftieth- Maximum).

5) Calculation of net-peak counts by channel-content summation of the background-corrected spectra within a window 2.2. FWHM units wide around the peak centroid.

A typical print-out of the evaluation program is shown in fig. 6.

3.2. Correction for pulse losses

Gamma-spectromectric ^{235}U abundance measurements are based on the accurate determination of the characteristic 185 keV gamma counting rate. Therefore, dead-time and pulse pile-up causing counting losses in the measured 185 keV peak require careful corrections. Countermeasures and correction methods are described in detail in ref. /1/. One of the proposed methods is the normalization of the 185 keV counting rate relative to the counting rate observed in a reference peak. In the following two subsections we discuss the stability of the reference peaks in our measurements and the correction procedure finally applied in our data evaluation.

3.2.1 Stability of reference peaks

Pulse losses can be corrected for if we relate the counting rate in the peak of interest to the counting rate in a reference peak. However, a prerequisite for this method is that the input counting rate of the reference source is extremely constant or can be exactly measured. If we assume that the reference pulses underly the same counting-loss process as the peak events of interest do, then we can simply normalize the counting rate observed in the peak of interest to a constant counting rate in the reference peak, e.g., if the reference-peak counting rate observed in an actual measurement is 10% higher than in the reference run we have to divide all peak counting rates in this spectrum by a factor of 1.1, etc. Note however that in contrast to random gamma pulses the assumption of an identical pulse-loss behaviour for all pulses processed is not exactly fulfilled in case of a periodically running electronic pulser since such pulser pulses cannot pile up with each other. This will be discussed in the next Sub-Section 3.2.2.

In our measurements we have used two different reference-pulse sources:

1. a ^{241}Am gamma source attached to the collimator at a fixed distance from the detector, and

2. an electronic pulser fed into the test input of the preamplifier.

As mentioned above the normalization procedure to a reference peak necessitates a very stable input pulse rate to the counting system: Instabilities in the input pulse rate of the reference source will directly propagate into instabilities of the normalized counting rate in the peak of interest. It is therefore of utmost importance to verify the stability of the input pulse rate of the reference source.

Normally one cannot directly observe the input pulse rate for a gamma source. In this case one has to provide an invariable counting geometry and a gamma source with a comparatively long half-life in order to assure a constant input rate. In contrast to this, for an electronic pulser one can measure exactly the input pulse rate by means of an external counter and timer. These steps have been taken for both reference-pulse sources used as described in Chapter 1 of this paper.

Besides the pulse-rate constancy also the stability of the input amplitude of the reference pulse has to be observed. Whereas this is assured from physical principles of the detection process in case of a gamma source it may pose problems in case of an electronic pulser. As schown in Table D 1 in Appendix D we have indeed observed a slow drift in the amplitude of the pulser corresponding to a shift of the pulser-peak position of ± 4 channels in the spectrum during the measurement period. In contrast to this the positions of the two gamma peaks at 59 keV and 185 keV which have been used for digital stabilization purposes have been found to be extremely stable: The RMS deviation from the mean value of the respective peak positions was only 2% of a channel through all measurements performed. Also the stability of the energy resolution of the system or, correspondingly , of the peak-shape parameters is of particular interest. Variations of these parameters have been observed in our measurements too, as shown in

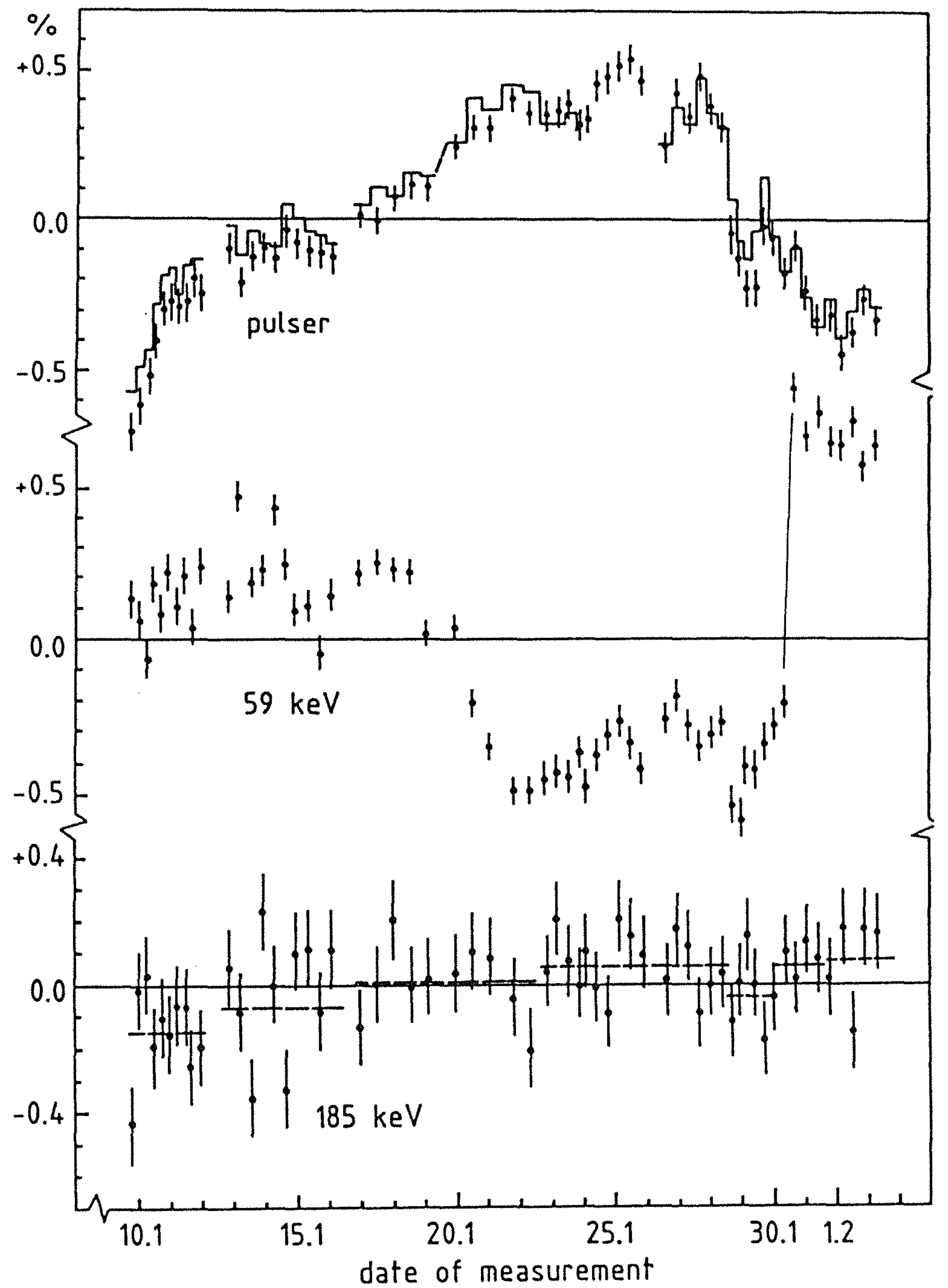

Fig. 7 *Relative deviations of uncorrected peak counting rates from their respective mean values shown for the pulser peak, the 59 keV peak of ^{241}Am and the 185 keV peak of ^{235}U (normalized to 1 % $^{235}U/U$ isotope abundance)*

Tables D2 and D3 in Appendix D. It should be noted that in our particular data evaluation program instabilities of peak position and energy resolution play only a secondary role because the position and width of the integration windows are always adjusted to the actual peak maximum and FWHM determined for each peak and each measurement individually.

Facing the impossibility to observe the gamma input rate directly we have plotted in fig. 7 the relative deviations of three output counting rates from their respective mean values as a function of the measurement date. These output counting rates refer to the uncorrected net-peak areas evaluated from the spectrum and to the live-time of the corresponding measurement. The figure shows from top to bottom the pulser counting rate, the counting rate in the 59 keV peak from the ^{241}Am reference source, and the 185 keV peak counting rate normalized to 1% ^{235}U/U abundance. The error bars given refer to the uncertainties in the background subtraction and to counting statistics.

Ideally all three counting rates should exhibit a similar behaviour since they all suffer from the same pulse-loss mechanism. Fig. 7 clearly demonstrates that this was not observed. Whereas the 185 keV counting rate was fairly stable, the counting rates in our "reference peaks" show variations of about $\pm$ 0.5%, and these variations are not correlated. From this finding we must conclude that our reference sources are not sufficiently stable to be used for normalization purposes. In case of the pulser the variation of the true input rate (measured by an external counter/- timer) is also shown in fig. 7 in form of a histogramme. A comparison of both pulser rates demonstrates that the observed variation of the pulser rate is really caused by frequency instabilities of the electronic pulser. The observed instability of the ^{241}Am reference source was somewhat discouraging as we had taken a lot of efforts to keep the counting geometry stable. The effect may be explained by the extreme sensitivity even to small distance variations if detector and source are located in close vicinity and a 2π geometry is used. We must conclude that the detector position relative to the flange of the detector cap that serves as reference point for the position of the gamma source is not invariably fixed but is susceptible to the filling level of liquid nitrogen and to mechanical schocks.

Therefore, a simple counting-loss correction by normalization to a reference peak could not be performed for the present measurements due to the apparent instabilities of our reference sources that are far away from the desired accuracy level. However, in case of the pulser we have observed both the true input rate and the peak counting rate in the MCA spectrum. The ratio of these two values can give the required information for pulse losses. This method has already been mentioned in ref. /1/ for normalization to randomly triggered pulsers. It will be discussed in more detail in the following Sub-Section.

3.2.2 Dead-time and pile-up correction

This Sub-Section gives some more information on the impact of system dead-time and pile-up effects on the result of the ^{235}U enrichment assay and it describes the correction procedure applied for the present REIMEP-86 UF_6 measurements.

As shown in the previous section the direct normalization of the value of interest - here the 185 keV peak counts - to a reference peak failed due to instabilities (geometrical and electronic, respectively) of both reference sources used for the measurements. In order to further investigate the effect of counting losses, fig. 8 shows again the relative deviation of the uncorrected 185 keV peak counting rates from their mean value, this time along with the total gamma counting rate observed for the corresponding measurements. The 185 keV counting rates have been normalized to 1% ^{235}U abundance, the mean values of successive measurements of identical samples are indicated by dashed lines. Though somewhat hidden in the counting statistics one can clearly observe an anticorrelation between total gamma counting rate and 185 keV peak counting rate, i.e., with increasing total gamma counting rate the 185 keV counting rate decreases, the effect is about 0.2% for a variation of the total counting rate by 130 cps only. Considering our goal of highest possible assay accuracy this effect cannot be tolerated, thus we have to look more carefully for the interdependence of total counting rates and peak counting rates.

Fig. 8 shows also the percentage correction finally applied to the observed 185 keV peak counting rates, anticipating the results of the considerations in this Sub-Section. The corrected peak counting rates are calculated from

$$\dot{N}^{185}_{corr} = \dot{N}^{185}_{peak} \cdot C_{el} \tag{3.1}$$

where the correction factor C_{el} is derived from the true pulser input rate $\dot{p}$ and the pulser-peak counting rate $\dot{P}_{peak}$ obtained from the spectrum accumulated during the measurement live-time :

$$C_{el} = \frac{\dot{p}}{\dot{P}_{peak}} \quad .^{*} \tag{3.2}$$

* *Note that capital letters (N, P, $\dot{N}$, $\dot{P}$,) describe counts and counting rates, respectively, observed in the MCA spectrum, whereas small letters ($\dot{n}$, $\dot{p}$) denote true input counting rates that would be observed with ideal electronics not suffering from dead-time and pile-up effects.*

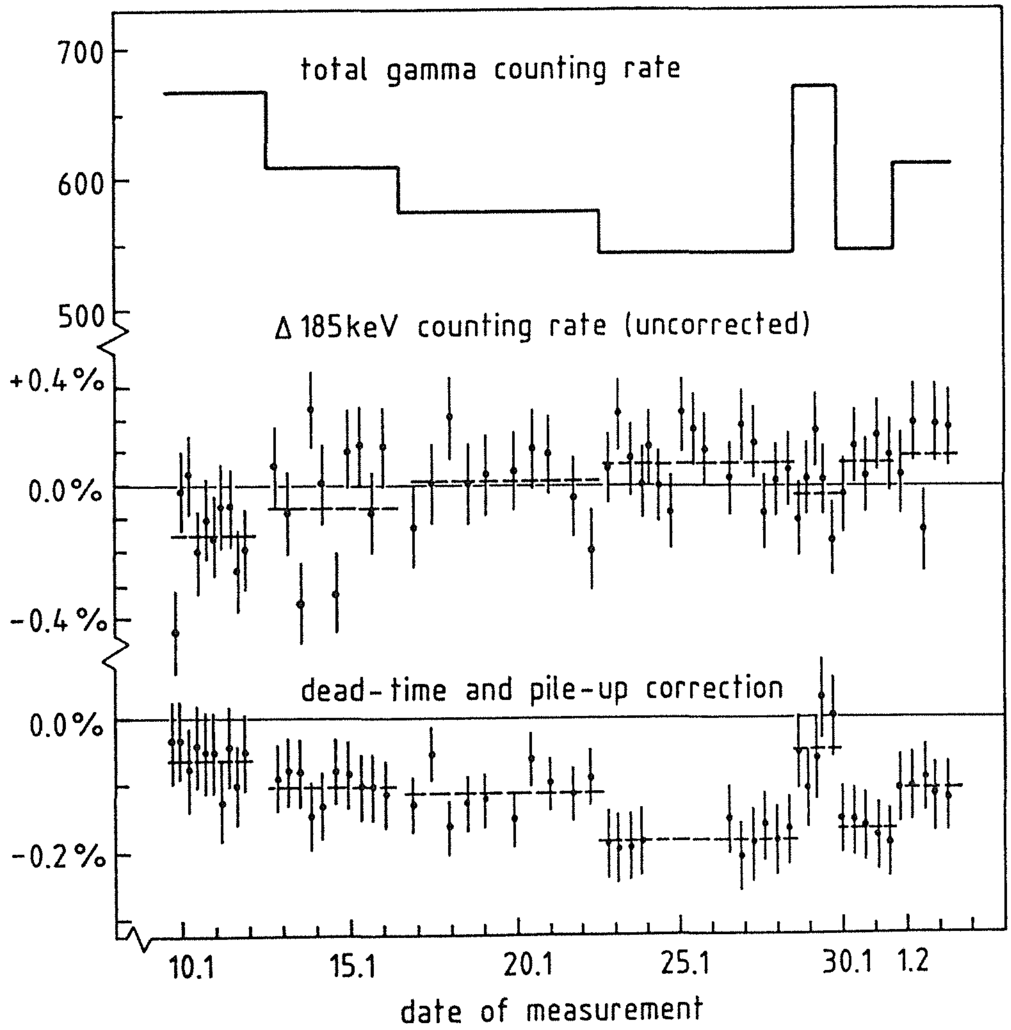

Fig. 8 *Total gamma counting rate, variation of uncorrected 185 keV peak counting rate (normalized to 1 % ^{235}U abundance) and correction for counting losses versus counting date*

A more detailed description of the notation is given below. It can be estimated from fig. 8 that this correction reduces the counting rate dependence of the 185 keV peak rate significantly. Note the different scales in fig. 8 for the 185 keV counting rate variation and the correction, respectively.

In the following we discuss a simple model for a better quantitative understanding of the impact of dead-time and pile-up effects on the peak counts in gamma peak and the pulser peak, respectively. We follow here to some extent the arguments and considerations given in ref. /4/. Let us first define some relevant terms:

- <u>dead-time *TD*</u>

  is the sum of all time intervalls during that the system is not ready to accept incoming pulses because it is busy with processing and storing of a previous event, thus causing counting losses for those events that occur during the dead-time. Dead-time effects increase with increasing total input counting rate. Since in our pulse processing system we have no pulsed feed-back preamplifier and no pile-up rejector, the system dead-time is determined by the characteristics of the ADC/MCA only.

- <u>live-time *TL*</u>
  is the sum of all time intervals during which the system is ready to accept incoming pulses, i.e., when it is not busy.

- <u>real-time or clock-time *TR*</u>
  is then simply the sum of live-time and dead-time.

- <u>live-time operation of the MCA</u>
  is available for most MCA's: In this mode the high frequency part of the system timer clock is gated off during dead-time thus prolongating the real counting time by the dead-time. The live-time operation mode eliminates dead-time effects almost completely if the time distribution of incoming pulses is governed by Poisson statistics which can be assumed for gamma rays from radioactive decay of istotopes with long half-lives. This dead-time correction method fails, however, for non-random events like periodically running pulsers as shown below.

- <u>real-time operation of the MCA</u>
  is based on a continuously running system clock in contrast to live-time operation where the system clock is gated off during dead-time.

- <u>pulse pile-up</u>
  is observed when the time interval between two or more succeeding pulses is so short that the pulses will partly or totally overlap and the multiple pulse presented to the analyzer is treated as one event. Of course, pile-up events result in distorted pulse amplitudes being analyzed and stored in the MCA spectrum. Thus an event that would have been registered in the peak if no pile-up occured is removed from the peak by pile-up. Pile-up will affect the peak counting rate of gamma pulses and pulser pulses as well.

In our measurements we have operated the MCA always in live-time mode, as recommended in ref. /1/, however the measurement real-time is also simultaneously recorded in the MCA.

If both the gamma pulses and pulser pulses are presented to the input of the counting system and the MCA is operated in live-time mode, then the real counting time *TR* is simply the sum of the system's live-time *TL* and the dead-time due to processing of gamma or pulser events, *TDg* and *TDp*, respectively:

$$TR = TL + TD_g + TD_p \qquad (3.3)$$

By definition we attribute to the pulser dead-time all those processed events where the pulser is involved: undistorted pulser events, pulser events contaminated by gamma interference, and gamma events disturbed by pulser interference.

First we consider the effect of dead-time and pile-up on the pulser-peak counts observed in the MCA spectrum. A constant-repetition-rate pulser differs from a "random" gamma source in two respects:

1) a pulser pulse cannot pile up with another pulser pulse, and

2) a pulser pulse will never find the system busy with processing of a previous pulser event.

From 1) we conclude that the probability to find an undistorted pulser event is equal to the probability that no gamma event is observed during the critical time interval t_l around the pulser event which is given by

$$W_{non-pile-up\,pulser} = e^{-\dot{n}t_1} \quad , \qquad (3.4)$$

where $\dot{n}$ is the total gamma input rate. The critical time interval t_l during which the appearance of another pulse will disturb the amplitude of the pulse being analyzed, is also called ' pulse-pair resolving time ' of the MCA or ' pile-up inspection time '. Its value depends on the width and shape of the pulses presented to the analyzer, and on details of the analyzer logic (e. g., pulse-peak detector). As a rough estimate we can assume that t_l is equal to the pulse width. We assume that the pulse widths of gamma- and pulser-pulses are equal. If a pile-up rejector is used in the pulse-processing chain, its resolving time and internal logic must also be taken into account.

From 2) we see that the time the pulser will find the system live is just the real counting time *TR* minus the time during which the system is busy with the processing of gamma events (see eq. 3.3):

$$TL_p = TR - TD_g = TL + TD_p \quad . \tag{3.5}$$

Therefore the number of pulser events expected in the pulser peak during the real counting time *TR* is given by

$$P_{peak} = \dot{p} \cdot TL_p \cdot W_{non-pile-up\,pulser} = \dot{p} \cdot (TL + TD_p) \cdot e^{-\dot{n}t_1} \ , \tag{3.6}$$

where $\dot{p}$ is the true pulser input rate that is measured externally by use of a counter/timer.

The system dead time TD_p due to the processing of undistorted and distorted pulser events, P_{peak} and $P_{non\text{-}peak}$, respectively, is given by

$$TD_p = t_2 P_{peak} + t'_2 P_{non-peak} \quad , \tag{3.7}$$

where t_2 is the conversion time of the ADC (inclusive overhead such as latency and storage time) for an undistorted pulser event, t_2' is the corresponding value for conversion of a distorted pulser event. In order to simplify the calculations we assume that

$$t'_2 = t_2 \quad , \tag{3.8}$$

i.e., that the processing time for a pile-up contaminated pulser event is equal to the processing time for an undisturbed pulser pulse. Whereas this assumption is justified for an ADC with fixed conversion time, it is not true for a Wilkinson-type ADC: Pulse summing of unipolar pulses will always cause the amplitude of a distorted pulser event to be higher than that of an undistorted event, thus resulting in a longer conversion time. On the other hand, considering our definition of TD_p and considering the possibility that gamma- and pulser-pulse do only partly overlap, it may happen that the peak detector of the ADC will lock on the amplitude of a leading gamma event being smaller than that of the pulser, thus resulting in a shorter conversion time. This time jitter of t_2' depends on peculiarities of the pulse processing system and, to some extent, on the pulse-height distribution of the spectrum being analyzed. However, for a comparatively small pile-up probability of less than 1% in our case, eq. 3.8 seems to be an acceptable approximation.

We further assume that the ratio of disturbed to undisturbed pulser events is equal for the incoming pulse train and for the corresponding pulser events really analysed, i.e.:

$$\frac{P_{non-peak}}{P_{peak}} = \frac{1 - e^{-\dot{n}t_1}}{e^{-\dot{n}t_1}} = e^{\dot{n}t_1} - 1 \quad , \tag{3.9}$$

and we define the observed pulser-peak counting rate as the number of pulser events registered in the pulser peak in the MCA spectrum per measurement live-time :

$$\dot{P}_{peak} =: \frac{P_{peak}}{LT} \quad . \tag{3.10}$$

Combining eqs. 3.6 - 3.10 we finally arrive at an expression for the observed pulser-peak counting rate :

$$\dot{P}_{peak} = \dot{p} \cdot \frac{e^{-\dot{n}t_1}}{1 - \dot{p}t_2} \tag{3.11}$$

Similar considerations are now applied to counts observed in a gamma peak in the MCA spectrum, in our case the counts in the 185 keV peak originating from the decay of ^{235}U. The probability to find a gamma event not disturbed by pile-up is given by the combined probability of non-pile-up with a pulser pulse and non-pile-up with another gamma pulse :

$$W_{non-pile-up\,gamma} = (1 - \dot{p}t_1) \cdot e^{-\dot{n}t_1} \quad , \tag{3.12}$$

using the same notation as above. The time a gamma event finds the system live is equal to the real-time minus the dead time due to processing of gamma and pulser events. According to eq. 3.3 the live-time for gamma events is then

$$TL_g = TL \quad . \tag{3.13}$$

The peak counts in the 185 keV peak observed in the MCA spectrum during real-time TR, or correspondingly, live-time TL is then given by :

$$N^{185} = \dot{n}^{185} \cdot TL \cdot (1 - \dot{p}t_1) \cdot e^{-\dot{n}t_1} \quad , \tag{3.14}$$

where $\dot{n}^{185}$ is the true input peak counting rate that would be observed in the MCA spectrum with an ideal analyzer exhibiting no dead-time and pile-up effects. Defining the observed 185 keV counting rate from measured peak counts during live-time TL :

$$\dot{N}^{185} =: \frac{N^{185}}{TL} \quad , \qquad (3.15)$$

we get an expression for the observed 185 keV-peak counting rate:

$$\dot{N}^{185} = \dot{n}^{185} \cdot (1 - \dot{p}t_1) \cdot e^{-\dot{n}t_1} \quad . \qquad (3.16)$$

Combining eqs. 3.11 and 3.16 we arrive at the pile-up and dead-time-corrected 185 keV peak counting rate

$$\dot{n}^{185} = \dot{N}^{185} \cdot \frac{\dot{p}}{\dot{p}_{peak}} \cdot \frac{1}{(1 - \dot{p}t_1)(1 - \dot{p}t_2)} \qquad (3.17)$$

Comparing eqs. 3.2. and 3.17 we find that the correction used in our data evaluation and the more exact correction given in eq 3.17 differ by the factor K :

$$K = \frac{1}{(1 - \dot{p}t_1)(1 - \dot{p}t_2)} \quad , \qquad (3.18)$$

that describes different counting losses for gamma-peak counts and pulser-peak counts, respectively. Note that for a constant-repetition-rate pulser ($\dot{p}$ = const.) with fixed amplitude the factor K is also a constant because the parameters t_2 = conversion time for a pulser event, and t_1 = pulse-pair resolving time are then fixed characteristics of the pulse-processing system, and do not depend on the counting rate of the input gamma spectrum. Therefore the correction for pile-up and dead-time applied in the present data evaluation according to eq. 3.2 seems to be justified.

It will be of interest to compare the predictions of our model with the experimental results. For this we rewrite eqs. 3.11 and 3.16 to present the relative deviations of the observed peak counting rates from the true input counting rates for the pulser and the 185 keV peak, respectively. Expanding the expressions into power series and neglecting nonlinear terms - which can be done for small pile-up and dead-time effects (about 1% in our case) - we get the following relations for both peak counting rates :

$$\frac{\dot{P}_{peak} - \dot{p}}{\dot{p}} = -\dot{n}t_1 + \dot{p}t_2 \quad , and \qquad (3.19)$$

$$\frac{\dot{N}^{185} - \dot{n}^{185}}{\dot{n}^{185}} = -\dot{n}t_1 - \dot{p}t_1 \qquad (3.20)$$

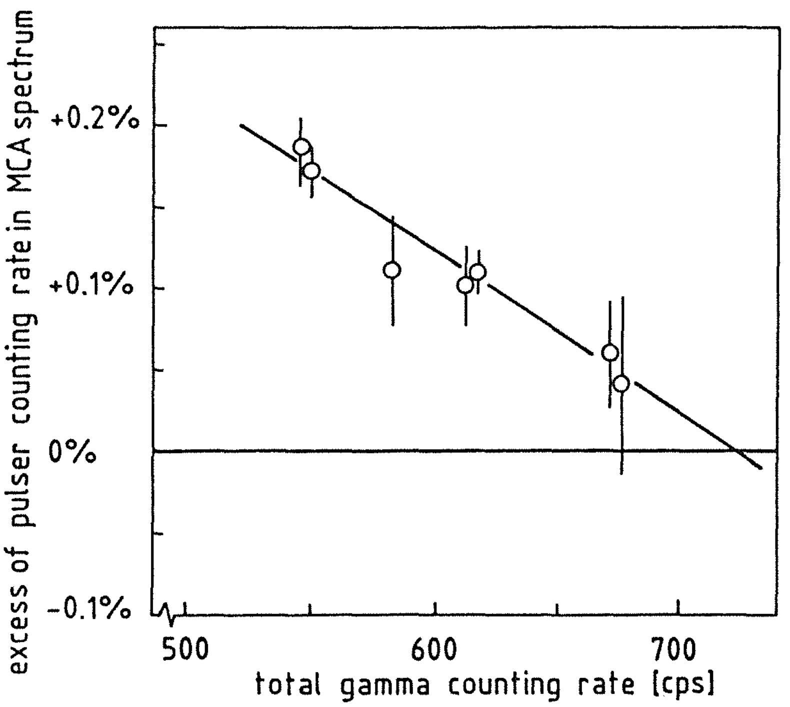

Fig. 9 *Relative deviations of the observed pulser-peak counting rates from the corresponding true pulser input rates versus total gamma counting rate.*

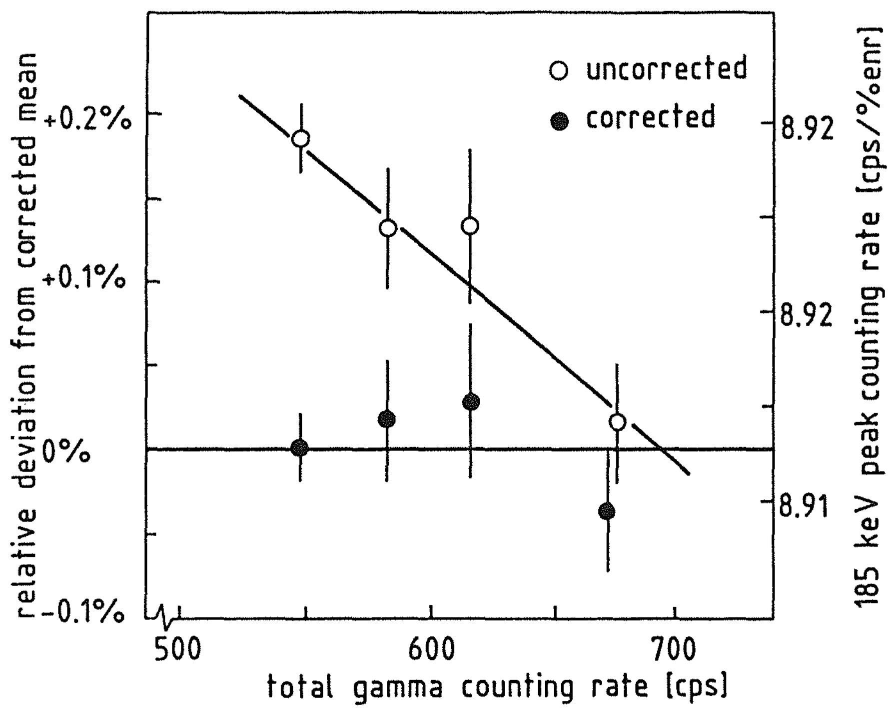

Fig. 10 *Relative deviations of observed 185 keV peak counting rates from the corrected mean value versus total gamma counting rate (open circles). Corrected values according to eq. 3.1 are given by closed circles. The corresponding peak counting rates in units of counts per second live-time are given on the right-hand scale.*

Eqs. 3.19 and 3.20 show that the relative deviations of the observed peak counting rates from the input counting rates are linear functions of the total gamma input rate exhibiting the same slope but different offsets. Because we cannot directly observe gamma input counting rates, instead of $\dot{n}^{185}$ in eq. 3.20 we refer to the mean value of the corrected 185 keV peak counting rates according to eq. 3.1. Note that all 185 keV counting rates are normalized to 1% ^{235}U abundance. For the relative deviation of the observed 185 keV counting rate per % enrichment from this mean value we obtain :

$$\frac{\dot{N}^{185} - \overline{\dot{N}^{185}_{corr}}}{\overline{\dot{N}^{185}_{corr}}} = -\dot{n}t_1 + \dot{p}t_2 \qquad (3.21)$$

Comparing eqs. 3.19 and 3.21 we expect the same functional dependence of the relative deviations for both types of peak counting rates when plotted versus total gamma counting rate $\dot{n}$. The experimental results are displayed in fig. 9 for the pulser peak (corresponding to eq. 3.19) and in fig. 10 for the 185 keV peak (corresponding to eq. 3.21). The data points given are mean values of measurements with same total gamma counting rates, the error bars represent the RMS errors from repeated measurements. The total gamma input rate $\dot{n}$ has been estimated from the total number of events registered in the MCA during live-time TL reduced by the pulser rate. The straight lines given in both figures have been obtained from weighted linear least-squares fits of the data. From these fits we can derive the system parameters t_1 and t_2 using the mean pulser input rate $\dot{p}$ = 140.79 cps from Table D4 in Appendix D:

	from fig. 9	from fig. 10
pulse-pair resolving time:	$t_1 = (10 \pm 1) \cdot 10^{-6}$ s	$t_1 = (12 \pm 3) \cdot 10^{-6}$ s
pulser-pulse conversion time:	$t_2 = (51 \pm 4) \cdot 10^{-6}$ s	$t_2 = (60 \pm 13) \cdot 10^{-6}$ s

Within the error limits the values of t_1 and t_2 compare quite well for the two types of peak counting rates considered indicating that our model is not in conflict with the experimental results. As expected the corrected 185 keV peak counting rates in fig. 10 are less dependent on the total gamma counting rates than the corresponding uncorrected values. Remembering the physical meaning of the parameters t_1 and t_2, the fitted values do not look very unrealistic : As mentioned above the pulse-pair resolving time is approximately equal to the total pulse width. For an amplifier shaping time of 1 µs used in the present experiments the total pulse width from the fit would then be about 10 times the shaping time which is a normal value for semi-gaussian filtering. The fitted pulser-pulse conversion time t_2 of about 50 µs also compares quite well to the ADC conversion time of 38 µs calculated from the ADC manual considering that the latter value does not include the transfer time to the MCA and the corresponding overhead.

In our data evaluation we have used eq. 3.1 for dead-time and pile-up correction instead of the correct formula given in eq. 3.17 assuming that the factor K defined in eq. 3.18 is constant. This assumption is not strictly fulfilled because the pulser frequency varied by ± 0.5% during the measurements. Using the fitted values of t_1 and t_2 we can get an estimate of the impact of pulser-rate variations on K and thus on the assay result. From Table D4 in Appendix D we get for the input pulser rate $\dot{p}$ and its variations :

$$\dot{p} = (140.79 \pm 0.37)\ \text{cps} \quad (\pm 0.26\%) \qquad \dot{p}_{min}(\#1) = 139.98\ \text{cps}\ (-0.58\%) \qquad \dot{p}_{max}(\#44) = 141.46\ \text{cps}\ (+0.48\%)$$

resulting in the corresponding values and variations of K :

$$K = (1.008611 \pm 0.000023) \quad (\pm 0.0023\%) \qquad K_{min} = 1.008561\ (-0.005\%) \qquad K_{max} = 1.008652\ (+0.004\%)$$

The variation of K is well below our desired accuracy level. Therefore the use of the more simple dead-time and pile-up correction according to eq. 3.1 is justified in our case thus avoiding the evaluation of the parameters t_1 and t_2 required for the more exact formulat 3.17.

If - for whatever reasons - the pulser rate is varied strongly then one should use eq. 3.17 instead of eq. 3.1 for dead-time and pile-up correction. In this case the determination of the required parameters is possible in a simple way from two measurements performed in addition to the routine assay :

1) measurement of the *pulser alone* : $\dot{p} = 0$, $\dot{n} = 0$, recording TL and TR, and the background-free pulser-peak counts. From eqs. 3.5 - 3.11 we obtain for this particular case :

$$\dot{p} = \frac{P_{peak}}{TR} \quad , \qquad (3.23)$$

$$t_2 = \frac{TR - TL}{P_{peak}} \quad , \tag{3.24}$$

$$1 - \dot{p}t_2 = \frac{TL}{TR} \quad . \tag{3.25}$$

2) measurement of a *gamma source alone* (either the actual RM or an unknown uranium sample) : $\dot{p} = 0$, $\dot{n} \neq 0$, recording the net-peak counting rate (per live-time) of a prominent gamma peak, here the 185 keV peak of the uranium sample. From eq. 3.16 we get

$$\dot{N}^{185}_{without\ pulser} = \dot{n}^{185}\, e^{-\dot{n}t_1} \tag{3.26}$$

3) *routine measurement* with *pulser and gamma source* (same sample as in measurement 2 must be used - equal $\dot{n}$) : $\dot{p} \neq 0$, $\dot{n} \neq 0$, recording net-peak counting rate (per live-time) of same gamma peak as in 2). Now we get

$$\dot{N}^{185}_{with\ pulser} = \dot{n}^{185} \cdot (1 - \dot{p}t_1) \cdot e^{-\dot{n}t_1} \quad . \tag{3.27}$$

From eqs. 3.26 and 3.27 we obtain the desired values of $(1 - \dot{p}t_1)$ and t_1 :

$$1 - \dot{p}t_1 = \frac{\dot{N}^{185}_{with\ pulser}}{\dot{N}^{185}_{without\ pulser}} \quad , and \tag{3.28}$$

$$t_1 = \frac{1}{\dot{p}} \left(1 - \frac{\dot{N}^{185}_{with\ pulser}}{\dot{N}^{185}_{without\ pulser}} \right) \quad . \tag{3.29}$$

Once the constants t_1 and t_2 are known one can do the corrections of further routine assays according to eq. 3.17 using the true pulser input rate $\dot{p}$ and the pulser-peak counting rate $\dot{P}_{peak}$ recorded in the MCA spectrum.

Summary of Section 3.2 :

For highly accurate gamma-spectroscopic ^{235}U enrichment assays the counting losses due to pulse pile-up and system dead-time must be corrected for, even at the comparatively low counting rates observed with this NDA technique. The simple correction by normalizing the peak counting rate of interest to a constant peak counting rate in a reference peak failed in our measurements due to instabilities of the reference sources used (^{241}Am and electronic pulser).

The counting-rate instability of the reference gamma source attached to the collimator is most probably caused by small distance variations between source and detector during the measurements. The counting geometry used – small source-to-detector distance and 2π radiation characteristic of the gamma source - is extremely susceptible to distance variations. Instead of this geometry we will use in future measurements a highly collimated gamma reference source with the beam axis directed towards the center of the detector crystal hoping to arrive at a better counting rate stability.

The dead-time- and pile-up-correction with reference to an electronic pulser is possible and was applied for the data evaluation presented in this paper. However, due to frequency instabilities of the pulser used this could be achieved only at the cost of an external counter/timer for the determination of the true pulser input rate. Therefore it seems to be desirable to put a special wish on the "letter to Santa-Claus", i.e., the electronics industries, namely to provide a real "high-precision" pulser with a guaranteed stability of better than 10^{-4} in repetition rate and amplitude under all working conditions (temperature, line voltage), quartz-controlled with digital parameter selection (avoiding error-prone switches and pot's) and with selectable rise- and fall-time to allow the matching of pulser pulses to the shape of gamma pulses.

3.3 Calibration

Once the correction for pulse losses due to the counting electronis and for wall-thickness differences are made as described in the previous sections we expect a linear relationship between the corrected 185 keV peak counting rate and the $^{235}U/U$ enrichment :

$$enr\,\% = A \cdot \dot{N}^{185}_{corr} + C_{int} \quad , \tag{3.30}$$

where the parameter C_{int} accounts for interfering gamma rays from the decay of the ^{238}U daughter ^{234}Pa. For low enriched uranium and ^{234}Pa being in secular equilibrium with ^{238}U (about 30 days after chemical separation) the value of C_{int} is estimated in ref. /1/ to

$$C_{int} = 0.001\,(enr\%)$$

The determination of the parameters A and C_{int} for the assay system to be calibrated is generally performed by measurements of suitable reference materials with known $^{235}U/U$ abundance. For our calibration measurements we have used samples #194, #295 and #446 of the set No. 008 of the Reference Material EC-NRM-171/NBS-SRM-969 that is specially designed for gamma-spectrometric ^{235}U enrichment assay (quasi-infinite samples) and exhibits very tightly specified $^{235}U/U$ abundance values and a well characterized sample canning (see Appendix E).

The sequence of the calibration measurements with embedded measurements of the unknown UF_6 sample is given in Table 5. The table also shows the number of repeats and the preset live-time for each measurement. In order to test the stability of our assay system we have subdivided the series of measurements into two groups : group 1 comprises measurement #1 to #46, group 2 measurement #47 to #61. The data evaluation, the calibration and the determination of the ^{235}U enrichment have been performed for both groups independently. In addition to this we have done the evaluation also for all measurements #1 to #61 together, resulting in three different data sets being used. The corresponding total counting times and the total number of 185 keV peak counts accumulated are displayed in Table 6 which may give an impression of the effort spent for the measurements in the present REIMEP-86 exercise.

TABLE 5 MEASUREMENTS PERFORMED WITH CALIBRATION SAMPLES AND REIMEP-86 UF6 SAMPLE.

MEASUREMENT NR	NUMBER OF REPEATS	SAMPLE	COUNTING TIME (SECONDS)
# 1 - #10	10	RM 4.5 %	20 000
#11 - #20	10	RM 3.0 %	30 000
#21 - #30	10	RM 2.0 %	45 000
#30 - #46	10 (16)*	UF6	30 000
#47 - #51	5	RM 4.5 %	20 000
#52 - #56	5	UF6	30 000
#57 - #61	5	RM 3.0 %	30 000

TABLE 6 TOTAL COUNTING TIMES AND TOTAL 185 KEV NET COUNTS ACCUMULATED IN THE MCA SPECTRUM.

DATA SET	COUNTING TIME (HOURS)	185 KEV COUNTS (MILLION COUNTS)
1 : FIRST 40 (46)* MEASUREMENTS :		
CALIBRATION RUNS (30)	270.1 H	23.9 MIO
UF6 RUNS (10/16*)	85.1 H (136.1 H)	9.2 MIO (14.7 MIO)
ALL RUNS (40/46*)	355.2 H (406.3 H)	33.1 MIO (38.6 MIO)
2 : LAST 15 MEASUREMENTS :		
CALIBRATION RUNS (10)	71.1 H	8.0 MIO
UF6 RUNS (5)	42.5 H	4.6 MIO
ALL RUNS (15)	113.7 H	12.6 MIO
3 : ALL 55 (61)* MEASUREMENTS :		
CALIBRATION RUNS (40)	341.4 H	32.0 MIO
UF6 RUNS (15/21*)	127.6 H (178.7 H)	13.7 MIO (19.2 MIO)
ALL RUNS (55/61*)	468.9 H (520.0 H)	45.7 MIO (51.2 MIO)

*) FOR MEASUREMENTS #35 TO #40 THE EXTERNALLY DETERMINED TRUE COUNTING RATE OF THE PULSER HAVE NOT BEEN RECORDED DUE TO A PRINTER FAULT. THEREFORE THESE MEASUREMENTS HAVE BEEN INCLUDED IN THE EVALUATION PROCEDURE ONLY IN THOSE CASES WHERE NO NORMALISATION TO THE PULSER COUNTING RATE IS PERFORMED. THE CORRESPONDING COUNTING TIMES AND TOTAL 185 KEV COUNTS ARE GIVEN IN BRACKETS.

The calibration has been performed following the procedure given in Section 5.4.3 in ref. /1/ and outlined in the BASIC program ER2FIT in Appendix E of ref. /1/. Only minor changes have been made to the version of ER2FIT listed in /1/: The variance and covariance values are not multiplied by omega-square, and omega-square is set arbitrarily to 1 if the degree of freedom is zero. The program ER2FIT calculates the linear least-squares-fit solution for the parameters A and C_{int} in eq. 3.20 taking into account that both variables - the stated ^{235}U enrichment value and the 185 keV counting rate - are subject to errors. The former uncertainties have been taken from the certificate accompanying the Reference Material (see Appendix E of this paper). Note that the program ER2FIT expects the errors at the 1 σ level as input so that the uncertainties given in the certificate at 2 σ have to be divided by a factor of 2.

When using the program ER2FIT one should consider that it is based on the assumption that all input values are independent from each other. In repeated measurements this condition is not fulfilled for the observations of the ^{235}U enrichment and of the wall thickness because these values are unique for a particular sample and they are not determined independently anew for each repeat in contrast to the gamma counting rate. It is therefore recommended to evaluate first the mean values of 185 keV counting rates from repeated measurements of each particular sample and then to use these mean values as input to ER2FIT in order to provide independence of input data and to arrive at correct error estimates of the calculated fit parameters.

Two independent error estimates have been obtained for the counting statistics in the 185 keV peak : 1. from the peak evaluation of the spectral data for each measurement, 2. from the variance of repeated measurements. Though the differences of both error estimates turned out to be comparatively small we have performed the calculations for both types of error estimates separately. Note that the uncertainty from the wall-thickness determination has to be added to the error due to counting statistics to arrive at the total counting-rate error being input to ER2FIT.

In order to investigate the impact of the various corrections applied we have further carried out the data evaluation with and without correction for counting losses, and using both the wall-thickness values from the data sheets and from our own ultrasonic measurements.

The different data-evaluation conditions can be grouped in the following scheme :

a) no correction for dead-time and pile-up effects,
   correction for dead-time and pile-up,

b) wall-thickness correction from data sheets,
   wall-thickness correction from own measurements,

c) counting errors from peak evaluation,
   counting errors from repeated measurements,

d) measurements #1 to #46 only,
   measurements #47 to #61 only,
   all measurements.

Out of these conditions all possible combinations have been formed resulting in 24 different data sets. For each of these data sets the calibration and the evaluation of the $^{235}U/U$ abundance has been performed individually.

The input data and the results of the 24 calibration runs are given in Appendix B. The tables and printouts are self-explaining and do not require detailed comments. The Tables B1 to B4 in Appendix B display the corrected 185 keV gamma counting rates of individual calibration measurements evaluated according to combinations of conditions a) and b) given above. The errors are given at the 1 σ level. Besides the total error of the 185 keV peak counting rate also its two constituents are shown : the error due to counting statistics and the uncertainty from the wall-thickness correction. The statistical counting error is taken from the spectrum evaluation of a single measurement. It comprises the variance of the peak counting rate, the error from background subtraction and the error from pulse-loss corrections if applicable. The tables B1 to B4 also show the stated ^{235}U enrichment values of the respective Reference Material used. The given ^{235}U enrichment uncertainties refer to the 1 σ errors from the Certificate.

Following each of the Tables B1 to B4 the unweighted mean values of the 185 keV counting rates from the Reference Materials involved are listed along with the associated errors (two types of errors according to condition c above). The calibration has been performed for three different groups of measurements (see condition d above), so that finally from each of the Tables D1 to D4 six different sets of calibration parameters have been derived.

Note that in the printouts of the programme ER2FIT given in Appendix B the calibration parameters A and C_{int} of eq. 3.20 are denoted as "slope" and "offset", respectively. The variance and covariance values of "slope" and "offset" are shown at the end of the respective printout and will be used to determine the calibration error at the 185 keV counting rate of the unknown sample as described below.

The quality of the fits - i.e., the consistency of the data and of the associated errors with the assumption of a linear model including a fixed gamma-interference term $C_{int} = 0.001$ - has been tested as described in Section 5.4.4 in ref. /1/ : All fitted values of C_{int} passed the t-test, and also the omega-square test - if applicable. It shows that our data are in good agreement with the assumed linear relationship between the 185 keV gamma counting rate and the $^{235}U/U$ abundance.

4. EVALUATION OF $^{235}U/U$ ISOTOPE ABUNDANCE

The ^{235}U abundance is obtained by inserting the corrected 185 keV gamma counting rate observed from the measurement of the unknown sample into eq. 3.30 given in the previous Section using the parameters A and C_{int} from the corresponding calibration run. Note however, that we have to account for different gamma attenuation in the UF_6 samples and the U_3O_8 Reference Material used for calibration of the assay system. This matrix attenuation correction factor

$$K_m = 1.0231 \qquad (normalizes\ UF_6\ to\ U_3O_8)$$

has to be applied to the corrected 185 keV gamma counting rate of UF_6 material in order to normalize it to the 185 keV counting rate of U_3O_8 - the material used for calibration. The value of K_m given is taken from the data sheets REIMEP-86 App. 7 (see Appendix E of the present paper). A possible error for the matrix attenuation factor K_m is not accounted for in the present data evaluation. Normalization of the 185 keV counting rate from the UF_6 sample is done by

$$\dot{N} =: K_m \cdot \dot{N}^{185}_{corr\ all} \quad , \tag{4.1}$$

where $\dot{N}^{185}_{corr\ all}$ is the observed 185 keV counting rate corrected for wall-thickness differences (see Table 4) and - if applicable - for counting losses due to pile-up and dead-time (see eqs. 3.1 and 3.2). Using the abbreviation

$$C =: C_{int} \tag{4.2}$$

and eq. 4.1 we arrive at a corresponding form of eq. 3.30 for the UF_6 samples:

$$enr\% = A \cdot \dot{N} + C \tag{4.3}$$

where the calibration constants A and C must be taken from the particular calibration run observing the same evaluation conditions. The error estimate for the $^{235}U/U$ abundance obtained from eq. 4.3 is given by:

$$\Delta\, enr\% = \sqrt{A^2 \cdot \Delta^2\dot{N} + \dot{N}^2 \cdot var(A) + 2\,\dot{N} \cdot cov(A,C) + var(C)} \tag{4.4}$$

The uncertainty of the 185 keV counting rate ΔN comprises both the counting rate error and the wall-thickness correction error as well. The variance and covariance values are taken from the corresponding calibration runs. The first term of the square root in eq. 4.4 represents the error due to the measurement of the unknown UF_6 sample, the remaining three terms are considered as calibration error.

The $^{235}U/U$ abundance of the unknown UF_6 sample has been determined following the same scheme of evaluation conditions as outlined in the previous

Section. Therefore we obtain 24 different $^{235}U/U$ values for the UF_6 sample according to the selection of various data sets and of various corrections applied using the corresponding 24 sets of calibration constants evaluated under same conditions.. The calculations are documented in Appendix C. The tables and listings given are mostly self-explaining, they show the corrected 185 keV counting rates of individual measurements of the UF_6 sample, the associated errors, the mean values of the counting rates and the $^{235}U/U$ abundance values finally obtained. Besides the estimate of the total error of the ^{235}U enrichment also the two constituents - measurement error of UF_6 sample and calibration error, respectively - are listed in Appendix C.

TABLE 7 235U % ABUNDANCE VALUES OBTAINED FROM GAMMA-SPECTROMETRIC MEASUREMENTS OF THE REIMEP-86 UF6 SAMPLE USING DIFFERENT DATA SETS AND OBSERVING VARIOUS DATA-EVALUATION CONDITIONS. ESTIMATES OF TOTAL ERRORS AT 1 SIGMA LEVEL (68 % CONFIDENCE) ARE GIVEN BELOW 235U ABUNDANCE VALUES AT CORRESPONDING DECIMALS.

CONDITIONS OF DATA EVALUATION	DATA FROM FIRST MEASURE-MENTS ONLY	DATA FROM LAST MEASURE-MENTS ONLY	DATA FROM ALL MEASURE-MENTS
COUNTING-ERROR ESTIMATES FROM SPECTRUM EVALUATION			
NO COUNTING TIME CORRECTION, THICKNESS FROM DATA SHEETS	3.5046 17	3.5000 25	3.5034 15
NO COUNTING TIME CORRECTION, THICKNESS MEASURED AT KFK	3.5054 16	3.5009 24	3.5042 15
COUNTING TIME CORRECTION, THICKNESS FROM DATA SHEETS	3.5007 20	3.4970 26	3.4996 17
COUNTING TIME CORRECTION, THICKNESS MEASURED AT KFK	3.5014 19	3.4979 26	3.5004 17
COUNTING-ERROR ESTIMATES FROM REPEATED MEASUREMENTS			
NO COUNTING TIME CORRECTION, THICKNESS FROM DATA SHEETS	3.5049 18	3.5000 23	3.5036 16
NO COUNTING TIME CORRECTION, THICKNESS MEASURED AT KFK	3.5056 17	3.5009 22	3.5043 15
COUNTING TIME CORRECTION, THICKNESS FROM DATA SHEETS	3.5009 17	3.4970 21	3.4997 15
COUNTING TIME CORRECTION, THICKNESS MEASURED AT KFK	3.5016 17	3.4979 21	3.5005 * 15 *

* 235U % ABUNDANCE VALUE AND ASSOCIATED ERROR REPORTED TO CBNM GEEL.

The results of all 24 calculated $^{235}U/U$ abundance values and the associated errors at the 1 σ level are summarized in Table 7 along with the matching data-evaluation conditions. It can be seen from Table 7 that the differences of corresponding $^{235}U/U$ abundance values calculated with the two counting-error estimates (type I: from spectral evaluation of single measurements and type II:

from the variance of repeated measurments), are very small. They correspond to a mean bias of

Bias (counting error estimate II/I) = + 0.0001 enr%   (+0.003 % rel.)

for counting-error estimate type II as compared to type I. This difference is considered as statistically not significant. It demonstrates that both types of independent error estimates are in good agreement. Thus in the following we have somewhat arbitrarily used the mean value of the $^{235}U/U$ abundance and of the associated errors obtained with the two different types of counting-error estimates. Also the graphic presentation of the assay results shown in fig. 11 and the final $^{235}U/U$ abundance value reported to CBNM Geel refer to these mean values.

From Table 7 we can also extract information on the impact of the two different types of wall-thickness corrections performed (see Chapter 2): type I: all wall-thickness values from data sheets, and type II: all wall-thickness values from own ultrasonic measurements,. The resulting bias is

Bias (wall-thickness corr. I/II) = – 0.0008 enr%   (– 0.023 % rel.)

with correction type I as compared to correction type II which is finally used for the reported $^{235}U/U$ abundance. It should be noted here again that we had difficulties in measuring the wall thickness of the monel bottom of the UF_6 sample (see Chapter 2): Our measured value was about 3 μm thicker than that of the reference monel disk supplied with the REIMEP-86 sample, whereas the data sheet indicates identical thickness of both monel items with uncertainties of 1 μm only. Assuming same wall thickness for the UF_6 sample bottom and for the reference monel disk, and using the thicknes values from our own measurements in all other cases we arrive at a third type of wall-thickness correction. Compared to this correction our reported $^{235}U/U$ abundance value has a positive bias of

Bias (wall-thickness corr. II/III) = + 0.0014 enr%   (+ 0.04 % rel.).

This demonstrates that the thickness of the counting window of the sample to be measured must be very carefully controlled in order to arrive at highly accurate assay results.

The most important contribution to systematic errors in the present measurements is due to dead-time and pile-up effects. Table 7 shows that the $^{235}U/U$ abundance values calculated without counting loss correction exhibit a positive bias of

Bias (without/with counting loss corr.) = + 0.0036 enr%   (+ 0.1 %).

Therefore, counting-loss corrections should be applied to the measured 185 keV peak counts even at the comparatively low counting rates normally observed with gamma-spectrometer assays of low enriched uranium samples.

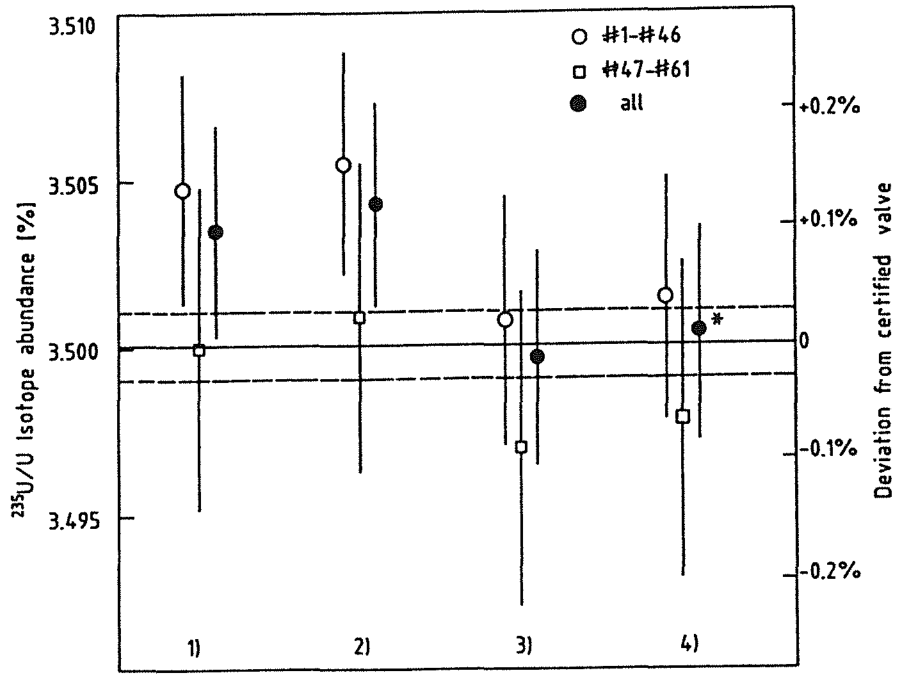

Fig. 11 $\quad$ *235U/U abundance of the REIMEP-86 UF_6 sample obtained from different measurement-data sets using various corrections. Errors are given at the 2 σ level (95 % confidence).*

1) No counting-loss corrections, wall thickness from data sheets
2) No counting-loss corrections, wall thickness from KfK measurements
3) Correction for counting loss, wall thickness from data sheets
4) Correction fro counting loss, wall thickness from KfK measurements

** 235U/U abundance value and associated error reported to CMNM Geel*

It may also be of interest to observe the time dependence of the assay results. Though the number of measurements is too small to get valid information at the desired accuracy level we may compare the $^{235}U/U$ abundance value obtained from the first 46 measurements to that independently evaluated from the last 15 measurements. The former value is about 0.1 % higher than the latter one. This difference is slightly outside the range expected from the counting statistics, however it does not give a clear indication for a time dependence of the measurement results.

The results shown in Table 7 obtained from different data sets, different evaluation conditions and different corrections applied are displayed in fig. 11. The data given in the figure are mean values of the corresponding data in the upper and lower half of Table 7. The error bars shown present the total uncertainty of the $^{235}U/U$ abundance values at the 2 σ level (95 % confidence) in contrast to Table 7 that gives the errors at the 1 σ level. These errors comprise the stated uncertainties of the $^{235}U/U$ values of the Reference Material used for calibration, the uncertainties introduced by wall-thickness corrections, counting statistics and, if applicable, by pulse-loss corrections. The certified $^{235}U/U$ abundance value for the REIMRP-86 UF_6 sample and its error are indicated by horizontal lines in fig. 11, the relative deviations from this value are given on the right-hand scale in the figure.

The data shown in fig. 11 clearly demonstrate that pulse losses due to dead-time and pile-up effects contribute in our measurements the most important fraction to the systematic error. Applying pulse-loss corrections and using all measurement data we finally arrive at three different values of the $^{235}U/U$ abundance of the REIMEP-86 UF_6 sample according to different data for the container-wall thickness:

1. Wall-thickness values from data sheets:

   3.4997 ± 0.0033 % $^{235}U/U$

2. Wall-thickness values from measurements at KfK:

   3.5005 ± 0.0031 % $^{235}U/U$

3. Wall-thickness values from measurements at KfK, except for the monel bottom of the UF_6 sample whose thickness is assumed here to be identical to that of the monel calibration disk:

   3.4991 ± 0.0031 % $^{235}U/U$.

Closing this Section, Tab. 8 shows the contribution of various errors to the final accuracy of the gamma-spectrometric $^{235}U/U$ abundance determination of the REIMEP-86 UF_6 sample given in terms of absolute and relative errors at the 2 σ level. It can be deduced from Table 8 that in our measurements we have brought down the counting error to the same magnitude as the contribution of the remaining uncertainties. Further, it can be seen that the errors due to the calibration and due to the measurement of the unknown sample, respectively, are approximately equal. Note however that an extremely long counting time of about 500 hours was required to arrive at this goal.

TABLE 8 CONTRIBUTION OF VARIOUS ERRORS TO FINAL ACCURACY OF THE GAMMA-SPECTROSCOPIC 235U ABUNDANCE DETERMINATION OF THE UF6 SAMPLE REIMEP-86. (UNCERTAINTIES ARE GIVEN IN TERMS OF ABSOLUTE AND RELATIVE ERRORS AT 2 SIGMA = 95 % CONFIDENCE.)

SOURCE OF ERROR	ABSOLUTE 235U ABUNDANCE ERROR (3.5005 +- ...)	RELATIVE 235U ABUNDANCE ERROR (%)
1) ERRORS DUE TO CALIBRATION USING REFERENCE MATERIALS :		
ERROR DUE TO UNCERTAINTIES OF NRM 235U ABUNDANCES :	+- 0.0016	0.046 %
ERROR DUE TO THICKNESS UNCERTAINTIES OF NRM BOTTOMS :	+- 0.0007	0.021 %
COUNTING ERRORS FROM PEAK EVALUATIONS :	+- 0.0015	0.044 %
(FROM REPEATED MEASUREMENTS :)	(+- 0.0017	0.050 %)
ALL CALIBRATION ERRORS AT 3.5 % U235 ABUNDANCE :	+- 0.0023	0.067 %
(SEE ABOVE)	(+- 0.0025	0.071 %)
2) ERRORS DUE TO UF6 SAMPLE MEASUREMENTS :		
ERROR DUE TO THICKNESS UNCERTAINTY OF UF6 SAMPLE BOTTOM :	+- 0.0009	0.026 %
COUNTING ERRORS FROM PEAK EVALUATIONS :	+- 0.0021	0.061 %
(FROM REPEATED MEASUREMENTS :)	(+- 0.0013	0.036 %)
ALL ERRORS FROM REIMEP-86 UF6 SAMPLE MEASUREMENTS :	+- 0.0023	0.066 %
(SEE ABOVE)	(+- 0.0015	0.044 %)
3) ERROR CONTRIBUTION OF BOTH CALIBRATION- AND UF6-MEASUREMENTS :		
ALL ERRORS EXCEPT COUNTING ERRORS *) :	+- 0.0020	0.057 %
ONLY COUNTING ERRORS FROM PEAK EVALUATIONS :	+- 0.0026	0.075 %
(FROM REPEATED MEASUREMENTS :)	(+- 0.0021	0.061 %)
TOTAL ERROR :	+- 0.0033	0.094 %
(VALUES IN BRACKETS REFER TO COUNTING-ERROR ESTIMATES FROM REPEATED MEASUREMENTS.)	(+- 0.0029	0.084 %)

*) DOESN'T INCLUDE UNCERTAINTY OF THE MATRIX CORRECTION FACTOR KM = 1.0231 GIVEN IN REIMEP-86 APP. 7/APP. NDA-1 THAT ACCOUNTS FOR DIFFERENT GAMMA ABSORPTION IN THE UF6 SAMPLE AND THE U3O8 NRM'S.

SUMMARY AND CONCLUSIONS

The REIMEP-86 exercise has shown that gamma-spectroscopic $^{235}U/U$ abundance measurements can deliver assay results with a relative accuracy of the order of 0.1 % at the 2 σ level (95 % confidence). This accuracy can only be achieved when the assay system is calibrated with adequately specified reference material. In our measurements the calibration was performed using the Reference Material EC-NRM-171 for gamma-spectroscopic ^{235}U enrichment assays providing a certified accuracy of about 0.05 % relative with respect to the $^{235}U/U$ isotope abundance.

The "enrichment-meter" principle applied for the measurement is based on the exact determination of the characteristic 185 keV gamma-radiation intensity emitted from a "quasi-infinite" ^{235}U bearing sample. The method is therefore susceptible to violations of the "quasi-infinite" sample condition, to varying gamma attenuation in the counting windows of the sample containers used, and to counting losses introduced by the electronic pulse-processing. A general scheme for the selection of counting geometries providing the "quasi-infinite-sample" condition is given in Chapter 1 of this report. The counting set-up used for the present measurements assures this condition for all samples assayed. The wall thickness of the sample containers used - Reference Material and UF_6 sample as well - have been remeasured at KfK by means of an ultrasonic thickness gauge (Chapter 2). The final $^{235}U/U$ abundance value of the REIMEP-86 UF_6 sample reported to CBNM Geel refers to these measured thickness values. The evaluation of the 185 keV net-peak counting rate and the correction for counting losses are described in Chapter 3 of the report. It should be noted that the counting-loss correction contributed the most important fraction to all corrections applied to the raw measurement data.

The total counting time spent for the measurements presented in this report was about 500 hours, more than 50 000 000 counts have been accumulated in the 185 keV peak of the measured spectra. The best value of the $^{235}U/U$ abundance of the REIMEP-86 UF_6 sample - evaluated from our measurements and reported to CBNM Geel was

$$3.5005 \pm 0.0031 \% \ ^{235}U/U \qquad \text{(measured at KfK)}$$

where the total error is given at the 2 σ level, ie., the true $^{235}U/U$ abundance value is expected to be enclosed within the error limits with a probability of 95 %. The total error given comprises uncertainties due to counting statistics, due to wall-thickness measurements and due to the limited accuracy of the Reference

TABLE 9 CHARACTERISTICS OF THE COUNTING SET-UP USED FOR REIMEP-86 UF6 SAMPLE COMPARED TO A VIRTUAL SET-UP OPTIMIZED FOR SHORT COUNTING TIME.

<table>
<tr><th></th><th>REIMEP-86 UF6</th><th>OPTIMIZED SET-UP</th></tr>
<tr><td colspan="3">SAMPLE PARAMETERS :</td></tr>
<tr><td>SAMPLE DIAMETER :</td><td>3.5 CM</td><td>6.0 CM</td></tr>
<tr><td>MIN. RECOMMENDED *)
UF6 SAMPLE MASS :</td><td>70 G</td><td>205 G</td></tr>
<tr><td>ACTUAL UF6 SAMPLE MASS :</td><td>80 G</td><td>235 G</td></tr>
<tr><td>UF6 SAMPLE DENSITY :</td><td colspan="2">5.1 G CM^{-3}</td></tr>
<tr><td>UF6 SAMPLE AREAL DENSITY :</td><td colspan="2">8.2 G CM^{-2}</td></tr>
<tr><td colspan="3">COLLIMATOR PARAMETERS :</td></tr>
<tr><td>COLLIMATOR DIAMETER :</td><td>2 CM</td><td>4 CM</td></tr>
<tr><td>COLLIMATOR HEIGHT :</td><td>2 CM</td><td>2 CM</td></tr>
<tr><td>ENTRANCE AREA :</td><td>3.14 CM^2</td><td>12.6 CM^2</td></tr>
<tr><td>REL. COLLIMATOR TRANSMISSION *)</td><td>0.172</td><td>0.382</td></tr>
<tr><td colspan="3">GAMMA-ATTENUATION CORRECTIONS :</td></tr>
<tr><td>GEOMETRY FACTOR K_{ABS} *) :</td><td>1.095</td><td>1.23</td></tr>
<tr><td>LIN. ATT. COEFF. MONEL :</td><td colspan="2">1.3 CM^{-1}</td></tr>
<tr><td>THICKNESS MONEL :</td><td colspan="2">0.2 CM</td></tr>
<tr><td>TRANSMISSION MONEL *) :</td><td>0.752</td><td>0.726</td></tr>
<tr><td>LIN. ATT. COEFF. AL :</td><td colspan="2">0.34 CM^{-1}</td></tr>
<tr><td>THICKNESS AL :</td><td colspan="2">0.20 CM</td></tr>
<tr><td>TRANSMISSION AL *) :</td><td>0.928</td><td>0.920</td></tr>
<tr><td>TRANSMISSION TOTAL :</td><td>0.698</td><td>0.668</td></tr>
<tr><td>MATRIX CORR. BETA(UF6/U METAL) *) :</td><td colspan="2">0.963</td></tr>
<tr><td colspan="3">185 KEV PEAK COUNTING RATES :</td></tr>
<tr><td>SPECIFIC 185 KEV SURFACE ACTIVITY
FOR THICK U METAL SAMPLE *) :</td><td colspan="2">77 CPS CM^{-2} $(\%ENR)^{-1}$</td></tr>
<tr><td>EXPECTED MAX. COUNTING RATE
AT COLLIMATOR OUTPUT *) :</td><td>27.9 CPS $(\%ENR)^{-1}$</td><td>237.8 CPS $(\%ENR)^{-1}$</td></tr>
<tr><td>OBSERVED COUNTING RATE :</td><td>8.7 CPS $(\%ENR)^{-1}$</td><td>95.1 CPS $(\%ENR)^{-1}$</td></tr>
<tr><td>--> TOT. PEAK EFFICIENCY :</td><td>31 %</td><td>40 %</td></tr>
</table>

<table>
<tr><td colspan="3">ESTIMATED COUNTING TIME REQUIRED FOR 0.09 % REL. ACCURACY (2 SIGMA)
FOR A UF6 SAMPLE WITH 3.5 % 235U ABUNDANCE (FROM PRESENT EXERCISE):</td></tr>
<tr><td>CALIBRATION :</td><td>341 HOURS</td><td>31 HOURS</td></tr>
<tr><td>ACCUMULATED 185 KEV COUNTS :</td><td colspan="2">32 000 000</td></tr>
<tr><td>UF6 MEASUREMENT :</td><td>128 HOURS</td><td>12 HOURS</td></tr>
<tr><td>ACCUMULATED 185 KEV COUNTS :</td><td colspan="2">13 700 000</td></tr>
<tr><td colspan="3">ESTIMATED COUNTING TIME REQUIRED FOR 0.2 % REL. ACCURACY (2 SIGMA)
FOR A UF6 SAMPLE WITH 3.5 % 235U ABUNDANCE :</td></tr>
<tr><td>CALIBRATION :</td><td>341 HOURS</td><td>31 HOURS</td></tr>
<tr><td>ACCUMULATED 185 KEV COUNTS :</td><td colspan="2">32 000 000</td></tr>
<tr><td>UF6 MEASUREMENT :</td><td>12 HOURS</td><td>1 HOUR</td></tr>
<tr><td>ACCUMULATED 185 KEV COUNTS :</td><td colspan="2">1 300 000</td></tr>
</table>

*) FROM " USER'S MANUAL " FOR EC NRM 171 (KFK REPORT 3752), (SEE APPENDIX F)

Material used for calibration. The error does not include uncertainties of the matrix correction factor K_m used for normalization of UF_6 material (REIMEP-86 sample) to U_3O_8 material (EC-NRM-171). The contribution of counting statistics to the total relative error of 0.09 % was about 0.07 % whereas the remaining uncertainties (wall thickness, $^{235}U/U$ abundance) added up to about 0.06 %.

The certified value for the $^{235}U/U$ abundance of the REIMEP-86 UF_6 sample

$$3.5001 \pm 0.0010 \, \% \, ^{235}U/U \qquad \text{(certified by CBNM Geel)}$$

reported by CBNM Geel after completion of the REIMEP-86 exercise compares very well with our result.

The experience gained from our measurements can be summarized in four salient points:

1. It must be stressed that "enrichment-meter" assays of low enriched uranium (LEU) are inherently suited only for measurements of bulk material quantities. This is due to the "quasi-infinite-sample" postulate and due to the comparatively low emission rate of the 185 keV gamma rays in LEU. In the present measurements an unduely long counting time was required to bring the statistical counting error down to a level comparable to the remaining uncertainties. A larger sample could have reduced the required counting time significantly. As shown in Table 9 we have calculated the peak counting rate expected from a larger sample with 6 cm diameter containing about 235 g UF_6 instead of 80 g UF_6 used in the REIMEP-86 sample. With this larger sample a 10 times higher counting rate is achievable, thus the counting time spent for the present exercise would have been reduced from one month to about 3 days preserving the same counting precision.

2. Relative errors of about 0.1 % (2 σ) for gamma-spectroscopic ^{235}U enrichment assays seem to be the ultimate accuracy limit. This is mainly due to practical reasons: counting time, accuracy of calibration standards, wall-thickness control. For in-field operations an accuracy limit of 0.2 % relative looks more realistic (see Table 9). When 250 g samples are used for the assays then counting times of one to two hours are required to arrive at relative accuracies of 0.2% at 2 σ. Note that the error in this case is dominated by the counting statistics from the measurement of the unknown sample. The errors due to calibration and due to the various corrections are assumed to be comparatively small. Therefore, in order to maintain the high performance of

the assay system, dynamic calibration strategies (i. e. , when, how long, and which reference material should be measured) and quality control measures need to be developed.

3. The exact determination of the wall thickness of the sample containers presents a serious problem since a precision of few µm is required when ultimate measurement accuracy is desired.

4. Counting-loss corrections are necessary even at comparatively small variations of the input counting rates. The availability of a highly accurate electronic pulser is strongly desired. The positional stability of the gamma-ray reference source relative to the detector created difficulties in our present measurements. The use of a collimated gamma source will probably remove this problem.

REFERENCES

/1/ P. Matussek, "Accurate Determination of the ^{235}U Isotope Abundance by Gamma Spectrometry - A User's Manual for the Certified Reference Material EC-NRM-171/NBS-SRM-969", Report KfK 3752 (1985)

/2/ H. Eberle, P. Matussek, "Computer Programs for the Accurate Determination of the ^{235}U Isotope Abundance by Gamma Spectrometry", unpublished internal report of the KfK (1987).

/3/ R.Gunnink, J.B. Niday, "Computerized Quantitative Analysis by Gamma-Ray Spectrometry", Report UCRL.51061 (1971).

/4/ E.T. Cohen, "Live Time and Pile-up Correction for Multichannel Analyzer Spectra", Nucl. Instr. and Meth. 121 (1974) 25.

Appendix A

REIMEP UF_6 1986 exercise.

Data from gamma-spectrometric measurements
recorded to file ' UDATA '.

TABLE A1 DATA FORMAT ON FILE 'UDATA'

```
HEADER RECORD:  'STANDARD'/'UNKNOWN',
                235U ABUNDANCE (%),
                ERROR OF 235U ABUNDANCE,
                LIFE TIME OF MEASUREMENT (S),
                BOTTOM THICKNESS CORRECTION I (CBNM VALUES),
                ERROR OF BOTTOM THICKNESS CORRECTION,
                BOTTOM THICKNESS CORRECTION II (KFK VALUES),
                ERROR OF BOTTOM CORRECTION II,

DATA RECORD:    DATE OF MEASUREMENT,
                TIME OF DAY MEASUREMENT START,
                REAL TIME PULSER COUNTER (S),
                TOTAL COUNTS PULSER COUNTER,
                NET COUNTS OF PULSER IN MCA SPECTRUM,
                ERROR OF OF PULSER COUNTS IN MCA SPECTRUM,
                NET COUNTS OF 59 KEV PEAK IN MCA SPECTRUM,
                ERROR OF 59 KEV PEAK COUNTS IN MCA SPECTRUM,
                NET COUNTS OF 185 KEV PEAK IN MCA SPECTRUM,
                ERROR OF 185 KEV PEAK COUNTS IN MCA SPECTRUM,
                TOTAL COUNTING RATE IN MCA SPECTRUM (1/S),
                CHANNEL POSITION OF 59 KEV PEAK,
                FWHM OF 59 KEV PEAK (EV),
                FWTM OF 59 KEV PEAK (EV),
                FWFM OF 59 KEV PEAK (EV),
                CHANNEL POSITION OF 185 KEV PEAK,
                FWHM OF 185 KEV PEAK (EV),
                FWTM OF 185 KEV PEAK (EV),
                FWFM OF 185 KEV PEAK (EV),
                CHANNEL POSITION OF PULSER PEAK,
                FWHM OF PULSER PEAK (EV),
                FWTM OF PULSER PEAK (EV),
                FWFM OF PULSER PEAK (EV
DATA RECORD:    ...
                ...
                ...
DELIMITER:      'END'
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TABLE A2 CONTENT OF FILE 'UDATA'

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FR/09/JAN/1987, 21:21:00, 20507, 2872953, 2802880, 1684, 2685674, 1675, 806274, 929
815. , 479. 12, 765, 1457, 3057, 1819. 05, 915, 1674, 2218, 2668. 29, 699, 1280, 1673
SA/10/JAN/1987, 03:03:55, 20512, 2875363, 2805702, 1685, 2682189, 1677, 806622, 929
815. , 479. 12, 759, 1442, 3094, 1819. 07, 911, 1665, 2206, 2668. 08, 691, 1269, 1654
SA/10/JAN/1987, 08:46:53, 20508, 2879079, 2808981, 1686, 2688913, 1681, 804857, 929
815. , 479. 16, 750, 1411, 2926, 1819. 07, 893, 1640, 2156, 2668. 23, 679, 1233, 1592
SA/10/JAN/1987, 14:29:48, 20516, 2882961, 2811898, 1686, 2686199, 1682, 805548, 924
815. , 479. 16, 753, 1412, 2949, 1819. 07, 895, 1639, 2164, 2668. 40, 681, 1236, 1597
SA/10/JAN/1987, 20:12:50, 20511, 2883023, 2812671, 1687, 2689866, 1683, 805128, 929
815. , 479. 16, 752, 1415, 2925, 1819. 05, 902, 1639, 2164, 2668. 34, 690, 1252, 1620
SU/11/JAN/1987, 01:55:49, 20520, 2881660, 2812216, 1687, 2686914, 1676, 805877, 929
815. , 479. 12, 767, 1453, 3026, 1819. 05, 913, 1673, 2212, 2667. 09, 699, 1282, 1667
SU/11/JAN/1987, 07:38:56, 20504, 2882200, 2812530, 1687, 2689616, 1673, 805836, 928
815. , 479. 11, 770, 1463, 3104, 1819. 05, 916, 1682, 2220, 2667. 29, 702, 1287, 1677
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815. , 479. 12, 768, 1455, 3101, 1819. 03, 912, 1672, 2223, 2666. 93, 698, 1283, 1671
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STANDARD, 2. 9857, . 00105, 30000, . 99959, . 00015, . 99969, . 00018
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756. , 479. 10, 766, 1454, 3078, 1819. 03, 913, 1679, 2212, 2667. 41, 710, 1306, 1701
TU/13/JAN/1987, 00:17:15, 30709, 4318012, 4221644, 2066, 4045334, 2071, 798856, 935
756. , 479. 08, 783, 1480, 3100, 1819. 02, 920, 1700, 2226, 2668. 88, 720, 1351, 1703
TU/13/JAN/1987, 08:50:10, 30708, 4321504, 4225296, 2067, 4033553, 2044, 796702, 934
756. , 479. 08, 779, 1470, 3108, 1819. 02, 926, 1691, 2228, 2668. 66, 712, 1303, 1691
TU/13/JAN/1978, 17:23:06, 30721, 4321550, 4226402, 2067, 4035053, 2045, 801385, 936
757. , 479. 07, 774, 1469, 3089, 1819. 03, 922, 1683, 2226, 2668. 83, 710, 1297, 1681
WE/14/JAN/1987, 01:56:14, 30718, 4320678, 4225210, 2068, 4043469, 2071, 799571, 935
756. , 479. 08, 784, 1478, 3158, 1819. 03, 927, 1696, 2224, 2669. 18, 717, 1307, 1692
WE/14/JAN/1987, 10:29:20, 30705, 4325016, 4229020, 2068, 4035890, 2061, 796969, 932
756. , 479. 12, 802, 1512, 3222, 1819. 05, 934, 1715, 2226, 2668. 47, 736, 1342, 1737
WE/14/JAN/1987, 19:02:11, 30708, 4323380, 4227231, 2068, 4029902, 2062, 800364, 934
756. , 479. 11, 799, 1508, 3180, 1819. 01, 941, 1718, 2265, 2668. 67, 732, 1337, 1727
WE/14/JAN/1987, 03:35:07, 30716, 4322669, 4226283, 2068, 4030388, 2060, 800451, 934
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TH/15/JAN/1987, 12:08:11, 30717, 4322334, 4225864, 2068, 4024339, 2059, 798877, 934
755. , 479. 10, 804, 1511, 3203, 1819. 06, 941, 1721, 2271, 2669. 15, 738, 1343, 1732
TH/15/JAN/1987, 20:41:15, 30713, 4320371, 4225134, 2067, 4031829, 2078, 800437, 939
756. , 479. 10, 804, 1511, 3135, 1819. 03, 937, 1720, 2253, 2669. 42, 737, 1340, 1727
```

(CONTINUED)

TABLE A2 (CONTINUED)   CONTENT OF FILE 'UDATA

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SA/17/JAN/1987,17:25:48,46037,6486092,6350238,2536,6052863,2522,791496,947
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SU/18/JAN/1987,06:14:12,46037,6491092,6352820,2535,6052303,2530,789875,947
723.,479.14,792,1487,3132,1819.01,932,1703,2235,2666.02,733,1324,1710
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MO/19/JAN/1987,16:13:08,46045,6499308,6361387,2536,6041344,2502,790195,949
723.,479.11,772,1488,3086,1819.04,920,1674,2211,2664.87,709,1281,1660
TU/20/JAN/1987,05:01:45,46009,6503948,6365216,2538,6026823,2505,790717,949
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TU/20/JAN/1987,17:49:43,46024,6503191,6364863,2538,6018443,2507,790591,949
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TU/27/JAN/1987,20:24:53,30632,4327773,4246391,2068,4013907,2048,915513,982
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TH/29/JAN/1987,07:09:18,20492,2883936,2813962,1687,2672953,1678,806415,924
814.,479.13,751,1405,2940,1819.03,895,1633,2154,2667.75,687,1236,1598
TH/29/JAN/1987,14:05:05,20496,2889654,2819795,1690,2675095,1676,805026,923
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FR/30/JAN/1987,13:12:39,30628,4307872,4226558,2063,4059956,2049,915642,986
689.,479.13,767,1432,3058,1819.07,910,1665,2190,2668.56,712,1276,1647
FR/30/JAN/1987,21:44:50,30628,4300938,4220417,2062,4053508,2047,916762,987
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688.,479.12,780,1458,3045,1819.07,918,1673,2208,2670.86,714,1287,1660
STANDARD,2.9857,.00105,30000,.99959,.00015,.99969,.00018
SA/31/JAN/1987,15:09:58,30713,4312734,4217257,2066,4052670,2049,799708,935
756.,479.13,776,1451,3064,1819.05,925,1677,2215,2669.87,721,1301,1684
SA/31/JAN/1987,23:43:56,30713,4307082,4211549,2064,4052325,2048,800993,936
756.,479.11,782,1466,3120,1819.05,921,1677,2223,2671.00,718,1291,1668
SO/01/FEB/1987,08:17:31,30716,4311329,4214777,2065,4055714,2050,798369,935
756.,479.12,775,1454,3079,1819.04,919,1675,2222,2670.07,732,1323,1713
SO/01/FEB/1987,16:51:10,30716,4314610,4219183,2066,4049597,2051,800941,936
756.,479.12,772,1448,3094,1819.06,920,1671,2201,2669.42,712,1284,1657
MO/02/FEB/1987,01:24:50,30718,4312046,4216427,2066,4052318,2049,800861,935
756.,479.13,775,1453,3080,1819.04,918,1675,2198,2670.20,713,1286,1662
END
```

Appendix B

Calibration measurements.

Corrected counting 185 keV rates, evaluation of calibration constants.

TABLE B1 CALIBRATION DATA SET NR. 1,
WITHOUT COUNTING-TIME CORRECTION,
BOTTOM THICKNESS: X5 FROM CERTIFICATE EC-NRM-171,
MONEL FROM DIMENSION SHEET UF6-REIMEP 1986 APP. 6

OBS. NR	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	STANDARDS 235U ENR.	ENR. ERROR
1	40.12168	.04708	.04632	.00842	4.5168	.0016
2	40.29033	.04719	.04643	.00846	4.5168	.0016
3	40.30772	.04719	.04643	.00846	4.5168	.0016
4	40.21952	.04718	.04642	.00844	4.5168	.0016
5	40.25406	.04694	.04617	.00845	4.5168	.0016
6	40.23306	.04718	.04642	.00844	4.5168	.0016
7	40.27050	.04719	.04643	.00845	4.5168	.0016
8	40.26845	.04714	.04638	.00845	4.5168	.0016
9	40.19263	.04713	.04637	.00844	4.5168	.0016
10	40.21977	.04714	.04638	.00844	4.5168	.0016
11	26.65608	.03144	.03118	.00400	2.9857	.00105
12	26.61762	.03141	.03116	.00399	2.9857	.00105
13	26.54585	.03137	.03112	.00398	2.9857	.00105
14	26.70189	.03144	.03118	.00400	2.9857	.00105
15	26.64145	.03141	.03115	.00399	2.9857	.00105
16	26.55475	.03131	.03106	.00398	2.9857	.00105
17	26.66787	.03138	.03112	.00400	2.9857	.00105
18	26.67076	.03138	.03112	.00400	2.9857	.00105
19	26.61832	.03138	.03113	.00399	2.9857	.00105
20	26.67030	.03154	.03129	.00400	2.9857	.00105
21	17.52026	.02156	.02104	.00473	1.9664	.0007
22	17.54331	.02154	.02101	.00473	1.9664	.0007
23	17.57860	.02156	.02103	.00474	1.9664	.0007
24	17.54260	.02156	.02103	.00473	1.9664	.0007
25	17.54707	.02156	.02103	.00473	1.9664	.0007
26	17.54971	.02160	.02107	.00474	1.9664	.0007
27	17.56130	.02160	.02107	.00474	1.9664	.0007
28	17.55850	.02160	.02107	.00474	1.9664	.0007
29	17.53559	.02145	.02092	.00473	1.9664	.0007
30	17.50764	.02147	.02094	.00472	1.9664	.0007
47	40.25006	.04694	.04617	.00845	4.5168	.0016
48	40.29853	.04694	.04617	.00846	4.5168	.0016
49	40.35829	.04724	.04647	.00847	4.5168	.0016
50	40.29738	.04694	.04617	.00846	4.5168	.0016
51	40.22797	.04689	.04612	.00844	4.5168	.0016
57	26.64601	.03141	.03115	.00400	2.9857	.00105
58	26.68883	.03144	.03118	.00400	2.9857	.00105
59	26.60140	.03141	.03116	.00399	2.9857	.00105
60	26.68710	.03144	.03118	.00400	2.9857	.00105
61	26.68443	.03141	.03115	.00400	2.9857	.00105

MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B1

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK-AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE: COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	STANDARDS: 235U ENR.	ENR. ERROR
10	40.23778	.01692	.01467	.00845	4.5168	0.00160
		(.01902	.01704	.00845)		
10	26.63449	.01063	.00985	.00399	2.9857	0.00105
		(.01666	.01617	.00399)		
10	17.54446	.00816	.00665	.00473	1.9664	0.00070
		(.00797	.00642	.00473)		

****

CALIBRATION RUN B1-1

****

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B1, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.23778	0.01692	4.51680	0.00160
2.	26.63450	0.01063	2.98570	0.00105
3.	17.54446	0.00816	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51538	-0.00142	+-0.00248	+-0.00215
2.	2.9857	2.98715	0.00145	+-0.00159	+-0.00096
3.	1.9664	1.96594	-0.00046	+-0.00115	+-0.00108

****

SLOPE = 0.1123434E+00 +- 0.1149222E-03
OFFSET = -.5064172E-02 +- 0.2794709E-02

OMEGA SQUARE = 1.310
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1320712E-07
VARIANCE OFFSET = 0.7810400E-05
COV (SLOPE, OFFSET) = -.3050646E-06

****

CALIBRATION RUN B1-2

****

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B1, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.23778	0.01902	4.51680	0.00160
2.	26.63450	0.01666	2.98570	0.00105
3.	17.54446	0.00797	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51575	-0.00105	+-0.00267	+-0.00241
2.	2.9857	2.98740	0.00170	+-0.00215	+-0.00109
3.	1.9664	1.96611	-0.00029	+-0.00114	+-0.00109

****

SLOPE = 0.1123518E+00 +- 0.1224513E-03
OFFSET = -.5038684E-02 +- 0.2865131E-02

OMEGA SQUARE = 0.843
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1499433E-07
VARIANCE OFFSET = 0.8208976E-05
COV (SLOPE, OFFSET) = -.3314161E-06

MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B1
****

COUNTING ERRORS GIVEN REFER
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE: COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	STANDARDS: 235U ENR.	ENR. ERROR
5	40.28645	.02233	.02067	.00846	4.5168	0.00160
		(.02408	.02255	.00846)		
5	26.66156	.01450	.01394	.00400	2.9857	0.00105
		(.01746	.01700	.00400)		

CALIBRATION RUN B1-3

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B1, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.28645	0.02233	4.51680	0.00160
2.	26.66156	0.01450	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00298	+-0.00298
2.	2.9857	2.98570	0.00000	+-0.00194	+-0.00194

****

SLOPE = 0.1123752E+00 +- 0.2606753E-03
OFFSET = -.1040075E-01 +- 0.8171051E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.6795163E-07
VARIANCE OFFSET = 0.6676611E-04
COV (SLOPE,OFFSET) = -.2087484E-05

CALIBRATION RUN B1-4

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B1, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.28645	0.02408	4.51680	0.00160
2.	26.66156	0.01746	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00314	+-0.00314
2.	2.9857	2.98570	0.00000	+-0.00223	+-0.00223

****

SLOPE = 0.1123750E+00 +- 0.2826872E-03
OFFSET = -.1038529E-01 +- 0.9007676E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.7991208E-07
VARIANCE OFFSET = 0.8113821E-04
COV (SLOPE,OFFSET) = -.2494051E-05

MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B1
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				STANDARDS	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
15	40.25400	.01464 (.01679	.01196 .01451	.00845 .00845)	4.5168	0.00160
15	26.64351	.00898 (.01293	.00804 .01230	.00399 .00399)	2.9857	0.00105
10	17.54446	.00816 (.00797	.00665 .00642	.00473 .00473)	1.9664	0.00070

CALIBRATION RUN B1-5

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B1, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.25400	0.01464	4.51680	0.00160
2.	26.64351	0.00898	2.98570	0.00105
3.	17.54446	0.00816	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51523	-0.00157	+-0.00229	+-0.00199
2.	2.9857	2.98728	0.00158	+-0.00146	+-0.00090
3.	1.9664	1.96580	-0.00060	+-0.00115	+-0.00107

****

SLOPE = 0.1122622E+00 +- 0.1086724E-03
OFFSET = -.3774424E-02 +- 0.2702347E-02

OMEGA SQUARE = 1.921
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1180968E-07
VARIANCE OFFSET = 0.7302681E-05
COV (SLOPE, OFFSET) = -.2790926E-06

CALIBRATION RUN B1-6

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B1, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.25400	0.01679	4.51680	0.00160
2.	26.64351	0.01293	2.98570	0.00105
3.	17.54446	0.00797	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51545	-0.00135	+-0.00247	+-0.00220
2.	2.9857	2.98747	0.00177	+-0.00179	+-0.00100
3.	1.9664	1.96597	-0.00043	+-0.00114	+-0.00108

****

SLOPE = 0.1122645E+00 +- 0.1148289E-03
OFFSET = -.3647095E-02 +- 0.2764972E-02

OMEGA SQUARE = 1.420
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1318567E-07
VARIANCE OFFSET = 0.7645070E-05
COV (SLOPE, OFFSET) = -.3004278E-06

TABLE B2 CALIBRATION DATA SET NR. 2,
WITHOUT COUNTING-TIME CORRECTION,
BOTTOM THICKNESS: FROM ULTRASONIC MEASUREMENTS
NORMALIZED TO 1.9950 MM AL CALIBRATION DISK AND
2.0000 MM MONEL CALIBRATION DISK.

OBS. NR	185 KEV COUNTING RATE: COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. ERROR	STANDARDS: 235U ENR.	ENR. ERROR
1	40.13130	.04672	.04633	.00602	4.5168	.0016
2	40.30000	.04683	.04644	.00604	4.5168	.0016
3	40.31739	.04683	.04644	.00605	4.5168	.0016
4	40.22917	.04682	.04643	.00603	4.5168	.0016
5	40.26371	.04658	.04619	.00604	4.5168	.0016
6	40.24271	.04682	.04643	.00603	4.5168	.0016
7	40.28015	.04683	.04644	.00604	4.5168	.0016
8	40.27810	.04678	.04639	.00604	4.5168	.0016
9	40.20228	.04677	.04638	.00603	4.5168	.0016
10	40.22942	.04677	.04638	.00603	4.5168	.0016
11	26.65874	.03156	.03119	.00480	2.9857	.00105
12	26.62029	.03152	.03115	.00479	2.9857	.00105
13	26.54851	.03149	.03113	.00478	2.9857	.00105
14	26.70456	.03156	.03119	.00481	2.9857	.00105
15	26.64411	.03152	.03115	.00479	2.9857	.00105
16	26.55740	.03142	.03105	.00478	2.9857	.00105
17	26.67055	.03149	.03112	.00480	2.9857	.00105
18	26.67344	.03149	.03112	.00480	2.9857	.00105
19	26.62098	.03149	.03112	.00479	2.9857	.00105
20	26.67297	.03166	.03129	.00481	2.9857	.00105
21	17.52446	.02127	.02103	.00315	1.9664	.0007
22	17.54752	.02125	.02101	.00316	1.9664	.0007
23	17.58282	.02127	.02103	.00316	1.9664	.0007
24	17.54681	.02127	.02103	.00316	1.9664	.0007
25	17.55128	.02127	.02103	.00316	1.9664	.0007
26	17.55392	.02132	.02108	.00316	1.9664	.0007
27	17.56552	.02132	.02108	.00316	1.9664	.0007
28	17.56272	.02132	.02108	.00316	1.9664	.0007
29	17.53979	.02116	.02092	.00316	1.9664	.0007
30	17.51184	.02118	.02094	.00315	1.9664	.0007
47	40.25971	.04658	.04619	.00604	4.5168	.0016
48	40.30819	.04658	.04619	.00604	4.5168	.0016
49	40.36797	.04688	.04649	.00605	4.5168	.0016
50	40.30704	.04658	.04619	.00604	4.5168	.0016
51	40.23762	.04653	.04614	.00603	4.5168	.0016
57	26.64868	.03152	.03115	.00480	2.9857	.00105
58	26.69150	.03156	.03119	.00480	2.9857	.00105
59	26.60406	.03152	.03115	.00479	2.9857	.00105
60	26.68976	.03156	.03119	.00480	2.9857	.00105
61	26.68710	.03152	.03115	.00480	2.9857	.00105

MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B2
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				STANDARDS	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
10	40.24742	.01586	.01467	.00604	4.5168	0.00160
		(.01808	.01704	.00604)		
10	26.63716	.01096	.00985	.00480	2.9857	0.00105
		(.01687	.01617	.00480)		
10	17.54867	.00736	.00665	.00316	1.9664	0.00070
		(.00715	.00642	.00316)		

CALIBRATION RUN B2-1

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B2, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.24742	0.01586	4.51680	0.00160
2.	26.63716	0.01096	2.98570	0.00105
3.	17.54867	0.00736	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51572	-0.00108	+-0.00239	+-0.00210
2.	2.9857	2.98694	0.00124	+-0.00162	+-0.00094
3.	1.9664	1.96607	-0.00033	+-0.00108	+-0.00102

SLOPE = 0.1123257E+00 +- 0.1102869E-03
OFFSET = -.5099622E-02 +- 0.2654445E-02

OMEGA SQUARE = 0.884
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1216320E-07
VARIANCE OFFSET = 0.7046075E-05
COV (SLOPE, OFFSET) = -.2776104E-06

CALIBRATION RUN B2-2

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B2, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.24742	0.01808	4.51680	0.00160
2.	26.63716	0.01687	2.98570	0.00105
3.	17.54867	0.00715	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51599	-0.00081	+-0.00259	+-0.00235
2.	2.9857	2.98712	0.00142	+-0.00217	+-0.00106
3.	1.9664	1.96619	-0.00021	+-0.00107	+-0.00103

SLOPE = 0.1123320E+00 +- 0.1180040E-03
OFFSET = -.5084083E-02 +- 0.2728310E-02

OMEGA SQUARE = 0.567
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1392494E-07
VARIANCE OFFSET = 0.7443671E-05
COV (SLOPE, OFFSET) = -.3040652E-06

MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B2
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				STANDARDS	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
5	40.29611	.02154	.02068	.00604	4.5168	0.00160
		(.02335	.02256	.00604)		
5	26.66422	.01474	.01394	.00480	2.9857	0.00105
		(.01767	.01700	.00480)		

CALIBRATION RUN B2-3

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B2, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.29611	0.02154	4.51680	0.00160
2.	26.66422	0.01474	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00290	+-0.00290
2.	2.9857	2.98570	0.00000	+-0.00196	+-0.00196

****

SLOPE = 0.1123177E+00 +- 0.2568188E-03
OFFSET = -.9166546E-02 +- 0.8110003E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.6595587E-07
VARIANCE OFFSET = 0.6577215E-04
COV (SLOPE, OFFSET) = -.2040602E-05

CALIBRATION RUN B2-4

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B2, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.29611	0.02335	4.51680	0.00160
2.	26.66422	0.01767	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00307	+-0.00307
2.	2.9857	2.98570	0.00000	+-0.00225	+-0.00225

****

SLOPE = 0.1123176E+00 +- 0.2791388E-03
OFFSET = -.9158528E-02 +- 0.8953312E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.7791845E-07
VARIANCE OFFSET = 0.8016178E-04
COV (SLOPE, OFFSET) = -.2447455E-05

MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B2
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE: COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	STANDARDS: 235U ENR.	ENR. ERROR
15	40.26365	.01340	.01196	.00604	4.5168	0.00160
		(.01572	.01451	.00604)		
15	26.64618	.00937	.00804	.00480	2.9857	0.00105
		(.01320	.01230	.00480)		
10	17.54867	.00736	.00665	.00316	1.9664	0.00070
		(.00715	.00642	.00316)		

CALIBRATION RUN B2-5

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B2, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.26365	0.01340	4.51680	0.00160
2.	26.64618	0.00937	2.98570	0.00105
3.	17.54867	0.00736	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51558	-0.00122	+-0.00220	+-0.00193
2.	2.9857	2.98710	0.00140	+-0.00149	+-0.00088
3.	1.9664	1.96595	-0.00045	+-0.00108	+-0.00101

****

SLOPE = 0.1122442E+00 +- 0.1037255E-03
OFFSET = -.3783234E-02 +- 0.2558164E-02

OMEGA SQUARE = 1.363
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1075898E-07
VARIANCE OFFSET = 0.6544200E-05
COV (SLOPE, OFFSET) = -.2515911E-06

CALIBRATION RUN B2-6

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B2, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.26365	0.01572	4.51680	0.00160
2.	26.64618	0.01320	2.98570	0.00105
3.	17.54867	0.00715	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51574	-0.00106	+-0.00238	+-0.00213
2.	2.9857	2.98724	0.00154	+-0.00182	+-0.00097
3.	1.9664	1.96608	-0.00032	+-0.00106	+-0.00102

****

SLOPE = 0.1122458E+00 +- 0.1101316E-03
OFFSET = -.3680989E-02 +- 0.2623718E-02

OMEGA SQUARE = 1.005
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1212897E-07
VARIANCE OFFSET = 0.6883894E-05
COV (SLOPE, OFFSET) = -.2731015E-06

TABLE B3 CALIBRATION DATA SET NR. 3,
WITH COUNTING-TIME CORRECTION FROM PULSER,
BOTTOM THICKNESS: X5 FROM CERTIFICATE EC-NRM-171,
MONEL FROM DIMENSION SHEET UF6-REIMEP 1986 APP. 6

OBS. NR	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. ERROR	STANDARDS 235U ENR.	ENR. ERROR
1	40.10828	.05288	.05221	.00842	4.5168	.0016
2	40.27659	.05302	.05234	.00845	4.5168	.0016
3	40.27739	.05299	.05231	.00845	4.5168	.0016
4	40.20206	.05298	.05230	.00844	4.5168	.0016
5	40.23334	.05275	.05207	.00844	4.5168	.0016
6	40.21199	.05297	.05229	.00844	4.5168	.0016
7	40.21922	.05294	.05226	.00844	4.5168	.0016
8	40.25160	.05294	.05226	.00845	4.5168	.0016
9	40.15219	.05288	.05220	.00843	4.5168	.0016
10	40.19939	.05293	.05225	.00844	4.5168	.0016
11	26.63171	.03401	.03377	.00399	2.9857	.00105
12	26.59666	.03398	.03375	.00399	2.9857	.00105
13	26.52432	.03393	.03370	.00398	2.9857	.00105
14	26.66225	.03400	.03376	.00400	2.9857	.00105
15	26.60662	.03396	.03372	.00399	2.9857	.00105
16	26.53397	.03387	.03364	.00398	2.9857	.00105
17	26.64560	.03395	.03371	.00400	2.9857	.00105
18	26.64215	.03395	.03371	.00399	2.9857	.00105
19	26.59047	.03394	.03371	.00399	2.9857	.00105
20	26.63836	.03409	.03386	.00399	2.9857	.00105
21	17.49730	.02263	.02213	.00472	1.9664	.0007
22	17.53363	.02264	.02214	.00473	1.9664	.0007
23	17.55024	.02264	.02214	.00474	1.9664	.0007
24	17.52067	.02264	.02214	.00473	1.9664	.0007
25	17.52586	.02264	.02214	.00473	1.9664	.0007
26	17.52327	.02267	.02217	.00473	1.9664	.0007
27	17.55054	.02270	.02220	.00474	1.9664	.0007
28	17.54095	.02269	.02219	.00473	1.9664	.0007
29	17.51516	.02253	.02203	.00473	1.9664	.0007
30	17.49199	.02255	.02205	.00472	1.9664	.0007
47	40.22881	.05274	.05206	.00844	4.5168	.0016
48	40.25428	.05273	.05205	.00845	4.5168	.0016
49	40.33219	.05304	.05236	.00846	4.5168	.0016
50	40.30786	.05281	.05213	.00846	4.5168	.0016
51	40.22696	.05272	.05204	.00844	4.5168	.0016
57	26.61668	.03398	.03374	.00399	2.9857	.00105
58	26.66060	.03402	.03378	.00400	2.9857	.00105
59	26.57649	.03397	.03374	.00398	2.9857	.00105
60	26.65453	.03401	.03377	.00400	2.9857	.00105
61	26.65171	.03398	.03374	.00400	2.9857	.00105

MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B3
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	STANDARDS 235U ENR.	ENR. ERROR
10	40.21321	.01855	.01652	.00844	4.5168	0.00160
		(.01871	.01670	.00844)		
10	26.60731	.01139	.01067	.00399	2.9857	0.00105
		(.01543	.01490	.00399)		
10	17.52496	.00845	.00700	.00473	1.9664	0.00070
		(.00789	.00632	.00473)		

****

CALIBRATION RUN B3-1

****

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B3, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.21321	0.01855	4.51680	0.00160
2.	26.60731	0.01139	2.98570	0.00105
3.	17.52496	0.00845	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51575	-0.00105	+-0.00263	+-0.00227
2.	2.9857	2.98674	0.00104	+-0.00166	+-0.00101
3.	1.9664	1.96608	-0.00032	+-0.00118	+-0.00111

****

SLOPE = 0.1123782E+00 +- 0.1202293E-03
OFFSET = -.3341003E-02 +- 0.2897120E-02

OMEGA SQUARE = 0.628
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1445508E-07
VARIANCE OFFSET = 0.8393306E-05
COV (SLOPE, OFFSET) = -.3309932E-06

****

CALIBRATION RUN B3-2

****

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B3, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.21321	0.01871	4.51680	0.00160
2.	26.60731	0.01543	2.98570	0.00105
3.	17.52496	0.00789	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51599	-0.00081	+-0.00264	+-0.00237
2.	2.9857	2.98689	0.00119	+-0.00203	+-0.00107
3.	1.9664	1.96618	-0.00022	+-0.00113	+-0.00108

****

SLOPE = 0.1123846E+00 +- 0.1209758E-03
OFFSET = -.3359130E-02 +- 0.2839295E-02

OMEGA SQUARE = 0.480
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1463514E-07
VARIANCE OFFSET = 0.8061594E-05
COV (SLOPE, OFFSET) = -.3247693E-06

MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B3
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE COUNTING RATE	TOTAL / ERROR	COUNT / ERROR	THICKN. / ERROR	STANDARDS 235U ENR.	ENR. ERROR
5	40.27002	.02480	.02331	.00845	4.5168	0.00160
		(.02294	.02133	.00845)		
5	26.63200	.01561	.01510	.00399	2.9857	0.00105
		(.01635	.01586	.00399)		

CALIBRATION RUN B3-3

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B3, COUNTING RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.27002	0.02480	4.51680	0.00160
2.	26.63200	0.01561	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00321	+-0.00321
2.	2.9857	2.98570	0.00000	+-0.00204	+-0.00204

****

SLOPE = 0.1122672E+00 +- 0.2790736E-03
OFFSET = -.4200596E-02 +- 0.8701348E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.7788208E-07
VARIANCE OFFSET = 0.7571345E-04
COV (SLOPE, OFFSET) = -.2380193E-05

CALIBRATION RUN B3-4

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B3, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.27002	0.02294	4.51680	0.00160
2.	26.63200	0.01635	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00303	+-0.00303
2.	2.9857	2.98570	0.00000	+-0.00211	+-0.00211

****

SLOPE = 0.1122669E+00 +- 0.2710474E-03
OFFSET = -.4190058E-02 +- 0.8604872E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.7346668E-07
VARIANCE OFFSET = 0.7404382E-04
COV (SLOPE, OFFSET) = -.2284456E-05

MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B3
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE: COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	STANDARDS: 235U ENR.	ENR. ERROR
15	40.23215	.01591	.01348	.00844	4.5168	0.00160
		(.01689	.01463	.00844)		
15	26.61554	.00958	.00871	.00399	2.9857	0.00105
		(.01203	.01135	.00399)		
10	17.52496	.00845	.00700	.00473	1.9664	0.00070
		(.00789	.00632	.00473)		

CALIBRATION RUN B3-5

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B3, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.23215	0.01591	4.51680	0.00160
2.	26.61555	0.00958	2.98570	0.00105
3.	17.52496	0.00845	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51572	-0.00108	+-0.00240	+-0.00208
2.	2.9857	2.98676	0.00106	+-0.00150	+-0.00093
3.	1.9664	1.96601	-0.00039	+-0.00118	+-0.00110

****

SLOPE = 0.1122867E+00 +- 0.1127577E-03
OFFSET = -.1811625E-02 +- 0.2786709E-02

OMEGA SQUARE = 0.810
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1271430E-07
VARIANCE OFFSET = 0.7765747E-05
COV (SLOPE, OFFSET) = -.2986926E-06

CALIBRATION RUN B3-6

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B3, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.23215	0.01689	4.51680	0.00160
2.	26.61555	0.01203	2.98570	0.00105
3.	17.52496	0.00789	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51584	-0.00097	+-0.00248	+-0.00218
2.	2.9857	2.98686	0.00116	+-0.00171	+-0.00098
3.	1.9664	1.96610	-0.00030	+-0.00113	+-0.00107

****

SLOPE = 0.1122875E+00 +- 0.1145904E-03
OFFSET = -.1734481E-02 +- 0.2756965E-02

OMEGA SQUARE = 0.682
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1313097E-07
VARIANCE OFFSET = 0.7600860E-05
COV (SLOPE, OFFSET) = -.2993578E-06

TABLE B4 CALIBRATION DATA SET NR. 4,
WITH COUNTING-TIME CORRECTION FROM PULSER,
BOTTOM THICKNESS: FROM ULTRASONIC MEASUREMENTS
NORMALIZED TO 1.9950 MM AL CALIBRATION DISK AND
2.0000 MM MONEL CALIBRATION DISK.

OBS.	185 KEV COUNTING RATE				STANDARDS	
NR	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
1	40.11790	.05256	.05221	.00602	4.5168	.0016
2	40.28625	.05270	.05235	.00604	4.5168	.0016
3	40.28706	.05268	.05233	.00604	4.5168	.0016
4	40.21172	.05266	.05231	.00603	4.5168	.0016
5	40.24300	.05244	.05209	.00603	4.5168	.0016
6	40.22162	.05265	.05230	.00603	4.5168	.0016
7	40.22887	.05263	.05228	.00603	4.5168	.0016
8	40.26125	.05262	.05227	.00604	4.5168	.0016
9	40.16182	.05256	.05221	.00602	4.5168	.0016
10	40.20903	.05261	.05226	.00603	4.5168	.0016
11	26.63437	.03412	.03378	.00479	2.9857	.00105
12	26.59932	.03408	.03374	.00479	2.9857	.00105
13	26.52697	.03403	.03369	.00477	2.9857	.00105
14	26.66490	.03410	.03376	.00480	2.9857	.00105
15	26.60928	.03407	.03373	.00479	2.9857	.00105
16	26.53663	.03397	.03363	.00478	2.9857	.00105
17	26.64826	.03406	.03372	.00480	2.9857	.00105
18	26.64581	.03405	.03371	.00479	2.9857	.00105
19	26.59313	.03404	.03370	.00479	2.9857	.00105
20	26.64102	.03420	.03386	.00479	2.9857	.00105
21	17.50150	.02236	.02214	.00315	1.9664	.0007
22	17.53784	.02236	.02214	.00316	1.9664	.0007
23	17.55445	.02237	.02215	.00316	1.9664	.0007
24	17.52487	.02237	.02215	.00315	1.9664	.0007
25	17.53006	.02237	.02215	.00315	1.9664	.0007
26	17.52748	.02240	.02218	.00315	1.9664	.0007
27	17.55475	.02242	.02220	.00316	1.9664	.0007
28	17.54516	.02242	.02220	.00316	1.9664	.0007
29	17.51936	.02226	.02204	.00315	1.9664	.0007
30	17.49619	.02228	.02206	.00315	1.9664	.0007
47	40.23846	.05242	.05207	.00603	4.5168	.0016
48	40.26393	.05241	.05206	.00604	4.5168	.0016
49	40.34186	.05272	.05237	.00605	4.5168	.0016
50	40.31753	.05249	.05214	.00605	4.5168	.0016
51	40.23662	.05240	.05205	.00603	4.5168	.0016
57	26.61934	.03408	.03374	.00479	2.9857	.00105
58	26.66326	.03413	.03379	.00480	2.9857	.00105
59	26.57915	.03408	.03374	.00478	2.9857	.00105
60	26.65719	.03412	.03378	.00480	2.9857	.00105
61	26.65437	.03409	.03375	.00480	2.9857	.00105

MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B4
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				STANDARDS	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
10	40.22285	.01759	.01653	.00603	4.5168	0.00160
		(.01776	.01670	.00603)		
10	26.60997	.01169	.01067	.00479	2.9857	0.00105
		(.01565	.01490	.00479)		
10	17.52916	.00768	.00700	.00315	1.9664	0.00070
		(.00706	.00632	.00315		

CALIBRATION RUN B4-1

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B4, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.22285	0.01759	4.51680	0.00160
2.	26.60997	0.01169	2.98570	0.00105
3.	17.52916	0.00768	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51606	-0.00074	+-0.00254	+-0.00222
2.	2.9857	2.98651	0.00081	+-0.00168	+-0.00099
3.	1.9664	1.96619	-0.00021	+-0.00111	+-0.00105

****

SLOPE = 0.1123603E+00 +- 0.1158251E-03
OFFSET = -.3392914E-02 +- 0.2761771E-02

OMEGA SQUARE = 0.354
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1341546E-07
VARIANCE OFFSET = 0.7627379E-05
COV (SLOPE, OFFSET) = -.3035588E-06

CALIBRATION RUN B4-2

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM FIRST 30 MEASUREMENTS IN TABLE B4, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.22285	0.01776	4.51680	0.00160
2.	26.60997	0.01565	2.98570	0.00105
3.	17.52916	0.00706	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51623	-0.00057	+-0.00256	+-0.00231
2.	2.9857	2.98662	0.00092	+-0.00205	+-0.00104
3.	1.9664	1.96625	-0.00015	+-0.00106	+-0.00102

****

SLOPE = 0.1123650E+00 +- 0.1165068E-03
OFFSET = -.3409313E-02 +- 0.2701323E-02

OMEGA SQUARE = 0.270
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1357384E-07
VARIANCE OFFSET = 0.7297145E-05
COV (SLOPE, OFFSET) = -.2974625E-06

MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B4
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				STANDARDS	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
5	40.27969	.02409	.02332	.00604	4.5168	0.00160
		(.02217	.02133	.00604)		
5	26.63466	.01584	.01510	.00479	2.9857	0.00105
		(.01657	.01586	.00479)		

CALIBRATION RUN B4-3

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B4, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.27969	0.02409	4.51680	0.00160
2.	26.63466	0.01584	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00314	+-0.00314
2.	2.9857	2.98570	0.00000	+-0.00206	+-0.00206

****

SLOPE = 0.1122093E+00 +- 0.2754694E-03
OFFSET = -.2955425E-02 +- 0.8644700E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.7588340E-07
VARIANCE OFFSET = 0.7473085E-04
COV (SLOPE, OFFSET) = -.2333450E-05

CALIBRATION RUN B4-4

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM LAST 10 MEASUREMENTS IN TABLE B4, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.27969	0.02217	4.51680	0.00160
2.	26.63466	0.01657	2.98570	0.00105

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51680	0.00000	+-0.00296	+-0.00296
2.	2.9857	2.98570	0.00000	+-0.00214	+-0.00214

****

SLOPE = 0.1122096E+00 +- 0.2673515E-03
OFFSET = -.2961775E-02 +- 0.8547844E-02

OMEGA SQUARE = 1.000
DEGREES OF FREEDOM = 0

VARIANCE SLOPE = 0.7147681E-07
VARIANCE OFFSET = 0.7306558E-04
COV (SLOPE, OFFSET) = -.2237913E-05

MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B4

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				STANDARDS	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
15	40.24180	.01477	.01348	.00603	4.5168	0.00160
		(.01583	.01464	.00603)		
15	26.61820	.00994	.00871	.00479	2.9857	0.00105
		(.01232	.01135	.00479)		
10	17.52916	.00768	.00700	.00315	1.9664	0.00070
		(.00706	.00632	.00315)		

CALIBRATION RUN B4-5

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B4, COUNTING-RATE ERRORS FROM PEAK-AREA EVALUATIONS)

1.	40.24180	0.01477	4.51680	0.00160
2.	26.61820	0.00994	2.98570	0.00105
3.	17.52916	0.00768	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51604	-0.00076	+-0.00230	+-0.00202
2.	2.9857	2.98654	0.00084	+-0.00153	+-0.00091
3.	1.9664	1.96614	-0.00026	+-0.00111	+-0.00104

SLOPE = 0.1122680E+00 +- 0.1079940E-03
OFFSET = -.1827861E-02 +- 0.2646672E-02

OMEGA SQUARE = 0.469
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1166271E-07
VARIANCE OFFSET = 0.7004876E-05
COV (SLOPE, OFFSET) = -.2711301E-06

CALIBRATION RUN B4-6

INPUT DATA TO EVALUATION PROGRAM ' E R 2 F I T ' /1/:
(MEAN VALUES FROM ALL 40 MEASUREMENTS IN TABLE B4, COUNTING-RATE ERRORS FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS)

1.	40.24180	0.01583	4.51680	0.00160
2.	26.61820	0.01232	2.98570	0.00105
3.	17.52916	0.00706	1.96640	0.00070

TABLE OF RESIDUALS

OBS. NR	OBS. VALUE	ESTIMATE	RESIDUAL	EXPECTED ERROR	CONFIDENCE LIMITS OF FIT
1.	4.5168	4.51611	-0.00069	+-0.00239	+-0.00212
2.	2.9857	2.98661	0.00091	+-0.00174	+-0.00096
3.	1.9664	1.96620	-0.00020	+-0.00106	+-0.00101

SLOPE = 0.1122685E+00 +- 0.1099201E-03
OFFSET = -.1773634E-02 +- 0.2615252E-02

OMEGA SQUARE = 0.394
DEGREES OF FREEDOM = 1

VARIANCE SLOPE = 0.1208243E-07
VARIANCE OFFSET = 0.6839540E-05
COV (SLOPE, OFFSET) = -.2720525E-06

Appendix C

Measurements of UF_6 samples.

Corrected 185 keV counting rates, evaluation of ^{235}U enrichment and of associated errors.

TABLE C1 UF6 MEASUREMENT DATA SET NR. 1,
WITHOUT COUNTING-TIME CORRECTION,
BOTTOM THICKNESS: FROM DIMENSION SHEET
UF6-REIMEP 1986 APP. 6

OBS. NR	185 KEY COUNTING RATE: COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. ERROR	UF6 SAMPLE: 235U ENR.	ENR. ERROR
31	30.52954	.03318	.03277	.00519	?	?
32	30.57900	.03314	.03273	.00520	?	?
33	30.54000	.03318	.03277	.00519	?	?
34	30.51594	.03314	.03273	.00519	?	?
35	30.54725	.03314	.03273	.00519	?	?
36	30.51377	.03314	.03273	.00519	?	?
37	30.49131	.03317	.03276	.00518	?	?
38	30.57963	.03321	.03280	.00520	?	?
39	30.56300	.03318	.03277	.00520	?	?
40	30.54580	.03321	.03280	.00519	?	?
41	30.52174	.03314	.03273	.00519	?	?
42	30.56857	.03334	.03293	.00520	?	?
43	30.55300	.03334	.03293	.00519	?	?
44	30.48894	.03331	.03290	.00518	?	?
45	30.51710	.03314	.03273	.00519	?	?
46	30.52790	.03314	.03273	.00519	?	?
52	30.50607	.03331	.03290	.00519	?	?
53	30.54893	.03331	.03290	.00519	?	?
54	30.52140	.03327	.03286	.00519	?	?
55	30.55874	.03331	.03290	.00519	?	?
56	30.54083	.03327	.03286	.00519	?	?

MEAN VALUE OF FIRST 16 MEASUREMENTS IN TABLE C1
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	UF6 235U ENR.	ENR. ERROR
16	30.53641	.00970	.00820	.00519	?	?
		(.00873	.00702	.00519)		

****
*   *
*   PRODUCTION RUN C1-1   *
*   *
****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.53641 +- 0.00970

(MEAN OF FIRST 16 MEASUREMENTS IN TABLE C1, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B1-1, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50463	0.00168	0.048%	0.032%	0.036%

****
*   *
*   PRODUCTION RUN C1-2   *
*   *
****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.53641 +- 0.00873

(MEAN OF FIRST 16 MEASUREMENTS IN TABLE C1, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B1-2, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50492	0.00175	0.050%	0.029%	0.041%

MEAN VALUE OF LAST 5 MEASUREMENTS IN TABLE C1
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				UF6	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
5	30.53520	.01560	.01471	.00519	?	?
		(.01084	.00952	.00519)		

****

PRODUCTION RUN C1-3

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.53520 +- 0.01560

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C1, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B1-3, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50002	0.00245	0.070%	0.051%	0.048%

****

PRODUCTION RUN C1-4

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.53520 +- 0.01084

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C1, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B1-4, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50003	0.00225	0.064%	0.036%	0.053%

MEAN VALUE OF ALL 21 MEASUREMENTS IN TABLE C1
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				UF6	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
21	30.53612	.00884	.00716	.00519	?	?
		(.00771	.00570	.00519)		

****
*   PRODUCTION RUN C1-5   *
****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.53612 +- 0.00884

(MEAN OF ALL 21 MEASUREMENTS IN TABLE C1, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B1-5, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50338	0.00154	0.044%	0.029%	0.033%

****
*   PRODUCTION RUN C1-6   *
****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.53612 +- 0.00771

(MEAN OF ALL 21 MEASUREMENTS IN TABLE C1, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B1-6, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50358	0.00157	0.045%	0.025%	0.037%

TABLE C2 UF6 MEASUREMENT DATA SET NR. 2,
WITHOUT COUNTING-TIME CORRECTION,
BOTTOM THICKNESS: FROM ULTRASONIC MEASUREMENTS:
2.003 MM MONEL PLUS 1.995 MM ALUMINIUM

OBS. NR	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	UF6 SAMPLE 235U ENR.	ENR. ERROR
31	30.54145	.03302	.03278	.00397	?	?
32	30.59094	.03299	.03275	.00398	?	?
33	30.55192	.03302	.03278	.00397	?	?
34	30.52784	.03298	.03274	.00397	?	?
35	30.55915	.03299	.03275	.00397	?	?
36	30.52568	.03298	.03274	.00397	?	?
37	30.50320	.03302	.03278	.00397	?	?
38	30.59157	.03305	.03281	.00398	?	?
39	30.57493	.03302	.03278	.00398	?	?
40	30.55772	.03305	.03281	.00397	?	?
41	30.53365	.03299	.03275	.00397	?	?
42	30.58050	.03318	.03294	.00398	?	?
43	30.56492	.03318	.03294	.00397	?	?
44	30.50083	.03315	.03291	.00397	?	?
45	30.52901	.03299	.03275	.00397	?	?
46	30.53982	.03299	.03275	.00397	?	?
52	30.51797	.03315	.03291	.00397	?	?
53	30.56086	.03315	.03291	.00397	?	?
54	30.53331	.03312	.03288	.00397	?	?
55	30.57066	.03315	.03291	.00398	?	?
56	30.55275	.03312	.03288	.00397	?	?

MEAN VALUE OF FIRST 16 MEASUREMENTS IN TABLE C2
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				UF6	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
16	30.54832	.00911 (.00807	.00820 .00703	.00397 .00397)	?	?

****
* PRODUCTION RUN C2-1 *
****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.54832 +- 0.00911

(MEAN OF FIRST 16 MEASUREMENTS IN TABLE C2, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B2-1, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50541	0.00161	0.046%	0.030%	0.035%

****
* PRODUCTION RUN C2-2 *
****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.54832 +- 0.00807

(MEAN OF FIRST 16 MEASUREMENTS IN TABLE C2, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B2-2, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50562	0.00168	0.048%	0.026%	0.040%

MEAN VALUE OF LAST 5 MEASUREMENTS IN TABLE C2
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				UF6	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
5	30.54711	.01524	.01471	.00397	?	?
		(.01032	.00953	.00397)		

****

PRODUCTION RUN C2-3

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.54711 +- 0.01524

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C2, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B2-3, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50086	0.00242	0.069%	0.050%	0.048%

****

PRODUCTION RUN C2-4

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.54711 +- 0.01032

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C2, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B2-4, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50086	0.00222	0.063%	0.034%	0.053%

MEAN VALUE OF ALL 21 MEASUREMENTS IN TABLE C2
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	UF6 235U ENR.	ENR. ERROR
21	30.54804	.00819	.00716	.00397	?	?
		(.00695	.00571	.00397)		

****

PRODUCTION RUN C2-5

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.54804 +- 0.00819

(MEAN OF ALL 21 MEASUREMENTS IN TABLE C2, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B2-5, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50418	0.00147	0.042%	0.027%	0.032%

****

PRODUCTION RUN C2-6

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.54804 +- 0.00695

(MEAN OF ALL 21 MEASUREMENTS IN TABLE C2, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B2-6, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50433	0.00149	0.043%	0.023%	0.036%

TABLE C3 UF6 MEASUREMENT DATA SET NR. 3,
WITH COUNTING-TIME CORRECTION FROM PULSER,
BOTTOM THICKNESS: FROM DIMENSION SHEET
UF6-REIMEP 1986 APP. 6

OBS. NR	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	UF6 SAMPLE 235U ENR.	ENR. ERROR
31	30.47075	.03629	.03592	.00518	?	?
32	30.51802	.03626	.03589	.00519	?	?
33	30.47995	.03628	.03591	.00518	?	?
34	30.45868	.03625	.03588	.00518	?	?
41	30.47406	.03627	.03590	.00518	?	?
42	30.50378	.03643	.03606	.00519	?	?
43	30.49457	.03644	.03607	.00518	?	?
44	30.43904	.03640	.03603	.00517	?	?
45	30.46026	.03625	.03588	.00518	?	?
46	30.47618	.03626	.03589	.00518	?	?
52	30.45856	.03644	.03607	.00518	?	?
53	30.50050	.03644	.03607	.00519	?	?
54	30.47074	.03640	.03603	.00518	?	?
55	30.50323	.03643	.03606	.00519	?	?
56	30.48287	.03640	.03603	.00518	?	?

*) FOR MEASUREMENTS #35 TO #40 NO TIME CORRECTION COULD BE PERFORMED DUE TO FAILURE IN RECORDING TOTAL COUNTS AND REAL TIME OF PULSER.

MEAN VALUE OF FIRST 10 MEASUREMENTS IN TABLE C3

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				UF6	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
16	30.47753	.01249	.01137	.00518	?	?
		(.00897	.00732	.00518)		

PRODUCTION RUN C3-1

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.47753 +- 0.01249

(MEAN OF FIRST 10 MEASUREMENTS IN TABLE C3, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B3-1, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50071	0.00195	0.056%	0.041%	0.037%

PRODUCTION RUN C3-2

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.47753 +- 0.00897

(MEAN OF FIRST 10 MEASUREMENTS IN TABLE C3, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B3-2, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50089	0.00173	0.050%	0.029%	0.040%

MEAN VALUE OF LAST 5 MEASUREMENTS IN TABLE C3
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				UF6	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
5	30.48318	.01694	.01612	.00518	?	?
		(.01000	.00855	.00518)		

PRODUCTION RUN C3-3

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.48318 +- 0.01694

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C3, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B3-3, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.49702	0.00263	0.075%	0.056%	0.050%

PRODUCTION RUN C3-4

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.48318 +- 0.01000

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C3, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B3-4, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.49702	0.00212	0.061%	0.033%	0.051%

MEAN VALUE OF ALL 15 MEASUREMENTS IN TABLE C3
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

	185 KEV COUNTING RATE				UF6	
NR OF REPEATS	COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	235U ENR.	ENR. ERROR
15	30.47941	.01064	.00929	.00518	?	?
		(.00757	.00552	.00518)		

****

PRODUCTION RUN C3-5

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.47941 +- 0.01064

(MEAN OF ALL 15 MEASUREMENTS IN TABLE C3, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B3-5, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.49964	0.00171	0.049%	0.035%	0.034%

****

PRODUCTION RUN C3-6

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.47941 +- 0.00757

(MEAN OF ALL 15 MEASUREMENTS IN TABLE C3, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B3-6, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.49974	0.00154	0.044%	0.025%	0.036%

TABLE C4 UF6 MEASUREMENT DATA SET NR. 4,
WITH COUNTING-TIME CORRECTION FROM PULSER,
BOTTOM THICKNESS: FROM ULTRASONIC MEASUREMENTS:
2.003 MM MONEL PLUS 1.995 MM ALUMINIUM

OBS. NR	185 KEV COUNTING RATE: COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	UF6 SAMPLE: 235U ENR.	ENR. ERROR
31	30.48264	.03615	.03593	.00396	?	?
32	30.52993	.03613	.03591	.00397	?	?
33	30.49185	.03615	.03593	.00397	?	?
34	30.47056	.03612	.03590	.00396	?	?
41	30.48595	.03613	.03591	.00396	?	?
42	30.51568	.03630	.03608	.00397	?	?
43	30.50647	.03630	.03608	.00397	?	?
44	30.45092	.03627	.03605	.00396	?	?
45	30.47215	.03612	.03590	.00396	?	?
46	30.48808	.03613	.03591	.00396	?	?
52	30.47044	.03630	.03608	.00396	?	?
53	30.51240	.03630	.03608	.00397	?	?
54	30.48263	.03626	.03604	.00396	?	?
55	30.51513	.03630	.03608	.00397	?	?
56	30.49477	.03626	.03604	.00397	?	?

*) FOR MEASUREMENTS #35 TO #40 NO TIME CORRECTION COULD BE PERFORMED DUE TO FAILURE IN RECORDING TOTAL COUNTS AND REAL TIME OF PULSER.

MEAN VALUE OF FIRST 10 MEASUREMENTS IN TABLE C4
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	UF6 235U ENR.	ENR. ERROR
10	30.48943	.01204	.01137	.00396	?	?
		(.00833	.00732	.00396)		

****

PRODUCTION RUN C4-1

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.48943 +- 0.01204

(MEAN OF FIRST 10 MEASUREMENTS IN TABLE C4, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B4-1, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50147	0.00189	0.054%	0.040%	0.037%

****

PRODUCTION RUN C4-2

****

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.48943 +- 0.00833

(MEAN OF FIRST 10 MEASUREMENTS IN TABLE C4, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B4-2, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50160	0.00167	0.048%	0.027%	0.039%

MEAN VALUE OF LAST 5 MEASUREMENTS IN TABLE C4
****

COUNTING ERRORS GIVEN REFER:
A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE COUNTING RATE	/ TOTAL / ERROR	/ COUNT / ERROR	/ THICKN. / ERROR	UF6 235U ENR.	ENR. ERROR
5	30.49508	.01661	.01613	.00397	?	?
		(.00943	.00856	.00397)		

PRODUCTION RUN C4-3

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.49508 +- 0.01661

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C4, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B4-3, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.49785	0.00260	0.074%	0.055%	0.051%

PRODUCTION RUN C4-4

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.49508 +- 0.00943

(MEAN OF LAST 5 MEASUREMENTS IN TABLE C4, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B4-4, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.49786	0.00209	0.060%	0.031%	0.051%

MEAN VALUE OF ALL 15 MEASUREMENTS IN TABLE C4

COUNTING ERRORS GIVEN REFER:

A) TO ERROR ESTIMATES FROM PEAK AREA EVALUATIONS
B) TO STANDARD DEVIATIONS OF REPEATED MEASUREMENTS (VALUES GIVEN IN BRACKETS)

NR OF REPEATS	185 KEV COUNTING RATE: COUNTING RATE	TOTAL ERROR	COUNT ERROR	THICKN. ERROR	UF6: 235U ENR.	ENR. ERROR
15	30.49131	.01010	.00929	.00396	?	?
		(.00679	.00552	.00396)		

PRODUCTION RUN C4-5

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.49131 +- 0.01010

(MEAN OF ALL 15 MEASUREMENTS IN TABLE C4, COUNTING-RATE ERROR FROM PEAK-AREA EVALUATIONS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B4-5, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50040	0.00165	0.047%	0.033%	0.034%

PRODUCTION RUN C4-6

INPUT DATA TO EVALUATION PROGRAM:

UF6 COUNTING RATE = 30.49131 +- 0.00679

(MEAN OF ALL 15 MEASUREMENTS IN TABLE C4, COUNTING-RATE ERROR FROM STANDARD DEVIATION OF REPEATED MEASUREMENTS, CORRESPONDING CALIBRATION CONSTANTS FROM RUN B4-6, MATRIX CORRECTION FACTOR 1.0231)

235U ENRICHMENT	ABSOLUTE ERROR	REL. ERROR	THEREOF ERRORS THROUGH UF6 MEASUREMENT	/ CALIBRATION
3.50048	0.00147	0.042%	0.022%	0.036%

Appendix D

Stability of spectral peaks.

Peak positions, peak counting rates
and peak-shape parameters.

TABLE D1 STABILITY OF PEAK POSITIONS IN MCA SPECTRUM

MEAS. NR.	59 KEV PEAK PEAK POSITION (CHN)	DEVIATION FROM MEAN (CHN)	185 KEV PEAK PEAK POSITION (CHN)	DEVIATION FROM MEAN (CHN)	PULSER PEAK PEAK POSITION (CHN)	DEVIATION FROM MEAN (CHN)
# 1	479.10	-0.02	1819.05	0.00	2668.54	1.76
# 2	479.12	0.00	1819.05	0.00	2668.28	1.50
# 3	479.12	0.00	1819.07	0.02	2668.08	1.30
# 4	479.16	0.04	1819.07	0.02	2668.23	1.45
# 5	479.16	0.04	1819.07	0.02	2668.40	1.62
# 6	479.16	0.04	1819.05	0.00	2668.34	1.56
# 7	479.12	0.00	1819.05	0.00	2667.09	0.31
# 8	479.11	-0.01	1819.05	0.00	2667.29	0.51
# 9	479.12	0.00	1819.03	-0.02	2666.93	0.15
#10	479.12	0.00	1819.06	0.01	2667.46	0.68
#11	479.10	-0.02	1819.03	-0.02	2667.41	0.63
#12	479.08	-0.04	1819.02	-0.03	2668.88	2.10
#13	479.08	-0.04	1819.02	-0.03	2668.66	1.88
#14	479.07	-0.05	1819.03	-0.02	2668.83	2.05
#15	479.08	-0.04	1819.03	-0.02	2669.18	2.40
#16	479.12	0.00	1819.05	0.00	2668.47	1.69
#17	479.11	-0.01	1819.01	-0.04	2668.67	1.89
#18	479.10	-0.02	1819.06	0.01	2669.10	2.32
#19	479.10	-0.02	1819.06	0.01	2669.15	2.37
#20	479.10	-0.02	1819.03	-0.02	2669.42	2.64
#21	479.12	0.00	1819.08	0.03	2666.89	0.11
#22	479.12	0.00	1819.04	-0.01	2667.09	0.31
#23	479.12	0.00	1819.05	0.00	2666.74	-0.04
#24	479.14	0.02	1819.01	-0.04	2666.02	-0.76
#25	479.12	0.00	1819.08	0.03	2666.13	-0.65
#26	479.11	-0.01	1819.04	-0.01	2664.87	-1.91
#27	479.10	-0.02	1819.03	-0.02	2664.39	-2.39
#28	479.09	-0.03	1819.03	-0.02	2664.24	-2.54
#29	479.11	-0.01	1819.02	-0.03	2663.13	-3.65
#30	479.10	-0.02	1819.06	0.01	2663.19	-3.59
#31	479.11	-0.01	1819.07	0.02	2663.47	-3.31
#32	479.11	-0.01	1819.05	0.00	2663.61	-3.17
#33	479.11	-0.01	1819.04	-0.01	2664.48	-2.30
#34	479.10	-0.02	1819.05	0.00	2664.84	-1.94
#35	479.10	-0.02	1819.03	-0.02	2664.69	-2.09
#36	479.11	-0.01	1819.01	-0.04	2663.48	-3.30
#37	479.11	-0.01	1819.05	0.00	2663.05	-3.73
#38	479.12	0.00	1819.05	0.00	2662.57	-4.21
#39	479.11	-0.01	1819.03	-0.02	2661.90	-4.88
#40	479.12	0.00	1819.04	-0.01	2662.48	-4.30
#41	479.12	0.00	1819.05	0.00	2665.24	-1.54
#42	479.14	0.02	1819.05	0.00	2664.56	-2.22
#43	479.13	0.01	1819.04	-0.01	2665.14	-1.64
#44	479.14	0.02	1819.06	0.01	2663.62	-3.16
#45	479.13	0.01	1819.07	0.02	2664.64	-2.14
#46	479.13	0.01	1819.02	-0.03	2665.00	-1.78
#47	479.14	0.02	1819.08	0.03	2666.37	-0.41
#48	479.12	0.00	1819.06	0.01	2667.14	0.36
#49	479.12	0.00	1819.08	0.03	2667.85	1.07
#50	479.13	0.01	1819.03	-0.02	2667.75	0.97
#51	479.13	0.01	1819.04	-0.01	2666.19	-0.59
#52	479.12	0.00	1819.05	0.00	2667.55	0.77
#53	479.11	-0.01	1819.04	-0.01	2668.70	1.92
#54	479.13	0.01	1819.07	0.02	2668.56	1.78
#55	479.13	0.01	1819.05	0.00	2669.94	3.16
#56	479.12	0.00	1819.07	0.02	2670.86	4.08
#57	479.13	0.01	1819.05	0.00	2669.87	3.09
#58	479.11	-0.01	1819.05	0.00	2671.00	4.22
#59	479.12	0.00	1819.04	-0.01	2670.07	3.29
#60	479.12	0.00	1819.06	0.01	2669.42	2.64
#61	479.13	0.01	1819.04	-0.01	2670.20	3.42
MEAN	479.12		1819.05		2666.78	
RMS ERR.	0.02		0.02		2.39	

TABLE D2 PEAK SHAPE PARAMETERS

FWHM = FULL WIDTH AT HALF MAXIMUM
FWTM = FULL WIDTH AT TENTH MAXIMUM
FWFM = FULL WIDTH AT FIFTIETH MAXIMUM

MEAS.	59 KEV PEAK			185 KEV PEAK			PULSER PEAK		
NR	FWHM (EV)	FWTM (EV)	FWFM (EV)	FWHM (EV)	FWTM (EV)	FWFM (EV)	FWHM (EV)	FWTM (EV)	FWFM (EV)
# 1	778	1477	3101	920	1686	2242	709	1305	1700
# 2	765	1457	3057	915	1674	2218	699	1280	1673
# 3	759	1442	3094	911	1665	2206	691	1269	1654
# 4	750	1411	2926	893	1640	2156	679	1233	1592
# 5	753	1412	2949	895	1639	2164	681	1236	1597
# 6	752	1415	2925	902	1639	2164	690	1252	1620
# 7	767	1453	3026	913	1673	2212	699	1282	1667
# 8	770	1463	3104	916	1682	2220	702	1287	1677
# 9	768	1455	3101	912	1672	2223	698	1283	1671
#10	772	1463	3079	914	1682	2226	704	1293	1683
#11	766	1454	3078	913	1679	2212	710	1306	1701
#12	783	1480	3100	920	1700	2226	720	1351	1703
#13	779	1470	3108	926	1691	2228	712	1303	1691
#14	774	1469	3089	922	1683	2226	710	1297	1681
#15	784	1478	3158	927	1696	2224	717	1307	1692
#16	802	1512	3222	934	1715	2226	736	1342	1737
#17	799	1508	3180	941	1718	2265	732	1337	1727
#18	803	1515	3195	940	1713	2264	738	1343	1733
#19	804	1511	3203	941	1721	2271	738	1343	1732
#20	804	1511	3135	937	1720	2253	737	1340	1727
#21	803	1510	3184	945	1720	2258	745	1345	1736
#22	804	1512	3172	942	1722	2275	742	1343	1732
#23	800	1502	3159	941	1716	2249	739	1335	1725
#24	792	1487	3132	932	1703	2235	733	1324	1710
#25	785	1476	3137	932	1700	2231	726	1311	1695
#26	772	1488	3086	920	1674	2211	709	1281	1660
#27	759	1430	3028	907	1652	2188	693	1267	1647
#28	748	1411	3007	899	1643	2156	667	1230	1602
#29	734	1382	2957	888	1623	2148	623	1186	1557
#30	730	1376	2908	883	1618	2138	628	1186	1554
#31	740	1397	2947	891	1634	2147	634	1203	1579
#32	739	1396	2967	889	1635	2161	650	1209	1581
#33	730	1375	2911	882	1616	2130	662	1206	1572
#34	734	1382	2972	888	1619	2151	662	1205	1572
#35	734	1383	2934	883	1623	2137	670	1213	1580
#36	732	1376	2877	885	1616	2129	633	1187	1663
#37	728	1369	2860	881	1613	2116	641	1185	1543
#38	727	1369	2889	876	1608	2120	609	1165	1527
#39	727	1367	2865	878	1603	2107	534	1127	1497
#40	727	1367	2850	880	1612	2119	560	1140	1508
#41	746	1396	2934	891	1634	2156	712	1259	1621
#42	752	1406	2934	897	1633	2153	720	1259	1621
#43	753	1408	2969	899	1638	2144	709	1243	1603
#44	749	1399	2966	898	1634	2149	679	1226	1586
#45	744	1394	2957	890	1629	2142	702	1232	1586
#46	743	1392	2926	893	1627	2146	700	1229	1582
#47	745	1393	2926	891	1625	2142	685	1225	1581
#48	749	1402	2983	895	1628	2150	682	1226	1584
#49	752	1408	2969	898	1637	2155	685	1233	1598
#50	751	1405	2940	895	1633	2154	687	1236	1598
#51	758	1411	2959	900	1646	2167	704	1249	1608
#52	758	1416	3015	901	1645	2169	698	1256	1623
#53	758	1422	3033	905	1647	2172	693	1249	1614
#54	767	1432	3058	910	1665	2190	712	1276	1647
#55	770	1411	3068	916	1667	2189	712	1282	1657
#56	780	1458	3045	918	1673	2208	714	1287	1660
#57	776	1451	3064	925	1677	2215	721	1301	1684
#58	782	1466	3120	921	1677	2223	718	1291	1668
#59	775	1454	3079	919	1675	2222	732	1323	1713
#60	772	1448	3094	920	1671	2201	712	1284	1657
#61	775	1453	3080	918	1675	2198	713	1286	1662
MEAN	763	1435	3029	908	1660	2188	693	1264	1640
RMS ERR	23	45	98	19	34	45	42	54	62

TABLE D3 STABILITY OF PEAK SHAPE PARAMETERS

	59 KEV PEAK			185 KEV PEAK			PULSER PEAK		
MEAS. NR.	FWHM DEV. FROM MEAN (EV)	FWTM DEV. FROM GAUSS %	FWFM DEV. FROM GAUSS %	FWHM DEV. FROM MEAN (EV)	FWTM DEV. FROM GAUSS %	FWFM DEV. FROM GAUSS %	FWHM DEV. FROM MEAN (EV)	FWTM DEV. FROM GAUSS %	FWFM DEV. FROM GAUSS %
# 1	15.2	4.16%	67.78%	11.6	0.55%	2.58%	16.3	0.99%	0.93%
# 2	2.2	4.50%	68.21%	6.6	0.38%	2.04%	6.3	0.47%	0.75%
# 3	-3.8	4.24%	71.59%	2.6	0.28%	1.93%	-1.7	0.76%	0.76%
# 4	-12.8	3.22%	64.22%	-15.4	0.76%	1.63%	-13.7	-0.37%	-1.31%
# 5	-9.8	2.88%	64.85%	-13.4	0.48%	1.78%	-11.7	-0.42%	-1.29%
# 6	-10.8	3.24%	63.73%	-6.4	-0.30%	0.99%	-2.7	-0.45%	-1.17%
# 7	4.2	3.94%	66.07%	4.6	0.54%	1.98%	6.3	0.63%	0.39%
# 8	7.2	4.25%	69.68%	7.6	0.75%	2.02%	9.3	0.59%	0.56%
# 9	5.2	3.95%	69.96%	3.6	0.59%	2.60%	5.3	0.85%	0.77%
#10	9.2	3.98%	67.88%	5.6	0.97%	2.52%	11.3	0.77%	0.63%
#11	3.2	4.15%	69.14%	4.6	0.90%	1.98%	17.3	0.92%	0.85%
#12	20.2	3.71%	66.65%	11.6	1.38%	1.85%	27.3	2.95%	-0.44%
#13	16.2	3.53%	67.94%	17.6	0.19%	1.28%	19.3	0.41%	-0.03%
#14	11.2	4.13%	67.99%	13.6	0.15%	1.63%	17.3	0.23%	-0.34%
#15	21.2	3.43%	69.55%	18.6	0.38%	0.99%	24.3	0.01%	-0.67%
#16	39.2	3.44%	69.11%	25.6	0.74%	0.32%	43.3	0.04%	-0.66%
#17	36.2	3.55%	67.53%	32.6	0.17%	1.32%	39.3	0.21%	-0.69%
#18	40.2	3.51%	67.48%	31.6	-0.02%	1.38%	45.3	-0.16%	-1.16%
#19	41.2	3.11%	67.69%	32.6	0.35%	1.59%	45.3	-0.16%	-1.21%
#20	41.2	3.11%	64.13%	28.6	0.71%	1.21%	44.3	-0.24%	-1.26%
#21	40.2	3.17%	66.91%	36.6	-0.14%	0.58%	52.3	-0.95%	-1.91%
#22	41.2	3.18%	66.07%	33.6	0.30%	1.66%	49.3	-0.69%	-1.74%
#23	37.2	3.01%	66.22%	32.6	0.05%	0.60%	46.3	-0.88%	-1.74%
#24	29.2	3.01%	66.46%	23.6	0.25%	0.94%	40.3	-0.90%	-1.80%
#25	22.2	3.16%	68.21%	23.6	0.08%	0.76%	33.3	-0.92%	-1.72%
#26	9.2	5.75%	68.26%	11.6	-0.17%	1.16%	16.3	-0.87%	-1.45%
#27	-3.8	3.37%	67.93%	-1.4	-0.07%	1.54%	0.3	0.31%	0.04%
#28	-14.8	3.50%	69.22%	-9.4	0.27%	0.95%	-25.7	1.18%	1.10%
#29	-28.8	3.30%	69.58%	-20.4	0.28%	1.82%	-69.7	4.45%	5.20%
#30	-32.8	3.42%	67.68%	-25.4	0.54%	1.92%	-64.7	3.62%	4.16%
#31	-22.8	3.58%	67.63%	-17.4	0.62%	1.43%	-58.7	4.11%	4.83%
#32	-23.8	3.64%	69.00%	-19.4	0.91%	2.32%	-42.7	2.05%	2.38%
#33	-32.8	3.34%	67.85%	-26.4	0.53%	1.65%	-30.7	-0.05%	-0.04%
#34	-28.8	3.30%	70.44%	-20.4	0.03%	1.96%	-30.7	-0.13%	-0.04%
#35	-28.8	3.38%	68.26%	-25.4	0.85%	1.87%	-22.7	-0.67%	-0.74%
#36	-30.8	3.14%	65.44%	-23.4	0.19%	1.26%	-59.7	2.88%	10.59%
#37	-34.8	3.18%	65.37%	-27.4	0.45%	1.10%	-51.7	1.43%	1.33%
#38	-35.8	3.32%	67.27%	-32.4	0.71%	1.87%	-83.7	4.96%	5.54%
#39	-35.8	3.17%	65.88%	-30.4	0.17%	1.01%	-158.7	15.79%	18.00%
#40	-35.8	3.17%	65.01%	-28.4	0.50%	1.36%	-132.7	11.69%	13.35%
#41	-16.8	2.67%	65.55%	-17.4	0.62%	1.86%	19.3	-2.98%	-4.17%
#42	-10.8	2.58%	64.23%	-11.4	-0.12%	1.03%	27.3	-4.06%	-5.23%
#43	-9.8	2.59%	65.97%	-9.4	-0.03%	0.39%	16.3	-3.81%	-4.83%
#44	-13.8	2.48%	66.69%	-10.4	-0.17%	0.73%	-13.7	-0.93%	-1.68%
#45	-18.8	2.80%	67.30%	-18.4	0.42%	1.31%	9.3	-3.71%	-4.90%
#46	-19.8	2.79%	65.77%	-15.4	-0.04%	1.16%	7.3	-3.67%	-4.87%
#47	-17.8	2.59%	65.32%	-17.4	0.06%	1.19%	-7.7	-1.88%	-2.85%
#48	-13.8	2.70%	67.64%	-13.4	-0.20%	1.12%	-10.7	-1.37%	-2.24%
#49	-10.8	2.73%	66.19%	-10.4	0.02%	1.01%	-7.7	-1.24%	-1.80%
#50	-11.8	2.65%	64.79%	-13.4	0.11%	1.31%	-5.7	-1.29%	-2.09%
#51	-4.8	2.13%	64.32%	-8.4	0.34%	1.35%	11.3	-2.66%	-3.86%
#52	-4.8	2.49%	67.43%	-7.4	0.17%	1.33%	5.3	-1.27%	-2.12%
#53	-4.8	2.93%	68.43%	-3.4	-0.15%	1.02%	0.3	-1.11%	-1.96%
#54	4.2	2.44%	67.82%	1.6	0.39%	1.30%	19.3	-1.67%	-2.63%
#55	7.2	0.54%	67.72%	7.6	-0.15%	0.59%	19.3	-1.21%	-2.04%
#56	17.2	2.56%	64.33%	9.6	-0.01%	1.24%	21.3	-1.10%	-2.14%
#57	13.2	2.59%	66.20%	16.6	-0.53%	0.80%	28.3	-1.00%	-1.69%
#58	19.2	2.86%	67.94%	12.6	-0.10%	1.60%	25.3	-1.35%	-2.21%
#59	12.2	2.94%	67.23%	10.6	0.00%	1.77%	39.3	-0.84%	-1.49%
#60	9.2	2.91%	68.70%	11.6	-0.35%	0.70%	19.3	-1.06%	-2.04%
#61	12.2	2.87%	67.29%	9.6	0.11%	0.79%	20.3	-1.04%	-1.88%

TABLE D4 STABILITY OF COUNTING RATES

MEAS. NR	TOTAL COUNT. RATE (CPS)	PULSER (EXT.) COUNT. RATE (CPS)	PULSER (EXT.) DEV. FROM MEAN	PULSER (MCA) COUNT. RATE (CPS)	PULSER (MCA) DEV. FROM MEAN	59 KEV PEAK COUNT. RATE (CPS)	59 KEV PEAK DEV. FROM MEAN	185 KEV PEAK *) COUNT. RATE (CPS)	185 KEV PEAK *) DEV FROM MEAN
# 1	815	139.98	-0.58%	140.02	-0.71%	134.38	0.13%	8.885	-0.43%
# 2	815	140.10	-0.49%	140.14	-0.62%	134.28	0.06%	8.922	-0.02%
# 3	815	140.18	-0.43%	140.29	-0.52%	134.11	-0.07%	8.926	0.03%
# 4	815	140.39	-0.28%	140.45	-0.40%	134.45	0.18%	8.907	-0.19%
# 5	815	140.52	-0.19%	140.59	-0.30%	134.31	0.08%	8.914	-0.11%
# 6	815	140.56	-0.16%	140.63	-0.27%	134.49	0.22%	8.910	-0.16%
# 7	815	140.43	-0.25%	140.61	-0.29%	134.35	0.11%	8.918	-0.06%
# 8	815	140.57	-0.16%	140.63	-0.28%	134.48	0.21%	8.917	-0.07%
# 9	815	140.60	-0.13%	140.74	-0.20%	134.25	0.03%	8.901	-0.26%
#10	815	140.60	-0.14%	140.67	-0.25%	134.52	0.24%	8.907	-0.19%
#11	756	140.75	-0.03%	140.88	-0.10%	134.39	0.14%	8.929	0.06%
#12	756	140.61	-0.13%	140.72	-0.21%	134.84	0.48%	8.916	-0.09%
#13	756	140.73	-0.04%	140.84	-0.12%	134.45	0.19%	8.892	-0.36%
#14	757	140.67	-0.08%	140.88	-0.10%	134.50	0.22%	8.944	0.22%
#15	756	140.66	-0.09%	140.84	-0.13%	134.78	0.43%	8.924	0.00%
#16	756	140.86	0.05%	140.97	-0.04%	134.53	0.24%	8.895	-0.32%
#17	756	140.79	0.00%	140.91	-0.08%	134.33	0.10%	8.933	0.10%
#18	756	140.73	-0.04%	140.88	-0.10%	134.35	0.11%	8.934	0.11%
#19	755	140.71	-0.05%	140.86	-0.11%	134.14	-0.04%	8.916	-0.08%
#20	756	140.67	-0.08%	140.84	-0.13%	134.39	0.14%	8.934	0.11%
#21	723	140.85	0.04%	141.03	0.01%	134.49	0.21%	8.912	-0.13%
#22	723	140.93	0.10%	141.01	-0.01%	134.54	0.25%	8.924	0.00%
#23	723	140.89	0.07%	141.12	0.07%	134.51	0.23%	8.942	0.20%
#24	723	141.00	0.15%	141.17	0.11%	134.50	0.22%	8.923	-0.00%
#25	723	140.99	0.14%	141.16	0.10%	134.23	0.02%	8.926	0.02%
#26	723	141.15	0.26%	141.36	0.25%	134.25	0.04%	8.927	0.04%
#27	723	141.36	0.41%	141.45	0.31%	133.93	-0.20%	8.933	0.10%
#28	723	141.30	0.36%	141.44	0.30%	133.74	-0.34%	8.931	0.09%
#29	723	141.42	0.45%	141.59	0.40%	133.55	-0.49%	8.920	-0.04%
#30	723	141.39	0.43%	141.51	0.35%	133.56	-0.48%	8.906	-0.20%
#31	688	141.23	0.32%	141.51	0.35%	133.60	-0.45%	8.927	0.04%
#32	688	141.23	0.32%	141.52	0.35%	133.63	-0.42%	8.942	0.20%
#33	688	141.28	0.35%	141.56	0.38%	133.61	-0.44%	8.931	0.08%
#34	687	141.20	0.29%	141.46	0.32%	133.72	-0.36%	8.923	-0.00%
#35	688	- +)	-	141.49	0.34%	133.57	-0.47%	8.933	0.10%
#36	688	-	-	141.65	0.45%	133.71	-0.37%	8.923	-0.01%
#37	688	-	-	141.69	0.48%	133.79	-0.30%	8.916	-0.08%
#38	688	-	-	141.74	0.51%	133.85	-0.27%	8.942	0.21%
#39	688	-	-	141.77	0.54%	133.75	-0.34%	8.937	0.15%
#40	688	-	-	141.67	0.46%	133.65	-0.41%	8.932	0.10%
#41	687	141.14	0.25%	141.36	0.24%	133.87	-0.25%	8.925	0.02%
#42	688	141.31	0.37%	141.61	0.42%	133.95	-0.19%	8.939	0.17%
#43	688	141.23	0.32%	141.50	0.34%	133.83	-0.28%	8.934	0.12%
#44	688	141.46	0.48%	141.69	0.48%	133.74	-0.35%	8.916	-0.09%
#45	688	141.28	0.35%	141.55	0.37%	133.80	-0.30%	8.924	0.00%
#46	688	141.21	0.30%	141.45	0.31%	133.84	-0.27%	8.927	0.04%
#47	814	140.88	0.06%	140.95	-0.05%	133.49	-0.53%	8.913	-0.12%
#48	814	140.68	-0.08%	140.84	-0.13%	133.43	-0.58%	8.924	0.00%
#49	814	140.60	-0.13%	140.69	-0.23%	133.66	-0.41%	8.937	0.15%
#50	814	140.73	-0.04%	140.70	-0.23%	133.65	-0.41%	8.924	0.00%
#51	814	140.99	0.14%	140.99	-0.02%	133.75	-0.33%	8.908	-0.17%
#52	687	140.71	-0.06%	140.93	-0.06%	133.84	-0.27%	8.921	-0.03%
#53	687	140.54	-0.17%	140.77	-0.18%	133.93	-0.20%	8.933	0.11%
#54	689	140.65	-0.10%	140.89	-0.09%	135.33	0.84%	8.925	0.02%
#55	688	140.43	-0.26%	140.68	-0.24%	135.12	0.68%	8.936	0.14%
#56	688	140.28	-0.36%	140.55	-0.33%	135.22	0.76%	8.931	0.08%
#57	756	140.42	-0.26%	140.58	-0.31%	135.09	0.66%	8.925	0.02%
#58	756	140.24	-0.39%	140.38	-0.45%	135.08	0.65%	8.940	0.18%
#59	756	140.36	-0.30%	140.49	-0.37%	135.19	0.74%	8.910	-0.15%
#60	756	140.47	-0.23%	140.64	-0.27%	134.99	0.58%	8.939	0.17%
#61	756	140.38	-0.29%	140.55	-0.33%	135.08	0.65%	8.938	0.16%
MEAN		140.79		141.02		134.20		8.924	
RMS ERR		0.37		0.45		0.51		0.013	

*) 185 KEV GAMMA COUNTING RATES ARE GIVEN PER % 235U ABUNDANCE. ABUNDANCE VALUES FOR REFERENCE MATERIALS ARE TAKEN FROM EC-NRM-171 CERTIFICATE, FOR UF6 3.5001 % 235U AND MATRIX CORRECTION FACTOR OF 1.0231 IS ASSUMED. WALL THICKNESS CORRECTION IS MADE ACCORDING TO VALUES MEASURED AT KFK.

+) DUE TO PRINTER FAULT EXTERNALLY MEASURED PULSER COUNTING RATES ARE NOT RECORDED.

Appendix E

Certified and specified data
for the Reference Samples EC-NRM-171
and the REIMEP-86 UF_6 sample.

Certified Nuclear Reference Material

Certificate of Analysis

EC CERTIFIED NUCLEAR REFERENCE MATERIAL 171

^{235}U Isotope Abundance Certified Reference Material (U_3O_8) for Gamma-Spectrometry.

$^{235}U/U$ Abundances

Material	Atom percent	Mass percent	Uncertainties
031	0.3206	0.3166	± 0.0002
071	0.7209	0.7119	± 0.0005
194	1.9664	1.9420	± 0.0014
295	2.9857	2.9492	± 0.0021
446	4.5168	4.4623	± 0.0032

The indicated uncertainties, valid for the atom and mass abundances, correspond to a confidence level of 95%.
This certificate applies to the reference samples:

CBNM 031 -
CBNM 071 -
CBNM 194 -
CBNM 295 -
CBNM 446 -

The Certified Nuclear Reference Material has been prepared in cooperation with the National Bureau of Standards (NBS), Gaithersburg, MD, USA. EC Certified Nuclear Reference Material 171 corresponds to NBS Standard Reference Material 969

Commission of the European Communities
Joint Research Centre
Geel Establishment (CBNM)

EC Nuclear Reference Material Set 171

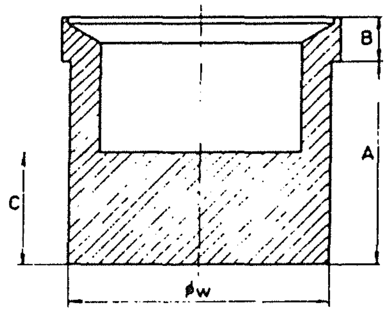
^{235}Uranium Isotope Abundance certified Reference Material

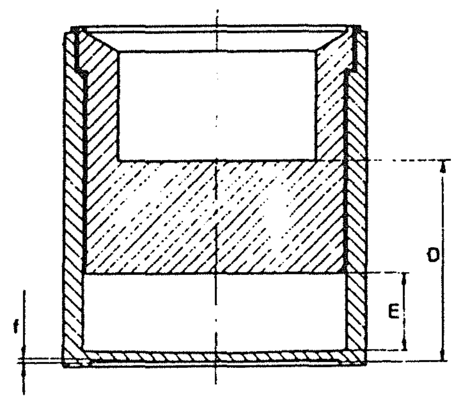
for Gamma Spectrometry

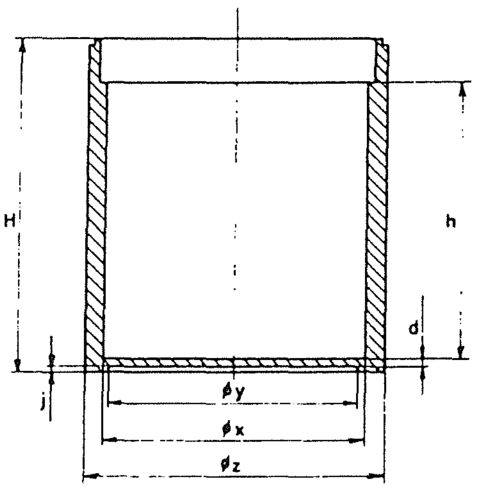
Can dimensions and U_3O_8 mass

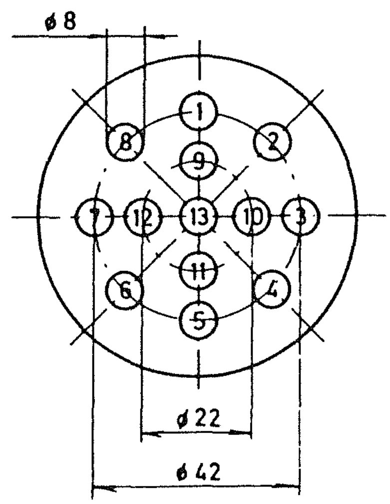
Container N°:	CBNM 194 - 008
Tot. Mass U_3O_8:	(200.1 ± 0.2)g
A :	54.20 mm
B :	11.98
C :	30.00
ϕ_w:	69.88
d :	1.983
H :	88.99
h :	87.00
j :	1.02
ϕ_x:	70.03
ϕ_y:	66.0
ϕ_z:	79.97
D :	52.77
E :	20.79
f :	<0.1

Bottom thickness:	
1	2.001 mm
2	1.996
3	2.000
4	2.003
5	1.998
6	1.996
7	1.996
8	1.996
9	1.978
10	1.984
11	1.980
12	1.978
13	1.995
$\bar{x}_{13}$	1.993
$\bar{s}_{13}$	0.009
$\bar{x}_5$	1.983
$\bar{s}_5$	0.007







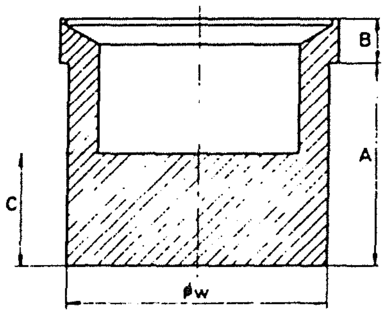


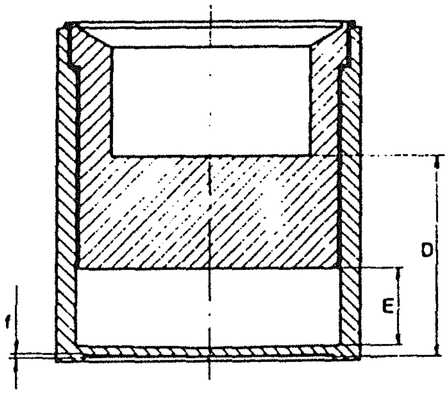
EC Nuclear Reference Material Set 171
^{235}Uranium Isotope Abundance certified Reference Material
for Gamma Spectrometry

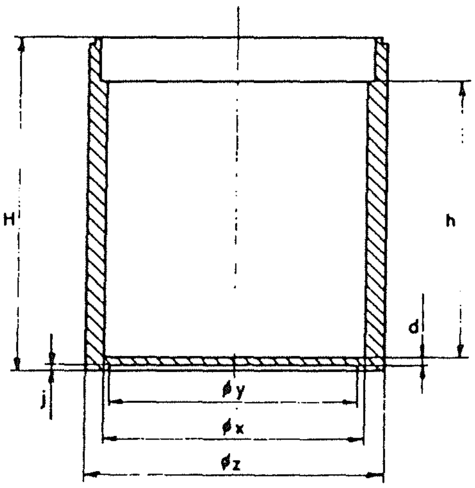
Can dimensions and U_3O_8 mass

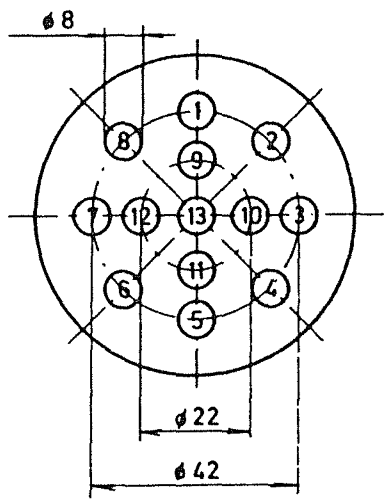
Container N°:	CBNM 295 - 008
Tot. Mass U_3O_8:	(200.1 ± 0.2)g
A :	54.20 mm
B :	11.98
C :	29.99
ϕ_w:	69.88
d :	1.988
H :	88.98
h :	87.00
j :	1.02
ϕ_x:	70.04
ϕ_y:	66.0
ϕ_z:	79.97
D :	52.80
E :	20.82
f :	<0.1

Bottom thickness: 1	1.986 mm
2	1.981
3	1.986
4	1.991
5	1.986
6	1.984
7	1.980
8	1.982
9	1.990
10	1.988
11	1.986
12	1.987
13	1.991
$\bar{x}_{13}$	1.986
$\bar{s}_{13}$	0.004
$\bar{x}_5$	1.988
$\bar{s}_5$	0.002









EC Nuclear Reference Material Set 171

^{235}Uranium Isotope Abundance certified Reference Material

for Gamma Spectrometry

Can dimensions and U_3O_8 mass

NDA-U_3O_8 RM programme.

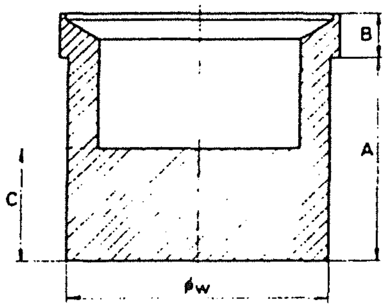
Container N°: CBNM 446 - 008

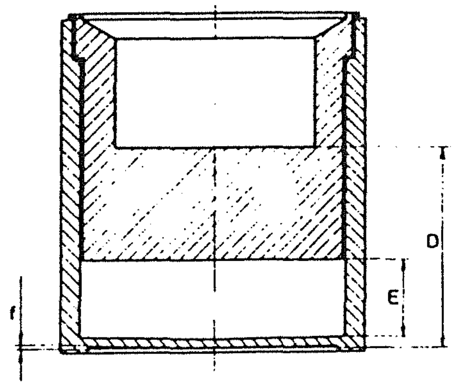
Tot. Mass U_3O_8: (200.1 ± 0.2)g

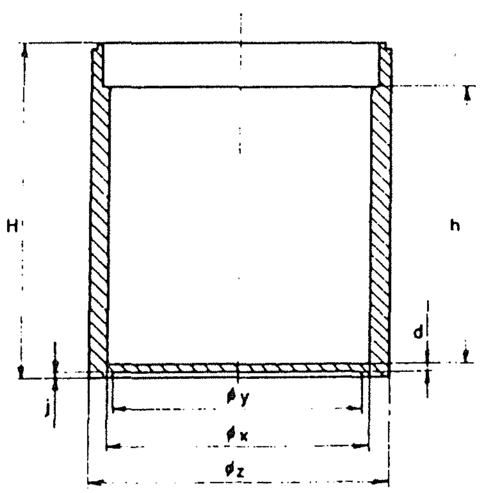
A	54.18 mm
B	12.00
C	35.00
ϕ_w	69.88
d	1.983
H	88.99
h	86.99
j	1.01
ϕ_x	70.01
ϕ_y	66.0
ϕ_z	79.99
D	52.79
E	15.81
f	<0.1

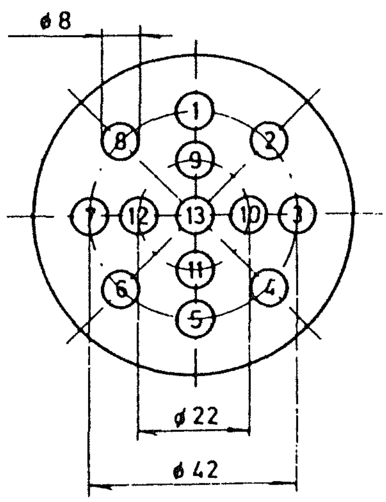
Bottom thickness:

1	1.989 mm
2	1.987
3	1.987
4	1.984
5	1.992
6	1.988
7	1.988
8	1.992
9	1.981
10	1.979
11	1.981
12	1.980
13	1.992
$\bar{x}_{13}$	1.986
$\bar{s}_{13}$	0.005
$\bar{x}_5$	1.983
$\bar{s}_5$	0.005







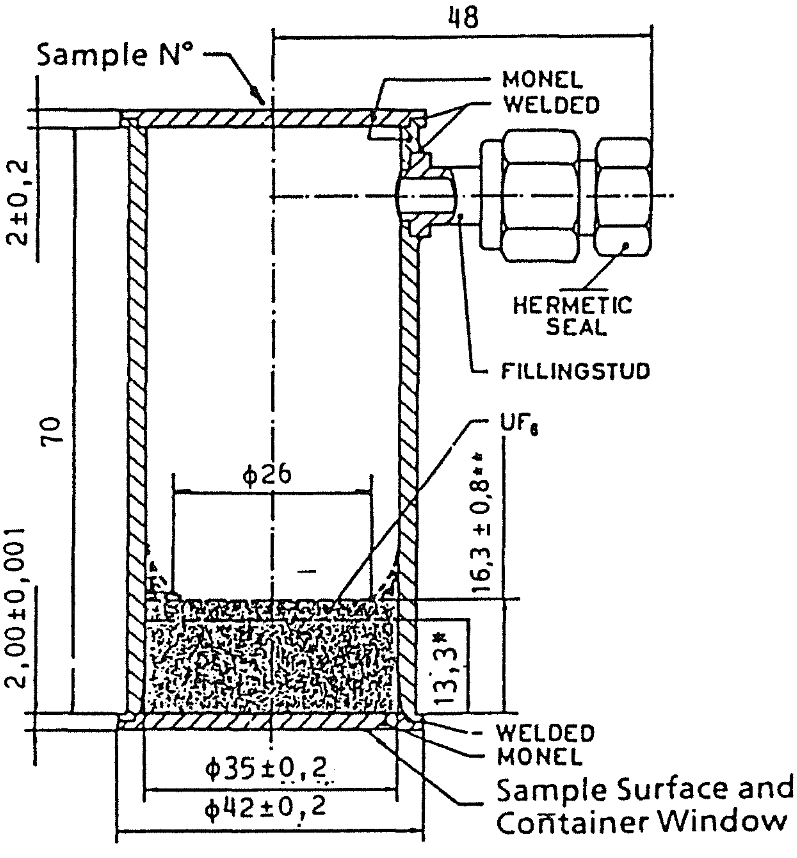


App. 6

UF6 REIMEP 1986

Dimensions in mm

UF6 sample for NDA
(UF6 weight 80±1g)

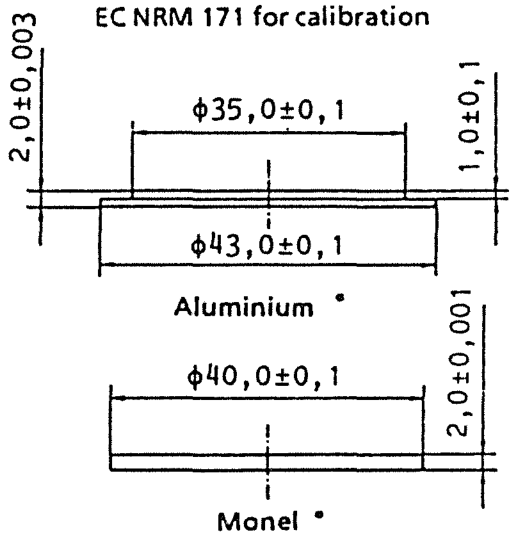


*/ height for 99.9 % infinite thickness for 185.7 keV γ-line and radiation perpendicular to the sample surface

**/ height of used amount UF6 in solid state equivalent to a surface density of 8,2 ± 0,4 g.cm-2 (at 25°C)

Calibration Disks

For the Use of the Enrichment meter Technique and EC NRM 171 for calibration



*/ materials identical with those used for UF6 test samples and reference samples EC NRM 171 respectively

App. NDA-1

UF_6 IMEP 1986

FURTHER INFORMATION

Measurement of 235U atomic isotope abundance by Gamma Spectrometry and using EC NRM 171 for calibrations (see also App. NDA-2).

1) UF_6 Sample

- The impurity content of the UF_6 was determined by SSMS (spark source mass spectrometry) after conversion to U_3O_8 and found to be less than 200 ± 100 $\mu g \cdot g^{-1}$.

- The date of the filling of the monel containers with UF_6 (equivalent to the date of chemical separation of protactinium) is given below (please note that the individual sample N° is located on the top of each sample):

Sample N°	2	3	4	6	7	8	10	11	12	14
Filling date (1986)	01.08	31.07	24.07	24.07	07.08	31.07	24.07	30.07	29.07	30.07

- In order to obtain a uniform sample thickness in solid state (temperature < 65°C!!) and almost infinite thickness for 185.7 keV gamma rays over almost the full sample surface, a special temperature treatment has been performed ensuring an infinity of thickness > 99.9 %.

2) Calibration of gamma measurements by using EC NRM 171

- Participants are invited to study the User's Manual for EC NRM 171 (KFK Report 3752) supplied together with the reference samples.

- All participants are requested to use the same matrix correction factor, Km = 1.0231 for calibrating their UF_6 gamma measurements with U_3O_8 reference material in order to get comparable results. CBNM is presently working on an accurate experimental determination of Km and will inform participants about the results as soon as these are available.

- Container windows through which the gamma radiation is measured are different for UF_6 samples (~ 2 mm monel) and EC NRM 171 reference samples (~2 mm aluminium). In order to avoid or minimize correction procedures, calibration disks are provided which will allow to perform all measurements with almost identical windows. For performing corrections:

  - the window thicknesses of EC NRM 171 samples are available together with the corresponding documentation (the material for the EC NRM 171 windows is identical to the one of the Al calibration disks).

  - the attenuation of gamma rays of 185.7 keV is (for small corrections):

    - 3.4 % per mm for the aluminium used.
    - 13 % per mm for the monel used.

Caution: Keep the ambient temperature of UF_6 samples always below 55°C.

Appendix F

Relevant formulae, values and figures
from "User's manual", KfK Report 3752

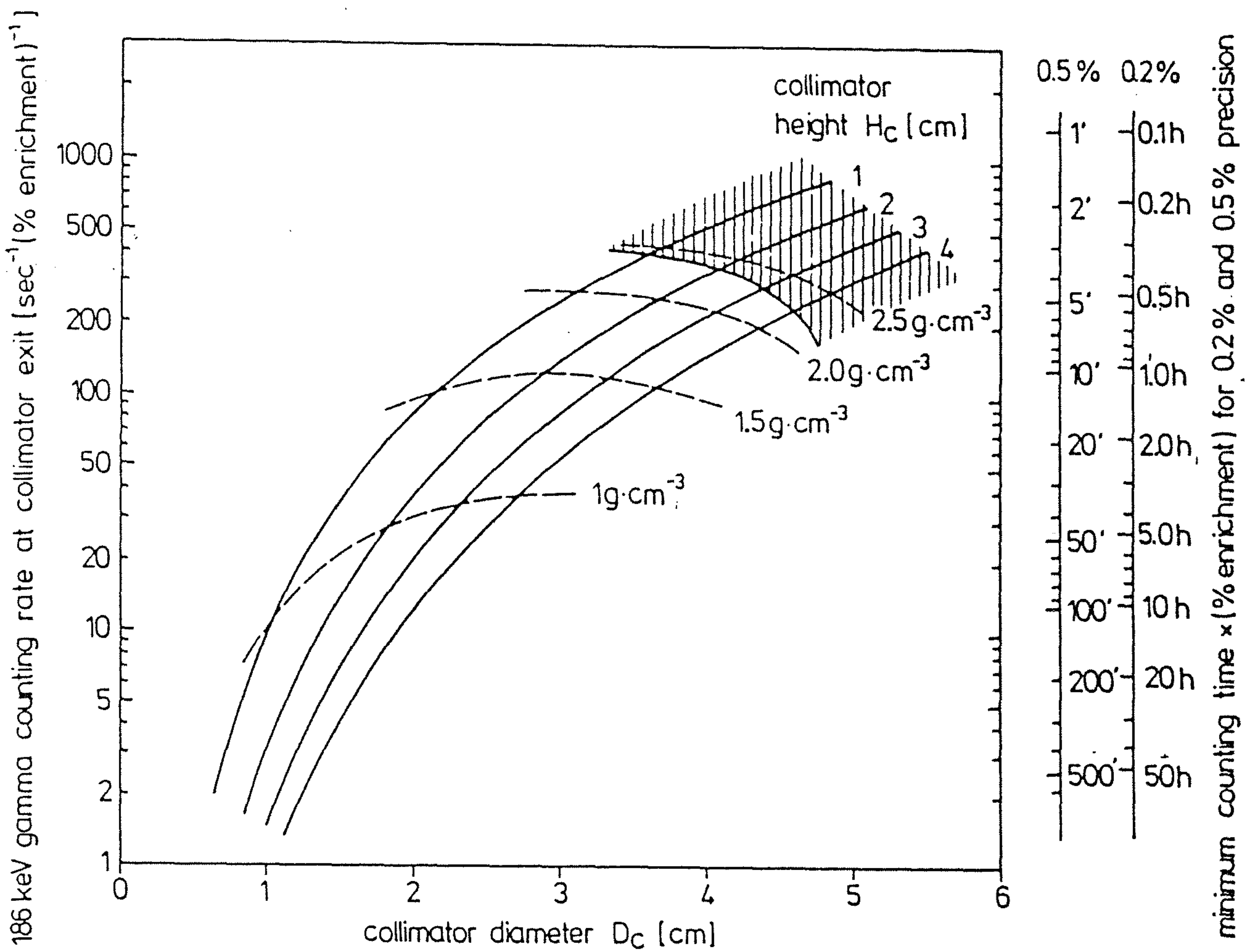


Fig. 3.7 Recommended collimator dimensions, expected counting rates and approximate counting times.
Upper limits for collimator dimensions given by dashed lines refer to the indicated U_3O_8 material density, and to standard sample containers with 7 cm inner diameter.
Collimator geometries in the shaded region do not fulfill the "quasi-infinite" sample condition for the Reference Samples EC-NRM-171/NBS-SRM-969.

Fig. 3.7 can be utilized also to determine the suitable collimator geometries if uranium compounds other than U_3O_8 are measured in the empty reference can. In this case, instead of using the true sample density ρ_x of the uranium compound x under assay, an effective sample density ρ_{eff} must be applied in Fig. 3.7:

$$\rho_{eff} = \frac{\mu\ (x)}{\mu\,(U_3O_8)} \cdot \rho_x, \tag{3.9}$$

where $\mu(x)$ and $\mu(U_3O_8)$ denote the mass attenuation coefficients of the uranium compound x and U_3O_8, respectively. For UO_2, e.g., the μ ratio in eq. 3.9 evaluates to a value of 1.035, which is very close to 1. Therefore, Fig. 3.7 may be directly used for both types of uranium oxides, UO_2 and U_3O_8, as well.

Table C2 Mass attenuation coefficients for 185.7 keV photons for some uranium compounds.

Uranium compound	Molecular mass ($g \cdot mol^{-1}$) [21]	Mass attenuation coefficient ($cm^2 \cdot g^{-1}$)
U metal	238	1.473
UO_2	270	1.313
U_3O_8	842	1.268
UF_4	314	1.145
UF_6	352	1.034
Uranyl nitrate $UO_2\ (NO_3)_2 \cdot 6H_2O$	502	0.767

3.3 Sample matrix composition

All elements other than uranium present in the sample material are considered here as matrix material. Obviously, the attenuation of photons in the matrix material reduces the observed 186 keV gamma-ray flux at the sample surface, and thus influences the measured ^{235}U enrichment value. This influence is described by the matrix attenuation factor ß derived in Appendix A:

$$ß = \frac{1}{1 + \sum\limits_{i \neq U} \frac{N_i \cdot \sigma_i}{N_U \cdot \sigma_U}} \qquad (3.16)$$

for the case that the matrix is given in terms of atom fraction N_i/N_U, or, equivalently,

$$ß = \frac{1}{1 + \sum\limits_{i \neq U} \frac{\rho_i \cdot \mu_i}{\rho_U \cdot \mu_U}} \qquad (3.16a)$$

if the matrix is given as mass fraction ρ_i/ρ_U of uranium. ρ_i/ρ_U are the mass ratios, N_i/N_U are the atom ratios, μ_i and μ_U are the mass attenuation coefficients, and σ_i and σ_U are the photon attenuation cross sections for matrix material i and uranium, respectively. The summation extends over all matrix elements i.

Table 3.4 Matrix attenuation factors, matrix correction factors, and relative change of the 186 keV gamma-ray counting rate for some uranium compounds (U_3O_8 used as reference)

Uranium compound	Matrix attenuation factor ß	Relative change of 186 keV gamma counting rate	Matrix correction factor $C_{compound}$
U metal	1.0000	+ 1.51 %	0.9849
UO_2	0.9886	+ 0.38 %	0.9962
U_3O_8	0.9849	0 (reference)	1
UF_4	0.9750	- 1.00 %	1.0101
UF_6	0.9630	- 2.22 %	1.0228
Uranyl nitrate $UO_2(NO_3)_2 \cdot 6H_2O$	0.9098	- 7.62 %	1.0825

A.2 Gamma-ray transmission through a collimator

For a cylindrically shaped collimator with a diameter D_c and a height H_c, we get the number of 186 keV photons penetrating this collimator per unit time:

$$I_{\gamma}^{cyl} = enr \cdot I_{186} \underbrace{\left(\pi \frac{D_c^2}{4}\right)}_{\text{collimator-entrance area}} \cdot \left[\frac{2H_c^2}{D_c^2} \left(1 + \frac{D_c^2}{2H_c^2} - \sqrt{1 + \frac{D_c^2}{H_c^2}} \right) \right] \qquad \text{(A22)}$$

Number of 185.7 keV photons emitted per cm² surface area of an infinitely thick U metal sample into the halfspace (2π) per second per % ^{235}U isotope abundance (atom %), neglecting coherent photon scattering and assuming uniform ^{235}U isotope abundance in the sample:

$$I_{186} = \frac{\dot{n}_{186}}{4 \cdot \sigma_U} \cdot \frac{1}{100}$$

$$= (77 \pm 4) \ [cm^{-2} \cdot s^{-1} \cdot (\% \ ^{235}U)^{-1}]$$

A.3 Gamma absorbing material between sample and detector

In a real gamma counting set-up one will always find some gamma-absorbing material between sample and detector, as, e.g., the sample containment or, at least, the detector cover. It is of interest here to quantify the influence of such absorber materials on the observed gamma counting rate. We assume that it is possible to combine all absorbers to a layer of uniform thickness, which is oriented in parallel to the collimator surface. As can be seen from Fig. A4, the path length of an 186 keV photon through the absorber layer depends on the inclination angle θ between the direction of the radiation and the collimator axis. The photon attenuation increases with increasing angle θ.

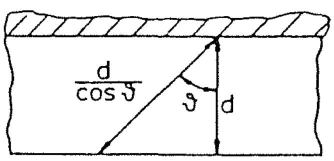


Fig. A4
Path length of gamma rays through an absorber layer.

The mean path length through the absorber with respect to the photons, which are observed in the gamma detector, depends on the angular distribution of the radiation source and on the angular acceptance of the counting geometry.

The photon attenuation in an absorbing layer is usually given as the ratio of photon counting rates observed with and without the absorber. In order to simplify the presentation of the attenuation correction required for varying container wall thickness d, we define a wall thickness correction factor K_{abs} by:

$$\frac{\dot{N}_{186}(d)}{\dot{N}_{186}(d=0)} =: e^{-\lambda \cdot K_{abs} \cdot d} .$$

or (A27)

$$K_{abs} =: \frac{\ln \dot{N}_{186}(d=0) - \ln \dot{N}_{186}(d)}{\lambda \cdot d} .$$

Then the term

$$K_{abs} \cdot d = d_{eff}$$

describes the effective mean path length d_{eff} of the photons through the absorbing layer with a thickness d. It should be noted that the value of K_{abs} depends on the specific parameters of the particular counting geometry and on properties of the canning of the samples under assay.

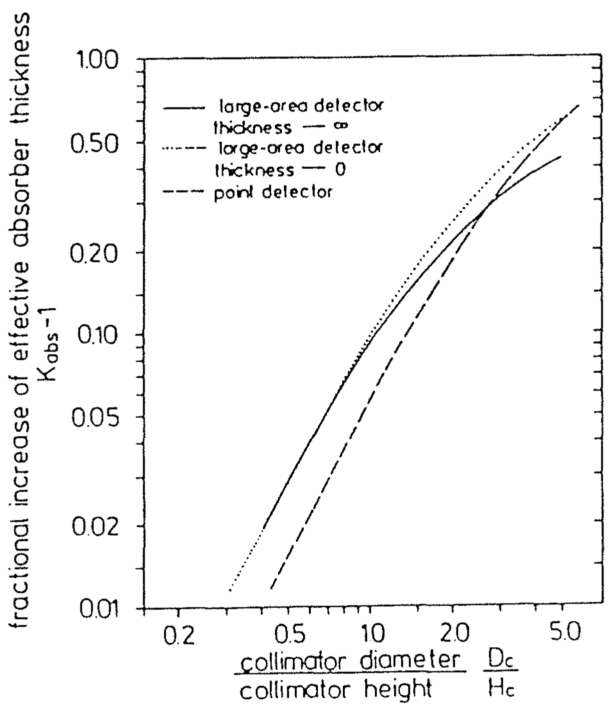


Fig. A6 Fractional increase of the effective absorber thickness (K_{abs} - 1) relative to a very narrow collimator as a function of the collimator geometry, given for three types of gamma detectors.

Table C3 Linear attenuation coefficients for 185.7 keV photons for some absorber materials.

Absorber material	Density ($g \cdot cm^{-3}$)	Linear attenuation coefficient (cm^{-1})
Polyethylene $(CH_2)_n$	0.95	0.14
Aluminium	2.70	0.329
Steel	7.9	1.25
Copper	8.92	1.38
Brass (61.5 % Cu 35.5 % Zn 3.0 % Pb)	8.5	1.58
Cadmium	8.64	2.78
Lead	11.3	12.8
Tungsten	19.4	17.1