CCRI(III)-S2.Hp(10):

Supplementary Comparison for the Calibration of Personal Dose Equivalent Meters in ISO Neutron Reference Fields

Technical Protocol

Pilot Laboratory:

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1 Introduction

The monitoring of neutron personal dose equivalent is one of the most important tasks for the radiation protection of workers in the nuclear power plant and other places. The reliability of the monitoring of the neutron personal dose equivalent depends on the capability of the calibration of neutron personal dose equivalent meters. In practice, many difficulties lie in the fact that the sensitivities of neutron personal dose equivalent meters are generally small. This fact makes it difficult to make the comparison for the calibration of the neutron personal dose equivalent meters. If a transfer instrument has small sensitivity, it can be hard to distinguish between the statistical fluctuation of the measurand and the calibration capability of the participants. Unlike neutron ambient dose equivalent rate meters, neutron personal dose equivalent meters measure the dose equivalent rather than the dose equivalent rate. Reducing statistical uncertainties by the repeated measurements makes the measurement time long.

The procedure of the calibration of neutron personal dose equivalent is not written clearly in ISO 8529-3 [3]. One ambiguity is the method to subtract the contribution of the scattered neutrons in the neutron irradiation room. In ISO 8529-2 [2], four methods (Shadow-cone method, Generalized-fit method, Semi-empirical method, and Reduced-fitting method) are presented for the correction H*(10) for the influence of the scatted neutrons. However, there are no recommended methods to correct the scatter-contributions of H_p(10). It is estimated to be about several percent for the neutron irradiation room with dimensions of 6.6 m x 7.6

m x 6.3 m surrounded by concrete walls [4]. Conversion coefficients $h_{p\Phi}(10)$ in the ICRU tissue slab phantom are evaluated for parallel neutron irradiation. Unlike conversion coefficient $h_{\Phi}^*(10)$ for ambient dose equivalent, $h_{p\Phi}(10, \alpha)$ is dependent for angles of incidence α . In practice, when the normal direction of the phantom surface coincides with the neutron source, $h_{p\Phi}(10,0^\circ)$ can be used as $h_{p\Phi}(10)$.

Many national metrology institutes list the calibration of neutron personal dose equivalent in their CMC table and offer the calibration of neutron personal dose equivalent meters. But there is no CCRI comparison supporting the CMC because of the difficulties and complexity to realize the comparison for the neutron personal dose equivalent. Since 2017, a CCRI supplementary comparison for the calibration of neutron ambient dose equivalent (CCRI(III)-S1) is going on. A similar procedure could be applied the supplementary comparison for the calibration.

CCRI comparison for the calibration of neutron personal dose equivalent meter could be conducted using ISO neutron reference fields [1]. Two neutron personal dose equivalent meters will be used as transfer instruments and the calibration factors for two transfer instruments could be derived.

2 Participants

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Full contact information is given in Appendix A.

3 Schedule

Two transfer instruments will be circulated and the stability of the transfer instruments will be checked at the pilot laboratory (KRISS) during circulations.

One month is scheduled for the calibration measurement. The following month, the equipment will be shipped back to KRISS, which will be transported to the next participant after check of stability. If there is a problem with customs, participants will be given an additional month.

Start of the comparison 2022-02

No.	Participant	Measurement at the participant	Transfer to next participant or to KRISS	Report of th results to pil
1	KRISS (KR)	2022-02		
	KRISS*	2022-02	2022-02	
2	NIM (CN)	2022-03	2022-04	2022-07
3	BARC	2022-05	2022-06	2022-09
	KRISS	2022-07	2022-07	
4	CMI (CZ)	2022-08	2022-08	2022-11
5	IRSN (FR)	2022-09	2022-09	2022-12
6	NPL (UK)	2022-10	2022-10	2023-01
	KRISS*	2022-11	2023-11	
7	SCK/CEN (BE)	2022-12	2023-01	2023-04
8	PTB (DE)	2023-02	2023-04	2023-07
9	CIEMAT (ES)	2023-05	2023-05	2023-08
	KRISS	2023-06	2023-06	
10	NMIJ (JP)	2023-07	2023-09	2023-12
11	SMU (SK)	2023-10	2023-11	2024-02
12	VNIIM (RU)	2023-12	2024-01	2024-04
	KRISS	2024-02	2024-02	
13	NIST (USA)	2024-03	2024-03	2024-06
14	NRC (CA)	2024-04	2024-06	2024-09
	KRISS*	2024-07	2024-07	
15	NMISA (ZA)	2024-08	2024-09	2024-12
16	LNMRI/IRD (BR)	2024-10	2024-11	2025-02
	KRISS*	2024-12		
nd of raft c omm	KRISS* f the comparison of Report nents of partners	2024-12 2024-12 2025-03 2025-05	* stabi	lity test

Participants should inform the pilot laboratory as soon as possible if the scheduled procedure has to be changed. In case of delays of more than one month, the whole schedule might be changed in accordance with the availability of the calibration facilities of the participants. The pilot laboratory will cover the expenses for shipping the equipment to the participants while the participants have to cover the costs of the return shipment or shipment to the next participant, respectively. After arrival of the transfer instruments the participant should inform the pilot about the reception. Before dispatching the package for delivery to the pilot or next participating laboratory, the participant should inform the contact person of the pilot laboratory or contact person of the next participant giving transportation details. Information on dimensions, content, and weight of the transport containers are given in Appendix B.

4 Measurements

The calibration factor of a personal dose equivalent meter is a unique property of the type of device. It depends on the neutron energy spectrum, the location of the phantom attachment, and the angle of incidence of the neutrons to the phantom surface. But it should not be a function of the characteristics of the calibration facility or experimental techniques employed.

ISO 8529, parts 1 to 3, [1-3] recommends several radionuclide sources for the calibration of neutron personal dose equivalent meters.

The calibration factor, N, is obtained by

$$N = h_{p\Phi}(10,\alpha) \Phi / M_c, \tag{1}$$

where M_c is the measured reading corrected for all extraneous effects, Φ is the neutron fluence of the direct neutrons from the source to the point of test, and $h_{p\Phi}(10, \alpha)$ is the conversion coefficient of the neutron fluence-to-personal dose equivalent. The fluence is determined by the product of neutron irradiation time *T* and the fluence rate $\varphi = B_{\Omega} / I^2$ using the neutron angular source strength B_{Ω} and the distance *I* from the source axis of symmetry to the point of test. $h_{p\Phi}(10, \alpha)$ is dependent for angles of incidence α for parallel neutron radiation to the phantom surface normal. In practice, the phantom should be installed so as the normal direction of the phantom surface coincides with the neutron source and $h_{p\Phi}(10,0^\circ)$ is used for the conversion coefficient, although the neutron radiation is not parallel.

The calibration procedure should follow the recommendations of ISO 8529, 1-3 [1-3], using those neutron reference fields of radionuclide sources available at the participating laboratory. The sources have to be characterized in terms of neutron source strength and anisotropy. No guidelines are provided for the scattering neutron correction, so the participants should follow their own methods used for nominal calibration of external customer device.

4.1 Quantity to be measured by the participants

The participants should determine the calibration factor in terms of neutron personal dose equivalent for the two transfer instruments using available radionuclide neutron sources recommended by ISO 8529. The operation of the instruments is briefly described in Appendix C. The calibration factor (eq. 1) should be determined for one direction of incidence as defined in Appendix C.

4.2 Neutron fields

ISO 8529 recommends the following neutron fields for the calibration of neutron personal dose equivalent meters:

- ²⁵²Cf
- ²⁴¹Am-Be
- ²⁵²Cf(D2O-moderated)
- ²⁴¹Am-B

Each laboratory should determine the calibration factor for the ISO recommended sources they have available, at least for those for which CMC entries exist and offered to customers.

4.3 Transfer instruments

The comparison will be performed with two identical transfer instruments, DMC3000 Neutrons, and one reader (LDM320D) manufactured by MIRION Technologies.

- 1) DMC3000 Neutron: S/N 09171430 00047A
- 2) DMC3000 Neutron: S/N 09172996 000493
- 3) LF LDM320D : S/N 18016806 (optional for reading)

Handling and usage advice are given in Appendix C. The pilot laboratory (KRISS) will determine the calibration factor for both devices at the beginning of the comparison. Before and after the calibration measurements of the participants, the stability of the reading of the devices will be checked with a ²⁵²Cf source.

4.4 Calibration phantom

ISO 8529-3 recommends the specification of the calibration phantom. Measurements of the responses as a function of neutron energy and direction of neutron radiation incidence and calibrations of neutron personal dose equivalent meters should be carried out on a phantom of outer dimensions $30 \text{ cm} \times 30 \text{ cm} \times 15 \text{ cm}$ made of PMMA walls (front wall 2.5 mm thick, other walls 10 mm thick) and filled with water, termed the ISO water slab phantom. The neutron personal dose equivalent meter is fixed on the front face of the phantom in such a way that the reference point of the meter is placed at the point of test. The participants can use a PMMA phantom instead of the ISO water slab phantom, but the outer dimensions should be equal to $30 \text{ cm} \times 30 \text{ cm} \times 15 \text{ cm}$.

4.5 Neutron irradiation and calibration conditions

Measurements should be carried out by positioning the reference point of the instrument at the point of test. Distance between the radiation source and the instrument should be taken as the perpendicular distance between the axis of symmetry of the radiation source and the reference point of the instrument. The instruments should be fixed on the phantom front face in such a way that their reference direction coincides with the normal to the front face.

The participants are encouraged to irradiate neutrons to the instruments until the reading of the instruments reaches 10 mSv in order to stabilize the reading. The uncertainty of the reading can be obtained by repeated measurements or evaluated using counts from DMC*User* program. The relative uncertainty of 10 mSv reading is estimated to be about 1.2 % (k = 1). The uncertainty of reading is $\sigma_{Dose}(\mu Sv) = 1.246\sqrt{Dose}(\mu Sv)$. The coefficient 1.246 may be slightly different depending on the instrument. This Details on how to estimate uncertainty in a single measurement are given in Appendix E.

Participants who take a long time to irradiate due to weak source strength can set the minimum reading as 4 mSv for ²⁵²Cf and 2 mSv for ²⁴¹Am-Be and D₂O(²⁵²Cf). The supplementary comparison mean value (SCMV) will be calculated for above 10 mSv for ²⁵²Cf and above 4 mSv for ²⁴¹Am-Be and D₂O(²⁵²Cf). Any measurements not applied to the SCMV calculation are also included in the report. (See Appendix E.5)

	Minimum reading (mSv)	Minimum reading for SCMV (mSv)
²⁵² Cf	4	10
²⁴¹ Am-Be	2	4
D ₂ O(²⁵² Cf)	2	4

The minimum distance / from the source axis of symmetry to the point of test should be 75 cm. If the shadow cone or the distance variation methods are applied, other distances can be chosen. The irradiations conditions and procedure used to determine the influence of scattered neutrons should be described in detail by the participants in their report.

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The location where the instrument is attached on the phantom and how to align the instrument are given in Appendix C.

4.6 Reports from the participants

The participants should prepare a detailed report about the calibration procedure and the results. The report should contain all necessary details of:

- Date and place of calibration
- Description of the source employed (source strength, anisotropy, traceability, geometry...) For the ²⁵²Cf(D2O-moderated) source the followings should be described: source strength of the ²⁵²Cf source, diameter of the moderator, thickness of housing, drawing of the moderator (if available), information about H/D ratio in heavy water, thickness of Cd shell
- Description of the phantom (size, material, geometry...)
- Description of the neutron irradiation room (size, position of the source in the room, reference point, ...)
- Description of the reference conditions, calibration conditions, and/or standard test conditions
- Description of the distance from the source axis of symmetry to the point of test
- Description of the method used for the correction of scattered neutrons and the uncertainty evaluation of the method
- Description of the calibration procedure and geometry
- Calibration factors N (eq. 1) in terms of $H_p(10)$ determined for the two transfer instruments and the neutron fields available.
- Description of the conversion factors $h_{p\Phi}(10)$ used with their uncertainties
- List of the uncertainties
- Any other necessary things to be commented.

The participants should send their final report to the pilot laboratory at the least three months after finishing their measurements.

Uncertainties should be calculated in accordance with the "Guide to Uncertainty in Measurement" (GUM) [5] for a coverage factor of k = 1.

5 Evaluation of the Results

The participants are asked to determine the calibration factor N in terms of personal dose equivalent for the two transfer instruments for the reference neutron fields available and used in routine service at their laboratory.

For the comparison, the calibration factors reported by the participants will be evaluated by the pilot laboratory. Since the evaluation of uncertainties is not uniform and differs for the participants and to avoid bias due to small uncertainties, the arithmetic mean will be used for

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the determination of the reference values [6].

The evaluation of the results could proceed in the same way as in the technical protocol of CCRI(III)-S1 comparison [7].

As there are two transfer instruments, the single value for each participant and the supplementary comparison mean value (SCMV) have to be derived by combining the results obtained for the two instruments in every specific neutron field. If one instrument fails during the stability test or not be operational anymore, only one value will be evaluated and the procedure described below will be simplified.

In a first step the reference value \bar{N}_j for the calibration factor of each transfer instrument j (j=1,2) is calculated by $\bar{N}_j = \frac{1}{n} \sum_{i=1}^n N_{i,j}$. For each participant i the deviation for each transfer instrument is calculated by $\bar{x}_{i,j} = \frac{N_{i,j}}{N_j}$. A single value \bar{x}_i for each participant i is derived by averaging the two results $\bar{x}_i = \frac{1}{2} \sum_{j=1}^2 \bar{x}_{i,j}$. The supplementary comparison reference value \bar{x} for the specific neutron field is then $\bar{x} = 1$.

From the SCMV and the specified uncertainties, the degree of equivalence (DoE) will be calculated.

References

- [1] International Standard ISO 8529-1 *Reference neutron radiations: Characteristics and methods of production* (2001).
- [2] International Standard ISO 8529-2 Reference neutron radiations: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field (2000).
- [3] International Standard ISO 8529-3 Reference neutron radiations: Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence (1998).
- [4] V. Gressier and G C Taylor, *Calibration of neutron-sensitive devices*, Metrologia 48 S313-S327 (2011)
- [5] JCGM 100:2008 Evaluation of Measurement Data Guide to the Expression of Uncertainty in Measurement, www.bipm.org.
- [6] G. Ratel, Evaluation of the uncertainty of the degree of equivalence, Metrologia 42 140-144 (2005)
- [7] Désirée Radeck, Technical Protocol of CCRI(III)-S1 (2017).

Appendix A : Full contact information of the participants

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	Laboratorio de Metrología de Radiaciones Ionizantes	
	[Ionizing Radiations Metrology Laboratory]	Roberto Méndez Villafañe
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Appendix B : Details on transport containers

One package will be sent with the following dimensions and weight.

Dimensions : 42 x 33 x 17 cm^3

Weight : 3.4 kg

Main contents : Two DMC3000 Neutrons, LF LDM320D, Torx screwdriver, USB



Fig. 1. Transport container

Appendix C : Instruction for the use of the equipment provided by the pilot laboratory

C.1 Equipments

- 1. Two DMC3000 Neutrons (neutron personal dose equivalent meter)
- 2. LF LDM320D (reader)
- 3. Torx screwdriver for battery replacement
- 4. USB with DMCUser software, a manual of DMCUser and a manual of DMC3000 Neutron.

DMCUser is a program that can read readings from LF LDM320D reader.



Battery (AAA type) replacement



Fig. 2. Equipments

The DMC3000 Neutron consists of two parts. One is a DMC3000, a gamma dosimeter, and the other is a neutron module. When replacing batteries, be careful not to mix the parts.



Fig. 3. DMC3000 S/N 09172996 (left) and neutron module S/N 000493 (right)



Fig. 4. DMC3000 S/N 09171430 (left) and neutron module S/N 00047A (right)

C.2 Description of reference conditions for the calibration

Reference point:

The neutron module of the DMC 3000 Neutron has a mark on the front surface and the side surface.



Reference point

Fig. 5. Reference point of DMC 3000GN

C.3 Setup of the instrument

The instrument should be fixed and positioned on the phantom surface and installed so that the front reference point coincides with the center of the phantom. The phantom should be placed in such a way that the normal direction of the phantom front surface faces the source.

The minimum distance / from the source axis of symmetry to the point of test should be 75 cm.





Fig. 6. Setup of the instrument

C.4 Brief instructions on how to use DMC3000 Neutron

Detailed instructions are given in the manual.

(1) Three modes; Sleep, Pause and Run

Sleep : a low-power consumption state.

Pause : You can check the data by pressing

Run : Data aquisition mode.

■ Sleep mode to Pause mode



When either button ("+" or "-") on front face is pressed, the dosimeter automatically goes into Pause mode with a backlit display and all display segments activate for 2 seconds.

Pause mode to Run mode



In Pause mode, press "+" > 2 sec. "Enter" appears on the screen. Next go to "-" button and press shortly to enter Run mode.

Run mode to Pause mode



In Run mode, press "+" > 2 sec. "Exit" appears on the screen. Next go to "-" button and press shortly to enter Pause mode.



Fig. 7. Instructions of mode change

(2) Status monitoring of the dosimeter

Pause mode : You can check the status of the dosimeter by pressing "-" button. By pressing again, you can find other information. Data list is configurable with DMCUser.

Current setting is below.

last recorded dose (γ) \rightarrow last maximum peak rate (γ) \rightarrow last recorded dose (neutron) \rightarrow

last total dose (γ and neutron) \rightarrow last duration in Run \rightarrow current date

Run mode : You can check the status of the dosimeter by pressing "-" button. By pressing again, you can find other information. Data list is configurable with DMC*User*.

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Appendix D : Data acquisition with DMCUser

D.1 Installation of DMCUser

If you have problems with history reading, try installing it in English version Windows. (See page 26)

(1) Double Click the installation program : DmcUserSetup 1.12.00 Full.exe (280 MB)





(2) Select Destination Location



Fig. 9

(3) Select Additional Tasks : Select DMC User only - that's enough

🔀 Setup - DMC User	—		×
Select Additional Tasks Which additional tasks should be performed?		Ę	
Select the additional tasks you would like Setup to perform while in then click Next.	stalling D№	IC User,	
Additional icons:			
DMC User			
Extra tools			
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Fig. 10

(4) Ready to Install : Click Install to continue

🔀 Setup - DMC User	_		×
Ready to Install Setup is now ready to begin installing DMC User on your computer.		Ę	
Click Install to continue with the installation, or click Back if you want change any settings.	to revie	w or	
Destination location: C:₩Program Files (x86)₩Mirion₩DMC User Additional tasks: Additional icons: DMC User		^	
<		>	
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Fig. 11

D.2 Setup of the instrument

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allered 12.0 Demo. Defaultures

e Parameters Hi	torical Leno Setting Technical s			
	Support contact			
	Americas	Europe	Asia	
	Mirion Technologies (MPGI) Inc. 5000 Highlands Parkway Suite 150 Smyrna, GA 30082 USA	Mirion Technologies (MPGI) SA Route d'Eyguières F-13113 Lamanon, France	Mirion Technologies Shanghai Room 801 78 Jiangchang SanLu - Zhabei District	
	Tel: +1 770-432-2744 Fax: +1 770-432-9179	Tel: +33 (0)4 90 59 59 59	Shanghai 200436, China Tel: +86-21-6180 6520 Fax: +86-21-6180 6924	
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(1) Start DMCUser program and go to Technical support. Check License.

Fig. 12

(2) Input the following information and click OK. You have to restart the program.

Company: KRISS, User: JUNG HO KIM, License: MGP-BA6kq-3rsX-7p84HY



Fig.13

. . .

(3) (Optional) You can download new version.

Click blue icon on the top to download a new release and install it.

tect Dosimeter Dosimete	r Number 🕴 🚺			Events
ta Parameters Batch in a	Out Hit A new release (V. 1.13.0) is callable. Click to download the setup.	non Views Manager Demo S	ettings Technical support 💫	
	Support contact	_		
	Americas	Europe	Asia	
	Mirion Technologies (MPGI) Inc. 5000 Highlands Parkway Suite 150 Smyrna, GA 30082 USA	Mirion Technologies (MPGI) SA Route d'Eyguières F-13113 Lamaron, France	Märion Technologies Shanghai Room 801 78 Jiangchang SanLu - Zhabel District	
	Tel: +1 770-432-2744 Fax: +1 770-432-9179	Tel: +33 (0)4 90 59 59 59	Shanghai 200436, China Tel: -86-21-6180 6920 Fax: +86-21-6180 6924	
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Fig.14

(4) After finishing the download, you can follow the same installation process.



Fig.15

(5) Connect the dosimeter and detect dosimeter.

Click "Detect Dosimeter" shows the information of the dosimeter. Click "Read data" in Data menu and you can see the final data. Internal measures are for gamma and Additional measures for neutron.

Dosimeter Number 01972996	DMC3000 Neutron (N)	• 🕕			
Data Parameters Batch In Jout How Ical DM Editor	Batch Configuration Lists Custo	onizer Views Manager Denvo	Settings 1	echnical support 🖗	
New : DMC1000 M					Reset
ANY - DWCJOOD P					
Global data					
Dosimeter life dose (µSv)		6,409			
Dosimeter life run-time (HPtPIPtSS)		39:14:00			
Dose total since last maintenance / calibration (µSv)					
Duration since last maintenance / calibration (HPCPIPESS)		39(10:06			
Date (and					
Hav rate (uSu/h)		413			
Bate (uSw/h)		19			
Duration in measurement (1012101:55)		14:37:03			
Entry time (DateTime)		14 Jun 2021 @ 17:53:59			
Additional measures		and the second se			
Additional dose (pSv)		3.049			
Additional max rate (pSv/h)		353			
Additional rate (µSv/h)		260			
Summed dose (µSv)		3,263			

Fig.16

(6) Menu "Parameters" shows the parameters. You can read and change the parameters of the dosimeter by clicking "Read parameters".

Please do not change the parameters except the "Histogram period".

a Parameters Batch In / Ou	t Hannied DM Editor Batch	Configuration Lists Customizer	Views Manager Demo Setting	Technical support	
DMC3000 N	Read parameters Write parameters	Multi column			Reset Layo
kor data		Additional data alarm set not	et (i 500.000	Docimeter callurations	
Weater ID	000003	Additional dose marning set o	and 500,000	KoHul Ho(10) (Efficiency coel mu	1.00
Weater name	MIRION	Additional rate alarm set nois	at (m 500,000	Last calibration (Date)	11 Eab 2019
User data area	000003	Additional rate warning set p	oint 500.000	Next calibration (Date)	01 Feb 2025
Task code	000001	Summed dose alarm set poin	t (ut 500.000	Rate algo response time / Rate d	Fast response (max 10s) / 10 uS
TLD / Badge	123456	Summed dose warning set po	int (500,000	Additional module	
RWP	000004	Constants		KnTask Hp(10) (Efficiency coef, m)	1.00
losimeter interface	8	Hanufacturing number	00136959 N	KnHul Hp(10) (Efficiency coef, mu	1.00
Display in pause	Pause	Customization number	NM001203	Module last calibration (Date)	01 Feb 2021
User message	DMC3000	Manufacturing Log	DC003322 B	Module next calibration (Date)	01 Feb 2023
Display contrast	15	Configuration		A Hodule check interval (in months	24
Displayed units	uSv	Raw count in histogram	Enable	Chirp mode	Beep inc. dose 1 µSv (0.1 mrem)
Allow display of rate	Yes	Histogram period	1 min	Blue led source	Module measure
Allow desplay of dose	Yes	Histogram error message	No	tilue led configuration	Inc. dose 1 µSv
Displayed dose resolution	1 µSv (0.1 mRem)	Enable vibrator	Yes		
Display mode in measurement	List by PB (no return by timeout)	Enable speaker	W Yas		
Rate alarm pattern type	Regular	Enable backlight	W Yes		
Enable 3 seconds beep	Enabled	Enable backlight on alarm	Yes		
Chirp mode	Beep inc. dose 1 µSv (0.1 mrem)	Enable rate alarms	W Yes		
Chirp source	Internal measure	Enable warnings	W Yes		
Sound level	High	Enable run-time alarm	W No		
Dosimeter mode	Autonomous	Ack of run time alarm	No		
Time of day	Yes	Assignment	No		
Display upon activation	Nothing	Total the dose in AUT mode	Reset dose		
Date format	DD/MM/YY	Dosimeter activation	W Normal		
Time format	24H	Allow sleep mode	Yes		
hresholds	*	Enable stay time	No		
Dose alarm set point (µ5v)	500,000	tnable flash led	Yes		
Dose warning set point (µ5v)	500,000	Enable green led	Yes		
Rate alarm set point (µSv/h)	10,000	Enable blue led	Yes		
Rate warning set point (µ5v/h)	10,000	Enable red led	Yes		
Beer Manual and and a function	H 13-00-00	Accepted additional module	4 AI		

Fig.17

(7) Change "Histogram period".

"Histogram period" is the time interval for reading history. Choose the time interval as you want. If history number exceeds 2000, it is overwritten. Therefore, 10 min or 1 hour is recommended. Click "Write parameters" and check the change using "Read parameters".

ta Paraletters Catchiers	Out Historical DM Editor Bat	tch Configuration Lists Customizer V	levs Manager Deno Settings	Technical support	
w = [DMC3000 N •	Read parameters Wite parame	ters Multi column Show dependencies			Reset Layou
User data		Additional dose alarm set point (a 500,000	Dosimeter calibrations	
Wearer ID	000002	Additional dose warning set point	4 500,000	KpHul Hp(10) (Efficiency coef. mu	1.00
Wearer name	MIRION	Additional rate alarm set point (\$ 500,000	Last calibration (Date)	11 Feb 2019
User data area	000003	Additional rate warning set point	500,000	Next calibration (Date)	01 Feb 2025
Task code	000001	Summed dose alarm set point ()	t 500.000	Rate algo response time / Rate d	Fast response (max 10s) / 10 uSw
TLD / fladge	123456	Summed dose warning set point	1 500.000	Additional module	
RWP	000004	Constants	8	KnTask Hp(10) (Efficiency coef, m	1.00
Dosimeter interface		# Hanufacturing number	00116950 M	KnHul Ha(10) (Efficiency coef, mu	1.00
Display in page	W Pasta	Customization number	104001203	Module last calibration (Date)	01 Eeb 2021
User message	DMC2000	Hamfacturing tag	DC0033333 B	Module pest calibration (Date)	01 Eeb 20173
Display contrast	15	Configuration		Module check interval (in months	24
Displayed units	urba	and count in his base and	Enable	China mada	Been inc. down 1 offic (0.1 means)
Allow divelop of rate	Var	Ann count in mitoly an	1.000	the led course	Module measure
Allow durality of down	alle Var		10.4	Bine led configuration	Inc. does 1 uSu
Displayed does resolution	1 cfu (0.1 mftam)	I makin utkratur	1 mil	and its comparation	BIC: 0096 1 834
Unpuryed dose resolution	1 pSV (0.1 micem)	Enable vibrator	10 min		
Unputy mode in measuremen	 Lisc by PB (no recurr by cmeouc) 	Enable Speaker	1 Hour		
Kate aurm pattern type	Keguar	Enable backaght	24 Hours		
Enable 3 seconds beep	Enabled	Enable backlight on alarm	and the second se		
Chirp mode	Beep inc. dose 1 µSv (0.1 mrem)	Enable rate alarms			
Chirp source	Internal measure	thable warnings	*		
Sound level	High	Enable run-time alarm	r No		
Dosimeter mode	W Autonomous	Ack of run time alarm	110		
Time of day	Yes	Assignment	No		
Display upon activation	Nothing	Total the dose in AUT mode	Reset dose		
Date format	DD/MM/YY	Dosimeter activation	Normal		
Time format	24H	Allow sleep mode	Yes		
Thresholds		Enable stay time	No		
Dose alarm set point (pSv)	500,000	Enable flash led	Yes		
Dose warning set point (µ5v)	500,000	Enable green led	Yes		
Rate alarm set point (µSv/h)	10,000	Enable blue led	Yes		
Rate warning set point (µSv/l) 10,000	Enable red led	Yes		
Run-time alarm set point (HH	HIN 15:00:00	Accepted additional module	r Al		

Fig.18

(8) Read histories of the readings.

Go to "Historical" menu.

Click "Get current" to get a current history. Be patient, it may take several miniutes.

🕦 DmcUser v1.13.0 - Basic License - NEKOPADUJungho Kim	- 🗆 X
Detect Dosimeter Number 01972002 Please walt 2000 Neutron (N) =	Events
Data Parameters Batch In / Our Historical DM Editor Eatch Conliguration Lists Eastennizer Views Manager Demo Settings	
+ - Append histo Get current Get previous Get all Save Load Export (.xls or .xlsx)	Close
Text Graph	
Source: Read dosimeter Dosimeter number: 01972002	
ID * Datetime * Record Type Origin Primary d Primary ra Secondary Informations	
MIRION - Handle DMCUSET Detach Module & Go to Pause Options	🖷 Go to Measure
	Deader Status

23

Fig.19



Doses and dose rates for primary (gamma) and secondary (neutron) are graphed.

Fig.20

(9) Write the parameter.

Click "Export (.xls or .xlsx)" to save the history into Excel file.

DmcUser v1.13.0 - Basic Li	cense - NEKOPAD	Vungho Kim				- 0	
Detect Dosimeter	osimeter Number	01972002 D	MC3000 Neut	tron (N) ¥		Events	
Data Parameters B	atch in / Out	Historical DM Editor B	latch Configuration	Lists Customizer	Views Manager D	emo Settings Technical support 🕅	
		Append hist	Cory Get current	Get previous	Get all Save	Load Export (.xls or .xlsx) Close	
Text Graph							
Source: Read dosimeter	Dosimeter num	ber: 01972002					
200							
ID • Datetime	Record Type	Origin Primary dose (µSv)	Primary rate (µSv/h)	Secondary dose (µSv)	Secondary rate (µSv/h)	Informations	
History Number: 1 (from	14 Jun 2021 21:24	4:51 to 15 Jun 2021 13:52:38,	16h 27mn 47s)				
1997 14 Jun 2021 21:24:51	Measure					Max rate value since last primary measure record=286.22	
1996 14 Jun 2021 21:25:47	Measure	illean the second		0.000	Contract of Contra	Max rate value since last secondary measure record=1395.10	
1995 14 Jun 2021 21:25:51	Measure	2881	245	15253	1395	Raw couting Tn=40914.56 N10pHp10=149859.44 N20pHp10=82404.78 N21pHp10=32958.43	
1993 14 Jun 2021 21:25:51	Measure	1911 - 19			117	Max rate value since last secondary measure record=1395.10	
1994 14 Jun 2021 21:26:49	Measure	2005	310	15353	1330	Max rate value since last primary measure record=310.08	
1992 14 Jun 2021 21:26:51	Measure	2885	310	15262	1238	Kaw couting Th=409/4.56 N10pHp10=150057.44 N20pHp10=82512.78 N21pHp10=33003.43	
1991 14 Jun 2021 21:20:51	Measure		1			Max rate value since last primary measure record=310.08	
1990 14 3 0 2021 21 20.51	Manaure	2000	240	15301	1200	Plan rate value since kits secondary measure record=1236.76 Devices Ta=41024 51 N10aHe10=150252 44 N20aHe10=92528 78 N21aHe10=22052 42	
1967 14 Jun 2021 21.27.51	Measure	2000	275	13201	1209	Naw codenig 11=1103-31 https://pio-130283.44 https://pio-62628.78 https://pio-53032.45	
1968 14 Jun 2021 21:28:34	Measure					Max rate value since last primary measure records 363.40	
1986 14 Jun 2021 21:28:51	Measure	2893	272	15292	1095	Raw couting Tn=41094.51 N10pHp10=150495.44 N20pHp10=82778.78 N21pHp10=33115.43.	
1984 14 Jun 2021 21:28:51	Measure					Max rate value since last secondary measure record=1095.91	
1965 14 Jun 2021 21:29:17	Measure					Max rate value since last primary measure record=287.42	
1983 14 Jun 2021 21:29:51	Measure	2898	244	15317	1095	Raw couting Tn=41154.51 N10pHp10=150716.44 N20pHp10=82901.78 N21pHp10=33164.43	
1981 14 Jun 2021 21:29:51	Measure					Max rate value since last secondary measure record=1148.01	
1982 14 Jun 2021 21:29:59	Measure					Max rate value since last primary measure record=319.53	
1980 14 Jun 2021 21:30:51	Measure	2902	173	15334	1148	Raw couting Tn=41214.51 N10pHp10=150926.44 N20pHp10=83027.78 N21pHp10=33219.43	
1978 14 Jun 2021 21:30:51	Measure					Max rate value since last secondary measure record=1148.01	
1979 14 Jun 2021 21:31:13	Measure					Max rate value since last primary measure record=307.83	
1977 14 Jun 2021 21:31:51	Measure	2906	245	15363	1107	Raw couting Tn=41274.51 N10pHp10=151175.44 N20pHp10=83150.78 N21pHp10=33268.43	
MIRION	Health Physics		DM	Clicor		Detach Module Go to Pause Options + Go to Measur	
I I I CHARD OGIES					-		
						Reader Status	

Fig.21

(10) Read the data with Excel.

You can read the values by opening the file in the Excel program.

	Ś	¢	-					01972002_20	210614_233514	[Compatibility N	lode] - Excel		Sign in	m – 1	a x
Fil	e •	lome	Insert	Draw Pag	ge Layout		ulas Data	Review	View He	ip 💡 Tell me	what you war	nt to do			9 Share
Past		Taho B	ma • I <u>U</u>	11 • Å • ⊞ • <u>ふ</u> •	Ă A-			eb Wrap 1	″ext & Center ⇒	Text \$ - % 9	€.0 .00 .00 €.0	Conditional Format as Cell Formatting * Table * Styles *	Insert * ∑ * Delete * ↓* Format *	AZY P	
Clip	board	5	Fc	int	5		Align	ment	6	Numbe	r G	Styles	Cells	Editing	^
E8		* : :	× ✓	fx											~
11	в		с	D	E	F	G	н	1	J		к		L	
1	ID	Da	tetime	Record	Туре	Origin	Primary dose (uSv)	Primary rate (uSv/h)	Secondary dose (uSv)	Secondary rate (µSv/h)		Information	าร		
2 #	:1							()							
3	1994	6/14/20	021 21:24	Measure							Max rate v	alue since last primary measu	re record=286.22		
4	1993	6/14/20	021 21:25	Measure						L	Max rate v	alue since last secondary mea	sure record=1395.10		
5	1992	6/14/20	021 21:25	Measure			2881	245	15253	1395	Raw coutin	ig Tn=40914.56 N10pHp10=	149859.44 N20pHp10	=82404.78 N2	1pHp1
6	1990	6/14/20	021 21:25	Measure							Max rate v	alue since last secondary mea	sure record=1395.10		
7	1991	6/14/20	021 21:26	Measure		-					Max rate va	alue since last primary measu	re record=310.08		
8	1989	6/14/20	021 21:26	Measure			2885	310	15262	1238	Raw coutin	Ig Tn=40974.56 N10pHp10=	150057.44 N20pHp10	=82512.78 N2	1pHp1
9	1988	8 6/14/20	021 21:26	Measure							Max rate v	alue since last primary measu	re record=310.08		
10	1987	6/14/20	021 21:26	Measure							Max rate v	alue since last secondary mea	sure record=1238.78		
11	1986	6/14/20	021 21:27	Measure			2888	249	15281	1209	Raw coutin	ig Tn=41034.51 N10pHp10=	150263.44 N20pHp10	=82628.78 N2	1pHp1
12	1984	6/14/20	021 21:27	Measure							Max rate v	alue since last secondary mea	sure record=1209.45		
13	1985	6/14/20	021 21:28	Measure							Max rate v	alue since last primary measu	re record=363.40		
14	1983	6/14/20	021 21:28	Measure			2893	272	15292	1095	Raw coutin	Ig Tn=41094.51 N10pHp10=	150495.44 N20pHp10	=82778.78 N2	1pHp1
15	1981	6/14/20	021 21:28	Measure		_					Max rate v	alue since last secondary mea	sure record=1095.91		
16	1982	6/14/20	021 21:29	Measure							Max rate v	alue since last primary measu	re record=287.42		
17	1980	6/14/20	021 21:29	Measure			2898	244	15317	1095	Raw coutin	g Tn=41154.51 N10pHp10=	150716.44 N20pHp10)=82901.78 N2	1pHp1
18	1978	6/14/20	021 21:29	Measure							Max rate v	alue since last secondary mea	sure record=1148.01		
19	1979	6/14/20	021 21:29	Measure						5 d d D	Max rate v	alue since last primary measu	re record=319.53		
20	1977	6/14/20	021 21:30	Measure			2902	173	15334	1148	Raw coutin	g Th=41214.51 N10pHp10=	150926.44 N20pHp10	=83027.78 N2	1pHp1
21	1975	6/14/20	021 21:30	Measure	-						Max rate v	alue since last secondary mea	sure record=1148.01		Ŧ
4	• 0	1972002	2_2021061	4_233514	(+)						E 4)
Ready													III II -	-	+ 100%

Fig.22

In Column "Information", there is information such as Tn, Tm, N10pHp10, etc. MIRION company says these are used as raw data for the formula of evaluation of the personal dose equivalent (rate). The formula itself is not disclosed to customers.

The information received from the manufacturer is as follows. (Examples)

Tn=147.83	(the value is: cumulated time 1)
Tm=147.83	(the value is: cumulated time 2)
N10pHp10=266.02	(the value is: gamma counter 1)
N20pHp10=125.01	(the value is: gamma counter 2)
N21pHp10=45.00	(the value is: gamma counter 3)
N20pNeutron=33.00	(the value is: neutron counter 1)
N21pNeutron=8.00	(the value is: neutron counter 2)
N20bNeutron=5.00	(the value is: neutron counter 3)
M20pNeutron=33.00	(the value is: neutron counter 4)
M21pNeutron=8.00	(the value is: neutron counter 5)
M20bNeutron=5.00	(the value is: neutron counter 6)

(11) Error during reading Histrorical

When you use non-English Windows, no histories may appear. Click "Events" to check the messages. If you have such problem, please try English Windows to solve the problem.

OmcUser v1 12.0 - Sasic License - NEKÖABLA-Wiktowig Detect Dosimeter Dosimeter Number 01972	996 DMC3000 Neutron (N) =	- C X
Data Parameters Batch In / Out Historical D	Editor Batch Configuration Lists Customber Views Manager Demo Settings Technical support 🗉	
•	□ Append history Get current Get previous Get all Save Load Export (.xh) Close	
Text Graph		
Source: Read dosimeter Dosimeter number: 01972990		
2 7	🕅 Events List — 🗆 🗙	
D Y Datetime A Record	Iside 2 error(s) Iside 0 warming(s) Iside 6 info(s)	
	Events Dist. 2012 Dist. 2012<	
MIRION Management Ministry management finds with setting carried fibrory	DMCÜser Detsch Model	► Notions

Fig.23

(12) DMCUser Help

"F1" key navigates to Help.



Fig.24

(13) Unit Settings

You can change units in the "Settings" menu. If readings are written in mrem and mrem/h, please change units to μ Sv and μ Sv/h.



Fig.25

(14) Measure Options

In the bottom, there is "Go to Measure" menu. By clicking the menu, the dosimeter turns into measure state. There are three measure options. Default is "Go to measure (with dose reset)".



Fig.26

Appendix E : Reading uncertainty in one measurement

E.1 Principle of evaluating the neutron dose

On page 14 of the User Manual, there is a principle of evaluating the neutron dose.

Neutron dose = $\frac{N \text{ (counts)}}{Kn \times KnMul \times KnTask}$

Kn is the factory efficiency coefficient and cannot be changed by the user.

KnMul is the Neutron efficiency coefficient multiplier and is set to 1.

KnTask is an optional neutron efficiency coefficient multiplier. This multiplier is managed by the dosimetry system or end user and may be used to adjust the neutron response of the dosimeter as a function of the energy spectrum related to the stask in which the dosimeter is used. Therefore, if the N used in the dose evaluation can be obtained, the uncertainty of neutron dose can be calculated from the uncertainty of N.

E.2 Evaluation of counts, N

In the above principle, N is set as counts. As shown in D.2 (10), three neutron counts (N20pNeutron, N21pNeutron and N20bNeutron) are available using the DMC*User* program. M20pNeutron, M21pNeutron and M20bNeutron are the same as N20pNeutron, N21pNeutron and N20bNeutron. It is not clear what is stored in the parameters N20pNeutron, N21pNeutron and N20bNeutron.

Dr. Zdenek Vykydal from CMI kindly provided his measurement data from DMC*User* (²⁵²Cf source, ²⁴¹AmBe source and Thermal neutrons). The pilot laboratory analyzed the data and found the followings.

N20pNeutron, N21pNeutron and N20bNeutron depend on the neutron fields.



Fig. 27. Instructions of mode change

 Reading doses are almost proportional to N20pNeutron but not to N21pNeutron and N20bNeutron. This trend is well seen in the thermal neutron measurement.



Fig. 28. N20pNeutron, N21pNeutron, and N20bNeutron for the reading dose in the thermal field

 Let N be N20pNeutron - N21pNeutron - N20bNeutron. Then the reading doses are linear to N and the slope is constant regardless of the neutron field. Reading doses and counts from three neutron reference fields and one field from ²⁴¹AmBe with PE moderator have a linear relationship as follows.



Fig. 29. Linearity between N and reading doses (left : ²⁵²Cf, right : ²⁴¹AmBe)



Fig. 30. Linearity between N and reading doses (left : thermal, right : ²⁴¹AmBe with PE moderator)

- The slope is 1/Kn in the formula of evaluating the neutron dose. In this case, Kn is 0.6444 for CMI DMC3000 Neutron (0.6480 for KRISS one). Kn is the factory efficiency coefficient and cannot be changed by the user. Kn may be different for each instrument. Neutron doses can be evaluated with Kn and N. The results for four neutron fields (²⁵²Cf source, ²⁴¹AmBe source, Thermal neutrons and ²⁴¹AmBe with PE moderator) are shown in the graph below.
- It can be seen that the Reading dose and the calculated dose from N agree well in any case of the source. Note that the same Kn is used for ²⁵²Cf source, ²⁴¹AmBe source, and Thermal neutrons.



Fig. 31. Reading Dose .vs. Calculated Dose from N (left : ²⁵²Cf, right : ²⁴¹AmBe)



Fig. 32. Reading Dose .vs. Calculated Dose from N (left : thermal, right : ²⁴¹AmBe with PE moderator)

• The difference in dose by calculation and measurement is shown in the figure below.



Fig. 33. Difference in dose by calculation and measurement for ²⁵²Cf

E.3 Uncertainty of reading

Let N20pNeutron be abbreviated as N_{20p}, N21pNeutron as N_{21p}, and N20bNeutron as N_{20b}. The number of counts for evaluating the neutron dose is $N = N_{20p} - N_{21p} - N_{20b}$. It is not clear what is stored in the N_{20p}, N_{21p} and N_{20b} parameters, but N20p and N21p are proportional to each other, and N20b has a strong correlation, but not directly. The figure below shows the case of ²⁴¹AmBe.



Fig. 34. N_{20p} .vs. N_{21p} and N_{20b} for ²⁴¹AmBe

There are three situations to consider.

Case 1. N_{20p} , N_{21p} and N_{20b} are independent. Assume that they follow the statistical uncertainty.

Case 2. N_{20p}, N_{21p} and N_{20b} are completely related to each other.

Case 3. Ignore the uncertainties of N_{20p}, N_{21p} and N_{20b}. And N follows the statistical uncertainty.

Case 1. The uncertainty of N can be expressed as

$$u(N) = \sqrt{u(N_{20p})^2 + u(N_{21p})^2 + u(N_{20b})^2} = \sqrt{N_{20p} + N_{21p} + N_{20b}}$$

Let $N_{sum} = N_{20p} + N_{21p} + N_{20b}$. Then, the relative uncertainty of reading is

$$\frac{u(N)}{N} = \frac{\sqrt{N_{20p} + N_{21p} + N_{20b}}}{N_{20p} - N_{21p} - N_{20b}} = \frac{\sqrt{N_{sum}}}{N}$$

Case 2. Let N_{21p} and N_{20b} be aN_{20p} and bN_{20p} . Then, N = N_{20p} - N_{21p} - N_{20b} = (1 - a - b)N_{20p} = kN_{20p} . The uncertainty of N can be expressed as $u(N) = k\sqrt{N_{20p}}$. Then, the relative uncertainty of reading is

$$\frac{u(N)}{N} = \frac{k\sqrt{N_{20p}}}{kN_{20p}} = \frac{1}{\sqrt{N_{20p}}}$$

Case 3. The relative uncertainty of reading is

$$\frac{u(N)}{N} = \frac{1}{\sqrt{N_{20p} - N_{21p} - N_{20b}}} = \frac{1}{\sqrt{N}}$$

To verify the above three cases, the uncertainty was evaluated using actual data. Since the readings from DMC*User* program are stored at the same time interval and the dose rate is constant, the average and standard deviation can be obtained by collecting the reading difference at each time interval. By increasing the time interval, another average and standard deviation can be evaluated.

Readings from ²⁵²Cf, ²⁴¹Am-Be and thermal neutrons were analyzed. Dose averages and their standard deviations were given the following table. The relative uncertainties based on the experimental data and the relative uncertainties based on Case 1, Case 2, and Case 3 were calculated.

No		Dose	σ	Relative uncertainty					
of data Source	Source	average	(USV)	Measurement	Case 3.	Case 1.	Case 2.		
		(µSv)	(μΟν)	σ _{Dose} /Dose	$1/\sqrt{N}$	$\sqrt{N_{sum}}/N$	$1/\sqrt{N_{20p}}$		
395	²⁵² Cf	20.8	5.9	0.282	0.273	0.364	0.232		
124	Thermal	29.0	6.7	0.232	0.231	0.236	0.229		
197	²⁵² Cf	41.6	8.1	0.194	0.193	0.258	0.164		
62	Thermal	58.0	7.7	0.133	0.164	0.167	0.162		
131	²⁵² Cf	62.4	10.2	0.164	0.158	0.210	0.134		
98	²⁵² Cf	83.2	11.3	0.136	0.137	0.182	0.116		
41	Thermal	87.1	9.7	0.112	0.133	0.136	0.132		
427	²⁴¹ AmBe	102.8	12.4	0.120	0.123	0.180	0.098		
79	²⁵² Cf	104.2	13.7	0.132	0.122	0.163	0.104		
31	Thermal	115.9	11.8	0.102	0.116	0.118	0.115		
65	²⁵² Cf	124.9	13.5	0.108	0.111	0.149	0.095		
105	²⁵² Cf	136.2	14.5	0.106	0.107	0.145	0.090		
56	²⁵² Cf	145.7	17.2	0.118	0.103	0.138	0.088		
49	²⁵² Cf	166.5	16.8	0.101	0.097	0.129	0.082		
43	²⁵² Cf	187.0	18.6	0.100	0.091	0.121	0.077		
213	²⁴¹ AmBe	205.6	17.2	0.084	0.087	0.127	0.069		

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39	²⁵² Cf	208.2	19.3	0.092	0.086	0.115	0.073
35	²⁵² Cf	228.5	17.2	0.075	0.082	0.110	0.070
32	²⁵² Cf	249.6	18.7	0.075	0.079	0.105	0.067
52	²⁵² Cf	272.5	17.5	0.064	0.075	0.102	0.063
142	²⁴¹ AmBe	308.4	21.6	0.070	0.071	0.104	0.057
106	²⁴¹ AmBe	411.3	24.3	0.059	0.061	0.090	0.049
85	²⁴¹ AmBe	514.1	27.5	0.054	0.055	0.081	0.044
71	²⁴¹ AmBe	616.7	28.7	0.047	0.050	0.074	0.040
61	²⁴¹ AmBe	719.7	34.1	0.047	0.046	0.068	0.037
53	²⁴¹ AmBe	822.5	35.3	0.043	0.043	0.064	0.035
47	²⁴¹ AmBe	925.5	40.2	0.043	0.041	0.060	0.033
42	²⁴¹ AmBe	1028.0	35.4	0.034	0.039	0.057	0.031
38	²⁴¹ AmBe	1131.2	38.1	0.034	0.037	0.054	0.030
35	²⁴¹ AmBe	1233.7	37.6	0.030	0.035	0.052	0.028
32	²⁴¹ AmBe	1336.2	42.5	0.032	0.034	0.050	0.027

In order to reduce statistical uncertainty, only more than 30 data were collected. Comparing with the measurement results, it can be seen that Case 1 is overestimated and Case 2 is underestimated. Case 3 seems to fit the experimental data best.



Fig. 35. Relative uncertainty changes for Reading Dose. Case 3 seems to fit the experimental data best.

Assuming that the relative uncertainty of the experimental data follows \sqrt{Dose} (in case of Case 3), fitting was performed with a function \sqrt{Dose} .



Fig. 36. Standard deviation for reading (current study)

This fitting result is in good agreement with the previous pilot study results. A similar study of estimating uncertainty from Reading Dose has been previously conducted. The fitting parameter obtained from measurements up to about 400 μ Sv is 1.192, which agrees with the above result within 1 %.



Fig. 37. Standard deviation for reading (previous pilot study)

In the pilot study, 30 repeated measurements were also performed using a ²⁵²Cf source. The average is 724 µSv and the standard deviation is 37 µSv. The standard deviation is calculated as 32 µSv by the above equation $\sigma_{Dose}(\mu Sv) = 1.192\sqrt{Dose(\mu Sv)}$. These results agree well within 10 %.



Fig. 38. Average and standard deviation by 30 repeated measurement (previous pilot study)

E.4 Uncertainty of reading in one measurement

Participants can evaluate the uncertainty of a single reading by using the DMC*User*. Proceed according to the procedure below. See Appendix D for how to use DMC*User*.

- (1) Install the DMCUser program.
- (2) Read data of the dosimeter. histories of the readings.
- (3) Read histories of the readings
- (4) Find neutron dose, N20pNeutron, N21pNeutron and N20bNeutron.
- (5) Calculate N = N20pNeutron N21pNeutron N20bNeutron.
- (6) Calculate the relative uncertainty of the neutron dose as $1/\sqrt{N}$.

If participants have difficulty using DMC*User*, they can refer to the following. However, the recommended method is the above procedure.

Since Reading Dose is proportional to N and uncertainty is proportional to $1/\sqrt{N}$, the relationship between Reading dose and uncertainty can be expressed as the graph below. The result of fitting is $\sigma_{Dose}(\mu Sv) = 1.246\sqrt{Dose(\mu Sv)}$. (See the picture below)



Fig. 39. Evaluation of standard deviation for single reading

E.5 Minimum readings for participation

With a neutron source whose source strength of 1×10^7 s⁻¹ neutron source at 75 cm distance, the irradiation time can be evaluated as follows.

source	φ	hp(10)	Dose rate	Time to reach (hour)				
	(cm ⁻² s ⁻¹)	(pSv cm²)	(µSv/h)	1 mSv	2 mSv	4 mSv	10 mSv	
²⁵² Cf	141.5	400	203.7	4.9	9.8	19.6	49.1	
²⁴¹ Am-Be	141.5	411	209.3	4.8	9.6	19.1	47.8	
D ₂ O(²⁵² Cf)	141.5	110	56.0	17.8	35.7	71.4	178.5	

- The recommended readings are 10 mSv for ²⁵²Cf, ²⁴¹Am-Be and D₂O(²⁵²Cf).
- In general, the source strength of ²⁴¹Am-Be source is weaker than that of ²⁵²Cf.
- At 75 cm distance, 49 hours (2.04 days) is required to reach 10 mSv for ²⁵²Cf 178.5 hours (7.44 days) for D₂O(²⁵²Cf) with a source strength of 1 x 10⁷ s⁻¹.

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Reading (µSv)	Standard deviation (µSv)	Rel. unc
1000	39.4	3.9%
2000	55.7	2.8%
3000	68.2	2.3%
4000	78.8	2.0%
5000	88.1	1.8%
6000	96.5	1.6%
7000	104.2	1.5%
8000	111.4	1.4%
9000	118.2	1.3%
10000	124.6	1.2%

The relative uncertainties of readings, u(N)/N, can be calculated by the following equation $\sigma_{Dose}(\mu Sv) = 1.246\sqrt{Dose(\mu Sv)}$.

The relative uncertainty of the calibration factor $N = h_{p\Phi}(10, \alpha) \Phi / M_c$ can be represented by the following.

$$\frac{u(N)}{N} \sim \sqrt{\left(\frac{u(B)}{B}\right)^2 + \left(\frac{u(h_p)}{h_p}\right)^2 + \left(\frac{u(M_c)}{M_c}\right)^2}$$

Assume the the relative uncertainty of the source strength is 1.0 %. Then u(N)/N can be roughly calculated as in the following table.

M _c (mSv)	u(<i>B</i>)/ <i>B</i>	$\mathrm{u}(h_{ ho})/h_{ ho}(\%)$		u(<i>Mc</i>)/ <i>Mc</i>	u(<i>N</i>)/N (%)		
	(%)	²⁵² Cf	²⁴¹ Am-Be / D ₂ O(²⁵² Cf)	(%)	²⁵² Cf	²⁴¹ Am-Be / D ₂ O(²⁵² Cf)	
1	1.0		4.0	3.9	4.1	5.7	
2		1.0		2.8	3.1	5.0	
4		1.0 1.0		2.0	2.4	4.6	
10				1.2	1.9	4.3	

Unlike ²⁵²Cf, since the uncertainty of hp(10) of ²⁴¹Am-Be and D₂O(²⁵²Cf) is 4%, the influence of the uncertainty of the reading on the overall uncertainty is not large. For example, the difference between 4 mSv and 10 mSv is only 0.3%. Therefore, for ²⁴¹Am-Be and D₂O(²⁵²Cf), it is considered reasonable to set the minimum readings to 4 mSv instead of 10 mSv in order to reduce the irradiation time. Of course, participants are encouraged to irradiate 10 mSv for ²⁴¹Am-Be and D₂O(²⁵²Cf) if they have strong sources.

SCRV calculations will only include results from participants above 10 mSv for 252 Cf and above 4 mSv for 241 Am-Be and D₂O(252 Cf). However, the report will include all results for participants who meet the minimum readings.

For participants with a weak neutron source, the minimum readings are set as follows.

²⁵²Cf : 4 mSv ²⁴¹Am-Be : 2 mSv D₂O(²⁵²Cf) : 2 mSv