pIRIR fading test

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1 Summary

1.1 Fading measurement results

The performed fading measurement of B19 LU-1 showed significant fading for both, the IRSL as well as the post-IR IRSL measurement. However, as expected from literature, the post-IR IRSL fading values are lower. While the IRSL measurements at 50°C are probably effected of thermal and not-thermal (anomalous) fading, the post-IR IRSL measurements should effected only by anomalous fading.

For the analysis of the fading measurement, the function `analyse_FadingMeasurement()` by Kreutzer and Burow (2023) was used. As signal integral, the first three stimulated channels were used for both types of measurements (IRSL and pIR-IRSL). In case of IRSL measurements, these are the first 1.5 sec of stimulation and in case of pIR-IRSL measurements these are the first 3 sec of stimulation. As background integral, the last 50 sec were used in both cases.

Table 1: Fading measurement results for sample B19 LU-1

	IRSL at 50°C	pIR-IRSL at 290°C
g-value (%/decade) after Huntley & Lamothe (2001)	3.875 ± 0.519	1.975 ± 0.254
Recombination center density (Kars et al., 2008)	2.72e-06 ± 3.49e-07	1.37e-06 ± 1.67e-07

Analysed file: 3-Permafrost_fading_pIR290_18al_LU1.binx

1.2 B19 LU-1 fading correction

The obtained fading values were used to correct the central age model (CAM) ages obtained from the B19 LU-1 dating measurement. The correction was done with the function `calc_FadingCorr()` (Kreutzer 2023) which uses the algorithm from Huntley and Lamothe (2001).

The fading correction leads to significant older ages in both, the IRSL and the pIR-IRSL measurements. However, both still not match. Huntley and Lamothe (2001) as well as Kars et al. (2008) point out, that the used fading correction algorithm is not reliable if the equivalent dose values were obtained from the not-linear part of the growth curves which they expect to begin usually at about 50 ka. As this is the case for all B19 LU-1 (and also all other B19 samples), the fading corrected age can not be considered as accurate.

Analysed file: `3-Permafrost-1mm-63-100-Fsp-pIR290-sample_B19-LU-1-24al.binx`

Table 2: Estimated age of sample B19 LU-1 with and without fading correction.

	IRSL at 50°C	pIR-IRSL at 290°C
Central age model paleodose	498.7 Gy ± 31.06 Gy	1069.23 Gy ± 29.59 Gy
Aliquots that passed rejection criteria	14 of 24	17 of 24
Estimated uncorrected age	168 ka ± 16 ka	359 ka ± 28 ka
Estimated fading corrected age	260 ka ± 31 ka	440 ka ± 37 ka

1.3 Fading dependence on signal integral shift

In the De(t) plots shown in the dating analysis report of B19 LU-1, it was observed that for at least half of the aliquots the equivalent dose increases if the signal integral is shifted towards later time spans in the stimulation. One possible explanation for this effect could be, that the initial signal is affected to fading by a higher extend. As the test below shows, this seem indeed to be true. The fading values decrease under an integration shift while the uncorrected age estimation increases also. However, the number of aliquots which fail the rejection criteria increase also, resulting in lower statistical reliability of the results. Interestingly, the fading corrected age stays at about ~ 450 ka, independently of the integral range. This might point towards a successfully working fading correction but could also be coincidence.

Table 3: Dependence of the fading values and the resulting uncorrected and corrected sample age estimations on the signal integral range.

Signal integral range	0 sec to 2 sec	2 sec to 5 sec	5 sec to 10 sec	10 sec to 20 sec
g-value (%/decade)	2.061 ± 0.335	1.456 ± 0.333	1.652 ± 0.456	0.973 ± 1.053
CAM paleodose	1039 Gy ± 30 Gy	1130 Gy ± 31 Gy	1152 Gy ± 51 Gy	1213 Gy ± 71 Gy
RC passed aliquots	15 of 24	11 of 24	5 of 24	3 of 24
Uncorrected age	349 ka ± 27 ka	380 ka ± 30 ka	387 ka ± 33 ka	408 ka ± 38 ka
Fading corrected age	434 ka ± 38 ka	442 ka ± 38 ka	456 ka ± 45 ka	446 ka ± 68 ka

1.4 B19 LU-7 fading correction

Here the fading values of B19 LU-1 are used to perform the fading correction at the younger sample LU-7 to a) approximate the impact of fading on the calculated sample age and b) test whether corrected IRSL age might match the pIR-IRSL age. The test showed, that a) the impact of fading is significant and b) a match in the ages is still not given.

Analysed file: `3-Permafrost-1mm-63-90-Fsp_LU-7_24al.binx`

Table 4: Estimated age of sample B19 LU-7 with and without fading correction.

	IRSL at 50°C	pIR-IRSL at 290°C
Central age model paleodose	171.61 Gy ± 6.94 Gy	324.91 Gy ± 9.57 Gy
Aliquots that passed rejection criteria	22 of 24	24 of 24
Estimated uncorrected age	58 ka ± 5 ka	109 ka ± 9 ka
Estimated fading corrected age	87 ka ± 9 ka	132 ka ± 11 ka

1.5 Conclusion

The fading test and the re-evaluation of two data sets led to the following conclusions.

- B19-LU samples show significant signal fading. The pIR-IRSL protocol does reduce the effect of fading but does not fully remove it. Thus anomalous fading is an issue with B19-LU samples.
- The age underestimation of IRSL at 50°C dating results can not be corrected by fading correction alone.
- Applying fading correction to the pIR-IRSL measurements leads to ages which are about 20 % to 30 % older than uncorrected ages. However, according to literature, the samples are too old for a reliable age correction.
- Shifting the signal integral range used for the equivalent dose estimation towards later points in the measurement, results in lower fading rates and older sample ages. Both are in accordance to each other.
- The sample B19-LU 1 has an approximated age of about ~ 350 ka (CAM model). However, taking the results of this analysis into account, it is likely that the sample is at least 400 ka old.

1.6 Acknowledgment

This report describes the data analysis work flow for the pIRIR fading measurement of the sample *B19-LU 1* , measured by Steffi Hesse and Dr. Tobias Lauer. The data analysis was performed by Dirk Mittelstraß on behalf of Dr. Margret Fuchs from HZDR Innovation GmbH and paid for by the HZDR Innovation GmbH.

The data was processed using the open-source statistical programming language R and multiple open-source function libraries (called ‘packages’), especially the R package Luminescence. This PDF was formatted and created with Quarto.

2 Fading measurement

2.1 Data set structure

The data set contains fading measurements of 18 aliquots. Apparently each aliquot was measured with the same sequence but with switching aliquots after each sequence cycle.

Table 5: Structure of the BIN file content

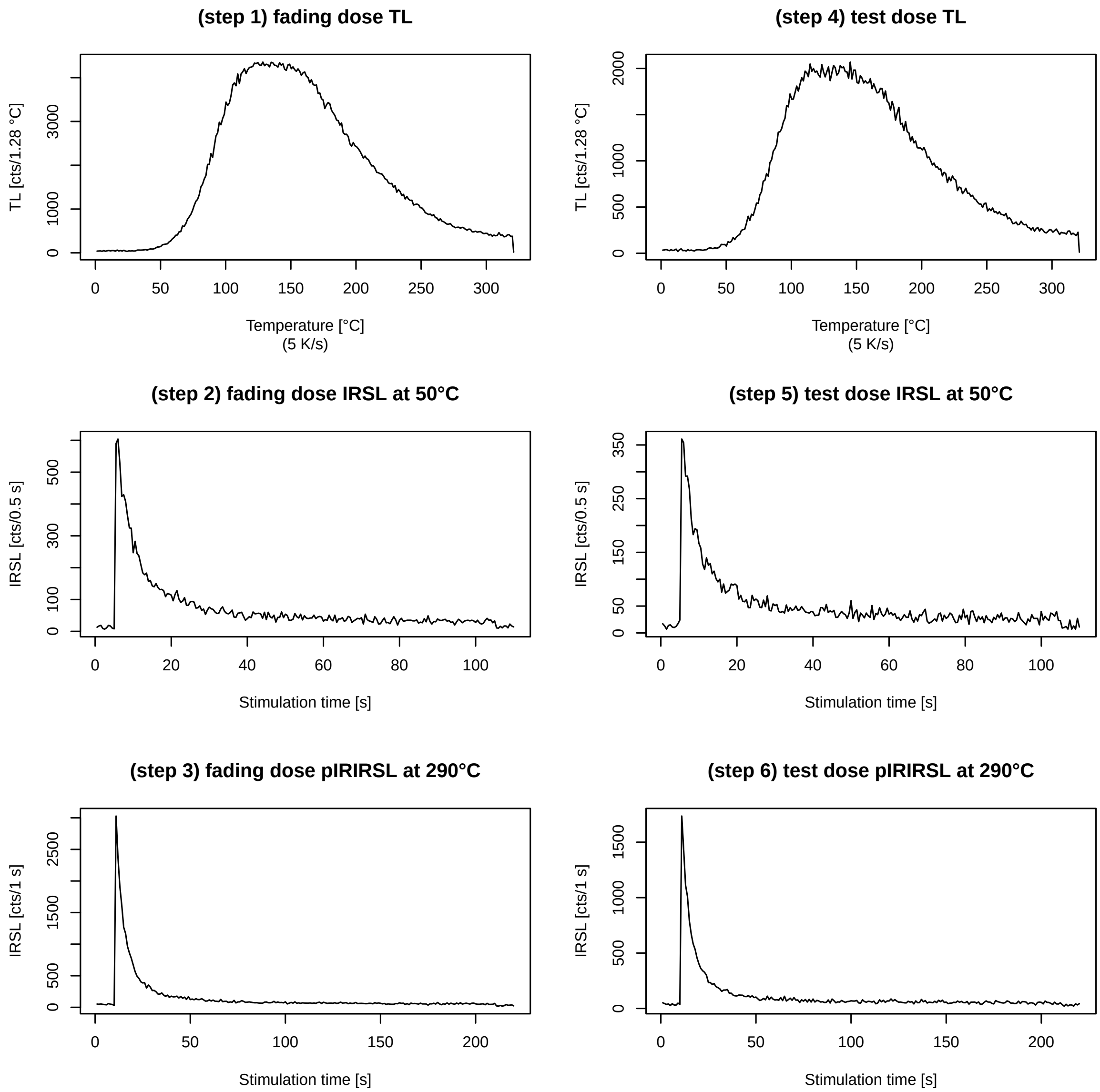
index	SAMPLE	DATE	RUN	SET	POSITION	records
1	Sample1	021222	2	1	1	69
2	Sample3	021222	2	1	3	69
3	Sample5	021222	2	1	5	69
4	Sample7	021222	2	1	7	69
5	Sample9	021222	2	1	9	69
6	Sample11	021222	2	1	11	69
7	Sample13	021222	2	1	13	69
8	Sample15	031222	2	1	15	69
9	Sample17	031222	2	1	17	69
10	Sample19	031222	2	1	19	69
11	Sample21	031222	2	1	21	69
12	Sample23	031222	2	1	23	69
13	Sample25	031222	2	1	25	69
14	Sample27	031222	2	1	27	69
15	Sample29	031222	2	1	29	69
16	Sample31	031222	2	1	31	69
17	Sample33	031222	2	1	33	69
18	Sample35	031222	2	1	35	69

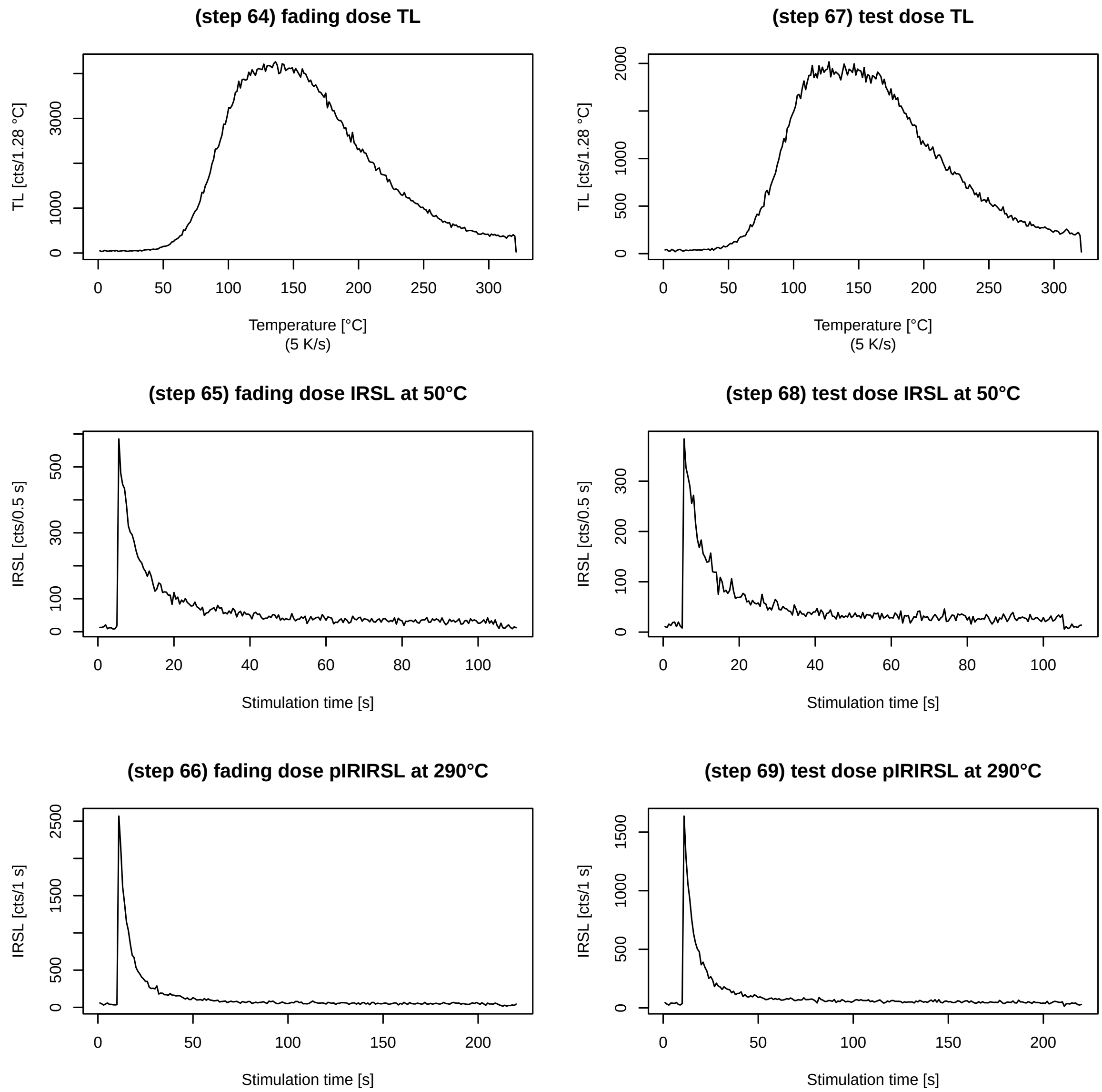
Table 6: Measurement sequence structure for aliquot 1

Step	Type	Max. Temp. [°C]	Irr. time [s]	Channel width [s]	Meas.lenght [s]	Date & time	Elapsed time [h]
1	TL	321	1000	1.285	321.3	021222 09:48:20	0 h
2	IRSL	50	1000	0.5	110	021222 09:51:09	0.05 h
3	IRSL	290	1000	1	220	021222 09:56:31	0.09 h
4	TL	321	500	1.285	321.3	021222 10:08:09	0.19 h
5	IRSL	50	500	0.5	110	021222 10:10:59	0.05 h
6	IRSL	290	500	1	220	021222 10:16:21	0.09 h
7	IRSL	325	500	0.4	100	021222 10:19:41	0.06 h
8	TL	321	1000	1.285	321.3	021222 10:39:40	0.33 h
9	IRSL	50	1000	0.5	110	021222 10:42:30	0.05 h
10	IRSL	290	1000	1	220	021222 10:47:52	0.09 h
11	TL	321	500	1.285	321.3	021222 10:59:30	0.19 h
12	IRSL	50	500	0.5	110	021222 11:02:20	0.05 h
13	IRSL	290	500	1	220	021222 11:07:42	0.09 h
14	IRSL	325	500	0.4	100	021222 11:11:02	0.06 h
15	TL	321	1000	1.285	321.3	021222 11:31:01	0.33 h
16	IRSL	50	1000	0.5	110	031222 22:20:27	34.82 h
17	IRSL	290	1000	1	220	031222 22:25:50	0.09 h
18	TL	321	500	1.285	321.3	031222 22:37:28	0.19 h
19	IRSL	50	500	0.5	110	031222 22:40:18	0.05 h
20	IRSL	290	500	1	220	031222 22:45:40	0.09 h
21	IRSL	325	500	0.4	100	031222 22:49:00	0.06 h
22	TL	321	1000	1.285	321.3	041222 01:45:59	2.95 h
23	IRSL	50	1000	0.5	110	041222 01:48:49	0.05 h
24	IRSL	290	1000	1	220	041222 01:54:12	0.09 h
25	TL	321	500	1.285	321.3	041222 02:05:50	0.19 h
26	IRSL	50	500	0.5	110	041222 02:08:40	0.05 h
27	IRSL	290	500	1	220	041222 02:14:03	0.09 h
28	IRSL	325	500	0.4	100	041222 02:17:23	0.06 h
29	TL	321	1000	1.285	321.3	041222 02:37:22	0.33 h
30	IRSL	50	1000	0.5	110	041222 02:40:12	0.05 h
31	IRSL	290	1000	1	220	041222 02:45:35	0.09 h
32	TL	321	500	1.285	321.3	041222 02:57:13	0.19 h
33	IRSL	50	500	0.5	110	041222 03:00:04	0.05 h
34	IRSL	290	500	1	220	041222 03:05:26	0.09 h
35	IRSL	325	500	0.4	100	041222 03:08:46	0.06 h
36	TL	321	1000	1.285	321.3	041222 03:28:46	0.33 h
37	IRSL	50	1000	0.5	110	041222 13:45:22	10.28 h
38	IRSL	290	1000	1	220	041222 13:50:45	0.09 h
39	TL	321	500	1.285	321.3	041222 14:02:23	0.19 h
40	IRSL	50	500	0.5	110	041222 14:05:13	0.05 h
41	IRSL	290	500	1	220	041222 14:10:36	0.09 h
42	IRSL	325	500	0.4	100	041222 14:13:56	0.06 h
43	TL	321	1000	1.285	321.3	041222 14:33:55	0.33 h
44	IRSL	50	1000	0.5	110	061222 12:00:59	45.45 h
45	IRSL	290	1000	1	220	061222 12:06:22	0.09 h
46	TL	321	500	1.285	321.3	061222 12:18:00	0.19 h
47	IRSL	50	500	0.5	110	061222 12:20:50	0.05 h
48	IRSL	290	500	1	220	061222 12:26:13	0.09 h
49	IRSL	325	500	0.4	100	061222 12:29:34	0.06 h
50	TL	321	1000	1.285	321.3	061222 17:01:00	4.52 h
51	IRSL	50	1000	0.5	110	061222 17:03:50	0.05 h
52	IRSL	290	1000	1	220	061222 17:09:13	0.09 h
53	TL	321	500	1.285	321.3	061222 17:20:51	0.19 h
54	IRSL	50	500	0.5	110	061222 17:23:41	0.05 h
55	IRSL	290	500	1	220	061222 17:29:04	0.09 h
56	IRSL	325	500	0.4	100	061222 17:32:24	0.06 h
57	TL	321	1000	1.285	321.3	061222 17:52:24	0.33 h
58	IRSL	50	1000	0.5	110	061222 17:55:15	0.05 h
59	IRSL	290	1000	1	220	061222 18:00:37	0.09 h
60	TL	321	500	1.285	321.3	061222 18:12:15	0.19 h
61	IRSL	50	500	0.5	110	061222 18:15:05	0.05 h
62	IRSL	290	500	1	220	061222 18:20:28	0.09 h
63	IRSL	325	500	0.4	100	061222 18:23:49	0.06 h
64	TL	321	1000	1.285	321.3	061222 18:43:48	0.33 h
65	IRSL	50	1000	0.5	110	071222 11:09:05	16.42 h
66	IRSL	290	1000	1	220	071222 11:14:28	0.09 h
67	TL	321	500	1.285	321.3	071222 11:26:06	0.19 h
68	IRSL	50	500	0.5	110	071222 11:28:56	0.05 h
69	IRSL	290	500	1	220	071222 11:34:19	0.09 h

2.2 Measurement plots

The data has a Lx / Tx structure with six TL/IRSL measurements as shown below and one IRSL bleaching step (not shown).




(step 64) fading dose TL
TL [cts/1.28 °C]
Temperature [°C]
(5 K/s)
(step 67) test dose TL
TL [cts/1.28 °C]
Temperature [°C]
(5 K/s)
(step 65) fading dose IRSL at 50°C
IRSL [cts/0.5 s]
Stimulation time [s]
(step 68) test dose IRSL at 50°C
IRSL [cts/0.5 s]
Stimulation time [s]
(step 66) fading dose pIRIRSL at 290°C
IRSL [cts/1 s]
Stimulation time [s]
(step 69) test dose pIRIRSL at 290°C
IRSL [cts/1 s]
Stimulation time [s]

2.3 Data clean-up

We use the function `RLum.OSL_correction()` of the package `OSLdecomposition` (Mittelstraß et al. 2022) to perform consistency checks of the IRSL records and to remove the zero-stimulation parts. The correction procedure log is shown below.

```
CORRECTION STEP 1 ----- Check records for consistency in the detection settings -----
Frequency table of different sets of detection settings (Channels, Channel width):
  settings frequency record_type
1 220, 0.5       360        IRSL
2   220, 1       360       IRSL2
3 250, 0.4       162       IRSL3
RLum.Data.Curve@RecordType changed to IRSL2 or IRSL3 in sequence: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
Further data manipulations are performed just on IRSL records
(time needed: 1.4 s)

CORRECTION STEP 2 ----- Remove not stimulated measurement parts -----
Measurement parts with stimulation light turned off detected and removed:
 5 s at the beginning and 0 s at the end.
-> Length of 360 IRSL records reduced from 110 s to 105 s
(time needed: 4.07 s)

CORRECTION STEP 3 ----- Limit measurement duration -----
Reduced length of 360 IRSL records from 105 s to 100 s
(time needed: 0.03 s)
```

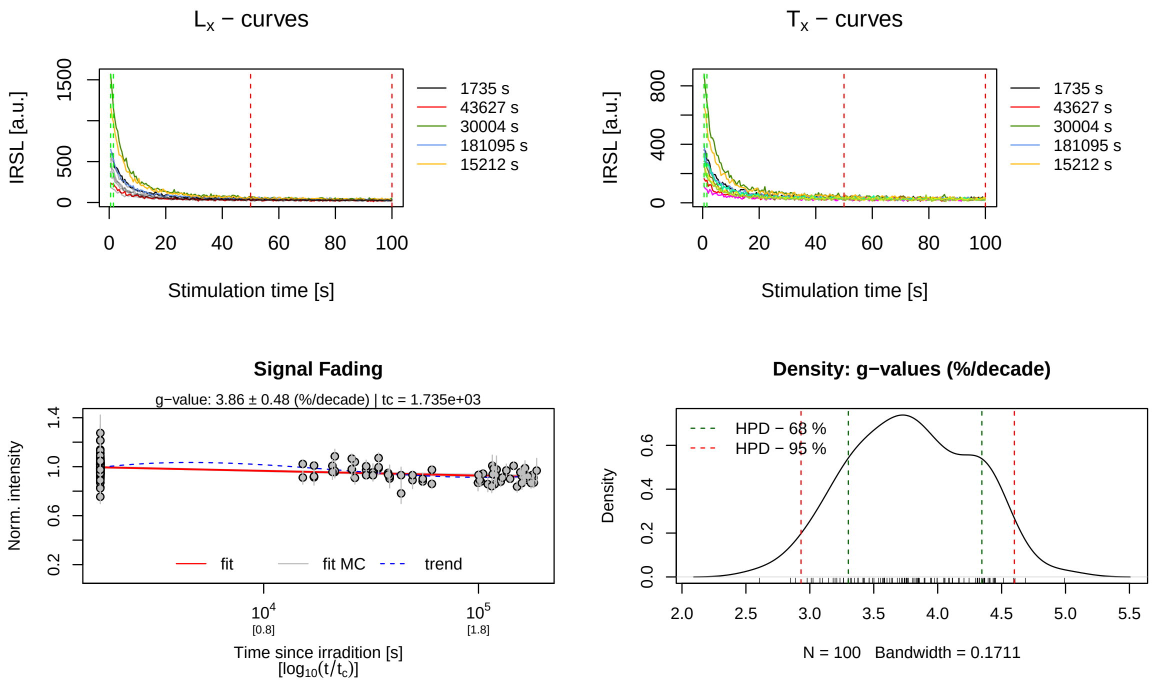
We perform the code again but only for IRSL2 records to clean also 290°C IRSL records. We also separate the 50°C IRSL and 290°C IRSL measurements from each other and the TL and bleaching steps and put them in two data sets (not shown).

```
CORRECTION STEP 1 ----- Check records for consistency in the detection settings -----
All IRSL2 records have the same detection settings
(time needed: 0.69 s)

CORRECTION STEP 2 ----- Remove not stimulated measurement parts -----
Measurement parts with stimulation light turned off detected and removed:
 10 s at the beginning and 0 s at the end.
-> Length of 360 IRSL2 records reduced from 220 s to 210 s
(time needed: 3.35 s)

CORRECTION STEP 3 ----- Limit measurement duration -----
Reduced length of 360 IRSL2 records from 210 s to 200 s
```

```
(time needed: 0.02 s)
```

2.4 Fading of IRSL at 50°C

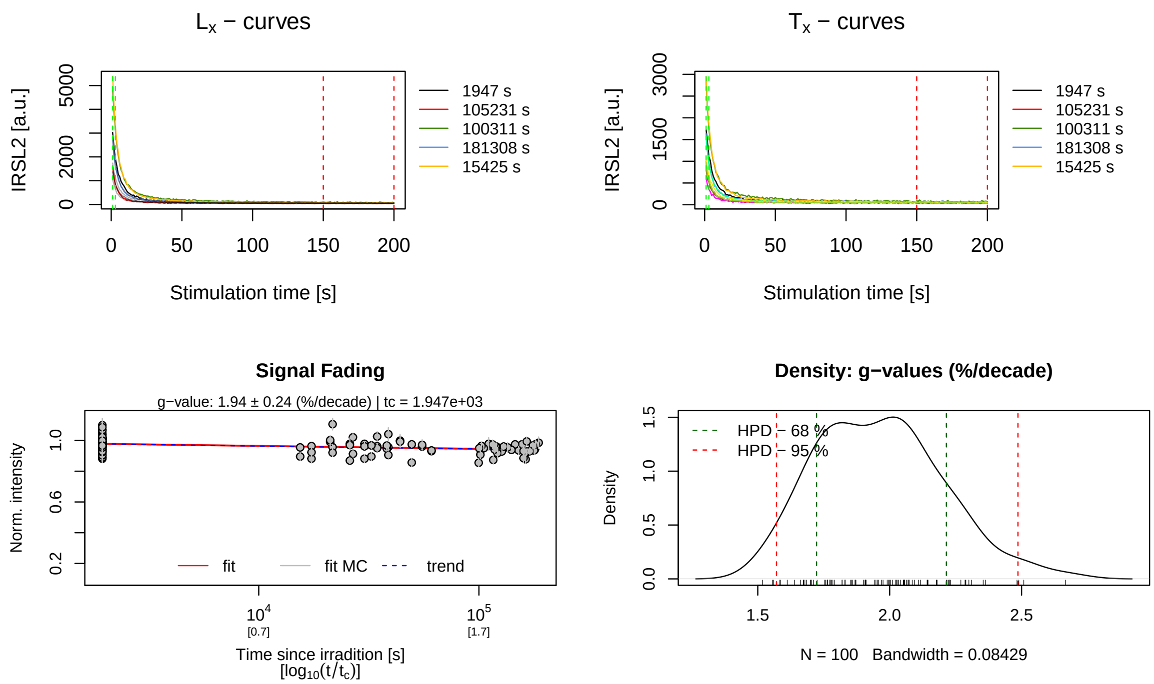
As expected, the fading rate is quite high. In the analyses of the data sets, much lower De values were observed for the IRSL measurements than for the pIR-IRSL measurements. The high fading rate provides a possible reason for this.




```
[analyse_FadingMeasurement()]

 n.MC:   100
 tc:     1.735e+03 s
---------------------------------------------------
T_0.5 interpolated: NA
T_0.5 predicted:    1.1e+06
g-value:         3.86 ± 0.48 (%/decade)
g-value (norm. 2 days): 4.18 ± 0.48 (%/decade)
---------------------------------------------------
rho':            2.76e-06 ± 3.81e-07
log10(rho'):        -5.56 ± 0.06
---------------------------------------------------
```

2.5 Fading of pIR-IRSL at 290°C

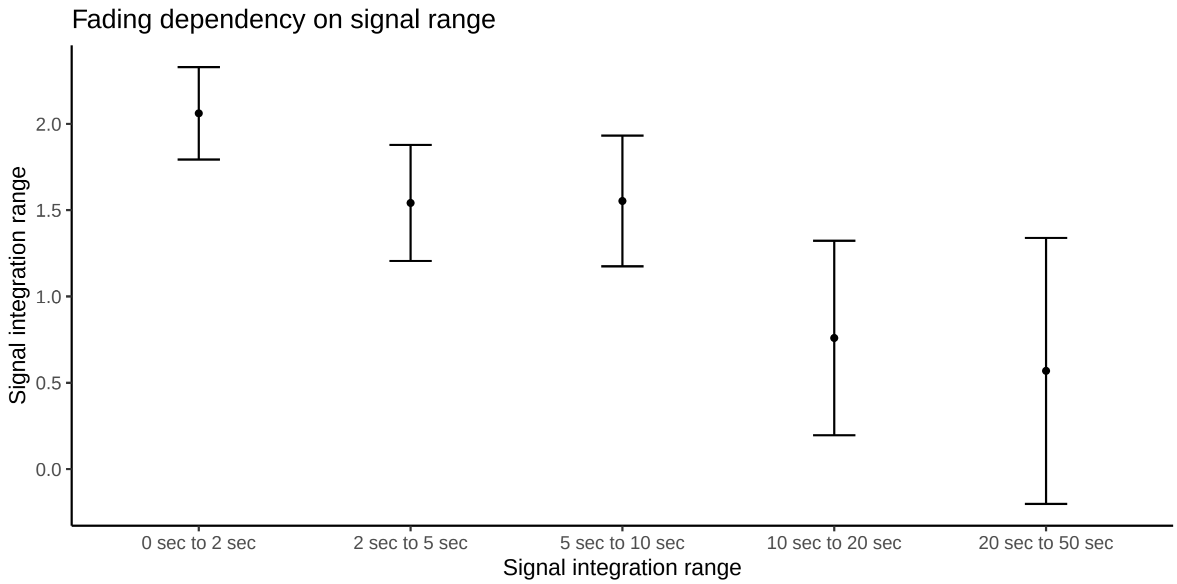
As expected, the fading values for the IRSL290 measurements are much lower. However, fading is still significant.




```
[analyse_FadingMeasurement()]

 n.MC:  100
 tc:    1.947e+03 s
---------------------------------------------------
T_0.5 interpolated: NA
T_0.5 predicted:    5.3e+06
g-value:        1.94 ± 0.24 (%/decade)
g-value (norm. 2 days): 2.02 ± 0.24 (%/decade)
---------------------------------------------------
rho':           1.35e-06 ± 1.53e-07
log10(rho'):        -5.87 ± 0.05
---------------------------------------------------
```

2.6 Fading dependence on signal integral range

We test if the fading value decrease if the signal integral range is shifted to later channels. And indeed, the g-value decreases to lower values.



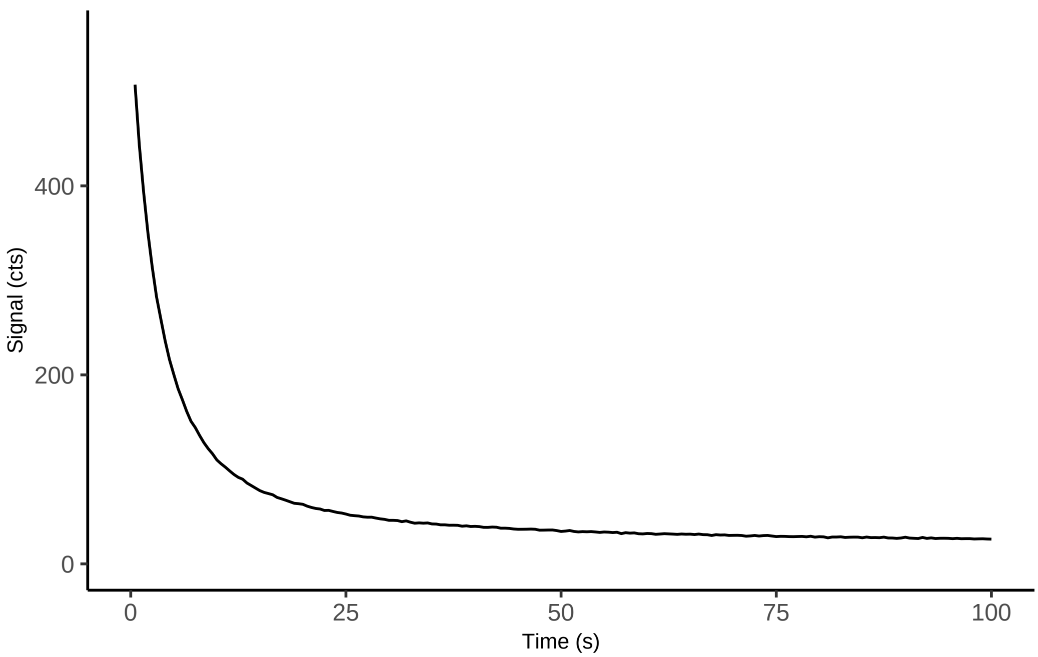
3 Fading per component

3.1 Global curve fitting

For the IRSL at 50°C measurements:

```
STEP 1.1 ----- Build global average curve from all CW-OSL curves -----
Built global average curve from arithmetic means from first 200 data points of all 360 IRSL records
(time needed: 2.84 s)

STEP 1.2 ----- Perform multi-exponential curve fitting -----

Decay rates (s^-1):
Cycle       Comp. 1     Comp. 2     Comp. 3     Comp. 4     Comp. 5         RSS     F-value
K = 1        0.1068                                                   1.871e+05         Inf
K = 2        0.2421     0.01207                                            3586        5016
K = 3        0.3774      0.1021    0.005749                               85.42        3975
K = 4        0.5459      0.2321     0.06705    0.003891                   34.81       139.6
Left loop because F-test value (F = 139.6) fell below threshold value (F = 150)
```

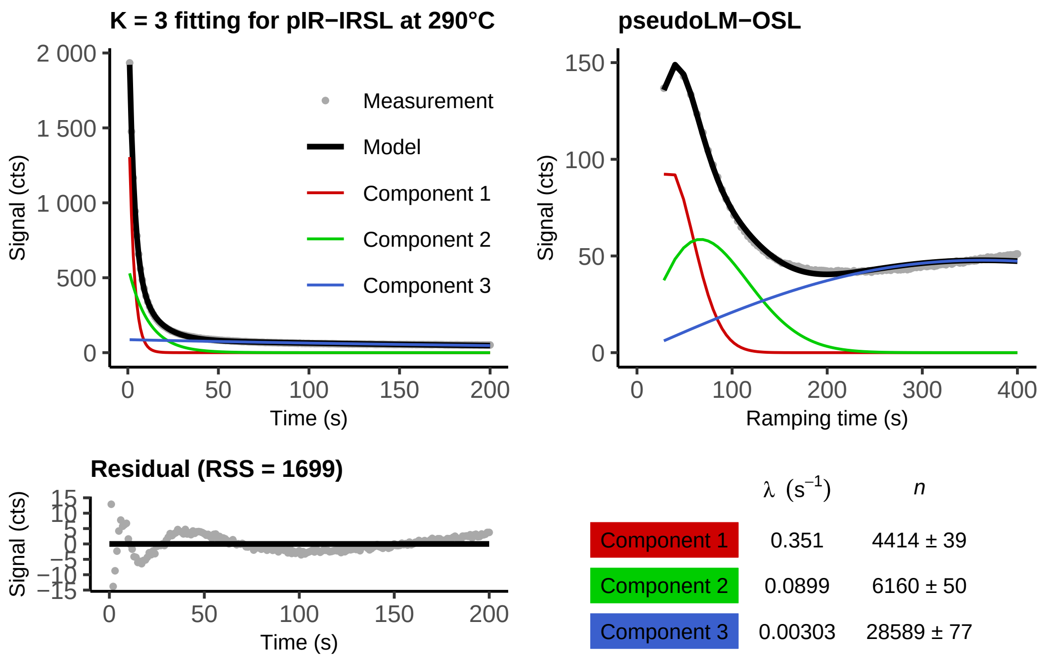
```
-> The F-test suggests the K = 3 model

Photoionisation cross sections (cm^2):
Cycle     Comp. 1              Comp. 2              Comp. 3              Comp. 4              Comp. 5
K = 1    7.13e-19
K = 2    1.62e-18             8.06e-20
K = 3    2.52e-18             6.82e-19             3.84e-20
K = 4    3.65e-18             1.55e-18             4.48e-19              2.6e-20
(time needed: 6.81 s)
```



For the pIR-IRSL measurements measurements:

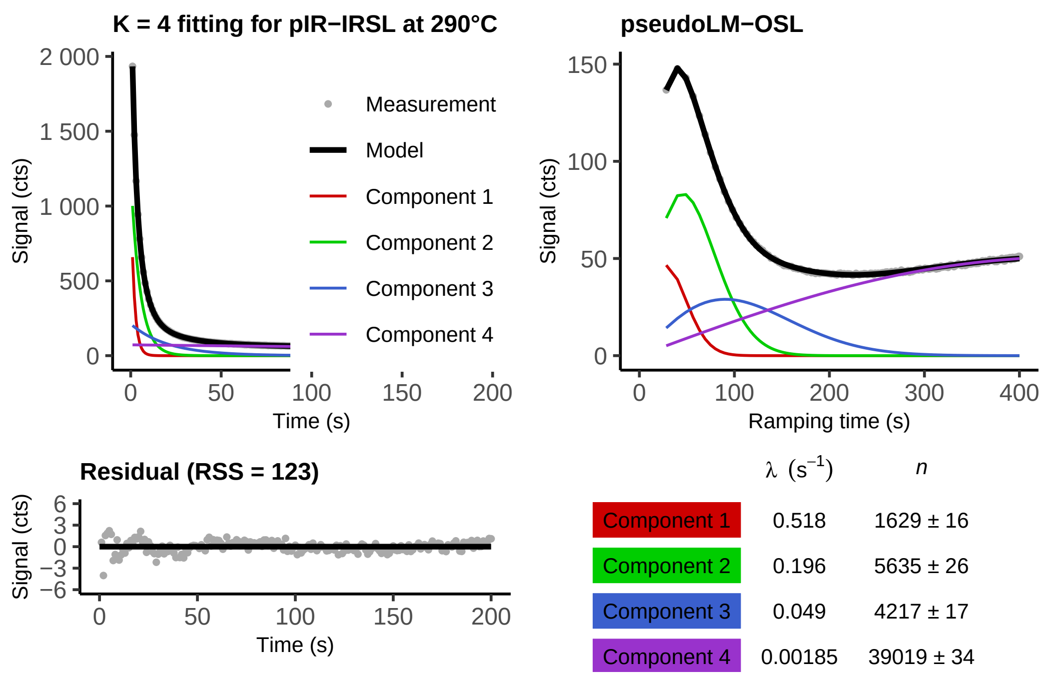
```
STEP 1.1 ----- Build global average curve from all CW-OSL curves -----
Built global average curve from arithmetic means from first 200 data points of all 360 IRSL2 records
(time needed: 2.69 s)

STEP 1.2 ----- Perform multi-exponential curve fitting -----

Decay rates (s^-1):
Cycle       Comp. 1     Comp. 2     Comp. 3          RSS     F-value
K = 1        0.1591                            9.815e+05         Inf
K = 2        0.2274    0.006932                5.257e+04        1732
K = 3        0.3505     0.08985    0.003028         1691        2918
```

```
Left loop because maximum number of allowed components K is reached
-> The F-test suggests the K = 3 model

Photoionisation cross sections (cm^2):
Cycle     Comp. 1               Comp. 2               Comp. 3
K = 1    1.06e-18
K = 2    1.52e-18              4.63e-20
K = 3    2.34e-18              6e-19                 2.02e-20
(time needed: 4.03 s)
```




```
STEP 1.1 ----- Build global average curve from all CW-OSL curves -----
Built global average curve from arithmetic means from first 200 data points of all 360 IRSL2 records
(time needed: 2.84 s)

STEP 1.2 ----- Perform multi-exponential curve fitting -----

Decay rates (s^-1):
Cycle        Comp. 1      Comp. 2      Comp. 3      Comp. 4           RSS       F-value
K = 1         0.1591                                             9.815e+05           Inf
K = 2         0.2274     0.006932                                5.257e+04          1732
K = 3         0.3505      0.08985     0.003028                        1691          2918
K = 4         0.5178       0.1956      0.04896     0.001852          121.6          1239
```

```
Left loop because maximum number of allowed components K is reached
-> The F-test suggests the K = 4 model

Photoionisation cross sections (cm^2):
Cycle      Comp. 1                Comp. 2                Comp. 3                Comp. 4
K = 1     1.06e-18
K = 2     1.52e-18              4.63e-20
K = 3     2.34e-18              6e-19                  2.02e-20
K = 4     3.46e-18              1.31e-18              3.27e-19              1.24e-20
(time needed: 6.9 s)
```



3.2 Decomposing

Fading rates of the IRSL at 50°C signal components:

```
STEP 2.1 ----- Define signal bin intervals -----
Find intervals with lowest component cross correlation by maximising the denominator determinant in Cramers rule:
Maximum determinant = 0.1106 with interval dividing channels at i = 9, 53
(time needed: 0.48 s)

STEP 2.2 ----- Decompose each  IRSL  curve -----
Calculate signal intensity n in each IRSL  by ' det+nls ' algorithm with empiric error estimation
```

```
Table of input decay constants and signal bin intervals for [decompose_OSLcurve()]:
         name      lambda t.start t.end ch.start ch.end
1 Component 1 0.377411871     0.0   4.5        1      9
2 Component 2 0.102117633     4.5  26.5       10     53
3 Component 3 0.005748679    26.5 100.0       54    200


.................
Successfully decomposed 360 records
(time needed: 2.37 s)
```

component	decay	g	g.error	tc	rho	rho.error
1	0.3774119	4.2628397	0.6466339	1235	3.2e-06	5e-07
2	0.1021176	2.3670680	0.5937279	1235	1.6e-06	5e-07
3	0.0057487	0.9713066	0.1881810	1235	7.0e-07	1e-07

Fading rates of the pIR-IRSL signal components with K = 3 components:

```
STEP 2.1 ----- Define signal bin intervals -----
Find intervals with lowest component cross correlation by maximising the denominator determinant in Cramers rule:
Maximum determinant = 0.1489 with interval dividing channels at i = 5, 36
(time needed: 0.47 s)

STEP 2.2 ----- Decompose each  IRSL2  curve -----
Calculate signal intensity n in each IRSL2  by ' det+nls ' algorithm with empiric error estimation
Table of input decay constants and signal bin intervals for [decompose_OSLcurve()]:
         name      lambda t.start t.end ch.start ch.end
1 Component 1 0.350521923       0     5        1      5
2 Component 2 0.089852623       5    36        6     36
3 Component 3 0.003028066      36   200       37    200


.................
Successfully decomposed 360 records
(time needed: 2.37 s)
```

Fading rates of the pIR-IRSL signal components with K = 4 components:

```
STEP 2.1 ----- Define signal bin intervals -----
Find intervals with lowest component cross correlation by maximising the denominator determinant in Cramers rule:
```

component	decay	g	g.error	tc	rho	rho.error
1	0.3505219	2.3491331	0.3074584	1447	1.7e-06	2e-07
2	0.0898526	0.9998203	0.3480469	1447	7.0e-07	3e-07
3	0.0030281	1.0367116	0.1599671	1447	7.0e-07	1e-07

```
Maximum determinant = 0.02264 with interval dividing channels at i = 3, 13, 59
(time needed: 1.14 s)

STEP 2.2 ----- Decompose each  IRSL2  curve -----
Calculate signal intensity n in each IRSL2  by ' det+nls ' algorithm with empiric error estimation
Table of input decay constants and signal bin intervals for [decompose_OSLcurve()]:
         name      lambda t.start t.end ch.start ch.end
1 Component 1 0.517825164       0     3        1      3
2 Component 2 0.195636175       3    13        4     13
3 Component 3 0.048962239      13    59       14     59
4 Component 4 0.001852441      59   200       60    200



..................
Successfully decomposed 360 records
(time needed: 2.76 s)
```

component	decay	g	g.error	tc	rho	rho.error
1	0.5178252	1.9550434	1.0547084	1447	1.4e-06	8e-07
2	0.1956362	1.4208465	0.5826385	1447	1.0e-06	4e-07
3	0.0489622	-1.2845698	0.9231060	1447	-9.0e-07	5e-07
4	0.0018524	0.9936386	0.1839587	1447	7.0e-07	1e-07

4 Re-evaluating LU-1

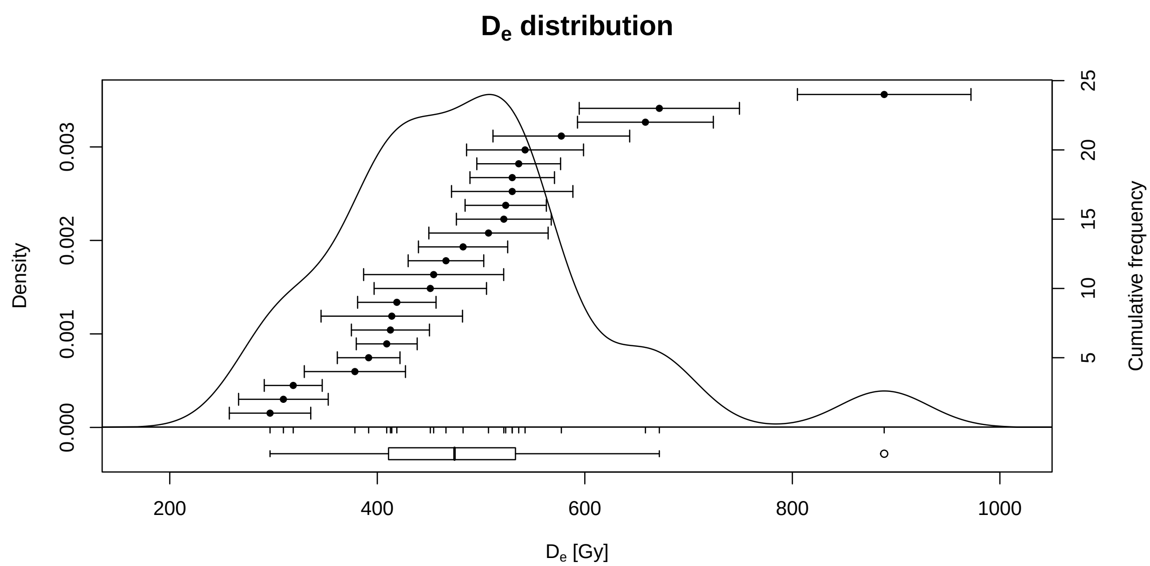
```
path <- "D:\\Data\\R\\Batagay-Analysis\\2022-12-06 B19-LU 1 and 6\\3-Permafrost-1mm-63-100-Fsp-pIR290-sample_B19

# Laboratory dose rate according to Tobias Lauer
dose_rate <- 0.1053 # Gy/s
rate_error <- 0.005 # Arbitrary but reasonable value

# Environmental dose rate according to DRAC calculations by Maggi Fuchs
```

```
envr_dose_rate <- 2.975 # Gy/ka
envr_dose_error <- 0.215 # Gy/ka
```

4.1 Fading correction for IRSL at 50°C

In the first step, we calculate the equivalent doses of all aliquots (see KDE plot below) of the regular dating data set of LU 1 (this is **not** the fading data set!). Those aliquots which pass the rejection criteria are used to calculate a CAM paleodose and an uncorrected IRSL50 sample age.

```
Median De =  474.425


Median De error =  44.45


Aliquots passed RC =  15
```




```
 [calc_CentralDose]

----------- meta data ----------------
 n:                         15
 log:                       TRUE
----------- dose estimate ------------
```

```
 abs. central dose:       493.25
 abs. SE:                 29.16
 rel. SE [%]:             5.91
----------- overdispersion -----------
 abs. OD:                 104.39
 abs. SE:                 22.30
 OD [%]:                  21.16
 SE [%]:                  4.52
-------------------------------------
```

We calculate the uncorrected age and the age error with the following equations:

```
# Calculate the age
age <- CAM_results$de / envr_dose_rate

# Calculate the error caused by the environmental dose rate error
age_min <- CAM_results$de / (envr_dose_rate + envr_dose_error)
age_max <- CAM_results$de / (envr_dose_rate - envr_dose_error)
age_sigma <- (age_max - age_min) / 2

# Combine the CAM paleodose error with the age rate rate error
age_error <- sqrt((CAM_results$de_err / envr_dose_rate)^2 +
                    age_sigma^2)
```

Uncorrected age: 165.8 ka ± 15.53 ka

Now we apply the fading correction proposed by Huntley & Lamothe (2001).

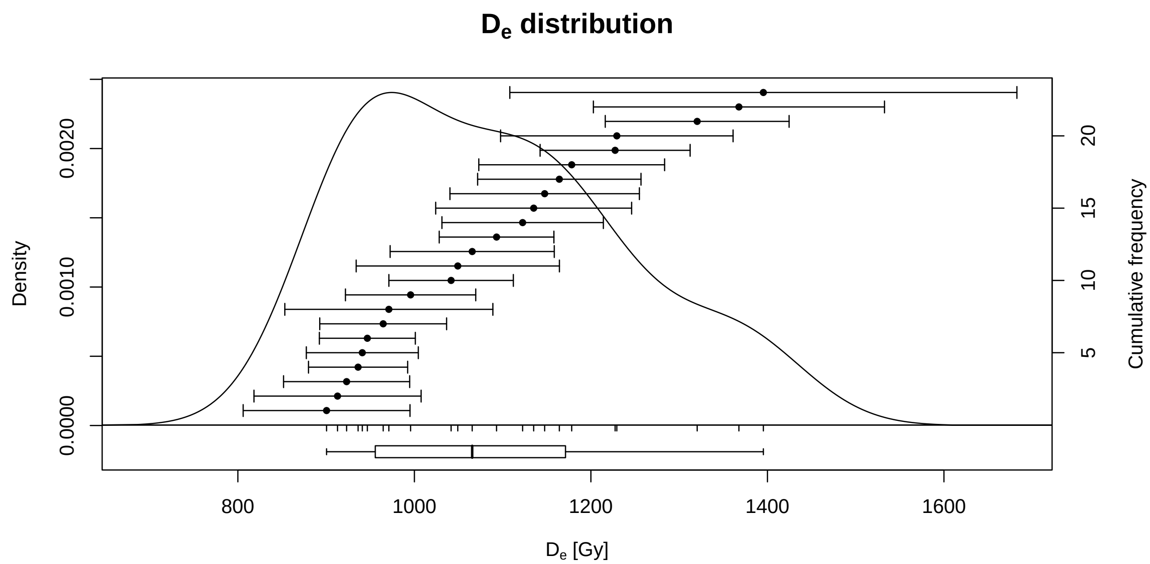
```
[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   3.857 ± 0.477 %/decade
 .. used tc:        5.498e-08 ka
 .. used kappa:     0.0168 ± 0.0021
 ----------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ----------------------------------------------
 Age (faded):       165.7983 ka ± 15.5298 ka
 Age (corr.):       257.5547 ka ± 31.1096 ka
```

```
--------------------------------------------
```

Corrected age: 257.55 ka ± 31.11 ka

4.2 Fading correction for pIR-IRSL at 290°C

```
Median De =  1065.5

Median De error =  92.98

Aliquots passed RC =  18
```




```
 [calc_CentralDose]

----------- meta data ----------------
 n:                       18
 log:                     TRUE
----------- dose estimate ------------
 abs. central dose:       1056.80
 abs. SE:                 28.02
 rel. SE [%]:             2.65
----------- overdispersion -----------
 abs. OD:                 84.33
```

```
 abs. SE:                 27.42
 OD [%]:                  7.98
 SE [%]:                  2.59
-------------------------------------
```

Uncorrected age: 355.23 ± 27.47 ka

We apply the fading correction proposed by Huntley & Lamothe (2001):

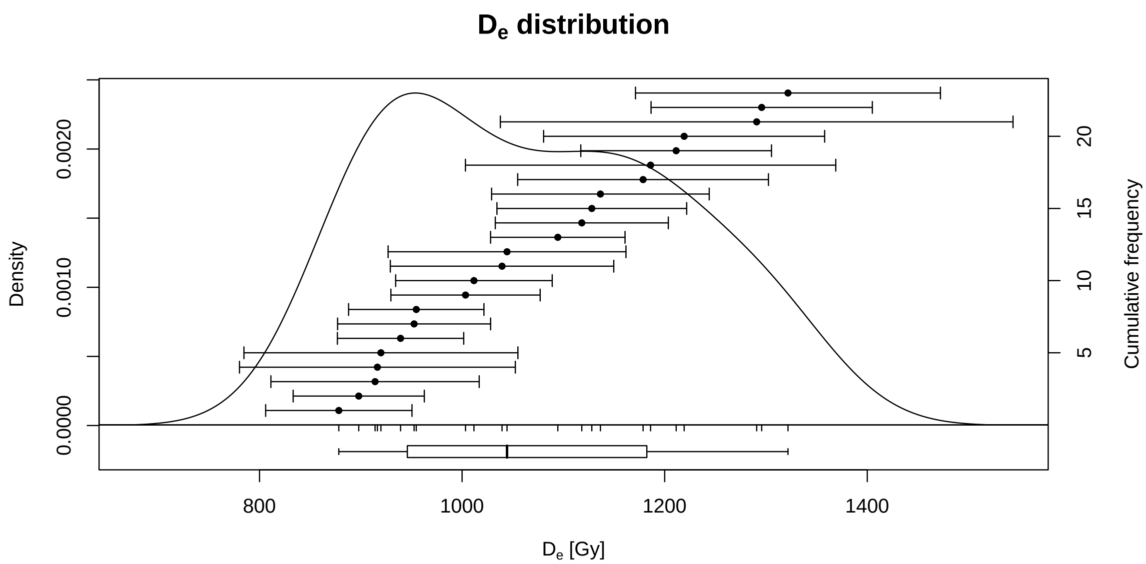
```
[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   1.942 ± 0.235 %/decade
 .. used tc:        6.17e-08 ka
 .. used kappa:     0.0084 ± 0.001
 ---------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ---------------------------------------------
 Age (faded):       355.2285 ka ± 27.4714 ka
 Age (corr.):       434.7027 ka ± 35.5817 ka
 ---------------------------------------------
```

Corrected age: 434.7 ka ± 35.58 ka

4.3 Age dependence on signal integral range

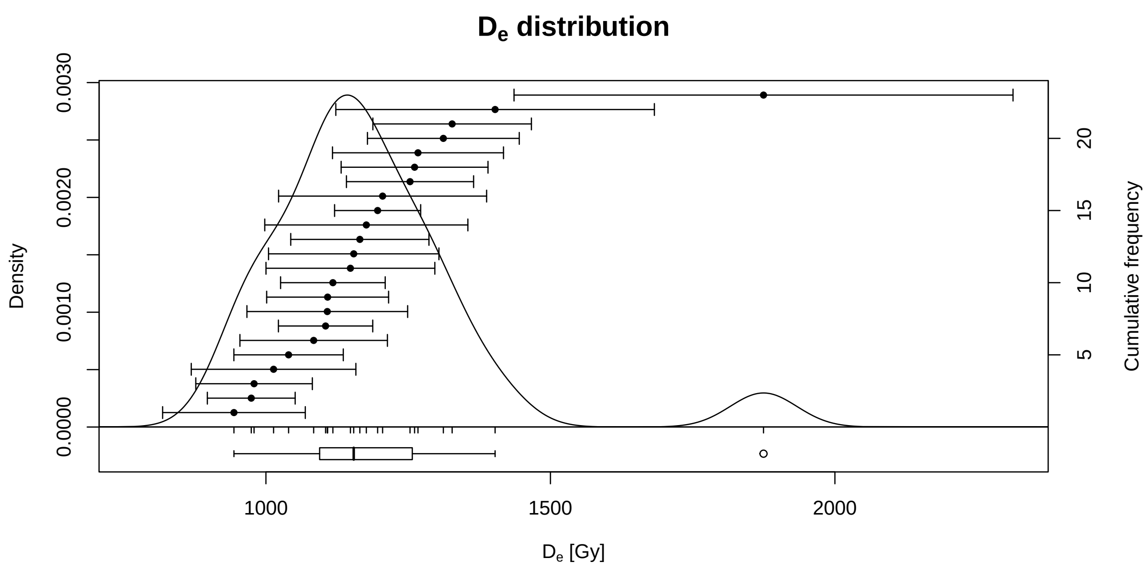
We calculate the paleodose for the signal integral ranges which were used in the section *Fading under integral variations*. Be aware that the channel width of the dating data set is 0.5 s while the fading data set used a channel width of 1 sec.

```
-------------- Signal integral 0 sec to 2 sec --------------
Median De =  1044.37
Median De error =  102.82
Aliquots passed RC =  14
```




```
 [calc_CentralDose]

----------- meta data ----------------
 n:                        14
 log:                      TRUE
----------- dose estimate ------------
 abs. central dose:        1037.85
 abs. SE:                  31.09
 rel. SE [%]:              3.00
----------- overdispersion -----------
 abs. OD:                  82.21
 abs. SE:                  30.75
 OD [%]:                   7.92
 SE [%]:                   2.96
-------------------------------------



[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   2.065 ± 0.268 %/decade
 .. used tc:        6.17e-08 ka
 .. used kappa:     0.009 ± 0.0012
```

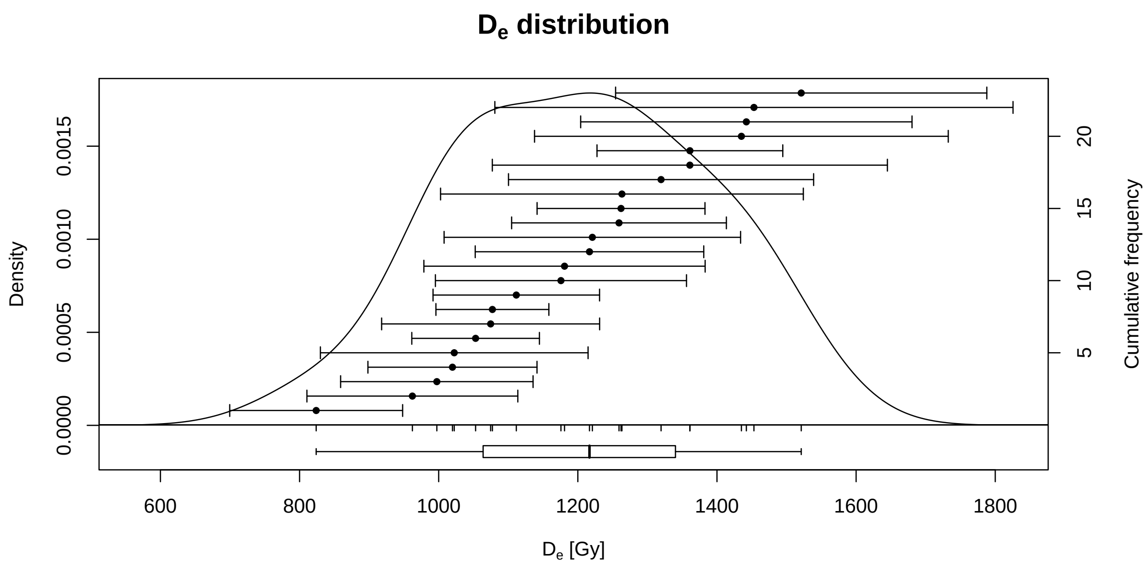
```
 ---------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ---------------------------------------------
 Age (faded):       348.8575 ka ± 27.4137 ka
 Age (corr.):       433.0083 ka ± 36.9626 ka
 ---------------------------------------------

-------------- Signal integral 2 sec to 5 sec --------------
Median De =  1154.3
Median De error =  129.61
Aliquots passed RC =  12
```




```
 [calc_CentralDose]

----------- meta data ----------------
 n:                        12
 log:                      TRUE
----------- dose estimate ------------
 abs. central dose:        1141.65
 abs. SE:                  31.01
 rel. SE [%]:              2.72
----------- overdispersion -----------
```

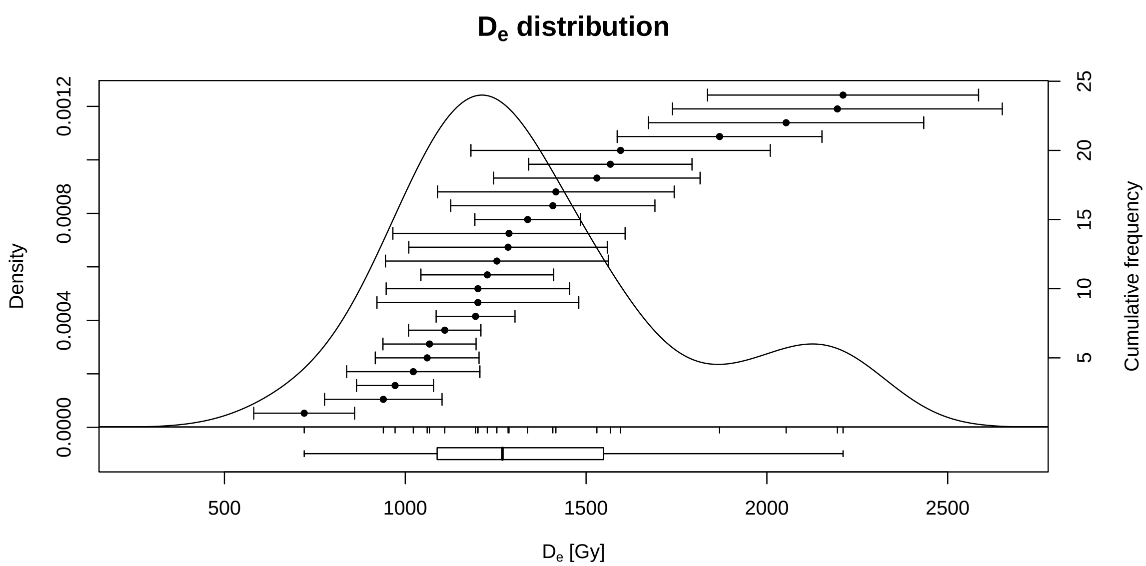
```
 abs. OD:                 36.24
 abs. SE:                 62.22
 OD [%]:                  3.17
 SE [%]:                  5.45
-------------------------------------
```

```
[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   1.494 ± 0.336 %/decade
 .. used tc:        6.17e-08 ka
 .. used kappa:     0.0065 ± 0.0015
 ----------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ----------------------------------------------
 Age (faded):       383.7479 ka ± 29.7637 ka
 Age (corr.):       446.6595 ka ± 38.9881 ka
 ----------------------------------------------

-------------- Signal integral 5 sec to 10 sec --------------
Median De =  1216.75
Median De error =  164.25
Aliquots passed RC =  5
```



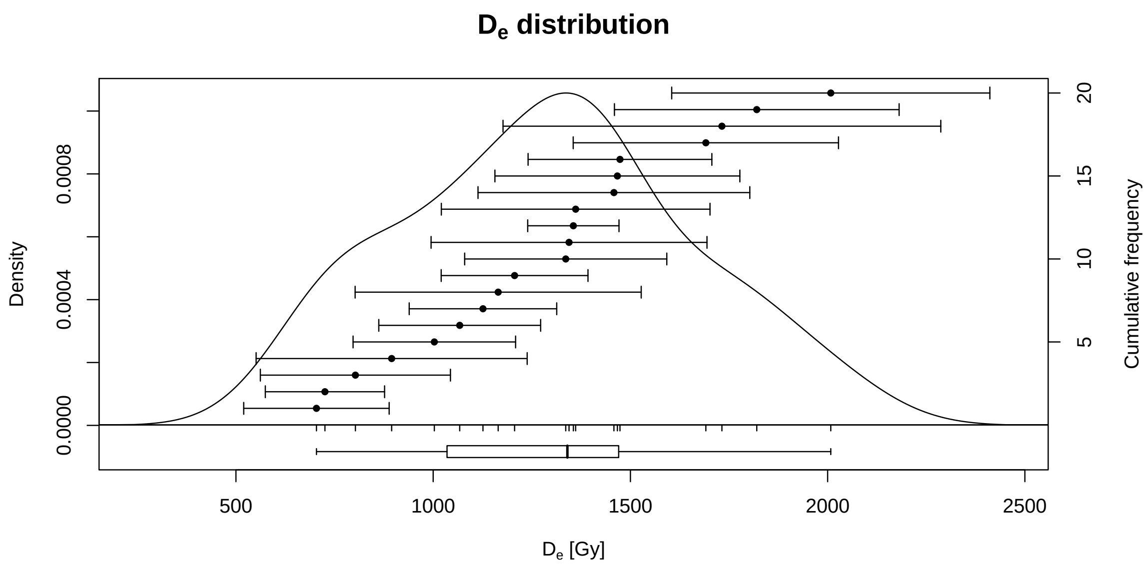

```
 [calc_CentralDose]

----------- meta data ----------------
 n:                        5
 log:                      TRUE
----------- dose estimate ------------
 abs. central dose:        1155.18
 abs. SE:                  50.34
 rel. SE [%]:              4.36
----------- overdispersion -----------
 abs. OD:                  39.95
 abs. SE:                  97.95
 OD [%]:                   3.46
 SE [%]:                   8.48
-------------------------------------



[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   1.586 ± 0.379 %/decade
 .. used tc:        6.17e-08 ka
 .. used kappa:     0.0069 ± 0.0016
```

```
 ---------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ---------------------------------------------
 Age (faded):       388.2953 ka ± 32.894 ka
 Age (corr.):       456.6482 ka ± 43.5156 ka
 ---------------------------------------------

-------------- Signal integral 10 sec to 20 sec --------------
Median De =  1268.835
Median De error =  264.06
Aliquots passed RC =  4
```




```
 [calc_CentralDose]

----------- meta data ----------------
 n:                        4
 log:                      TRUE
----------- dose estimate ------------
 abs. central dose:        1146.82
 abs. SE:                  56.60
 rel. SE [%]:              4.94
----------- overdispersion -----------
```

```
 abs. OD:                 1.44
 abs. SE:                 3084.48
 OD [%]:                  0.13
 SE [%]:                  268.96
-------------------------------------



[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   0.906 ± 0.564 %/decade
 .. used tc:        6.17e-08 ka
 .. used kappa:     0.0039 ± 0.0025
 ----------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ----------------------------------------------
 Age (faded):       385.4847 ka ± 33.8561 ka
 Age (corr.):       421.3517 ka ± 44.964 ka
 ----------------------------------------------

-------------- Signal integral 20 sec to 50 sec --------------
Median De =  1340.23
Median De error =  283.335
Aliquots passed RC =  1
```



4.4 Global curve fitting

5 Re-evaluating LU-7

We assume that the measured fading rates can be used not just for LU-1 but also for the other samples of B19. To test the impact of the fading correction on the younger sample, we re-evaluate B19 LU-7.

The environmental dose rate is not given, thus approximated as 2.6 Gy/ka from the DRAC values calculated for LU-3 to LU-6. To take this uncertainty into account, the dose rate error was arbitrarily set to 0.4 Gy/ka.

The dose rate is 0.1044 Gy/s with a dose rate error of 0.0052 Gy/s.

```
CORRECTION STEP 1 ----- Check records for consistency in the detection settings -----
Frequency table of different sets of detection settings (Channels, Channel width):
                settings frequency record_type
1               220, 0.5       336        IRSL
3               420, 0.5       336       IRSL2
2 420, 0.238095238095238       144       IRSL3
RLum.Data.Curve@RecordType changed to IRSL2 or IRSL3 in sequence: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
Further data manipulations are performed just on IRSL records
(time needed: 1.2 s)
```

```
CORRECTION STEP 2 ----- Remove not stimulated measurement parts -----
Measurement parts with stimulation light turned off detected and removed:
 5 s at the beginning and 5 s at the end.
-> Length of 336 IRSL records reduced from 110 s to 100 s
(time needed: 2.48 s)

CORRECTION STEP 1 ----- Check records for consistency in the detection settings -----
All IRSL2 records have the same detection settings
(time needed: 0.47 s)

CORRECTION STEP 2 ----- Remove not stimulated measurement parts -----
Measurement parts with stimulation light turned off detected and removed:
 5 s at the beginning and 0 s at the end.
-> Length of 336 IRSL2 records reduced from 210 s to 205 s
(time needed: 4.25 s)
```

5.1 Fading correction for IRSL at 50°C

```
Median De =  166.97


Median De error =  11.5


Aliquots passed RC =  22


 [calc_CentralDose]

----------- meta data ----------------
 n:                        22
 log:                      TRUE
----------- dose estimate ------------
 abs. central dose:        171.59
 abs. SE:                  6.93
 rel. SE [%]:              4.04
----------- overdispersion -----------
 abs. OD:                  30.22
 abs. SE:                  5.26
 OD [%]:                   17.61
 SE [%]:                   3.07
-------------------------------------
```

Uncorrected age: 66 ± 10.74 ka

```
[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   3.857 ± 0.477 %/decade
 .. used tc:        5.498e-08 ka
 .. used kappa:     0.0168 ± 0.0021
 ----------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ----------------------------------------------
 Age (faded):       65.9976 ka ± 10.7355 ka
 Age (corr.):       100.0604 ka ± 18.1486 ka
 ----------------------------------------------
```

Corrected age: 100.06 ka $\pm$ 18.15 ka

5.2 Fading correction for pIR-IRSL at 290°C

```
Median De =  327.7

Median De error =  17.42

Aliquots passed RC =  24

 [calc_CentralDose]

----------- meta data ----------------
 n:                         24
 log:                       TRUE
----------- dose estimate ------------
 abs. central dose:         324.90
 abs. SE:                   9.60
 rel. SE [%]:               2.95
----------- overdispersion -----------
 abs. OD:                   43.54
 abs. SE:                   7.33
 OD [%]:                    13.40
 SE [%]:                    2.26
-------------------------------------
```

Uncorrected age: 124.96 ± 20.03 ka

```
[calc_FadingCorr()]

 >> Fading correction according to Huntley & Lamothe (2001)

 .. used g-value:   1.942 ± 0.235 %/decade
 .. used tc:        6.17e-08 ka
 .. used kappa:     0.0084 ± 0.001
 ----------------------------------------------
 seed:          NA
 n.MC:          10000
 observations:      10000
 ----------------------------------------------
 Age (faded):       124.9609 ka ± 20.0339 ka
 Age (corr.):       151.2699 ka ± 24.6809 ka
 ----------------------------------------------
```

Corrected age: 151.27 ka ± 24.68 ka

6 References

Huntley, D.J., Lamothe, M., 2001. Ubiquity of anomalous fading in K-feldspars and the measurement and correction for it in optical dating. Canadian Journal of Earth Sciences 38, 1093-1106. doi: 10.1139/cjes-38-7-1093

Kars, R.H., Wallinga, J., Cohen, K.M., 2008. A new approach towards anomalous fading correction for feldspar IRSL dating-tests on samples in field saturation. Radiation Measurements 43, 786-790. doi:10.1016/j.radmeas.2008.01.021

Kreutzer, S., 2023. calc_FadingCorr(): Apply a fading correction according to Huntley & Lamothe (2001) for a given g-value and a given tc. Function version 0.4.3. In: Kreutzer, S., Burow, C., Dietze, M., Fuchs, M.C., Schmidt, C., Fischer, M., Friedrich, J., Mercier, N., Philippe, A., Riedesel, S., Autzen, M., Mittelstrass, D., Gray, H.J., Galharret, J., 2023. Luminescence: Comprehensive Luminescence Dating Data Analysis. R package version 0.9.21. https://CRAN.R-project.org/package=Luminescence

Kreutzer, S., Burow, C., 2023. analyse_FadingMeasurement(): Analyse fading measurements and returns the fading rate per decade (g-value). Function version 0.1.21. In: Kreutzer, S., Burow, C., Dietze, M., Fuchs, M.C., Schmidt, C., Fischer, M., Friedrich, J., Mercier, N., Philippe, A., Riedesel, S., Autzen, M., Mittelstrass, D., Gray, H.J., Galharret, J., 2023.

Luminescence: Comprehensive Luminescence Dating Data Analysis. R package version 0.9.21. https://CRAN.R-project.org/package=Luminescence

Kreutzer S, Burow C, Dietze M, Fuchs M, Schmidt C, Fischer M, Friedrich J, Mercier N, Philippe A, Riedesel S, Autzen M, Mittelstrass D, Gray H, Galharret J (2023). *Luminescence: Comprehensive Luminescence Dating Data Analysis*. R package version 0.9.21, https://CRAN.R-project.org/package=Luminescence.

Mittelstraß D, Kreutzer S, Schmidt C (2023). *OSLdecomposition: Signal Component Analysis for Optically Stimulated Luminescence*. R package version 1.0.1.