**Risø High Dose Reference Laboratory**

# Note on NPL comparison, 4th quarter 2015, verification of dose rate in Risø Gamma cells 1 and 3

Verification of dose rate by irradiation of NPL dosimeters in Risø gamma cell 1 (HDRL-I-45) and gamma cell 3 (HDRL-I-46).

The comparison was carried out in the search for a root-cause related to non-conformance HDRL-F-01 2015-05 (Change of alanine response).

*Note*: if not otherwise stated all uncertainties in this document are given with a coverage factor of $k$=2.

Irradiation at Risø: 2015.12.04-2015.12.08.
Irradiation temperature: 25°C.
NPL alanine reference dosimeters: Batch 71, 2244-2273, in holder type E (standard holder).
NPL certificate ref: 2015120010/1, 2015120010/2
Irradiation geometry: Risø HDRL standard geometries for gamma cell 1 and 3.

## Irradiation data:

| Gamma cell | Purpose | Dosimeter serial no. | | | Nominal dose, kGy | Irr. temp., C° | Irradiation date | Irradiation time, minutes | # of irr. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Dose rate | 2244 | 2245 | 2246 | 0.400 | 25 | 2015.12.07 | 80.79 | 1 |
| 1 | Dose rate | 2247 | 2248 | 2249 | 0.600 | 25 | 2015.12.07 | 121.22 | 1 |
| 1 | Dose rate | 2250 | 2251 | 2252 | 0.800 | 25 | 2015.12.04 | 161.46 | 1 |
| 3 | Dose rate | 2253 | 2254 | 2255 | 10 | 25 | 2015.12.08 | 68.52 | 1 |
| 3 | Dose rate | 2256 | 2257 | 2258 | 30 | 25 | 2015.12.04 | 205.4 | 1 |
| 3 | Dose rate | 2259 | 2260 | 2261 | 50 | 25 | 2015.12.07 | 342.8 | 1 |
| 1 | Transient | 2262 | 2263 | 2264 | 0.020 | 25 | 2015.12.07 | 3.99 | 1 |
| 1 | Transient | 2265 | 2266 | 2267 | 0.020 | 25 | 2015.12.07 | 0.35 | 10 |
| 3 | Transient | 2268 | 2269 | 2270 | 0.200 | 25 | 2015.12.07 | 1.29 | 1 |
| 3 | Transient | 2271 | 2272 | 2273 | 0.200 | 25 | 2015.12.07 | 0.053 | 10 |

**Results: Dose rate**

Dose rates based on measured dose values from NPL are verified by comparison to nominal dose rate using the E-value test (HDRL-I-31), see results in Table 1.

The uncertainty of the measured dose rate is given as the total NPL uncertainty (2.6%). In this comparison the uncertainty of the nominal dose rate is given by the random component of the uncertainty stated by HDRL for irradiation of dosimeters (0.86%, cf. Table 2; HDRL-App-08 (8)).

Table 1: Dose measurement results

| Gamma cell | Nominal dose, kGy | NPL meas. dose, kGy | Average meas. dose, kGy | 1 sd, % | Meas. dose rate, Gy/min | Uncertainty, Gy/min | Nominal dose rate, Gy/min * | Uncertainty, Gy/min | E-value |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.400 | 0.397 | 0.397 | 0.4 | 4.91 | 0.13 | 4.95 | 0.04 | **0.25** |
| | | 0.400 | | | 4.95 | 0.13 | 4.95 | 0.04 | **0.03** |
| | | 0.399 | | | 4.94 | 0.13 | 4.95 | 0.04 | **0.07** |
| 1 | 0.600 | 0.601 | 0.601 | 0.3 | 4.96 | 0.13 | 4.95 | 0.04 | **0.08** |
| | | 0.602 | | | 4.97 | 0.13 | 4.95 | 0.04 | **0.14** |
| | | 0.598 | | | 4.93 | 0.13 | 4.95 | 0.04 | **0.11** |
| 1 | 0.800 | 0.796 | 0.796 | 0.1 | 4.93 | 0.13 | 4.95 | 0.04 | **0.17** |
| | | 0.798 | | | 4.94 | 0.13 | 4.95 | 0.04 | **0.08** |
| | | 0.797 | | | 4.94 | 0.13 | 4.95 | 0.04 | **0.12** |
| 3 | 10 | 9.98 | 9.980 | 0.1 | 145.7 | 3.79 | 145.8 | 1.3 | **0.03** |
| | | 9.99 | | | 145.8 | 3.79 | 145.8 | 1.3 | **0.00** |
| | | 9.97 | | | 145.5 | 3.78 | 145.8 | 1.3 | **0.07** |
| 3 | 30 | 29.8 | 29.800 | 0.2 | 145.1 | 3.77 | 146.0 | 1.3 | **0.23** |
| | | 29.9 | | | 145.6 | 3.78 | 146.0 | 1.3 | **0.11** |
| | | 29.8 | | | 145.1 | 3.77 | 146.0 | 1.3 | **0.23** |
| 3 | 50 | 49.5 | 49.500 | 0.1 | 144.4 | 3.75 | 145.8 | 1.3 | **0.36** |
| | | 49.6 | | | 144.7 | 3.76 | 145.8 | 1.3 | **0.29** |
| | | 49.6 | | | 144.7 | 3.76 | 145.8 | 1.3 | **0.29** |

* Note: different days of irradiation.

Conclusion: All E-values are less than 1 and the dose rates of gamma cell 1 and 3 are successfully verified.

**Results: Transient dose**

Due to a mistake the determination of transient dose was not carried out as specified in HDRL-I-01 (the irradiations were fractionated in dose instead of time, cf. internal complaint 2015-20).

However, if the transient dose is calculated correctly the dose given by the sum of the fractionated irradiations should be equal to the dose given by the unfractionated irradiation.

The uncertainty budget for irradiation of dosimeters is given in Table 2.

Table 2: Uncertainty budget for irradiation of dosimeters in gamma cells 1 and 3

| **Irradiation of dosimeters at Gamma cells 1 and 3** | | | |
|---|---|---|---|
| | | Random (*k*=1) | Non-random (*k*=1) |
| Calibration of dose rate | A | | 1.32 |
| Cobalt-60 decay | A | 0.03 | |
| Irradiation time | B | 0.05 | |
| Transient dose | A | 0.40 | |
| Irradiation geometry | B | 0.15 | |
| Combined | | 0.43 | 1.32 |
| Combined uncertainty of doses given | | | 1.39 |
| At *k* = 2 | | | 2.79 |

The total random uncertainty (HDRL irradiation and NPL measurement) is 1.3% (*k*=2) (Table 3).
The total random uncertainty of the mean of 3 readings is found by dividing by the square root of 3 (0.8%).

Table 3: Random uncertainty

| Uncertainty, %, *k*=2 | |
|---|---|
| NPL, random | 1.0 |
| HDRL, random | 0.9 |
| Total | 1.3 |
| U(Total, random, n=3) | 0.8 |

Table 4 shows that the E-value test regarding transient dose passed for gamma cell 1, but fails for gamma cell 3.

Table 4:

| Gamma cell | Fractions | Nominal dose, kGy | Irr. time, minutes | NPL dose, Gy | | | Average NPL dose, Gy | 1 sd, % | Uncertainty, Gy | E-value |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **1** | 0.020 | 3.99 | 19.9 | 19.9 | 20.0 | **19.9** | 0.3 | 0.2 | **0.5** |
| 1 | **10** | 0.020 | 0.35 | 19.7 | 19.9 | 20.0 | **19.8** | 0.7 | 0.2 | |
| 3 | **1** | 0.200 | 1.29 | 200 | 200 | 200 | **200.0** | 0.0 | 1.5 | **1.1** |
| 3 | **10** | 0.200 | 0.05 | 200 | 203 | 204 | **202.3** | 1.0 | 1.5 | |

However, to our best knowledge this failure is caused by an underestimation of the uncertainty in the given dose for very short irradiations.

The transient dose for gamma cell 3 was 12.3 Gy equivalent to an irradiation time of 0.0845 minutes. This means that the transient dose is the dominant part of the dose given during a fractionated irradiation (20 Gy). It is likely that the random uncertainty in this case is higher than the estimated 0.9% ($k$=2). The E-value test would have passed had the random uncertainty been equal or higher than 1.1%, which is not unlikely.

The hypothesis is further strengthened by the fact that there is very good agreement between nominal and measured dose for the unfractionated irradiation (200 Gy).

It is concluded that:

- the failure of the E-value test for gamma cell 3 is caused by a higher than estimated random uncertainty for very short irradiations, and
- the failure does not affect irradiations within the accredited dose range (lower limit 200 Gy). The uncertainty budget is therefore maintained without changes.

**Overall conclusion**

The dose rates and transient doses have been verified successfully. No change in the calculation of irradiation time is made.

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