**Table S1. Irradiation characteristics during the ISS-type exposure experiment (schedule, dose and dose rates absorbed by European sea bass eggs)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Day of irradiation** | **Start time of irradiation (hh:mm, CET)** | **End time of irradiation (hh:mm, CET)** | **Irradiation duration (h)** | **Time without irradiation (h)** | **Mean dose rate (µGy h-1)** | **Mean cumulated dose (mGy)** | **Hatching rate containers dose rate (µGy h-1)** | **Hatching rate containers cumulated dose (mGy)** | **DNA damage & histology containers dose rate (µGy h-1)** | **DNA damage & histology containers cumulated dose (mGy)** |
| 1 | 09:26 | 17:26 | 8.00 | 0.40 | 16.7 | 0.13 | 16.9 | 0.14 | 15.9 | 0.13 |
| 1 | 17:50 | 21:05 | 3.25 | 12.00 | 16.7 | 0.19 | 16.9 | 0.19 | 15.9 | 0.18 |
| 2 | 09:10 | 10:10 | 1.00 | 0.40 | 16.7 | 0.20 | 16.9 | 0.21 | 15.9 | 0.19 |
| 2 | 10:35 | 12:51 | 2.27 | 0.38 | 16.7 | 0.24 | 16.9 | 0.25 | 15.9 | 0.23 |
| 2 | 13:15 | 16:15 | 3.00 | 0.20 | 16.7 | 0.29 | 16.9 | 0.30 | 15.9 | 0.28 |
| 2 & 3 | 16:28 | 09:08 | 16.7 |  | 16.7 | 0.57 | 16.9 | 0.57 | 15.9 | 0.54 |
| **Total** |  |  | **34.2** | **13.4** |  |  |  |  |  |  |

**Table S2. Dose rates calculated during the ISS-type exposure experiment based on container position (mean absorbed dose rate at the center of the container)**

|  |  |  |
| --- | --- | --- |
| **Container position** | **Dose rate (µGy h-1)** | **Total dose (mGy)** |
| Container n°1 (DNA damage & histology) | 15.9 | 0.54 |
| Container n°2 (hatching rate 1) | 17.5 | 0.60\* |
| Container n°3 (hatching rate 2) | 17.6 | 0.60\* |
| Container n°4 (hatching rate 3) | 15.7 | 0.51\* |
| **Mean for the 4 containers** | **16.7** |  |
| **SD for the 4 containers** | **1.0** |  |

\*Mean for the hatching rate triplicates: 0.57 ± 0.05

**Table S3. Neutron weighting factors as a function of energy (ICRP 103. 2003)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Neutron energy (MeV) | 1 | 3 | 7 | 15 | 20 | 23.5 | 30.6 |
| Weighting factor | 20.7 | 15.0 | 10.3 | 7.5 | 6.8 | 6.4 | 6.0 |

**Table S4. Irradiation characteristics during the lunar journey simulation (schedule, dose and dose rates absorbed by European sea bass eggs)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Day of irradiation** | **Start time of irradiation (hh:mm, CET)** | **End time of irradiation (hh:m, CET)** | **Irradiation duration (h)** | **Time without irradiation (h)** | **Mean dose rate (µGy h-1)** | **Mean cumulated dose (mGy)** | **Hatching rate containers dose rate (µGy h-1)** | **Hatching rate containers cumulated dose (mGy)** | **DNA damage containers dose rate (µGy h-1)** | **DNA damage containers cumulated dose (mGy)** | **Histology containers dose rate (µGy h-1)** | **Histology containers cumulated dose (mGy)** |
| 1 | 14:10 | 17:10 | 3.00 | 17.00 | 585 | 1.75 | 659 | 1.98 | 590 | 1.77 | 355 | 1.07 |
| 2 | 10:10 | 12:10 | 2.00 | 0.47 | 585 | 2.92 | 659 | 3.30 | 590 | 2.95 | 355 | 1.78 |
| 2 | 12:38 | 17:38 | 5.00 | 15.70 | 585 | 5.85 | 659 | 6.59 | 590 | 5.90 | 355 | 3.55 |
| 3 | 09:20 | 12:20 | 3.00 | 0.50 | 585 | 7.60 | 659 | 8.57 | 590 | 7.67 | 355 | 4.62 |
| 3 | 12:50 | 17:50 | 5.00 | 15.02 | 585 | 10.5 | 659 | 11.9 | 590 | 10.6 | 355 | 6.39 |
| 4 | 08:51 | 11:21 | 2.50 |  | 585 | 12.0 | 659 | 13.5 | 590 | 12.1 | 355 | 7.28 |
| **Total** |  |  | **20.5** | **48.7** |  |  |  |  |  |  |  |  |

**Table S5. Dose rates calculated during a lunar journey simulation in function of container position (mean absorbed dose rate at the center of the container)**

|  |  |  |
| --- | --- | --- |
| **Container position** | **Dose rate (µGy h-1)** | **Total dose (mGy)** |
| Container n°1 (DNA damage) | 590 | 12.09 |
| Container n°2 (hatching rate 1) | 686 | 14.06\* |
| Container n°3 (hatching rate 2) | 689 | 14.24\* |
| Container n°4 (hatching rate 3) | 603 | 12.36\* |
| Container n°5 (histology analysis) | 355 | 7.27 |
| **Mean for the 5 containers** | **585** |  |
| **SD for the 5 containers** | **136** |  |

\*Mean for the hatching rate triplicate: 13.55 ± 1.04

**Experimental approach to study neutron dose for the lunar mission experiment:**

The study is based on the fluence **Φ0** supplied by Yann Perrot, equal to 5.2 108 n/cm². Preliminary measurements were made with the long counter on AMANDE to establish the irradiation time required at 20 MeV to obtain the target fluence **Φ0**. The necessary irradiation time was calculated to be 20.5 hours, distributed over 3 days for practical reasons.

The aquarium (without fish eggs) was then irradiated, and results were checked using the NeusDesc software (v1. Oct-2008). The outcome of the simulation showed that the fluence was due to two reactions (T(d.n) and D(d.n)), as deuterium becomes implanted in the target over time.

Simulations were then performed to determine the equivalent dose deposited in each container, accounting for these two reactions. Since the simulation results are provided in mSv, the absorbed dose (in Gy) was determined by dividing the equivalent dose by the energy-dependent neutron quality factor (*w*R).

A different weighting factor was used for the two reactions, as the T(d.n) reaction produces neutrons of 20 MeV (*w*R=6.8) and the D(d.n) reaction produces neutrons of 7 MeV (*w*R=10.3). The fluence of the parasitic reaction (D(d.n)) was three times greater than that of the initial reaction:

[dφ/dt]T(d.n) = 1300 n/cm²/s

[dφ/dt]D(d.n) = 5000 n/cm²/s

[dφ/dt]Total = 6300 n/cm²/s

The weighting factor of 10.3 has a greater influence when calculating the absorbed dose, which means the dose obtained is lower than the target dose of 25.4 mGy calculated using the scenario. However, a lower absorbed dose with 7 MeV neutrons has the same effect as a higher absorbed dose with 20 MeV neutrons. This is because a neutron with a higher weighting factor requires depositing less energy to have the same effect on cells than a neutron with a lower weighting factor.

The equivalent doses calculated in fish eggs at the center of the containers, accounting for interactions with glass, plastic and water, are as follows:

* Equivalent dose (T(d.n)) = 50 mSv
* Equivalent dose (D(d.n)) = 104 mSv
* Total equivalent dose = 154 mSv

The absorbed doses were determined by dividing by the corresponding weighting factor (*w*R):

* Absorbed dose (T(d.n)) = 47/6.8 = 4.5 mGy
* Absorbed dose (D(d.t)) = 165/10.3 = 6.6 mGy
* Total absorbed dose = 11.1 mGy