
The Biological Effects of Radiation in Space

Radiation Effects

Stochastic effects:

“all or none”, can result from the effect on a single cell, e.g., cancer. Cannot predict effect on an individual basis; must use populations and risk probabilities.

Deterministic effects:

severity of the effect increases with increasing dose, e.g., cataracts, erythema.

USAF/NASA Proton Bioeffects Project

Proton energies were chosen to bracket the energies encountered in space:

<u>Proton energy</u>	<u>Range in tissue</u>
2 MeV	1 cm
55 MeV	2.5 cm
138 MeV	~ 15 cm
250 MeV	~ 40 cm
400 MeV	~ 80 cm
2300 MeV	~ 1000 cm

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~ 2000 Rhesus monkeys

~5000 mice

USAF/NASA Proton Bioeffects Project

**Dose estimates in
a primate head
phantom.**

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USAF/NASA Proton Bioeffects Project

All endpoints except one, indicated a proton RBE of ~ 1.

Cataract formation is the exception: protons showed an LET dependency.

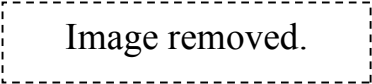


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Carcinogenesis

See [ALPEN-94] Alpen, E. L, P. Powers-Risius, S. B. Curtis, R. DeGuzman and R J. M. Fry.
“Fluence-Based Relative Biological Effectiveness for Charged Particle Carcinogenesis in Mouse
Harderian Gland.” Advances in Space Research 14 no. 10 (1994): 573-581.

Objective: look at *low doses*

Novel approach: Fluence *versus* dose

Carcinogenesis

Image removed.
[ALPEN-94] Table 1.

Carcinogenesis

Mouse Harderian gland model.

(secretes, tears, lubricants, hormones)

Within 72 hours, 2 donor pituitary glands implanted into the spleen.

Hormone production promotes the expression of Harderian gland tumors.

Mice sacrificed at 16 months; Harderian glands examined macroscopically and histologically.

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Graph of Dose (Gy) vs. Percent Tumor Prevalence

$$\text{Dose} = \text{fluence} \times \text{LET}$$

Carcinogenesis

**Tumor incidence
as a function of
particle fluence.**

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[ALPEN-94] Fig. 2.

Carcinogenesis

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Table

- **These are some of the highest RBE values measured in any system.**
- **All tumors were measured, some were benign.**

Carcinogenesis

Cross section =
the increase in
proportion of
animals with
Harderian gland
tumors per unit
fluence.

This is a track
penumbra effect.

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Fig. 14.7 in Alpen, E. L. *Radiation Biophysics*, 2nd ed. San Diego, CA: Academic Press, 1998.

Carcinogenesis

The RBEs are significantly higher than other reports with high-LET particles.

The Harderian gland RBEs never dip below 1 at high LET values.

Image removed.
[ALPEN-94] Fig. 3.

Carcinogenesis

Image removed.
[ALPEN-94] Table 3.

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[ALPEN-94] Table 4.

Carcinogenesis

Much attention
has been drawn to
these results.

This is very
troubling to
NASA.

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[ALPEN-94] Fig. 4.

These data suggest that only a single hit by a high-LET iron particle is sufficient to cause transformation and tumor induction.

Skin Cancer

**Incidence of
skin
carcinomas
in rats at ~ 1
year after
irradiation.**

**Dose vs
fluence?**

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[ALPEN-94] Fig. 6.

Cataract Formation

With protons, low dose rate causes less damage.

Iron ions appear much more effective than x-rays for cataract induction.

Image removed.
[ALPEN-94] Fig. 9.

Chromosome Aberrations

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Premature Aging

See [SHUKITT-HALE]: Shukitt-Hale, Barbara, Gemma Casadeusus, John J. McEwen, Bernard M. Rabin and James A. Joseph. "Spatial Learning and Memory Deficits Induced by Exposure to Iron-56-Particle Radiation." Radiation Research 154 (2000): 28-33.

Previous data from this group has shown:

- Exposure to ^{56}Fe particles disrupts behavior mediated by the dopamine neurotransmitter system. Conditioned Taste Aversion Test.
- ***The changes are similar to those seen in aged rats.***

Current study looks at cognitive function: spatial memory and learning; areas known to be affected in aging.

Rats were tested at 1 month after 1.5 Gy whole-body exposure to 1 GeV/n ^{56}Fe .

Morris Water Maze

Requires rats to use *spatial learning* to find a hidden platform just below the surface of a pool and *remember* the location from the previous trial.

Testing on 4 consecutive days/6 trials per day.

- Day 1: Trials 1-6; put rat into pool, measure time to find the platform and escape.
- Days 2 and 3: Trial 6; remove platform, measure time spent in quadrant where platform was previously located. *Measures memory.*
- Day 4: Change location of platform
 - Trials 1-5; measure time to find platform and escape.
 - Trial 6; remove platform, measure time spent searching in the correct quadrant. *Measures learning.*

Morris Water Maze

Image removed.
[SHUKITT-HALE] Fig. 1.

Premature Aging

- **The escape platform has been removed.**
- **Measure the time spent searching in the correct location (where the platform used to be).**
- **Control rats are using a spatial strategy**

Irradiated rats are using non-spatial strategy.

Image removed.
[SHUKITT-HALE] Fig. 2.

Premature Aging

**Control rats
have better
memory and are
using spatial
cues for
orientation.**

Image removed.
[SHUKITT-HALE] Fig. 4.

Conclusions

Whole-body irradiation with 1.5 Gy of ^{56}Fe 1000 MeV/n disrupted spatial memory and learning.

Irradiated rats took longer to learn a new task, and forget the old one, during reversal training.

Irradiated group did not use spatial strategies to find the submerged platform. Random circular swimming.

Both of these are deficits *similar to those seen in aged rats*.

X-rays can produce similar effects, but at doses of 20-30 Gy and not until 200-280 days post irradiation.