# Positive trends in radiation risk assessment and consequent opportunities for LINAC applications

**Yehoshua Socol**

socol@FalconAnalytics.com

# Contents

- Introduction
- Radiation risk in perspective
- Linear no-threshold hypothesis – controversy
- Positive trends (since LINAC12)
- LINAC applications
- Conclusions

# Nice to meet: ionizing radiation (1895)

# Nice to meet: radioactivity (1896)

# Radon therapy
## *radiation before its discovery*

- Radon spas –

  Herodotus and Hippocrates:
  - arthritis & other inflammatory conditions

- Mainstream medicine – Europe
- "Alternative treatment" – USA

Radon Health Mine
Boulder, MT, United States

# First 50+ years: no fear
## *X-ray shoe fitter*

# Radiation Safety Norms

- 1895 – 1920 No control, high exposures
  - *frequent accidents*
- 1921 – 1936 700 mSv/year (0.2 R/day)
  - ***natural background × 300***
  - ***no damage reported till now***
  - *1927: X-ray mutagenesis discovered*
- 1936 – 1949 350 mSv/year (0.1 R/day)
- 1949 – 1958 150 mSv/year (0.3 R/week)
- 1958 – 1991 50 mSv/year – professional limit
- 1991 – 20 mSv/year – professional limit
  - ***natural background × 8***

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# Perception of nuclear hazards

http://polit.ru/gallery/elkin

# Perception of nuclear hazards

Darwin, Australia 1942

Sendai, Japan 2011

Kfar Yehezkel
Israel, 1976

# How many A-bomb survivors died of radiation-induced cancers?

# How many A-bomb survivors died of radiation-induced cancers?

Solid cancer

| Colon dose (Gy) | Number of subjects | Person-years | Number of deaths | Number of excess cases[a] |
|---|---|---|---|---|
| <0.005 | 38,509 | 1,465,240 | 4,621 | 2 |
| 0.005– | 29,961 | 1,143,900 | 3,653 | 49 |
| 0.1– | 5,974 | 226,914 | 789 | 46 |
| 0.2– | 6,356 | 239,273 | 870 | 109 |
| 0.5– | 3,424 | 129,333 | 519 | 128 |
| 1– | 1,763 | 66,602 | 353 | 123 |
| 2+ | 624 | 22,947 | 124 | 70 |
| Total | 86,611 | 3,294,210 | 10,929 | 527 |

1950-2003:

**527 + 94 ≈ 600**

Leukemia

| | | 死亡 Deaths | | |
|---|---|---|---|---|
| | | 観察数 Observed | 推定過剰数 Estimated excess | 寄与率 Attributable risk |
| | | 69 | 4 | 6% |
| 0.1–0.2 | 5,841 | 14 | 5 | 36% |
| 0.2–0.5 | 6,304 | 27 | 10 | 37% |
| 0.5–1.0 | 3,963 | 30 | 19 | 63% |
| 1.0–2.0 | 1,972 | 39 | 28 | 72% |
| >2.0 | 737 | 25 | 28 | 100% |
| 合計 Total | 49,204 | 204 | 94 | 46% |

**600 / 11,000 :**

**Radiation is a rather weak (!) carcinogen**

# How many radiation-induced mutations?

# How many radiation-induced mutations?

**0 (none)**

**Radiation mutagenesis**

- 1927 – discovered in flies (Herman Műller)
- 1946 – Nobel prize
- **2014 – "not yet" observed in the offspring of the A-bomb survivors**

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# LNT – too mechanistic; Physiology is not linear!

## LNT for Paracetamol:

Lethal Dose LD50 = 2 g/kg (50% die)
LD50 ≤ 200 g (few of us weigh above 100 kg)
1 caplet: 0.5 g
Lethal probability: 50% × 0.5 / 200 = 0.125%

**1 out of 800 patients**
**should die of single caplet – obviously wrong**

## Radiation:
## less toxic => non-linearity less clear

# A-bomb survivors' life-span study

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# A-bomb survivors' life-span study

Socol & Dobrzynski, *Dose-Response* (in print)

# CT-induced childhood cancer?

Pearce et al. (Lancet 2012; 380: 499–505) **p=2%** (0.12×0.18)

**Too good to be honest**

# To summarize: LNTH

- Has never been proven
- Cannot be refuted – even A-bomb survivors do not provide enough statistics

"*A theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory (as people often think) but a vice*."

Karl Popper
*Conjectures and Refutations* 1963

# Hormesis (adaptive response)

- Immunization
- Physical exercise (gym)

***May bio-active radiation be***
**beneficiary**
***for human health?***

**Yes – UV !** ☼

High dose – sunburns and skin cancers ☹

**Low dose – sun tanning** ☺ ☺ ☺

Underexposure – severe health problems ☹

# Radiation hormesis (adaptive response) hypothesis

Sponsler R. and Cameron J.R.
*Int J Low Radiation* 1(2005) 463 – 478

**U.S. Shipyard workers**

# Radiation hormesis (adaptive response) hypothesis

Cuttler J. and Pollycove M.
*Dose-Response* 7 (2009) 52–89

**Mean home radon level (pCi/liter) by US county**

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# Positive trends (since LINAC12)

- Offensive on Linear No-Threshold hypothesis; defensive stance of LNTH proponents
- Softening of advisory bodies' position regarding LNTH
- Japan – pro-nuclear changes

# Offensive on LNTH

- New group formed (2013): SARI – Scientists for Accurate Radiation Information http://RadiationEffects.org
- Publications
- Debates
  - E.Calabrese vs. R.Cicerone *Archives of Toxicology* 87(2013):2063-81, 88(2014):171-172
  - M.Doss vs. M.Little *Med. Phys.* 41 (2014), 070601

# Softening of advisory bodies' position

- ICRP on low-dose cancers: “Speculative, unproven, undetectable and ‘phantom’ numbers”

  Gonzalez et al. J. Radiol. Prot. 33(2013):497–571

- IAEA: “safe for everyone” level:

  2.5 mrem/h ≈ 100 × (natural background)

  http://www-ns.iaea.org/downloads/iec/health-hazard-perspec-charts2013.pdf

- UNSCEAR: “no discernible health effects” due to Fukushima

  http://www.unscear.org/docs/reports/2013/13-85418_Report_2013_Annex_A.pdf

# Japan – pro-nuclear changes

- Fukushima prefecture – partial re-settlement
- Tokyo – pro-nuclear governor elected (2014)
- Nuclear phase-out plans scrapped (2014)

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# LINAC Applications

- Medical
  - cancer
  - inflammations & infections
- FEL
  - for EUV lithography
- food, plastics etc.

# Leukemia: supplementary low-dose irradiation (LDI)

**TBI: Total Body Irradiation**
**HBI: Half-body Irradiation**

**Survival, supplementary irradiation**

**Survival, without irradiation**

**Irradiation:**
**15 R per exposure**
**150 R total**
**Twice per week**

# Low-dose irradiation for cancer

- Increased efficiency
  - especially for leukemia & angiosarcoma
- No adverse side effects
- Potential prophylaxis

**BUT**

- Serious R&D needed

# Low-dose irradiation for inflammations & infections

- Used for centuries
- Clinically proven
- Attractive: *concerning development of antibiotic-resistance*

e.g., Group A Streptococcus (GAS):
~ 500,000 deaths / year
( “flesh-eating bacteria” )

Rheumatol Int (2013) 33:2839–2850
DOI 10.1007/s00296-013-2819-8

ORIGINAL ARTICLE

**Long-term benefits of radon spa therapy in rheumatic diseases: results of the randomised, multi-centre IMuRa trial**

Franke Annegret · Franke Thomas

Human and Experimental Toxicology
1–12
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DOI: 10.1177/0960327113493303
het.sagepub.com
SAGE

**Historical use of x-rays: Treatment of inner ear infections and prevention of deafness**

EJ Calabrese and G Dhawan

# FEL for EUV source

## Example of high power FEL [~ >10kW]

**An FEL has the potential of high power source, for example over 10kW to multiple scanners.**

**But FEL for EUV source is still in the conceptual stage.**

TOSHIBA Leading Innovation >>>

2014 International Workshop on EUV Lithography

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http://www.euvlitho.com/2014/P3.pdf

**Takayuki UCHIYAMA, TOSHIBA Corporation**

# Conclusions

- “The (radiation) devil is not as dangerous as usually depicted”
- More and more people understand this
- Medical, semiconductor lithography, and other applications anticipated

# Appendices

# Radiation around us
# *curious facts*

- I'm radioactive;

  You're too.
  - $^{40}K$, $^{14}C$ et al. present in all living cells

- US FDA:

  spirits *should be* radioactive for human consumption!

Radionuclides in the Body (Bq = $s^{-1}$)

| | |
|---|---|
| $^{40}K$ | 4000 |
| $^{14}C$ | 3700 |
| $^{210}Po$ | 40 |
| $^{3}H$ | 23 |
| $^{235}U$ | 2.3 |

# Radiation accidents

"Radium girls" ~ 1925

Biological Effects of Ionizing Radiation (US NAS)
BEIR IV (1988, pp. 186, 198)

Acute radiation effects: ~5000 workers
Bone sarcomas: 85 workers

http://MikeColes.net

Photo: Mike Coles (2006)

# Chernobyl vs. natural

Source: Z. Jaworowski, 2006