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# Internal exposure in post-accidental situations: a multi pollution to take into account?

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Fontenay aux roses

# Numerous studies on the health effects of post accidental exposure

- On the long term, a limited number of radionuclides are of concern for the radiation protection of the populations. Mainly $^{137}Cs$, $^{134}Cs$ and $^{90}Sr$.
- The level of exposure is low: generally 1-10 mSv/year, much more during the first year after the accident
- The study of health effects of exposure in post accidental situations remains a high level concern:
  - Compensations for evacuation
  - Return in evacuated areas
  - Daily life in contaminated areas.

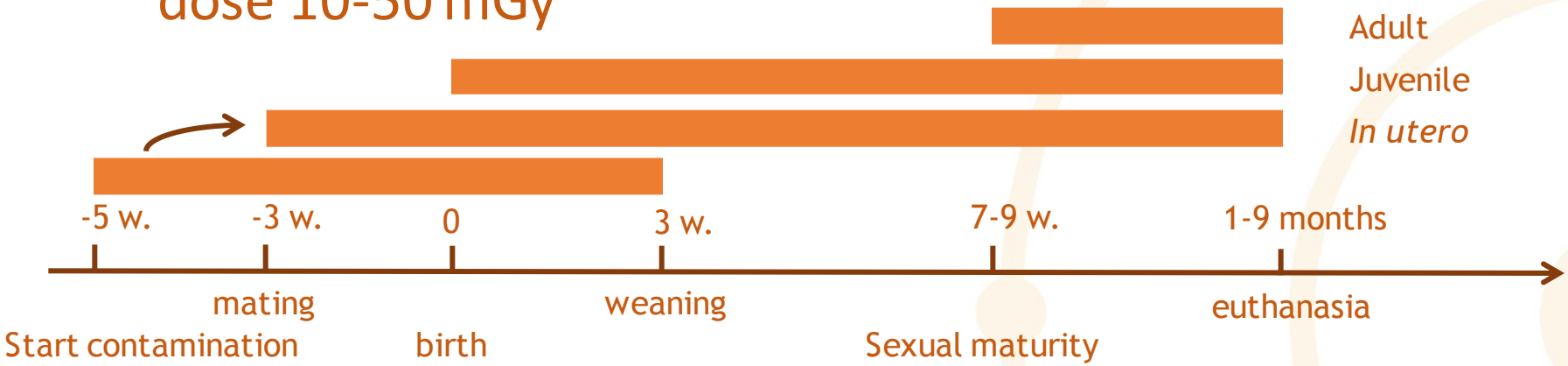
- Numerous studies in epidemiology, in physiology and on the psychological impact.

# Studies in humans

- Post-Chernobyl epidemiological studies:
  - Thyroid cancers (Kazakov, 1992, Stsjazhko et al., 1995), leukemia in clean-up workers (Kesminiene, 2008) and in the general population (Davis et col., 2006)
  - Cardiovascular pathologies in clean-up workers (Ivanov et al., 2006), cataracts in clean-up workers and in general population (Day et al, 1995, Worgul et al, 2007)
- Numerous studies describing some somatic effects or pathologies on limited size populations:
  - Changes in the immune system (Titov, 1995, McMahon, 2014)
  - Thyroid pathologies (Eheman, 2003)
  - Congenital effects (Wertelecki, 2010, Sperling, 1994)
- However, numerous uncertainties on the exposure.

# Animal studies

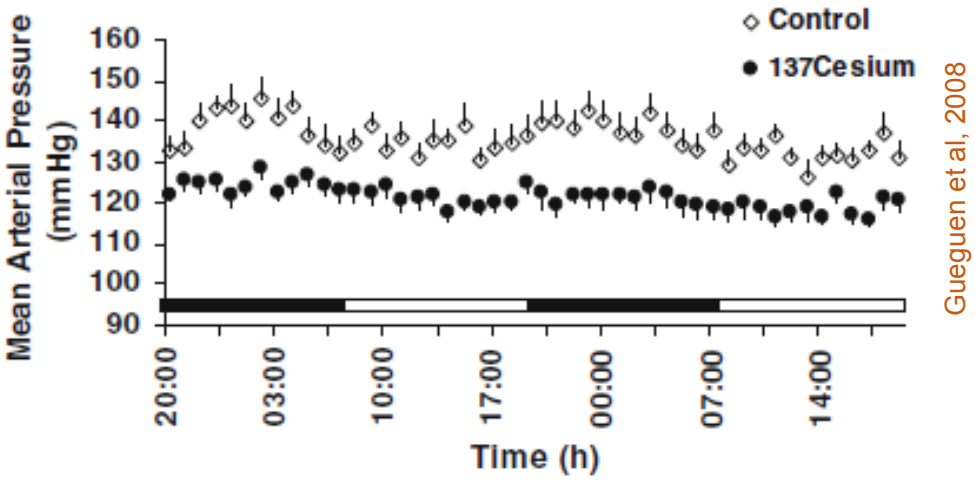
- Chronic contamination in rodents with $^{137}Cs$. Absorbed dose 10-50 mGy



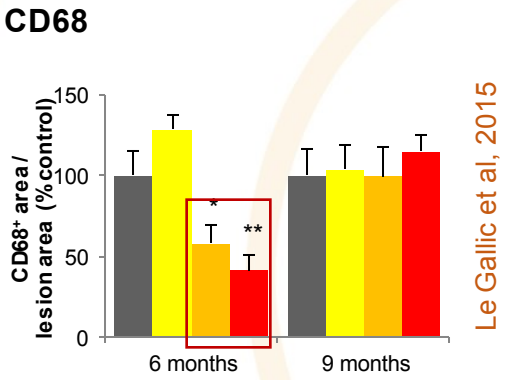

- Numerous biological effects of low amplitude: sleep modification (Lestaevel et col., 2006), oxysterol metabolism (Souidi et col., 2006, Grignard et col, 2007)
- Most of them do not give rise to significant troubles or pathologies
- For some other physiological systems (almost) no effects: Jejunum (Dublineau et col., 2007); immune system (Bertho et col., 2010); hematopoietic system (Bertho et col., 2010)

# A significant cardiovascular effect?

- Arterial pressure changes (Gueguen et col., 2008) and reduced inflammatory status of arteriosclerotic lesions (Le Gallic et col., 2015)




Gueguen et al, 2008



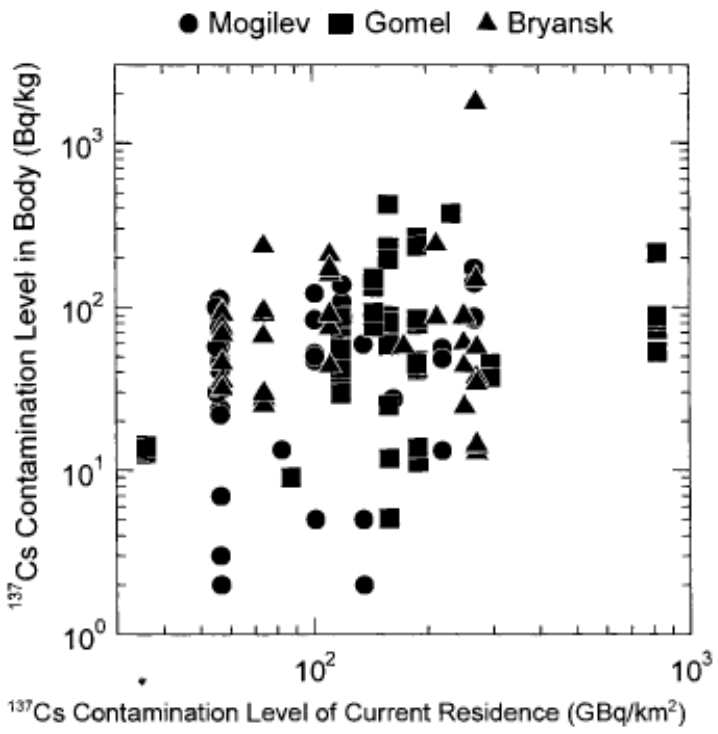

Le Gallic et al, 2015

- In contradiction with some studies in clean-up workers (Ivanov et col., 2006)
- And with the recently published study EPICE (Jourdain et al, 2017)

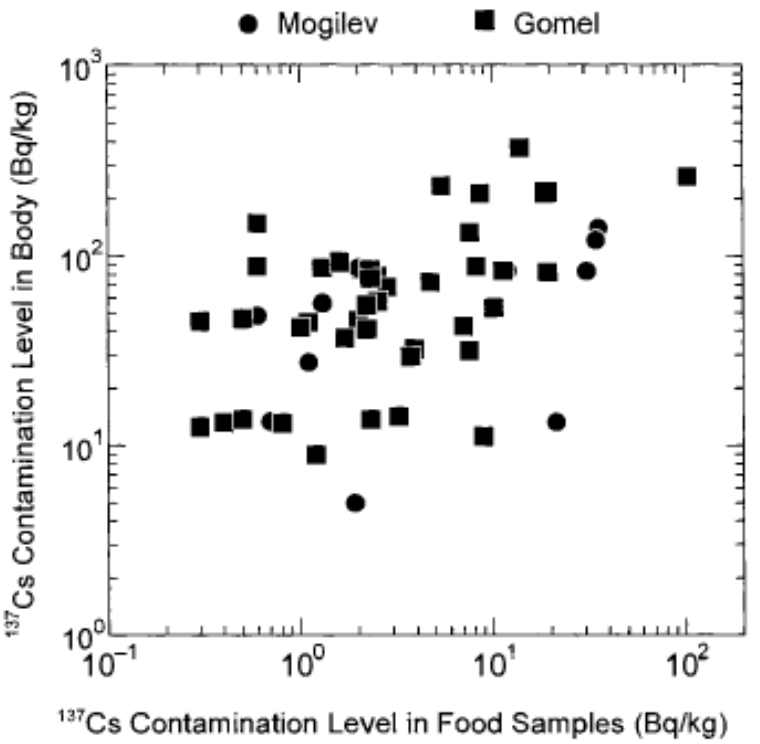
***Does the uncertainty on the exposure could explain these discrepancies?***

# Relationship between soil contamination, RN ingestion and whole body counting

## Local soil contamination with $^{137}Cs$ and whole body counting




## $^{137}Cs$ foodstuff contamination and whole body counting



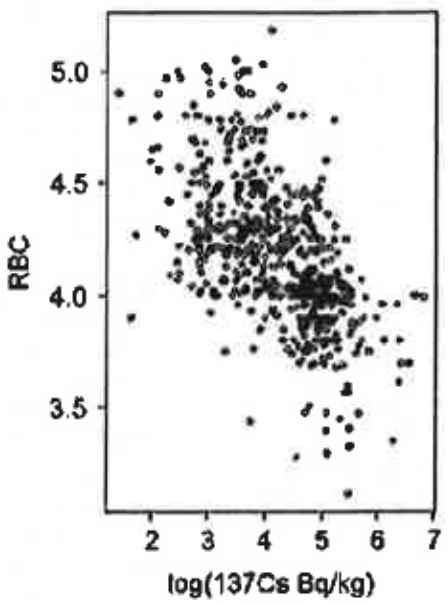

Takatsuji et al, 2000

*Better correlation with whole body counting*

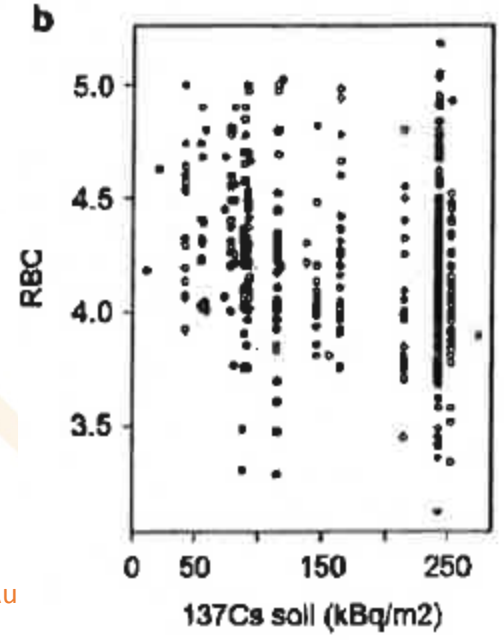
# Effects on blood cell counts

## An interesting study:

- 590 children 0 - 18 years old, born after the accident
- Blood cell counts, WBC and soil contamination
- Correlation between red blood cell decrease and whole body counting
- Far less evident correlation with the level of soil contamination at the place of living.




Lindgren et al, 2015




This strongly suggests that this is the internal contamination which is responsible for the observed effect.

Clear lack of such WBC measurements in most studies.

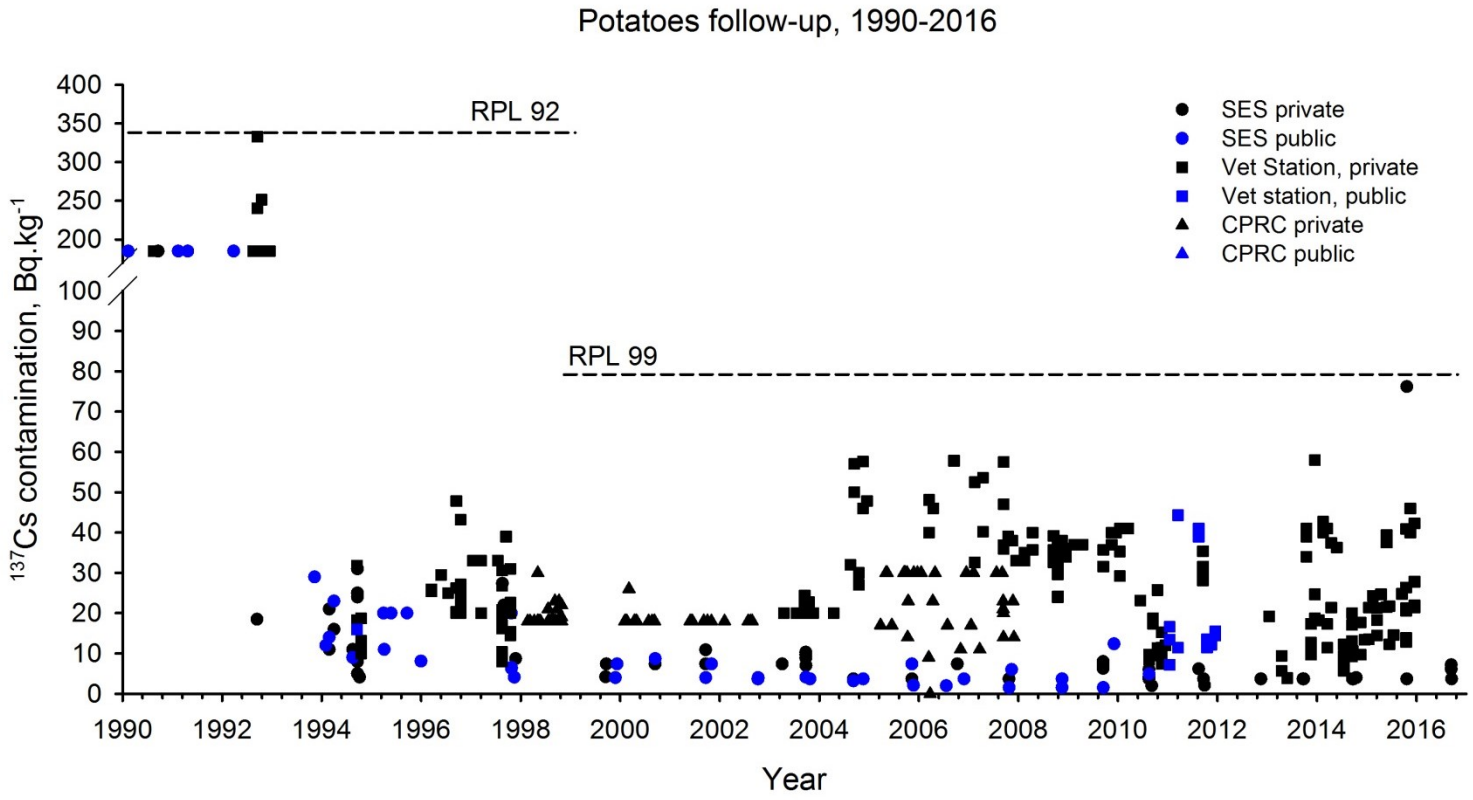
# Daily ingestion of radionuclides, Bq.d$^{-1}$

| Product | quantity kg.j$^{-1}$ | De Ruig et al, 1992 | | Cooper et al, 1992 | | Hoshi et al, 1994 | | Handl et al, 2003 | Shutov et al, 2002 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{137}$Cs | $^{90}$Sr | $^{137}$Cs | $^{90}$Sr | $^{137}$Cs | $^{90}$Sr | $^{137}$Cs | $^{137}$Cs | $^{90}$Sr |
| Milk | 1 | 15 | 4 | 80 | 7.9 | 44 | 6.5 | 54 | 7.8 | 1.8 |
| Potatoes | 0.5 | 1 | 0.25 | | - | - | - | 4.5 | 0.28 | 0.55 |
| Vegetables | 0.3 | 0.3 | 0.15 | 30.6 | 2.7 | - | - | 0.2 | 0.8 | 0.9 |
| Fruits | 0.4 | - | - | 3.6 | - | - | - | 1.9 | 0.44 | 0.2 |
| meat | 0.2 | - | - | 1.2 | - | - | - | 4.0 | 2.1 | 0.1 |
| River fish | 0.05 | - | - | 17 | - | - | - | 0.6 | 11 | 3.95 |
| eggs | 0.014 | - | - | | - | - | - | 0.04 | 0.05 | 0.025 |
| mushrooms | 0.01 | 240 | 3.4 | 1310 | 1.65 | 61.1 | 1.18 | 2000 | | - |
| Wild berries | 0.011 | - | - | 46.6 | 0.1 | - | - | 28 | 0.022 | 0.018 |
| water | 1.5 | - | - | - | - | - | - | - | - | - |
| Total, Bq.j$^{-1}$ | | 256.3 | 7.8 | 1489 | 12.35 | 105.1 | 7.68 | 2093 | 22.5 | 7.55 |

These are means… Variability is very high!!!

# Temporal evolution of the foodstuff contamination

Study in a Belarussian village close to the exclusion zone
25 years of records for foodstuff and environmental products



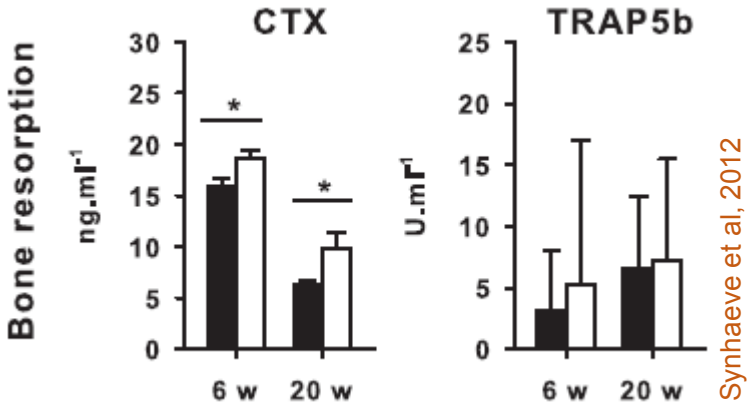

***Great variations due to changes in individual and collective behaviour***

# $^{90}Sr$, another potential actor

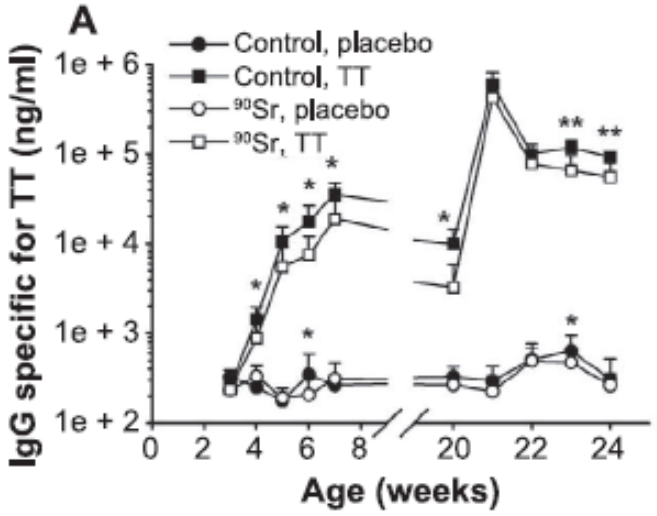
- Long term remnant in the environment
- Stored in bones
- But :
  - Difficult to measure, asking for sample preparation
  - Intrusive sampling: bones, teeth.
- Techa river population:
  - Increased risk of tumor and leukemia (Kossenko et col, 1996)
  - Accelerated bone resorption and increased risk of osteoporosis (Tolstykh et col 2011)
  - Hematopoietic deficit: reduced number of white blood cells in elderly (Akleyev et col, 2010)

# Experimental studies

- Chronic contamination in mouse model
- Accelerated bone resorption (Synhaeve et col., 2012) and decreased immune response (Synhaeve et col., 2016)




Synhaeve et al, 2012




Synhaeve et al, 2016

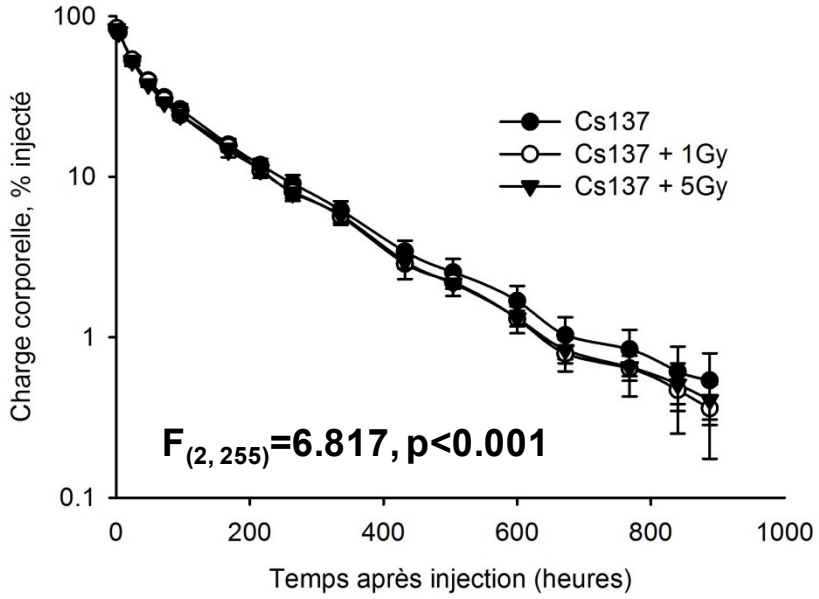
***In accordance with studies on the Techa river population***

***Could internal contamination with $^{90}Sr$ explain everything?***

# Effects of a multiple exposure?

*Hypothesis: the multiplicity of exposure is the key parameter to take into account*

- Almost no experimental study on the effect of multiple exposure, either RN + external irradiation or mixture of radionuclides.
- The ICRP recommendations are based on the principle of dose additivity.




- A change in $^{137}$Cs elimination after irradiation, whatever the radiation dose used.
- Thus the multiple exposure give rise to a different pattern as compared to single exposure.
- Biological effects?

# Combined external + Internal exposure

- Calvi et al, IJRB, 2019 (last Friday): External irradiation 6 Gy + i.p. injection of $3.7 \times 10^9$ Bq of $^{137}Cs$

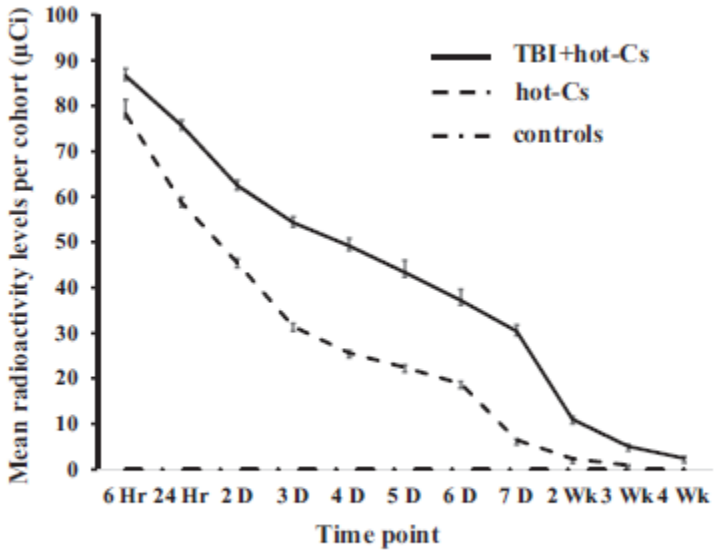



**Figure 1.** Measurements of radioactivity count over the first 30 days following 0 Gy + IP cesium, 6 Gy external TBI ± internal (IP) 100 μCi $^{137}Cs$.

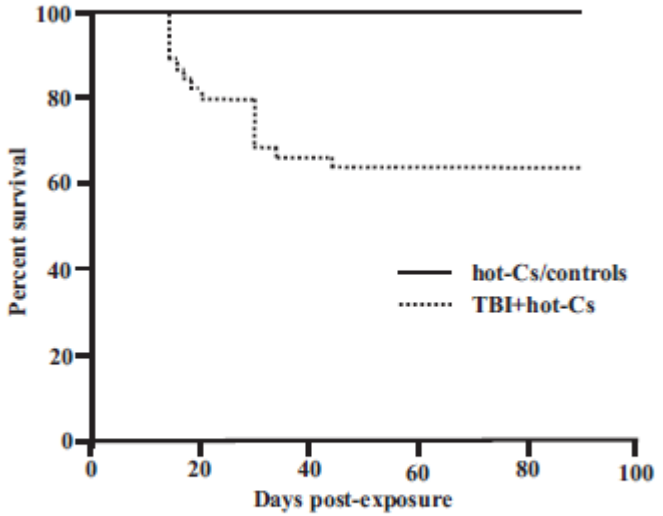



**Figure 2.** Kaplan–Meier survival curve of C57BL/6J mice exposed to sham irradiation + IP cesium (controls: $n = 23$), sham irradiation followed by 100 μCi $^{137}Cs$ (hot-Cs: $n = 25$), 6 Gy TBI followed by IP cesium (TBI; $n = 25$) or 6 Gy TBI followed by IP 100 μCi $^{137}Cs$ (TBI + hot-Cs; $n = 21$).

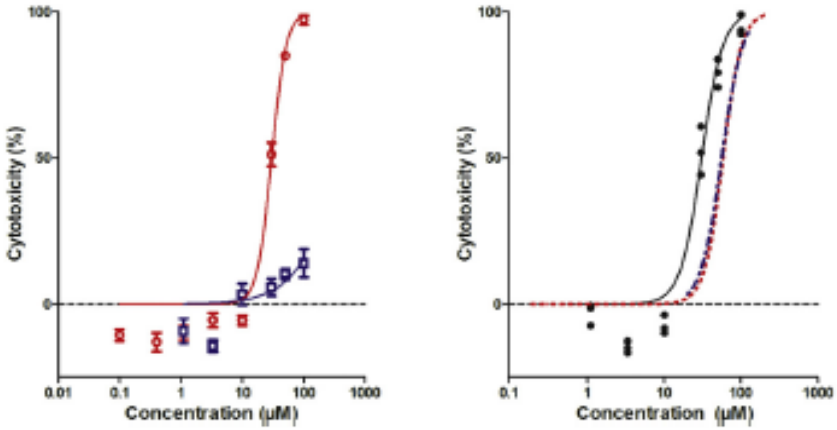
- Slowed excretion of $^{137}Cs$ resulting in increased dose due to internal exposure. Estimate of increase from 2.5 Gy up to 3.2 Gy.
- Increased death with combined exposure

# In true life …

- A complex exposure with both external exposure, internal contamination with a mix of radionuclides, but also with a mix of chemicals.
- Chemical toxicity studies clearly demonstrates the existence of supra additive effects

**Dieldrin**

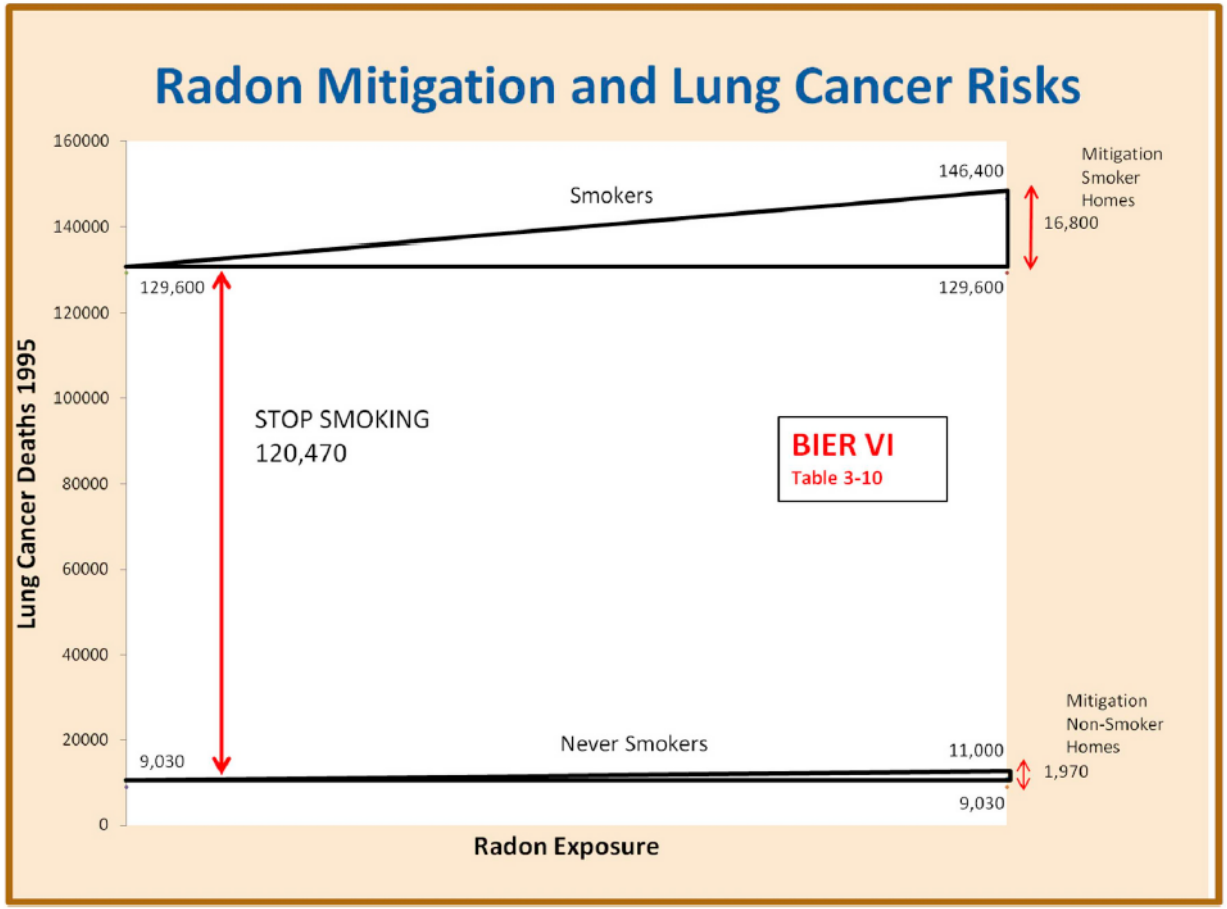
**DDT**




- What about the effects of a mix of chemicals and radionuclides? Very sparse data …

# Radon and cigarette smoke

- Radon, smoking and lung cancer: evidence of a combined effect of radon and cigarette smoke on lung cancer frequency (Catelinois, 2006, BEIR 1999).



# Thyroid cancer and nitrates in drinking water

- Well-known link between nitrate exposure and thyroid hypertrophy (Drozd, 2015).
- Increased incidence of thyroid cancers induced by $^{131}I$ in areas of high concentrations of nitrates in drinking water in Belarus

**Table 1. Mean thyroid dose from $^{131}I$, nitrate in groundwater, number of pediatric thyroid cancers, and incidence rate of pediatric thyroid cancer among Belarusians 0–18 years old at the time of the Chernobyl accident.**

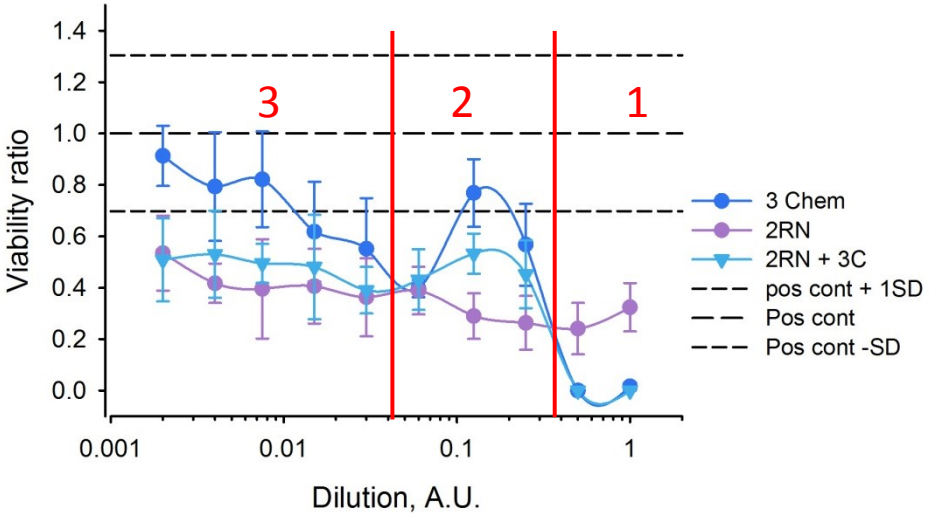
| Oblast | Mean $^{131}I$ thyroid dose[a] (mGy) | Nitrate in groundwater (mg/L) | Number of pediatric thyroid cancers | Incidence rate[b] (per 100,000 PY) |
|---|---|---|---|---|
| Minsk[c] | 26 | 130 | 114 | 1.20 |
| Gomel | 320 | 112 | 552 | 11.0 |
| | | | | |
| Grodno | 11 | 53 | 58 | 1.74 |
| Vitebsk | 3.5 | 77 | 19 | 0.48 |
| Belarus | 78 | - | 1,044 | 3.48 |

**Table 3. Relationship between childhood thyroid cancer incidence, radiation thyroid dose and nitrate in groundwater in Belarus.**

| Predictor | Deviance | Degrees of freedom | *P*-value |
|---|---|---|---|
| None[a] | 6.190 | 5 | |
| Dose | 2.539 | 4 | 0.029[b] |
| Nitrate | 4.761 | 4 | 0.301[b] |
| Dose + Nitrate | 1.355 | 3 | 0.002[b] |

# RN + chemicals: experimental

- In vitro model using MSC or HepG2 cell line and mixtures of chemicals (PCBs, Methyl-Hg and Thiaclopride) and RNs ($^{137}Cs$, $^{90}Sr$)
- 7 days exposure, MTT viability test




Concentration-dependent effect:

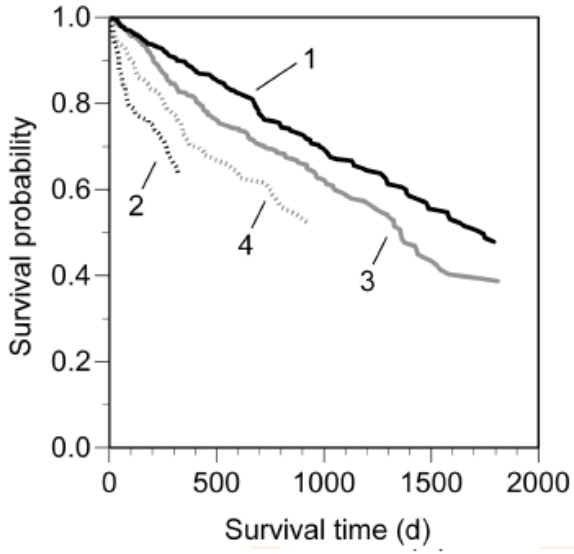
1. Dominant effect of chemicals
2. Interactions between chemicals and RNs ?
3. Dominant effect of RNs

# Effects of a mixture of RN?

- The extrapolation of results from chemical toxicology but also from the recent study of Calvi et al. (2019) to internal contamination with a mix of radionuclides +/- external exposure raise some concerns about the principle of dose additivity.
- Moreover, no consideration for other parameters:
  - Non linear effects of ionizing radiations at low doses
  - Cross fire effects?
  - Chemical effects of RN
- And what about ….
  - Combined exposure to chemicals and radionuclides ?
  - Psychosomatic effects ?

# And what about psychosomatic effects?

- Difficult to study (Bromet et al, 2002)
  - Study of nursing homes experiencing the earthquake (Nomura et al, 2016)
  - Decrease life expectancy in evacuated nursing homes
  - No direct link with the real exposure




1: Before earthquake, Nursing home group A
2: After earthquake, Nursing home group A
3: Before earthquake, Nursing home group B
4: After earthquake, Nursing home group B

- Hayano et al, 2014, 2015:
  - WBC of 2700 babies and young children
  - None with detectable $^{137}Cs$ activity
  - But decreased stress of the mothers…

# Conclusions

- Future experimental studies should take into account mixed exposures
  - Realistic mix of radionuclides
  - External exposure + internal contamination
  - Mixed radiological and chemical exposures
- These future studies should change our current vision of the radiation protection of populations …
- Especially in post-accidental situations with low dose exposures.
- How to cope with the psychosomatic effects in an experimental setting?

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# Many thanks to …

## N. Synhaeve, S. Musilli,

## K. Tack, F. Paquet

Whish to discuss a little bit more?

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