ASNR Autorité de sûreté nucléaire et de radioprotection

LESSONS LEARNED FROM EPIDEMIOLOGY ON HEALTH RISKS IN THE FIELD OF LOW DOSES

DOMINIQUE LAURIER, ASNR, FRANCE

“Build Back Better, Together”

2026 Fukushima Medical University International Symposium on the Fukushima Health Management Survey

Fukushima City, Thursday, March 12, 2026

FUKUSHIMA MEDICAL UNIVERSITY

Content

- **Radiation Epidemiology**
- Cancer
- Non-cancer diseases
- Conclusions

Effects of exposure to ionising radiation

Deterministic effects (tissue reactions)

- seriousness is function of the dose
- high doses (> 500 mGy)
- early and specific effects
- threshold model

(rash, burns, modification of blood formula…)

Medical Case Reports/Series

Stochastic effects

- frequency is function of the dose
- low and moderate doses
- late and non-specific effects
- no threshold model

(cancers, hereditary effects…)

Epidemiology

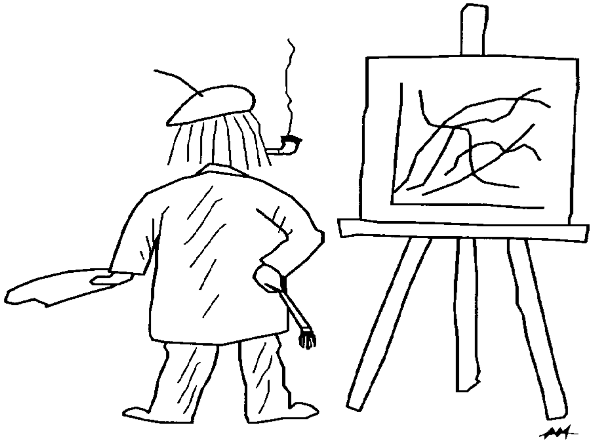
Objectives of epidemiology in the field of ionizing radiation

To identify the effects induced by radiation

To characterize the time sequence between exposure and effect

To quantify the dose-risk relationship

To determine the modifying factors of the relationship



"Which line do you like best ?"

Bands of radiation dose

Terminology for dose bands	*Range of absorbed dose for low-LET radiation*[a, b]	*Scenarios*
High	Greater than about 1 Gy	Typical dose (whole or partial body) to individuals after severe radiation accidents or from radiotherapy
Moderate	About 100 mGy to about 1 Gy	Doses to about 100,000 of the recovery operation workers after the Chernobyl accident (annex D [U14])
Low	About 10 to about 100 mGy[c]	Dose to an individual from multiple whole-body computerized tomography (CT) scans
Very low	Less than about 10 mGy	Dose to an individual dose from conventional radiology (i.e. without CT or fluoroscopy)

Bands (approximate ranges) of total absorbed dose (to the whole body or to a specific organ or tissue of an individual) received in addition to the total from normal background exposure to natural sources of radiation. The bands of radiation dose do not account for the rate at which the dose is delivered.

[UNSCEAR 2012, Annex A, p23, tab 1]

History of epidemiological studies of ionizing radiation

1950	Radiologists (1900-30)
1950	Radium dial painters (1910-30)
1950	Medical exposures for non malignant illnesses, diagnostic exposures (1920-40)
1950	Hiroshima-Nagasaki A-Bomb survivors “Life Span Study (LSS)” (1945)
1960	Miners (uranium) (1940-90)
1970	Population exposed to fallout from atmospheric nuclear weapons (1950-60)
1970	Nuclear workers (1950-)
1980	Population exposed to natural background radiation
1990	Population exposed to releases from the Chernobyl accident (1986)
2000	Children with CT-scan examination (1985)
2011	Population exposed to releases from the Fukushima accident (2011)

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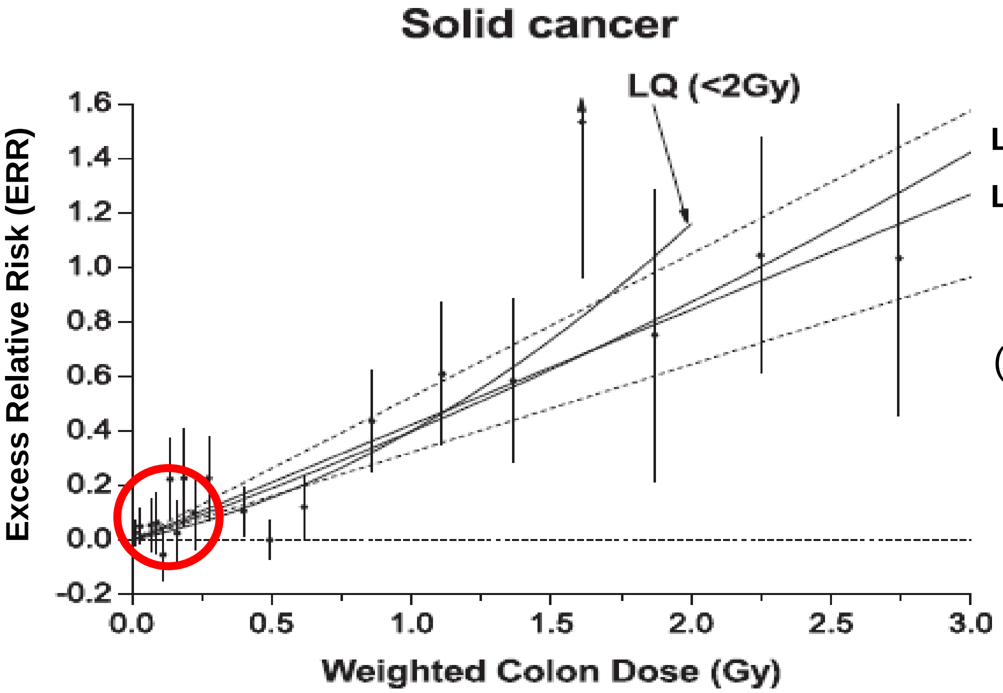
Study of Hiroshima and Nagasaki A-bomb survivors

The Life Span Cohort Study (LSS)

- 120 000 individuals alive in 1950
- 86 611 individuals with reconstructed dose
- External irradiation (gamma + neutron) at high dose rate
- 80% of doses lower than 100 mGy
- both sexes - all ages (and *in utero*)
- mortality follow-up from 1950 to 2009
- incidence follow-up from 1958 to 2009

→ **radiation induced cancers**
estimates of the dose-risk relationship
latency between exposure and increased risk
effect of age

Life span study - dose-risk relationship for solid cancers



Linear-Quadratic (LQ)

Linear

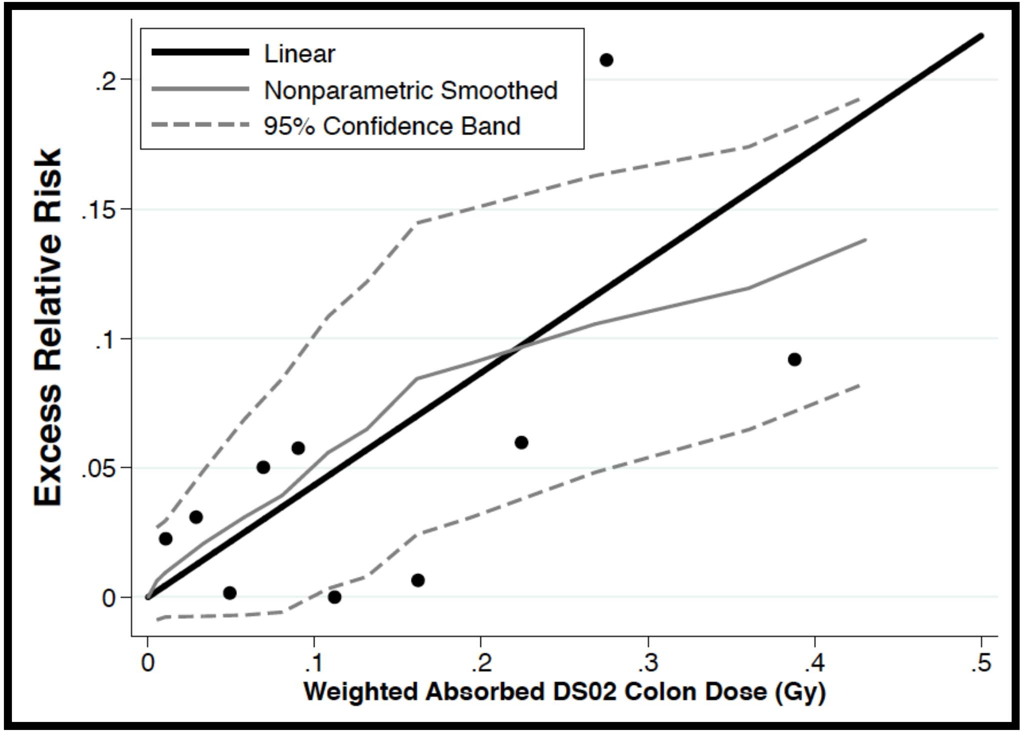
Linear ERR/Gy = 0.47

(95% Confidence Interval: 0.38 ; 0.56)

Mortality
Follow-up 1950-2003

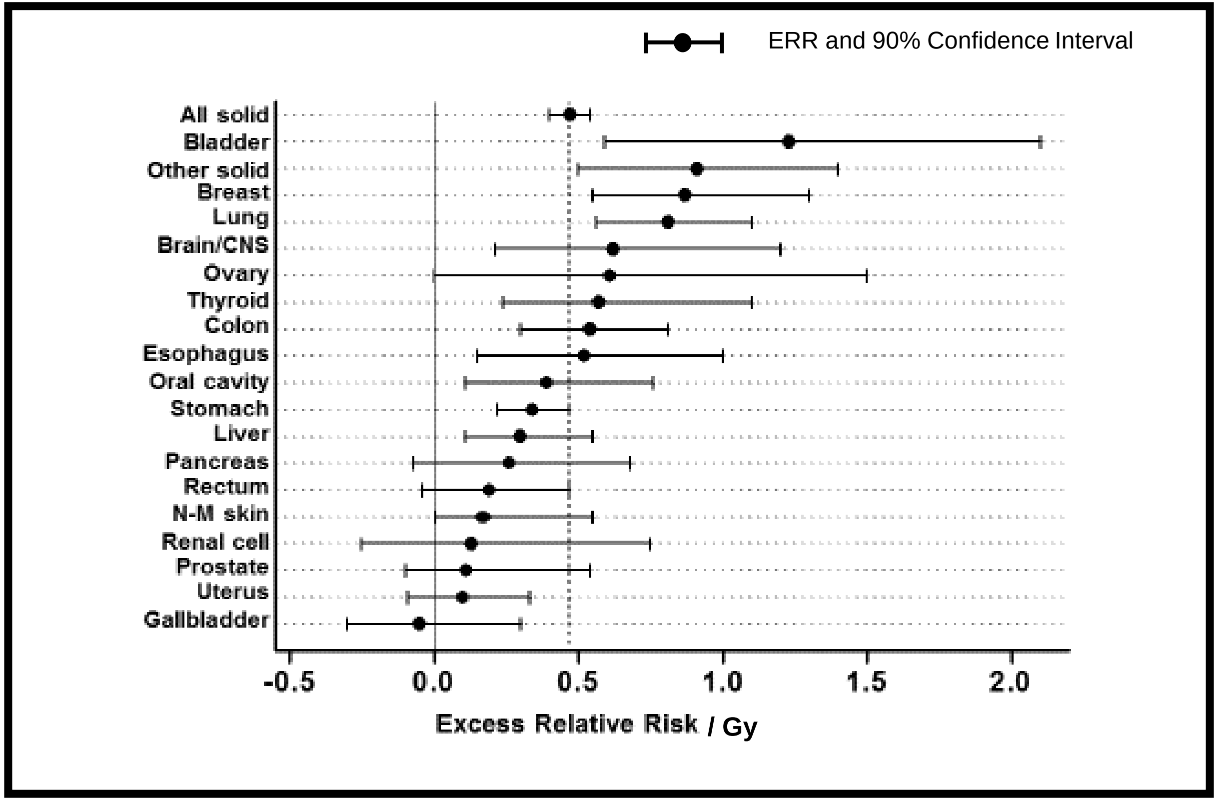
[Ozasa et al. Rad Res 2012]

Life span study - dose-risk relationship for solid cancers



[NCRP Commentary No. 27, 2018]

Excess relative risk of specific solid cancers incidence in A-bomb survivors

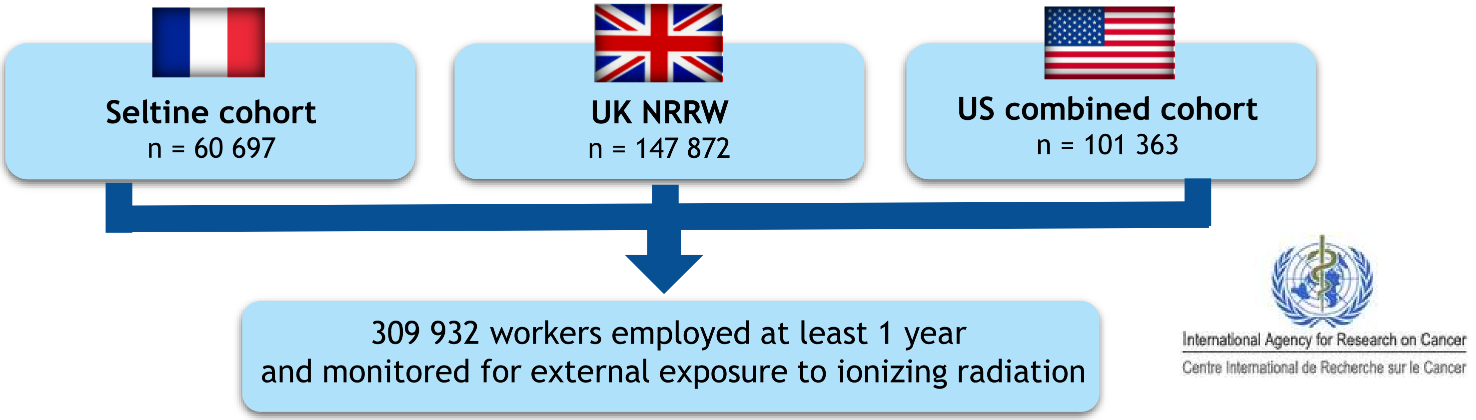


Incidence
Follow-up 1958-1998
[Preston et al. Rad Res 2007]

Life Span Study – Summary of results

- Still new results **70 years after bombings**
- **Demonstrated radiation induced risk** for many specific cancer sites: leukemia, breast, lung, thyroid, colon cancer…
- The risk of solid cancer et leukemia **increases with the dose**
- Excess relative risk per unit dose **decreases with age at exposure** for leukemia and most solid cancers (window of sensitivity during puberty for female breast cancer)
- **Latency** of a few years (leukemia) to several decades (solid cancer)
- Dose-risk relationship for solid cancer **still significant after exclusion of highly exposed individuals**
- **No element to support the existence of a dose threshold** for cancer
- Indications of **variation of the dose-risk relationship** between incidence and mortality, with sex, and with cancer type

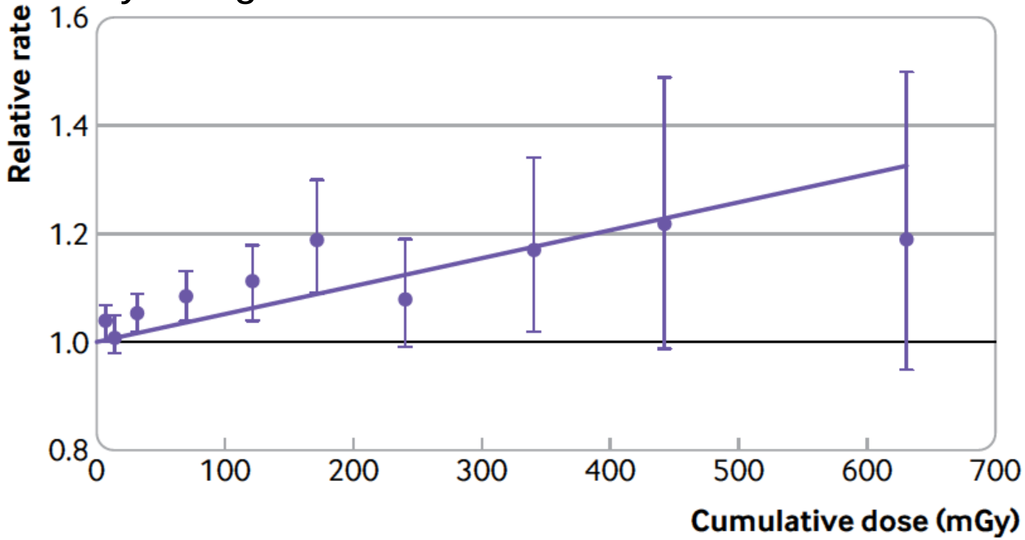
INWORKS - Study population



Mean duration of employment (y)	15
Mean age at last observation (y)	66
Mean duration of follow-up (y)	34
Total person years (million)	10.7
Mean cumulative whole-body dose (Hp10, mSv, exposed)	20
Number of deaths	103 553
solid cancers	28 089
leukaemia (excluding chronic lymphatic leukaemia)	771

INWORKS - Dose-risk relationship for solid cancers

Relative rate of mortality due to solid cancers by categories of cumulative colon dose



Bars indicate 90% confidence intervals, and purple line depicts fitted linear model for change in excess relative rate of solid cancer mortality with dose; 10-year lag; * Strata: country, age, sex, birth cohort, socioeconomic status, duration employed, neutron monitoring status

Dose-risk relationship for solid cancers

ERR/Gy = 0.52 (90%CI: 0.27; 0.77)

- Relationship still significant when dose range is restricted to < 100 mGy
- Modification by period of hire
- Indication of downward curvature of the dose-risk relationship

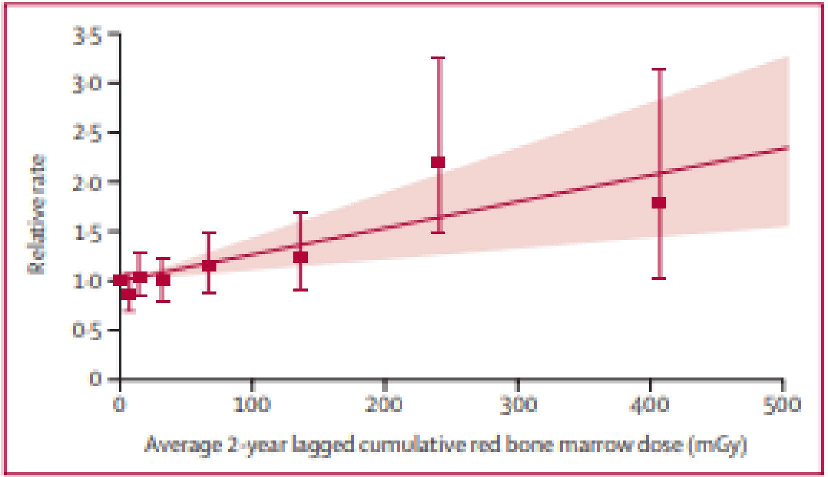
[Richardson et al. BMJ 2023]
https://www.bmj.com/content/382/bmj-2022-074520

INWORKS - Dose-risk relationship for leukemia

[Leuraud et al. Lancet Haematol 2024]

https://doi.org/10.1016/S2352-3026(24)00240-0

Relative rate of mortality due to leukemia (excluding chronic lymphocytic leukemia) by categories of cumulative red bone marrow dose



N=771 - 2-year lagged dose - vertical bars indicate 90% CIs - solid line is the fitted linear excess relative rate of leukemia with dose.
Model stratified on country, sex, birth cohort, and attained age

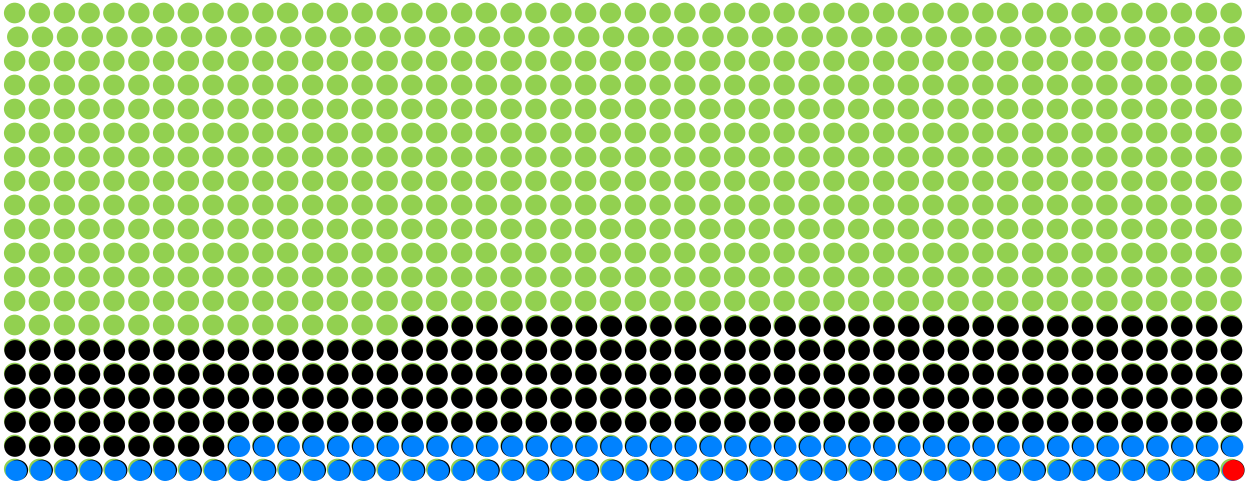
Dose-risk relationship for leukemia-CLL

ERR/Gy = [2·68, 90%CI 1·13 to 4·55]

- Well described by a linear model
- Not modified by neutron exposure, internal contamination status, or period of hire
- Still significant when dose range restricted to 0–300 mGy

INWORKS: Order of magnitude of attributable risk

Among 1000 workers



334 deaths

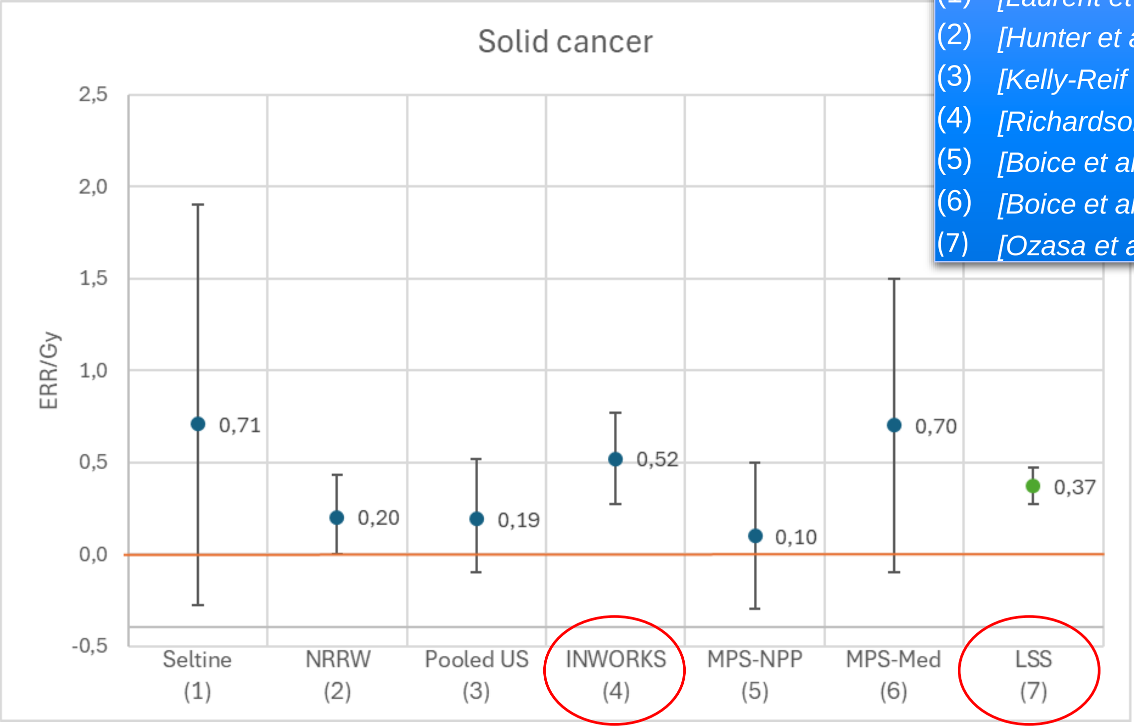
including 93 from solid cancers or leukaemia (excl. CLL)

including 1 attribuable to ionizing radiation exposure

(based on the INWORKS cohort: 309,932 workers followed for 35 years - age at end of follow-up 66 years)

Comparison of results of some recent studies: solid cancers

Excess relative rates of death per Gy of cumulative dose and 95% confidence intervals, estimated from a linear model



(1)	*[Laurent et al., Cancers 2023]*	males only
(2)	*[Hunter et al., Radiat Res 2023]*	incidence, dose in Sv
(3)	*[Kelly-Reif et al., Int J Epidemiol 2023]*	90%CI, dose in Sv
(4)	*[Richardson et al., BMJ 2023]*	90%CI
(5)	*[Boice et al., IJRB 2022]*	-
(6)	*[Boice et al., IJRB 2023]*	-
(7)	*[Ozasa et al., Radiat Res 2012]*	age at exposure ≥ 20 y

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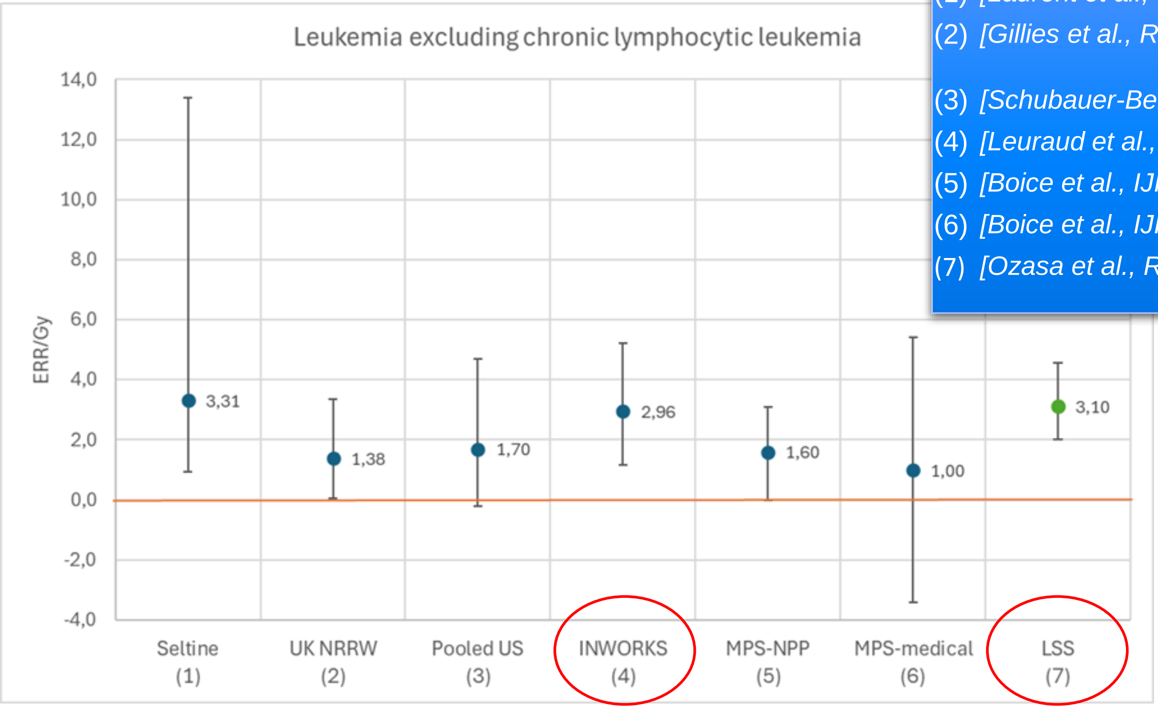
Comparison of results of some recent studies: leukaemia

Excess relative rates of death per Gy of cumulative dose and 95% confidence intervals, estimated from a linear model



(1)	*[Laurent et al., Cancers 2023]*	males only
(2)	*[Gillies et al., Radiat Res 2019]*	incidence, males only, 90%CI, dose in Sv
(3)	*[Schubauer-Berigan et al., Radiat Res 2015]*	dose in Sv
(4)	*[Leuraud et al., Lancet Haematol 2015]*	90%CI
(5)	*[Boice et al., IJRB 2022]*	-
(6)	*[Boice et al., IJRB 2023]*	-
(7)	*[Ozasa et al., Radiat Res 2012]*	age at exposure ≥ 20 y, all leukemia

Pooled analysis of cancer risk after childhood CT-scan

EPI-CT

SEVENTH FRAMEWORK PROGRAMME

Thierry-Chef I et al. Radiat Res 2021
Bernier et al Int J Epidemiol 2019
Bosch de Basea M et al. J Radiol Prot 2015

Record based retrospective cohort study

- Children and young adults who underwent at least 1 CT scan before age 22
- 9 European countries
- Nearly 1 million individuals

Common core protocol

Particular attention to

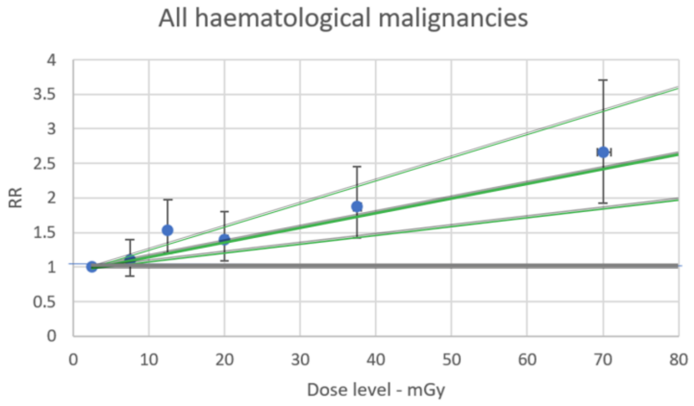
- Identification and assessment of possible biases/uncertainty
- Individual dose (and uncertainty) reconstruction

Pooled analysis of hematological malignancy risk after childhood CT-scan

- 876,771 individuals followed up at least 2 years from 1st CT
- Median follow-up 7.8 years – 6.9 M Person-Years
- 790 cases of haematological malignancies
- 1,331,896 CT-scans (mean 1.5 per individual)
- Mean bone marrow dose: 15.5 mGy (20 among cases)

ERR per 100 mGy: 1.96 (95% CI: 1.10-3.12)

(2-year lagged cumulated dose to Red Bone Marrow)



Attributable risk: **Per 10 000 people** receiving a single CT examination today (dose of 8 mGy), about **1.4 radiation-induced case** of hematological malignancy is expected 2–12 years after the CT examination

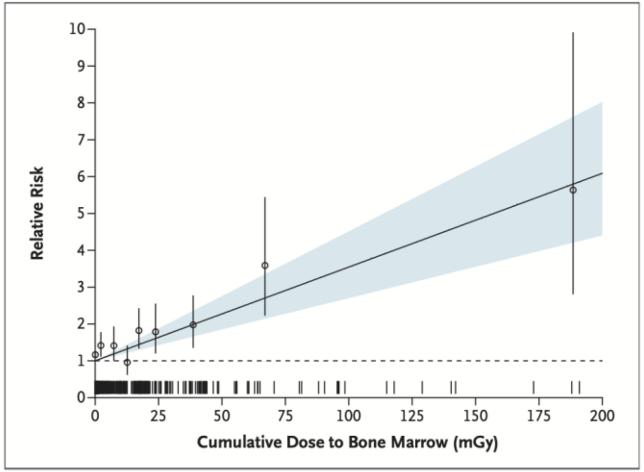
[Bosch de Basea Gomez et al. Nature Medicine 2023]
https://www.nature.com/articles/s41591-023-02620-0

Analysis of the risk of hematological malignancy after childhood CT-scan

- Retrospective cohort: Ontario, Canada, and 6 U.S. Systems – 3,724,623 children
- Children followed from birth until age 21
- Mean duration of follow-up 10.1 years - 35,715,325 Person-Years
- 2961 cases of hematologic cancers
- Mean cumulated RBM dose 14.0 mGy (24.5 among cases)
- Detailed information on the indication for all exams
- Identification of Down syndromes

ERR per 100 mGy: 2.54 (95% CI: 1.70-3.51)

(6-month lagged cumulated dose to Red Bone Marrow)



[Smith-Bindman et al. N Engl J Med. 2025]
https://www.nejm.org/doi/10.1056/NEJMoa2502098

Cancer risks: results at low dose / dose rate

Solid cancers – INWORKS — [Richardson et al. BMJ 2015; Richardson et al. BMJ 2023]

Pooled analysis - 3 cohorts of workers - n > 308000

Solid cancers – ICRP TG91 — [Shore et al. IJRB 2017]

Meta-analysis – 22 Low Dose Rate studies – n > 900000

Solid cancers – NCI Monograph — [Hauptmann et al. JNCI Monog 2020]

Meta-analysis – 22 studies – Mean dose < 100 mSv

Thyroid cancer – PIRATES — [Lubin et al. JCEM 2017]

Pooled analysis - 9 cohorts of children - n > 107000 - low-dose (< 200 mGy)

Leukemia (excluding CLL) — [Little et al. Lancet Haematol 2018]

Pooled analysis - 9 cohorts of children - n = 262000 - low-dose (< 100 mSv)

Brain tumors and hematological malignancies – Epi-CT — [Hauptmann et al. Lancet Oncol 2023; Bosch de Basea et al. Nature Med 2023]

Pooled analysis - 9 cohorts of children - n > 658000 – CT scans

Hematological malignancies – RIC — [Smith-Bindman et al. N Engl J Med. 2025]

Pooled analysis USA-Canada cohorts of children - n > 3.7M – CT scans

➡ **Significant association when excluding doses above 100 mGy**

Interpretation of cancer risks at low dose and dose rate

- Clear **improvement in knowledge in the last 2 decades** about cancer risks associated with low doses
- There is **some evidence of some excess risk of some cancers following low-level exposure to radiation**
- There is **some evidence of an increased risk of cancer with repeated or protracted dose**
- The epidemiological evidence for an overall material deviation from a **linear no-threshold dose-risk relationship at low doses or low dose-rates** is not persuasive
- **Low doses** are associated with **low excess risks.** If a dose threshold exists, it cannot be more than a few tens of mGy

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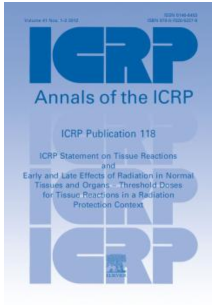
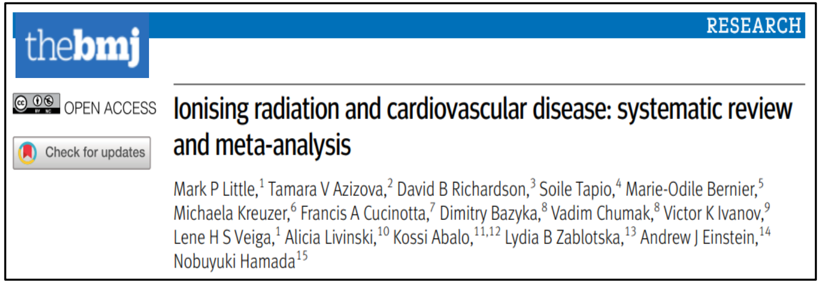
Risk of diseases of the circulatory system



Classification of cardiovascular diseases as a tissue reaction

with a dose threshold at 0.5 Gy by ICRP in 2012



thebmj RESEARCH

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Check for updates

Ionising radiation and cardiovascular disease: systematic review and meta-analysis

Mark P Little,[1] Tamara V Azizova,[2] David B Richardson,[3] Soile Tapio,[4] Marie-Odile Bernier,[5] Michaela Kreuzer,[6] Francis A Cucinotta,[7] Dimitry Bazyka,[8] Vadim Chumak,[8] Victor K Ivanov,[9] Lene H S Veiga,[1] Alicia Livinski,[10] Kossi Abalo,[11,12] Lydia B Zablotska,[13] Andrew J Einstein,[14] Nobuyuki Hamada[15]

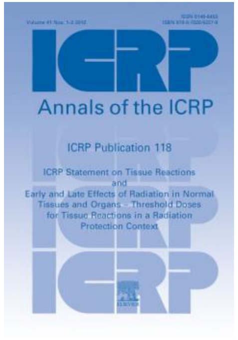
[Little BMJ 2023]

- Systematic review and meta-analysis
- 93 relevant studies
- All DCS + major subtypes (ischemic heart diseases, cerebrovascular diseases …)

"Evidence for cardiovascular disease will soon need to be added to the existing list of radiation induced health risks. The consequences will be extensive: concepts and standards in radiological protection will need to be revisited by national and international professional and radiation protection organisations"

[Auvinen BMJ 2023]

Risk of cataract / lens opacity



Classification of cataracts as a tissue reaction

with a dose threshold at 0.5 Gy by ICRP in 2012

Several recent syntheses

[Hamada BJR 2020; Ainsbury Environ Int 2021; Little IJRB 2022]

Review of epidemiological results (12 studies since 1999)

- Accumulating evidence of excess risks at lower dose and low dose rate in various cohorts (Chernobyl liquidators, US Radiologic Technologists and Russian Mayak nuclear workers)
- Radiation-associated excess risk of both posterior subcapsular and cortical cataract
- Significant excess risk under 100 mGy in the USRT cohort

➡ **Results ”bordering on inconsistency” with the current classification** [Little IJRB 2022]

Risk of neurocognitive diseases

2 meta-analyses [Lopes Brain Sc 2022; Srivastava Rad Res 2023]

- 21 studies - Chernobyl cleanup workers, nuclear workers, miners, aircrew, medical staff, test veterans, patients

➡ **Significant positive relative risk (>100 mSv) for dementia and Parkinson's disease**

Recent literature overview [Hamada Mut Res 2025]

"Evidence for neurodegenerative diseases (Parkinson's disease and dementia) after occupational adulthood exposure is beginning to emerge »

- Very recent results, heterogeneity of endpoints, small number of studies, variation in results…

➡ **Caution needed in interpreting the results**

Hereditary effects

- Genetic effects observed at moderate to high doses among animals
- Risk of genetic damage from radiation introduced in ICRP recommendations (*ICRP 1956*), considered as stochastic effects (*ICRP 1977*)

Review of more than 130 epidemiological studies published over the last 30 years

INTERNATIONAL JOURNAL OF RADIATION BIOLOGY
https://doi.org/10.1080/09553002.2024.2306328
Taylor & Francis
Taylor & Francis Group
REVIEW
OPEN ACCESS Check for updates

A systematic review of human evidence for the intergenerational effects of exposure to ionizing radiation

Jade Stephens[a], Alexander J. Moorhouse[a,b,c*], Kai Craenen[a], Ewald Schroeder[a], Fotios Drenos[a], and Rhona Anderson[a]

INTERNATIONAL JOURNAL OF RADIATION BIOLOGY
https://doi.org/10.1080/09553002.2024.2309917
Taylor & Francis
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REVIEW
OPEN ACCESS Check for updates

Intergenerational effects of ionizing radiation: review of recent studies from human data (2018–2021)

A. Amrenova[a], C. Baudin[a], E. Ostroumova[b], J. Stephens[c], R. Anderson[c], and D. Laurier[a]

- **Large heterogeneity** of endpoints, and **limitations** of epidemiological studies
- **No coherent evidence** of effects in the offspring of exposed human populations
- **“If adverse health effects do arise in children of exposed parents, then these effects are small and difficult to reproducibly measure”**

Nuclear disasters and health

Epidemiological lessons from the Chernobyl and Fukushima accidents

- **Consequences of inadequate medical support during evacuation** of hospitals and nursing care facilities
- Among evacuees, increase in the frequency of **metabolic disorders** (hypertension, obesity, diabetes, dyslipidaemia) attributed to a lack of social support and changes at the societal and community level, rather than individual factors such as the perception of risk associated with radiation exposure
- **Deterioration in mental health**: numerous psychological effects such as increased incidence of post-traumatic stress disorder, anxiety and depression have been reported among emergency workers, pregnant women, but also in the impacted population. They are attributed to changes in the living environment and the social and economic consequences of the accident, without any direct link to exposure to radioactive fallout
- People who have been relocated to a new place of residence may be victims of social rejection by local populations. This phenomenon of **stigmatisation** can cause psychological distress among evacuated and relocated populations

Non-cancer effects – summary of results

- Increasing number of epidemiological results on non-cancer long-term health effects in the last decades
- Increasing evidence of dose-risk relationships in the moderate to low dose range, especially for **lens opacities** and **diseases of the circulatory system**. Emerging results for **neurocognitive effects**
- Large **heterogeneity of results**, lack of knowledge on potential biological mechanisms
- **Non radiation induced effects** of a nuclear accident (**mental heath**, metabolic disorders…)

➡ Several expert groups currently reviewing the scientific literature, and assessing the potential impact on the system of radiological protection (UNSCEAR, ICRP)

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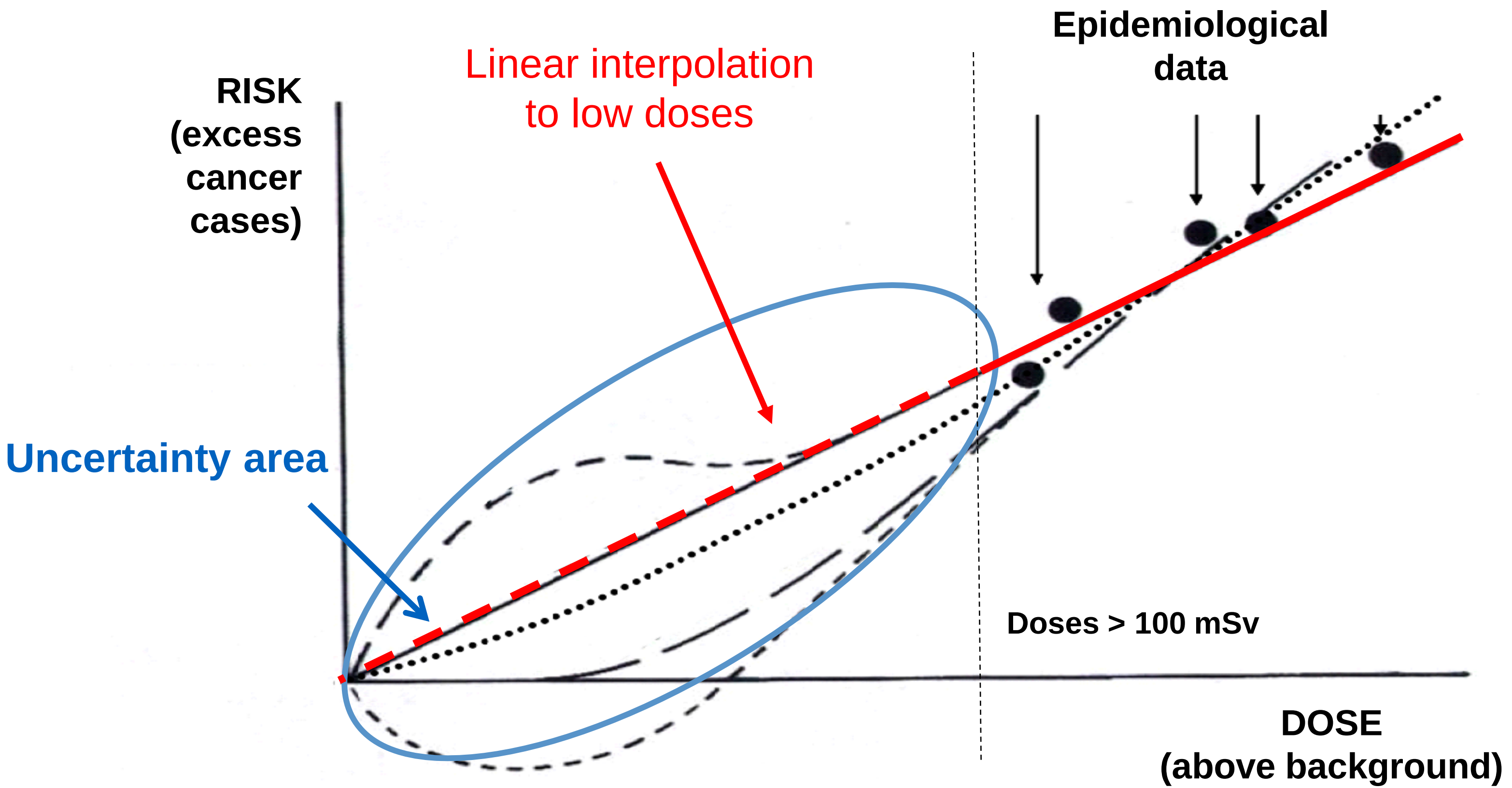
Radiation epidemiology at low dose and dose rate

- Low dose studies are **difficult** to design, conduct, and reliably interpret
- Observational studies (design **limits, confounding factors, potential biases, variation of baseline rates**)
- Still **lack of knowledge** and **uncertainties**, especially for very low doses (<10 mSv)

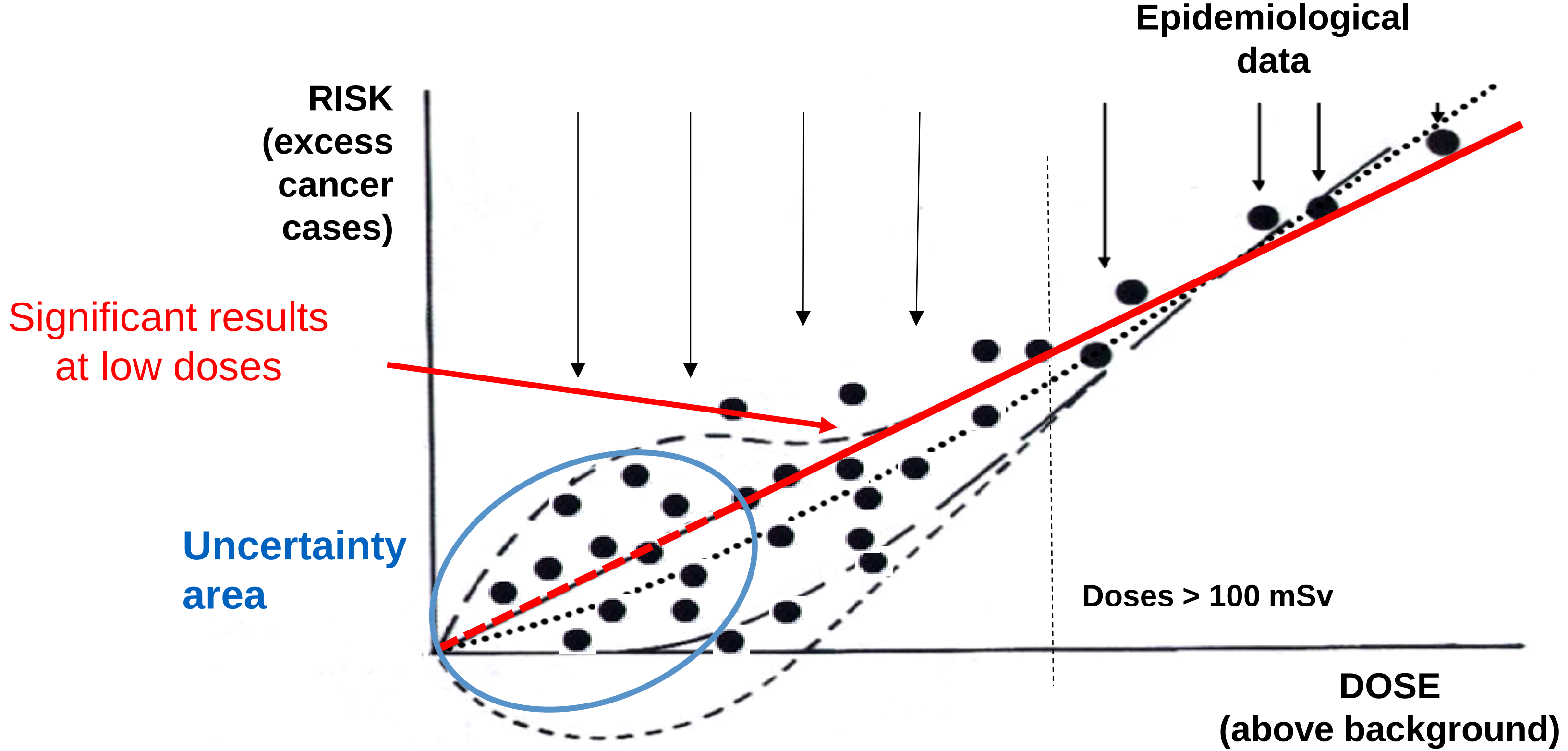
- **Need to take into account all available data**

- **New results – new questions !**

Dose-risk relationship for cancer: 20 years ago



Dose-risk relationship for cancer: today

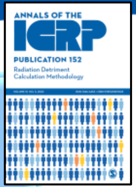


Radiation epidemiology: support for radiological protection

- **Shape of the dose-risk relationship at low doses and dose rates** (model for specific cancer sites, LNT, DDREF) - At present, the standard (LNT) risk model is the most parsimonious description of the available scientific evidence
- **Modifying effects of the dose-risk relationship** (sex, age at exposure, genetic specificity…)
- **Differences between populations** (baseline rates, multiplicative or additive transfer, specific exposure situations)
- **Non-cancer effects at low doses** (diseases of the circulatory system, cataracts, cognitive effects, effects among offspring)

ICRP Committee 1 Task groups

TG 102 – Detriment Calculation



TG 91 – Dose and dose rate effects

TG 111 – Individual response

TG 115 – Risk and dose of astronauts

TG 119 – Circulatory diseases

Radiation related risks for humans

TG 121 – Risks for next generations

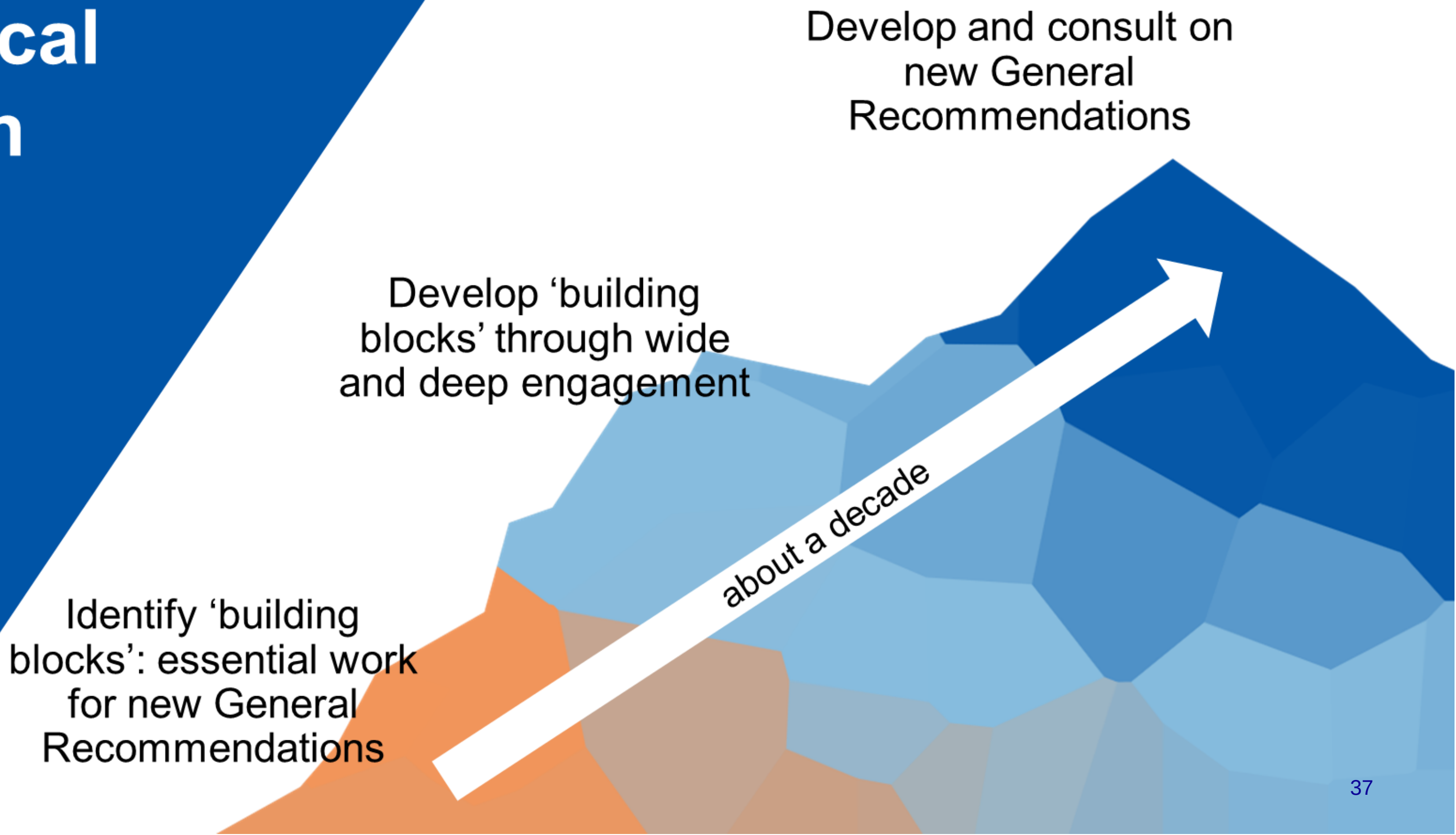
TG 122 – Update of cancer detriment

TG 123 – Effects classification

TG 128 – Stratification of RP

TG 118 – RBE, Q, WR

Review & Refinement of the System of Radiological Protection



Preparedness for post-accidental epidemiological surveillance

To build upon lessons learned from experiences of populations affected by Chernobyl, Fukushima and other radiation accidents

To develop recommendations for medical and health surveillance of populations affected by previous and future radiation accidents

SHAMISEN

Nuclear Emergency Situations Improvement of Medical and Health Surveillance

Contents lists available at ScienceDirect

Environment International

2021 146; 106278

journal homepage: www.elsevier.com/locate/envint

ELSEVIER

The SHAMISEN Recommendations on preparedness and health surveillance of populations affected by a radiation accident

Liudmila Liutsko [a,b,c,*], Deborah Oughton [d], Adelaida Sarukhan [a], Elisabeth Cardis [a,b,c], on behalf of the SHAMISEN Consortium [1]

Preparedness for post-accidental epidemiological surveillance

FHMS

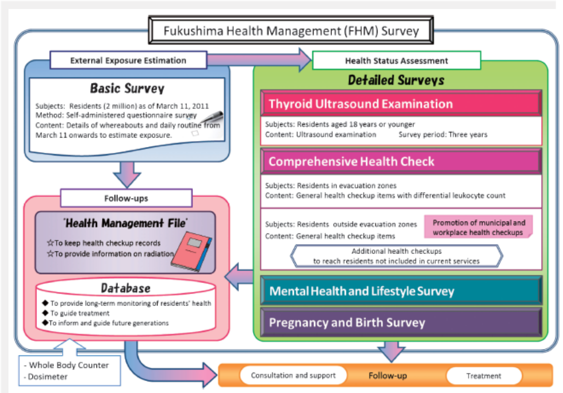
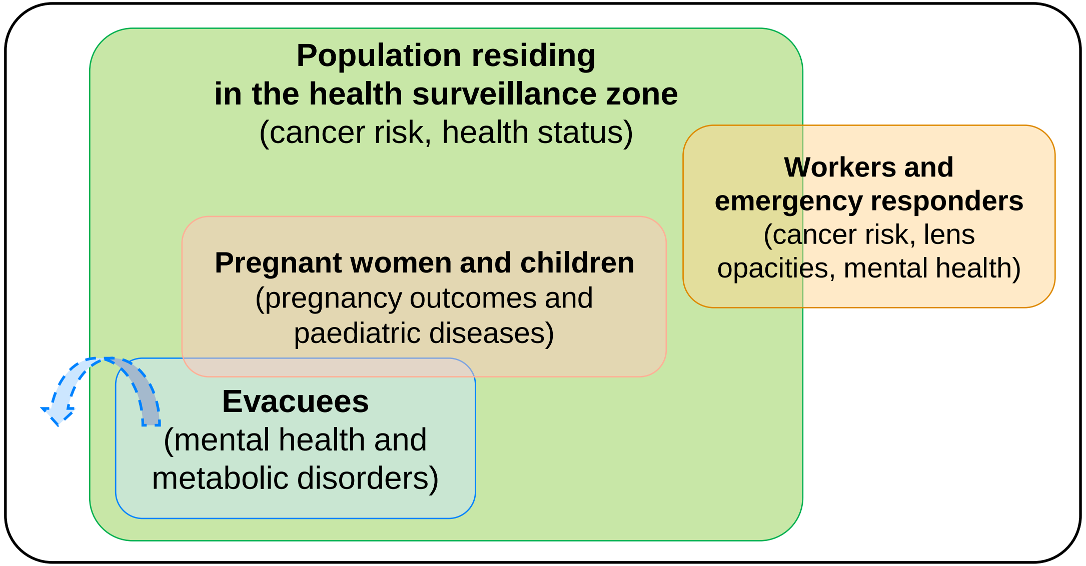


Figure 1. Framework of the Fukushima Health Management Survey

Proposed scheme for epidemiological surveillance following a major nuclear accident in France *(preliminary)*



THANK YOU FOR YOUR ATTENTION

Thanks to Enora Cléro, Klervi Leuraud, David Richardson and Richard Wakeford