# Cancer Risk Modelling and Radiological Protection

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# Stochastic Health Effects

- It is established beyond reasonable doubt that moderate and high doses of radiation (>100 mGy), delivered at a high dose-rate, increase the risk of *stochastic health effects – cancer and hereditary disease*.
- Cancer in the exposed individual is the main stochastic effect, and therefore of primary concern to radiological protection.

# Cancer Risk Models

- Statistical models describing how the radiation-related risk of cancer varies with the received dose of radiation have been developed empirically from the findings of epidemiological studies (although guided by radiobiological understanding).
- BEIR VII, UNSCEAR and ICRP have developed risk models for around a dozen types of cancer in the past few years.

# Cancer Risk Models

Sophisticated cancer risk models take into account not only the dose of radiation, but also a number of factors that modify the risk of a particular type of cancer, such as

- The rate at which the dose is delivered
- Sex
- Age-at-exposure
- Time-since-exposure
- Type of radiation (e.g. γ-ray, α-particle)
- Interaction with tobacco smoke

# Atomic Bomb Survivors

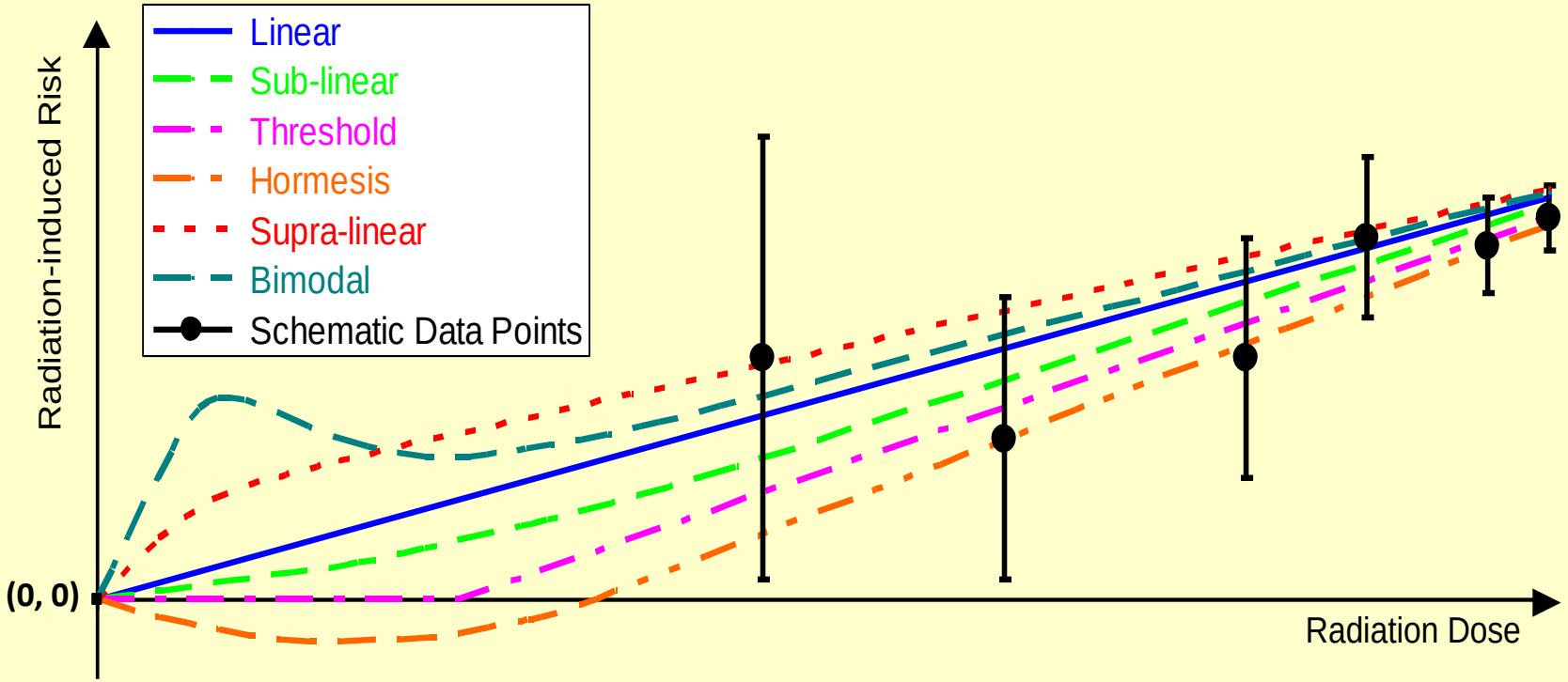
- The experience of the Japanese survivors of the atomic bombings of Hiroshima and Nagasaki is the principal source of epidemiological information for cancer risk models, but supported by many other epidemiological studies (e.g. of those inhaling radon and its decay products).
- Much of the information on cancer risk comes from individuals receiving doses >100 mGy at a high dose-rate.

# Low Doses and Dose-rates

- Radiological protection is primarily concerned with low doses (<100 mGy) and low dose-rates (<5 mGy/h).
- Cancer risk models are used to predict the excess risk at low doses or low dose-rates.
- The small predicted risk at low doses/dose-rates is difficult to detect against variations in background risk factors (e.g. smoking).

# Dose-response Curves

Some possible dose-response curves describing the excess risk of stochastic health effects at low doses of radiation



# Conventional Approach

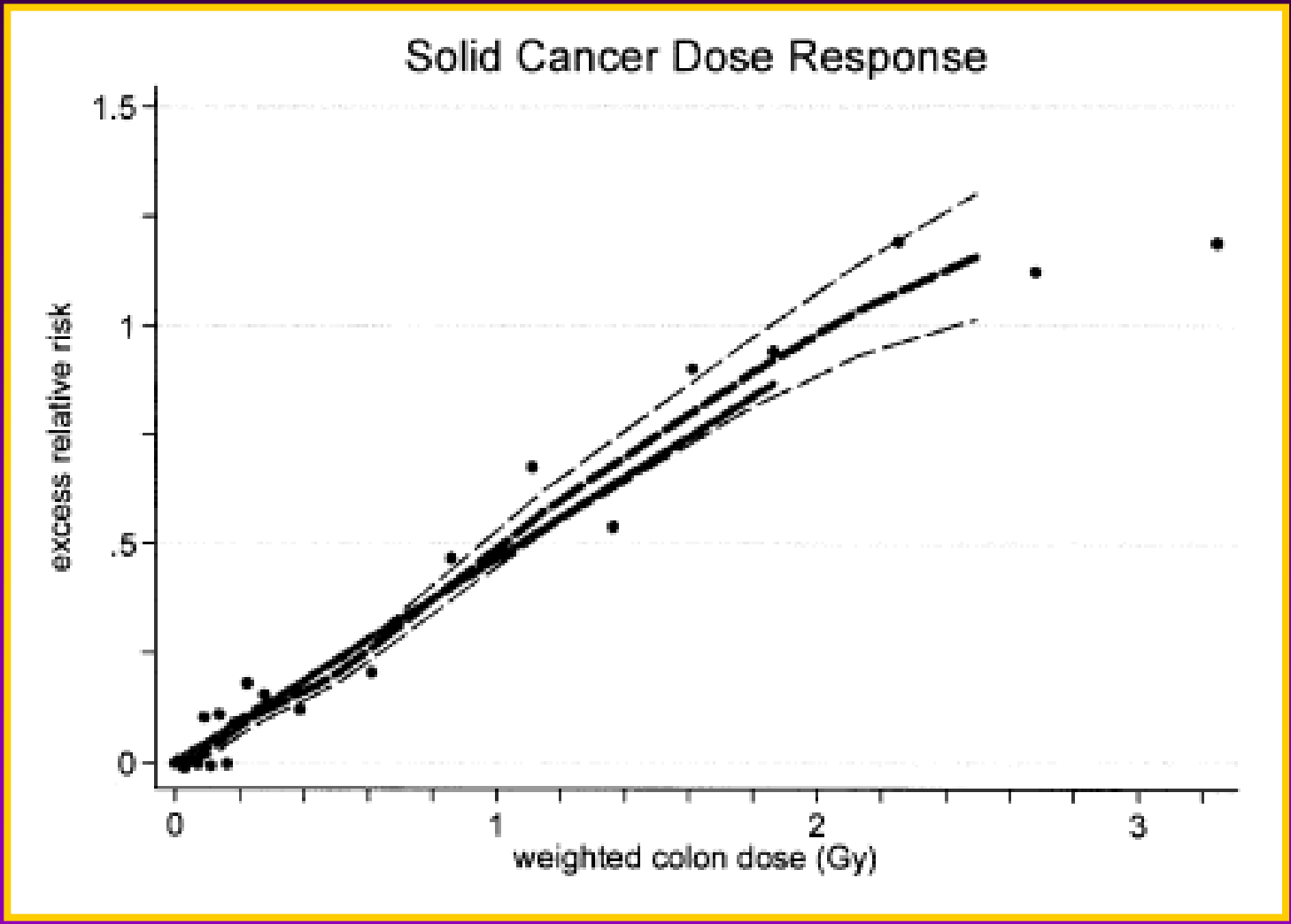
For low doses (<100 mGy) **or** low dose-rates (<5 mGy/h) the excess risk of cancer is taken to be *directly proportional* to the dose received with *no threshold dose* below which there is an absence of risk – the *linear no-threshold (LNT) dose-response relationship*.

# LNT Cancer Risk Model

- Inferred overall average lifetime risk of developing a serious cancer is ~5% per Sv.
- The LNT model is simple to apply in practice, but has been criticised as either *under*- or *over*-estimating cancer risk.
- However, there is evidence suggesting that a small excess risk at low doses/dose-rates does exist and that it is at about the level predicted by the LNT model.

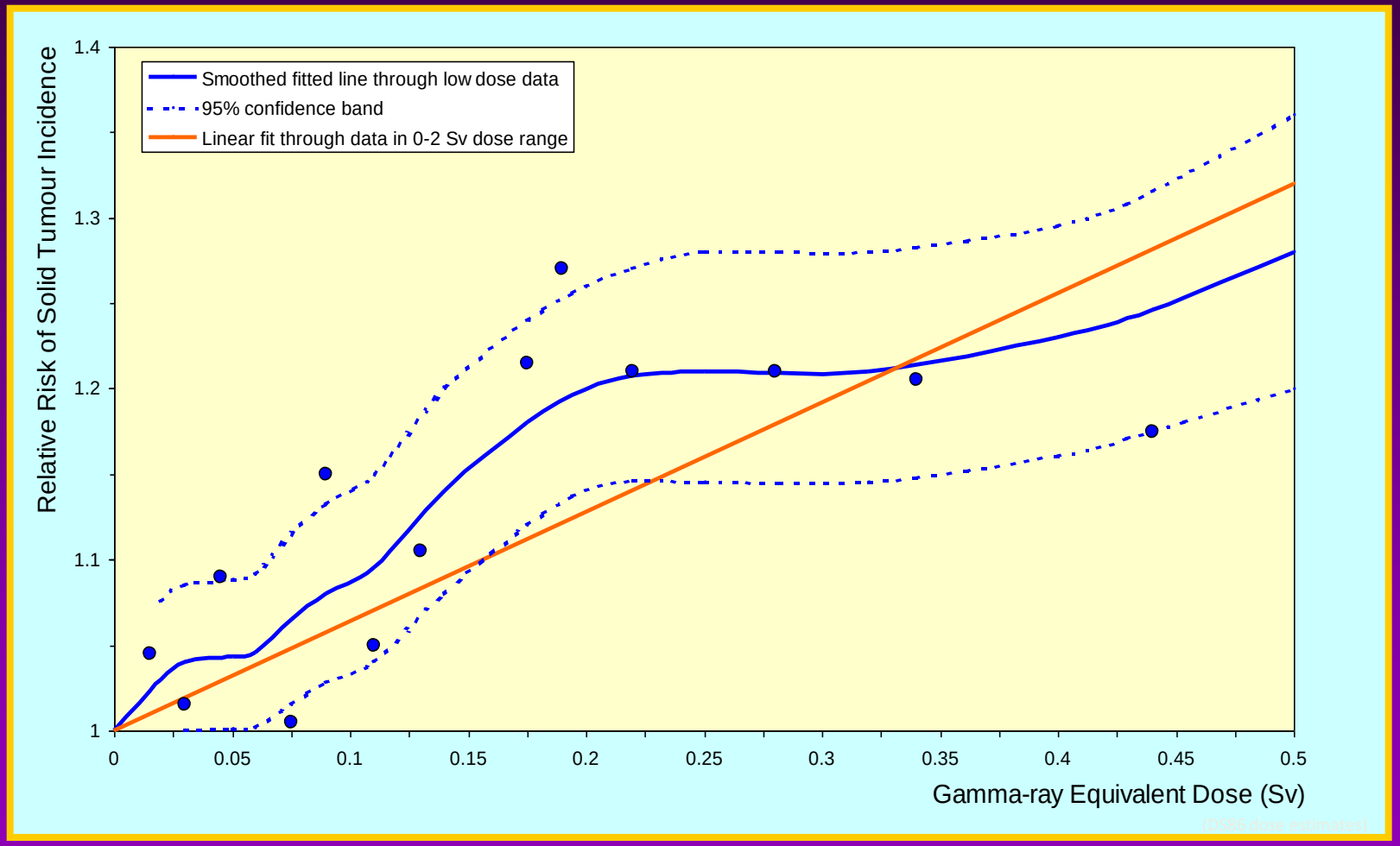
# Solid Cancer Incidence among Japanese Atomic Bomb Survivors (1958-1998)

(Preston *et al*. *Radiat Res* 2007; **168**: 1-64)



# Relative Risk of Solid Tumour Incidence among the Japanese Atomic Bomb Survivors (1958-1994)

(Pierce & Preston, *Radiat Res* 2000; **154**: 178-186)



# The View of The Master

"I base my own view on the belief … that a linear dose-response relationship will not suddenly dive to zero immediately below the lowest level at which a statistically significant excess is observed"

Professor Sir Richard Doll

Opening Address to the British Nuclear Energy Society conference "Health Effects of Low Dose Radiation", Stratford-upon-Avon, UK, May 1997.

# Medical Radiography

- Patients with tuberculosis or scoliosis monitored with a series of X-ray examinations, each giving a dose ~10 mGy.
- Subsequent excess risk of breast cancer is proportional to the number of examinations.
- Suggests that breast cancer can be induced by a dose of ~10 mGy of X-rays.

# Obstetric Radiography

- Antenatal X-ray examinations in the mid-20$^{th}$ century delivered fetal doses of ~10 mGy.
- Case-control studies show a consistent association between the risk of childhood cancer and obstetric radiography.
- Suggests that fetal doses of ~10 mGy of X-rays increase the risk of cancer in childhood.

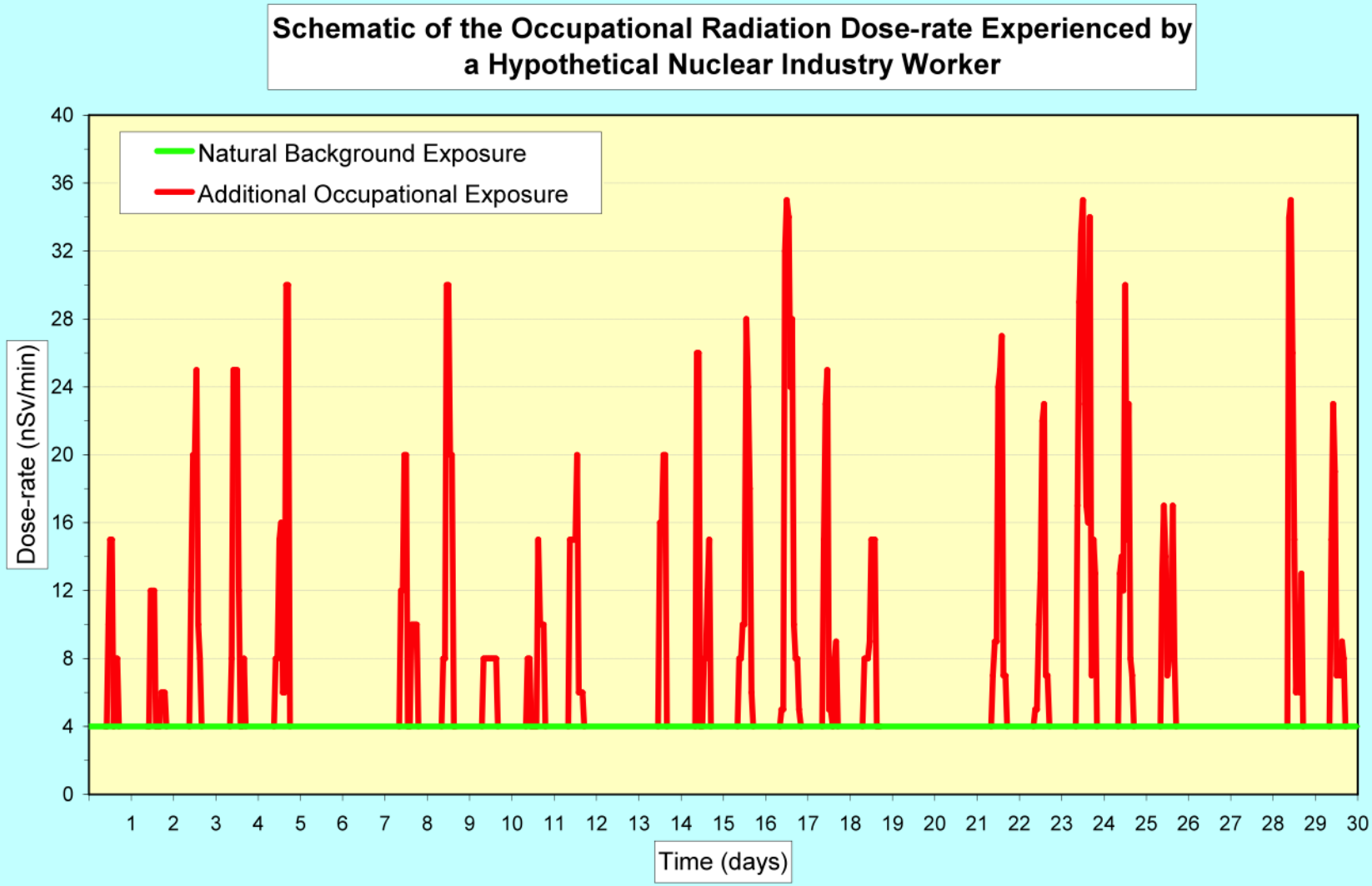
# Low Doses/Dose-rates

- This (and other) evidence indicates that a small excess risk of (at least some types of) cancer exists after low dose/dose-rate exposure to radiation.
- This small risk is compatible with the predictions of the LNT cancer risk models.
- Substantial additional evidence is likely to become available soon.

# New Epidemiological Evidence

- Large studies of childhood leukaemia and natural background radiation – predicted to cause ~15% of incident cases.
- Childhood leukaemia following (increasingly prevalent) paediatric CT scans.
- Large studies of early nuclear industry workers, who have accumulated moderate doses (>100 mGy) over protracted periods.

# Pattern of Occupational Exposure



# Sellafield, Cumbria, UK

# National Registry for Radiation Workers (NRRW)

(Muirhead*et al.*, *Br J Cancer* 2009; **100**: 206-212)

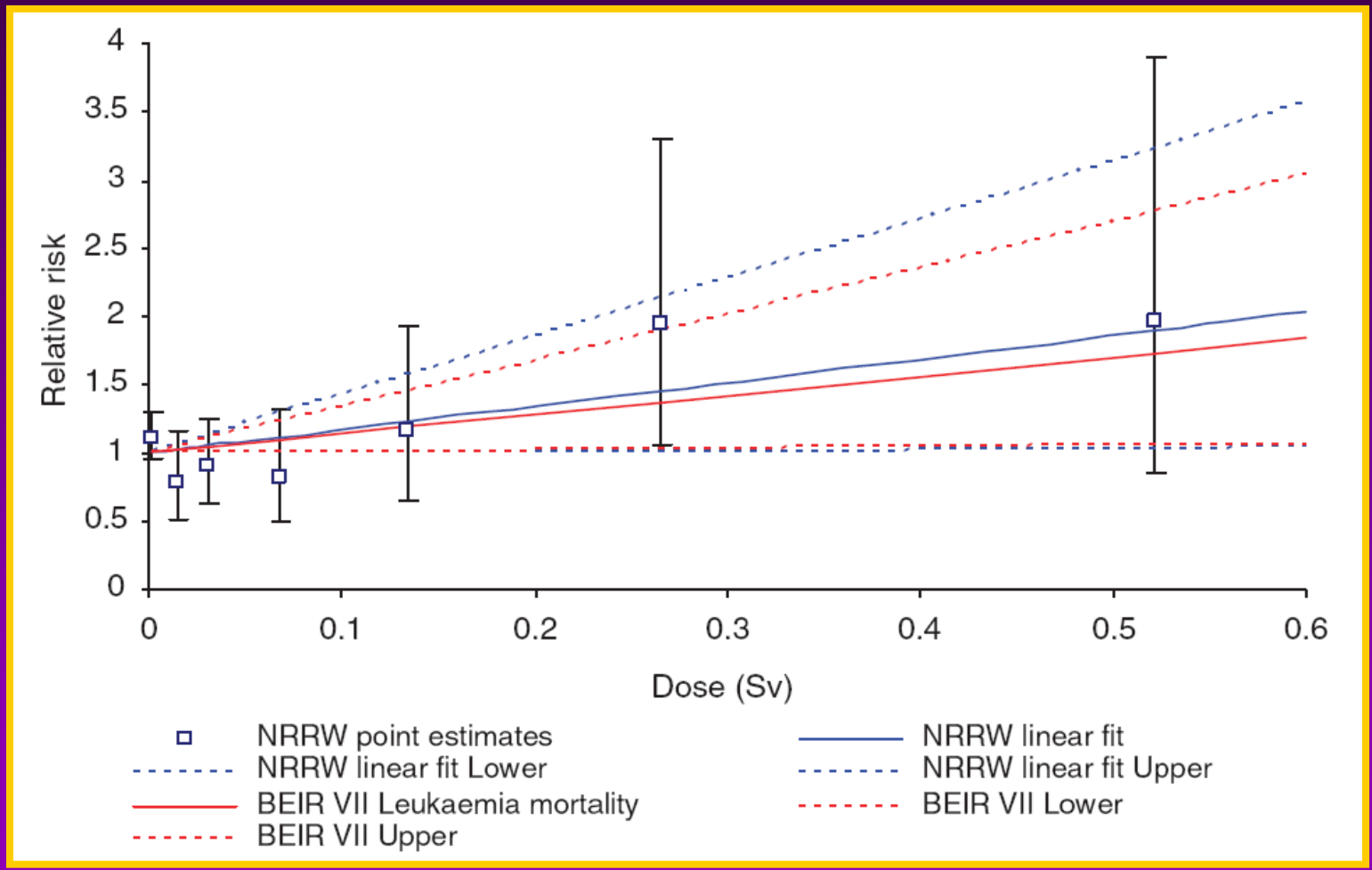
*Third Analysis of NRRW (NRRW-3)*

- ~175 000 radiation workers in the UK
- Average individual cumulative dose 25 mSv
  - ~10 000 workers with doses >100 mSv, only ~¼ of whom had died in NRRW-3
- Collective dose 4350 person.Sv
- Average follow-up 22.3 years
- 8100 cancer deaths (and 11 165 incident cancer cases)

# Third Analysis of NRRW

(Muirhead *et al.*, *Br J Cancer* 2009; **100**: 206-212)

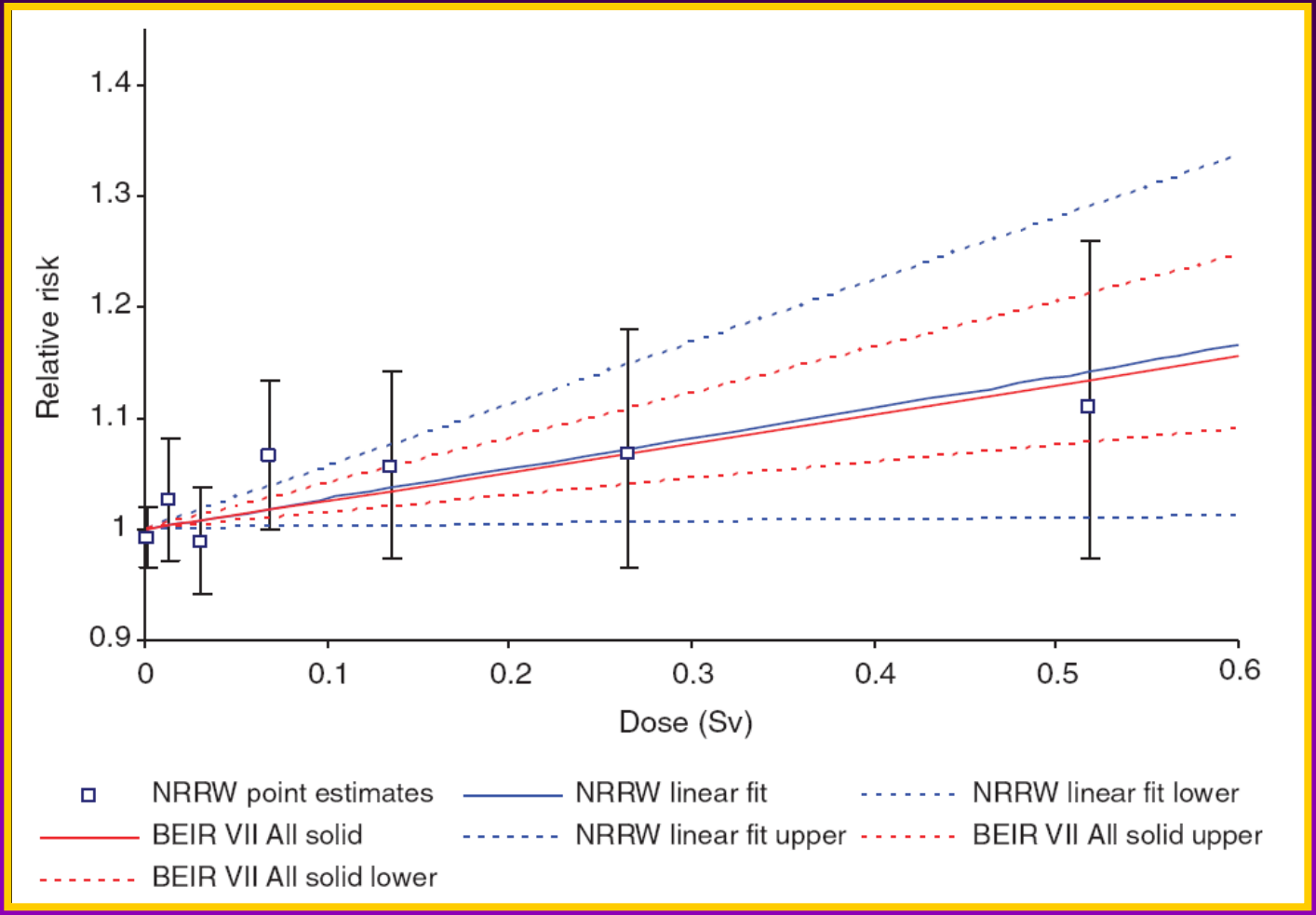
**Leukaemia** (excluding chronic lymphocytic leukaemia)



# Third Analysis of NRRW

(Muirhead *et al.*, *Br J Cancer* 2009; **100**: 206-212)

## All Cancers Excluding Leukaemia



# Conclusions

- Cancer risk models predict a small excess risk of cancer following low dose or low dose-rate exposure to radiation, based on LNT cancer risk models.
- This prediction is difficult to test because the excess risk of cancer is small relative to variations in the background risk, but some supporting evidence does exist.
- Additional evidence may be expected soon.