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Dosimetry for Mayak and Sellafield workers: Challenges for Epidemiology

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Topics

Why study radiation worker cohorts?

The Mayak and Sellafield cohorts

Why good dosimetry matters to epidemiologists

Two examples of dosimetry issues from SOLO

Final thoughts

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SOLO

Supported by the EC 7th Framework Programme (Euratom)

March 2010 – March 2015 Total value 9 M€ - 5 M€ from the EC

Project Coordinator : John Harrison

Scientific Secretary : Richard Haylock

9 Contract Partners: PHE, SUBI (RF), URCRM (RF), Helmholtz Zentrum München (D), IARC (France), UNIMAN (UK), ISS (I), LUMC (NL), Univ Florida (USA)

"Aimed to derive improved estimates of long term risk from protracted external & internal exposure using Mayak,Techa River & Sellafield cohorts"

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Why study radiation worker cohorts?

Life Span Study only provides direct information on external gamma exposure

- LSS external doses are acute
- LSS information mainly from survivors with high doses >100mGy
- Issues transferring risk to other populations

The RP community want to estimate risks to the public and workers from

- low doses
- chronic external exposures
- internal exposures

Radiation worker cohorts can provide direct evidence.

Mayak Production Association

Opened in 1948 to produce weapons grade ^{239}Pu

Workers housed in a closed city called Ozyorsk

Main plants:

Reactors

Protracted external gamma radiation exposures

Radiochemical plant

Protracted external gamma radiation exposures

Inhalation of ^{239}Pu compounds

Plutonium plant

Protracted external gamma radiation exposures

Inhalation of ^{239}Pu compounds

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Main Consequences of Mayak Operations

Large scale over-exposure of workers in the early years.

Irradiation of the local Techa river population from discharges.

Irradiation of Mayak workers and local population as a result of the Kyshtym accident in 1957

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Mayak Worker Cohort (MWC)

Workers first employed between 1948-82 (published)

main facilities : 22,366

+ auxiliary plants : 25,757

Related cohort:

Ozyorsk Offspring Cohort : 72,185 children (below 15 years) resident in Ozyorsk > 1 year between 1934 and 1988

of these 8,562 were offspring of female Mayak workers

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Mayak dosimetry

Three dosimetry systems to date (used for epidemiological analyses):

- Doses 2005
- Mayak Worker Dosimetry System-2008 (MWDS-2008)
- Mayak Worker Dosimetry System-2013 (MWDS -2013)

External dosimetry:

- Based on archived records of photographic film dosimeters
- Whole body and organ specific annual doses calculated for major organs

Internal dosimetry: primarily to calculate internal plutonium doses

- evolved considerably to take account of changes to :
  - Biokinetic models
  - Radiation transport models
  - Calculation methodology – now using Bayesian modelling

- Based on approximately 70,000 bioassay and 1000 autopsy measurements

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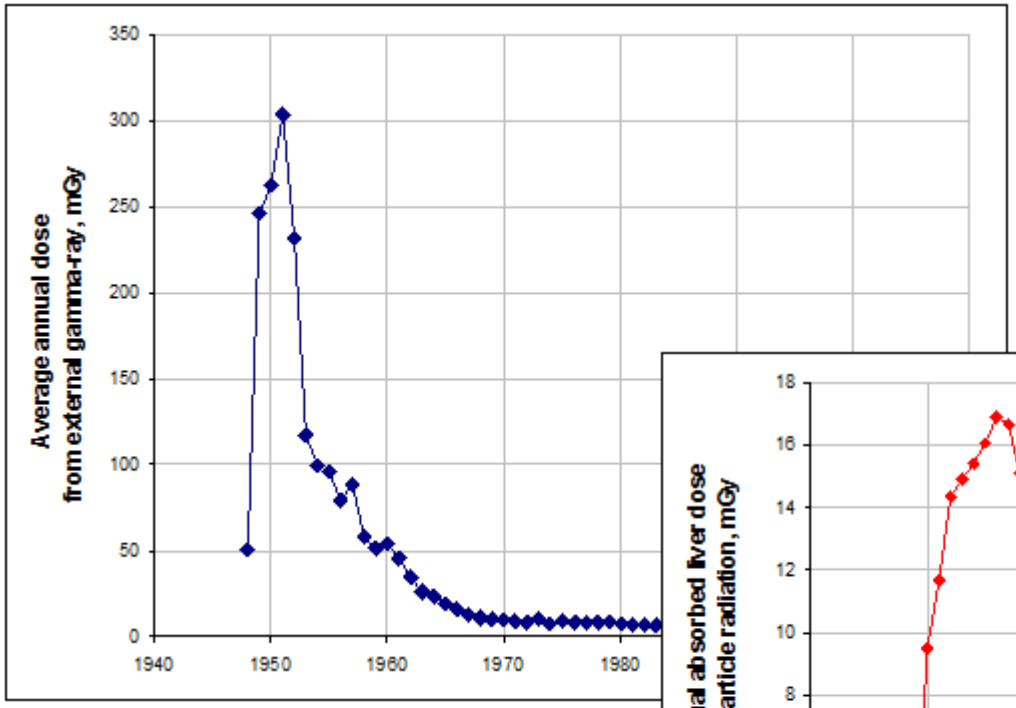
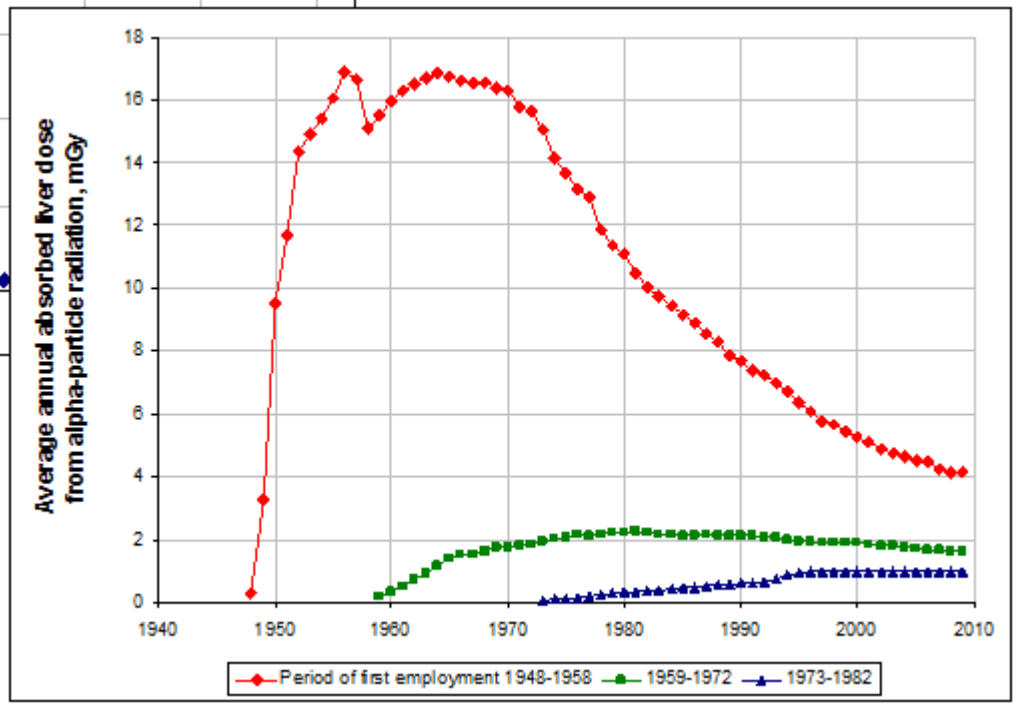
MWC annual doses



Average annual whole body dose from external gamma-rays based on MWDS-2008



Average annual absorbed liver dose from internal alpha radiation due to incorporated plutonium based on MWDS-2008

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Epidemiological value

- Stable population – all workers lived in the ‘closed city’
- Large female workforce – 25%
- Regular medicals for all workers
  - during working period and in retirement if resident in Ozyorsk
  - lots of information: smoking status 90%
    alcohol status 78%

- Mortality and incidence data available for Ozyorsk residents up
  - Incidence data not restricted to cancers

- Mortality data for migrants up to 2005

- Vital status known for 95% : 48% deceased, 41% migrated
  ~ 500,000 person years

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Sellafield worker cohort (SWC)

Part of the British Nuclear Fuels Limited Cohort

Site	Number of internal radiation workers (%)	Number of external radiation workers (%)	Number of non-radiation workers (%)
Springfields	9211 (40.62)	4895 (24.78)	5407 (24.15)
Sellafield	12 569 (55.43)	10 420 (52.74)	7524 (33.61)
Capenhurst	471 (2.08)	2723 (13.78)	9058 (40.46)
Chapelcross	424 (1.87)	1718 (8.70)	400 (1.79)
Total	22 675 (100%)	19 756 (100%)	22 389 (100%)

Workers employed 1946-2002 followed up to 2005

Mortality and cancer incidence data (from 1971) available

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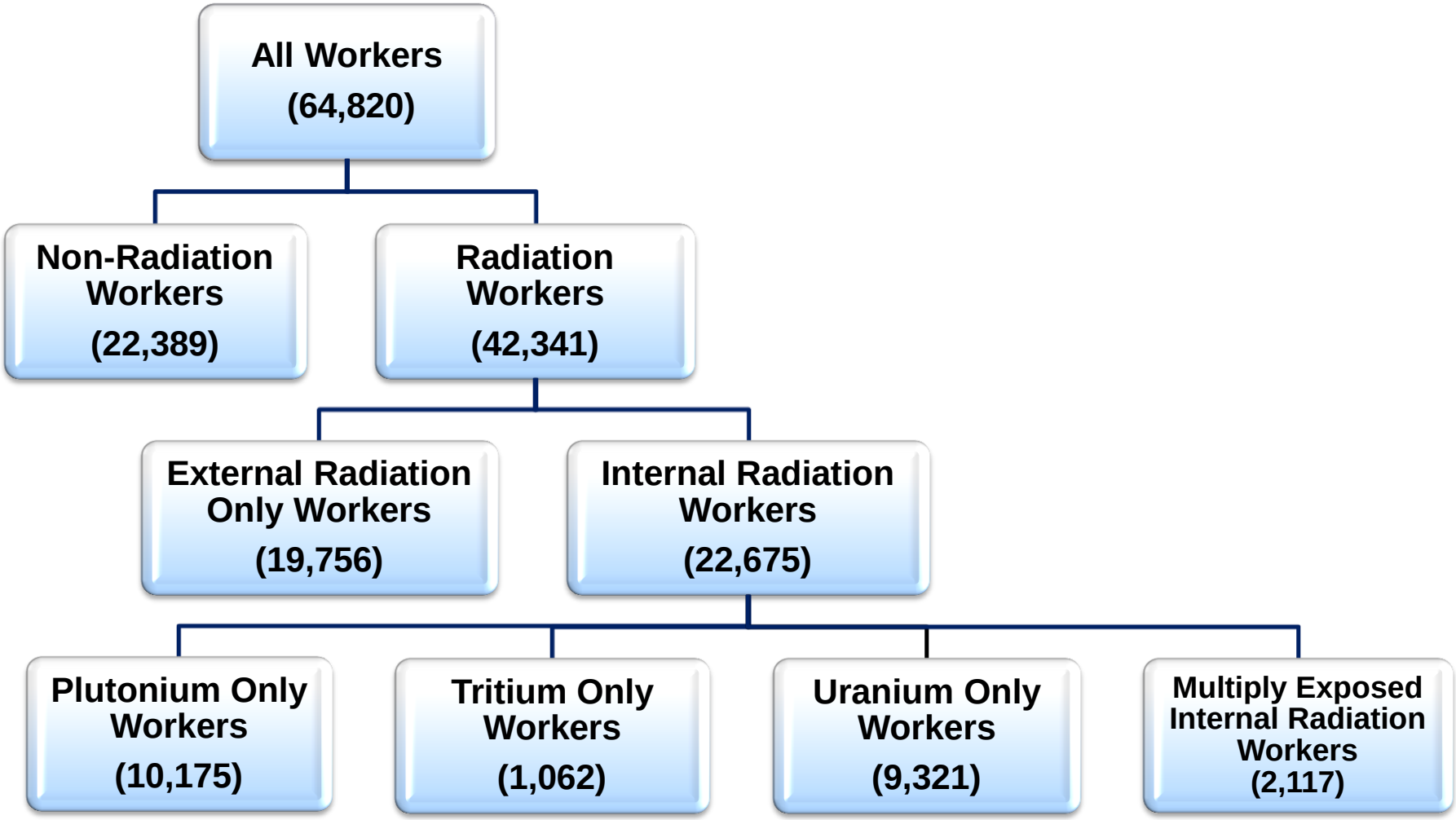
BNFL cohort



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BNFL cohort dosimetry

Sellafield 1951 to 2005

- **12,862 plutonium workers**
  - *~485,000 samples*
- **2,150 uranium workers**
  - *~43,500 samples*
- **910 tritium workers**
  - *~ 27,000 samples*

Springfields 1949 to 2005

- **9,422 uranium workers**
  - *~822,000 urine samples*

Capenhurst ~1950 to 2005

- **3,580 uranium workers**
  - *~72,000 samples*
  - *Not included in current analyses*
- **730 tritium workers**
  - *several 100,000 urine samples*
- **Tritium doses yet to be calculated**
  - *awaiting data reconciliation*

Chapelcross ~1980 to 2002

- **412 tritium workers**
  - *~120,000 urine samples*
- **Tritium doses yet to be calculated**
  - *awaiting data reconciliation*

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Sellafield cohort dosimetry

External

Prior to SOLO all external doses were ‘whole body’, from film badge dosimetry records, for the SOLO analysis individual organ doses were estimated from these records

Internal Plutonium

1999	LSHTM Study - Jones excretion function/ICRP48 biokinetic model and ICRP30 lung model (Both default solubility Class W and Class Y used as no information on Pu chemical form available at that time)
2003	Female Worker Study - Jones excretion function/ICRP67 biokinetic model and ICRP66 Human Respiratory Tract Model (Sellafield specific Pu nitrate solubility and default Type S for Pu oxide used)
2009	Alpha-risk Study – Leggett 2005 plutonium biokinetic model and ICRP66 Human Respiratory Tract Model (Sellafield specific Pu nitrate solubility and default Type S for Pu oxide used)
2014	SOLO - Leggett 2005 plutonium biokinetic model and ICRP130 OIR modified Human Respiratory Tract Model (Both Sellafield and Mayak specific Pu nitrate solubilities and also Mayak PA specific solubility for Pu oxide)

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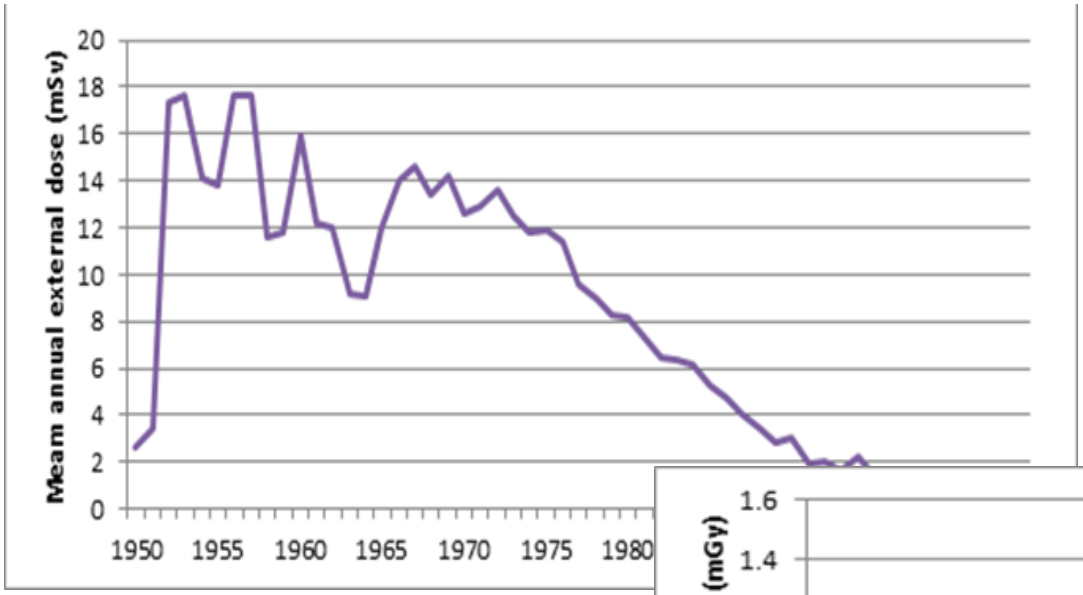
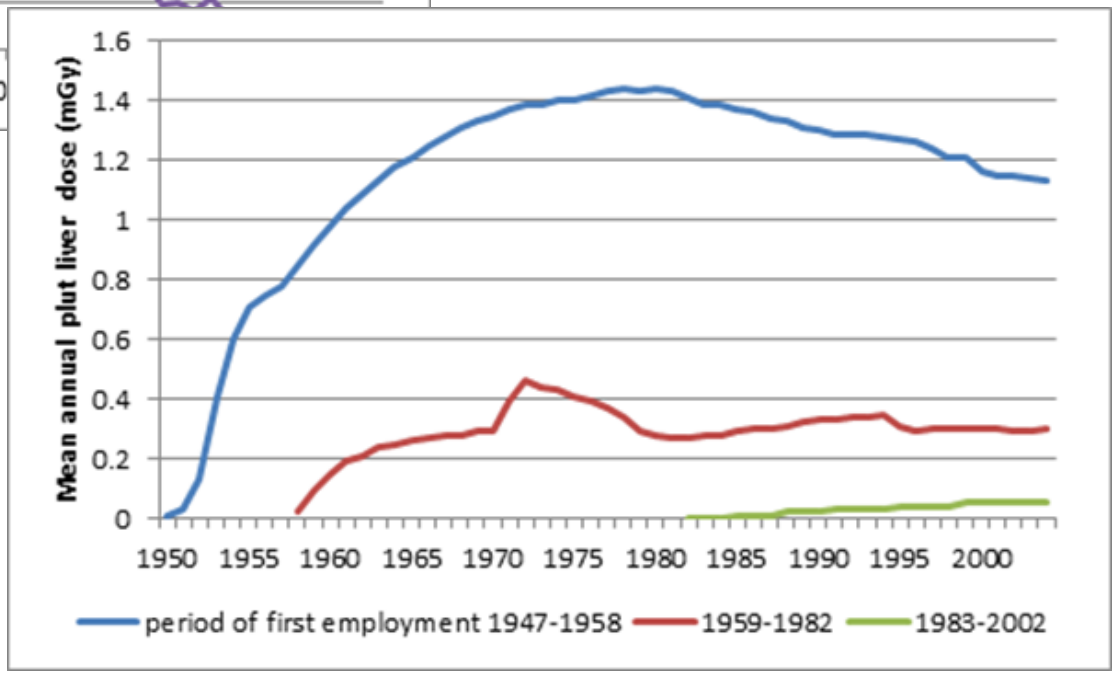
Sellafield annual doses



Average annual whole body dose from external gamma-rays based on SOLO



Average annual absorbed liver dose from internal alpha radiation due to incorporated plutonium based on SOLO

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Epidemiological value

- Contains both externally and internally exposed workers
- Non-radiation worker comparison group
- High quality mortality and cancer incidence information

But

- Cohort has lower statistical power – less mature cohort than MWC or LSS

  Vital status known for 99.3% overall: 27% deceased, 9% female

  1.2m person-years (all BNFL)

Potential to obtain lifestyle information in the future – maybe!

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Risk modelling: why good dosimetry matters

Epidemiologists aim to generate models to describe variation in disease risk with dose

How is the dose – risk relationship modified by:

- Age at exposure
- Time since exposure
- Sex
- Effects of confounding factors?

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Problems for risk modelling

ICRP 103 Excess relative risk model for all solid cancer incidence :

ERR = 0.35*DOSE * Exp[-0.17(AAE-30/10) -1.65*Log(ATT/70)]

↑

Male risk at age 70 given exposure age 30

AAE= age at exposure ATT = attained age

Poisson regression modelling generally assumes dependent variables

DOSE, AAE, ATT are known exactly.

Not true for dose!

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Uncertainty related to dose

Three types of uncertainty:

Model uncertainty: Linear model only an approximation

-extrapolation outside data region i.e. young ages at exposure increases uncertainty

Measurement error:

External dose meters not accurate

Internal dosimetry modelling not accurate

-can result in underestimation of dose response slope

Berkson error: a single measurement applied to many workers

- can result in too narrow confidence bounds

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Effects of dodgy dosimetry

Two examples of dosimetry issues that occurred in SOLO:

1) The Limit of Detection problem

2) Dosimetry model parameter value problem.

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SOLO sub-projects

SP 2: Epidemiology for Mayak workers

Non-cancer mortality and incidence

- Circulatory disease incidence and mortality for extended cohort (- 1972; - 1982) and MWDS 2008
- Feasibility study for respiratory disease, starting with first employment 1948 – 1958 and *MWDS 2008*

Cancer incidence

- Separate analyses for leukaemia/ lymphoma, lung, liver, skeletal and other solid cancers for extended cohort to 1982 and MWDS 2008

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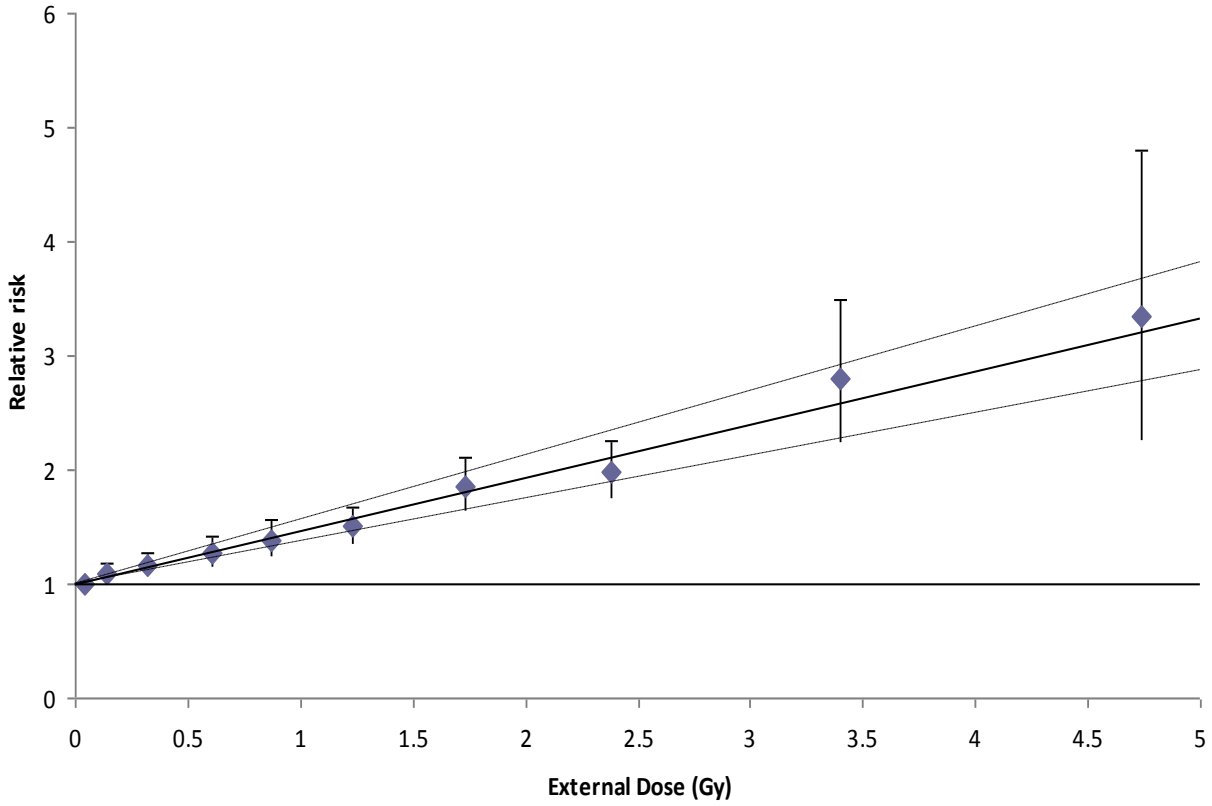
SOLO dosimetry issues

SP2: Analysis of cerebrovascular disease: Cumulative external dose

Based on MWDS-2008



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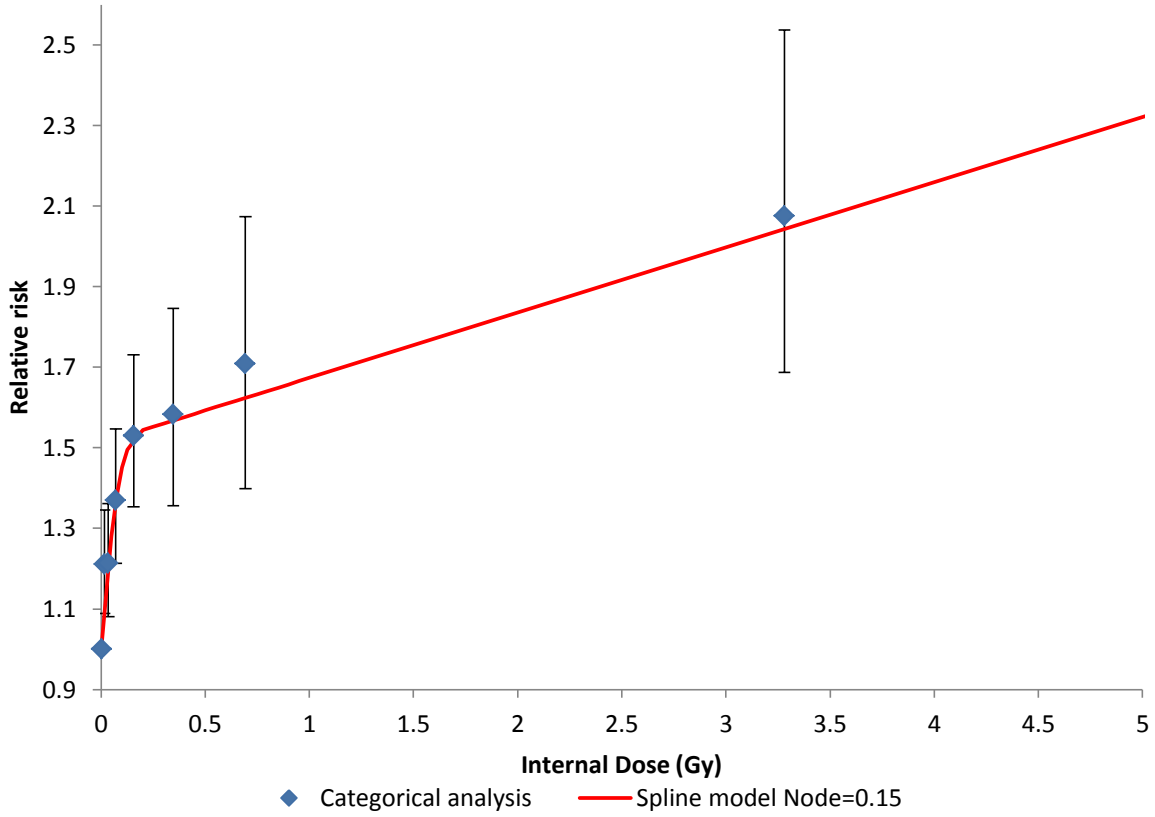
SOLO dosimetry issues

SP2: Analysis of cerebrovascular disease: Cumulative internal dose

Based on MWDS-2008



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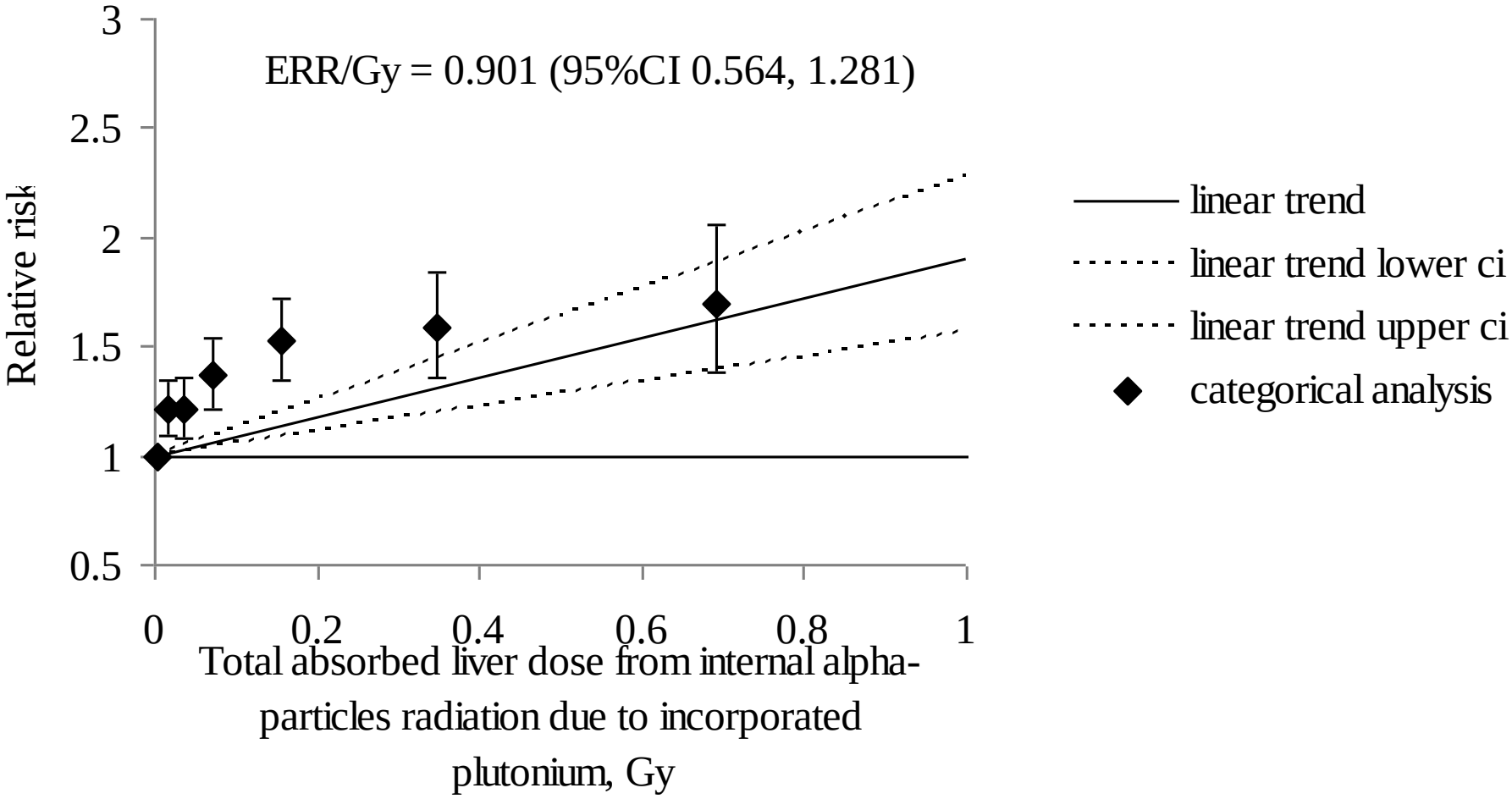
SOLO dosimetry issues

SP2: Analysis of cerebrovascular disease: Cumulative internal dose

Based on MWDS-2008 and restricted to doses < 1Gy



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Limit of detection

If bioassay reports below limit of detection (LoD) what value should be selected?

Zero?

The limit?

The mid point? - as used in MWDS2008

Validity = 1 : all bioassay measurements > LoD – good information

Validity = 0 : no bioassay measurements > LoD - poor information

Validity	Cases	ERR/Gy (95% CI)	ERR/Gy <1Gy (95% CI)
All	5070	0.28 (0.16, 0.42)	0.9 (0.56, 1.28)
1	1036	0.32 (0.14, 0.56)	0.98 (0.39, 1.77)
>0	3453	0.18 (0.08, 0.30)	0.58 (0.26, 0.95)

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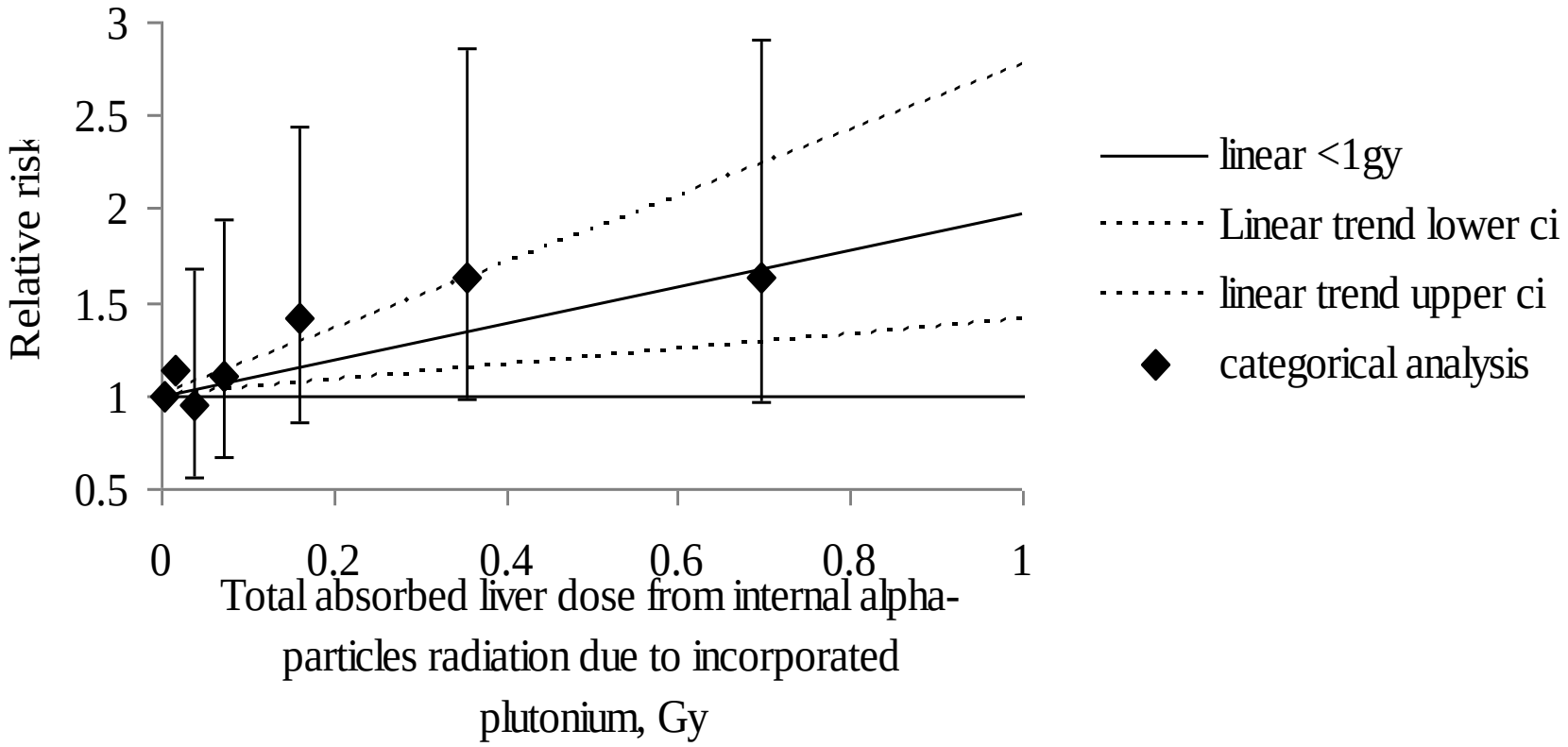
SOLO LoD issue

SP2: Analysis of cerebrovascular disease: Cumulative internal dose

Based on MWDS-2008 and restricted to doses < 1Gy and Validity = 1

ERR/Gy = 0.981 (95% CI 0.394, 1.767)



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SOLO sub-projects

SP 3: Pooled analysis of Pu worker cohorts

Preliminary pooled analysis: leukaemia, lung cancer and circulatory diseases :

- Sellafield 1946 – 2003 cohort, follow-up to 2005
- Mayak 1948 – 1982 cohort, follow-up to 2008

Requiring :

- Harmonisation of health data - are deaths coded the same way?
- Harmonisation of dosimetry – are systems compatible?

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Compatible dosimetry systems?

External dosimetry:

- Reviewed by independent expert from USA
- Qualified approval ✓

Internal dosimetry:

- New joint system developed based in MWDS2013
- Doses calculated using IMBA software
- Using up-to-date ICRP biokinetic models
- Aimed to provide point estimates and uncertainty

But there was a problem!

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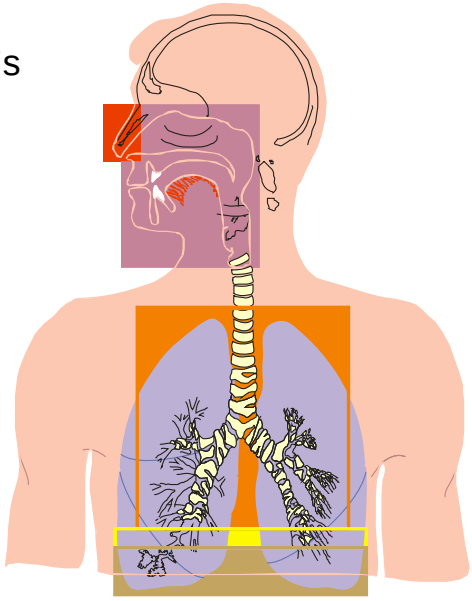
Compatible dosimetry systems?

Issue with slow absorption rate for plutonium nitrate S_s



Based on 20 Mayak autopsy cases with urinalysis results:

S_s = Lognormal median = 2.5×10^{-4}
GSD = 1.08

Based on Sellafield workers with only urinalysis results:

$S_s = 2 \times 10^{-3} – 8 \times 10^{-3}$

Different S_s values result in different doses

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The S_s value problem

Russians and British people all the same – well mostly…

Expect true value of S_s to be independent of nationality

Distribution of number of workers by the period of Pu examination			
Period of Pu examination	Mayak Worker Cohort	Sellafield Worker Cohort	Pooled Worker Cohort
During the work at the enterprise	5,207 – 69.4%	12,192 – 100%	17,399 – 88.4%
After the work was terminated	2,292 – 30.6%	0	2,292 – 11.6%

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How to select the S_s value?

Which estimate to choose?

Option 1: Use the Mayak value for both cohorts

Option 2: Use Sellafield value for both cohorts

Option 3: Use Mayak value for Mayak and Sellafield value for Sellafield

Option 4:

Create two datasets: one with Mayak S_S value for all workers

one with Sellafield S_S value for all workers

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Results of S_s value selection

Characteristics of accumulated doses in lung due to Pu-239 exposure, mGy						
Cohort	s_s origin	Mean	10%	Median	90%	Max
MWC	Mayak PA	175.6	1.9	29.3	303.4	19,743.7
	PHE	129.0	1.2	19.0	203.1	16,532.7
SWC	Mayak PA	5.5	0.04	0.85	13.02	653.98
	PHE	1.9	0.02	0.22	3.77	490.46

Ratio of accumulated doses, calculated using different values of s_s parameter by plant and period of employment, Mean(Dose[s_s of Mayak]) / Mean(Dose(s_s of PHE])				
Organ	Mayak Workers Cohort			Sellafield Workers Cohort
	Radiochemical plant	Plutonium plant	All plants	All plants
Lung	1.8±5.0	1.2±6.6	1.4±7.4	2.8±8.5
Liver	0.8±6.0	0.8±6.6	0.8±6.6	1.2±13.3

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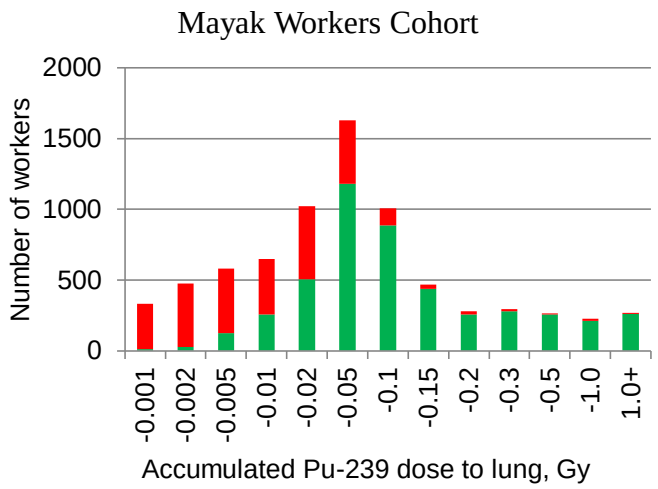
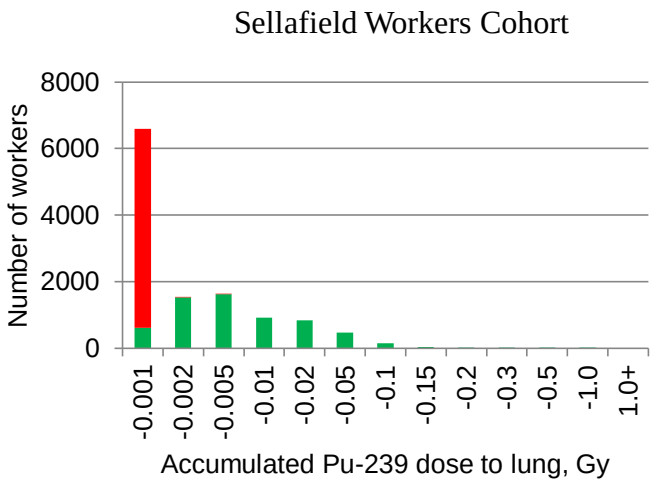
The LoD issue - again

Lung dose assessment based on only LOD sample results			
	Mayak Worker Cohort	Sellafield Worker Cohort	Pooled Worker Cohort
Yes	2,804 – 37.4%	6,017 – 49.4%	8,821 – 44.8%
No	4,695 – 62.6%	6,175 – 50.6%	10,870 – 55.2%





green bar: doses based on some results >LOD; red bar: doses based on LOD values only

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Final thoughts

Good dosimetry is vital for informative epidemiological studies

Estimating/minimising uncertainty in doses very important

Today: epidemiology uses point estimates for doses

Future: want to replace point estimates with something better?

e.g. distributions.

Not a simple task! – generates a lot of information

The challenge for radiation epidemiology will be using this information