Towards Risk Reduction: Predicting the Future Burden of Occupational Cancer

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Aims of the overall study

- Current Burden of Occupational Cancer:
  - to develop and apply methodology to estimate current attributable risk, cancer numbers and DALYs caused by work
  - to identify important cancer sites
  - to identify industries and occupations for targeting for reduction measures

- Prediction of Future Burden of Occupational Cancer
  - Estimate size of future burden based on current and past exposures
  - Identify cancer sites, carcinogens and industry sectors where the burden is greatest
  - Demonstrate effects of measures to reduce exposure

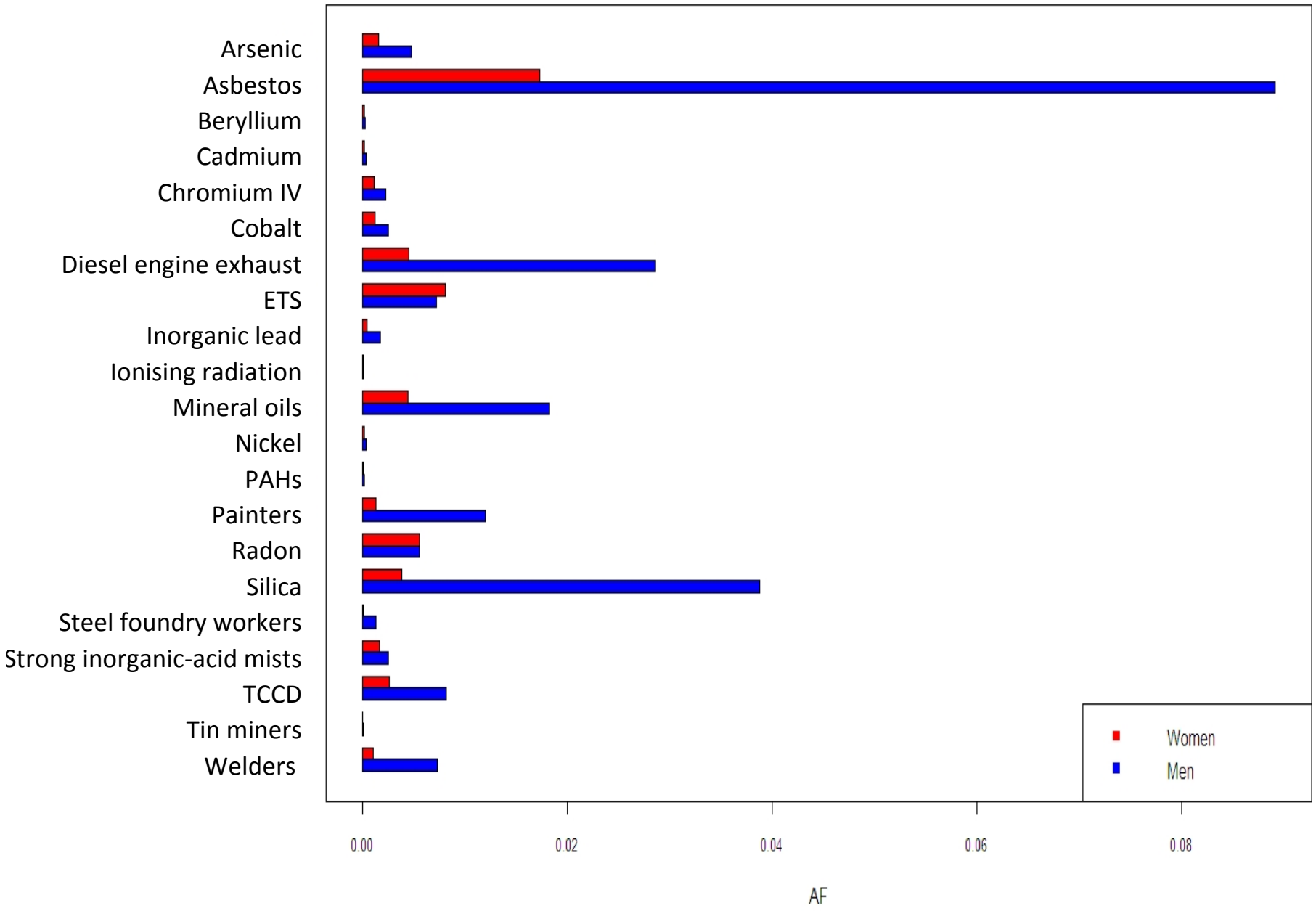
Current Burden Methodology: Attributable Fraction approach

- Attributable fraction (AF): the proportion of cases due to occupational exposure, estimated using Levin's formula. Requires:
  - Risk of Disease (relative risk estimates from published literature)
  - Proportion of Population Exposed (derived from national data sources, accounting for employment turnover and life expectancy; adjusted for employment trends).
- Define period of relevant exposure: Risk Exposure Period (REP) based on cancer latency (Solid tumours:10-50 years; Leukaemias, lymphomas etc 0-20 years)
- Dose-response risk estimates and proportions exposed at different levels not generally available; data therefore obtained for 'higher' and 'lower' levels.
- AFs applied to total current deaths and registrations to give attributable numbers (ANs).
- Estimation for IARC groups 1 (definite) and 2A (probable) carcinogens and occupational circumstances

Cancer Site	AF (%)			Deaths (2005)			Registrations (2004)		
	M	F	Total	M	F	Total	M	F	Total
Mesothelioma	97.0	82.5	94.9	1699	238	1937	1699	238	1937
Sinonasal	43.3	19.8	32.7	27	10	38	195	31	126
Lung	21.1	5.3	14.5	4020	725	4745	4627	815	5442
Nasopharynx	10.8	2.4	8.0	7	1	8	14	1	15
Bladder	7.1	1.9	5.3	215	30	245	496	54	550
Breast		4.6	4.6		555	555		1969	1969
NMSC	6.9	1.1	4.5	20	2	23	2513	349	2862
Larynx	2.9	1.6	2.6	17	3	20	50	6	56
Oesophagus	3.3	1.1	2.5	156	28	184	159	29	188
STS	3.4	1.1	2.4	11	3	13	22	4	27
Stomach	3.0	0.3	1.9	101	6	108	149	9	157
NHL	2.1	1.1	1.7	43	14	57	102	39	140
Melanoma (eye)	2.9	0.4	1.6	1	0	1	6	1	6
Total	8.2 (7.2, 9.9)	2.3 (1.7, 3.2)	5.3 (4.6, 6.6)	6355 (5640, 7690)	1655 (1249, 2287)	8010 (6888, 9977)	9988 (6938, 14794)	3611 (2370, 5412)	13598 (9308, 20206)

Carcinogen or Occupation	Total Registrations (% of total burden)	Cancer Sites
Asbestos	4216 (30.8%)	Larynx, **Lung, Mesothelioma**, Stomach
Shift work (+ Flight Personnel)	1957 (14.3%)	**Breast**
Mineral oils	1730	**Bladder, Lung**, **NMSC,** Sinonasal
Solar radiation	1541 (11.3%)	**NMSC**
Silica	907 (6.6%)	**Lung**
Diesel engine exhaust	801 (5.9%)	**Bladder, Lung**
PAHs - Coal tars and pitches	545 (4.0%)	**NMSC**
Painters	359 (3.2%)	Bladder, **Lung**, Stomach
Dioxins	316 (2.3%)	**Lung**, NHL, STS
Environmental Tobacco Smoke (non-smokers)	284 (2.1%)	**Lung**
Radon	209 (1.5%)	**Lung**
Welders	175 (1.3%)	**Lung**, Melanoma (eye)
Tetrachloroethylene	164 (1.2%)	Cervix, **NHL**, Oesophagus
Arsenic	129 (0.9%)	**Lung**
Strong inorganic-acid mists	122 (0.9%)	Larynx, **Lung**
Chromium	89	**Lung**, Sinonasal
Non-arsenical insecticides	73	Brain, Leukaemia, Multiple myeloma, N**HL**

Lung cancer AF by carcinogen/occupation



Industry Sector	Attributable Registrations			Exposures
	Male	Female	Total	
Construction	4573	64	4637	14
Painter + decorators	331	3	334	1
Roadmen + roofers	471	0	471	1
Total construction	**5375**	**68**	**5442**	**16**
Shift work (including flight personnel)	0	1969	1969	1
Metal workers	1083	169	1252	1
Personal + household services	256	403	659	17
Land Transport	454	42	497	9
Mining	283	12	296	10
Printing, publishing and allied trades	232	50	282	10
Public administration and defence	229	34	263	6
Wholesale + retail trades	51	136	187	11
Farming	180	39	220	5
Welders	165	16	181	2
Manufacture of instruments, etc	204	2	206	6
Manufacture of transport equipment	164	18	182	16
Non-ferrous metal basic industries	122	34	156	18

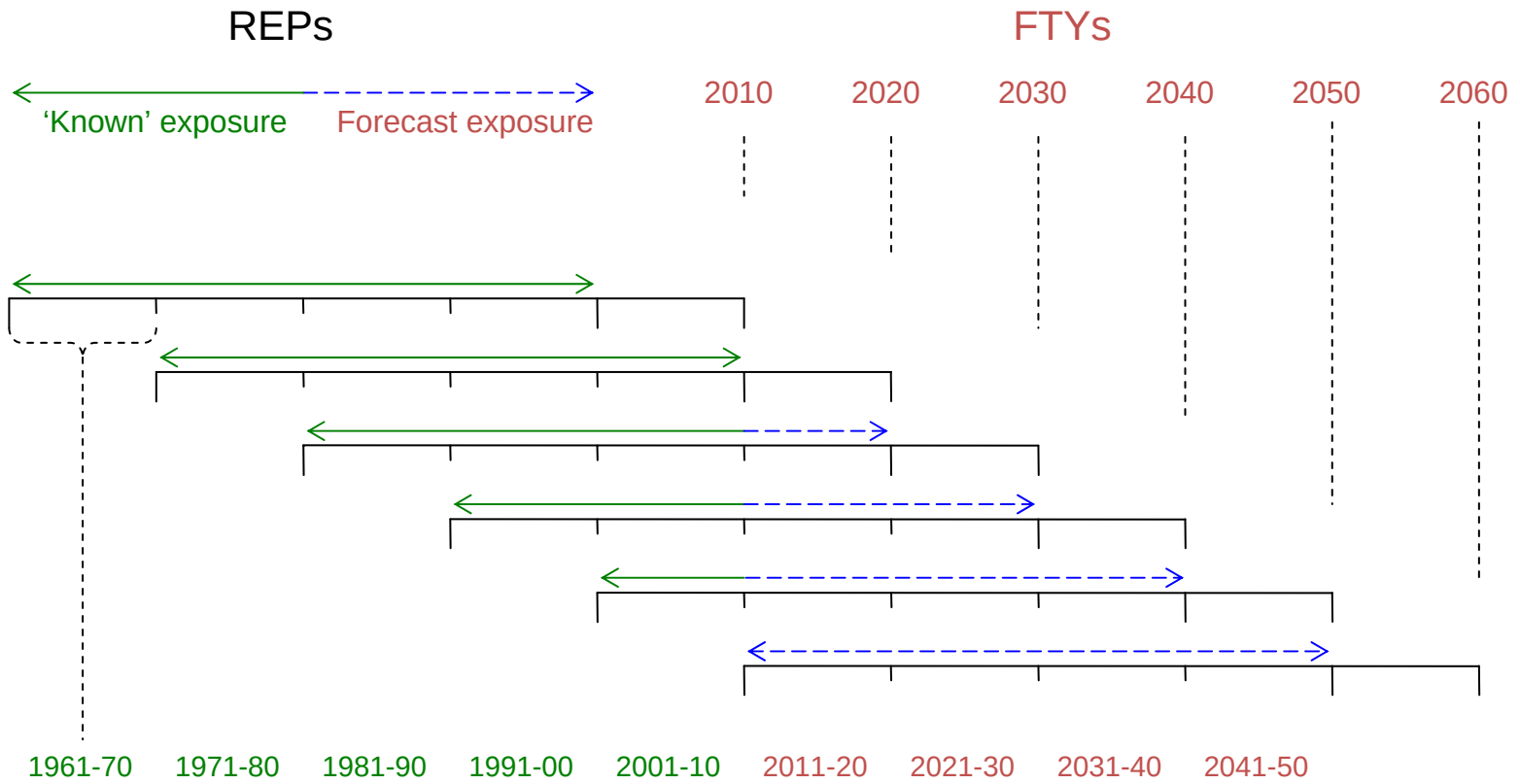
Summary of Outputs Available

- Separately for
  - cancer sites (23),
  - carcinogens (42)
  - industry sectors (>60)
- Attributable Fraction (AF)%
- Attributable Numbers (AN) (deaths and registrations)
- Years Life Lost (YLL) (numbers and average)
- Years Life (lived with a) Disability (YLD) (numbers and average)
- Disability-Adjusted Life-Year (DALY) (YLL + YLD)
- All these separately for men, women and total

Predicting Future Burden – Methodology 1

- AFs estimated for forecast years, e.g. 2010, 2020 … 2060
- Define the risk exposure period (REP) for each year e.g. for 2030, 1981 – 2020 (10-50 years latency assumed for solid tumours e.g. lung cancer, 0-20 years for leukaemia)
- Single exposure cancer initiation model assumed
- Assume latencies are distributed lognormally across the REPs
- Some past and some future exposure.
- Workers at the beginning assumed to be of all working ages
- Workers recruited through employment turnover are assumed to be only aged 15-24
- Methods being applied to ‘important’ carcinogens/occupations identified from current burden results

Forecast Risk Exposure Periods – 10-50 year latency



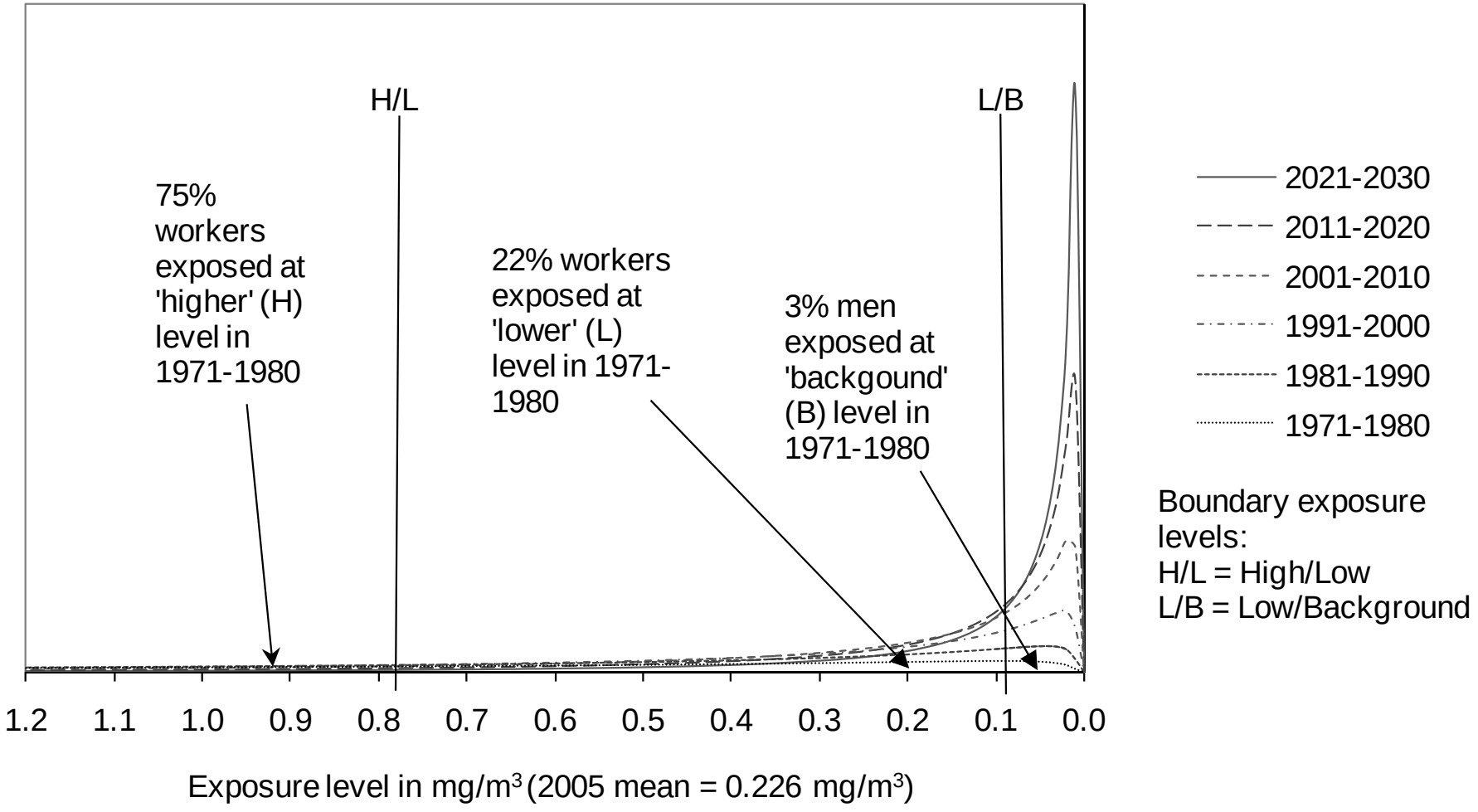
10 year estimation intervals

REP Risk exposure period
FTY Forecast target year

Predicting Future Burden Methodology 2

- Forecasted numbers take into account employment turnover and changes in different industry sector employment trends
- Method developed to shift the proportion of workers exposed in different exposure level categories (H/M/L/B) across time as exposures gradually decrease
- Estimated assuming
  - lognormal distribution of exposure levels with GM and GSD estimated from available exposure level data across all industries
  - GM reduces across time (for each REP estimation interval) in proportion to an estimated annual percent fall in exposure levels.
- H/M, M/L, L/B boundaries are the exposure levels separating H, M, L, B exposed groups
- Proportions of the distributions moving across these boundaries represent exposed workers moving from higher to lower exposure categories
- Adjustment factors also for changing numbers employed, and relative risks if appropriate

Exposure levels shifting with time (baseline trend scenario) and H/L, L/B boundaries – silica example



Change in future exposure: Possible Scenarios

- Estimates made for alternative scenarios of changes in exposure levels and/or numbers exposed
- (1) Baseline scenario - based on pattern of past exposure, but no future change in exposed numbers or exposure levels
- (2) Baseline trend scenario - based on pattern of past and current exposure, and on linear projections up to 20 years into the future, after which levels assumed constant due to prediction uncertainty.
- (3) 'Intervention scenarios' also based on past and current exposures, and suitably chosen target exposure levels in the future

Change in future exposure: Intervention Scenarios

Can test:

- Introduction of a range of possible exposure standards or reduction of a current exposure limit
- Improved compliance to an existing exposure standard
- Planned intervention such as engineering controls or introduction of personal protective equipment
- Industry closure

Also can vary:

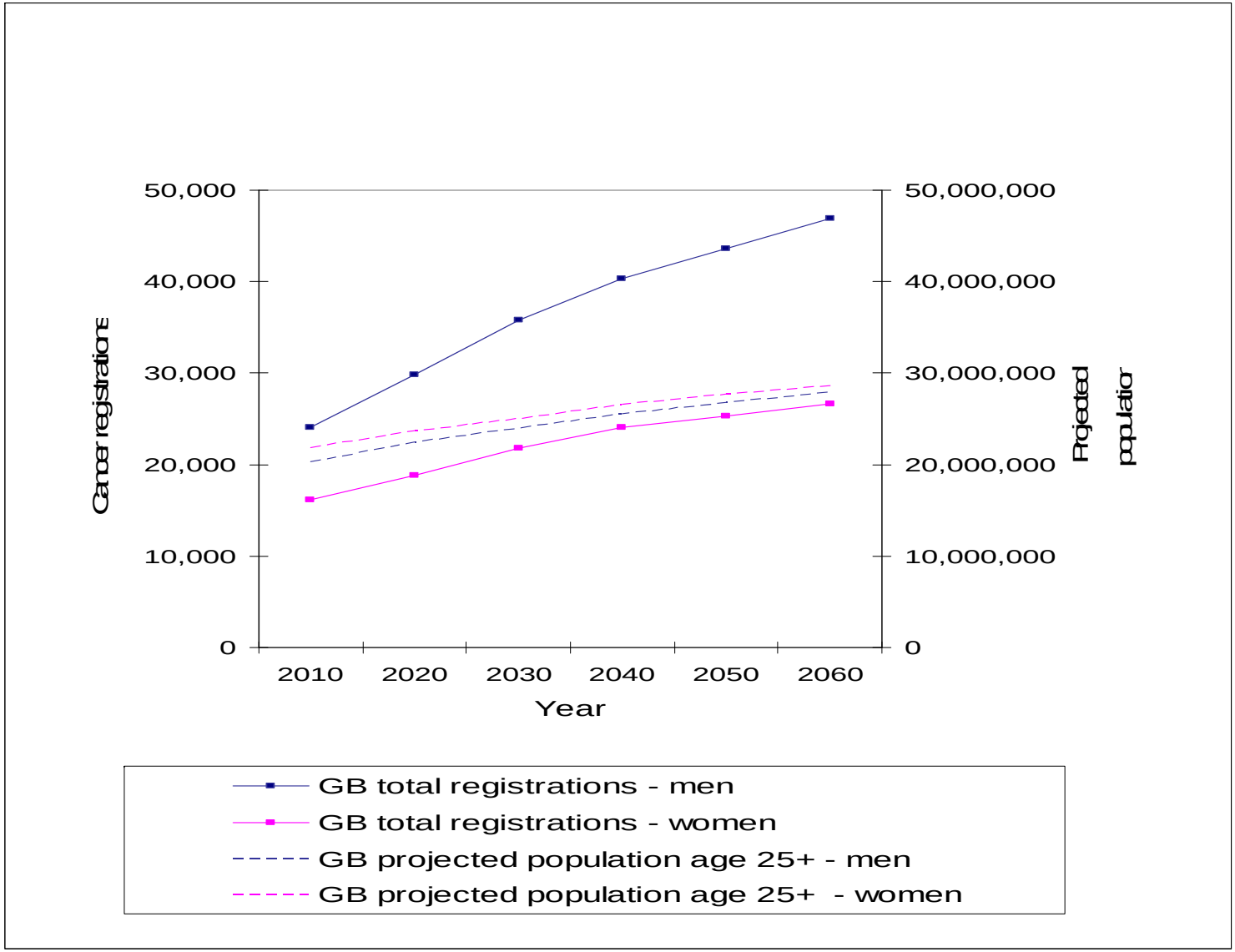
- Timing of introduction (2010, 2020 etc)
- Compliance levels e.g. according to workplace size (self-employed, 1-49, 50-249, 250+ employees)

Intervention scenario results compared to the 'baseline – no change' or 'baseline - trend' scenario to assess relative impact on reducing attributable numbers

Carcinogens where occupational standards/limits exist or could be introduced

- Arsenic, Diesel Engine Exhaust, Silica, Strong inorganic acid mists, Tetrachloroethylene, TCDD (dioxins)
- Example: silica
  - Reduce exposure limit from 0.1 to 0.05 mg/m^3 in all workplaces, in 2010, with the same proportion exposed above the new limit as above the old
  - Reduce exposure limit again to 0.025 mg/m^3
  - Improve compliance from 33% to 90% in all workplaces
  - Try doing both for all workplaces
  - Successively enforce the new limit and improve compliance in workplaces of different sizes

Forecast lung cancer registrations, age 25+, based on population projections and 2004/5 cancer rates by age



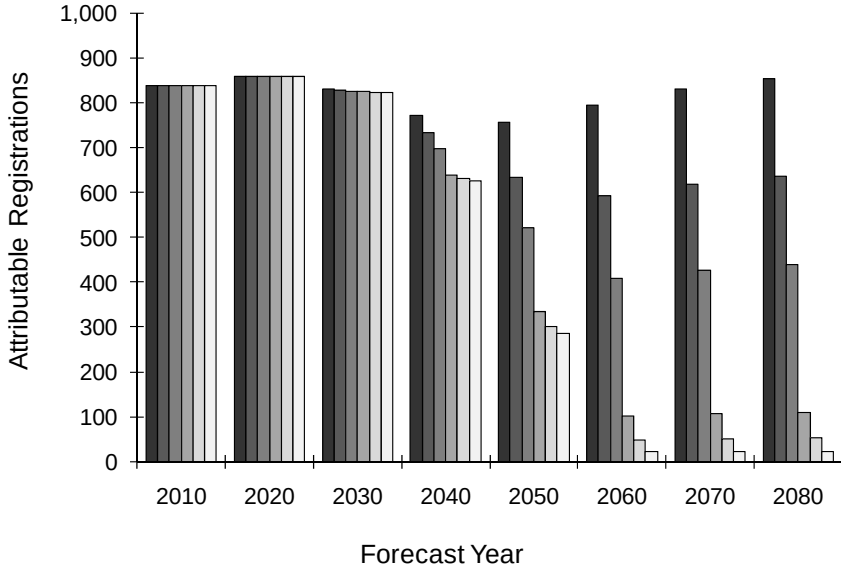
Testing reduction of exposure standard and changes in compliance
Forecast lung cancers for 2060 for Respirable Crystalline Silica

	2010		
	Attributable Fraction	**Attributable registrations**	**Avoided registrations**
	3.3	803	
	2060		
Base-line: exposure limit 0.1mg/m^3, compliance 33%	1.08	794	
Exposure limit 0.05mg/m^3, compliance 33%	0.80	592	**202**
Exposure limit 0.025mg/m^3, compliance 33%	0.56	409	**385**
Exposure limit 0.1mg/m^3, compliance 90%	0.14	102	**693**
Exposure limit 0.05mg/m^3, compliance 90%	0.07	49	**745**
Exposure limit 0.025mg/m^3, compliance 90%	0.03	21	**773**

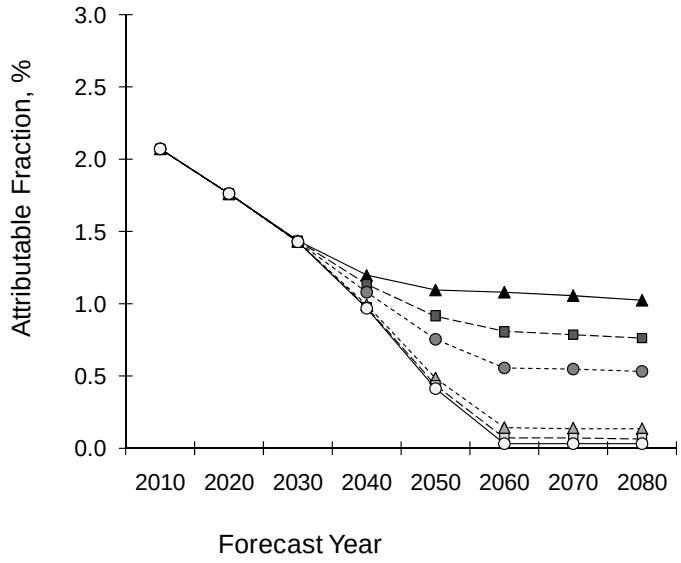
Lung cancer from exposure to RCS

Effect of reducing the exposure standard for RCS versus compliance

A) Attributable registrations



B) AFs



(1) Baseline: exposure limit 0.1mg/m^3 maintained, compliance 33%

(2) Exposure limit 0.05mg/m^3 from 2010, compliance 33%

(10) Exposure limit 0.025mg/m^3 from 2010, compliance 33%

(11) Exposure limit 0.1mg/m^3 maintained, compliance 90%

(12) Exposure limit 0.05mg/m^3 from 2010, compliance 90%

(13) Exposure limit 0.025mg/m^3 from 2010, compliance 90%

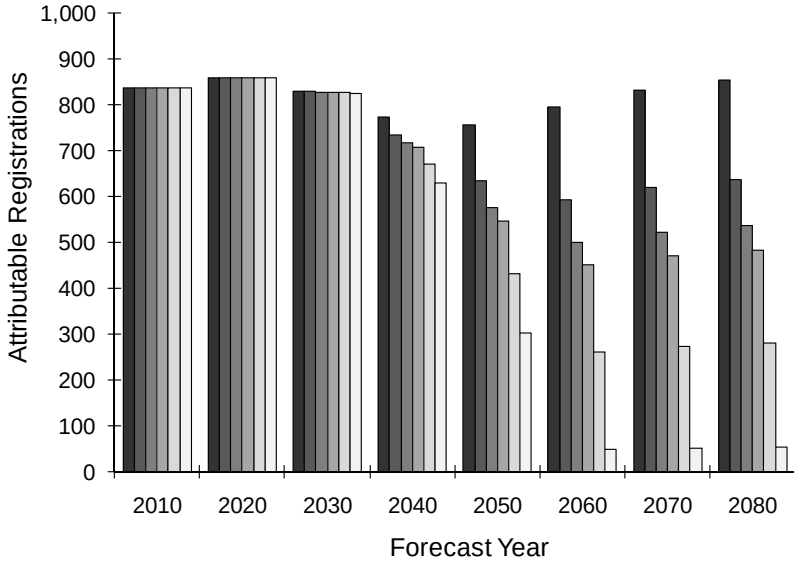
Testing improvement in compliance by workplace size
Forecast lung cancers for 2060 for Respirable Crystalline Silica

	2010		
	Attributable Fraction %	**Attributable registrations**	**Avoided registrations**
	3.3	803	
	2060		
Base-line: exposure limit 0.1mg/m^3, compliance 33%	1.08	794	
Exposure limit 0.05mg/m^3, compliance 33%	0.80	592	**202**
Exposure limit 0.05mg/m^3, % compliance changes by employed workplace size and self employed			
33% < 250, self employed; 90% 250+	0.68	499	**295**
33% < 50, self employed; 90% 50+	0.61	451	**344**
33% self employed; 90% all sizes employed	0.35	261	**533**
90% all workplaces	0.07	49	**745**

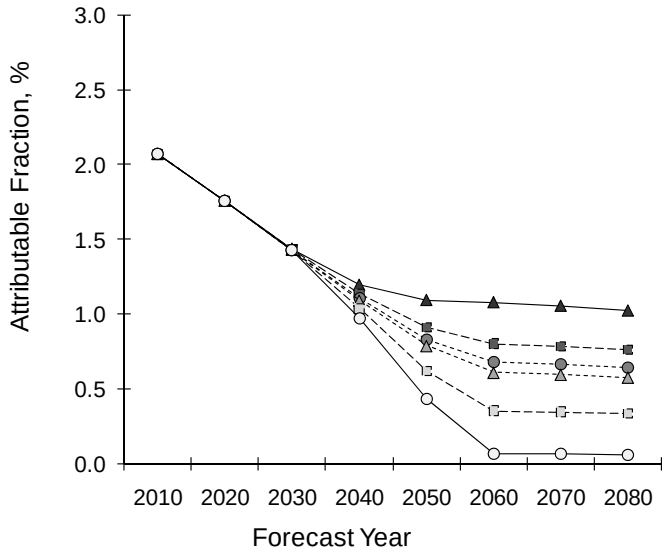
Lung cancer from exposure to RCS

Effect of improved compliance by workplace size

A) Attributable registrations



B) AFs



(1) Baseline: exposure limit 0.1mg/m^3, compliance 33%

(2) Exposure limit 0.05mg/m^3 from 2010, compliance 33% all workplaces

(6) Exposure limit 0.05mg/m^3 from 2010, compliance 33% < 250, self employed; 90% 250+

(7) Exposure limit 0.05mg/m^3 from 2010, compliance 33% < 50, self employed; 90% 50+

(8) Exposure limit 0.05mg/m^3 from 2010, compliance 33% self employed; 90% all sizes employed

(9) Exposure limit 0.05mg/m^3 from 2010, compliance 90% all workplaces

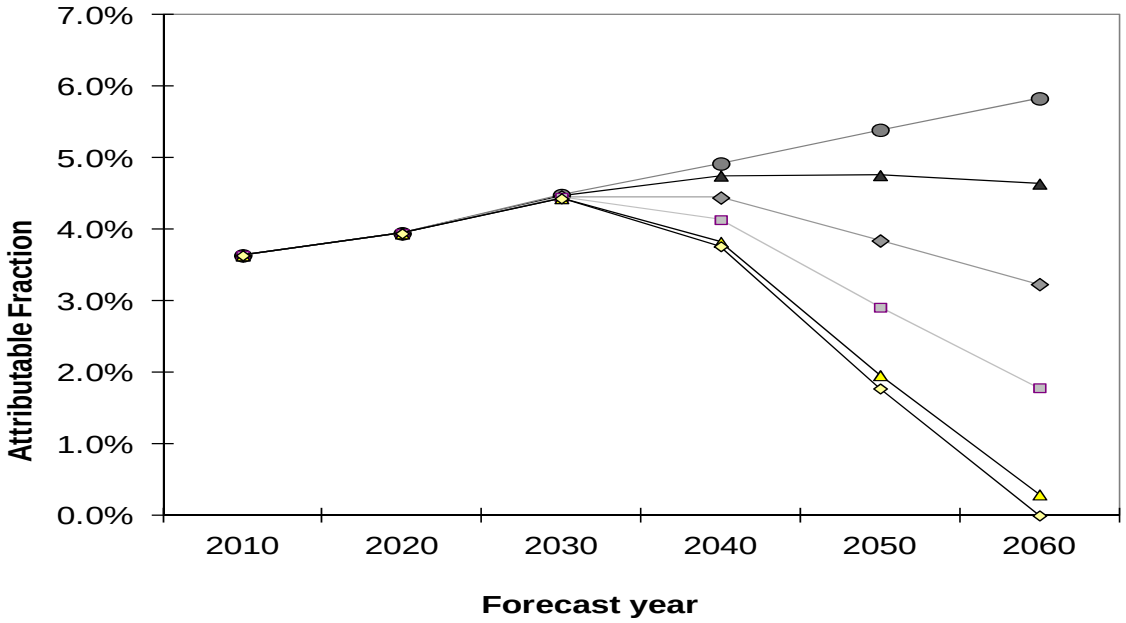
Occupational Circumstances no ‘exposure data’ Example: Shift Work (Night work)

- Breast cancer: AF 4.6%, approx. 555 deaths and 2000 cancer registrations; contributes14.3% of total current occupational cancer burden
- Exposure defined by nature of occupation – unknown agent, no exposure data
- Estimates of numbers of night shift workers from Labour Force Survey and British Airways data
- Evidence of dose response with duration of night work

Duration	Relative Risk	Proportion ‘exposed’
<5 years:	0.95	30%
5-14 years:	1.29	40%
15+ years:	2.21	30%

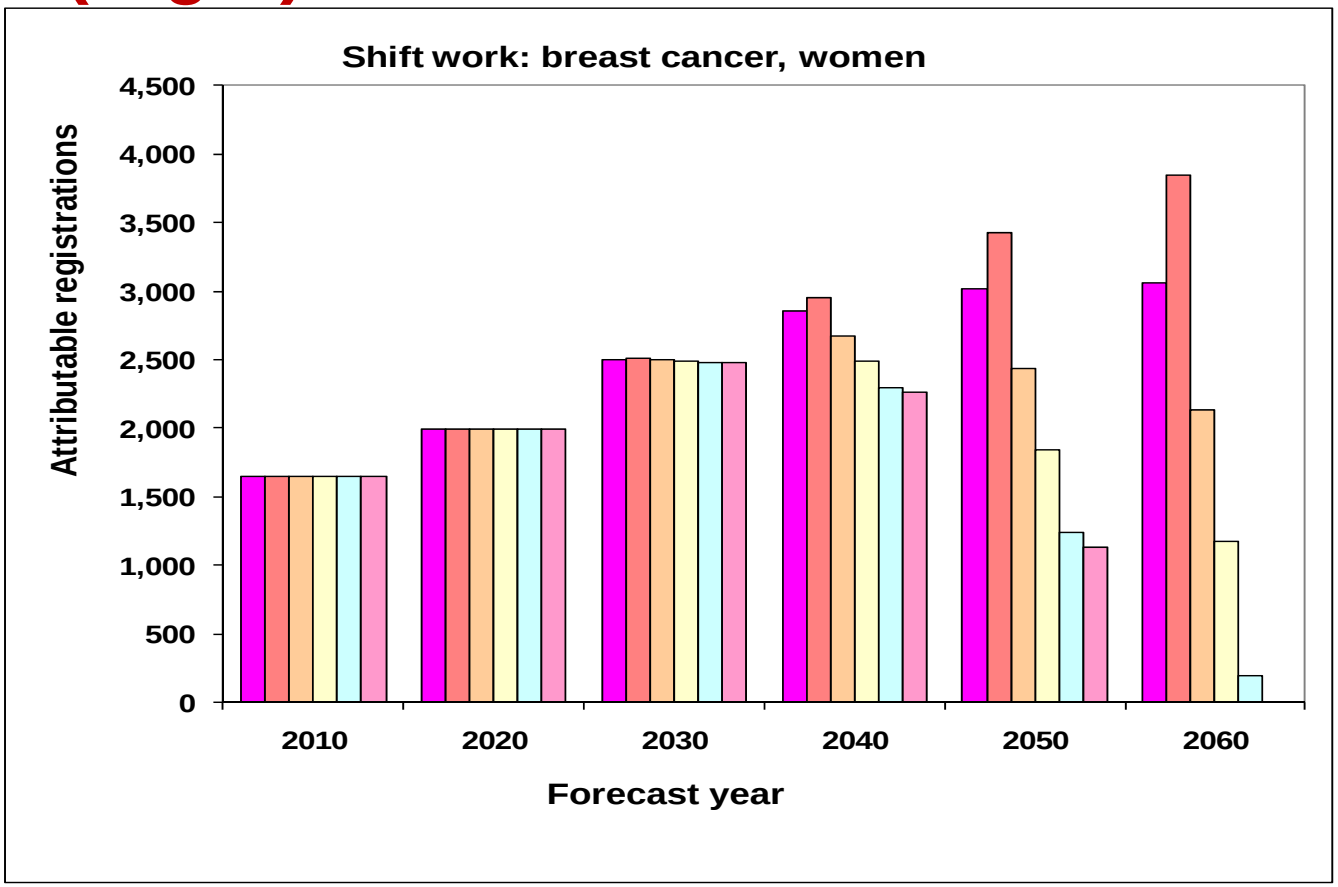
- Intervention scenarios expressed as limiting proportions in night work for durations of 15+ and 5+ years

Night shift work: Breast cancer, women



- Baseline scenario (1): Current (2005) employment levels are maintained, workers assumed exposed in the proportions 30% for 15+ years, 40% 5-14 years, 30% <5 years duration of night-shift working
- Baseline scenario (2): Linear employment trends assumed to 2021-30, constant thereafter, workers assumed exposed in the proportions 30% for 15+ years, 40% 5-14 years, 30% <5 years duration of night-shift working
- Intervention scenario (3): Restrictions on length of employment result in 20% at 15+ years, 30% at 5-14 years and 50% at <5 years duration from 2010
- Intervention scenario (4): Restrictions on length of employment result in 10% at 15+ years, 20% at 5-14 years and 70% at <5 years duration from 2010
- Intervention scenario (5): Restrictions on length of employment result in 0% at 15+ years, 10% at 5-14 years and 90% at <5 years duration from 2010
- Intervention scenario (6): 100% of workers restricted to <5 years duration from 2010

Shift (Night) Work: Attributable Cancers



(1) Current employment levels maintained, 30% <5, 40% 5-14, 30% 15+ years night shift work
(2) Linear employment trends to 2021-30
(3) 50%<5, 30% 5-14, 20% 15+ years night shift work
(4) 70%<5, 20% 5-14, 10% 15+
(5) 90%<5, 10% 5-14, 0% 15+
(6) 100% <5 years

Shift Work Results

Intervention scenario		AFs	AN (regs)	ANs avoided
		2060		
(1)	Current employment levels maintained, 30% <5, 40% 5-14, 30% 15+ years night shift work	4.64%	3062	
(2)	Linear employment trends to 2021-30	5.83%	3848	
Interventions to test the effect of restricting duration of exposure to under 15 years and under 5 years				
(3)	50%<5, 30% 5-14, 20% 15+ years night shift work	3.23%	2134	**928**
(4)	70%<5, 20% 5-14, 10% 15+	1.79%	1178	**1883**
(5)	90%<5, 10% 5-14, 0% 15+	0.29%	194	**2868**
(6)	100% <5 years	0.00%	0	**3062**

Substances with no suitable exposure data
Example: Solar Radiation

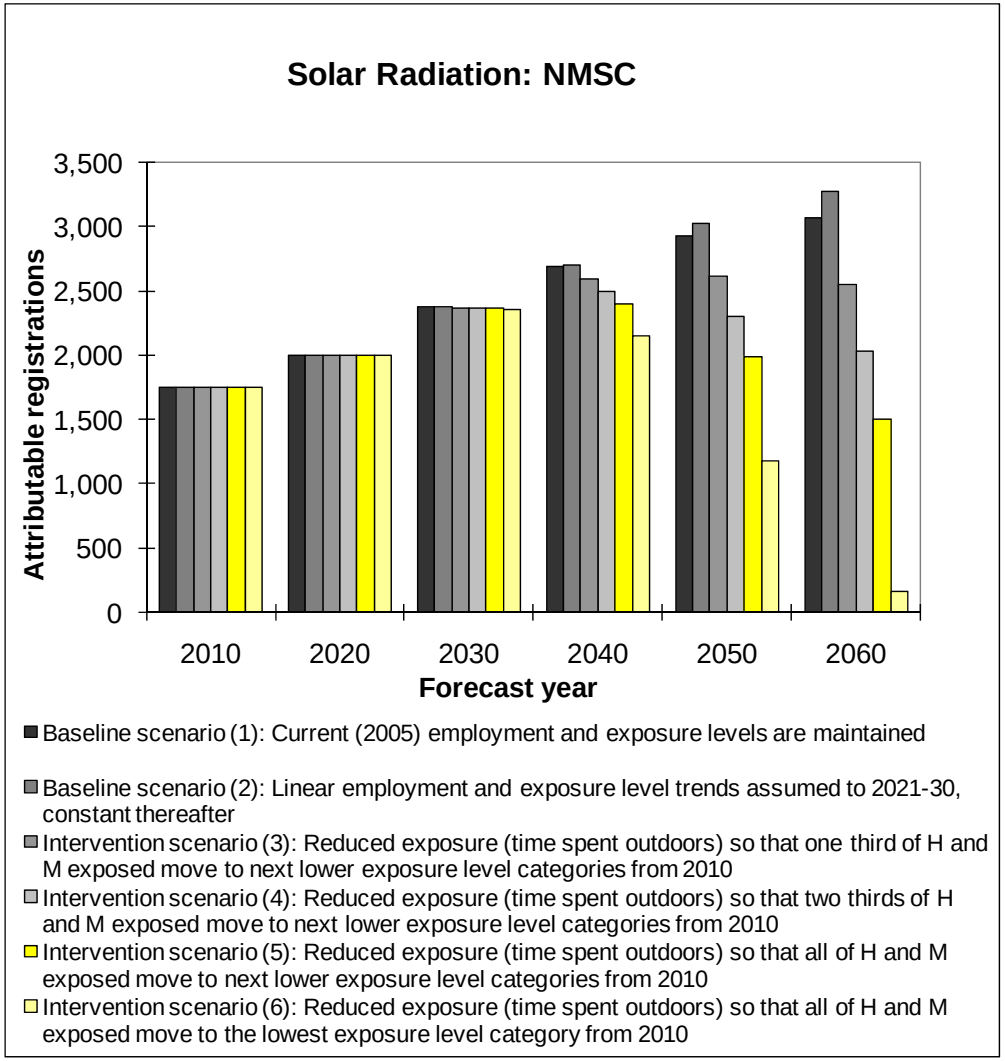
- Non-Melanoma Skin Cancer: AF 6.9%, 23 deaths, 2862 cancer registrations (good survival); contributes11.3% of total current occupational cancer burden
- Numbers exposed characterised as: mainly outdoor (H), farmer (M) and mixed indoor and outdoor (L) exposure

	Relative Risk	Industry Sectors
H	1.30	Fishing, Construction, Utilities, Land and Water Transport, Mining, Petroleum refineries, Armed Forces, Personal & Household Services, Recreational and Sanitary Services
M	1.15	Farming, Forestry
L	1.01	All other industries

- No exposure level data
- Test effect of reduced exposure as moving to lower exposure classes

Solar radiation

- Test reducing outdoor (H) and farmer (M) exposed numbers by 33%, 67% or 100% in 2010
- Attributable cancers fall by 1/6th, 1/3rd or a half by 2060, or
- 95% if all move to the lowest (mixed indoor and outdoor) risk category



Attributable non-melanoma skin cancers due to solar radiation

Intervention scenario		AFs	ANs (regs)	ANs avoided
		2060		
Baseline (1)	Maintain current employment and exposure levels	2.3%	3069	
Baseline (2)	Linear employment and exposure level trends assumed to 2021-30, constant thereafter	2.5%	3279	
(3)	1/3 of H, M exposed -> M, L resp.	1.9%	2552	**517**
(4)	2/3 of H, M exposed -> M, L resp.	1.5%	2030	**1039**
(5)	All H, M exposed -> M, L resp.	1.1%	1503	**1566**
(6)	All H, M exposed -> L exposure level	0.1%	163	**2906**

Solar Radiation: Reduction by industry sector

	Total workers ever exposed over the REP	Attributable Registrations					
Scenario:		**Base (1))**	**Trend (2)**	**(3)**	**(4)**	**(5)**	**(6)**
Industry /Job category		**2060**					
Other mining	48,213	25	10	21	17	13	1
Electricity, gas and steam	90,181	41	15	34	27	21	1
Water works and supply	44,451	20	7	17	13	10	1
Fishing	27,831	17	12	14	12	9	1
Construction	1,623,493	1463	1565	1225	985	742	50
Public administration and defence	441,359	542	620	454	365	275	19
Sanitary and similar services	145,433	149	180	125	100	75	5
Personal and household services	29,131	30	36	25	20	15	1
Recreational and cultural services	118,132	121	146	101	81	61	4
Land transport	372,474	382	461	319	256	193	13
Water transport	39,171	40	48	34	27	20	1
Forestry and logging	33,967	10	7	7	4	1	1
Agriculture and hunting	549,572	169	115	117	64	11	12
Total	5,563,663	3069	3279	2552	2030	1503	163

Forecast cancers attributable to leading occupational carcinogens for a range of baseline and intervention scenarios, 2060

		Attributable Numbers of Cancer Registrations						
		Scenarios						
		All	Base (1)	Trend (2)	(3)	(4)	(5)	(6)
Exposure	**Cancer Site**	**2010**	**2060**					
Exposure defined by agent; no appropriate exposure measurements								
ETS	Lung	1465	0	0	67	156		
Coal tars	NMSC	489	800	877	602	475	433	402
Radon	Lung	220	379	411	341	317	309	190
Solar radiation	NMSC	1749	3069	3279	2552	2030	1503	163
Occupational circumstances, no specified carcinogen								
Painters	Bladder, Lung, Stomach	461	640	639	481	383	347	321
Shift work	Breast	1649	3062	3848	2134	1178	194	0
Welders	Lung	189	140	63	105	83	76	70
Carcinogens for which exposure standards can be set								
Arsenic	Lung	128	92	47	92	88	87	87
Asbestos	Larynx, Lung Mesothelioma, Stomach	4281	2759	2864	2785	2689	2626	2307
Diesel	Bladder, Lung	380	406	399	451	412	374	34
Silica	Lung	837	794	442	102	49	21	10
Strong acids	Larynx, Lung	122	39	7	19	12	10	12
TCDD (Dioxins)	Lung, NHL, STS	286	123	30	22	8	5	6
Tetrachloro-ethylene	Cervix, NHL, Oesophagus	139	135	119	123	118	117	119
Total		12050	12327	12938	9812	7944	6064	3705

Summary of Results

- 14 agents account for 85.7% current occupation attributable cancer (2004), 12,000 cancers in 2010
- Will rise to nearly 13,000 by 2060 given current trends in employment and exposure levels (>12,300 if current levels maintained). Aging population is a factor.
- No impact seen until 2030 because of general increase in cancers due to aging population
- With modest intervention (e.g. scenario 3) over 2,000 cancers can be avoided (including 376 lung, 928 breast cancers, 432 NMSC)
- With stronger interventions (e.g. scenario 6) nearly 8,500 can be avoided (including 1,732 lung, 3,062 breast and 3,287 NMSC)
- Effective interventions
  - Silica - improve compliance
  - DEE - need for v. low exposure limit indicated
  - Shift work – If increasing risk with duration of exposure is valid then limiting years of night work reduces burden

Monitoring success

- **Monitor exposure levels**
- No reduction in cancer levels until 2030 at earliest (solid tumours)
- After 2030
  - Use achieved exposed numbers/proportions exposed at new exposure levels in same (target setting) forecast model to get achieved AF
  - Apply achieved AF to same (2005 based) cancer projections to get achieved attributable numbers
  - Do not apply achieved AF to real 2030 cancer numbers

Uncertainties and the impact on the burden estimation

Source of Uncertainty	Potential impact on burden estimate
Exclusion of IARC group 2B and unknown carcinogens e.g. for electrical workers and leukaemia	↓
Inappropriate choice of source study for risk estimate	↑↓
Imprecision in source risk estimate	↑↓
Source risk estimate from study of highly exposed workers applied to lower exposed target population	↑
Risk estimate biased down by healthy worker effect, exposure misclassification in both study and reference population	↓
Inaccurate latency/risk exposure period, e.g. most recent 20 years used for leukaemia, up to 50 years solid tumours	↓
Effect of unmeasured confounders	↑↓
Unknown proportion exposed at different levels	↑↓

Summary

- Adapted for WHO Global Burden update; Used to inform socio-economic impact analysis of effect of introducing limits for certain carcinogens for DG Employment; HSE costs of workplace illness will include cancer for the first time.
- On-going work: Evaluation of impact of source of bias and uncertainty
- Outputs: Current burden results
  - Preliminary work on 6 cancer sites: Occupational and Environmental Medicine 2008, 65, 789-800;
  - Results from all sites: British Journal of Cancer 2010, 102: 1428-1437 + Technical report on HSE website
  - Supplement (13 papers) submitted on current burden detailed results to BJC, 2011 + approx. 24 technical reports + database
  - Paper in preparation reporting DALYs/inequality of burden
- Outputs: Future burden
  - Methodology paper: American Journal of Epidemiology 2011, 173, 1069-1077+ technical report on HSE website
  - Future burden results: in preparation