	Atmospheric nuclear weapons test		Chernobyl	
	Global	Sweden	Global	Sweden
All nuclides (PBq)	2,600,000		5,300†	
Cs-137 (PBq)	890‡	1.25‡	89‡	4.25‡
Collective dose, excl ^{14}C (manSv)	4,500,000‡	10,000‡	600,000‡	6,000‡
Malignancies 1986-2036 ICRP 60	225,000	500	30,000	300
Malignancies 1988-1999 Tondel 2006				1,278

‡ Moberg, ed. The Chernobyl fallout in Sweden, 1991.

† UNSCEAR 2000

Increased incidence of malignancies in Sweden after the Chernobyl accident–a promoting effect?

Am J Ind Med 2006 Mar;49(3):159-68

Authors´ affiliations

Martin Tondel, Peter Lindgren, Bodil Persson
Division of Occupational and Environmental Medicine, Department of Molecular and Clinical Medicine, Faculty of Health Sciences, Linköping University, Linköping, Sweden

Peter Hjalmarsson
Department of Health and Society, Division of Social Medicine and Public Health Science, Linköping University, Linköping, Sweden

Lennart Hardell
Department of Oncology, University Hospital, Örebro, Sweden

- Inhabitants in 8 out of 21 counties in Sweden
- 0-60 years old 1986
- Same address, Dec 31, 1985 and Dec 31, 1987

Dwelling coordinate (100 m) National Land Survey of Sweden

Digital maps (200 x 200 m) Geological Survey of Sweden (TGR) and Swedish Radiation Protection Authority (Cs-137)

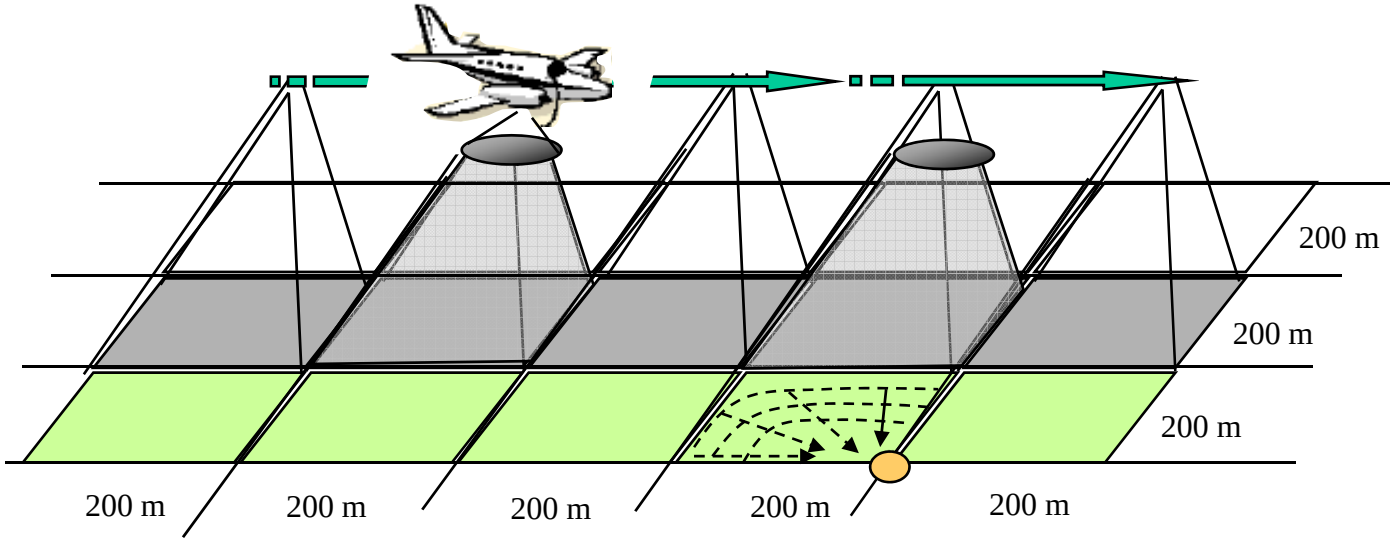
GIS-technique to match dwelling coordinate with TGR and Cs-137

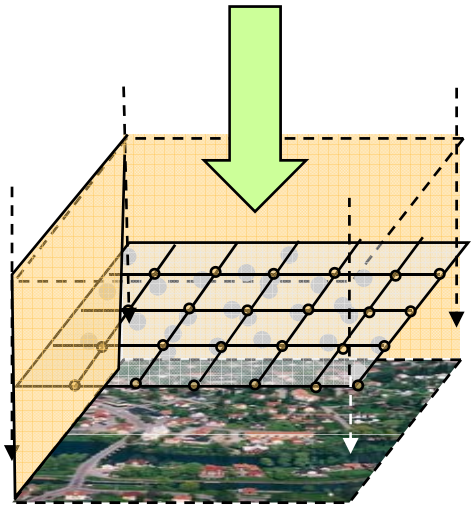
Categories for TGR and Cs-137 with the same proportions of population (30-25-20-15-5-5%)

Number of people and cases of malignancies

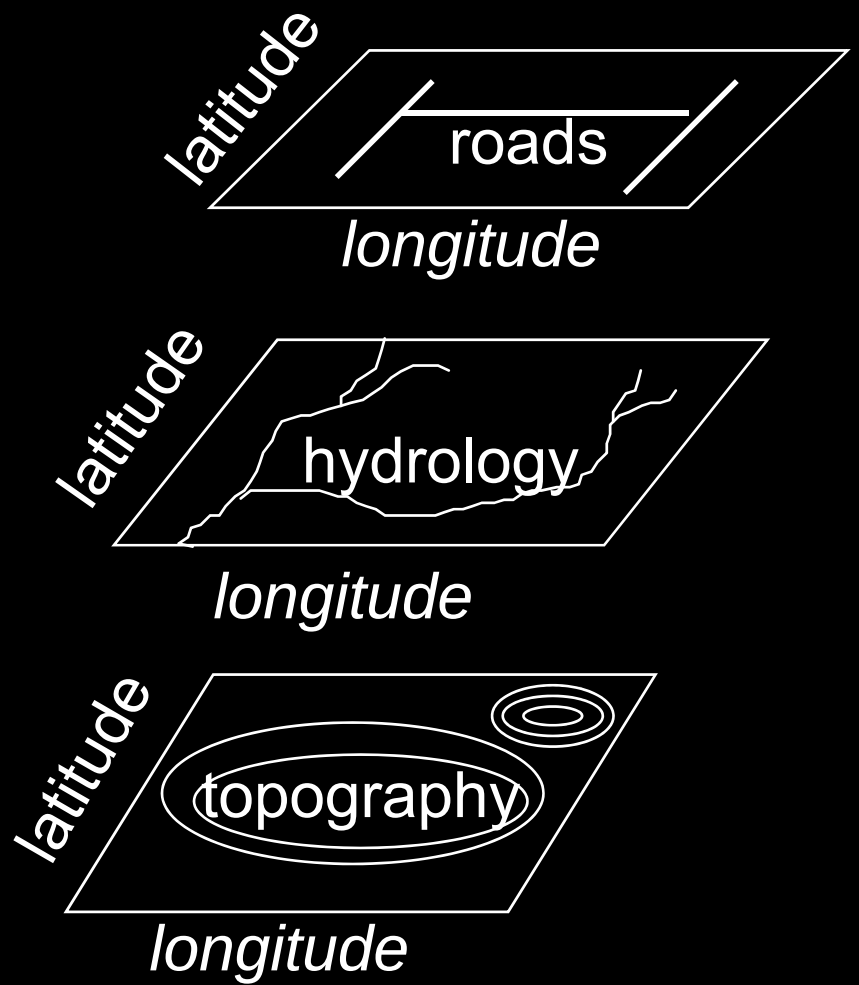
Cs-137 nGy/h	Population 1988 (%)	Malignancies 1988-1999
0-8	350,387 (30.8)	10,212
9-23	277,518 (24.4)	8,164
24-43	216,588 (19.1)	6,491
44-66	178,875 (15.7)	5,531
67-84	57,014 (5.0)	1,735
$\geq$ 85	56,724 (5.0)	1,718
Total	1,137,106 (100.0)	33,851

From airborne measurements to digital map



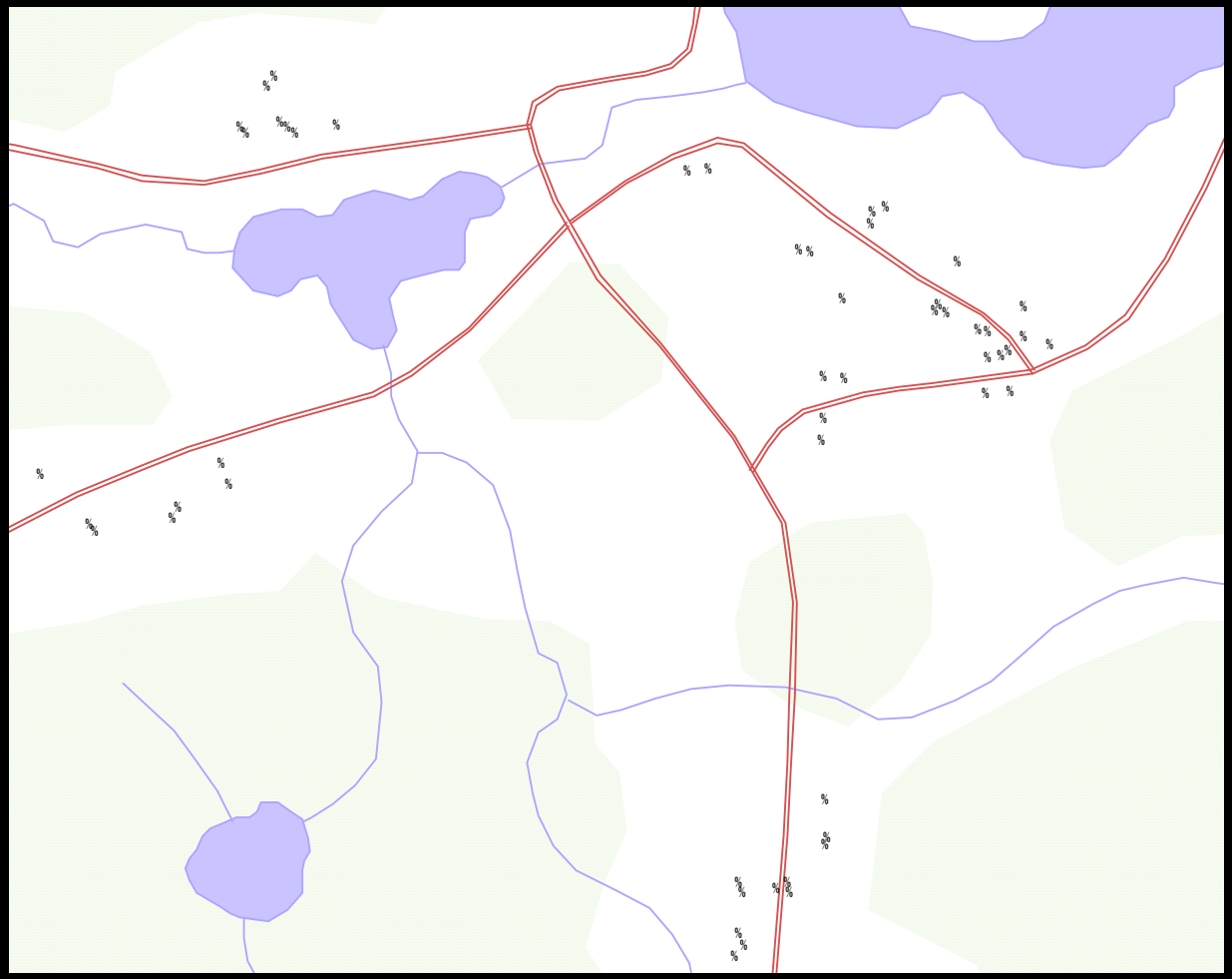


GIS - example of layers



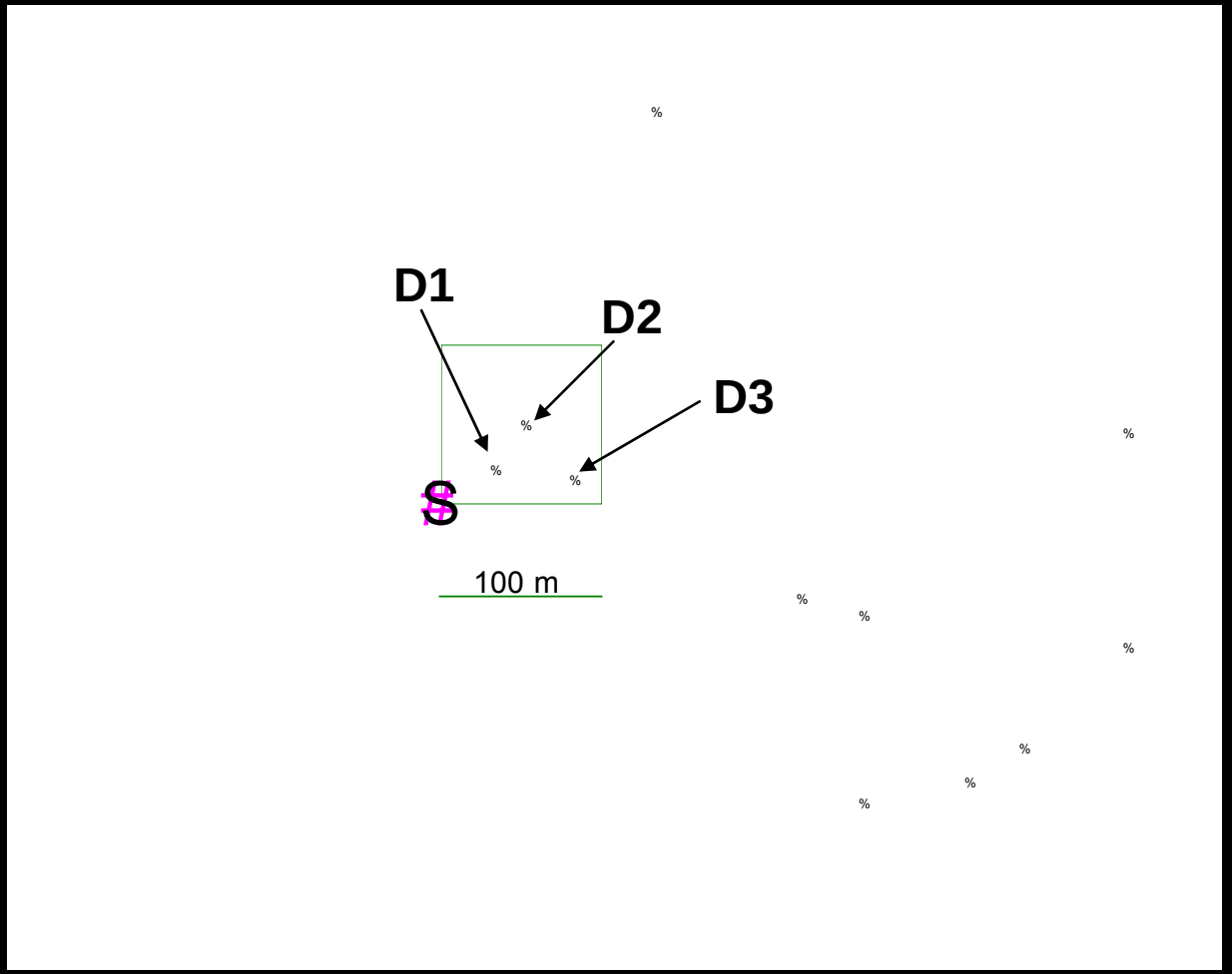
GIS - map

- grid
- caesium-137
- coordinate points
- V dwellings
- V roads
- V lakes
- V forest



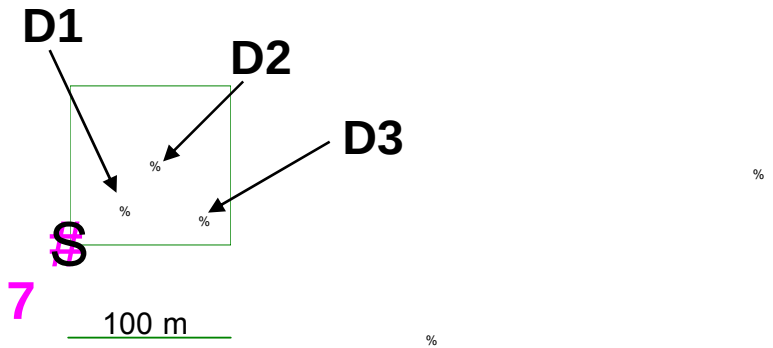
GIS – dwellings at a coordinate

- grid
- caesium-137
- V coordinate points
- V dwellings
- roads
- lakes
- forest



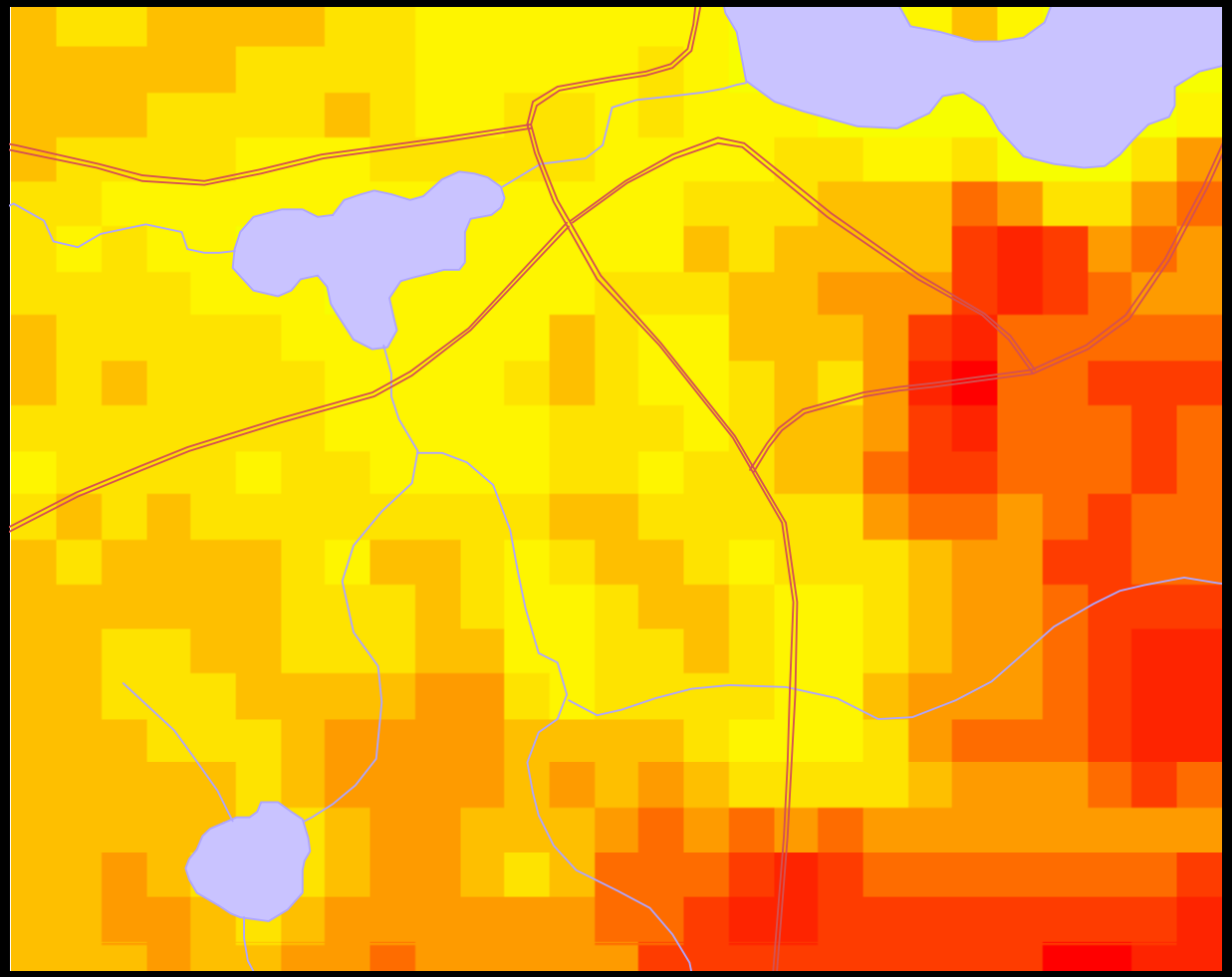
GIS – individuals at a coordinate

Id	Born	Sex	Dwelling	Coordinate id
391	1919	M	D1	15672
221	1982	M	D2	15672
235	1983	F	D2	15672
236	1974	M	D3	15672
237	1978	F	D3	15672
508	2000	M	D3	15672
509	2004	M	D3	15672



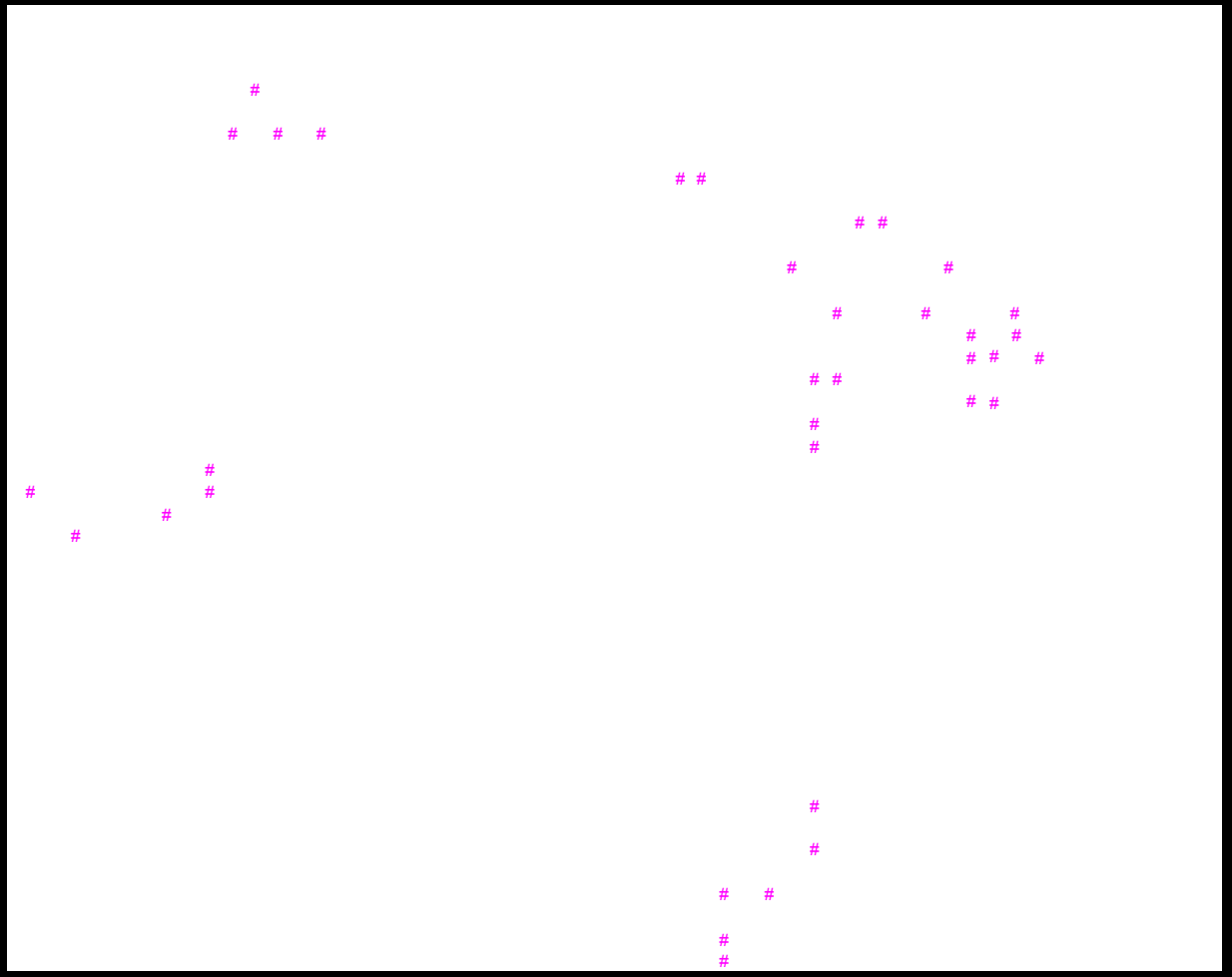
GIS – Cs-137 map

- grid
- √ caesium-137
- coordinate points
- dwellings
- √ roads
- √ lakes
- forest



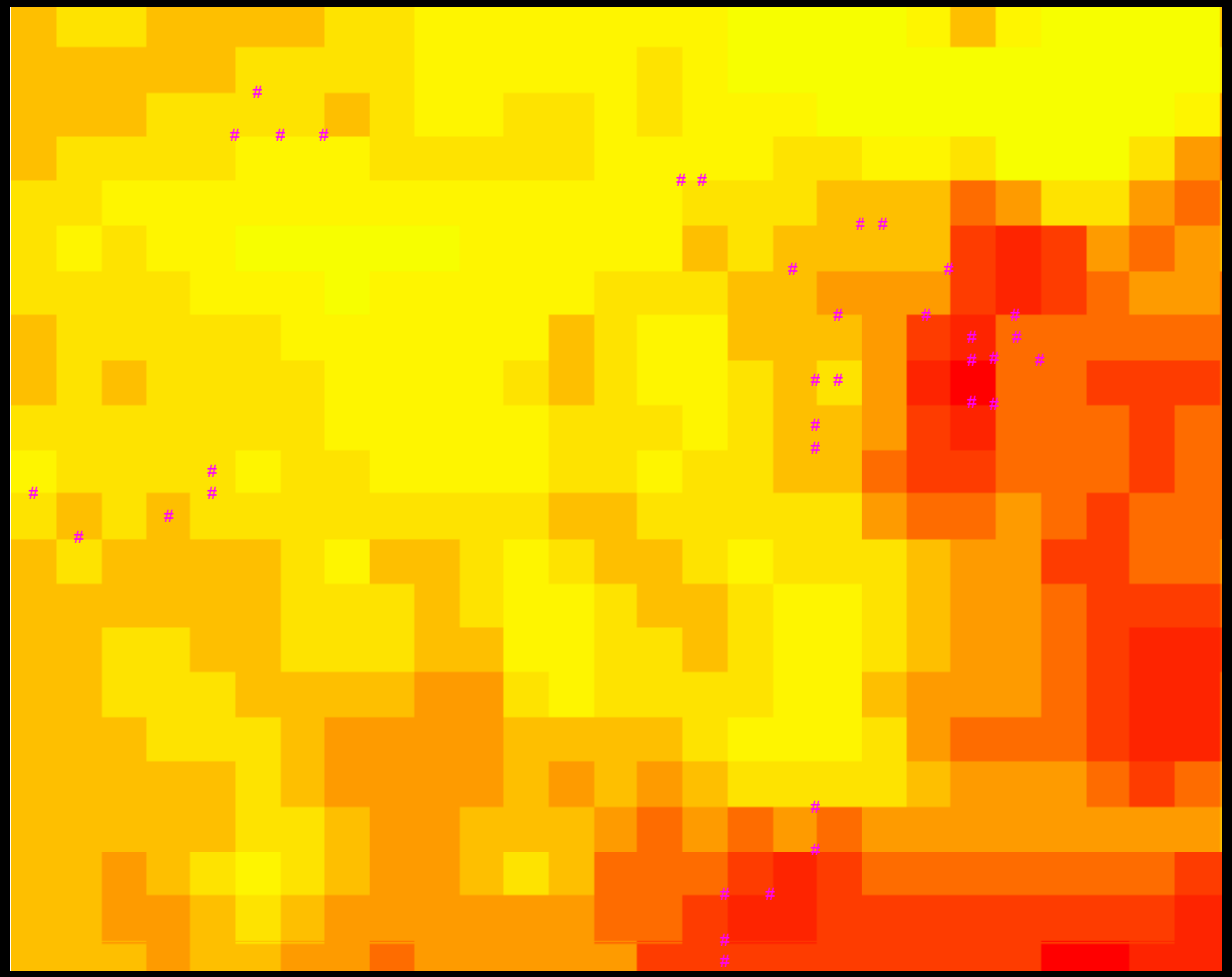
GIS – coordinates

- grid
- caesium-137
- V coordinate points
- dwellings
- roads
- lakes
- forest



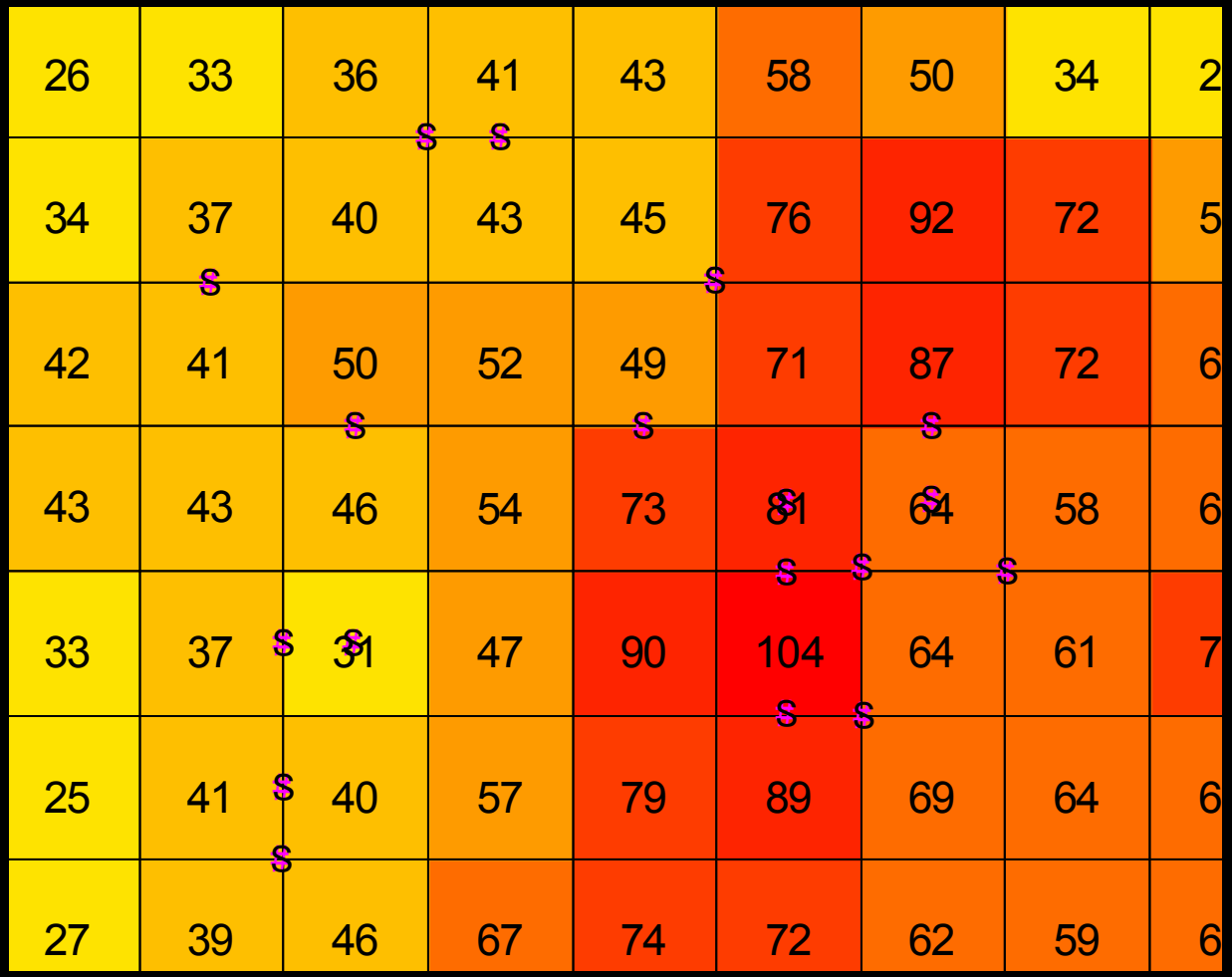
GIS – overlay Cs-137 and coordinates

- grid
- V caesium-137
- V coordinate points
- dwellings
- roads
- lakes
- forest

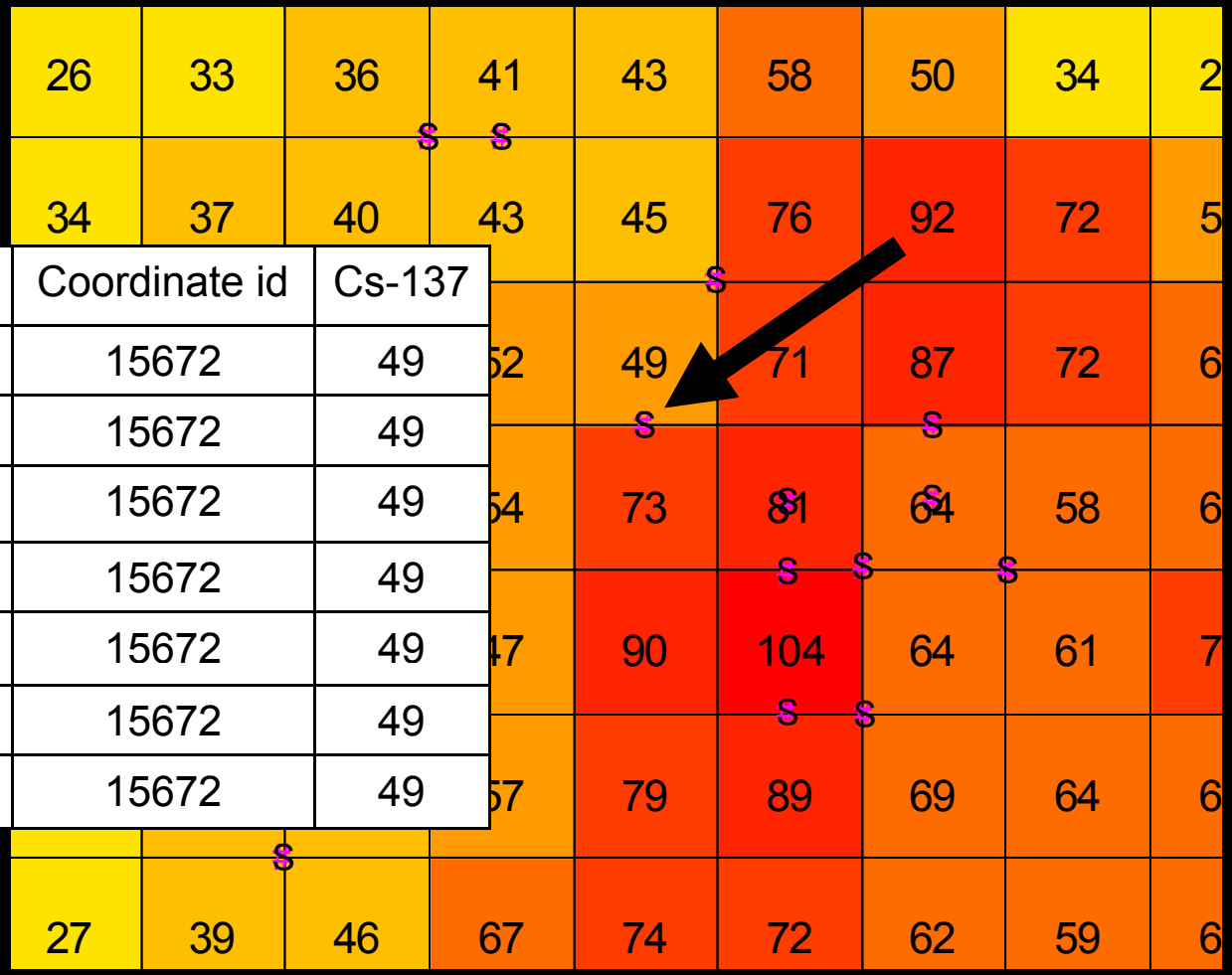


GIS – geometric join

- grid
- caesium-137
- coordinate points
- dwellings
- roads
- lakes
- forest



GIS – individuals and exposure



Id	Born	Sex	Dwelling	Coordinate id	Cs-137
391	1919	M	D1	15672	49
221	1982	M	D2	15672	49
235	1983	F	D2	15672	49
236	1974	M	D3	15672	49
237	1978	F	D3	15672	49
508	2000	M	D3	15672	49
509	2004	M	D3	15672	49

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MH-IRR, EAR and ERR adjusted for:

A. Population density by parish

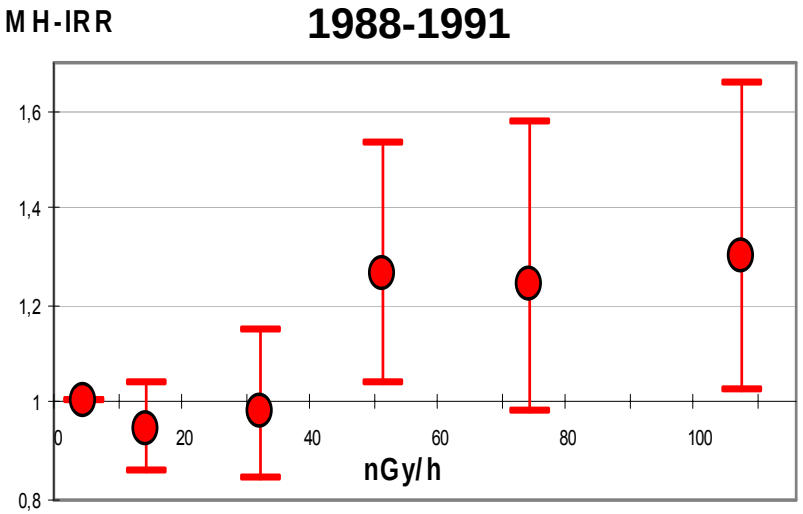
B. Population density by municipality (H-regions)

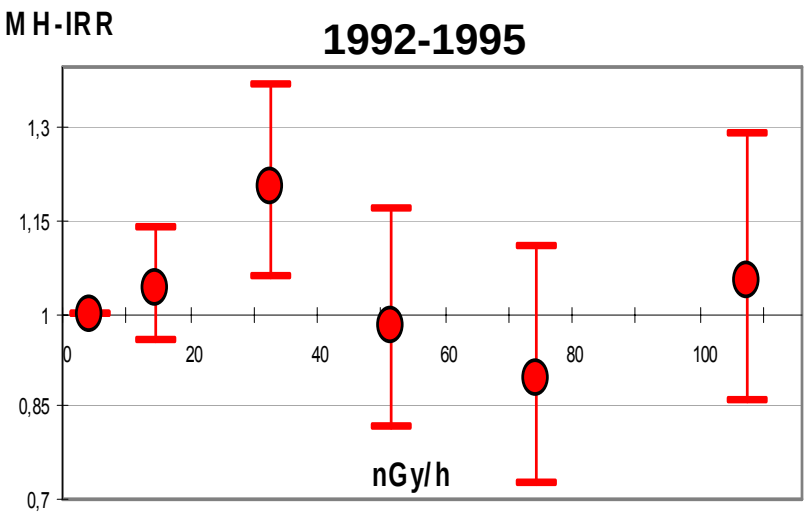
C. Lungcancer 1988-1996 by municipality (proxy for smoking)

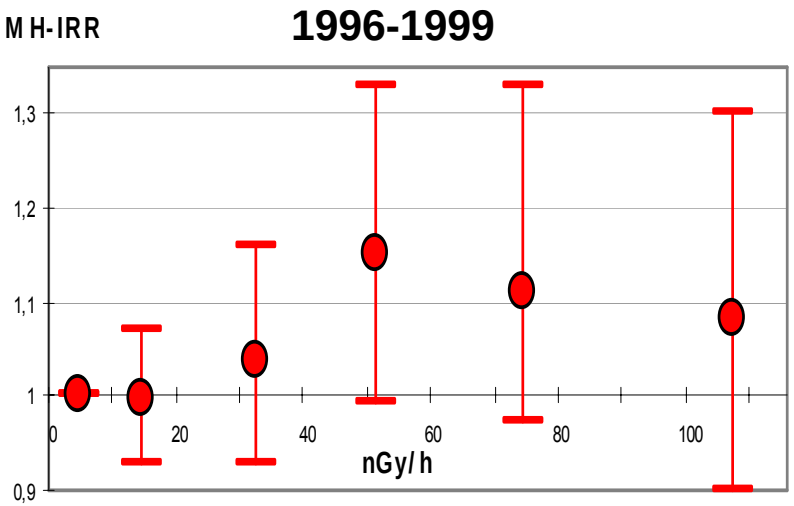
D. Total cancer incidence 1986-1987 (geographic difference)

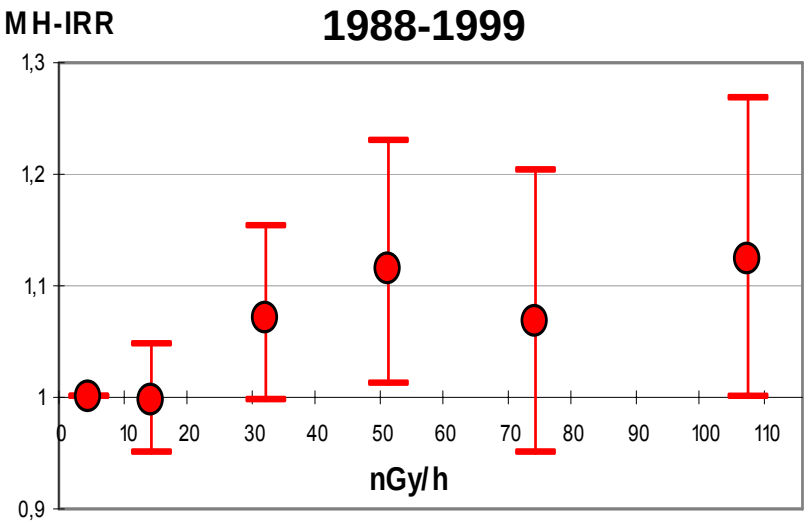
E. Terrestrial Gamma Radiation (TGR)

Total malignancies









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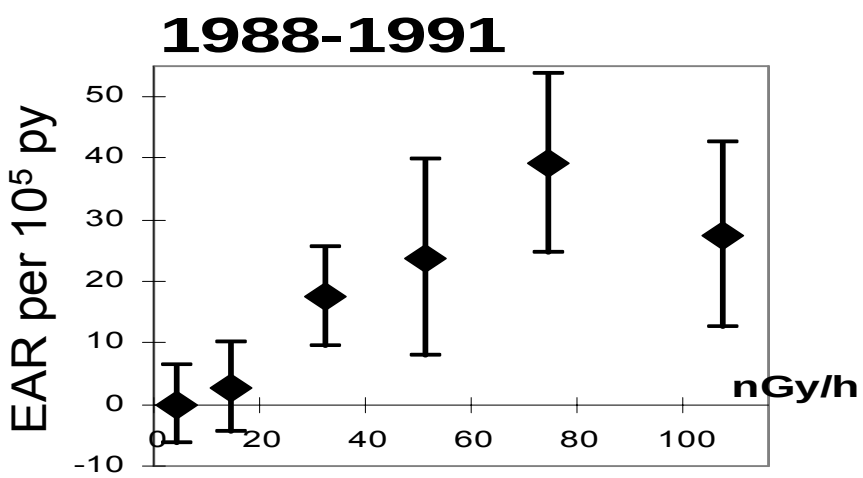
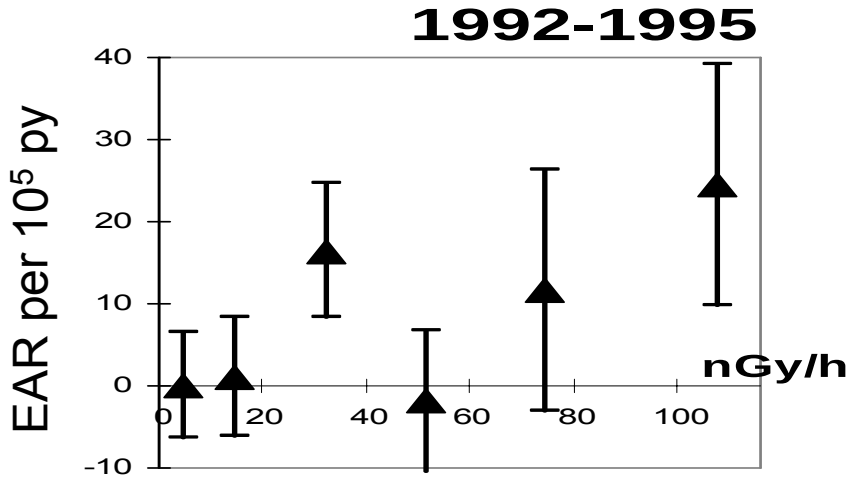
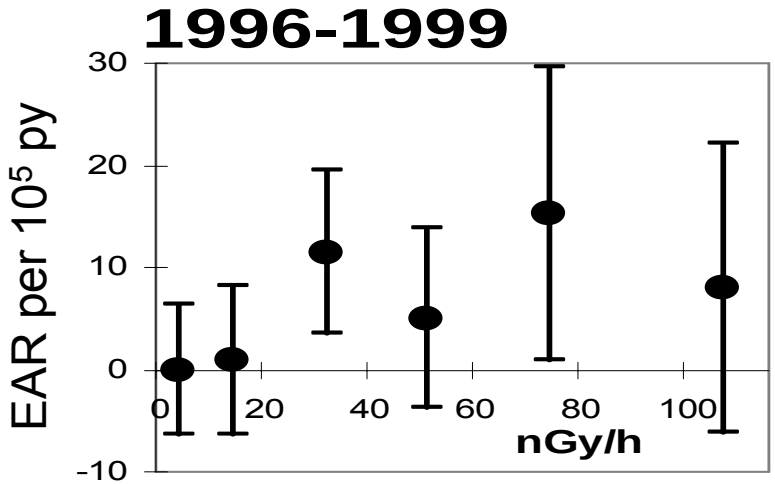
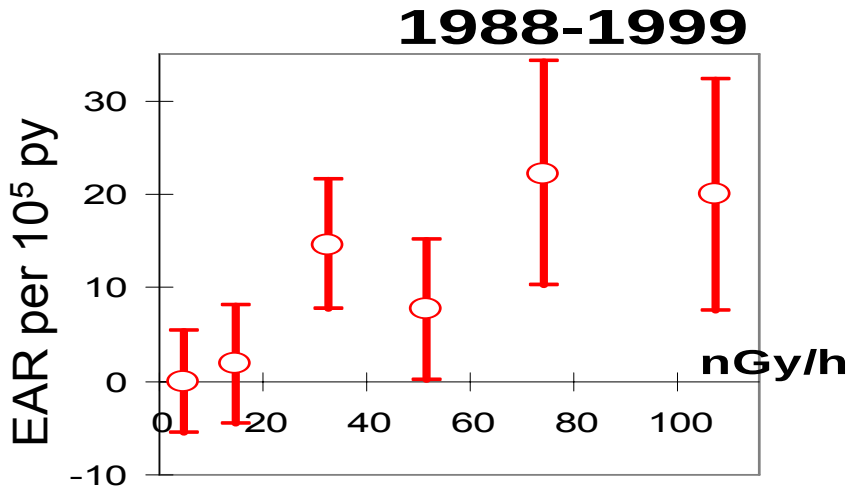
Total malignancies









Conclusion

- Increase in the incidence of total malignancies related to increasing caesium radiation in the time period 1988-1991 which contributes to the increase in the follow-up period 1988-1999.

  After control for confounding factors this increase can be seen in MH-IRR, EAR and ERR.

Environmental	
	Average (min-max)
Radon	0.8 (0.2-10)
Indoor γ	0.54 (0.08-11)
Cosmic	0.34 (0.30-0.50)
Food/water	0.17 (0-10)
K-40	0.16 (0.08-0.25)
Outdoor γ	0.045 (0-1)
Sum	**2.055 (0.66-32.75)**

Man-made	
	Average (min-max)
Medical	0.9 (0.010-100)
Flight	0.024 (0-3.4)
Chernobyl - External - Internal	 0.008 (0-0.500) 0.0025 (0-2)
Sum	**0.9345 (0.010-105.9)**

Annual effective dose (mSv) in Sweden 2005

SSI-rapport 2007:2

Total 2.9895

(0.67-138.65)

Transfer of 137Cs from Chernobyl debris and nuclear weapons fallout to different Swedish population groups

Rääf, Hubbard, Falk, Ågren, Vesanen. Sci Total Environ 2006;367:324-340

Effective dose over a 70 y period:

1. general Swedish population 20–30 μSv/kBq m^{-2}
2. reindeer herders ~700 μSv/kBq m^{-2}
3. hunters ~100 μSv/kBq m^{-2}
4. rural non-farming populations 40–150 μSv/kBq m^{-2}
5. farmers ~50 μSv/kBq m^{-2}

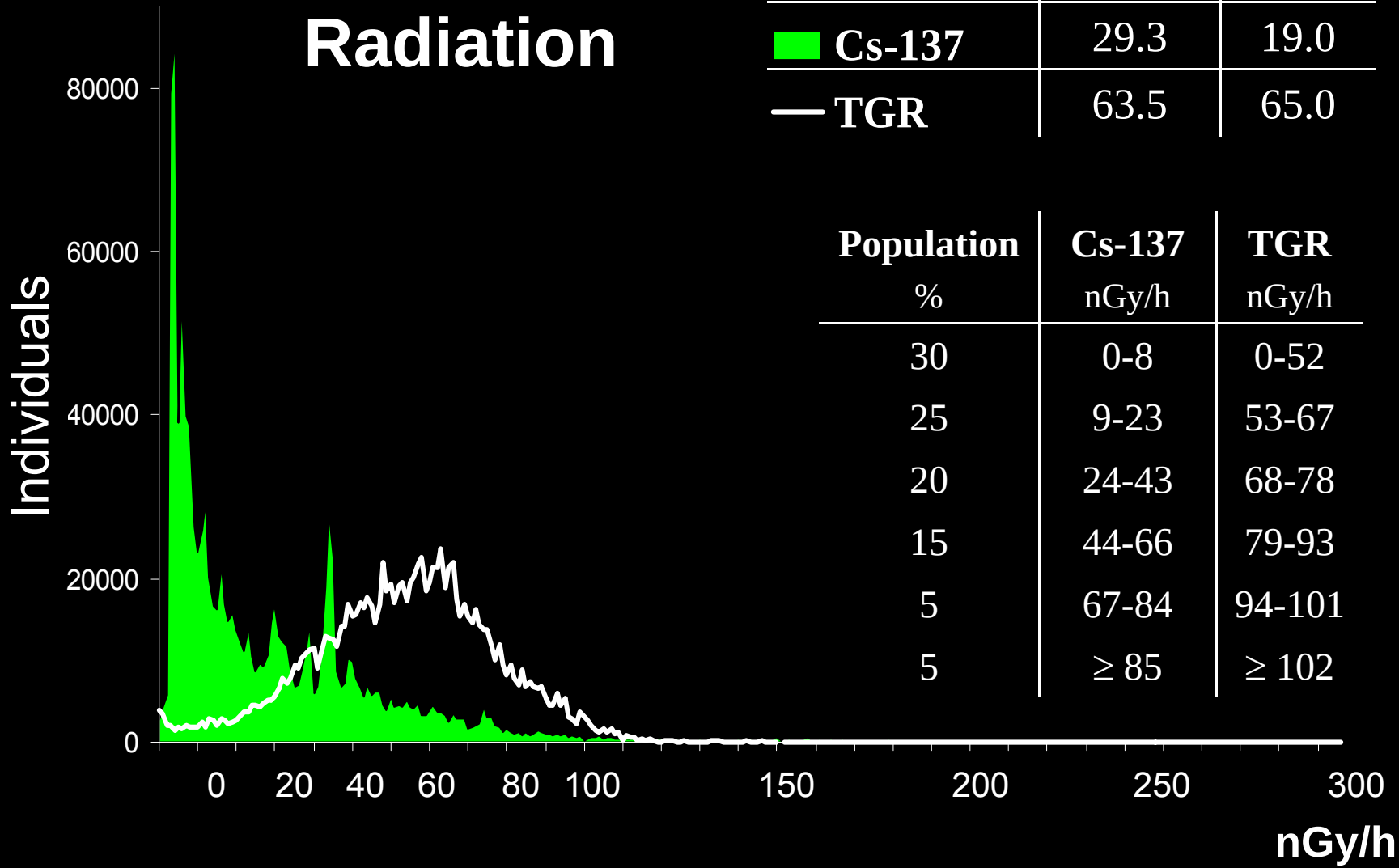
Transfer from ground deposition determined by:

1. dietary habits
2. inclination to follow the recommended food restriction by the authorities

Transfer to the general population is a factor 3 lower for the Chernobyl fallout than nuclear weapons fallout due to:

1. higher awareness of the public and authorities
2. nuclear weapons fallout during the growth season

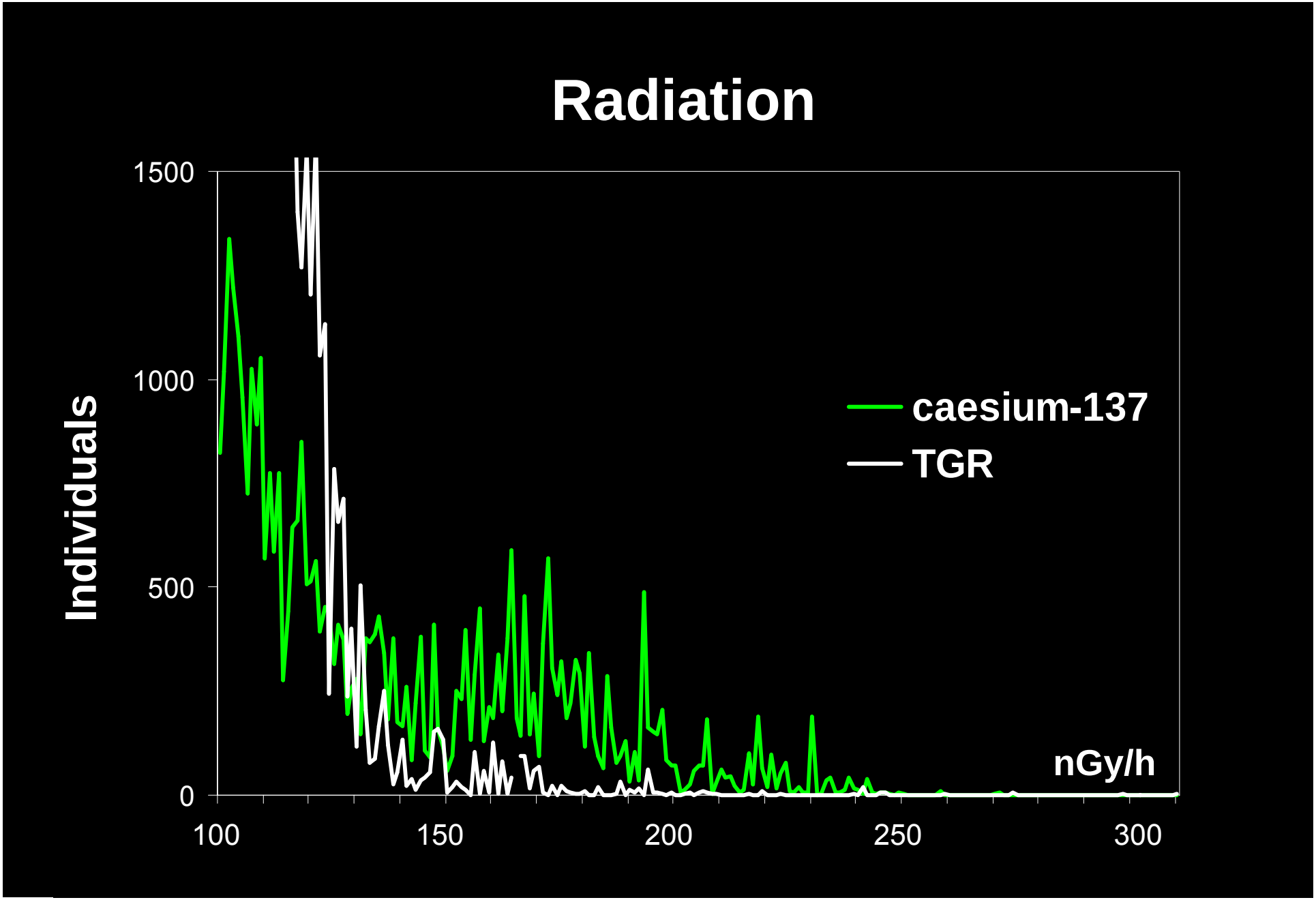
Radiation



nGy/h	mean	median
Cs-137	29.3	19.0
TGR	63.5	65.0

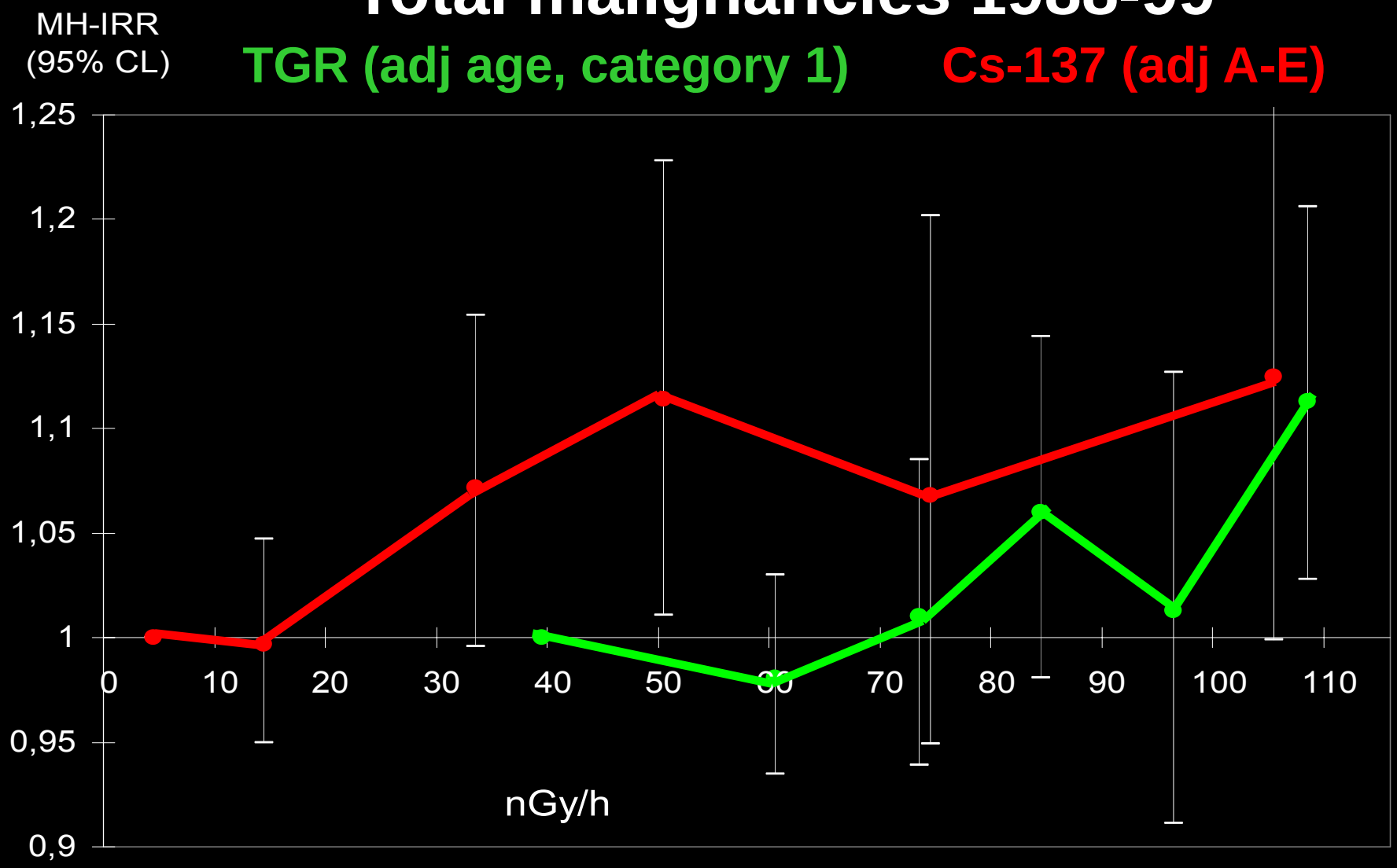
Population %	Cs-137 nGy/h	TGR nGy/h
30	0-8	0-52
25	9-23	53-67
20	24-43	68-78
15	44-66	79-93
5	67-84	94-101
5	≥ 85	≥ 102

Radiation


Individuals
1500
1000
500
0
100
150
200
250
300
caesium-137
TGR
nGy/h

Total malignancies 1988-99

Total malignancies 1988-99



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Cohorts	Follow-up period	Malignancies (n)	Person-years	Dose (mSv)	ERR per Sv (95% CL)
Chernobyl	1988-1999	33,851‡	13,391,362	0-10	10 (0;23)
Atom bombs	1950-2000	10,127†	3,184,354	5-3,000	0.42 (0.33;0.51)
Semipalatinsk	1960-1999	889†	582,750	20-4,000	1.77 (1.35;2.27)

‡ incident cases of total malignancies

† deaths in all solid cancer

The Excess Relative Risk (ERR):

RR-1 in the fully adjusted model using the Poisson regression

Dose rate as a continuous variable

The ERR 0.042 per 100 nGy/h (95% CL 0.001;0.084)

Excess Absolute Risk (EAR per 10^5 person-years)

$$SIRD_{ij} = (SIR_{ij} - SIR_{jk})$$
$$EAR_{ij} = (SIRD_{ij} – SIRD_{0i})$$

i = time period or follow-up,
j = exposure category,
k = 1986-1987,
0 = reference category (0-8 nGy/h).

By definition $SIRD_{0i}$ is not influenced by the exposure i.e. is an underlying time trend or secular trend.

	Hiroshima-Nagasaki, Japan	Chernobyl accident, USSR
Source	Atomic bombs	Nuclear power plant explosion
Exposure	Instant high 1945	Protracted low since 1986
Radiation	Neutron, gamma	Gamma
Route of exposure	External	External and internal
Dose assessment	Final dosimetry 2002?	Ongoing
Follow-up	1950-	1986-
Population	Two cities, 560,000 in 1945	Europe, 572,000,000 in 1986
Malignancies	Mortality	Incidence, mortality
Strength	Already long time follow-up High doses Individual dose assessment	Long time follow-up in future Low doses Dose assessment from 1986
Weakness	No data 1945-1950 Few persons with low dose Extrapolation to low dose	Short follow-up period Few persons with high dose No individual dose assessment