EURADOS European Radiation Dosimetry Group

Politecnico di Milano

9th EURADOS Winter School "Dosimetry for epidemiological cohorts"

DOSIMETRY FOR NUCLEAR WORKERS

Isabelle Thierry-Chef, on behalf of the INWORKS study group

International Agency for Research on Cancer

World Health Organization

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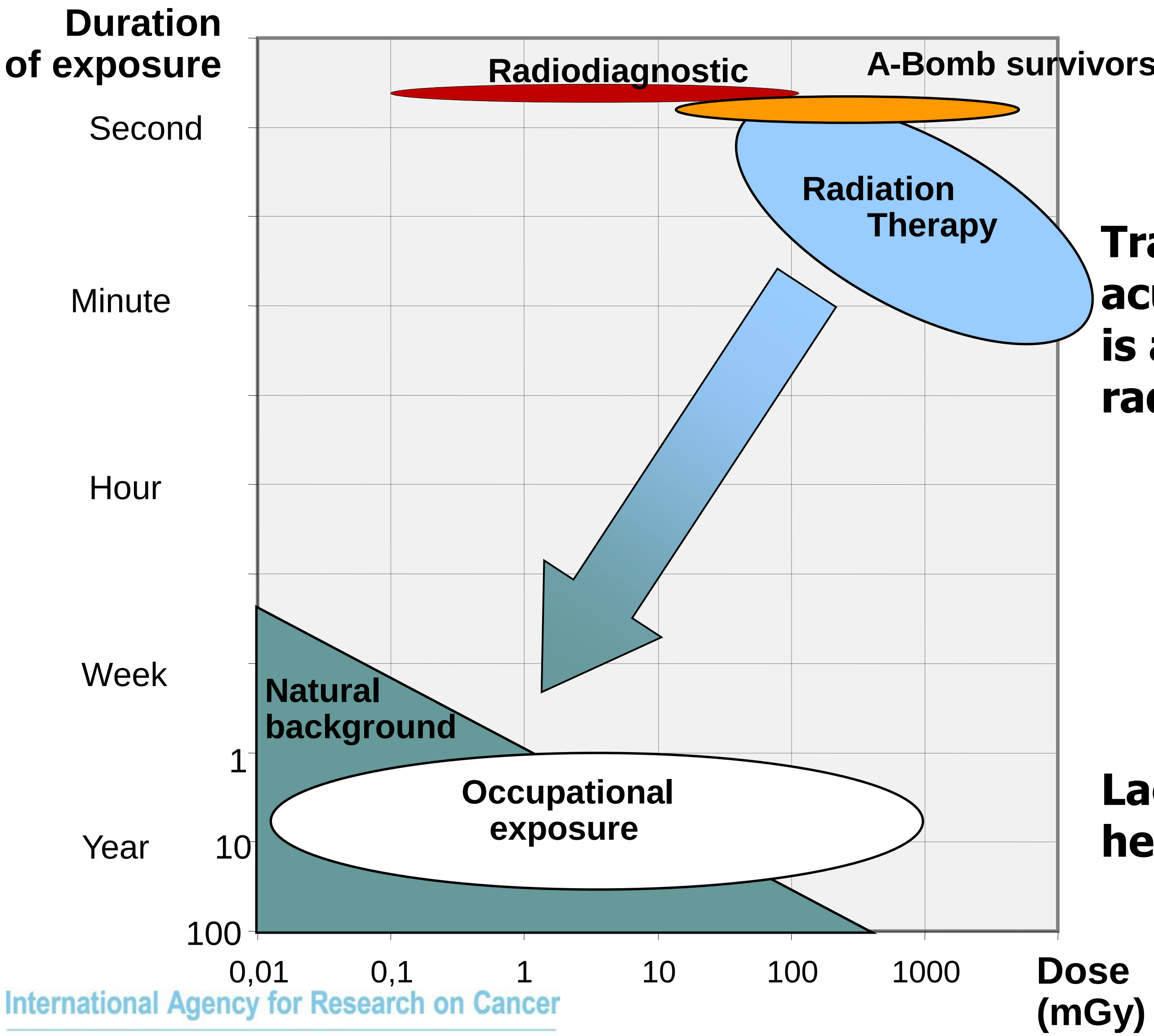
Extrapolation from acute to protracted low doses



Transposition of risks from acute to chronic exposure is a major hypothesis of the radiation protection system

Lack of information on health effects of low dose

Courtesy of Dr Laurier, IRSN

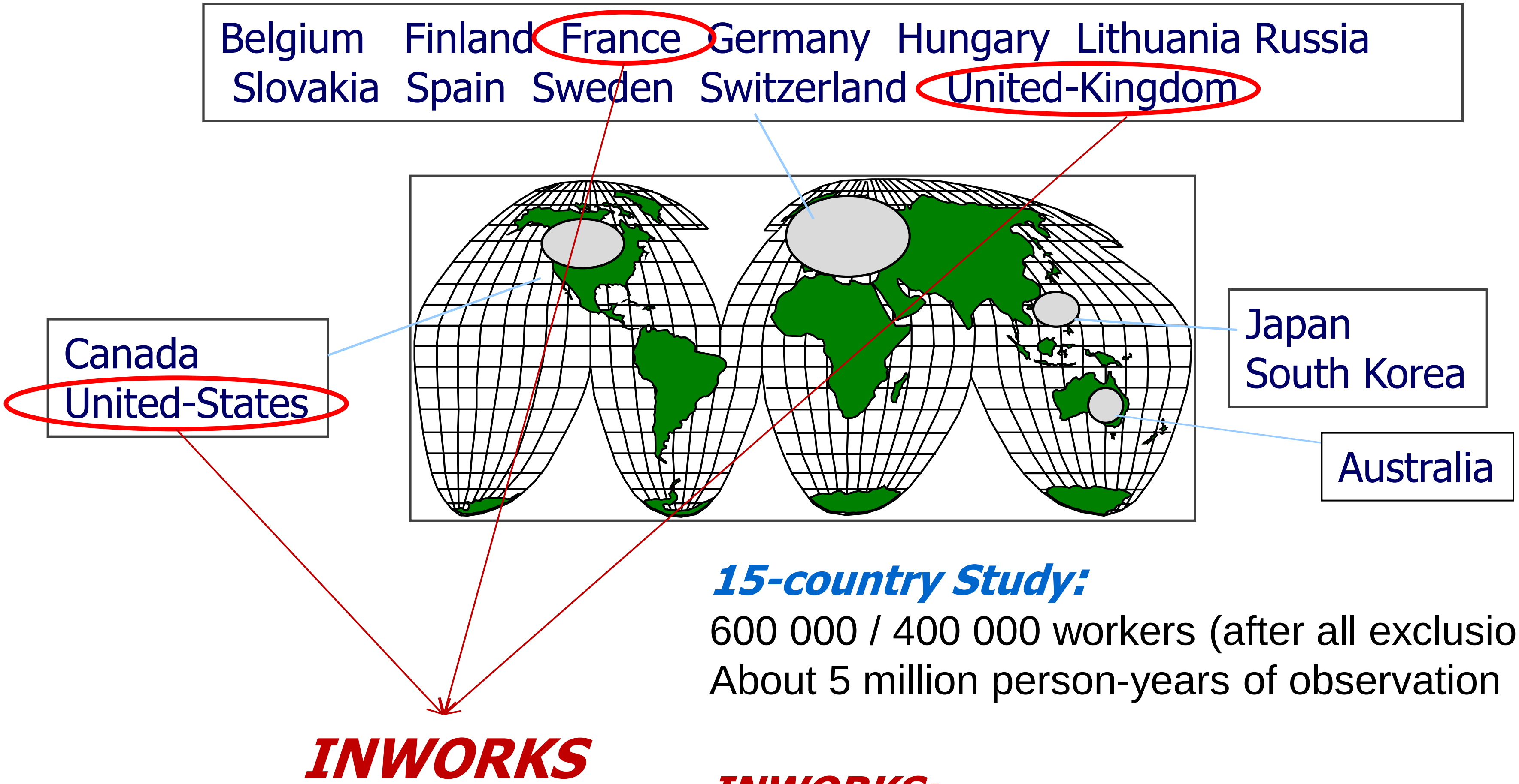
Advantages of Nuclear Workers

- **Well defined and stable population, since mid 40s**
- **Large cohort with**
  - **Stable work history and good quality of follow-up**
  - **Individual monitoring of external radiation exposure**

Very good capacity to characterize the shape of the dose-risk relationship associated with low dose protracted exposure

Epidemiological cohorts first implemented in the 70s

The 15-country Study



15-country Study:

600 000 / 400 000 workers (after all exclusions)

About 5 million person-years of observation

INWORKS:

300 000 workers

About 8 million person-years of observation

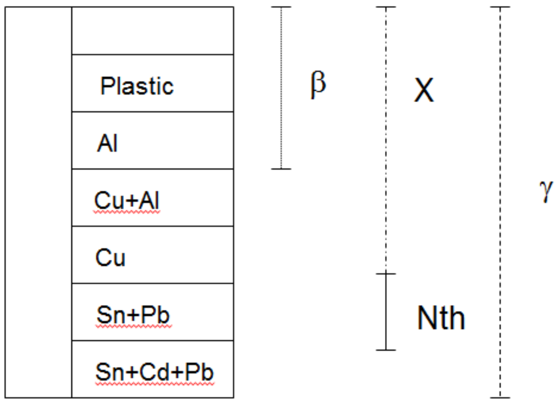
Study of Errors in Dosimetry

Workers exposed predominantly to "higher" energy photon radiation (100 to 3 000 keV)

- **Objectives of the Study**
  - Comparability of doses recorded in different facilities from the 1940 's up to now
  - Identification of sources of errors
  - Quantification of errors to take them into account in the risk estimate

Identification of sources of errors

- **Main sources of errors**
  - Dosimetry technology
  - Radiation fields
  - Calibration practices
  - Recording practices
    - Below threshold doses
    - Missing dosimeters



Study of the response of dosimeters to conditions of exposure

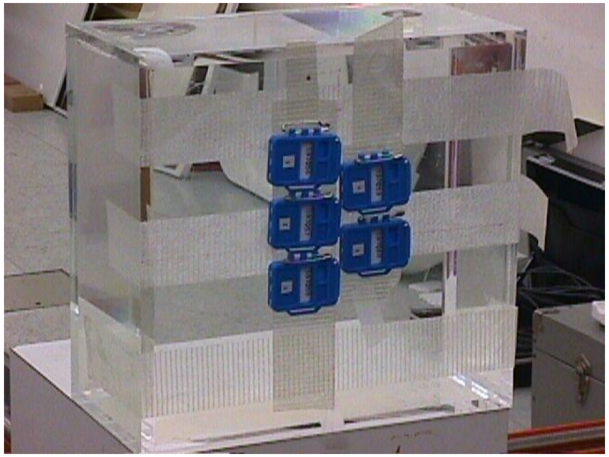
Dosimeter response - classification

- **Classification by category**
  - Photographic dosimeters
    - bare film
    - one filter
    - multi-element
  - TLDs
  - Uncommon dosimeters
- **Selection for experiments**
  - 10 types – 5 dosimeters per type
  - 3 energies (118 – 208 – 662 keV)
  - 3 geometries (AP – ROT – ISO)

Dosimeter response

Ka-in-air : 5 mGy
Distance: 2m

AP



Dosimeter response

Ka-in-air : 5 mGy
Distance: 2m

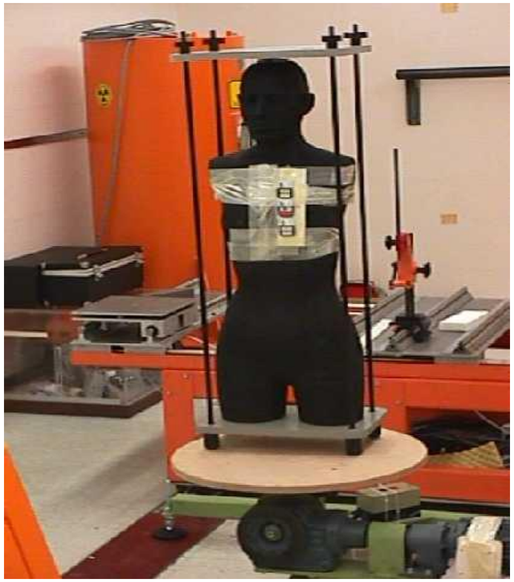
AP

Dosimeter response

Ka-in-air : 5 mGy
Distance: 2m

AP

Rotational

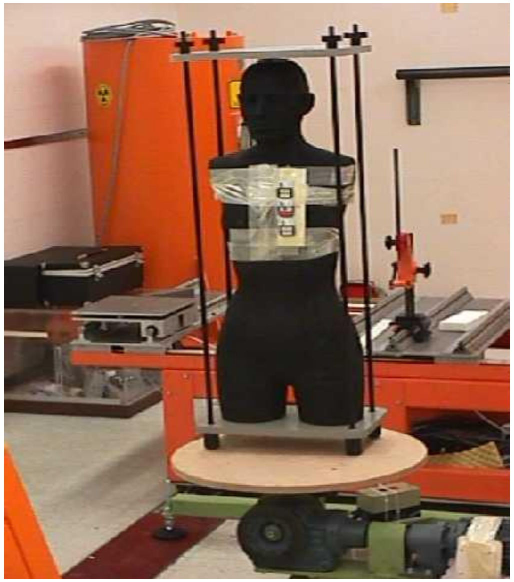


Dosimeter response

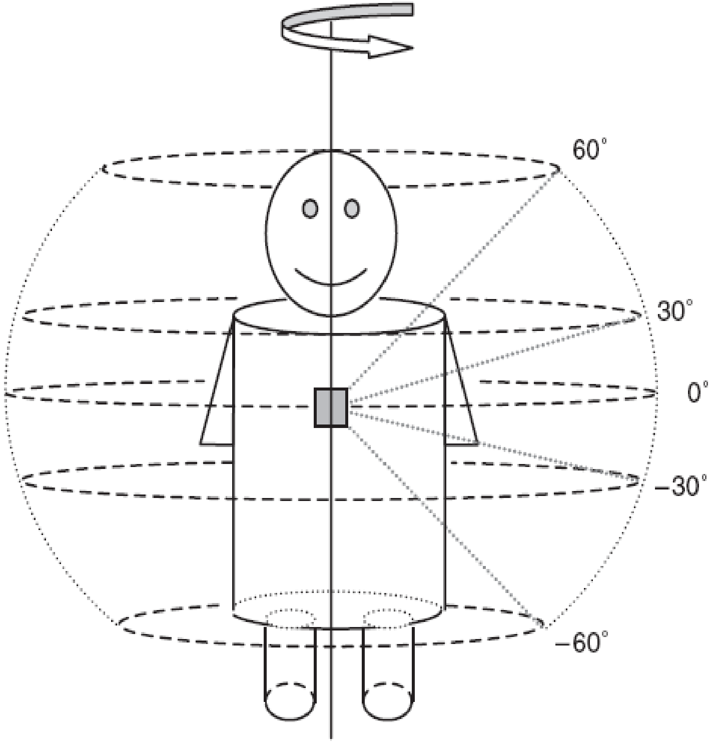
Ka-in-air : 5 mGy
Distance: 2m

AP

Rotational



Isotropic



Dosimeter response

Ka-in-air : 5 mGy
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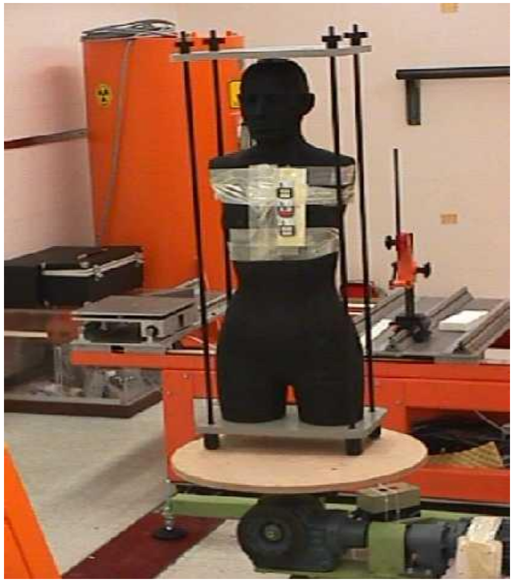
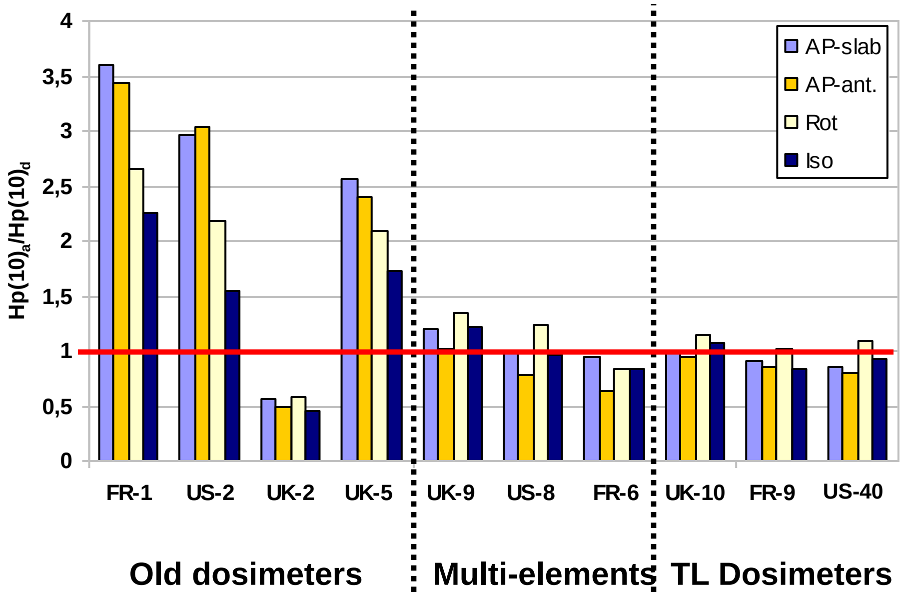
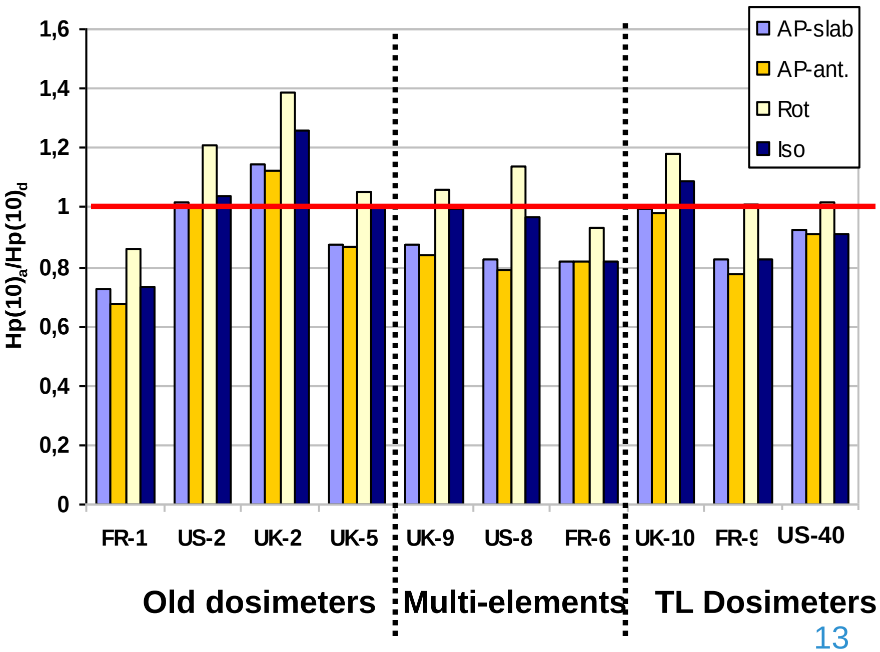


Dosimeter response



118 keV

662 keV



Conditions of exposure

- **Classification in two categories**
  - Nuclear Power Plants - Pilot study in 4 NPPs in Switzerland
  - Mixed activities facilities - Pilot study in Saclay (France)

Coefficients	ENERGY -keV-			GEOMETRY		
	0-100	*100-300*	*300-3000*	*A.P.*	*ISO*	*ROT*
NPP	***0***	***0.1***	***0.9***	***0.5***	***0.5***	***0***
Variations between workers	0-0.01	0.05-0.2	0.8-1	0.1-0.8	0.2-0.9	0
Mixed activities	***0***	***0.2***	***0.8***	***0.5***	***0.5***	***0***
Variations between workers	0	0.15-0.25	0.75-0.85	0-0.6	0.4-1	0
Variations between installations	0	0.15-0.25	0.75-0.85	0.4-0.55	0.45-0.6	0

Final "Dosimeter" Bias

$B = \exp[f(100\text{-}300)*f(AP)* \mathrm{Ln}(\mathbf{B}_{100\text{-}300,AP}) + f(100\text{-}300)*f(iso)* \mathrm{Ln}(\mathbf{B}_{100\text{-}300,iso}) + f(300\text{-}3000) * f(AP)* \mathrm{Ln}(\mathbf{B}_{300\text{-}3000,AP}) + * f(300\text{-}3000*f(iso)* \mathrm{Ln}(\mathbf{B}_{300\text{-}3000,iso})]$

Associated uncertainties

- **Uncertainties related to dosimeter response**
  - Based on the 5 dosimeters per type irradiated at each energy and for each geometry
- **Uncertainties related to conditions of exposure**
  - Based on the range provided by the experts

Final “dosimeter” bias (uncertainties)

	Facility	**type**				**Period**		**Dosimeter**		***100-300***		***300-3000***		***B***	***K***
		$f_{100-300}$	$f_{300-3000}$	f_{AP}	f_{ISO}					**AP**	**ISO**	**AP**	**ISO**	$H_p(10)$	$H_p(10)$
1	MA	0.2	0.8	0.5	0.5	50	56	Bare	Film	3.27	4.82	0.9	0.99	**1.26**	*1.40*
						57	66	E-1	Film	1.17	1.17	0.68	0.73	**0.78**	*1.12*
						67	95	E-6	Multi.	0.63	0.62	0.81	0.81	**0.77**	*1.11*
						85	95	E-9	TLD	0.86	0.83	0.78	0.82	**0.81**	*1.15*
2	NPP	0.1	0.9	0.5	0.5	68	82	E-3	Film	1.80	1.61	0.90	0.99	**1.00**	*1.12*
						82	97	E-4	Film	0.73	0.56	0.90	0.99	**0.91**	*1.12*
3	MA	0.2	0.8	0.5	0.5	44	56	Q-2	Film	1.50	1.21	1.00	1.04	**1.08**	*1.11*
						57	62	Q-7	Multi.	0.87	0.98	0.81	0.93	**0.88**	*1.19*
						62	71	Q-8	Multi.	0.87	1.12	0.79	0.97	**0.90**	*1.20*
						72	95	Q-21	TLD	0.91	0.97	0.89	0.94	**0.92**	*1.20*
4	NPP	0.1	0.9	0.5	0.5	87	99	Q-38	TLD	0.91	0.97	0.89	0.94	**0.92**	*1.19*

Conversion to organ doses

ICRP-116 report: coefficients for male and female separately

Coefficient	118 keV		208 keV		662 keV	
Hp(10) → organ	AP	ISO	AP	ISO	AP	ISO
RBM (male)	0,68	0,46	0,65	0,45	0,72	0,55
Colon (male)	0,78	0,41	0,78	0,43	0,83	0,54
Lung (male)	0,71	0,42	0,73	0,45	0,82	0,58
Breast (female)	0,88	0,48	0,93	0,54	0,98	0,67

uncertainty : K= 1.103

Calibration practices

- *Backscatter*
- *Calibration sources*
- *Factors affecting sources*

Facility	Period		Backscatter		Calibration source		Other factors		Final cal. factors	
	Start	End	B	K	B	K	B	K	B	K
1	43	52	1,06	1,05	1	1,2	1	1,05	**1,06**	**1,21**
	53	79	1,06	1,05	1	1	1	1,05	**1,06**	**1,07**
	80	05	0,96	1,04	1	1	1	1,05	**0,96**	**1,06**
2	63	06	1,06	1,05	1	1	1	1,05	**1,06**	**1,07**

Overall bias - uncertainty

- **Response of dosimeters in terms of $H_p(10)$**
  - B_1
  - K_1 (K_{dos}, K_{expo})
- **Conversion to organ dose**
  - B_2
  - K_2
- **Calibration practices**
  - B_3
  - K_3

- **Overall bias**
  - $B=B_1*B_2*B_3$

- **Overall uncertainty**
  - $\ln K= 1.96 \sqrt{(\sum_i S_i^2)}]$

Final bias (uncertainties)

	Period		$H_p(10)$		*Lung (male)*		*RBM (male)*		*Colon (male)*		*Breast (female)*	
			B	K	B	K	B	K	B	K	B	K
1	43	43	**1.50**	*1.52*	**2.27**	*2.28*	**2.45**	*2.04*	**2.31**	*2.70*	**1.91**	*2.19*
	44	52	**0.99**	*1.16*	**1.50**	*1.80*	**1.62**	*1.66*	**1.52**	*2.05*	**1.26**	*1.73*
	53	79	**0.88**	*1.31*	**1.33**	*1.90*	**1.44**	*1.78*	**1.35**	*2.12*	**1.12**	*1.81*
	80	05	**0.92**	*1.29*	**1.39**	*1.77*	**1.50**	*1.65*	**1.42**	*1.97*	**1.17**	*1.71*
2	82	87	**0.87**	*1.26*	**1.30**	*1.69*	**1.41**	*1.61*	**1.32**	*1.83*	**1.10**	*1.62*
	88	88	**0.91**	*1.28*	**1.35**	*1.64*	**1.46**	*1.57*	**1.37**	*1.78*	**1.14**	*1.59*
	89	06	**0.92**	*1.29*	**1.36**	*1.63*	**1.48**	*1.55*	**1.39**	*1.76*	**1.15**	*1.58*

Conversion of recorded doses

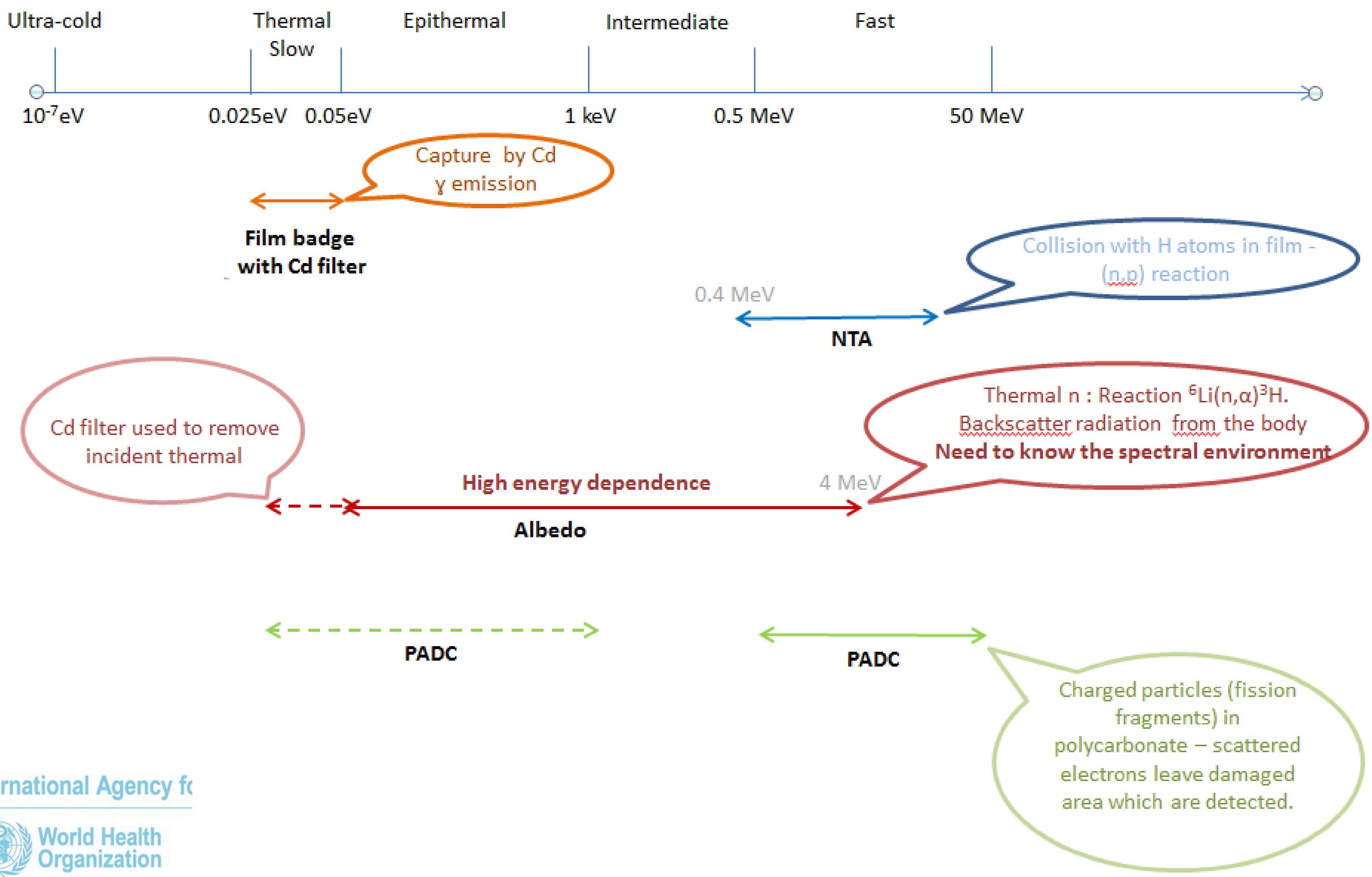
Conversion factor $CF = B/(\exp[S^2/2])$

Distribution of individual cumulative doses

Cohort	Total number of workers *(% of exposed workers)*	$H_p(10)$ (mSv)	Colon (mGy)	Lung (mGy)	RBM[b] (mGy)	Breast (mGy) (women only)
		Mean (median. IQR[c])	Mean (median. IQR[b])	Mean (median. IQR[b])	Mean (median. IQR[b])	Mean (median. IQR[b])
France	59 003 *(72%)*	18.4 (2.1; 0.0,17.0)	12.6(1.4; 0.0,11.6)	12.6 (1.4; 0.0,11.7)	11.6 (1.3; 0.0,10.7)	2.8 (0; 0.0,0.93)
UK	147 866 *(88%)*	28.7 (4.2; 0.6,2.4)	19.9 (2.9; 0.4,14.1)	19.8 (2.9; 0.4,14.1)	18.2 (2.6; 0.4,12.9)	5.1 (1.4; 0.4,4.3)
USA	101 428 *(83%)*	24.0 (2.9; 0.3,16.7)	16.7 (2.1; 0.2,11.6)	16.6 (2.0; 0.2,11.5)	15.2 (1.9; 0.2,10.6)	3.7 (0.4; 0.0,2.3)
Total	**308 297 *(83%)***	**25.2 (3.4; 0.4,18.4)**	**17.4 (2.3; 0.3,12.8)**	**17.4 (2.3; 0.3,12.7)**	**15.9 (2.1; 0.3,11.7)**	**4 (0.6; 0.0,2.8)**

The cohort includes 268,262 men and 40,035 women

Exposure to Neutrons



Exposure to Neutrons

- **Unrecorded neutron doses are possible**
  - Exposure outside the detection range
  - Not monitored but exposed workers
  - Area monitoring implemented for surveillance but no record of doses

	15-country Study		INWORKS	
Total number of workers		**598,068**		**308,297**
Workers with no monitoring or zero doses			Flag 1	*268,523*
Workers with recorded cumulative neutron doses **not exceeding** 10% of the total equivalent dose for external radiation			Flag 2	*27,632*
Workers with recorded cumulative neutron doses **exceeding** 10% of the total equivalent dose for external radiation	Flag	*19,041*	Flag 3	*12,142*

Excluded (15-country Study, 19,041)

NOT Excluded (INWORKS, 27,632 and 12,142)

Internal contamination

- **Reconstructing doses to individual organs requires:**
  - knowledge of the characteristics of the contaminant (particle size, chemical form and solubility)
  - knowledge of mode of intake and understanding of conditions of exposure
  - doses are received over a period that depends on retention of the nuclide in specific organs
  - complex models have been developed for dose estimation based on individual biological samples

- **Workers were grouped into two categories.**
  - Flag 1: Workers with no deposition.
  - Flag 2: Workers with known (France, UK and U.S.) or suspected (UK) deposition.

~ 40 000 Excluded in 15-country Study
~ 50 000 Not excluded in INWORKS
(IC + neutrons)

Internal contamination

- **Few studies with assessment of doses from internal contamination:**
  - Uranium mineurs_*Radon (Rn) and Uranium (U)*
  - Mayak workers, Sellafield (UK)_*Plutonium(Pu)*
  - US workers_ *Plutonium(Pu) and Uranium (U)*
- **Within α-risk project**
  - case-control study of workers contaminated with Pu and U (France, UK and Belgium)
  - Assessment of dose to the lung and red bone marrow
  - Study of the risk of lung cancer and leukaemia.

α RISK

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World Health Organization

Acknowledgements

Dosimetry subcommitee members

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INWORKS Study Group

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Publications

I. Thierry-Chef et al. Dose estimation for a study of nuclear workers in France, the United Kingdom and the United States of America: methods for the International Nuclear Workers Study (INWORKS). ***Radiat. Res**.* 2015; 183(6):632-42.

G.B. Hamra et al. Cohort Profile: The International Nuclear Workers Study (INWORKS). ***Int. J. Epidemiol***. 2015 Jul 6. pii: dyv122. doi: 10.1093/ije/dyv122.

K. Leuraud et al. Ionizing Radiation and Leukaemia and Lymphoma: Findings from an international cohort study of radiation-monitored workers (INWORKS). ***The Lancet Haematol***. 2015 July; 2: e276-e281.

D.B. Richardson et al. Solid cancer risk among Nuclear Workers in France, the United Kingdom, and the United States: The INWORKS Project. ***BMJ*** 2015; 351: h5359.