Dosimetry for epidemiology of internal emitters – risk assessment vs operational radiation protection

EURADOS Winter School

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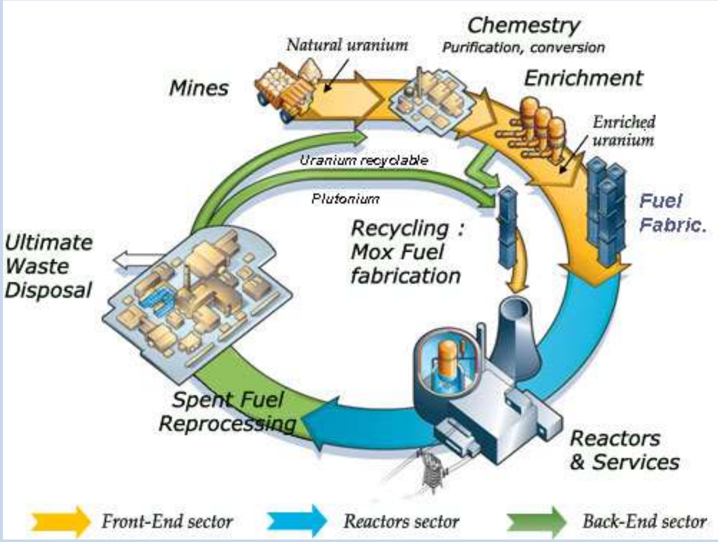


Summary

1. Context
2. Doses for risks vs doses for radiological protection
3. Example
4. Discussion on the need of guidelines and dose reliability
5. Conclusion

IRSN

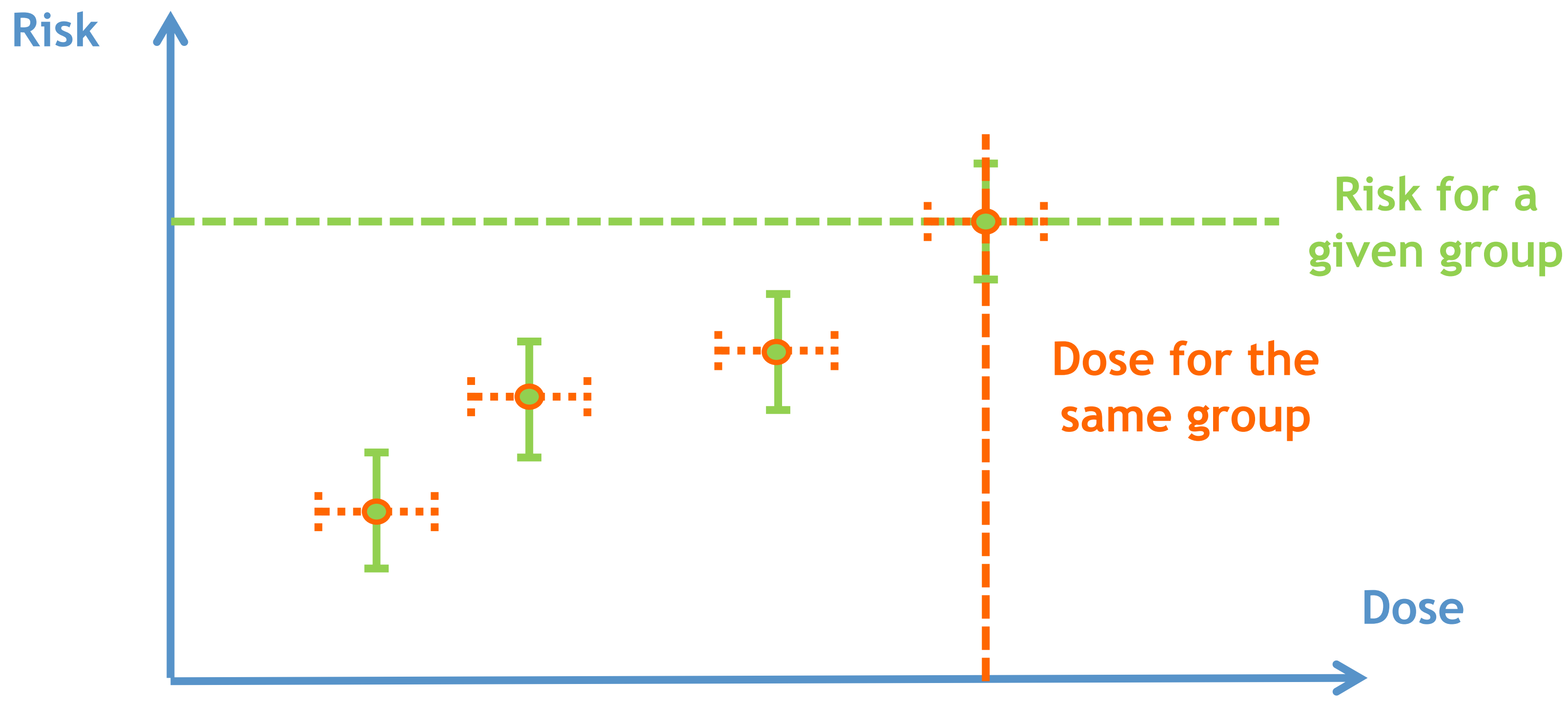
Evaluation of risk associated with radionuclide intakes

- Now based on:
  - Epidemiological follow-up of Hiroshima and Nagasaki A-Bomb survivors
  - Dosimetric system including biokinetic models and weighting factors

- Some results on populations exposed to intake of radionuclides:
  - Residential radon (Krewski et al, 2005, Darby et al, 2006…)
  - Population in contaminated areas (Cardis et al, 2005…)
  - Thorotrast injected patients (Travis et al, 2003, Becker et al, 2008…)
  - Radium watch dial painters (Rowland et al, 1983, Spiers et al 1983…)
  - Uranium miners (Rage et al, 2014, Kreuzer et al, 2015…)
  - Uranium millers (Boice et al, 2008, Kreuzer et al, 2015…)
  - Mayak workers (Sokolnikov et al, 2016, Kuznetsova et al, 2016…)
  - Uranium enrichment (Yiin et al, 2016…)…

↗ **Few with dose assessments from bioassay data**

Risk evaluation principle



- Need of reliable dose estimates and confidence interval
- But no reference methods to estimate them

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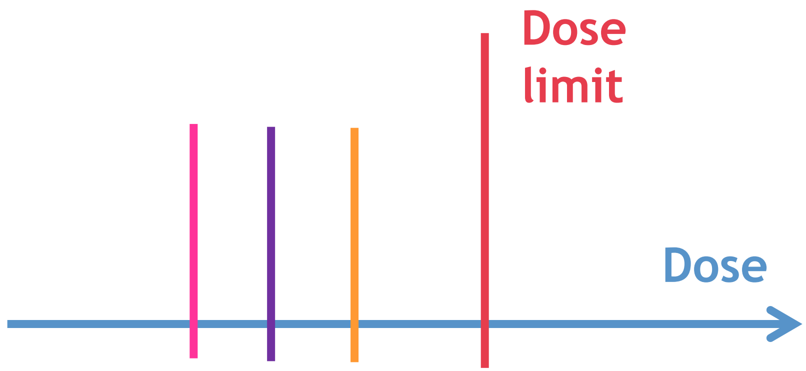
Purpose

↗ Operational RP

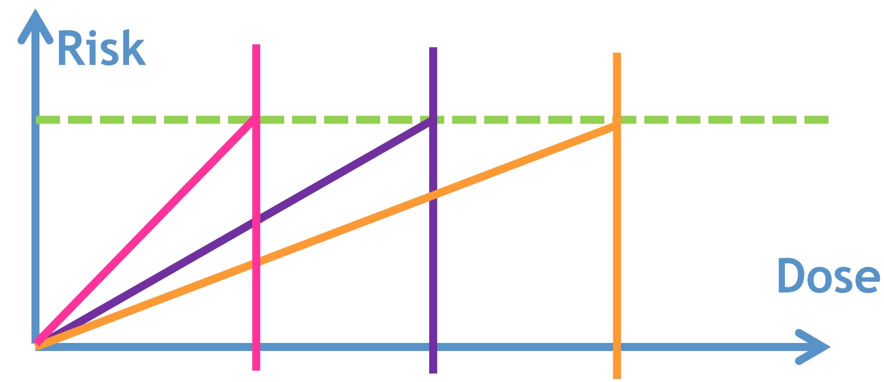
- To verify or not the compliance of exposure with dose limits



⇨ Overestimation is not a problem, underestimation is problematic.

↗ Epidemiology

- To assess risks



⇨ Dose overestimation leads to risk per dose underestimate, underestimation leads to risk per dose overestimate.

↗ Overestimation is often preferred.

↗ Unbiased estimates are needed.

Output

↗ Operational RP

- Effective dose
- Commitment period = 50 years
- Use of reference biokinetic and dosimetric model

⇨ Published dose coefficient

⇨ Easy validation

↗ Epidemiology

- Dose absorbed in relevant tissue:
  - Lung,
  - Liver…
- Absorbed during a year

⇨ Annual absorbed dose coefficient are not published

⇨ Validation can be tricky.

↗ Several tools/software are available.

↗ Dedicated tools are needed.

Number of dose assessments

↗ Operational RP

- Workers with unusual monitoring data
  - Depending on facilities
  - In 2015, in France, in nuclear industry facilities, 2 registered internal dose estimates (IRSN, 2016)
- Assessment of intakes for
  - A year exposure
  - An abnormal event

⇨ Limited number of bioassay

↗ Individual dose estimates are possible.

↗ Epidemiology

- Dose assessment for the whole cohort
  - Depending on cohorts and effects
  - For the TRACY cohort (Samson et al, 2016): 12,000 workers in the cohort, 3,000 with digitalized bioassay
- Assessment of intakes for
  - Each worker's whole career

⇨ 100,000s of bioassay data

↗ Automation is needed.

Bioassay

↗ Operational RP

- Urine, faeces, lung, whole-body…
- If needed,
  - New analysis can be performed.
  - More sensitive techniques can be used.
  - Re-analysis is possible.

⇨ New data can be provided.

↗ Dose estimates can be refined by new data.

↗ Epidemiology

- Urine, faeces, lung, whole-body…
- Even if needed,
  - No new analysis,
  - No more sensitive techniques,
  - No re-analysis.

⇨ No new data can be provided.

↗ Only the best estimate from available data.

Bioassay result

Operational RP

- Value below reporting level
  - Given as “<0.2mBq/l” for example

⇨ Value of the reporting level is known.

⇨ Possibility to contact the laboratory
  - ⇨ To try improving the result,
  - ⇨ To obtain the uncensored data with uncertainty.

Dose estimates can be refined by new data.

Epidemiology

- Some value below reporting level
  - Given sometimes as “<RL”

⇨ Need to assume a value for “RL”

⇨ No possibility to obtain uncensored data with uncertainty.

⇨ No new data can be provided.

Only the best estimate from available data.

Bioassay result

↗ Operational RP

- Specific information on:
  - Collection period
  - Measurement technique
  - Date of sampling
  - Bioassay purpose (routine, special…)

⇨ Good information on measurement uncertainty

⇨ Good reliability of data

↗ **Dose estimates can be refined by new data.**

↗ Epidemiology

- Often, no specific information on:
  - Collection period
  - Measurement technique
  - Date of sampling
  - Bioassay purpose (routine, special…)

⇨ No information on measurement uncertainty

↗ **Only the best estimate from available data.**

Exposure period

↗ Operational RP

- Routine/special monitoring

⇨ Information on exposure period
  - ⇨ normal conditions,
  - ⇨ high risk activity dates
  - ⇨ air sampler alerts

- Possibility to ask worker or management for more precise information

↗ **Dose estimates can be refined by new data.**

↗ Epidemiology

- Rarely information on special/routine monitoring

⇨ Scarce information on exposure period from
  - ⇨ Incident registry
  - ⇨ Medical files
  - ⇨ Ambient air monitoring
  - ⇨ Interviews

⇨ Interesting information provided by Job Exposure Matrix

↗ **Only the best estimate from available data.**

Physico-chemical parameters

↗ Operational RP

- Individual workplace identified

⇨ Sometimes, exposure is known:
  - ⇨ Chemical forms of handled compounds
  - ⇨ Particle size distribution
  - ⇨ Isotopic composition

- Possibility to obtain more precise data by contacting worker and radiological protection services.

↗ **Dose estimates can be refined by new data.**

↗ Epidemiology

- Workplace sometimes identified by JEM
  - ⇨ Information on exposure:
    - ⇨ Chemical forms
    - ⇨ Isotopic composition
  - ⇨ Information sometimes uninformative
    - ⇨ All chemical forms possible…
  - ⇨ Information not known
    - ⇨ Particle size distribution

- No possibility to obtain more precise data

↗ **Only the best estimate from available data.**

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Bioassay Database

Worker ID — Date — Why — Type — Volume — Creatinine — Ash weight — Technic — Unity — Result

id_worker	sample_day	sample_month	sample_year	monitoring	sample_type	uri_volume	uri_creatinine	fec_ash_weight	comment	num	meas1	unit1	result1	meas2	unit2	result2
worker_1	18	6	1964	Routine	Urine					1	U_mass	µg/l	<5			
worker_1	21	12	1964	Routine	Urine					2	U_mass	µg/l	<5			
worker_1	30	12	1965	Routine	Urine					3	U_mass	µg/l	<5			
worker_1	16	9	1966	Routine	Urine					4	U_mass	µg/l	<5			
worker_1	13	12	1966	Incident	Urine 24h					6	U_mass	µg/l	<5	U_activity	pCi	25
worker_1	14	12	1966	Incident	Urine 24h					7	U_activity	pCi	15			
worker_1	7	3	1967	Incident	Urine					8	U_mass	µg/l	<5	U_activity	pCi/l	25
worker_1	8	3	1967	Incident	Urine					10	U_mass	µg/l	<5	U_activity	pCi/l	5
worker_1	17	3	1967	Routine	Urine					11	U_mass	µg/l	<5			
worker_1	18	3	1967	Incident	Urine					13	U_mass	µg/l	24	U_activity	pCi/l	10
worker_1	20	3	1967	Routine	Urine					14	U_mass	µg/l	<5	U_activity	pCi/l	<5
worker_1	13	6	1967	Incident	Urine					15	U_mass	µg/l	<5	U_activity	pCi/l	<5
worker_1	28	6	1967	Routine	Urine					16	U_activity	pCi/l	199			
worker_1	26	7	1967	Routine	Urine					17	U_mass	µg/l	<5			
worker_1	31	7	1967	Routine	Feces				no indicatic	18	U_activity	pCi	1644			
worker_1	17	9	1967	Routine	Urine					19	U_mass	µg/l	5	U_activity	pCi/l	10
worker_1	10	11	1967	Routine	Urine					20	U_mass	µg/l	<5	U_activity	pCi/l	109
worker_1	13	11	1967	Routine	Urine					21	U_mass	µg/l	<5	U_activity	pCi/l	<5
worker_1	2	7	1968	Routine	Urine					22	U_activity	pCi/l	16			
worker_1	3	7	1968	Routine	Urine					23	U_mass	µg/l	<5			
worker_1	23	7	1968	Routine	Urine					24	U_activity	pCi/l	<5			
worker_1	26	8	1968	Routine	Urine					25	U_activity	pCi/l	5			
worker_1	10	9	1968	Incident	Urine				UF6 inhalat	26	U_mass	µg/l	<5	U_activity	pCi/l	41
worker_1	23	9	1968	Routine	Urine					27	U_activity	pCi/l	17			
worker_1	24	9	1968	Routine	Feces				no indicatic	28	U_mass	µg/g ash	31	U_mass	pCi	662
worker_1	26	9	1968	Routine	Urine					30	U_mass	µg/l	<5	U_mass	pCi/l	34
worker_1	9	10	1968	Exceptionnal	Urine					31	U_mass	µg/l	<5	U_activity	pCi/l	<5
worker_1	15	10	1968	Routine	Feces 48h					32	U_activity	pCi	787			
worker_1	15	10	1968	Routine	Urine					34	U_mass	µg/l	6	U_activity	pCi/l	10
worker_1	9	11	1968	Routine	Urine					35	U_mass	µg/l	<5	U_activity	pCi/l	<5
worker_1	11	11	1968	Routine	Feces 48h					36	U_mass	µg/g ash	6	U_mass	pCi	261
worker_1	17	12	1968	Routine	Urine					37	U_mass	µg/l	<5	U_activity	pCi/l	<5
worker_1	15	1	1969	Routine	Urine					38	U_mass	µg/l	<5	U_activity	pCi/l	<5

Job Exposure Matrix (JEM)

Worker ID — U_{nat} — U_{rep}

Job — F — M — S — F — M — S — Start Date — End Date

id_worker	job	Unat_1_freq	Unat_1_quant	Unat_2_freq	Unat_2_quant	Unat_3_freq	Unat_3_quant	Urp_1_freq	Urp_1_quant	Urp_2_freq	Urp_2_quant	Urp_3_freq	Urp_3_quant	start_day	start_month	start_year	end_day	end_month	end_year
worker_1	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	17	9	1962	31	12	1963
worker_1	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1964	31	12	1965
worker_1	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1966	30	6	1966
worker_1	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	1	7	1966	31	12	1966
worker_1	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	1	1	1967	7	1	1969
worker_1	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	8	1	1969	31	12	1973
worker_1	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	1	1	1974	31	12	1974
worker_1	77_UDG1	3	3	0	0	0	0	0	0	0	0	0	0	1	1	1975	31	12	1976
worker_1	3_CME4	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1977	31	3	1979
worker_1	3_CME4	1	1	1	1	0	0	0	0	0	0	0	0	1	4	1979	30	9	1980
worker_2	79_CEA1	3	3	1	1	1	1	0	0	0	0	0	0	1	6	1963	31	12	1963
worker_2	6_ADM	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1964	31	12	1966
worker_2	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1967	7	1	1969
worker_2	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	8	1	1969	31	12	1971
worker_2	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1972	31	12	1973
worker_2	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1974	31	12	1974
worker_2	31_DT-AT4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1975	31	12	1976
worker_2	31_DT-AT4	3	3	0	0	0	0	0	0	0	0	0	0	1	1	1977	31	3	1979
worker_2	31_DT-AT4	3	3	0	0	0	0	0	0	0	0	0	0	1	4	1979	31	1	1982
worker_2	31_DT-AT4	3	3	0	0	0	0	0	0	0	0	0	0	1	2	1982	30	9	1982
worker_3	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	26	7	1965	31	12	1966
worker_3	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	1	1	1967	7	1	1969
worker_3	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	8	1	1969	31	12	1973
worker_3	77_UDG1	3	2	0	0	0	0	0	0	0	0	0	0	1	1	1974	31	12	1974
worker_3	77_UDG1	3	3	0	0	0	0	0	0	0	0	0	0	1	1	1975	31	12	1976
worker_3	77_UDG1	3	3	0	0	0	0	0	0	0	0	0	0	1	1	1977	31	5	1978
worker_3	77_UDG1	3	3	0	0	0	0	0	0	0	0	0	0	1	6	1978	31	12	1981
worker_3														1	1	1982	31	1	1982

Incident register

Worker ID

Date

Description

Chemical form

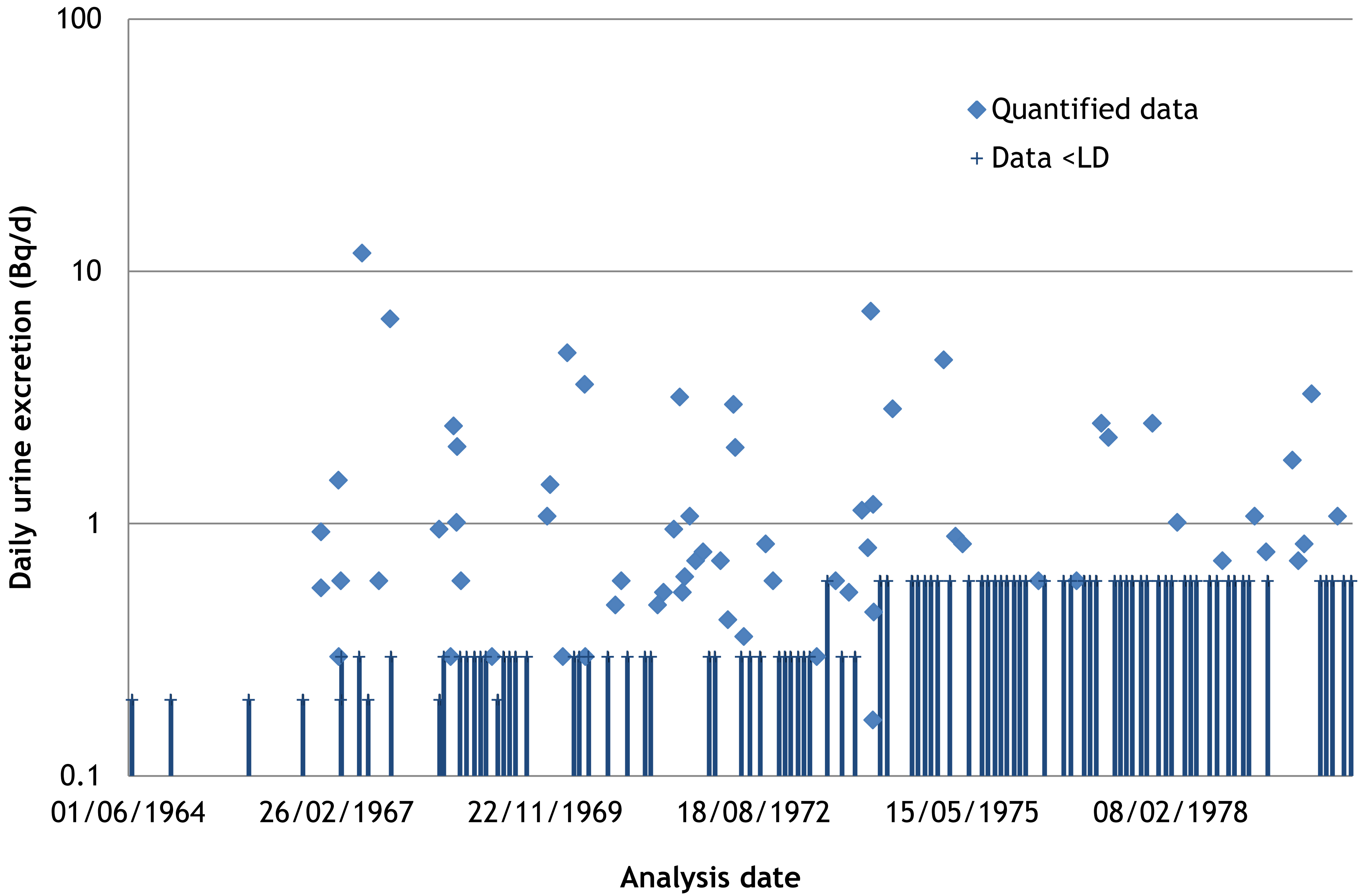
Localisation

Pathway

		time of intake					
identificatio	*identificatio*	*day/month/y*	*hour:minutes*		*radionuclide or c*	*body localisation of in*	*intake pathway*
id_worker	**incident_id**	**Date_Incid**	**Time_Incid**	**Description**	**Radionuclide**	**Localisation_Conta**	**Intake_path**
worker_1	28	17/03/1967	15:30	Was filling a vinyl barrel; wounded his left hand when removing it from the contaminated materi	U238	left hand	Wound
worker_1	29	10/11/1967	08:25	floor decontamination, filter overflowing, hairs were contaminated	U235	hair	External contamination
worker_1	83	03/06/1970	15:58	following MDU alarm setting off	U		Inhalation
worker_1	17	30/08/1971		Probable HF leakage from glovebox	U		Inhalation
worker_1	21	23/09/1971	15:05	Right side hit handle of transport device	uranyl nitrate	rigt side	Wound
worker_1	37	23/05/1972	09:00	Probable uranium inhalation	U		Inhalation
worker_1	2	04/03/1974	16:15	Uranyl nitrate projection	uranyl nitrate		Inhalation
worker_1	4	14/03/1974	16:00	Probable inhalation of uranium dust from unknown source	U		Inhalation

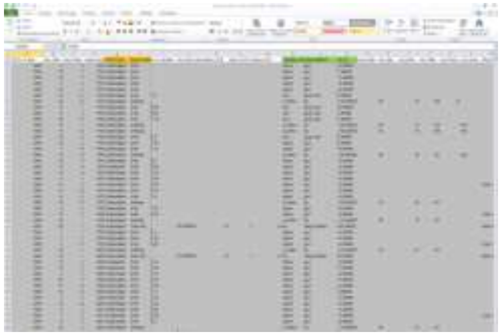
Example

Worker_1



Example

Data base



VBA macro

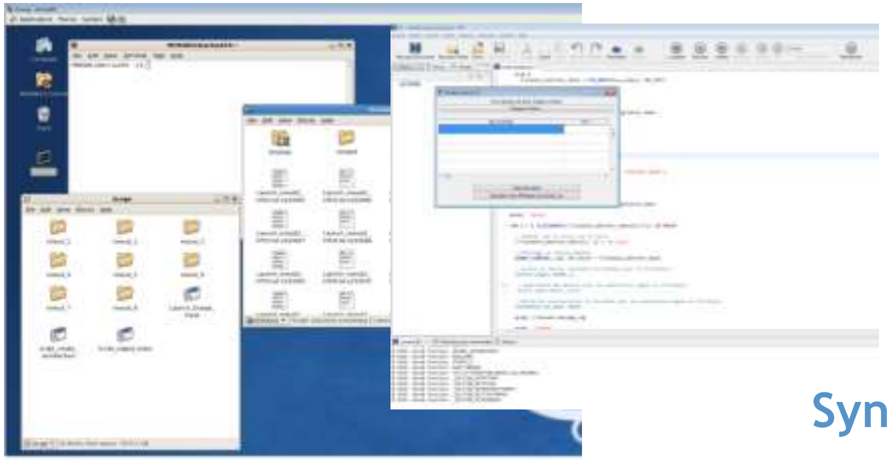
Individual input files

Containing:

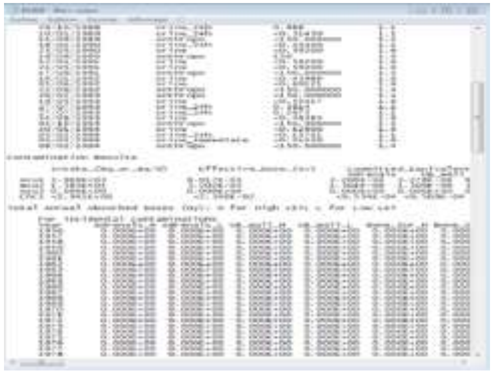
- Exposure conditions
- Bioassay

Computing cluster

DOSEPI



Individual output files



2h for 2900 workers

Containing:

- Input files content
- Doses

Synthesis file

Dose assessment for a case-control study

Zhivin et al, submitted

Cumulative dose (mGy)	Mean		IQR (25-75%)		Maximum	
Organ-specific uranium dose	Cases	Controls	Cases	Controls	Cases	Controls
Lung	1	0.7	0-1	0-0.6	27	11
Heart	0.01	0.01	0-0.01	0-0.01	0.2	0.3
Kidney	0.2	0.2	0-0.2	0-0.2	4	4
Whole-body external γ-radiation dose	3	2	0-0.3	0-0.2	72	70

Dose assessment

- Most dosimetrists involved in dose assessments for risk estimates are specialists in dose for radiological protection.
- Estimating doses for epidemiological study is different.
- Guidelines available for radiological protection are not directly applicable for risk estimates. Guidelines related to dose calculation for compensation scheme could be considered.

➚ Need for guidelines to assess doses for epidemiological studies

➚ Need to evaluate the reliability of doses

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Guidelines

- CURE project:
  - Concerted Uranium Research in Europe
  - Program funded by EU from July 2013 to December 2014
  - Objective
    - to develop a multidisciplinary and collaborative research protocol, integrating epidemiology, biology/toxicology and dosimetry to improve both the understanding and quantification of biological and health effects associated with occupational uranium exposure in Europe.
  - One of the results (Laurent et al, 2016, Blanchardon et al, 2015)
    - A dosimetric protocol to estimate doses in a pooled epidemiological study.

- Dosimetric protocols for Alpha-risk (Bingham et al, 2016) and Mayak (Birchall et al, 2016)

➚ **These protocols can help to estimate doses but not to evaluate the reliability of dose assessments.**

Intercomparison exercise

Aims

- To identify major sources of uncertainty
- To quantify uncertainty on dose estimates

Mean

- Intercomparison exercise inside the Task 7.5 – Uncertainty on dose assessments of EURADOS WG 7 on internal dosimetry
- Interpretation of results targeted to assess uncertainty on dose

Data provided to the participants

- Raw data for three workers of the French cohort of nuclear workers:
  - Worker 1 presenting several acute intakes,
  - Worker 2 with only one bioassay higher than reporting level (RL) ,
  - Worker 3 whose all bioassay data were below RL.

Main results

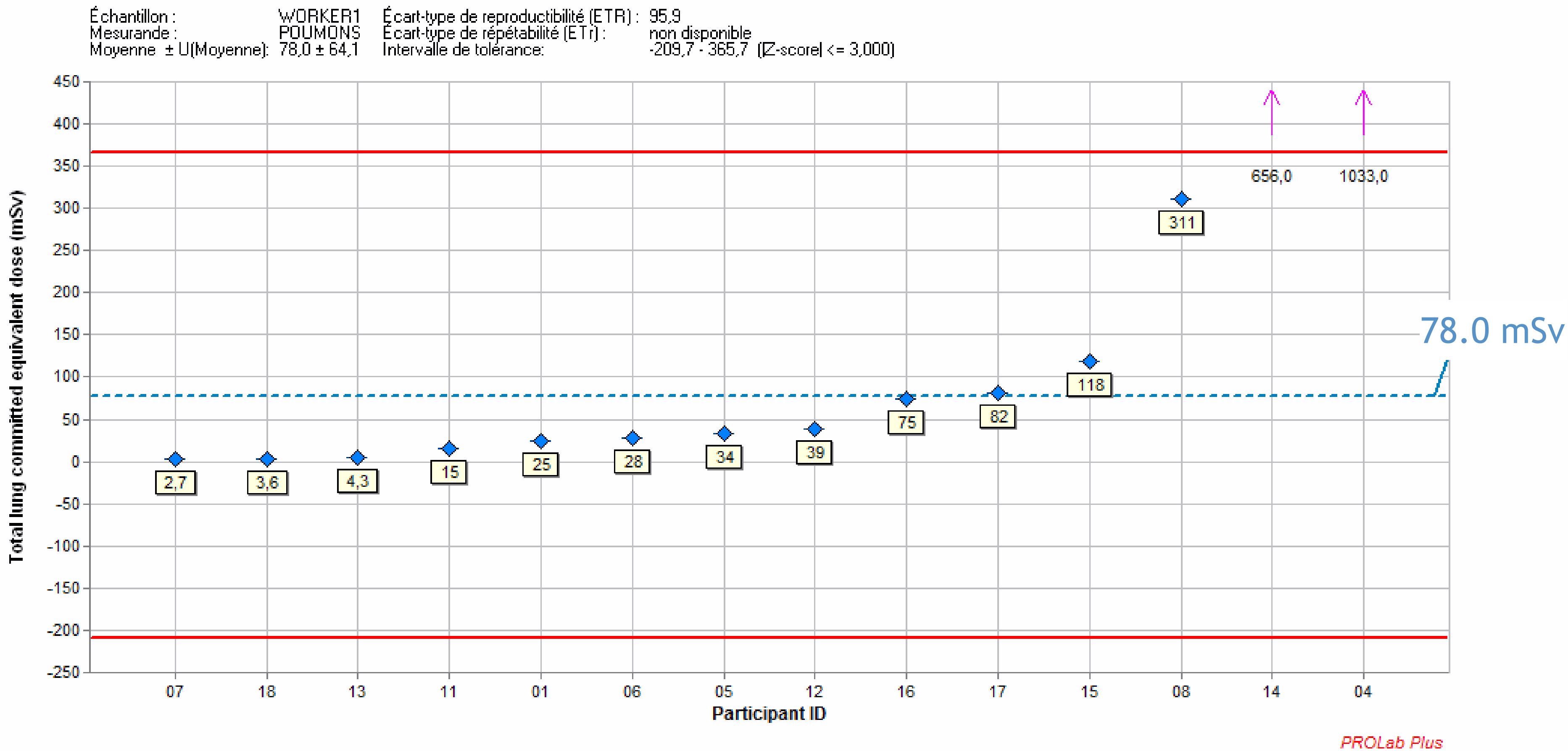
➚ 16 participants

- Data sent by participants, for each worker
  - Dose estimates
  - Exposure condition hypotheses
  - Bioassay data interpretation

- Estimation of **robust mean** and **robust standard deviation**

- **Review of the different procedures** to estimate doses

Committed lung dose for Worker 1



- Robust mean = 78.0 mSv, Robust SD = 95.9 mSv
- Relative SD = 123%

Main results

- **Significant uncertainty** on dose reconstructed for uranium workers
  - Dose estimates distributed over **several orders of magnitude**:
    - **Ratio Max/Min of 383** for lung equivalent doses estimated for Worker 1.

- What procedures are **consensual**?
  - the use of **ICRP biokinetic and dosimetric models**

- What procedures introduce **uncertainty**?
  - treatment of data below reporting level
  - pulmonary absorption
  - exposure period

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1. Context
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3. Example of data available in an epidemiological study
4. Discussion on the need of guidelines and dose reliability
5. Conclusion

Conclusion

- To estimate doses for risk estimates is different from assessment procedure for radiological protection.
- To define guidelines could be useful.
- And work is underway to estimate dose reliability.

Thank you for your attention