RÉPUBLIQUE
FRANÇAISE
Liberté
Égalité
Fraternité

IRSN
INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

HEALTH EFFECTS FROM THE CHERNOBYL AND THE FUKUSHIMA ACCIDENTS

Enora CLERO

ISOE International Symposium - Tours, France
June 22, 2022

MEMBRE DE
ETSON

Chernobyl accident : April 26, 1986

Short-term impact

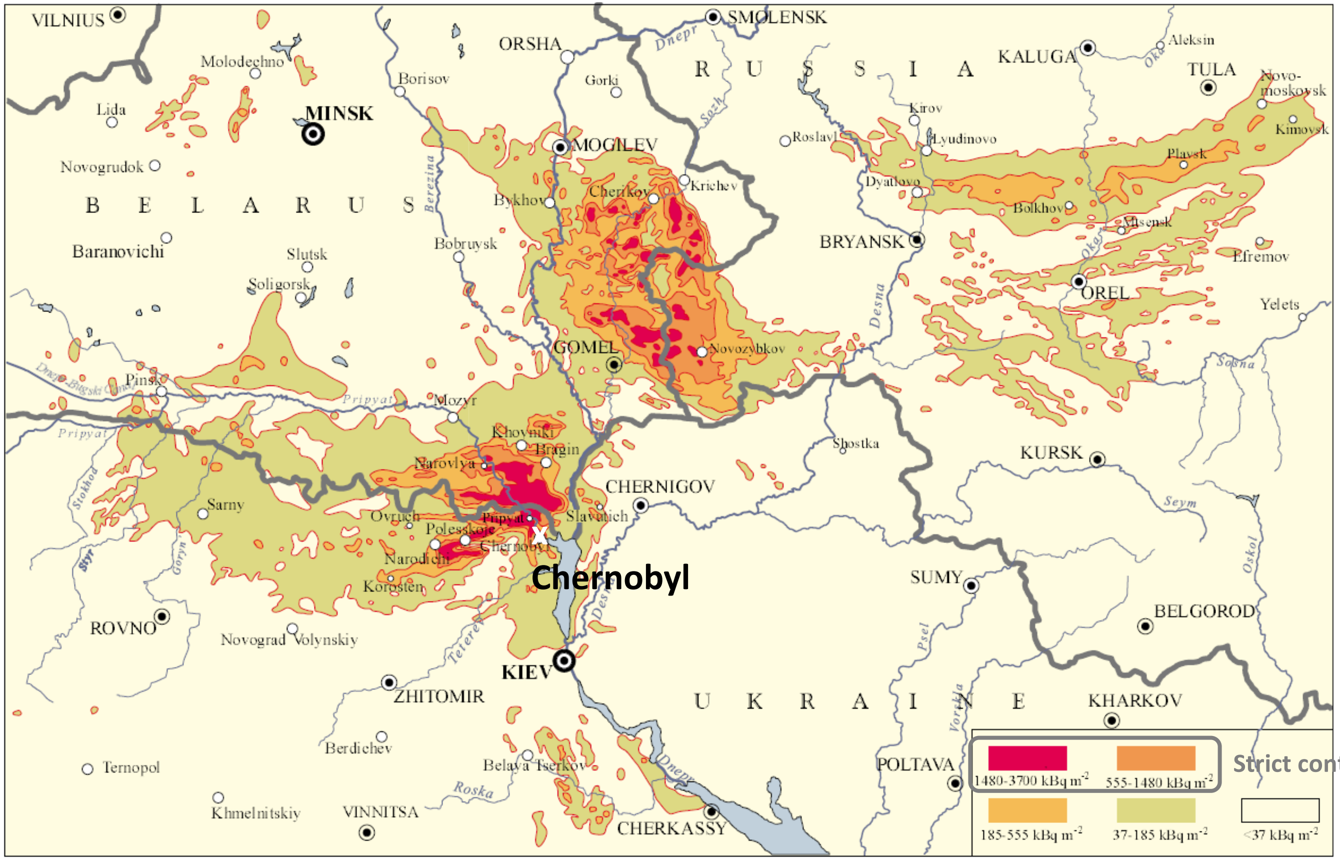
- 600 workers present on April 26, 1986
- 237 hospitalizations
- 134 acute radiation syndromes
(skin burns, hair loss, hematopoietic syndrome, intestinal syndrome…)
- 42 immediate deaths

Environmental impact

Main radionuclides released during the accident that present a health risk

- **Iodine 131**
  - Half-life : 8 days
  - Disappears from the environment after 2 months
  - Inhalation and ingestion (milk : 1st source of intake)
  - Accumulation in the thyroid gland
- **Caesium 137**
  - Half-life : 30 years
  - Persists in the environment
  - Eliminated from the body in 100 days
  - Internal and external exposure
  - Disseminated in all tissues

Caesium 137 deposition



Strict control area

Figure VI. Surface ground deposition of caesium-137 released in the Chernobyl accident [I1, I3].

IRSN

Exposed populations

Liquidators

Emergency workers	Liquidators
→ *site workers, firefighters, military personnel who worked on the reactor in the first few days*	→ *intervening in the 30 km exclusion zone*
≈ 600 people	≈ 600,000 people from Russia, Ukraine, Belarus, Baltic Republics
Mainly external radiation, with an inhalation component	Mainly external exposure, inhalation
Doses between 0.8 and 16 Gy	Doses between 0.01 and 1 Gy High exposure if intervention during 1st year

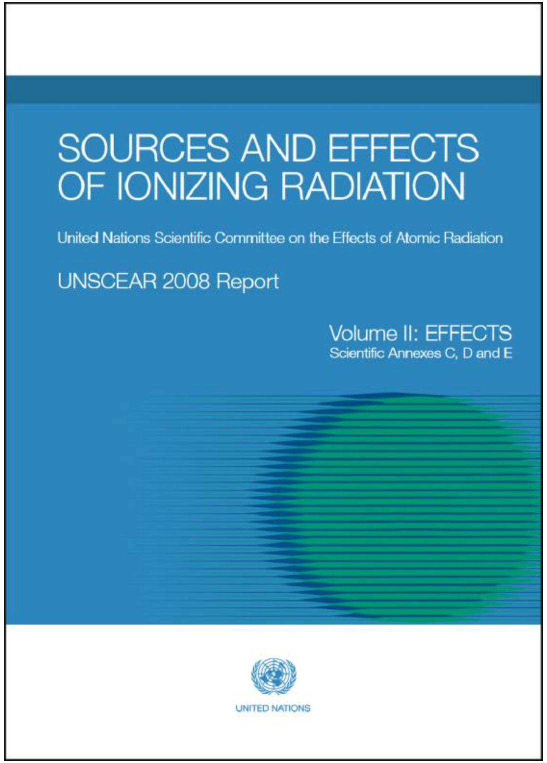
- Bias : inclusion of people potentially motivated by self-interest (access to care, compensation, etc.)

Exposed populations

General population in the contaminated areas (≥ 37 kBq/m² or 1 Cu/km²)

Evacuated population from the exclusion zone (< 30 km from the reactor)	**Population of the strict control area** (≥ 555 kBq/m² or 15 Cu/km²)	**Population of contaminated territories**
≈ 116,000 evacuees	≈ 270,000 people	≈ 5 million people in 3 countries (Ukraine, Belarus, Russia)
Mainly inhalation, external irradiation (ingestion)	Inhalation, external irradiation, ingestion	Inhalation, external irradiation
Doses from 0.1 to 380 mSv	Average dose of 50 mSv	Average dose of 10 to 20 mSv
Doses to the thyroid gland from 0.07 to 4.3 Gy (average per age group)	Doses to the thyroid from 0 to 2 Gy	Dose to the thyroid from 0 to 50 mGy

Health effects review



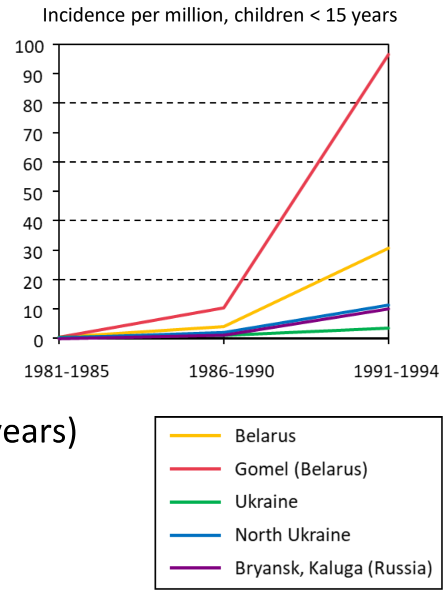
UNSCEAR 2008 Report
Annex D

« Health effects due to radiation from the Chernobyl accident »

Thyroid cancer risk among children

(< 15 years at diagnosis)

- Excess risk identified in 1992 in Belarus
- Incidence × 30 in the whole Belarus (× 100 in Gomel)
  Incidence × 8 in the whole Ukraine (× 100 in North Ukraine)
- More than 5,000 cases observed in the contaminated territories in 1990's
- Strongest excess among the youngest at the time of the accident (50% of cases < 4 years)
- Invasive tumors, mainly papillary
- Significant dose-risk relationship for thyroid cancer,
  consistent with results from HN survivors and medical studies
  (Cardis et al. JNCI 2005; Tronko et al. JNCI 2006; Cahoon et al. JCEM 2017)
  - RR at 1 Gy between 4.5 and 7.4 depending on the models used and the studies
  - RR increased if early age at exposure and if iodine deficiency



(Stsjazhko, 1995)

> ➢ Excess is real, not just explained by a screening bias
> ➢ Excess continues, including in adulthood
> ➢ Due to iodine 131 (+ stable iodine deficiency?)

Thyroid cancer incidence

Increase persists more than 20 years after the accident

Increase observed in adults to date

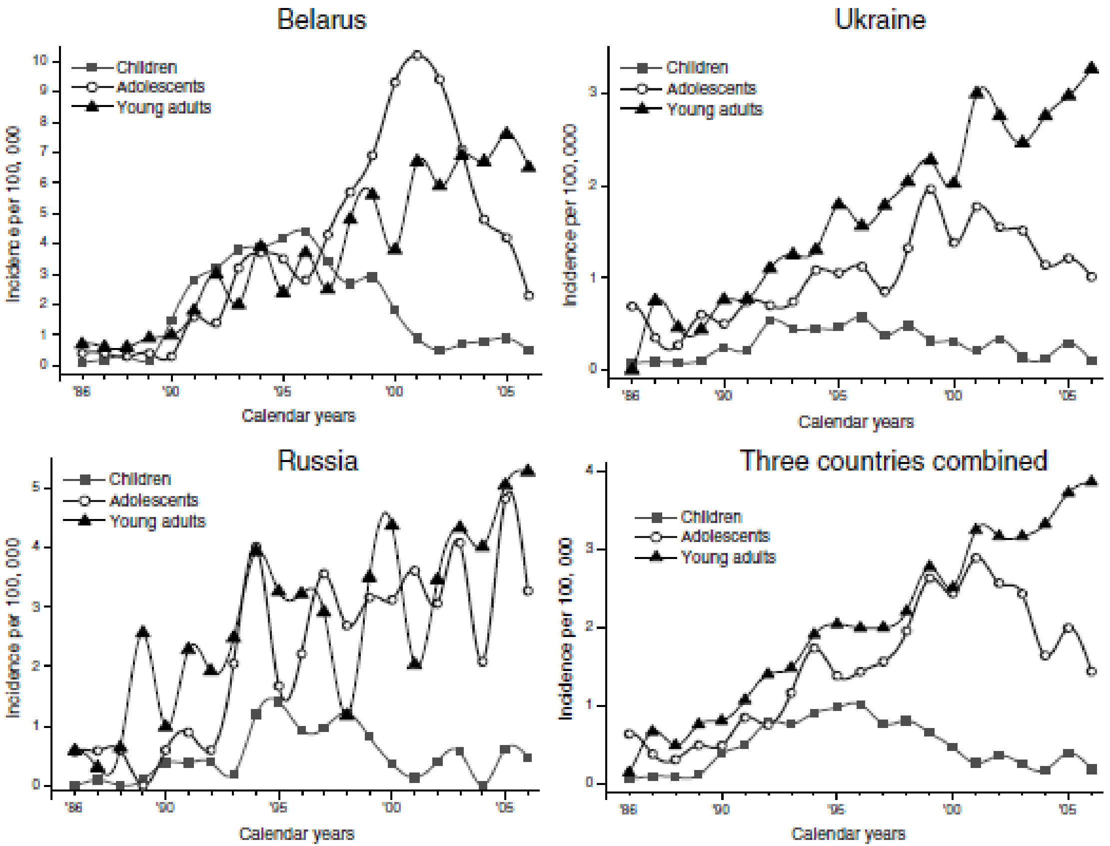


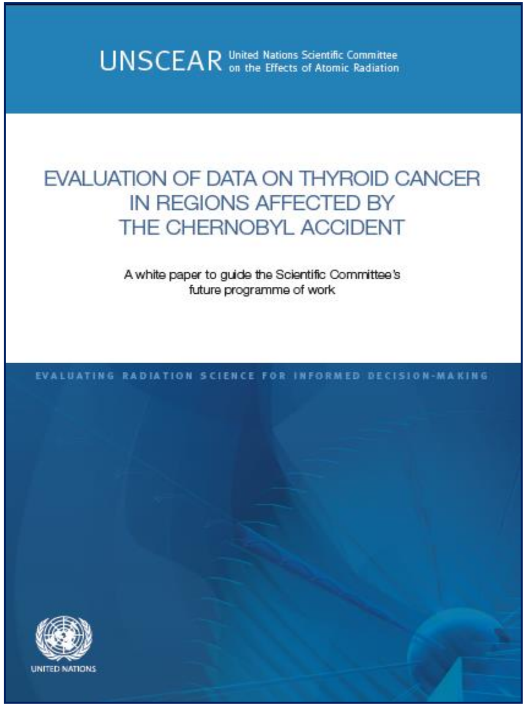
Fig. 2. Incidence of thyroid cancer in residents of radiocontaminated territories around Chernobyl. Data for Belarus is reproduced from Demidchik et al. (2007) with permission and for Ukraine is inferred from Tronko et al. (2007) and relate to whole countries. Data for four radiocontaminated regions of Russia (Bryansk, Kaluga, Orel, and Tula Oblasts) were kindly provided by V.K. Ivanov (National Radiation and Epidemiological Registry, Medical Radiological Research Center, Russia).

(Yamashita et al. HP 2014)

Evaluation of thyroid cancer risk in contaminated areas

Evaluation of data in regions affected by the accident : Belarus, Ukraine and the most contaminated Oblasts of Russia (< 18 years at the time of the accident)

- Monotonic increase of incidence over 2006-2015
- **Total number of cases estimated over 1991-2015 close to 20,000** (≈ 3 times higher than in 1991-2005)
- Incidence attributable to increasing baseline rates with age, exposure to ionizing radiation, and improvement in medical detection methods
- **Fraction attributable to ionizing radiation exposure estimated at ≈ 25%** (uncertainties between 7% and 50%)
  → ≈ 5,000 thyroid cancer cases attributable to radiation



UNSCEAR 2018

Thyroid cancer risk among liquidators (> 20 years at exposure)

Materials & methods

- Case-control study nested within cohorts
- Belarusian, Russian and Baltic liquidators who worked at Chernobyl between April 86 and Dec. 87
- Exposure : external gamma + internal contamination (Iodine 131)
- Dosimetry : RADRUE dosimetry model + individual internal dose calculation
  (RADRUE = "Realistic Analytical Dose Reconstruction with Uncertainty Estimation")

Results

- Large population : 107 thyroid cancer cases and 423 controls
- Thyroid dose (controls)
  - External dose :   9 mGy [0-508]   (median and range)
  - Internal dose : 62 mGy [0-1552]
- Significant dose-risk relationship : ERR / 100 mGy = 0.38 [0.1 ; 1.09]
- Significant relationship from 0-300 mGy

(Kesminiene et al. Radiat Res 2012)

Leukaemia risk among liquidators (in adults)

2 case-control studies with consistency of results

Ukrainian liquidators (NCI) *(Zablotska et al. 2012; Romanenko et al. 2008)*

- 117 cases / 716 controls
- Mean dose 132 / 82 mGy (Radrue)
- Leukaemia excluding CLL : ERR/Gy = 2.4 [0.5 - 5.9]
  CLL : ERR/Gy = 2.6 [0.1 - 8.4]

Liquidators from Belarus, Russia, Baltic countries (IARC) *(Kesminiene et al. 2008)*

- 60 cases / 287 controls
- Average dose 13 mGy (Radrue)
- Leukaemia excluding CLL : ERR/Gy = 5.0 [-0.4 ; 5.7]

ERR close to those from Hiroshima & Nagasaki

Leukaemia risk among children

→ **Inconsistent results by regions**

Case-control study in Ukraine

- Children < 5 years residing in the most contaminated areas
- 246 cases (1987-1997) / 492 controls
- Dose reconstruction : housing history, lifestyle, consumption × Cs137 contamination measurements, gamma dose rate (soil)
  Consider external exposure and internal contamination
- Doses from 0 to 313 mGy (92% < 10 mGy)
- Significant increase in the risk of leukaemia
  OR = 2.4 [1.4 ; 4.0] for a dose > 10 mGy

Limitations

- Control selection and dose estimation

(Noshchenko et al. IJC 2002; Noshchenko et al. IJC 2010)

Breast cancer risk among women

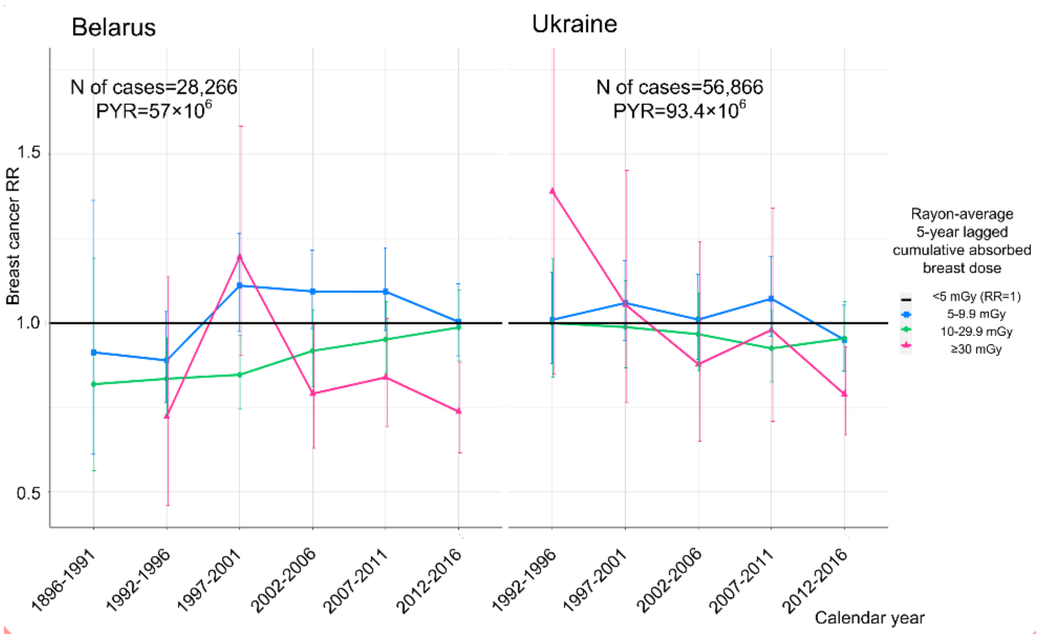
Breast cancer SIR in Ukraine

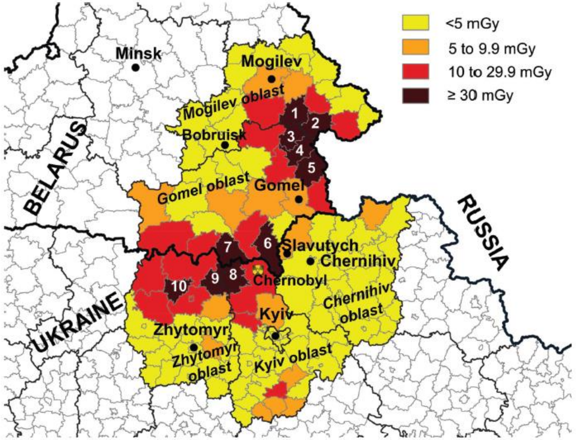
	Observed cases (N)	Expected cases (N)	SIR (95% IC)
Residents of contaminated areas (1990-2011)	1,168	1,835.7	0.63 (0.60 - 0.67)
Evacuees from Prypyat and 30 km area (1990-2011)	314	411.9	0.76 (0.68 - 0.85)
Liquidators involved in 1986-1987 (1994-2011)	303	185.7	1.63 (1.44 - 1.82)

- No indication of excess risk of breast cancer in the general population
- Possible excess risk in early liquidators
- Continue the follow-up

(Prysyazhnyuk et al. PRMR 2014)

Breast cancer risk among women





(Zupunski et al. IJC 2021)

- No evidence of increased breast cancer incidence with cumulative breast dose (rayon-average)

→ A case-control study with individual doses is needed

Other diseases after the Chernobyl accident

Cognitive (mental retardation) and behavioral performances

- Doubts (for *in utero* exposures at the time of the accident)

Congenital malformations

- Good Belarusian registry : no increase
- Doubts for trisomy 21 (for *in utero* exposure at the time of the accident) *(Zatzepin et al. Reprod Toxico 2007)*

Solid cancers

- Numerous studies : no consistent results (insufficient follow-up?)

Non-cancer diseases

- Cardiovascular pathologies (arrhythmias) : suggestion of a link with Cs^{137} not confirmed, excess observed in the cohort on Russian liquidators
- Cataracts : excess risk and possible relationship with the dose among Russian liquidators
- Various diseases (digestive, renal, endocrine, respiratory, immune) : no consistency in results

Fukushima accident : March 11, 2011

Fukushima Health Management Survey

Following-up the health of the residents for a long time
with the aim of future health promotion

FUKUSHIMA
MEDICAL
UNIVERSITY

Radiation Medical Science Center
For The Fukushima Health Management Survey,
Fukushima Medical University

(Source : K. Kamiya, FMU, Dec-2020)

Fukushima Health Management Survey

Basic Survey

External radiation exposure estimation
≈ 2,000,000 residents in the Fukushima Prefecture

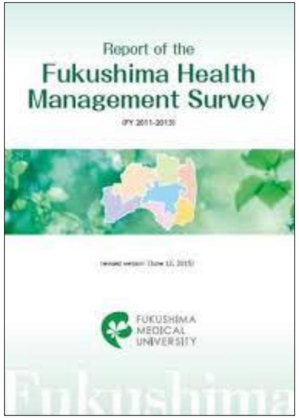
Detailed surveys

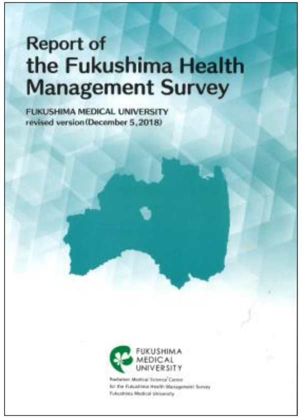
Comprehensive health check in evacuees
≈ 210,000 people in evacuation zones

Mental health and lifestyle
≈ 210,000 people in evacuation zones

Pregnancies and births
≈ 16,000 pregnant women (August 2010 - July 2011)

Thyroid ultrasound examination
≈ 360,000 residents aged from 0 to 18 years in March 2011

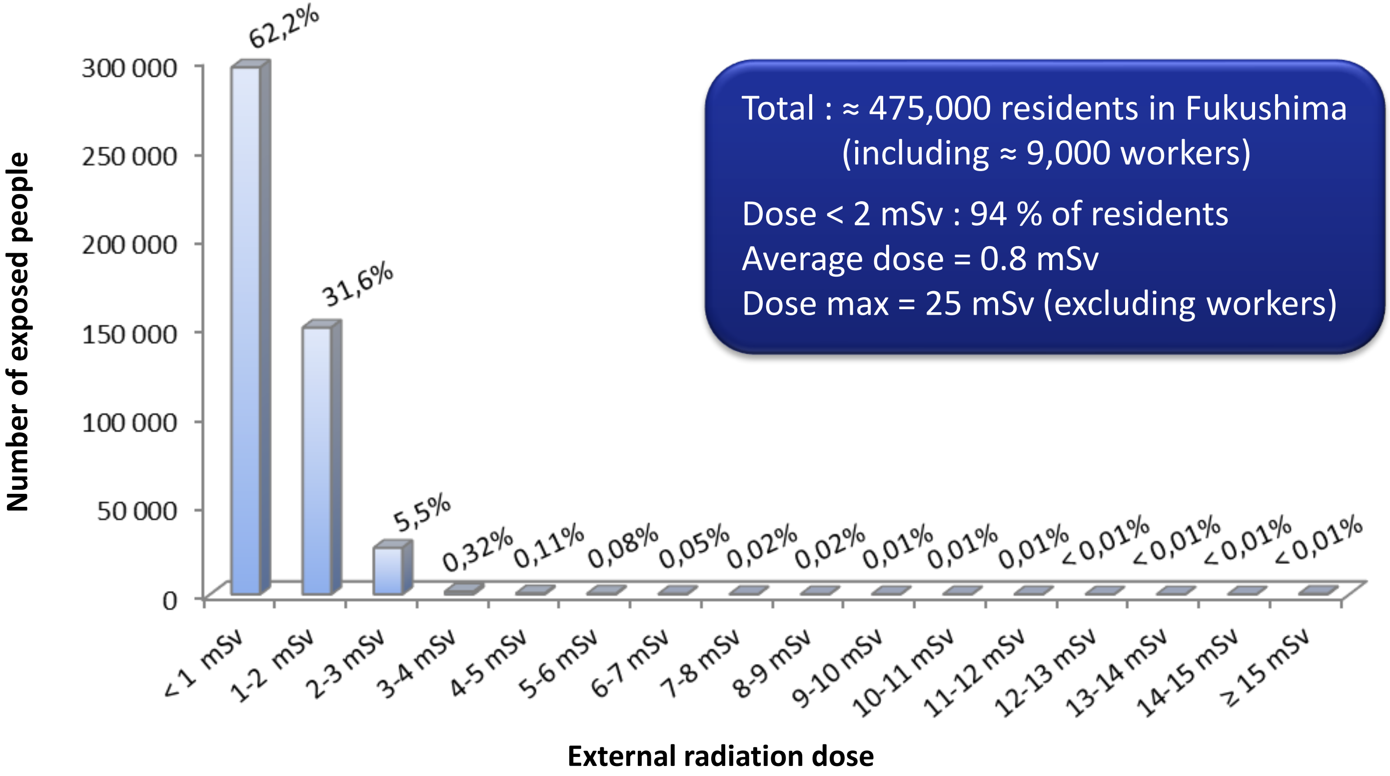




- Ambitious program implemented in July 2011
- Assessment, but also advice

(Source : K. Kamiya, FMU, Dec-2020)

Basic survey : estimation of the effective dose the first 4 months after the accident



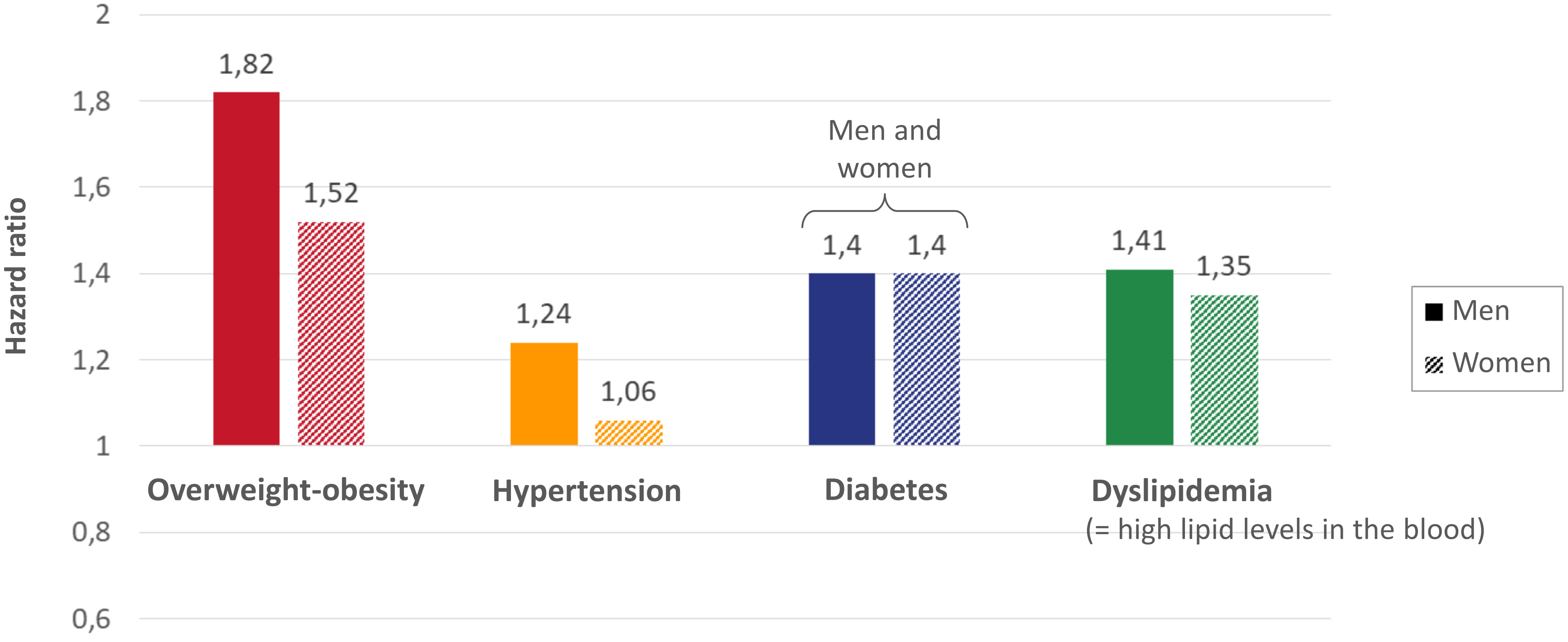
Total : ≈ 475,000 residents in Fukushima
(including ≈ 9,000 workers)

Dose < 2 mSv : 94 % of residents
Average dose = 0.8 mSv
Dose max = 25 mSv (excluding workers)

Health check of evacuees before/after the accident

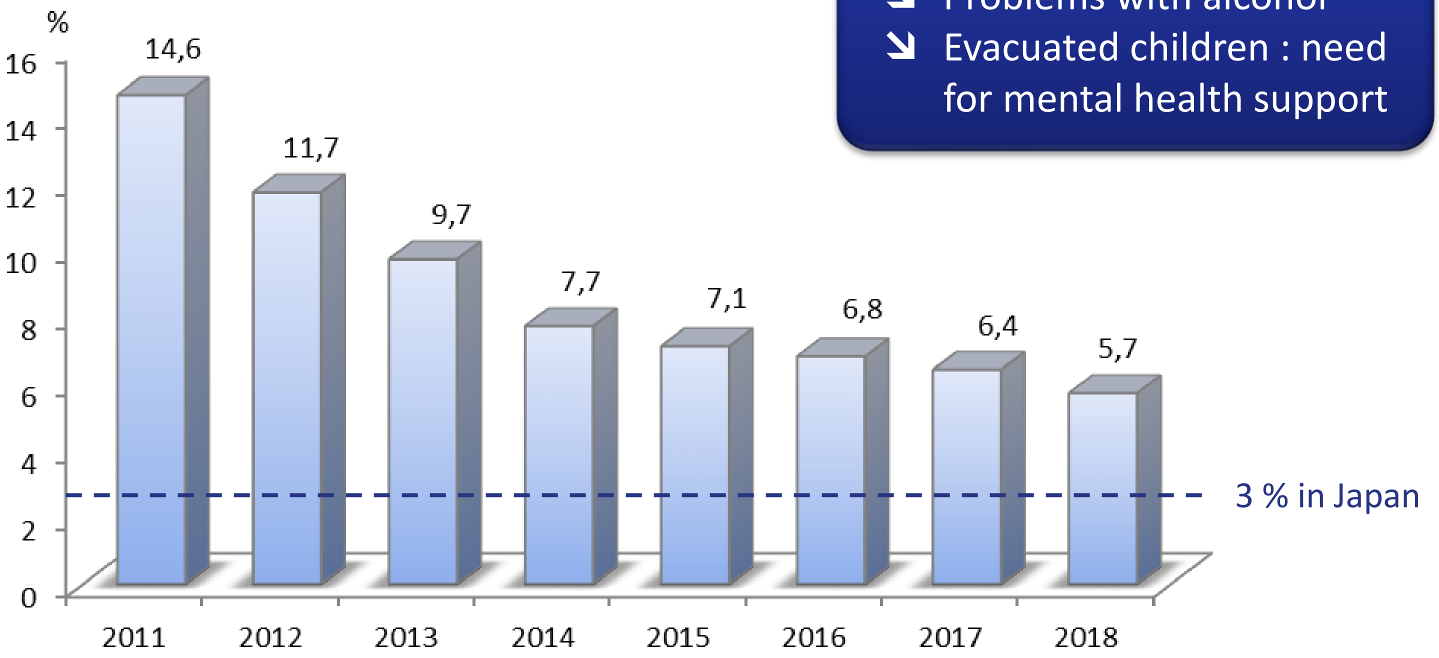
Significant increase in these risks related to evacuation
(changes in lifestyle, diet, physical activities…)

(Ohira et al. Asia Pacific J Public Health 2017)



Mental health of evacuees

Evacuees need support due to depression or anxiety



- ↘ Problems with alcohol
- ↘ Evacuated children : need for mental health support

% of evacuees needing support due to depression/anxiety is still 2 times higher than the national average

Pregnant women and births

Similar results to national surveys (%)

Year	Rate of preterm deliveries		Rate of low birth weight infants		Rate of congenital anomalies	
	Fukushima	*Japan*	Fukushima	*Japan*	Fukushima	*Japan*
2011	4,8	*5,7*	8,9	*9,6*	2,85	*≈ 2-5*
2012	5,7	*5,7*	9,6	*9,6*	2,39	
2013	5,4	*5,8*	9,9	*9,6*	2,35	
2014	5,4	*5,7*	10,1	*9,5*	2,30	
2015	5,8	*5,6*	9,8	*9,5*	2,24	
2016	5,4	*5,6*	9,5	*9,4*	2,55	
2017	5,4	*5,7*	9,4	*9,4*	2,38	
2018	5,3	*5,6*	9,2	*9,4*	2,19	

Thyroid cancer screening in children

in the Fukushima Prefecture

Source : The Japan Times

- Approximately 360,000 children ≤ 18 years at time of the accident
- **Examination by ultrasonography**
  - If cyst ≥ 20.1 mm or nodul ≥ 5.1 mm, confirmatory examination (advanced ultrasonography, blood and urine test, fine-needle aspiration biopsy) → **Medical follow-up or treatment** (surgery…)
  - **Next examination** once every 2 years (≤ 20 years) or every 5 years (≥ 25 years)
- 5 campaigns conducted to date (July 2021) :

Preliminary baseline screening	Prevalence	①	2011-2014	116 cases / 300 472	→ 39 / 100 000
Full-scale screening	Incidence	②	2014-2015	71 cases / 270 552	→ 13 / 100 000 per year
		③	2016-2017	31 cases / 217 922	→ 7 / 100 000 per year
		④	2018-2019	33 cases / 183 239	→ 9 / 100 000 per year
		⑤	2020-2021	0 case / 21 624	(in process)

→ **251 suspected cases**

IRSN

Thyroid cancers linked to a screening effect rather than a radiation effect (to date)

Screening effect

Exposed *versus* unexposed

Prevalence of thyroid nodules

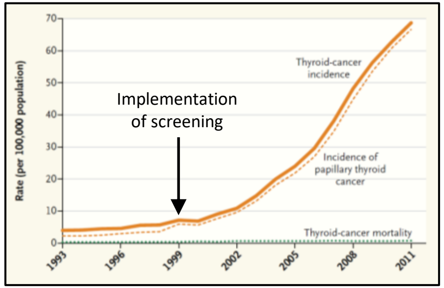
⇩

Similar results of screenings in :

- Fukushima
- 3 other Prefectures (Japan)

Overdiagnosis of thyroid cancer

Ex : South Korea
× 15 in 1993-2011



Identification of thyroid cancer cases

Systematic screening	>	Cancer registry
Small tumor nodules, without clinical expression		Registration of new cases (incident) only

- No neck mass detectable by palpation
- No endocrine disruption, good survival

- *Clinically expressed* ou incidentally discovered

→ *Important reservoir of subclinical diseases (ex : South Korea, autopsies)*

Thyroid cancers linked to a screening effect rather than a radiation effect (to date)

Radiation effect : results observed after Chernobyl *versus* Fukushima

Radiation dose

Estimated doses :
much higher after Chernobyl

No association shown to date between dose distribution and thyroid cancer frequency

Radiation-induced health effects will be difficult to discern in the future, due to low dose level

(UNSCEAR 2021)

Characteristics of cancers

Different frequency of genetic alterations : predominance of mutation BRAF in Fukushima *versus* RET/PTC in Chernobyl

(Mitsutake et al. Sci Rep 2015)

Different histopathological scenarios

(Bogdanova et al. Thyroid 2021)

Age distribution

Much younger exposed cases after Chernobyl

(Tronko et al. Thyroid 2014)

Study « NEWS »

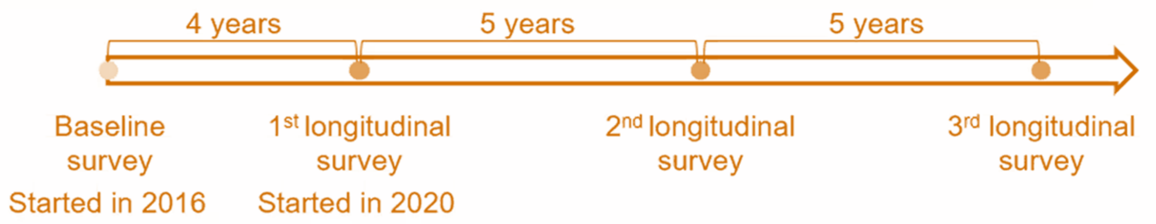
(Nuclear Emergency Workers Study)

放影研 Radiation Effects Research Foundation
RERF A Cooperative Japan-US Research Organization

≈ 20,000 workers in emergency situation (TEPCO)

99,9 % men (≈ 20 women)

No acute radiation syndrome



Program of the study

- Clinical study
  - ✓ *General health examination*
  - ✓ *Psychological effects*
  - ✓ *Thyroid cancer*
  - ✓ *Cataract*
- Study of mortality
- Study of cancer incidence
- Radiobiology : physiological and molecular biological parameters
- Individual dose reconstitution

(Source : H. Kitamura, 23 March 2021)

Conclusion

Chernobyl accident ≈ 35 years ago

- Excess of **thyroid cancers related to radiation** in people exposed during childhood
- Other health effects :
  - Excess of **leukaemias related to radiation** in liquidators
  - Importance of **psychological effects** (post-traumatic stress disorder, depression, anxiety…)

Fukushima accident ≈ 10 years ago

- Before the accident, **no cancer registry** in the Fukushima Prefecture
  → Implementation of systematic screening
  → High number of **thyroid cancer nodules** diagnosed in young people (screening effect)
- Health consequences **not only related to radiation** :
  evacuation effect, over-diagnosis (screening), psycho-social impact
- Follow-up of epidemiological studies → despite low predicted risks

Thanks for your attention !