Health Effects of Nuclear Reactor Accidents: TMI, Chernobyl, Fukushima

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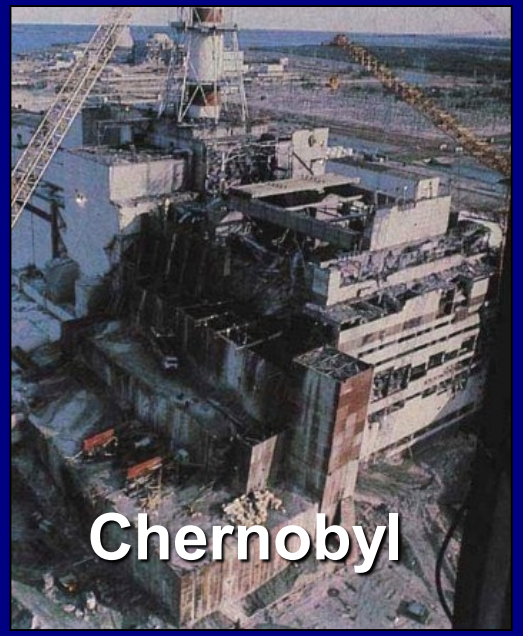
“Accidents Happen”

- Windscale, UK 1957
- Three Mile Island, USA 1979
- Chernobyl, USSR 1986
- Fukushima, Japan 2011

TMI, Chernobyl, Fukushima
Each is unique, but…



…there are similarities

- **Type of radiation released**
  - Principally Iodine-131 (I-131)
- **Large numbers exposed**
  - General population, workers
- **Risk perception**
  - High, and unrelated to dose

Other similarities

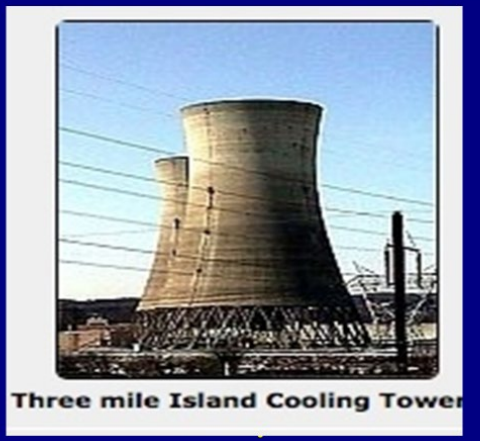
- •Type of radiation released
- - Principally Iodine-131 (I-131)
- ● Large numbers exposed
- - General population, workers
- ● Risk perception
- - High, and unrelated to dose
- ● Health effects
- - Mental > physical
- ● Susceptible subgroups
- - Young at exposure; pregnant women, mothers, evacuees

Relative Releases of I-131 (Bq x 10^{15})

- Chernobyl (Ukraine), 1986 — 1,800.0
- Fukushima (Japan), 2011 — 160.0
- Windscale (UK), 1957 — 0.74
- Three Mile Island (USA), 1979 — 0.0006

“Social Amplification of Risk”

Three-Mile Island



- Three Mile Island (TMI)
- Partial meltdown, March 28, 1979

- March 30th advisory for pregnant women and preschool children to evacuate the 5-mile area (later extended to 20 miles)

- 144,000 (~half the population) left the area temporarily

Columbia TMI Study

- Rationale:
  - Continuing public concern despite very low exposure
- Design:
  - Comparison of cancer rates through 1985 for 69 small geographic areas by dispersion-model-based estimates of radioactive emissions.
  - Focus on leukemia and childhood malignancies.

(Hatch et al., 1990)

Columbia TMI Study

- Findings/Conclusions:
  - No clear associations of estimated emissions with radiosensitive cancer types and population subgroups
  - Hence, no convincing evidence that accident releases influenced cancer risk (Hatch et al., 1991)

TMI Cancer Studies (1)

- PA Dept. of Health:
  SMR study (1979-1998)
  - No impact on cancer mortality overall
  - Dose-response trends for breast cancer and lymphatic/hematopoietic cancers
    (Talbott et al., 2000)
- Univ Pittsburgh:
  Cancer Incidence (1982-1995)
  - No increase overall
  - Increased risk of leukemia in men
    (Han et al., 2011)

TMI Cancer Studies (2)

- Penn State: Thyroid Cancer Incidence,
  3 high risk counties
  - Upward trend beginning in 1990. Few cases in those exposed as children
    (Levin et al., Laryngoscope 2008, 2013)

- Penn State: Thyroid Cancer Molecular Profile
  - ↓BRAF mutations – 15 cases
    (Goldenberg et al., Laryngoscope 2017)

Three Mile Island: Mental Health

- Workers at the plant

  -anger, worry, demoralization, somatic complaints

  -acute effect, short-lived (Kasl et al, 1981)

- Mothers of young children:

  -increased depression and anxiety disorders, esp. in 1st year,

  -distress elevated up to 10 years

  -3 x more likely to rate health as fair or poor

  -perceived risk a risk factor (Dew & Bromet, 1993)

- General population:

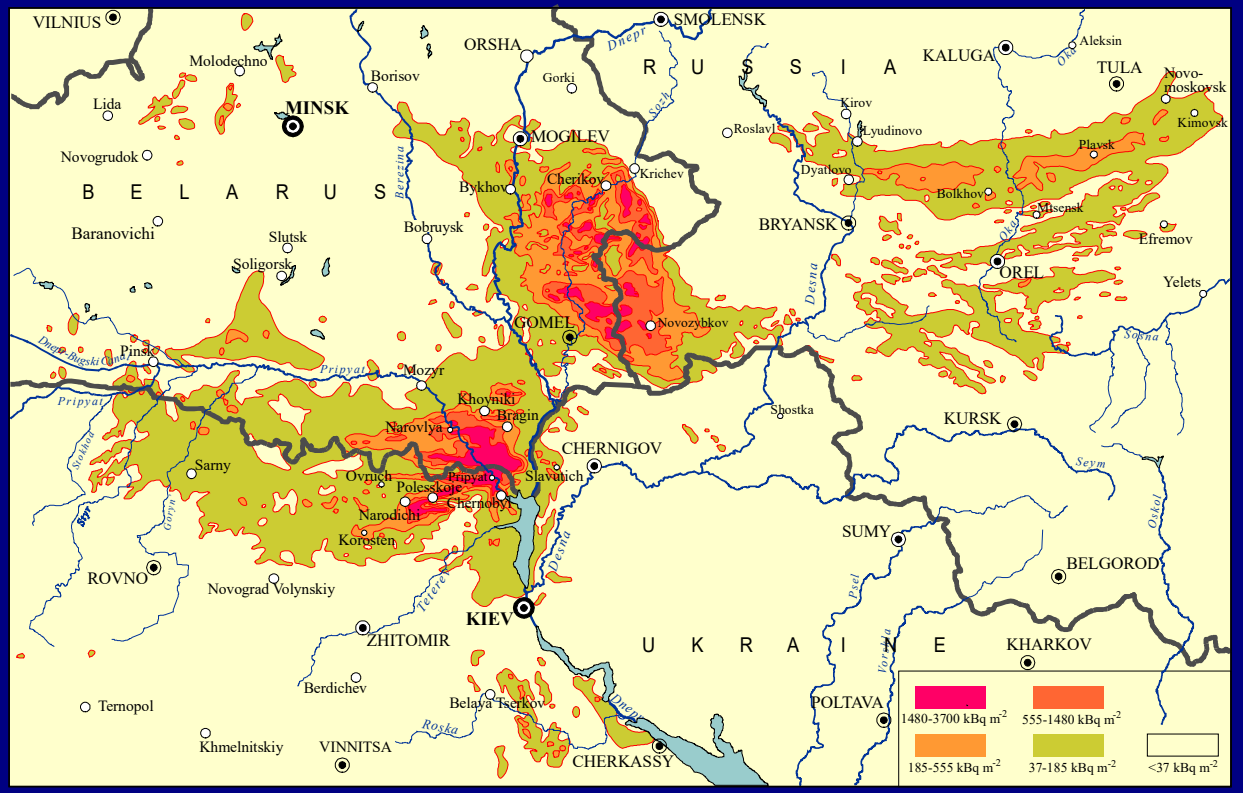
  -Increase in psychological symptoms and poorer subjective health; but no diagnosable psychiatric conditions (Bromet 2012)

President's Report on TMI

"The major health effect of the accident appears to have been on the mental health of the people living in the region of Three Mile Island and of the workers at TMI."

Chernobyl

April 26, 1986



What Was Known Then

- External radiation (gamma, x-ray):
  -has effects on exposed children

- I-131 in diagnosis and treatment:
  -no increase in adult patients
  -data on children sparse
  -considered non-carcinogenic

- Hence limited countermeasures against I-131 in fallout

Exposure to Radioactive I-131

- I-131 concentrates in the thyroid, can be inhaled and ingested
- Children received the highest doses (pasture/cow/milk pathway)
- Iodine Deficiency in contaminated areas increased uptake of radioiodines

Time Trends Point to a Problem

Year	Thyroid Cancer (No.)
1981	0
1982	0
1983	0
1984	0
1985	0
1986	0
1987	0
1988	0
1989	0
1990	3

Prisyazhiuk A, et al., The Lancet 1991

NCI Cohort Studies: Exposed Children

≈ 13,000 in Ukraine (UkrAm) (mean dose 0. 65 Gy)

≈ 12,000 in Belarus (BelAm) (mean dose 0.68 Gy)

Screened serially for thyroid disease using palpation and ultrasound,

FNA as needed

(Tronko et al., 2006; Zablotska et al., 2010; Brenner et al., 2011; Tronko et al., 2018)

Findings from UkrAm/BelAm

- Excess risk of thyroid cancer (2-fold in Belarus, 5-fold in Ukraine); results consistent with studies of external radiation
- Risk greatest for those youngest at exposure (>= 3-fold higher in 0-4 y age group)
- Risk remains elevated 30 y post-exposure
- Uncertain impact of iodine deficiency as a modifying factor

(Tronko et al., 2006; Brenner et al.,2011; Zablotska et al., 2010; Tronko et al., 2017)

NCI-Ukraine In Utero Study

- 2,682 mother-child pairs
- Mean fetal thyroid I-131 dose = 72 mGy (0-3,240 mGy)

- Screened for thyroid cancer, 2003-2006:
  7 cancers, 1 hurthle cell neoplasm
  EOR/Gy= 11.66 (P=0.12)
- 2nd screening, 2012-2015: 8 cancers
  EOR/Gy= 3.91, NS

Screening of parallel Belarus *in utero* cohort in progress

(Hatch et al. 2009; Likhtarev et al. 2011; Hatch et al. 2019)

“Liquidators”

- 2 plant workers died in the immediate aftermath of the accident.
- High radiation doses to 134 plant and emergency personnel resulted in acute radiation syndrome (ARS), 28 near-term deaths.

Liquidators in Ukraine: NCI and RCRM

- Cohort of ~110,000 clean-up workers, 1986-1990
- Sent by various military and civilian organizations, for a variety of tasks
- Exposed mainly to low dose-rate external radiation (mean ~ 100 mGy)

Focus on Leukemia

- Bone marrow very radiosensitive
- Highest risk per unit dose of radiation among all radiation-induced cancers
- Shortest latency (2-5 y)

Leukemia Case-Control Study

- 137 cases, 866 controls
- Official dosimetry records poor, missing for 60% of subjects
- New time-and-motion method developed – RADRUE (Realistic Analytical Dose Reconstruction with Uncertainty Estimation)

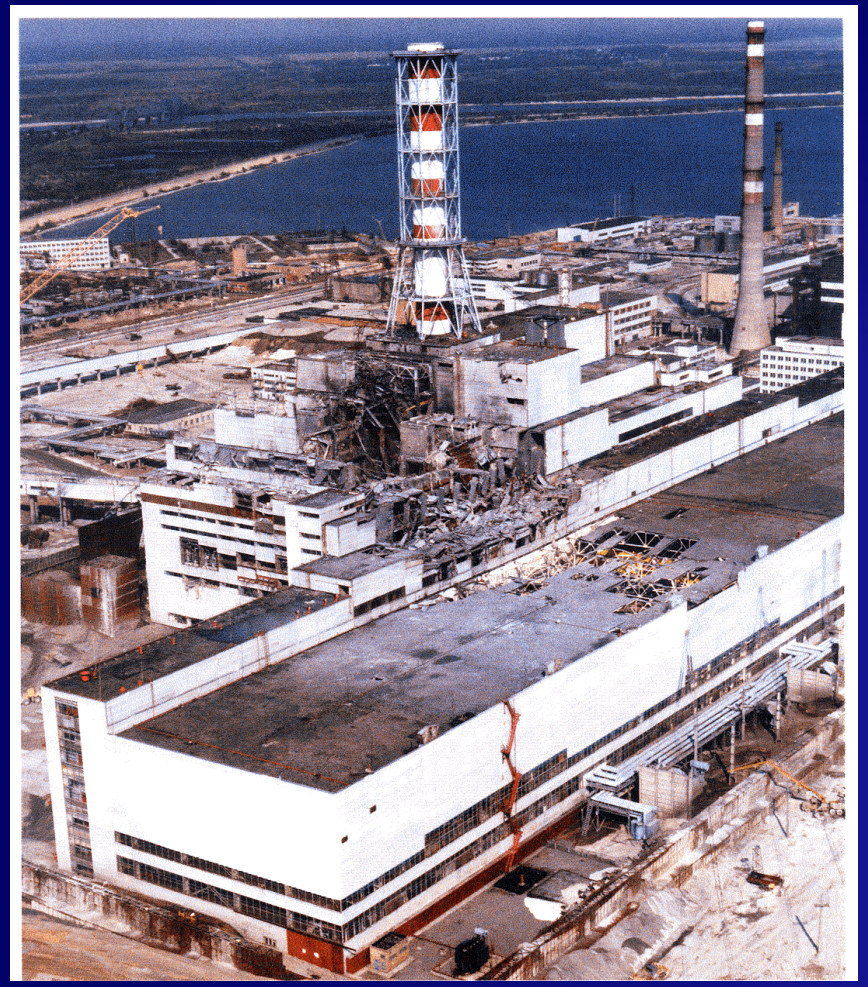
Dose-Response Results

- All Leukemias:
- ERR/Gy = 1.26 (95% CI: 0.03, 3.58)
- Significant linear dose-response

- Non-significant positive dose-response:
- -CLL: ERR/Gy = 0.76
- -Non-CLL: ERR/Gy = 1.87

- Zablotska et al. 2013

Leukemia in Liquidators:
What We Know Now



- Leukemia risk from low dose/low dose rate exposure to external radiation comparable to that in A-bomb survivors with acute exposure

- Elevated risk for both CLL (previously considered nonradiogenic) and non-CLL, consistent with study by IARC

Romanenko et al., 2008; Zablotska et al., EHP 2013

Thyroid Cancer in Early Liquidators

- Reports of Increased risk of thyroid cancer in early cleanup workers, exposed to I-131:

  - 8-fold ↑ in male recovery workers
  - ERR/100mGy= 0.38 in males, higher in females
  - SIR=350 for 1st cleanup mission in 1986

  (Prysyazknyuk A et al.,2007; Kesminiene A et al., 2012; Ostroumova E et al, 2014)

- NCI/RCRM study in progress

Non-Cancer Effects in Liquidators

- Cataracts at 1Gy

  Worgul BV et al. 2007; Ainsbury EA et al., 2009

- Cerebrovascular Disease
  (↑ at >150 mGy; ↑ at >300 mGy)

  Ivanov VK et al. 2006; Kashcheev VV et al. 2016

Mental Health: contextual issues

- Socioeconomic disruption from dissolution of the Soviet Empire in 1991
- Misinformation, mismanagement (“Fake News, Real Radiation”)
- Relocations
- Restrictions on social/cultural practices
  (e.g., picking mushrooms, berries)
- Chernobyl “victims, “Chernobylites”

Psychological Consequences

- In liquidators, depression and PTSD still elevated decades later; ↑ suicide (Estonian cohort); suicide ideation, depression, anxiety (Ukraine and Estonia)

- As at TMI, mothers of young children a high-risk group for depression, anxiety;
  Risk perception = powerful correlate

- Evacuee moms: > PTSD, depression, poor subjective health; Risk perception a predictor

(reviewed in Bromet and Havenaar 2011, Bromet 2014)

Transgenerational Effects

"My daughter said, Mom, if I give birth to a damaged child, I'm still going to love him….Her friends, too, they all think about it."

(Voices from Chernobyl)

NCI-Ukraine Trios Study

- **450 father-mother-child sets**
- **Survey of genetic changes using WGS**
  - *de novo* mutations, minisatellites, large CNVs and somatic mosaicism, telomere length, methylation status
  - changes traced to parental exposure, parent of origin

In Progress

Fukushima Daichi

- Accident occurred on March 11, 2011, following Great East Japan Earthquake

- No near-term deaths from radiation among plant workers or members of the public

Fukushima Post-Accident

- Thyroid screening examinations
- Health Management Survey
- Community programs to improve mental health

Lower Doses at Fukushima

- Smaller release and deposition
- No iodine deficiency
- Quick action to minimize exposure
  - Evacuation
  - Recommendation to stay indoors
  - Food restriction

97.7% < 5mSv (Health Management Survey, N= 460,408)

Thyroid Cancer, Fukushima Prefecture

- Ultrasound exams for all children <18y ATA (~360,000)
- 10 mHz or higher frequency probe
- Nodules/cysts confirmed by experts

(Nagataki &Takamura 2014)

Screening in 3 other Prefectures

(Hayashida et al., 2013)

Thyroid Cancer Screening Results

- 30-fold ↑ (but no regional differences)
- different age pattern (older at dx)
- shorter latency
- different genetic profile

  high BRAF, low RET/PTC (Mitsutake et al., 2015)

- True ↑? ↑Detection? (Wakeford et al., 2016)

Non-Cancer Somatic Effects

- Deaths during evacuation of hospital patients, and among displaced elderly (Tanigawa et al., 2012; Nomura et al., 2013; Hasegawa et al., 2016)
- ↑ prevalence of diabetes - >> in evacuees (Satoh et al., 2015)

Mental Health: Evacuees

- N=210,000
- 21.6% possible PTSD
- 14.6% depression
- chronic anxiety and guilt
- public and self-stigma
- concern about genetic effects (↓ intention to return)

(Maeda et al., 2016)

Mental Health: Workers

Doses ~ 100 mSv

- ↑ psychological distress (K-6 Scale, PTSR)
- risk factors: discrimination and slurs

(Shigemura et al., 2012)

Mental Health: Mothers

- ↑ depressive symptoms risk factors: evacuation, concern about radiation
- 40% believe future children could be affected
- ↓ pregnancy intention in mothers concerned about radiation

(Goto, Bromet et al., 2017)

Transgenerational Effects:
A Serious and Persistent Concern

- In 2014, 54% of residents in a village within 30 km of the FNPP had anxiety about radiation effects on children
  (Orita et al.,2015)

- In 2018, 7 years post-accident, anxiety about genetic effects among evacuees associated with reluctance to return home

  (Matsunaga et al., 2019)

Follow-Up at TMI, Chernobyl, Fukushima

- **TMI:** limited research, not seen as a real disaster, no medical support for those affected
- **Chernobyl:** extensive research, compensation program for Chernobyl “victims”, but social stigmatization
- **Fukushima:** TUE, Health Management Survey, support for pregnant women, community programs, etc.

Some Lessons Learned

- Risk communication is critical
- Prompt countermeasures are important
- Emotional consequences of disasters require attention
- Integrated, multidisciplinary targeted research should be undertaken
- Monitoring, medical care and research need to continue long-term

Question 1

Which of the following non-cancer effects have been seen after nuclear accidents?

a. CVD

b. mental health problems

c. diabetes

d. all of the above

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Acknowledgments

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