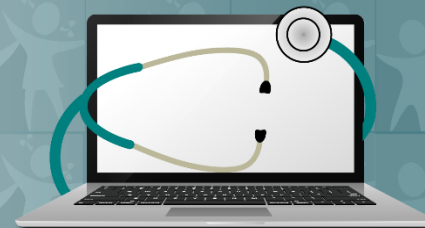




PEHSU NATIONAL CLASSROOM

Pediatric Environmental Health Specialty Units



www.pehsu.net/nationalclassroom.html



Webinars

Series of scientific webinars that provide a forum for discourse on scientific issues.

Live and On-Demand

Case Conferences
Journal Clubs
Grand Rounds

CE Available



Online Courses

Evidence-based online courses on a variety of children's environmental health topics.

Interactive and Self-Paced

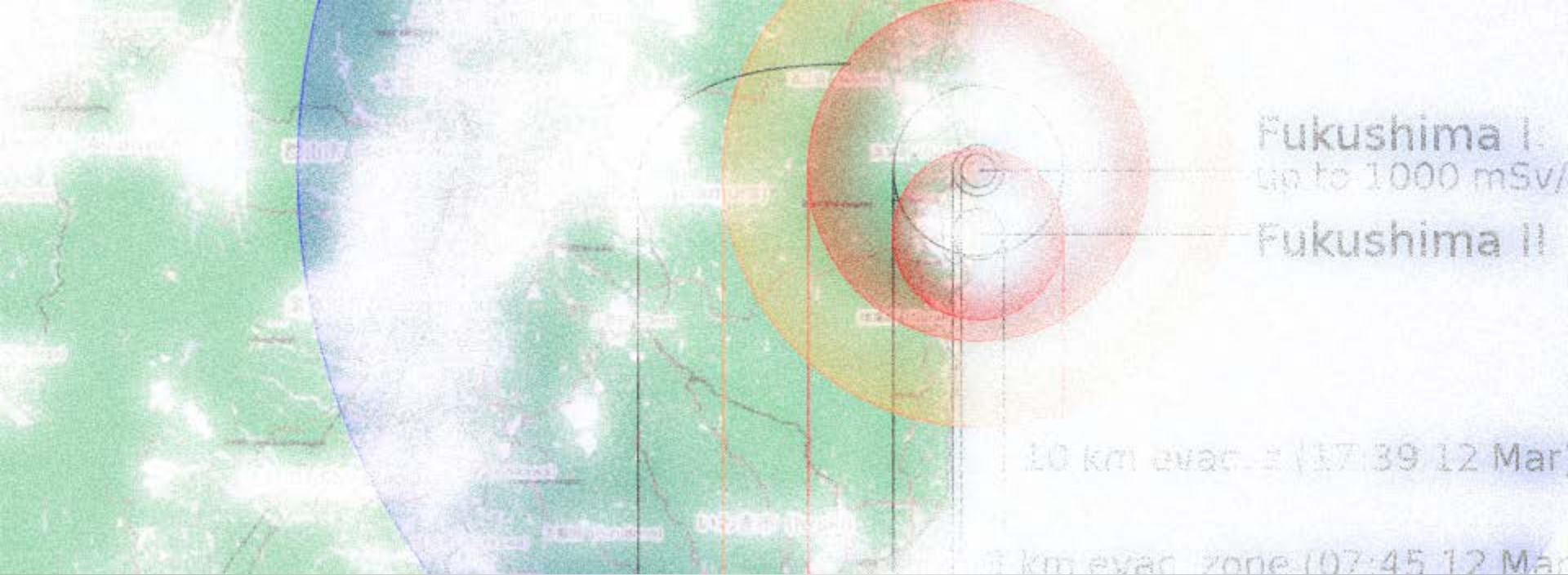
CE Available



Resource Catalog

Fact sheets, journal publications, reports, and other resources for parents, community members, patients and healthcare professionals

Topics included:
Air Quality, Pesticides,
Natural Disasters, BPA,
Mold, Lead, Mercury



Fukushima and Chernobyl: Near and Long-term Effects On Children

Stephen W. Borron, MD, MS
Southwest Center for Pediatric Environmental Health
Texas Tech University Health Sciences Center— El Paso
El Paso, TX, USA

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This material was supported by the American College of Medical Toxicology (ACMT) and funded (in part) by the cooperative agreement FAIN: U61TS000238-02 from the Agency for Toxic Substances and Disease Registry (ATSDR).

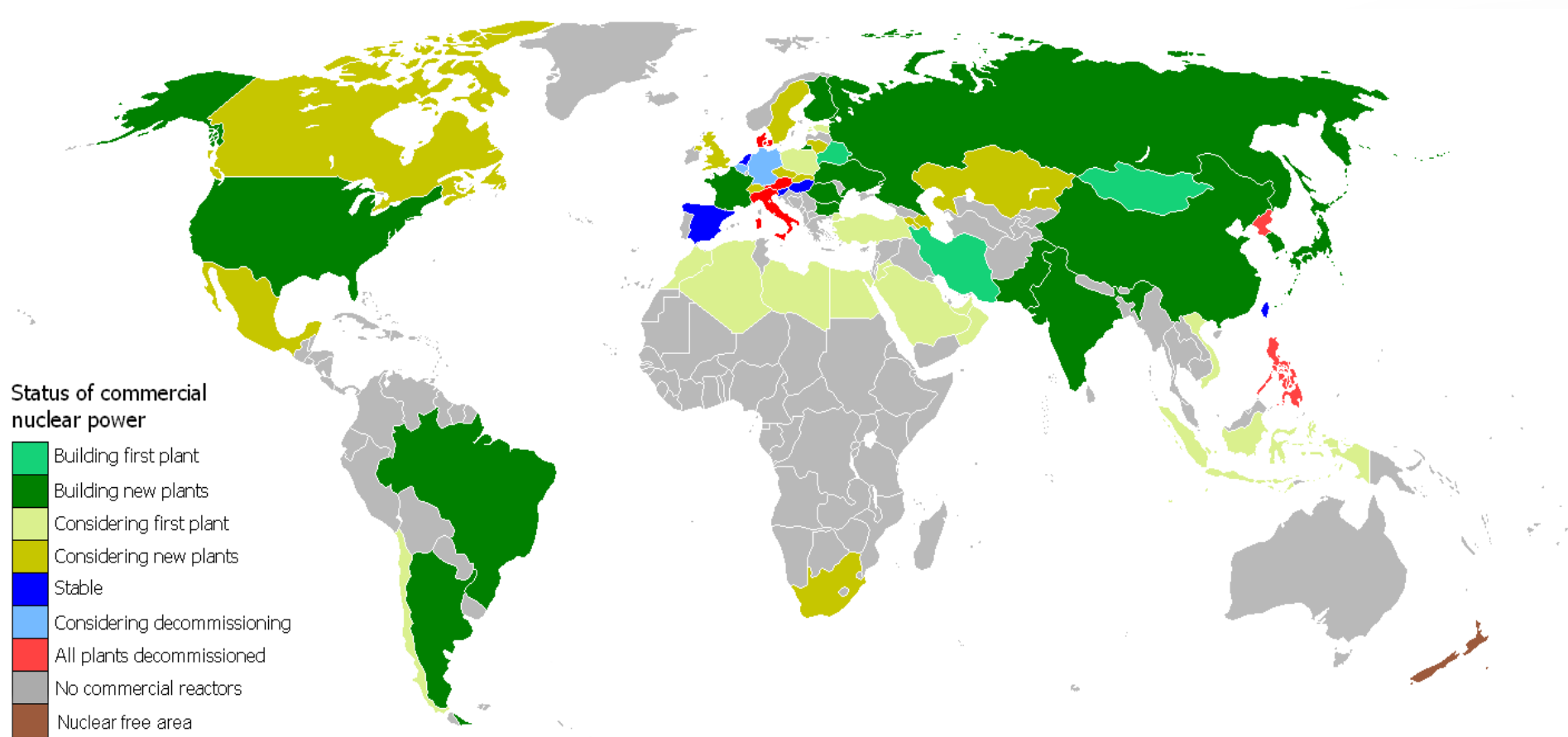
- The speaker has made liberal use of the training materials and illustrations of the US Centers for Disease Control and Prevention and gratefully acknowledges their contributions.
- <http://emergency.cdc.gov/radiation>

Outline

- Current status of nuclear power generation
- Power plant types, radiation basics, isotopes of concern
- Chernobyl, 1986 and its effects on children
- Fukushima, 2011 and children, now and in the future
- Radiological emergency resources

Current Status Of Nuclear Power Generation

Distribution of nuclear power plants



"Nuclear power stations". Licensed under CC BY-SA 3.0 via Wikimedia Commons – 2009

https://commons.wikimedia.org/wiki/File:Nuclear_power_stations.png#/media/File:Nuclear_power_stations.png

https://commons.wikimedia.org/wiki/File:Nuclear_power_stations.png#/media/File:Nuclear_power_stations.png

Nuclear Power – Current Status

According to the International Atomic Energy Agency (IAEA), there are:

- 446 nuclear power reactors in operation, worldwide

- 2 nuclear power reactors in long-term shutdown

- 63 nuclear power reactors under construction

The five newest connections to the grid include:

- 3 in China

- 1 in the Republic of Korea

- 1 in the US

Highlights of America's New Reactor

- Watts Bar-2: Tennessee Valley Authority
 - 1165 MWe net capacity
 - Construction start date: 09/01/1973
 - Construction suspension date: 09/17/1985
 - Construction restart date: 10/15/2007
 - First criticality date: 05/23/2016
 - First grid connection: 06/03/2016
 - Initial cost estimate: \$400 million
 - Total cost estimate: \$6.1 billion



<http://latimes.com>

<http://www.iaea.org/pris/CountryStatistics/ReactorDetails.aspx?current=700>

Highlights of America's Largest Solar Thermal Power Station

- Ivanpah Solar Power Facility: PG&E
 - 392 MWe net capacity
 - Construction start date: 10/27/2010
Construction suspension date: NA
 - Construction restart date: NA
 - First sync testing date: 09/2013
 - First grid connection: 02/13/2014
 - Initial cost estimate: ND
 - Total cost estimate: \$2.2 billion



Nuclear Power Plant Accidents of INES ≥ 4

Fukushima, 2011 – Japan - 7

Chernobyl, 1986 – Ukraine – 7

Kyshtym, 1957 – Russia - 6

Three Mile Island, 1979 – US – 5

Windscale Pile, 1957 – UK – 5

Chalk River, 1952 – Canada – 5

Fleurus, 2006- Belgium – 4

Tokaimura, 1999 – Japan – 4

Tomsk, 1993 – Russia – 4

RA-2, 1983 – Argentina - 4

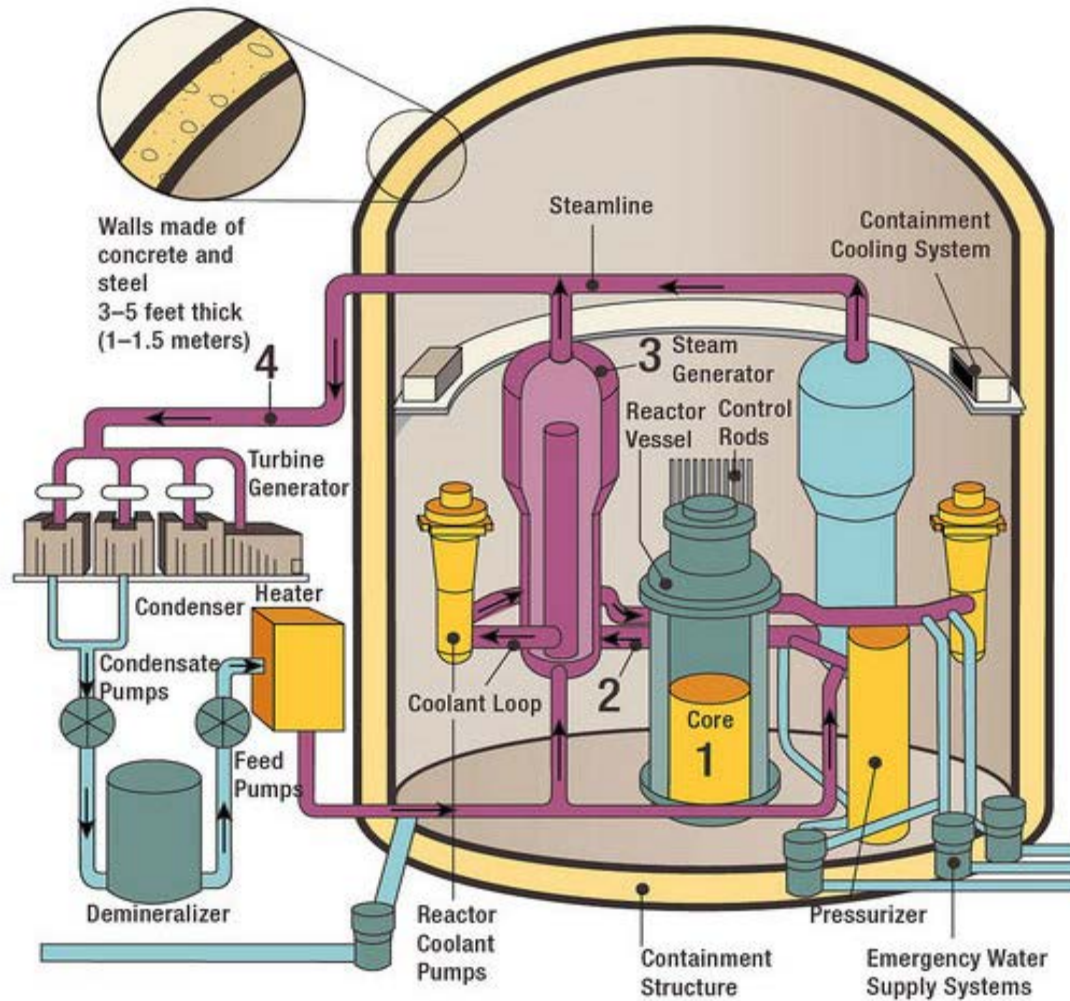
Saint Laurent des Eaux, 1980 – France - 4

Jaslovské Bohunice, 1977 –Czechoslovakia - 4

	OFF-SITE IMPACT	ON-SITE IMPACT
7 MAJOR ACCIDENT	MAJOR RELEASE: WIDESPREAD HEALTH AND ENVIRONMENTAL EFFECTS	
6 SERIOUS ACCIDENT	SIGNIFICANT RELEASE: LIKELY TO REQUIRE FULL IMPLEMENTATION OF PLANNED COUNTERMEASURES	
5 ACCIDENT WITH OFF-SITE RISK	LIMITED RELEASE: LIKELY TO REQUIRE PARTIAL IMPLEMENTATION OF PLANNED COUNTERMEASURES	SEVERE DAMAGE TO REACTOR CORE/RADIOLOGICAL BARRIERS
4 ACCIDENT WITHOUT SIGNIFICANT OFF-SITE RISK	MINOR RELEASE: PUBLIC EXPOSURE OF THE ORDER OF PRESCRIBED LIMITS	SIGNIFICANT DAMAGE TO REACTOR CORE/RADIOLOGICAL BARRIERS/FATAL EXPOSURE OF A WORKER

Power plant types
Radiation basics
Isotopes of concern

Pressurized Water Reactor



Boiling Water Reactor

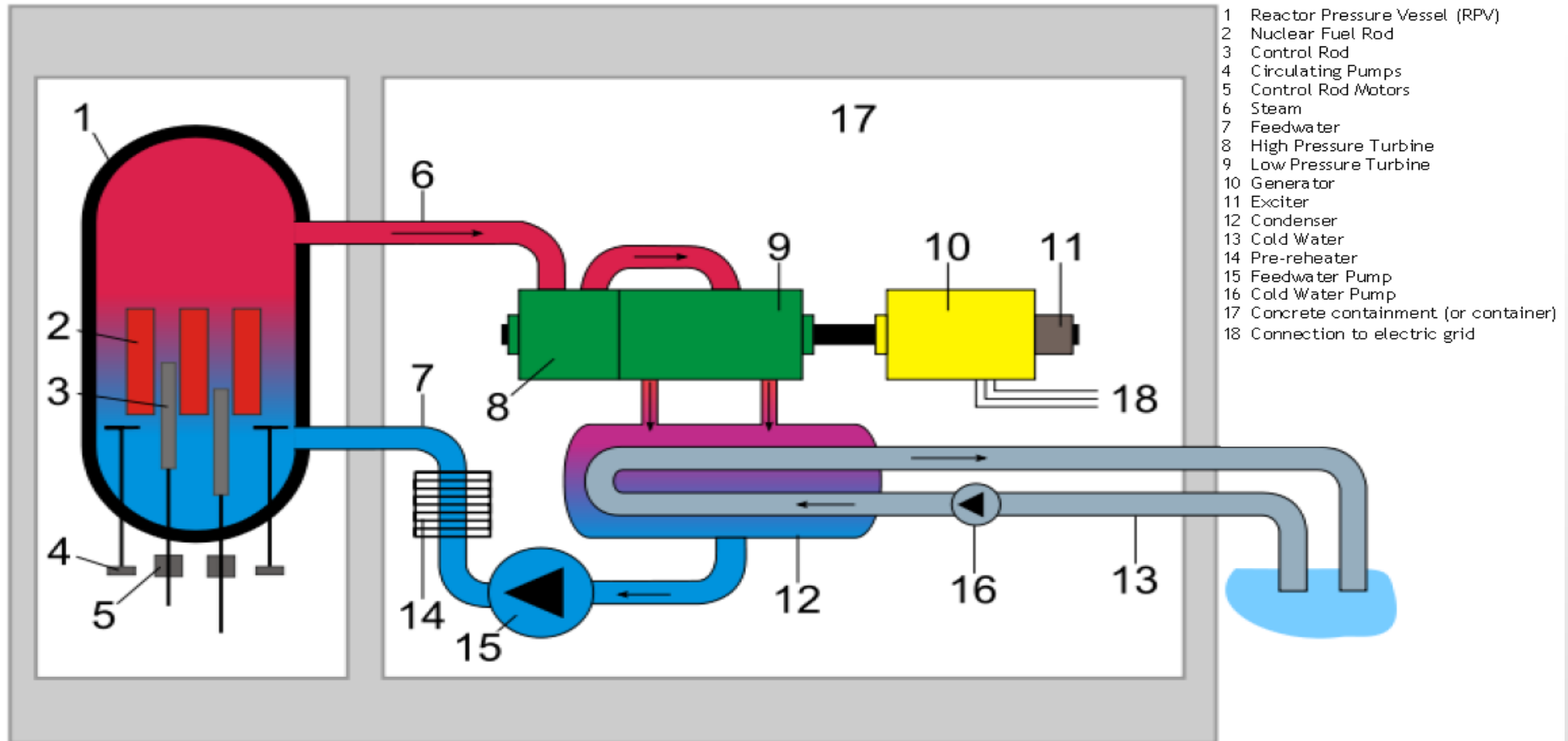


Figure 2-1 - Diagram of general operation of a BWR

Spectrum of Electromagnetic Energy

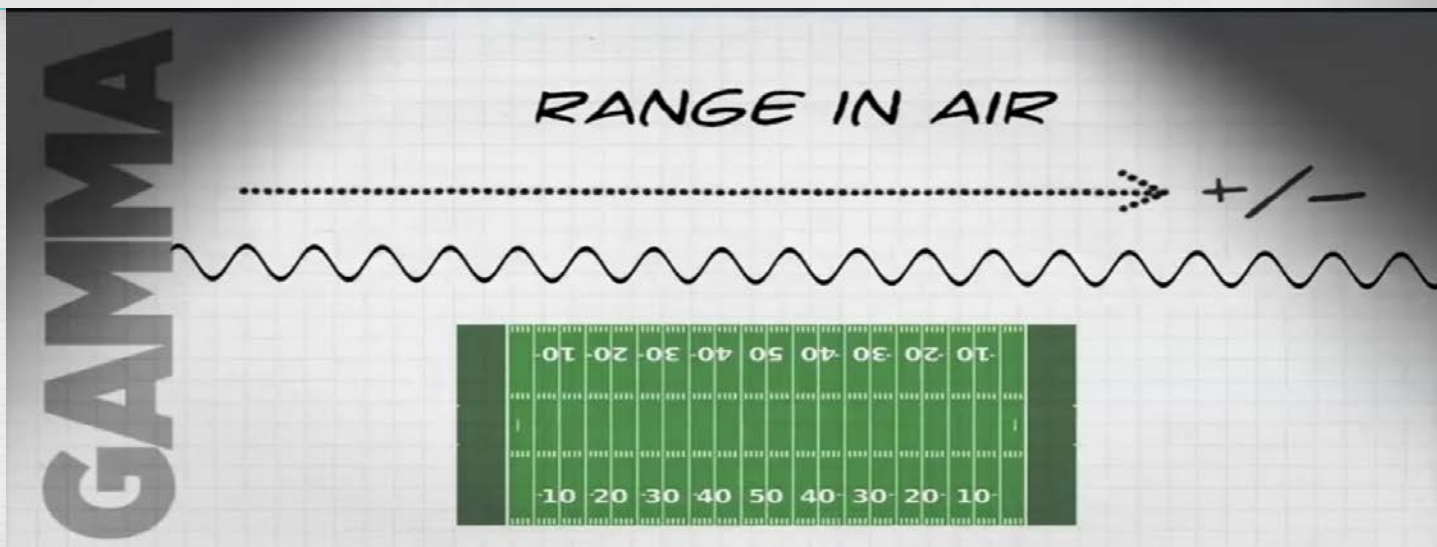
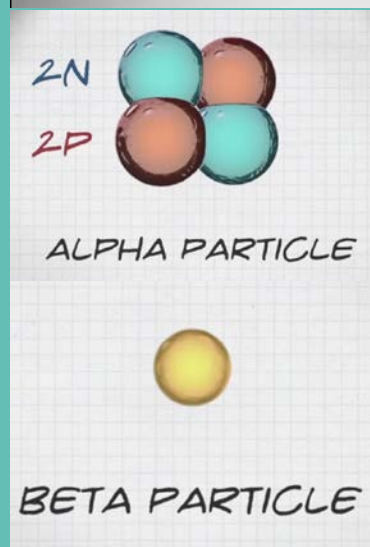
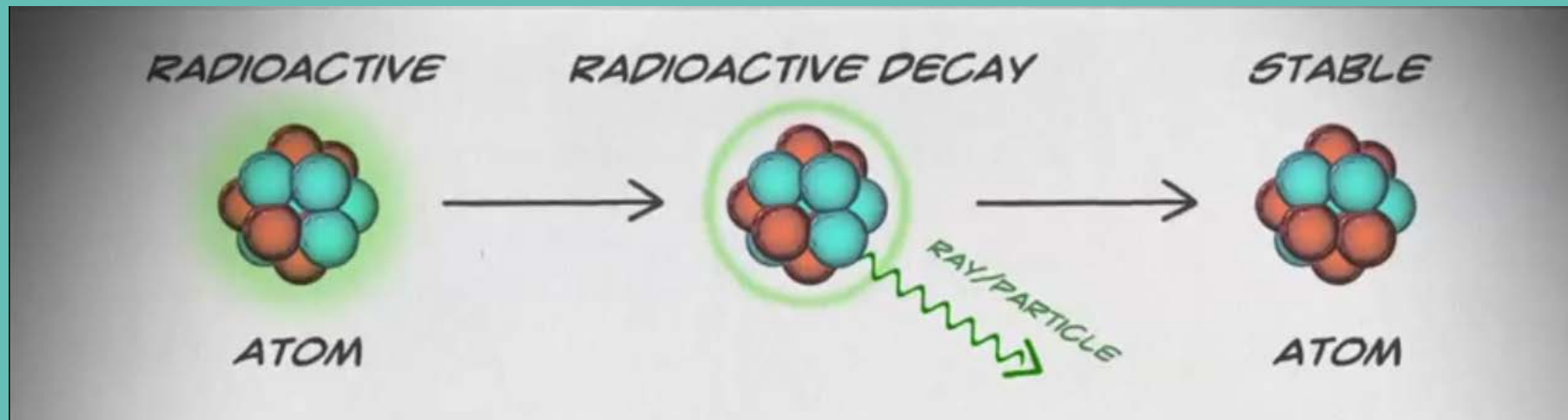
IONIZING RADIATION

RADIO MICROWAVE INFRARED VISIBLE ULTRAVIOLET X-RAY GAMMA RAY



ELECTROMAGNETIC SPECTRUM

Radioactive Decay



Radioactive Physical Half-life



Amount of Radioactivity

AMOUNT OF RADIOACTIVITY

BECQUEREL (Bq)

- INTERNATIONAL UNIT
- 1 RADIOACTIVE DECAY/SEC

CURIE (Ci)

- U.S. UNIT
- ACTIVITY IN 1 GRAM RADIUM

Average banana has 12 Bq radioactivity as K-40

Exposure Rate

AMBIENT RADIATION LEVEL

INT'L

Gray/hour (Gy/h)

Sievert/hour (Sv/h)

nGy/h

uSv/h

U.S.

Roentgen/hour (R/h)

rem/hour (rem/h)

uR/h

mrem/h

Dose of Radioactivity

COMMON UNITS OF RADIATION DOSE

INT'L		U.S.	
Sv	mSv	rem	mrem
1 Sv		→ 100 rem	
	10 mSv		← 1 rem

For our purposes,

1 Sievert (Sv) ~ 1 Gray (Gy)

Average Annual Radiation Doses

U.S. AVERAGE ANNUAL RADIATION DOSE

3mSv NATURAL SOURCES

*COSMIC RAYS
ENVIRONMENTAL
FOOD, ETC*

2/3 FROM RADON

3mSv MEDICAL PROCEDURES

X-RAY EXAMS, CT SCANS, ETC



Above Background Radiation Doses

TYPICAL DOSES IN MILLISIEVERTS (mSv)

NY TO LONDON BY AIR	0.05
CHEST X-RAY	0.1
CT SCAN (ABDOMEN)	10
NATURAL BACKGROUND (ANNUAL)	3

EXTERNAL CONTAMINATION

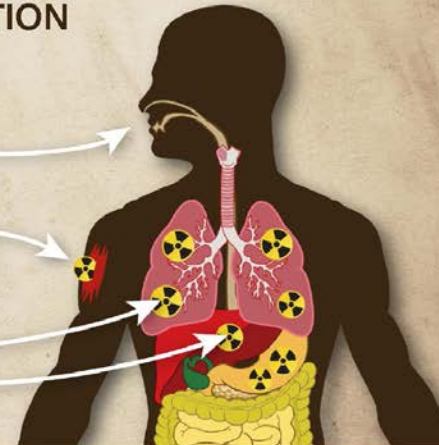


INTERNAL CONTAMINATION

Internal contamination can occur when radioactive material is swallowed or breathed in.

Internal contamination can also occur when radioactive material enters the body through an open wound.

Different radioactive materials can accumulate in different body organs.



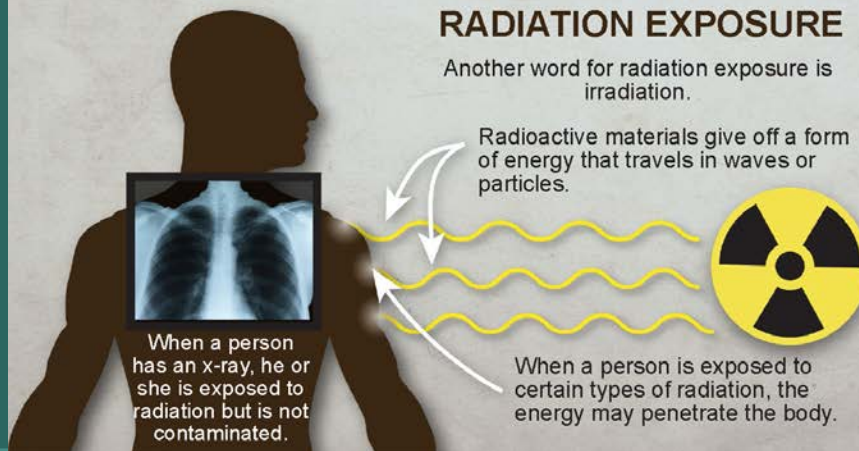
RADIATION EXPOSURE

Another word for radiation exposure is irradiation.

Radioactive materials give off a form of energy that travels in waves or particles.

A person exposed to radiation is not necessarily contaminated with radioactive material.

For a person to be contaminated, radioactive material must be on or inside of his or her body.



U.S. Department of
Health and Human Services
Centers for Disease
Control and Prevention

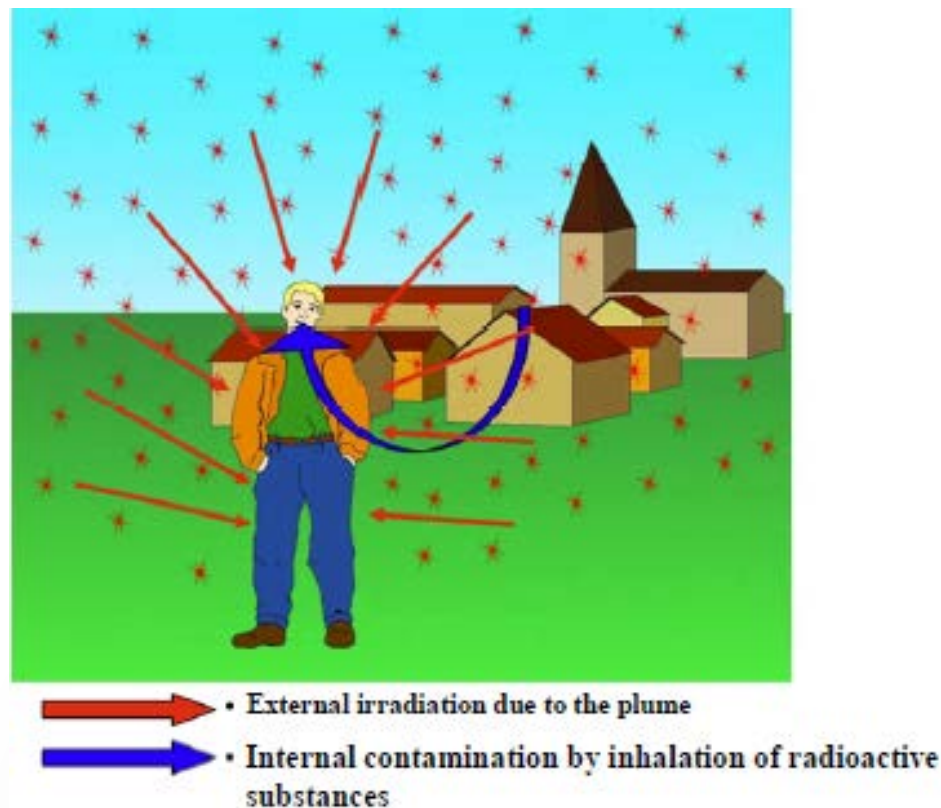
<http://emergency.cdc.gov/radiation>

Exposure from a Radioactive Plume

External exposure occurs by gamma-emitting radionuclides, such as cesium-137 and iodine-131

Internal exposure occurs by inhalation of radioactive gas or aerosols. Radioactive iodine tends to concentrate in the thyroid.

Once incorporated, the residence time in the body depends on the radioactive half-life of the radionuclide and how fast it is eliminated by natural bodily functions

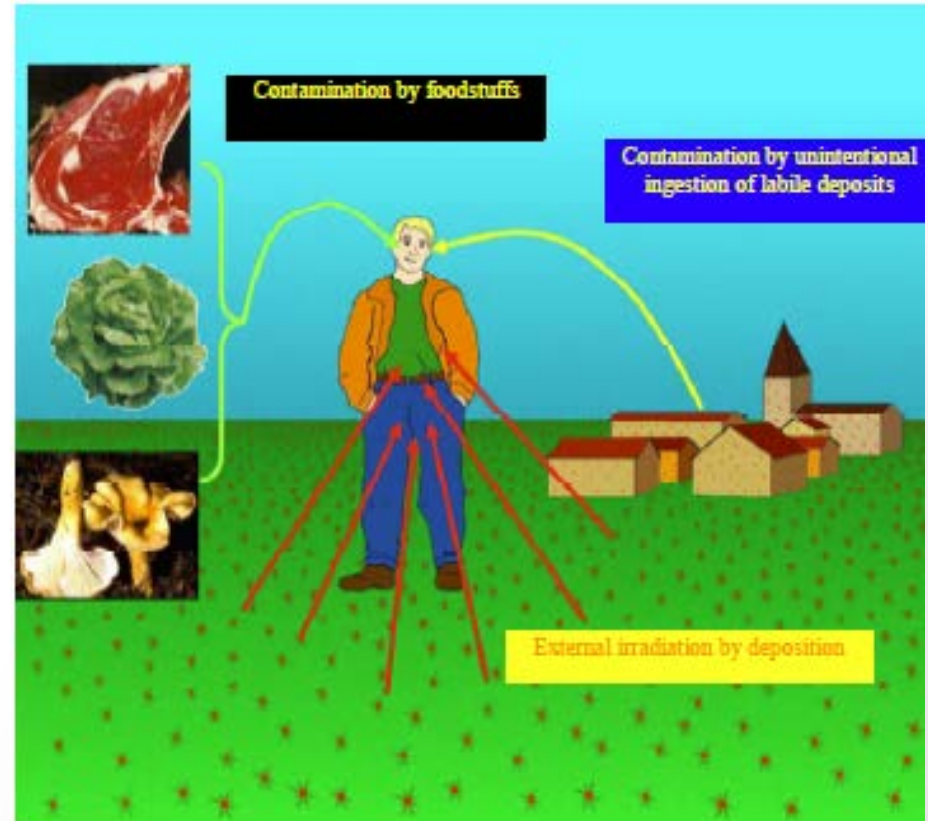


Continuing Exposure to Radioactivity

External exposure from gamma emitting radionuclides deposited on surfaces continues

Internal contamination may occur through contaminated foodstuffs harvested in these areas

Internal exposure may also occur from inadvertent ingestion of radioactive particles left on surfaces, including the soil. Young children are particularly at risk.



Isotopes of Concern



HHS/National Cancer Institute/Division of Cancer Epidemiology and Genetics

Target organs:
I: Thyroid

$$\text{I-131} - T_{1/2} = 8\text{d}$$

$$\text{I-132} - T_{1/2} = 2.3\text{h}$$

$$\text{Te-132} - T_{1/2} = 3.2\text{d}$$

Cs: Follows potassium

$$\text{Cs-137} - T_{1/2} = 30\text{y}$$

$$\text{Cs-134} - T_{1/2} = 2\text{y}$$

All emit β and γ radiation

Range of Radiation Doses

COMPARING RADIATION DOSES IN MILLISIEVERTS (mSv)

NY TO LONDON BY AIR	0.05
CHEST X-RAY	0.1
NATURAL BACKGROUND (ANNUAL)	3
CT SCAN (ABDOMEN)	10
OCCUPATIONAL LIMIT (ANNUAL)	50
50% SURVIVAL DOSE	4,000

Why is Radiation of Greater Risk to Children?

- Relatively larger body surfaces
- More actively dividing cells
- Greater sensitivity of central nervous system
- Greater hand-to-mouth activity and more rapid respirations
 - ↑ Risk of internal contamination
- Thinner skin (controversial)
 - ↑ Risk of local radiation injury, ↑ β penetration
- Longer life span (↑ “opportunity” for cancer due to latency of cancer effects)

Bartenfeld 2014 Biosecur Bioterror 12, 201-207

Derraik 2014 PLoS One

Pregnancy

- Gestation <2 wks:
Resistant to malformation,
sensitive to lethal effects at
doses much > 50mSv
- 3-8 wks: Not affected
unless dose > 200 mSv
- 8-15 wks: CNS sensitive
to doses > 300 mSv
- >20 wks: Fetus probably
no more vulnerable than
mother

<http://hps.org/hpspublications/articles/pregnancyandradiationexposureinfosheet.html>

- Offspring of atomic
bomb survivors:
- Cancer and noncancer
mortality rates were no
higher for subjects with
exposed parents (5+ mSv
or unknown dose) than for
reference subjects (0-4
mSv), and mortality did
not increase with
increasing dose.

Izumi S, Suyama A, Koyama K. Int J Cancer
2003, 107(2): 292-297.

Chernobyl, 1986 and children

Chernobyl – A brief history

- April 26, 1986– Meltdown of a boiling water reactor at Chernobyl
 - Exposure of roughly 5 million people in Ukraine, Belarus, and the Russian Federation to substantial amounts of radioactive contamination ($>35 \text{ kBq/m}^2$ of Cs-137)
 - Among these, 400,000 were contaminated with $>555 \text{ kBq/m}^2$ of Cs-137.
 - 116,000 were evacuated in spring and summer 1986
 - 220,000 additional people were relocated in subsequent years

Impact of Chernobyl

- Widespread release of radiation over Ukraine, Belarus and Russian Federation:
 - Estimated 50 immediate deaths, ~1000 emergency workers and plant personnel receiving the highest radiation doses
 - 600,000 registered as emergency workers ("liquidators")
 - By 2008, >6000 thyroid cancer cases diagnosed in children, largely attributed to radioactive iodine-contaminated milk
 - Since 1986, radiation levels have declined several hundredfold, rendering it "safe to return for settlement and economic activity." Chernobyl Exclusion Zone will be closed for decades

Chernobyl Forum 2003-2005 Chernobyl's legacy, 2nd ed.
Fushiki 2013 Brain Develop 35, 220-227

Summary of Exposures and Health Effects

- Whole body doses in the 50 km exclusion zone from 1986 to 2005 are estimated at 50 mSv; The estimation is 10 mSv for those living beyond the exclusion zone
- Leukemia, expected to occur in large numbers, fortunately has not.
- However, a large increase in thyroid papillary carcinoma has been observed. Thyroid carcinoma was seen most often in children less than five years age at the time of exposure, indicating greater risk for the young.
- Psychological effects appear to predominate in adults, according to some authors (Bromet, 2012)

Thyroid cancer risk in Belarus

- Study of 11,970 individuals 10-15y post-exposure, ≤ 18 years at time of Chernobyl incident who had iodine-131 thyroid dose based on individual thyroid activity measurements and dosimetric data questionnaires.
- For thyroid dose <5 Gy, the dose response was linear; at higher doses excess risk fell. Risk was greater for males and children less than five at time of exposure.

Thyroid Cancer Risk in Belarus

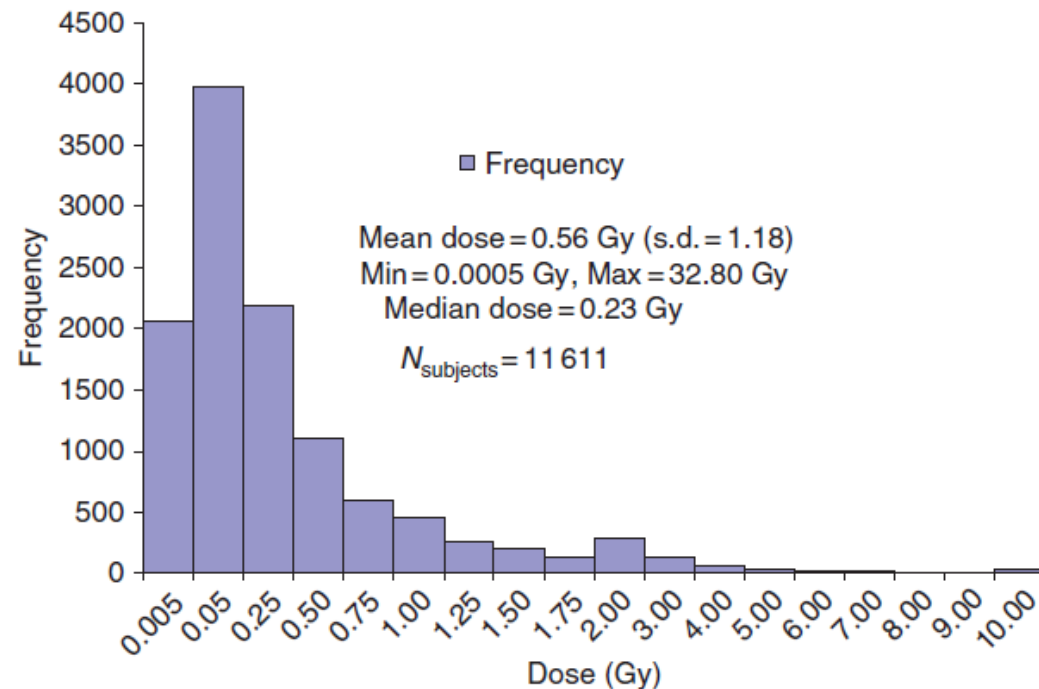


Figure 1 Distribution of thyroid doses in the cohort

- Mean thyroid dose 0.56 Gray (~Sv)
- 53 patients with self-described thyroid cancers prior to the study excluded
- 87 new thyroid cancers (86 papillary, one follicular) underwent surgery. Nine cases had two or more separate thyroid cancers in different locations

Thyroid Cancer Risk in Belarus

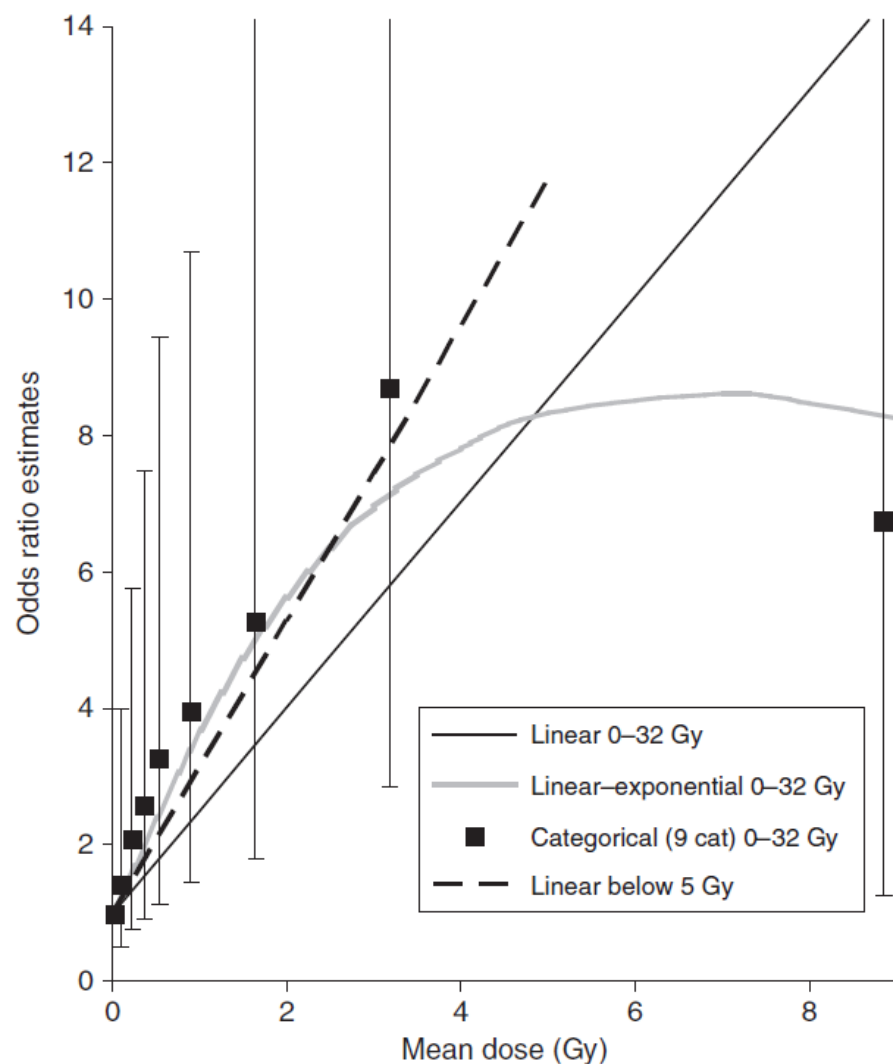


Figure 2 Categorical odds ratios and fitted dose-response lines

Cohort of 87 thyroid cancer cases and 11,524 non-cases, screened 1996-2004

Dose category, Gy*	Mean dose, Gy	Odds ratio	95% CI
0-0.049	0.02	1	
0.15-0.29	0.22	2.09	0.76-5.75
0.45-0.64	0.54	3.27	1.13-9.46
1.25-2.24	0.90	5.27	1.80-15.46
5.00-32.80	8.84	6.75	1.26-36.22

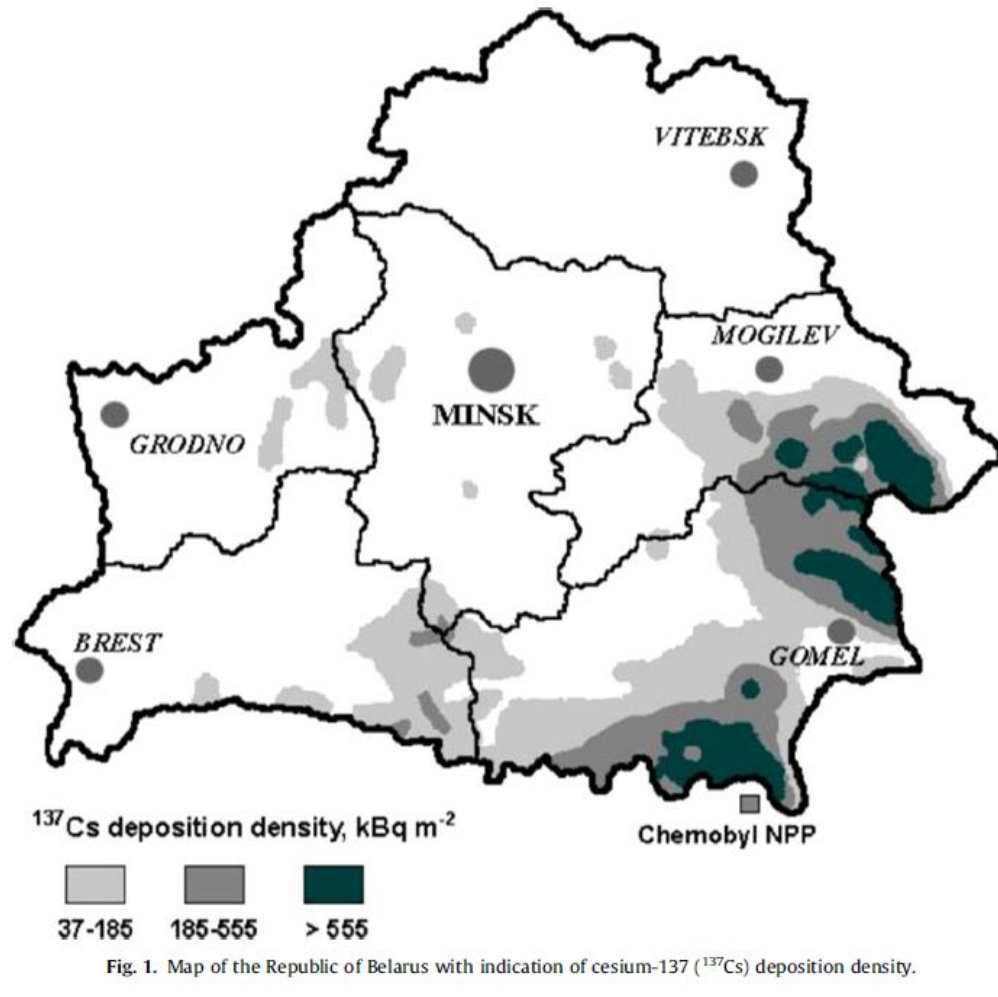
*See article for complete data. Table condensed for convenience and readability.

Non-Thyroid Cancer in Belarus

- 15 year study of 12,000 individuals exposed to Chernobyl fallout at average age of 7.9 years (1997-2011)
- 54 incident cancers, excluding thyroid identified
- Standardized incidence ratios showed no significant increase in solid non-thyroid tumors, lymphoma, or leukemia in the cohort, compared with sex, age, and calendar-time-specific national rates
- Authors caution that study subjects are still relatively young for radiation-related solid tumors

Deposition of cesium-137 in Belarus

Highest ground deposition of radioactive cesium occurred in Gomel oblast
Average effective whole body doses of 10 mSv from 1986 to 2005



Psychological Distress Post-Chernobyl

- Key findings of 3 studies of children exposed in utero to radiation from Chernobyl
 - Disorganized EEG
 - Increased emotional disorders
 - Increased speech-language disorders
 - Decreased IQ
 - Increased cases of borderline IQ (70-79)
 - Important role of social-psychological and social-cultural factors

Loganovskaja 1999 Int J Psychophysiol 34, 213-224
Kolominsky 1999 J Child Psychol Psychiatry 40, 299-305
Igumnov 2000 Eur Psychiatry 15, 244-253

Fukushima, 2011 and Children

Now and the Future

Fukushima – A Brief History

- 11 March 2011 - Fukushima I NPP hit by tsunami
- 15 March 2011 - 97% of the 76,000 people living within a 20 km radius were evacuated
- 800 patients from hospitals and nursing homes were evacuated without medical care, water or food. At least 50 died during transport
- 6 hospitals designated as primary radiation emergency hospitals closed or failed to function
- 31 March 2013 of the 460,000 people displaced to about 2400 shelters, 2688 died due to poor medical access or illnesses arising from poor living environments

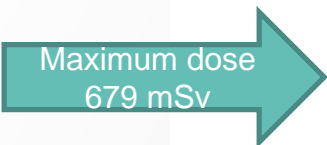
Impact of Fukushima

- Extraordinary damage, morbidity and mortality, exclusive of radiation:
 - Earthquake of magnitude 9.2 followed by enormous tsunami 40 m above sea level
 - 19,000 dead or missing, 6000 injured
 - Only 6.5% of these children or adolescents
 - 88,000 residents evacuated within 20 km of power plant

Radiation doses received by Fukushima workers as of 2012

Table 8-1 - Summary dated February 29th 2012 of doses recorded by TEPCO for its own workers and those of its subcontractor companies

Maximum dose
679 mSv

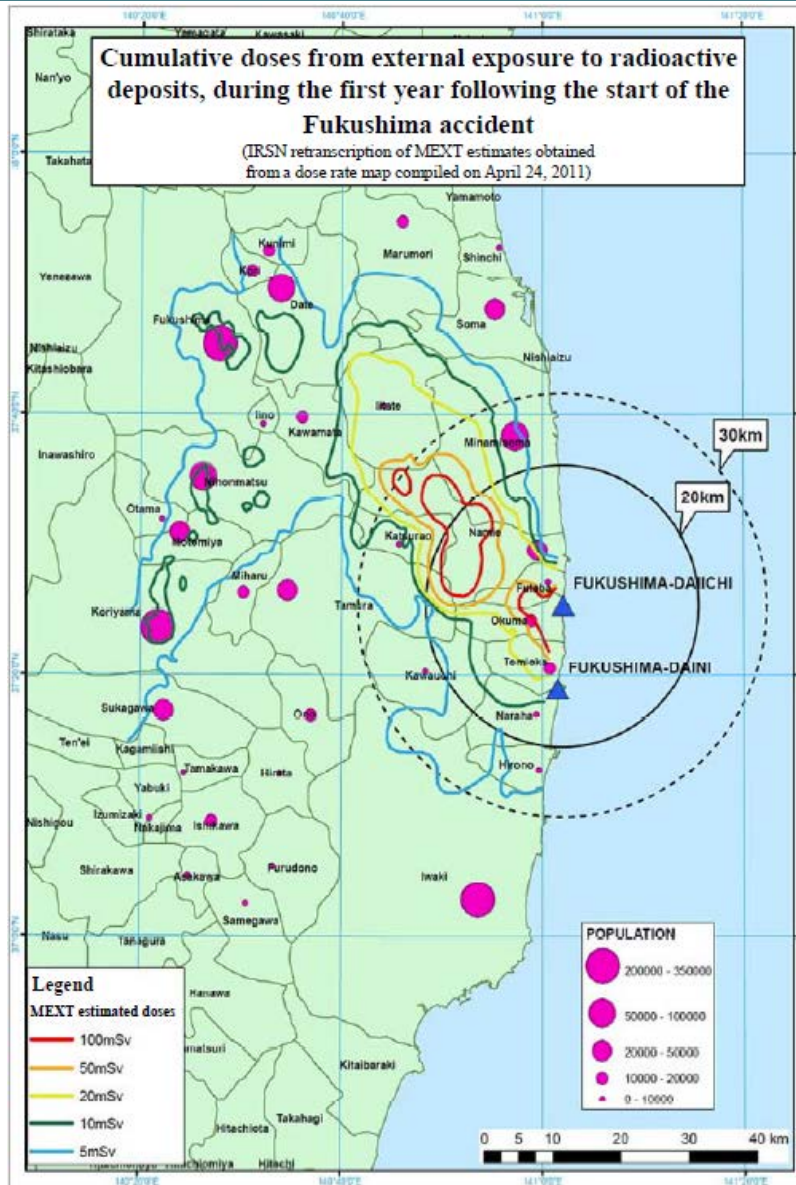


Cumulative dose	TEPCO	Contractors	Total
> 250 mSv	6	0	6
200 - 250 mSv	1	2	3
150 - 200 mSv	22	2	24
100 - 150 mSv	117	17	134
50 - 100 mSv	409	347	756
20 - 50 mSv	646	2,078	2,724
10 - 20 mSv	494	2,667	3,161
< 10 mSv	1,645	11,662	13,307
Total	3,340	16,775	20,115
Maximum (mSv)	678.80	238.42	678.80
Mean (mSv)	24.72	9.35	11.90

Fukushima – Measured exposures

- Fukushima I NPP hit by tsunami
 - Gamma radiation exceeding 100 $\mu\text{Sv/h}$ in city 60 km away on 16-17 March. French nuclear safety agency estimates first year dose of 5-10 mSv of Cs-137 and 134.
 - Unlike Chernobyl, contaminated milk not a major source, as parents avoided local food & water
 - Thyroids of 1149 children examined 28-30 March. Max dose rate 0.07 $\mu\text{Sv/h}$, max dose 35 mSv

Estimated 1 yr cumulative radiation doses



- Cumulative doses predicted during the first year after the accident from exposure to radioactive deposits
- In the area 20 to 30 km northwest of Fukushima, estimated doses reach 100 mSv, roughly equivalent to 10 abdominal CT scans per year
- IRSN estimates that outside the 20 km zone, 70,000 people were likely to receive a dose greater than 10 mSv in the first year

Fukushima – Estimated exposures

- According to the simulation, effective doses potentially received were:
 - 10 mSv up to 40 km to the south
 - 50 mSv inside a 20 km radius
 - 50 mSv effective thyroid dose as far as 60 km to the south of the power plant related to the release from Reactor 2.

Epidemiological Studies

- Japanese health authorities epidemiological studies:
 - Basic survey of all persons present Fukushima prefecture during the release: 2,057,053 people
 - Thyroid screening of all children under age of 18 during the release: 360,000 children
 - Monitoring for genetic or congenital abnormalities for women who declared the pregnancy between August 1, 2010 and July 31, 2011: 6,900 women and all the children born of mothers recruited into the Japanese Environment and Children's study until age 12
 - Special checkups of those most exposed: 210,000 people

Thyroid Cancer in Children – Fukushima

- As of 2014, more than 280,000 children were screened for thyroid cancer
- 90 cases of thyroid cancer identified (incidence rate of 313 cases per million)
- Although dose of radiation was approximately 1/10 of Chernobyl, incidence of thyroid cancer appears to be much higher

Observations on the LNT model

- LNT= Linear No-Threshold Model
- “The failure of LNT lies in the neglect of carcinogenesis and these biological mechanisms. Obstinate application of LNT continues to cause tremendous human, social, and economic losses. The 60-year-old LNT must be rejected to establish a new scientific knowledge-based system.”

Psychological distress post-Fukushima

- Extraordinary damage, morbidity and mortality, exclusive of radiation:
 - Earthquake of magnitude 9.2 followed by enormous tsunami 40 m above sea level
 - 19,000 dead or missing, 6000 injured
 - Only 6.5% of these children or adolescents
 - 88,000 residents evacuated within 20 km of power plant

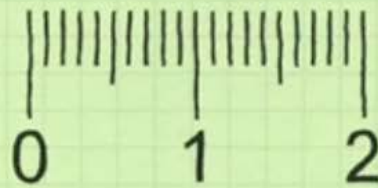
Radiological Emergency Response & Resources

Protective Principles

3 BASIC PRINCIPLES IN RADIATION PROTECTION



TIME



DISTANCE



SHIELDING

Exposure Assessment: Power Plant Release

All potentially exposed

Ask information about hours spent indoors and outdoors (where)

Means of transportation

Consumption of local water and locally grown foods

Exposure Assessment: Power Plant Release

Those extremely close to plant

The 3P's: Did you puke, poop, or pass out in 1st hour? These are extremely unlikely in this type of radiologic exposure (except plant workers & 1st responders), but indicate likely lethal doses of gamma radiation

Obtain blood for complete blood count and platelet count. Repeat every six hours for 24 to 48 hours, looking for a significant drop in absolute lymphocyte count

Types of Effects of Radiation

- Deterministic
 - Dose-related with a threshold
 - Typically acute or subacute
 - Examples: Acute radiation syndrome
- Stochastic
 - Increasing risk with increase in dose
 - Random and typically chronic
 - No threshold (?)
 - Example: Cancers, birth defects

Acute Radiation Syndrome (ARS)

- 3 syndromes, dose-dependent
- Hematopoietic syndrome: 1-2 Gy (100-200 rem)
- Gastrointestinal syndrome:
 - 4-6 Gy (400-600 rem)
- Neurovascular syndrome:
 - >12 Gy (1200 rem)

Dose (Gy)	12 and above	↑ Bone Marrow Suppression	Neurovascular syndrome onset	Multiple organ failure Probable death
	11			
	10			Consider stem cell transplants
	9			
	8			
	7			LD50/60 with supportive care
	6		GI syndrome onset	
	5			LD50/60 without treatment
	4			
	3			
	2		Hematopoietic syndrome onset	~100% survival without treatment
	1			
	0			

Medical Countermeasures

MEDICATIONS

Potassium Iodide

PROTECTS THYROID
FROM ABSORPTION
OF RADIOACTIVE
IODINE

Prussian Blue

HELPS EXCRETE
RADIOACTIVE
CESIUM AND
THALLIUM

DTPA

HELPS REMOVE
RADIOACTIVE
PLUTONIUM,
AMERICIUM AND
CURIUM

Medical Countermeasures

Potassium iodide

- Indication: Internal contamination with radioactive I-131
- Adults > 40y: 130 mg/d
- Adults 18-40y: 130 mg/d
- Pregnant/lactating: 130 mg/d
- Adolescents > 70kg: 130 mg/d
- Children 3-18y: 65 mg/d
- Infant 1m to Child 3y: 32.5 mg/d
- Neonates to 1m: 16 mg/d
- Decision to treat based on projected radiation dose to thyroid:
- Seek professional assistance

Prussian blue

- Indication: Internal contamination with radioactive Cs
- Adults/adolescents: 1-3g three times daily
- Children 2-12 y: 1g three times daily
- Minimum 30d course
- Whole body counts to assess efficacy

Radiological Emergency Resources

Resource	URL	Telephone
Poison Control Centers	http://www.aapcc.org	+1 800-222-1222
Radiation Emergency Assistance Center / Treatment Site (REAC/TS)	http://orise.orau.gov/reacts/	+1 865-576-1005 Emergency 24/7
U.S. Centers for Disease Control – Radiation Emergencies	http://emergency.cdc.gov/radiation/index.asp	+1 800-232-4636 Non-emergency US only
US Environmental Protection Agency Radiation Protection	http://www.epa.gov/radiation/	+1 202-343-9290
Radiation Emergency Medical Management	http://www.remm.nlm.gov/	NA
MRAT—Medical Radiobiology Advisory Team	https://www.usuhs.edu/afrrri/medicalradiobiologyadvisoryteam	NA
AFRRI Publications	https://www.usuhs.edu/afrrri/productsandpublications	NA

Summary

- Major nuclear accidents at power plants are fortunately rare
- In spite of previous catastrophes, preparation for nuclear accidents is inadequate and responses deplorable
- The impact of such accidents on human civilian populations, on animals, and the environment in general are enormous and long-lasting
- Greener energy resources (solar, wind, geothermal) do not pose the risks to children and the environment posed by nuclear energy and are now feasible on a large scale in some areas

Thank You

stephen.borron@ttuhsc.edu

Southwest Center for Pediatric Environmental Health

 TEXAS TECH UNIVERSITY
HEALTH SCIENCES CENTER™
EL PASO



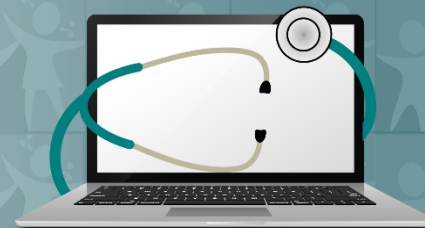
References

Available on Request



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Pediatric Environmental Health Specialty Units



www.pehsu.net/nationalclassroom.html



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