United Nations Scientific Committee
on the Effects of Atomic Radiation

UNEP

The UNSCEAR 2013 Report – Vol. II
"Effects of Radiation Exposure of Children"

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VMSÖ

EVALUATING RADIATION SCIENCE FOR INFORMED DECISION-MAKING

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Outline of the presentation

- **UNSCEAR's mandate, organization and function**
- **UNSCEAR's 2013 Report**
  - *Report to the General Assembly*
  - *Scientific annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami*
  - **Scientific annex B: Effects of radiation exposure of children**

UNSCEAR's mandate

- Established by UN General Assembly (GA) resolution in 1955
- Assess levels, effects & risks of ionizing radiation
- Disseminate findings to UN GA, scientific community & public
- Scientists from 27 UN Member States
- Other states & organizations provide relevant data
- Holds annual sessions in Vienna
- UNEP arranges secretariat and provides support

UNSCEAR's role in radiation protection

UNSCEAR
Scientific basis

issues
levels
impact
trends

IAEA, WHO, ILO, FAO etc.
-Safety standards
-Protection programmes

implemented by Member States

Effects of radiation exposure of children

- Introduction - What are the questions?
- Developmental anatomy and physiology
- Dosimetry variations
- Health effects
  - Stochastic effects
  - Deterministic effects
  - Hereditary effects
- Future research
- Conclusions

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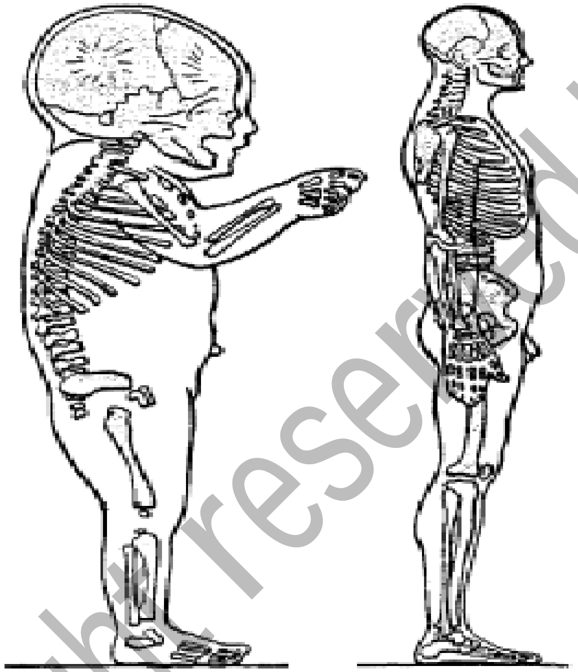
Anatomy and physiology



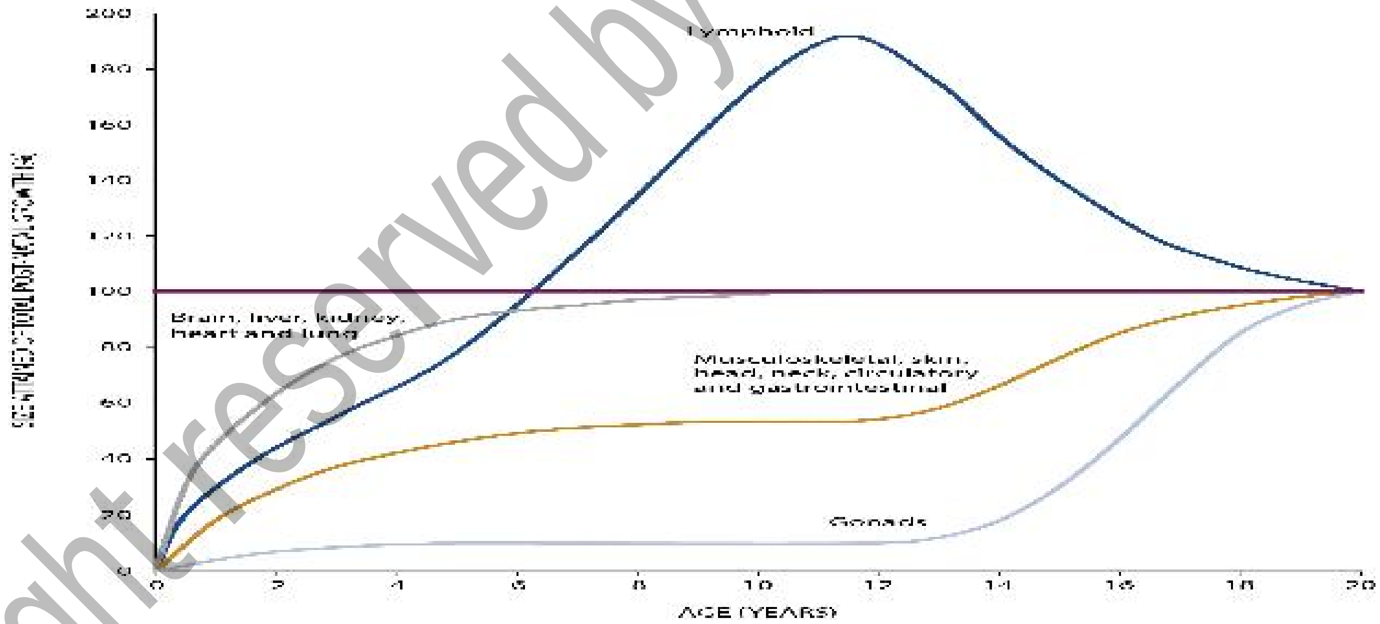
- Growth period is unusually long compared to other mammals and occurs for about 25% of lifespan.

- Proportional changes with age

- The head and brain are disproportionately large at birth

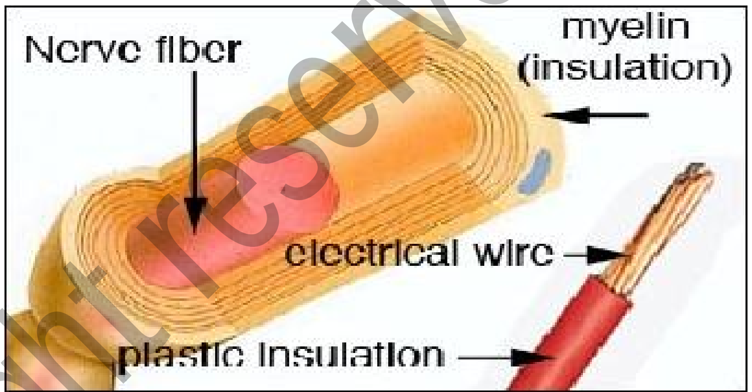
Anatomy and physiology

- Differences in tissue growth by age



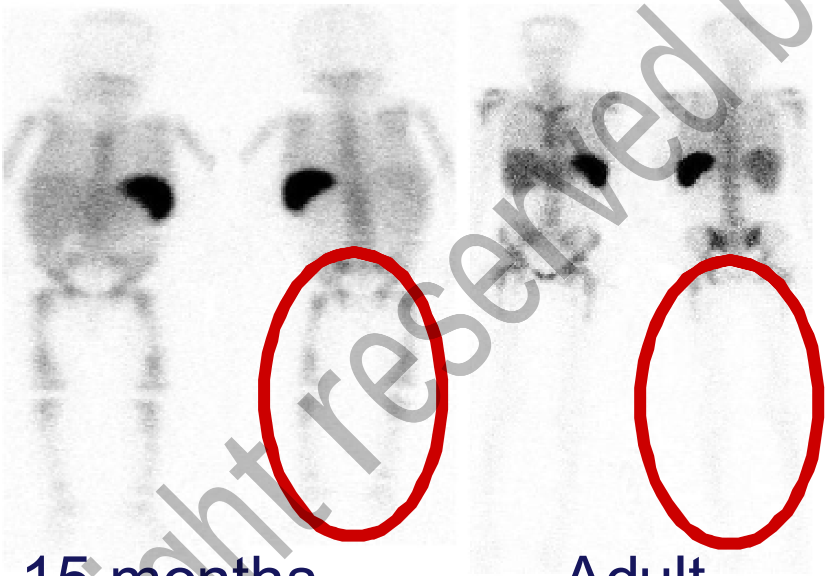
Anatomy and physiology

- Grey matter peaks at age 1-2 years; remains high until about age 12 years then declines 40% per year until age 16 years
- Development of insulation for the brain wiring occurs over the first several years of life
- 180,000 km of myelinated fibres



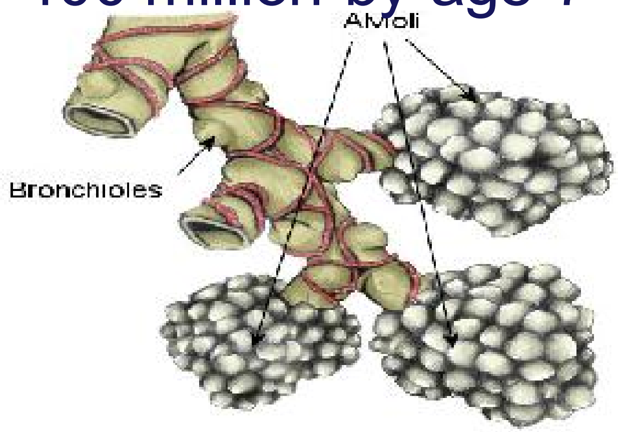
Anatomy and physiology

Children have more red bone marrow in extremities



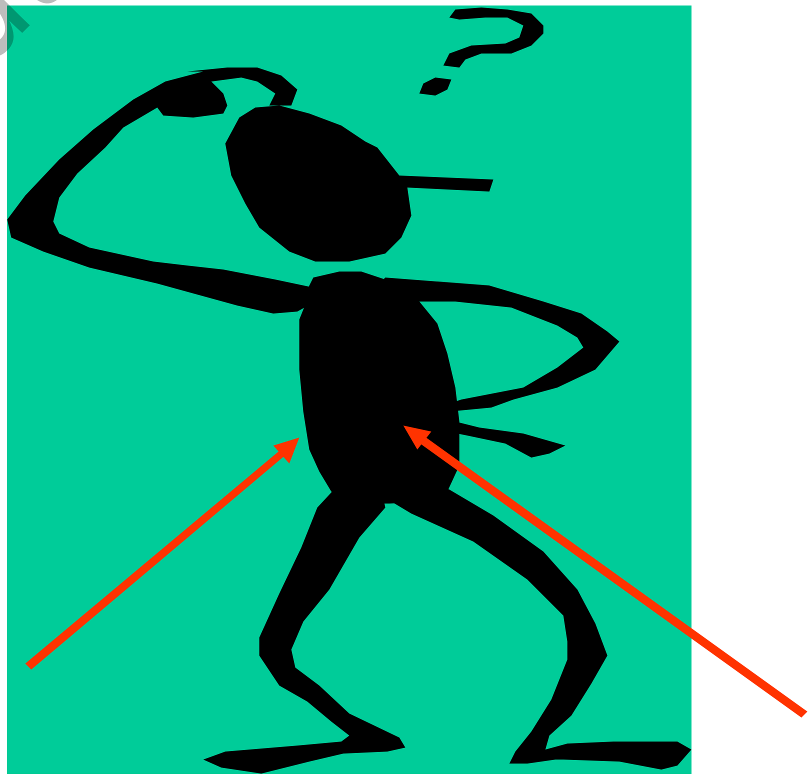
Alveoli (air sacs) of the lung

- 20 million at birth,
- 150 million by age 2
- 300-400 million by age 7



Dosimetry variations

A given amount of external radiation exposure causes higher doses to internal organs of children and infants because they are thinner and radiation penetration is easier



Dosimetric differences resulting from exposure of children versus that of adults

	General differences		Comments and exceptions
EXTERNAL EXPOSURE			
Environment (e.g. ^{137}Cs on ground)	Dose coefficients	More	Higher dose due to smaller size, organs closer
	Exposure	Same	
	Doses	More	
Medicine (X-rays or CT scan)	Exposure parameters	Less	
	Doses	Less	Due to lower exposure parameters

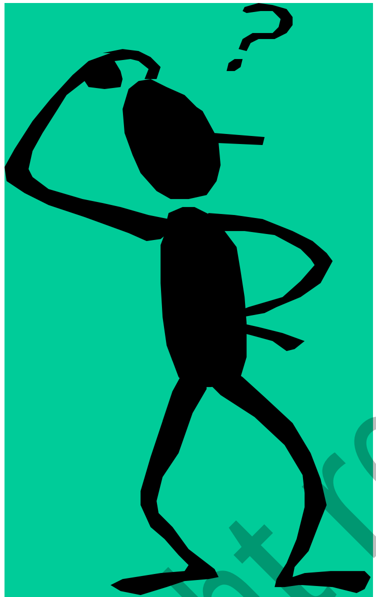
Dosimetric differences resulting from exposure of children versus that of adults

	General differences		Comments and exceptions
INTERNAL EXPOSURE			
Inhalation (e.g. radon)	Dose coefficients	More	Depends on the radionuclide; for ^{137}Cs, for example, nearly ‘o’
	Exposure	Less	Lower breathing rates
	Doses	Less	Depends on the radionuclide; for ^{131}I, for example, ‘+’
Ingestion (e.g. contaminated foods)	Dose coefficients	More	Depends on the radionuclide; for ^{137}Cs, for example, nearly ‘o’
	Exposure	Less	Depends on the food; for milk, for example, ‘+’ for young children
	Doses	Less	Depends on the radionuclide and food; for ^{131}I and alkaline earths, for example, ‘+’ and also for milk consumption of other radionuclides

Dosimetric differences resulting from exposure of children versus that of adults

	General differences		Comments and exceptions
INTERNAL EXPOSURE			
NUCLEAR MEDICINE	Dose coefficients	More	
	Exposure	Less	Less administered activity
	Doses	Same	

Stochastic effects / induced malignancies



"Children are 3-5 times more sensitive to radiation than adults"

- Is this actually true ?
- Is it true for all effects ?
- If they are, why is that ?
- Could they be less sensitive to some effects ?

Concerns raised by nuclear accidents

I don't care about myself. But what about my children?

Chernobyl, 1986

Fukushima, 2011

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Concerns from exposures in medicine

CT scans for young kids raise concerns

from **PAGE C1**

1930 to 1959.

Because 95 percent of Swedish men ages 18 and 19 are tested before military service, researchers were able to track information about the education and cognitive test results of these former pediatric patients.

The researchers found that the proportion of boys who attended high school decreased in relation to increasing doses of ionizing radiation — the type that penetrates the body — to the front and back of the brain.

The more radiation they were exposed to, the more impaired their learning ability and logical reasoning. Spatial recognition was unaffected. Because the dosages overlap those of CT scans, the findings raise questions about the long-term developmental effects of CT scans, which increasingly are used to assess minor head injuries, Swedish researchers wrote. Although they had data only about radiation exposure before the age of 18 months, they said the findings raised questions about exposure [...] children in general.

But Nelson said the type[...] used then are different fro[...] and that there are differe[...] various types of radiation [...] the brain.

"If the child has significa[...] as determined by the exam[...] would not hesitate to do a C[...] "The benefits far outweigh[...]

CT is the preferred test [...] suspects that a child has [...] injury. The signs are uneq[...] size, weakness or lack of [...] extremities and abnormal [...] unconsciousness for seve[...]

But it's not always requ[...] knocked out briefly, he a[...] observed and usually wai[...] scan, Nelson said.

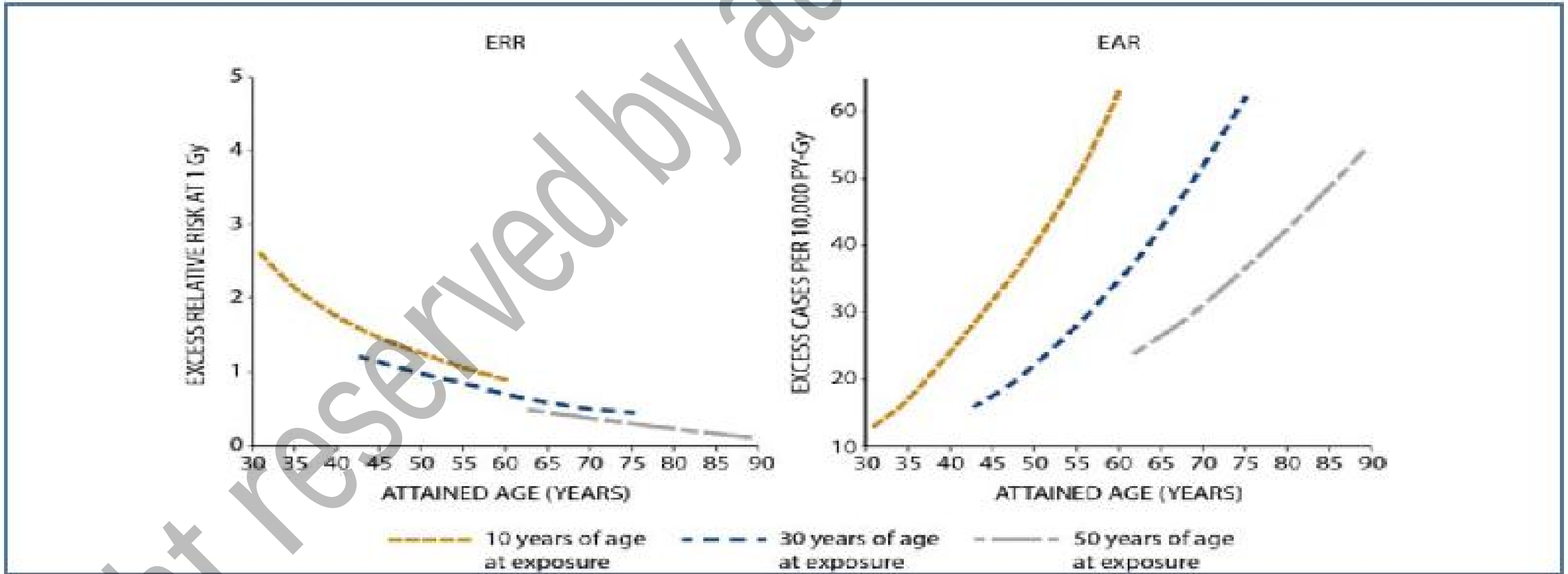
If a CT is recommended[...] suggests that parents ask [...]

[...]ray technician "whether the CT facility is using the proper reduced dose protocols

Main source of data

- Atomic bombings survivors (LSS)
  - 35,382 or 41% were 0-20 years old at exposure
- Radiotherapy for benign conditions (thousands)
- Childhood cancer survivor study
  - 14,359 5-year survivors treated 1970-1986
- Nuclear accidents
  - 27% of evacuees after Chernobyl were 0-17 years
- Future sources
  - CT (5 million children scans per year in the USA and many European studies)

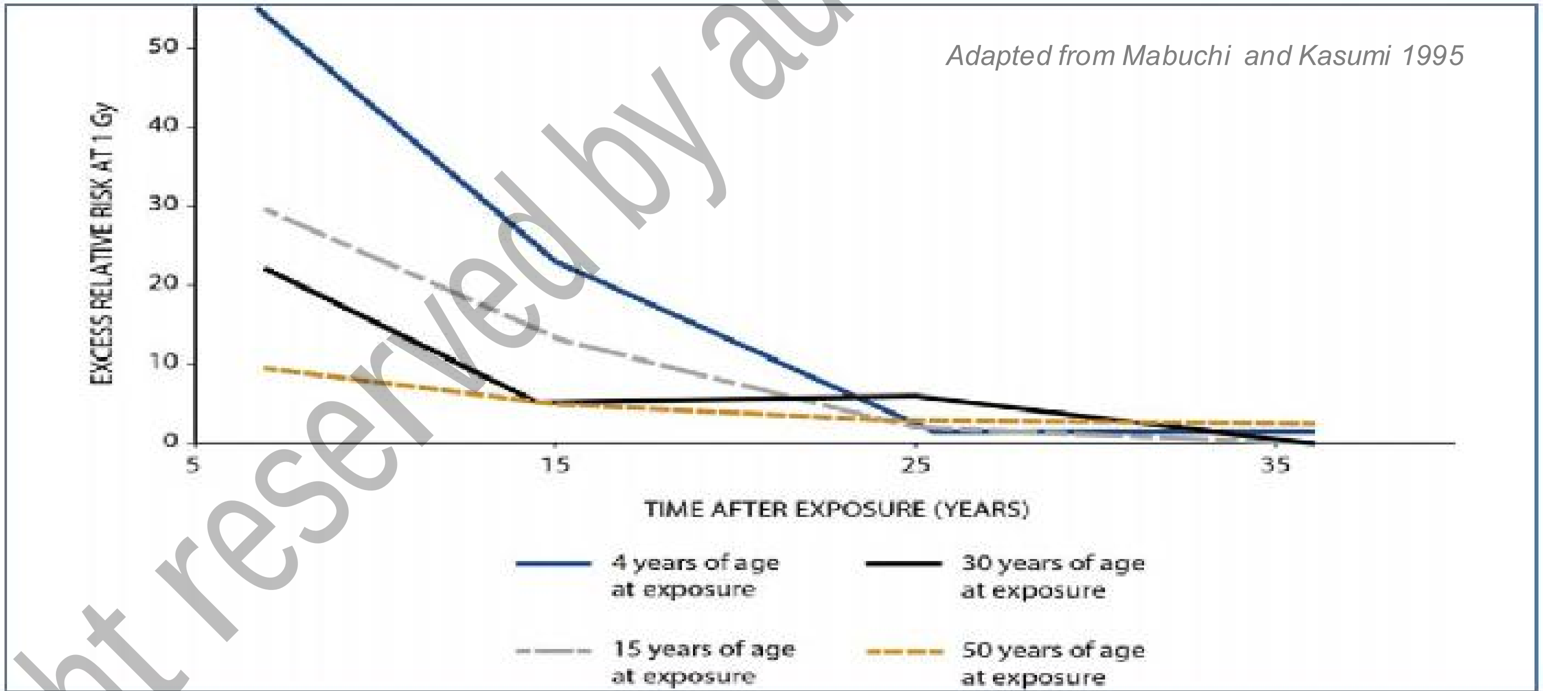
Excess risks for all solid cancers at various attained ages, after exposure at ages 10, 30 or 50 years



Adapted from Preston et al. Rad. Res. 2007

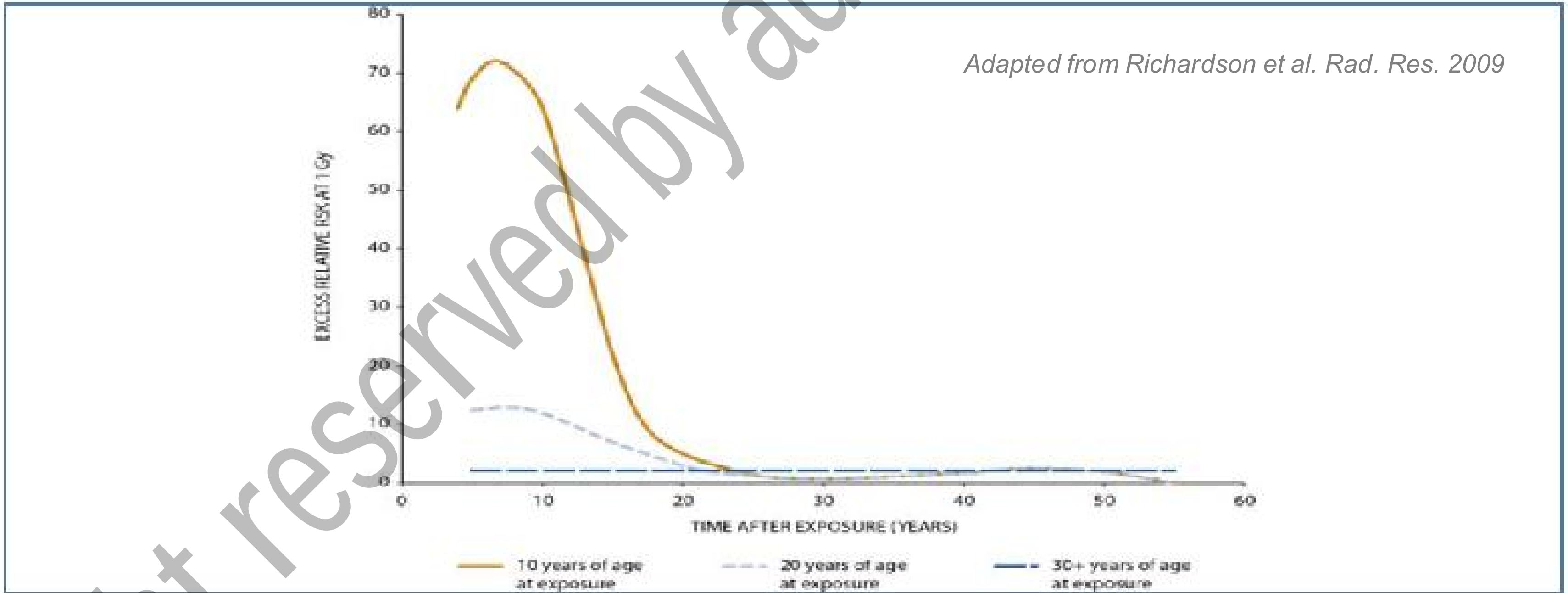
The curves represent sex-averaged risks after exposure to 1 Gy

Excess relative risk for all types of leukaemia, incidence, 1950–1987



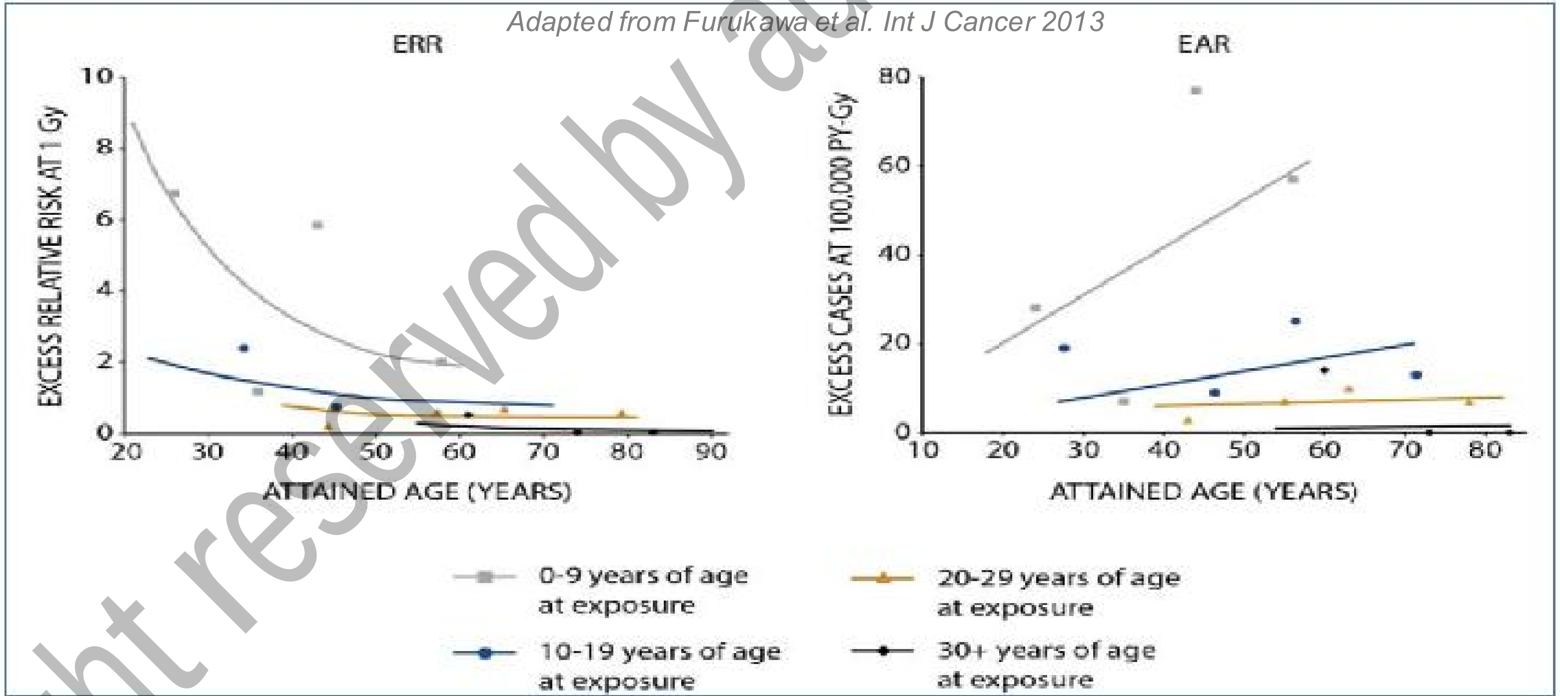
The curves represent sex-averaged risks after exposure to 1 Gy

Predicted city-averaged ERR at 1 Gy for leukaemia mortality



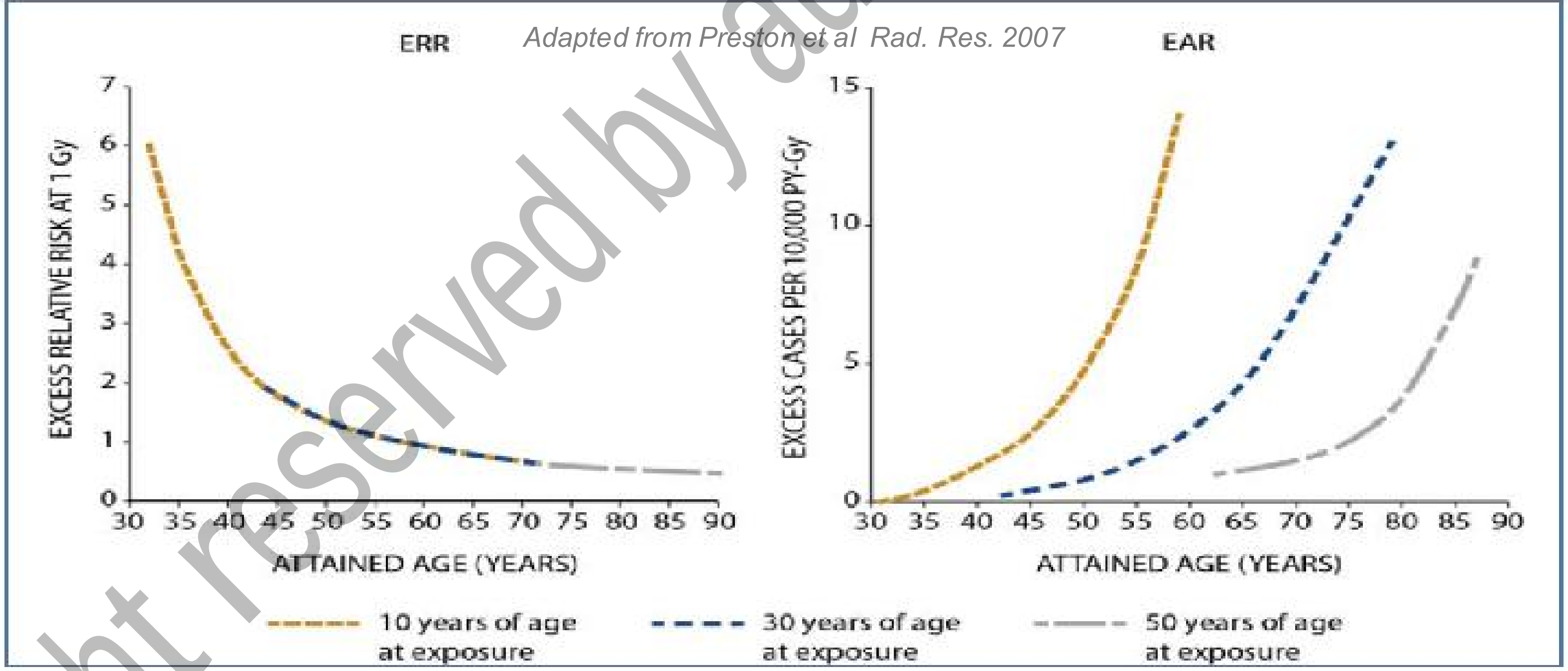
All types as a function of age at exposure and time since exposure

Excess risks for thyroid cancer at various attained ages after exposure



The curves represent sex-averaged risks after exposure to 1 Gy

Excess risks for colon cancer risk by age at exposure and attained age, averaged across sex



The curves represent sex-averaged risks after exposure to 1 Gy

Risk estimates for lung cancer mortality from LSS

Study		Average ERR[a] at 1 Sv	Average EAR[a] $(10^4\ PY\ Sv)^{-1}$
Mortality			
LSS [P50]			
Sex	Males	0.57 (0.30, 0.89)	0.19 (<0, 0.85)
	Females	1.28 (0.84, 1.80)	<0 (<0, 1269.1)
Age at exposure	<20 years	0.94 (0.42, 1.63)	0.11 (<0, 0.56)
	20–40 years	0.78 (0.43, 1.19)	0.51 (<0, 1.83)
	>40 years	0.76 (0.38, 1.23)	<0 (<0, 4062.9)
All		0.84 (0.59, 1.11)	0.37 (0.02, 0.87)
LSS [O25]			
Age at exposure	10 years [b]	0.86	8.7
	30 years	0.75 (95% CI: 0.51, 1.03)	6.5 (95% CI: 4.3, 9.0)
	50 years	0.65	4.6

[b] Sex-averaged risk at attained age 70, smoothed using the assumption that the ERR Gy-1 varies as a log-linear function of age at exposure.

Risk estimates for brain cancer mortality from LSS

Study		*Average ERR[a] at 1 Sv*	*Average EAR[a] (10[4] PY Sv)[-1]*
Mortality			
LSS [P50][c]			
Age at exposure	<20 years	5.72 (1.56, 17.04)	<0 (<0, <0)
	>20 years	0.77 (<0, 4.88)	<0 (<0, 35.70)
All		2.86 (0.83, 6.76)	<0 (<0, 35.75)

[c] *Data are for all brain and nervous system tumours combined.*

Carcinogenesis risks at age-at-exposure for children compared with adults

Cancer site	*More*	*No difference*	*Less*	*No sufficient data*	*Level of evidence*
Oesophagus				X	
Stomach (mortality)	ERR	EAR			Moderate
Small intestine [a]				X	
Colon					
- (incidence)	EAR	ERR			Weak
- (mortality)	EAR & ERR				
Rectum [a]				X	
Pancreas [a]				X	
Liver		X			Weak
Lung			X [b]		Moderate
Skin non-melanoma	X				Moderate
Breast	X				Strong
Uterus				X	
Cervix [a]				X	

Carcinogenesis risks at age-at-exposure for children compared with adults

Cancer site	More	No difference	Less	No sufficient data	Level of evidence
Ovary				X	
Prostate [a]				X	
Kidney				X	
Bladder		X			Moderate
Brain	X				Strong
Thyroid	X				Strong
Parathyroid				X	
Hodgkin's lymphoma [a]				X	
Non-Hodgkin's lymphoma				X	
Myeloma				X	
Leukaemia non-CLL	X				Strong
Myelodysplasia	X				Weak

[a] *These tumours are not definitely shown to be increased by radiation exposure.*

[b] *The limited data on radon and lung cancer indicate approximately the same risk after exposure at pre adult and adult ages.*

Summary of malignant neoplasms

• 23 tumour sites and differential sensitivity based on the epidemiological data

• Only a few tumours have strong data on differences with age-at-exposure

• No statistically significant projections of lifetime risk for specific tumour types following exposure at young ages

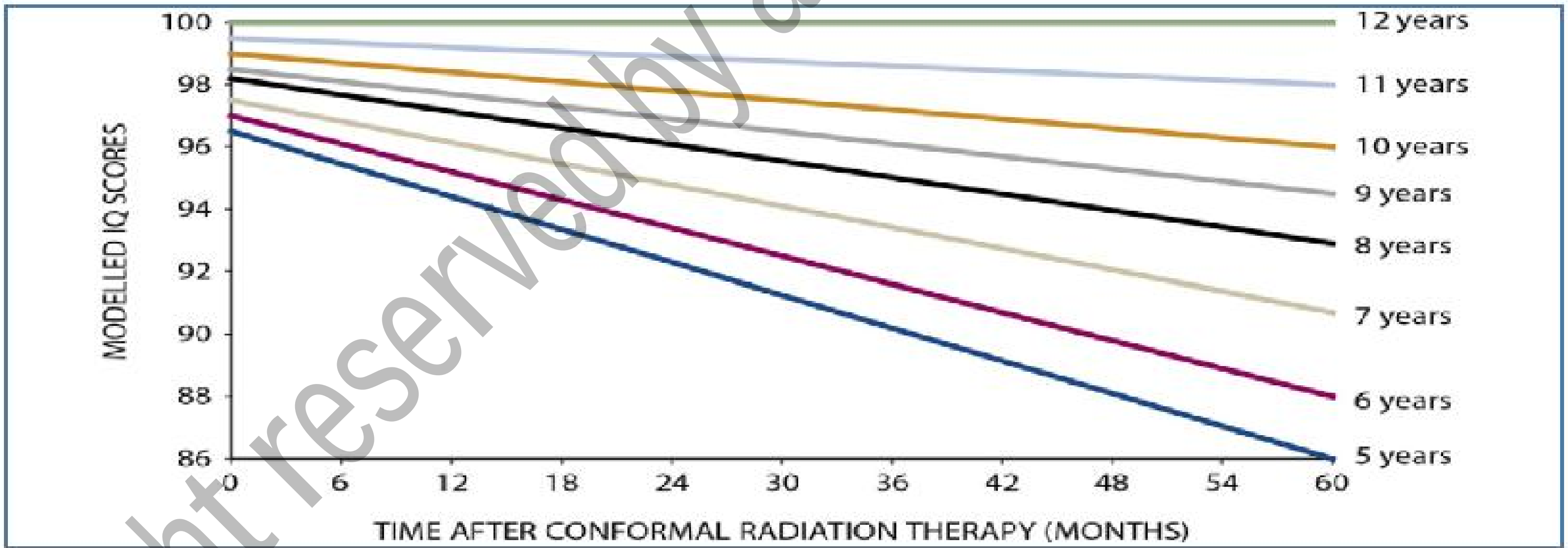
- Children more sensitive 25%
- Same as adults 15%
- Less than adults 10%
- No good data on difference 20%
- Poorly or not related to radiation 30%

Deterministic effects / tissue reactions

Accidental exposure to an unshielded industrial radiography source (iridium-192)

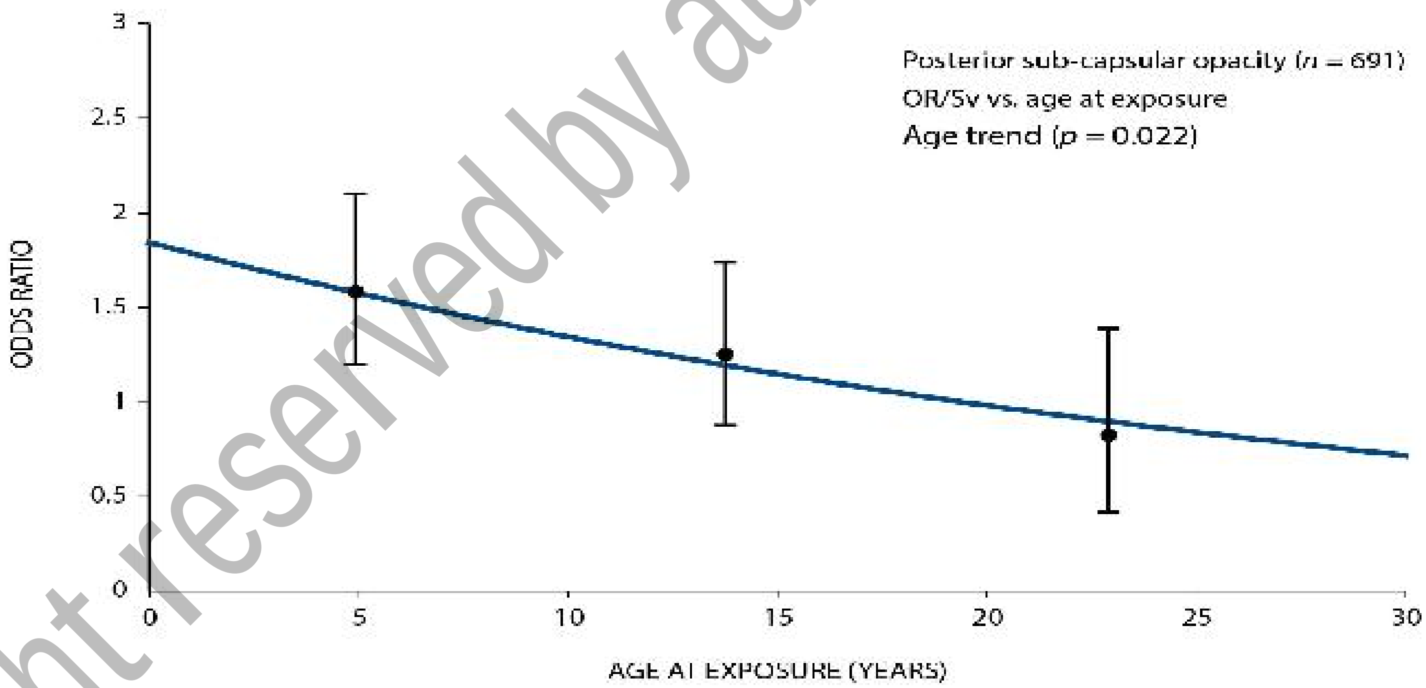
Data mostly from cancer treatment with high doses of radiation

Interpolation of IQ scores after conformal radiation therapy of children by age



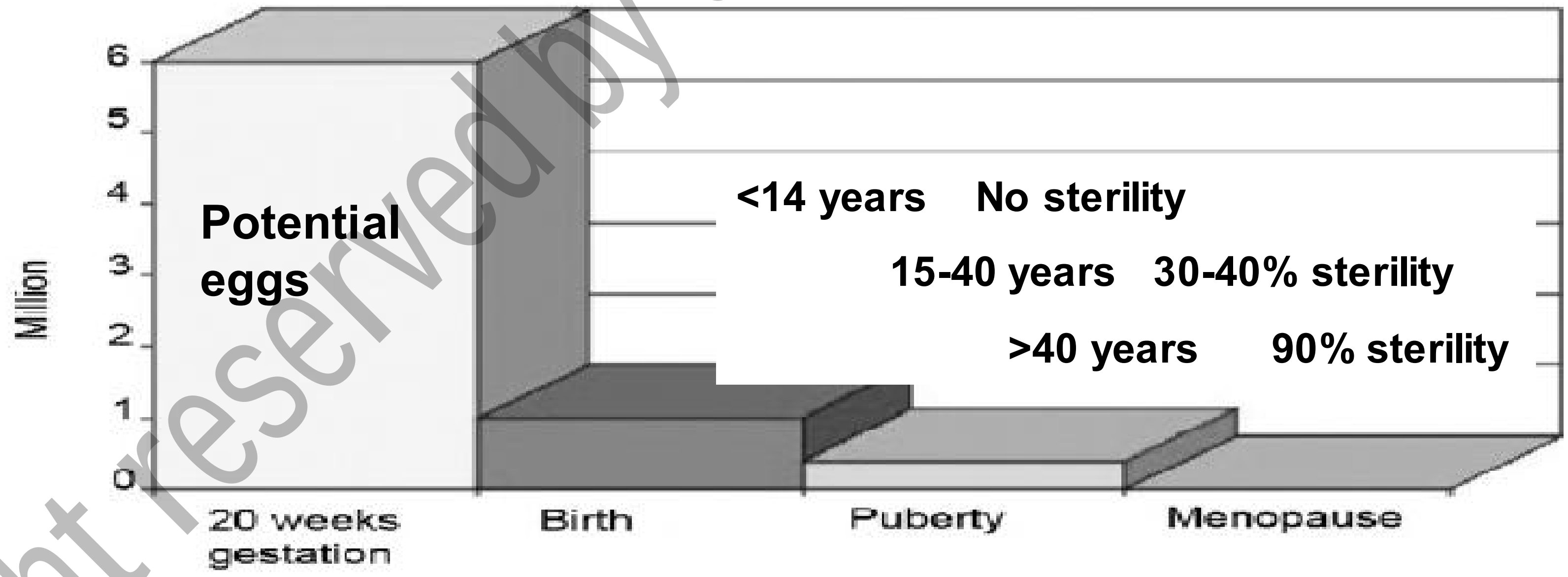
Adapted from Merchant et al, J Clin Oncol 2009

Risk of lens opacity vs age at a dose of 1 Gy



Adapted from Nakashima et al ,Health Physics 206

Chance of sterility from radiation (2.5-5 Gy) depends on age (potential eggs)



<14 years No sterility

15-40 years 30-40% sterility

>40 years 90% sterility

Adapted from Paulino et al. Semin, Rad Oncol 2010

Comparison of risks of developing physiological abnormalities in children and adults

Organs	*More*	*Same*	*Less*	*No sufficient data*	*Levels of evidence*	*Comments*
Deterministic risks following radiotherapy in children versus adults						
Brain	X				Strong	Neurocognitive reduction
Neuroendocrine		X			Strong	Consequences greater owing to growth hormone suppression
Cataracts	X				Weak	
Cerebrovascular accident	X				Moderate	Stroke
Heart	X				Strong	Prevents growth and remodelling, valvular abnormalities
Breast hypoplasia	X				Strong	Most severe during puberty
Lung			X		Weak	Depends on end point: maximum capacity decreased if chest wall growth is inhibited
Thyroid hypofunction		X			Weak	
Thyroid nodules	X				Strong	

Comparison of risks of developing physiological abnormalities in children and adults

Organs	More	Same	Less	No sufficient data	Levels of evidence	Comments
Deterministic risks following radiotherapy in children versus adults						
Thyroid autoimmune				X		
Kidney		X			Weak	
Bladder	X				Strong	Bladder capacity reduced
Testes	X				Strong	Most severe during puberty. Reduction in sperm and hormones
Ovaries			X		Moderate	Less sensitive at younger age
Uterus	X				Moderate	Uterine vasculature impaired
Musculoskeletal	X				Strong	Hypoplasia, deformity, osteochondroma
Immune				X		
Marrow whole body			X		Strong	Less available marrow when older

Comparison of risks of developing physiological abnormalities in children and adults

Organs	*More*	*Same*	*Less*	*No sufficient data*	*Levels of evidence*	*Comments*
Deterministic risks following internal exposures in children versus adults						
Thyroid hypofunction				X		
Thyroid nodules	X				Strong	
Thyroid autoimmune		X			Moderate	Insufficient evidence

Hereditary effects

No significant difference in birth defects or cancer in children of exposed children.

NCI Five – Center Study
Offspring of Cancer Survivors

	Survivors (2,198)	Controls (4,544)
Birth defect	3.37%	3.13%
Cancer	0.30%	0.23%

Byrne, Teratology 59:210, 1999

Byrne, Teratology 59:210:1999

Future Research

- Evaluation of potential radiation effects on children in areas of high radon and other natural background exposure; high dose medical interventional procedures; and radiotherapy (including potential interactions with other therapies);
- Development of radiation dose databases that can be combined and tracked long term;
- Evaluation of juvenile organ-specific and partial volume effects;
- Studies of developmental effects on the cellular organization of tissues, the response of tissues and cells to radiation damage, and identification of cells at risk; and
- Application of the range of available 'omics technologies.

Conclusions

- Children are not just small adults
- Children's tissues morph into adults at different rates and at different times
- Some differences in radiation effects with age are explicable, others are not
- Children are at more risk than adults for some effects, similar risk or more resistant for some other effects
- Accurate estimation of risks requires data derived from observations of exposed children and not just generalizations from observations of adults

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Thank you for your attention!