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Radiological Protection in Medicine
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ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

FUKUSHIMA MEDICAL UNIVERSITY

Individual Radiation Risk Estimates in Radiology:
Is it necessary and possible?

LUNDS UNIVERSITET

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- To inform patients and health-care personnel about risks in diagnostic as well as therapeutic applications of ionizing radiation, it is desirable that the individual patient's radiation dose and potential cancer risk can be prospectively assessed and documented.

- The current dose and risk reporting is based on effective dose, which ignores body size and does not reflect the strong dependence of risk on the age at exposure.

Overview of my talk:

- Need for information
  - Views of IAEA, regional/national organisations, …
- Effective dose
  - Views of ICRP, …
- Individual risk estimates
  - Patient specific phantoms/biokinetics
  - Risk coefficients for various ages and genders
- Examples of individual risk estimates
- A possible way forward

IAEA BSS 3.151 (2014).

Registrants and licensees shall ensure that no patient, whether symptomatic or asymptomatic, undergoes a medical exposure unless: … (d) The patient or the patient's legal authorized representative has been informed as appropriate of the expected diagnostic or therapeutic benefits of the radiological procedure as well as the radiation risks.

EU Directive 2013/59/EURATOM

specifies the need to give information on radiation risks to patients (§56).

Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 6 February 2018 (§106).

To do that in a meaningful way we need individual risk estimates.

Effective dose (E)

The only radiation dose quantity related to health detriment for stochastic effects.

Initially intended for radiation protection of a population of workers (18-65 years old).

Later extended to the general public.

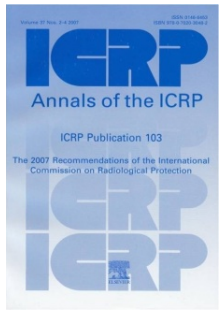
BUT, frequently used also for patients undergoing medical exposures and even for individual risk estimates.

$$H_T = \sum_R w_R \, x \, D_{R,T}$$ *D – Absorbed dose; H – Equivalent dose*

$$\boldsymbol{E = \sum_T w_T \, x \, H_T}$$

"Risk" = E x r *r - risk coefficient* r ≈ 5% per Sv

Effective dose



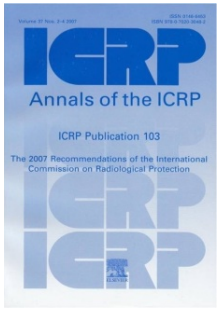
ICRP Publ. 103 (2007)

Table A.4.3. Proposed tissue weighting factors.

Tissue	w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder Tissues* (Nominal w_T applied to the average dose to 14 tissues)	**0.12**	0.72
Gonads	**0.08**	0.08
Bladder, Oesophagus, Liver, Thyroid	**0.04**	0.16
Bone surface, Brain, Salivary glands, Skin	**0.01**	0.04

* Remainder Tissues (14 in total): Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix.

Effective dose



ICRP Publ. 103 (2007)

- Detriment:
  - The total harm to health experienced by radiation.
- Detriment-adjusted risk:
  - A modification of the probability of the occurrence of a stochastic effect by the severity of the outcome e.g. adjust for morbidity and suffering of non-fatal cancers.

Table A.4.4. Detriment adjusted nominal risk coefficients for cancer and heritable effects (10^{-2} Sv^{-1})[1].

Exposed population	Cancer		Heritable effects		Total	
	Present	ICRP 60	Present	ICRP 60	Present	ICRP 60
Whole	5.5	6.0	0.2	1.3	5.7	7.3
Adult	4.1	4.8	0.1	0.8	4.2	5.6

[1] Values from Tables A.4.1a, A.4.1b, and *Publication 60*.

++ Advantages with effective dose (E):

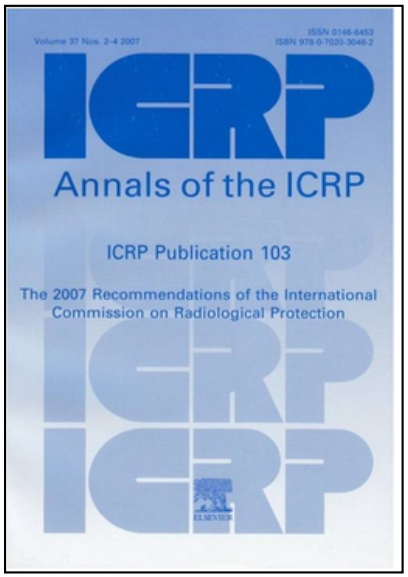
- Very helpful for planning and optimization, for describing dose limits and constraints, etc.
- Provides a relative index of harm for various procedures in diagnostic imaging. Compares different examinations, technologies and procedures in different hospitals and countries provided the patient populations are similar with regard to age and sex.

- - Disadvantages with E:

It don´t consider:

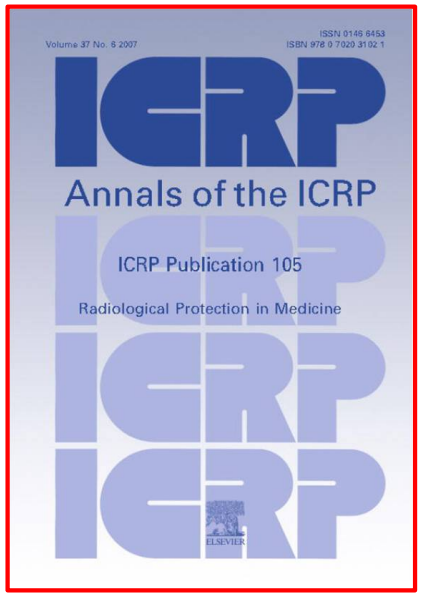
- Age at exposure
- Gender
- Body mass and size,
- Organ geometry
- Individual radiosensitivity, …

BUT ….



ICRP (2007) Publication 103, page 129:

”… risk assessment for medical diagnosis and treatment using ionising radiation is best evaluated using appropriate risk values for the individual tissues at risk and for the age and sex distribution of the individuals undergoing the medical procedures”.



ICRP (2007) Publication 105, page 21:

(effective dose) … should not be used to assess risks of stochastic effects in retrospective situations for exposures in identified individuals, nor should it be used in epidemiological evaluations of human exposure, …

A step forward

- Keep the tissue weighting factors.
- Use age dependent risk coefficients, *r(age).*

Wall et al., 2011; Balonov and Shrimpton, 2012; Balonov et al., 2015

- children and adolescents < 18 y: r x 2
- adults < 65 y: r x 1
- seniors 65+: r x 0.1

Almén and Mattsson, 1996 (for children and adolescents: r x 2-3).

Simple adjustments of ICRP's nominal risk coefficient to account for age differences can make effective dose a useful instrument for the description of the relative radiation detriment of an examination.

Steps towards individualized risk estimates

Individual exposure

External radiation – KAP, $CTDI_{vol}$, DLP, imaging parameters
Internal radiation – radiopharmaceutical, activity, iv. injection, inhalation, ingestion, blocking agents.

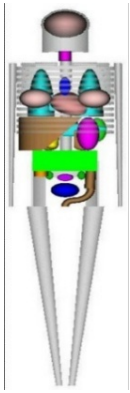
Exposure ⇨ *Individual organ doses*

External radiation – body size and shape of individual, organ anatomy.
Internal radiation – biokinetics, body size and shape, organ anatomy.

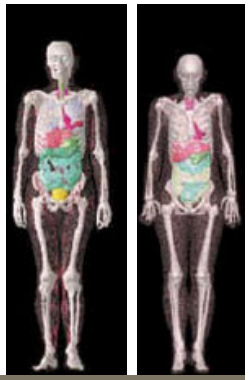
Organ doses ⇨ *Individual radiation risk*

Dose-response models for cancer incidence or mortality.
Age and gender dependence of the risk.
Individual susceptibilities, ….
…

Body size and shape of individual, organ anatomy

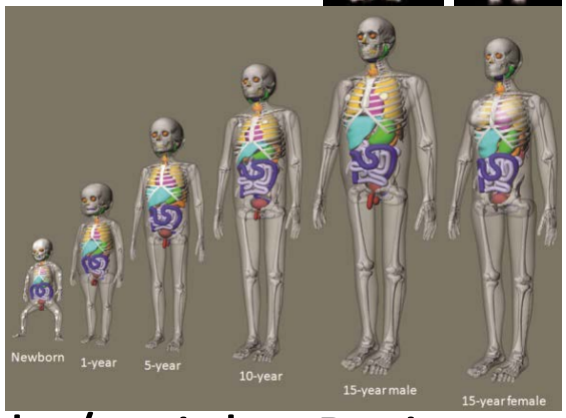


Stylized (or mathematical) phantoms Calculations are done for 70 kg standard patients (MIRD phantoms).



Voxel (or tomographic) phantoms (ICRP/ICRU reference computational voxel phantoms for adults, awaiting the paediatric phantoms; other phantoms).

Hybrid (or NURBS/PM) 4D phantoms (non-uniform rational B-spline/polygon meshes).



Phantom categories:

Reference - Patient matched by age only.

Patient-dependent - Patient matched by nearest height/weight; Patient matched to height, weight, and body contour.

Patient-specific - Patient-specific phantom, uniquely matching patient morphometry.

Risk coefficients for various ages and genders

$$r = \sum_T r_T(age, gender) \times H_T$$

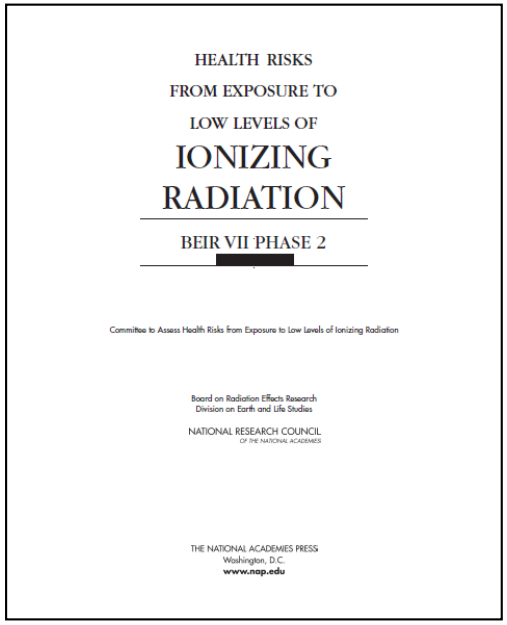
What is known?

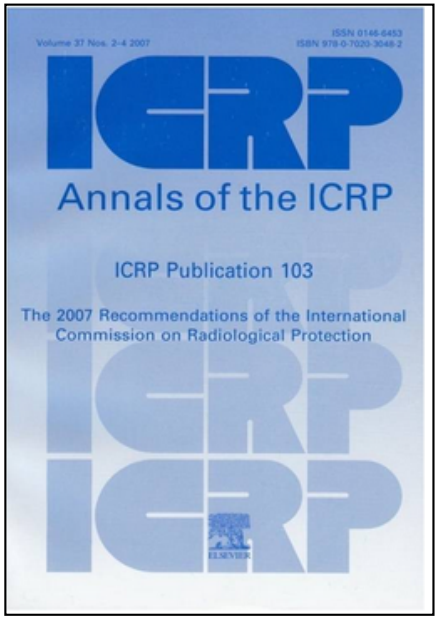
BEIR VII (2006)

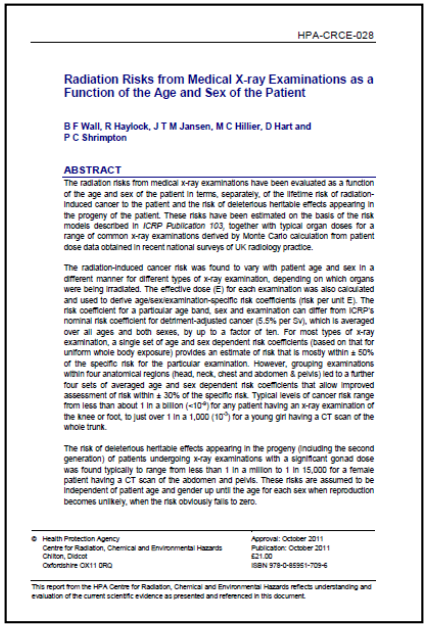
ICRP Publication 103 (2007)

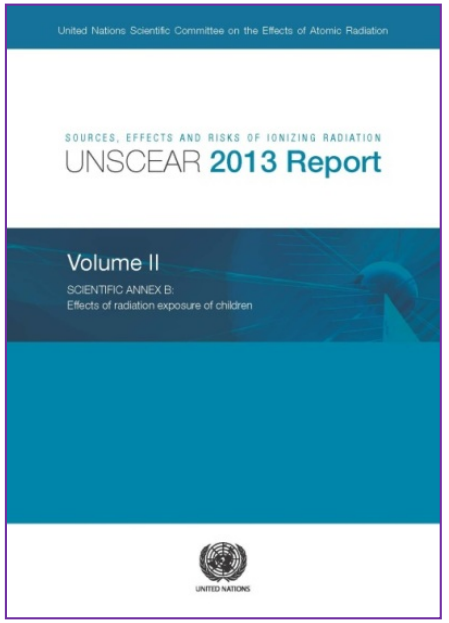
HPA-CRCE-028 (2011)

UNSCEAR 2006 report; UNSCEAR 2013 Report, vol II, scientific annex B: Effects of radiation exposure in children









- An alternative way could be to use the U.S. Environmental Protection Agency (EPA) Lifetime attributable risk (LAR) values.

- The LAR estimates are based on the same epidemiological data as ICRP uses for the risk coefficients related to effective dose, and differentiate the cancer risk into age and gender specific subgroups and have also a clearly defined detriment in the form of either the excess risk of receiving a cancer or the excess risk to die from the received cancer.

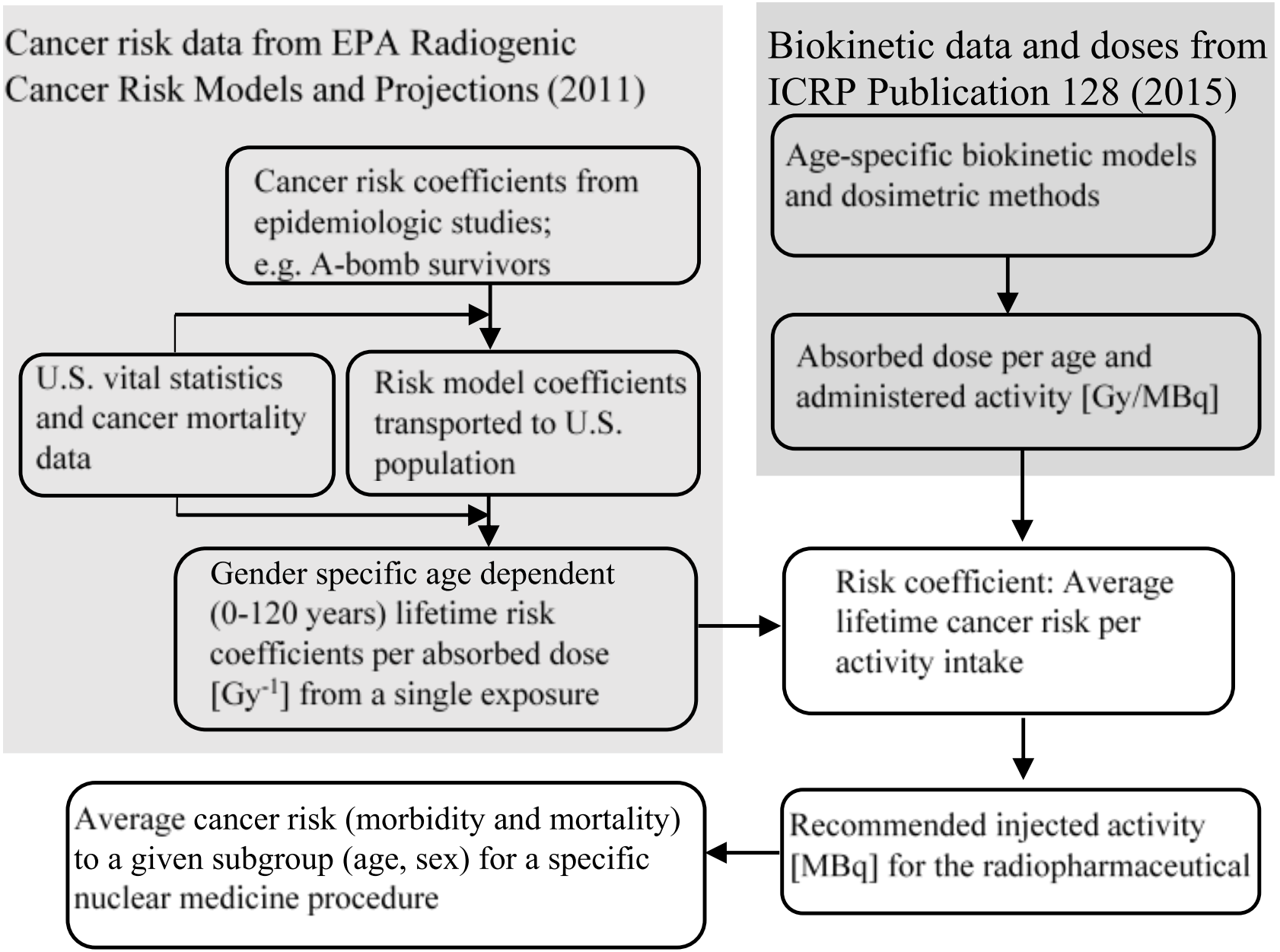
EPA 402-R-11-001

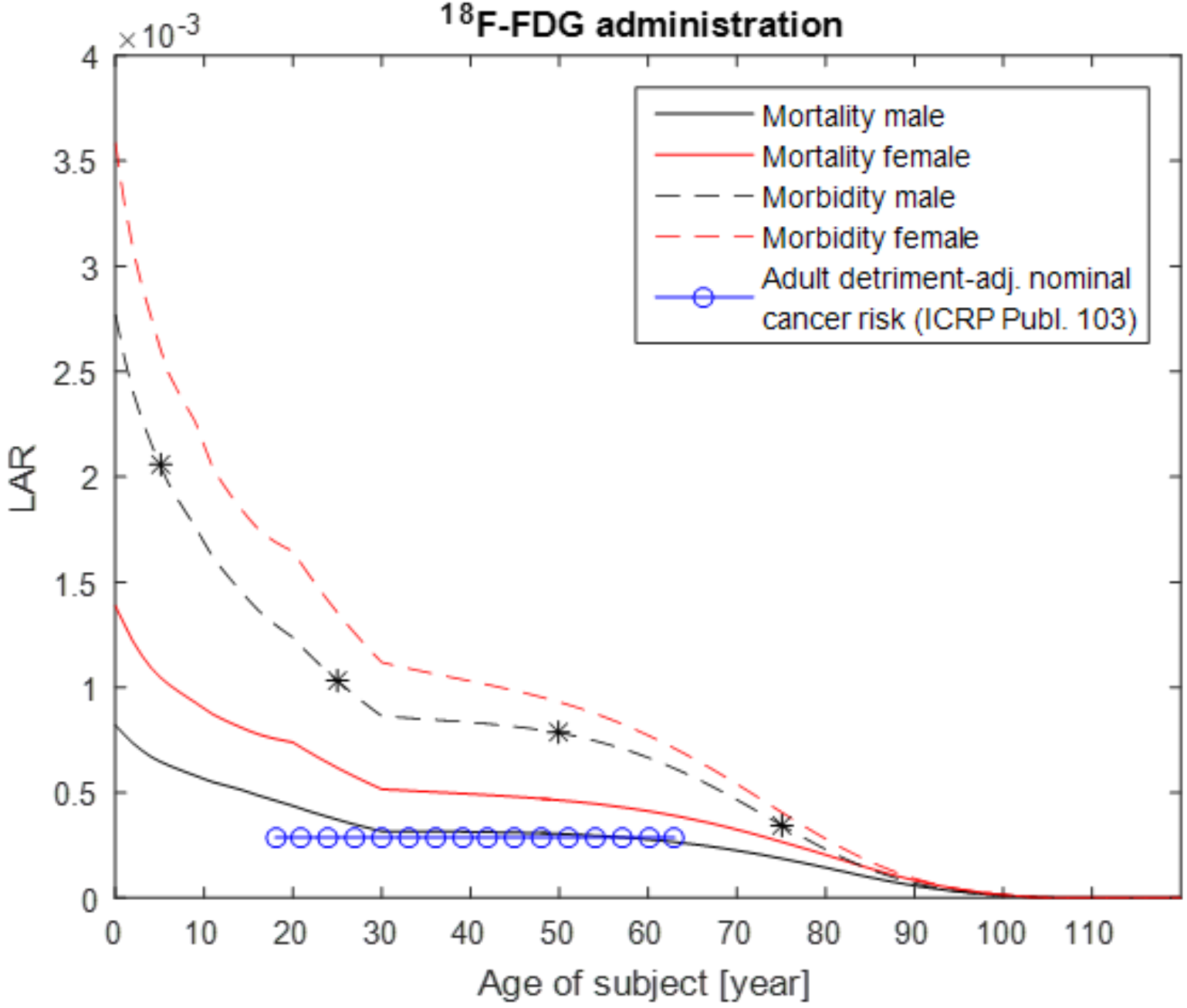
EPA Radiogenic Cancer Risk Models and Projections for the U.S. Population

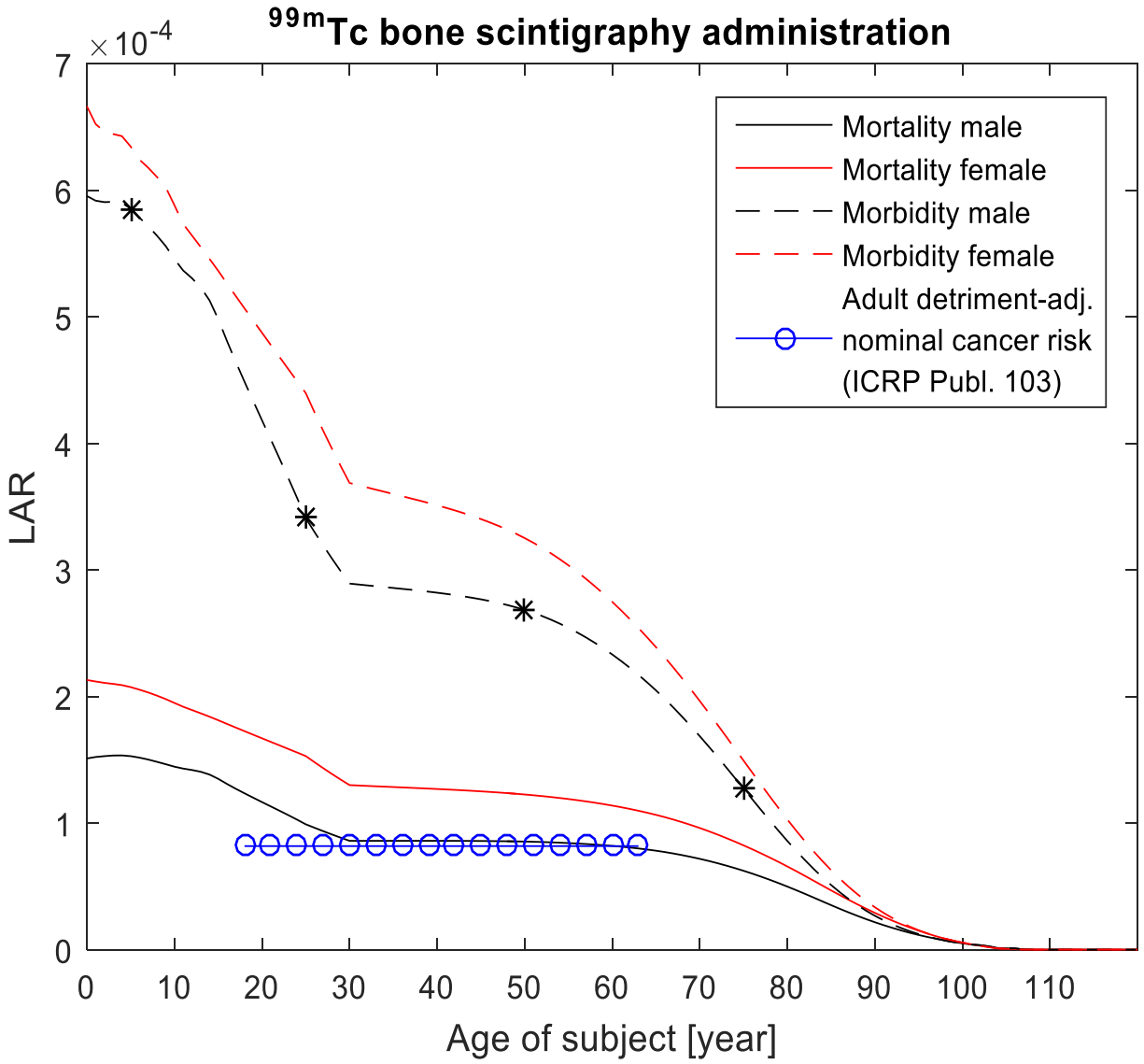
April 2011

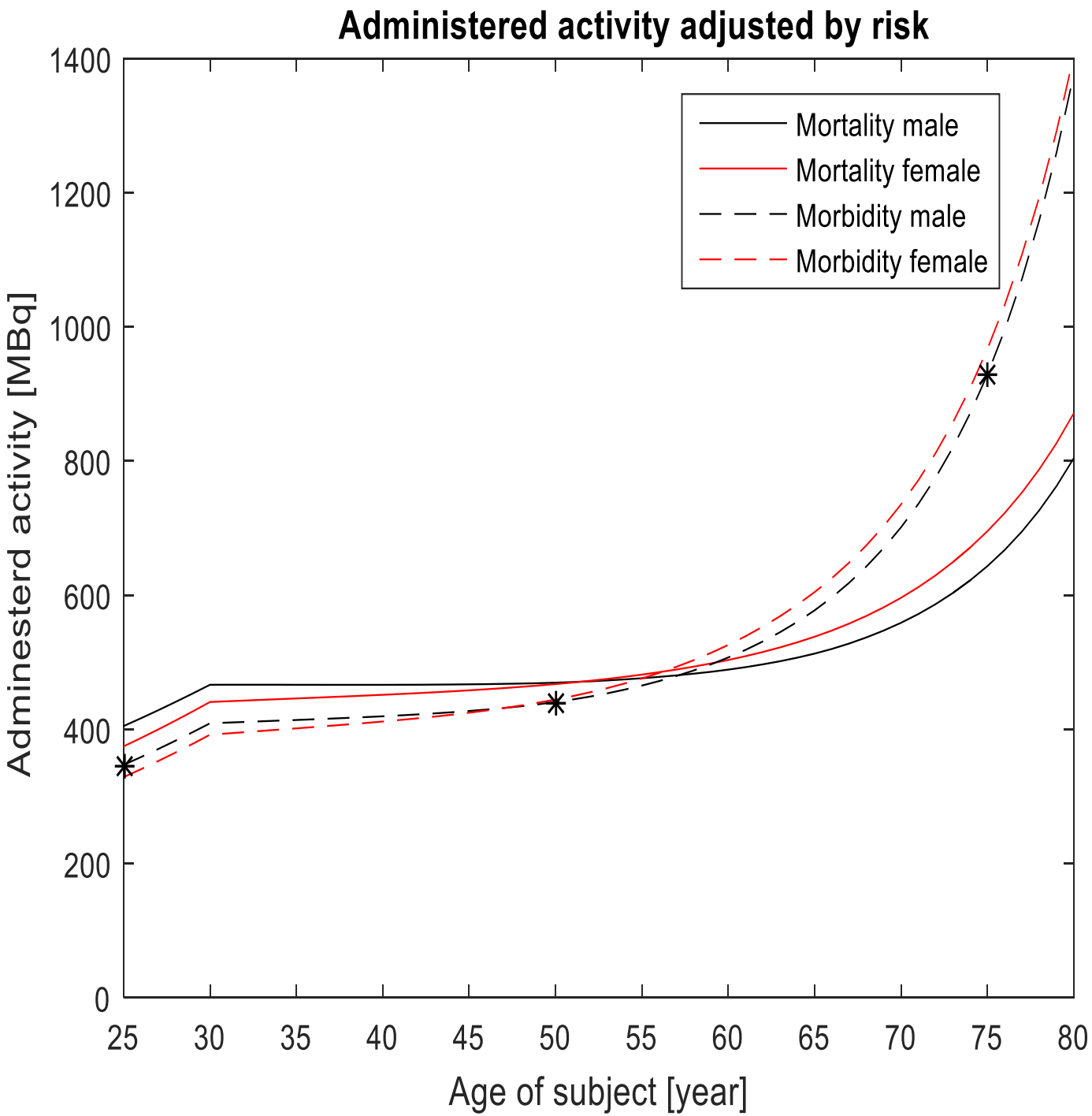
U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
1200 Pennsylvania Ave., NW
Washington, DC 20460

Applied to some examples in nuclear medicine




^{18}F-FDG administration
×10^-3
4
3.5
3
2.5
2
1.5
1
0.5
0
LAR
0
10
20
30
40
50
60
70
80
90
100
110
Age of subject [year]
Mortality male
Mortality female
Morbidity male
Morbidity female
Adult detriment-adj. nominal cancer risk (ICRP Publ. 103)


99mTc bone scintigraphy administration
×10-4
LAR
Age of subject [year]
Mortality male
Mortality female
Morbidity male
Morbidity female
Adult detriment-adj. nominal cancer risk (ICRP Publ. 103)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90
100
110


Administered activity adjusted by risk
Mortality male
Mortality female
Morbidity male
Morbidity female
Adminesterd activity [MBq]
Age of subject [year]
0
200
400
600
800
1000
1200
1400
25
30
35
40
45
50
55
60
65
70
75
80

Conclusion

The effective dose in combination with the nominal ICRP cancer risk coefficients for workers (18-65 years) and the general public, 5.5%/Sv and 4.1%/Sv respectively, will underestimate the risk for newborn, babies and adolescents, but overestimate the risk for senior people in comparison to the estimates using LAR-values from US EPA.

Other advantages with LAR compared to E is an easier understandable detriment.

A possible way forward?

- Effective dose ⇒ organ doses/cancer risk models.
- Reference phantoms ⇒ extended collections of phantoms ⇒ individual CT/MRI-images (when available).
- Reference biokinetic models ⇒ models describing different physiologic (normal/sick) conditions ⇒ individually measured parameters.
- Population-based cancer risk ⇒ to individual cancer risk (gene expression profiling)?
- ……..
- ……..

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Thank you for listening!

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