

Kotre, John ORCID: <https://orcid.org/0000-0002-1890-1160> (2023) Towards quantitative justification. In: British Institute of Radiology IR(ME)R Update, 28 September 2023, London, UK. (Unpublished)

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Towards Quantitative Justification

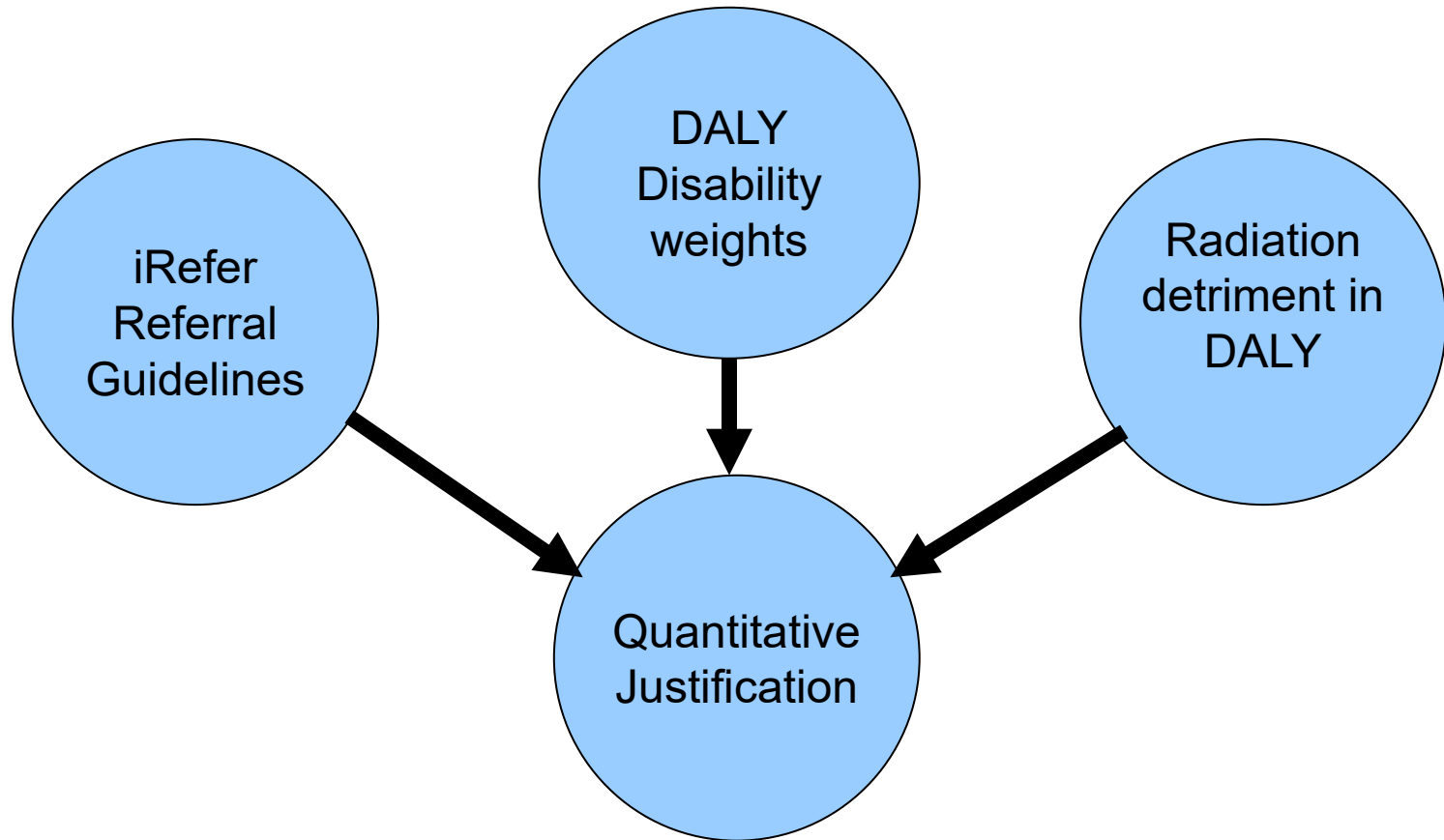
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Declarations:

Winner of BIR/GE Radiation Safety
Travel Award 2023

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Disability-adjusted life years

The disability-adjusted life year (DALY) is a measure of overall disease burden adopted by WHO. It quantifies the impact of a disease on a population by combining mortality and morbidity into a single metric:

$$\text{DALY} = \text{YLL} + \text{YLD} = N_m \times \text{LE} + N_i \times \text{DW} \times \text{YD}$$

DALY	Disability-adjusted life year
YLL	Years of life lost due to premature mortality (year)
YLD	Years lived with a disability (year)
N_m	Number of deaths (person)
LE	Standard life expectancy at age of death (year/person)
N_i	Number of incident cases (person)
DW	Disability Weight (DALY/year)
YD	Mean years of disability (year/person)



Disability-adjusted life years

For an individual experiencing a period of non-fatal disease, the loss of years of good health in DALY is made up just of the YLD term for the individual:

$$\mathbf{DALY}_{\text{(individual, non-fatal)}} = \mathbf{DW} \times \mathbf{YD}$$

DALY	Disability-adjusted life year
DW	Disability Weight (DALY/year)
YD	Years of disability (years)

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WHO health state	Disability Weight	iRefer code	iRefer disease description	Indicated examination(s)
Dental caries (symptomatic)	0.01	(none)		Intra-oral dental XR
Stroke: long term consequences, mild	0.019	N02	TIA	CT head
Fractured foot	0.026	T24	Foot injury	XR foot
Fractured clavicle/scapula/humerus	0.035	T19	Shoulder injury	XR orthogonal views
Dislocation of shoulder	0.062	T19	Shoulder injury	XR orthogonal views
Face bone	0.067	T06	Middle-third facial injury	XR facial bones
Stroke: long term consequences, moderate	0.070	N01	Acute Stroke	CT head
Traumatic brain injury (minor)	0.094	T01	Head injury	CT head
Fractured sternum/ribs	0.103	T31	Sternal injury	CXR PA and lateral
Hearing loss: severe	0.167	E01	Conductive hearing loss and other middle ear symptoms	CT head
Concussion	0.214	T01	Head injury	CT head
Cancer diagnosis and therapy	0.288	CA06	Lung cancer diagnosis	CXR and CT chest
Fractured neck of femur	0.402	T16	Pelvic injury with suspected femoral neck fracture	XR pelvis and lateral hip
Acute MI days 1-2	0.432	CC01	Acute chest pain: ST elevation myocardial infarction (STEMI)	CXR and Catheter coronary angiography & intervention
Cancer metastatic	0.451	CA23	Metastatic malignant disease of unknown primary origin: diagnosis	CXR and possible CT chest, abdomen, pelvis plus possible PET-CT



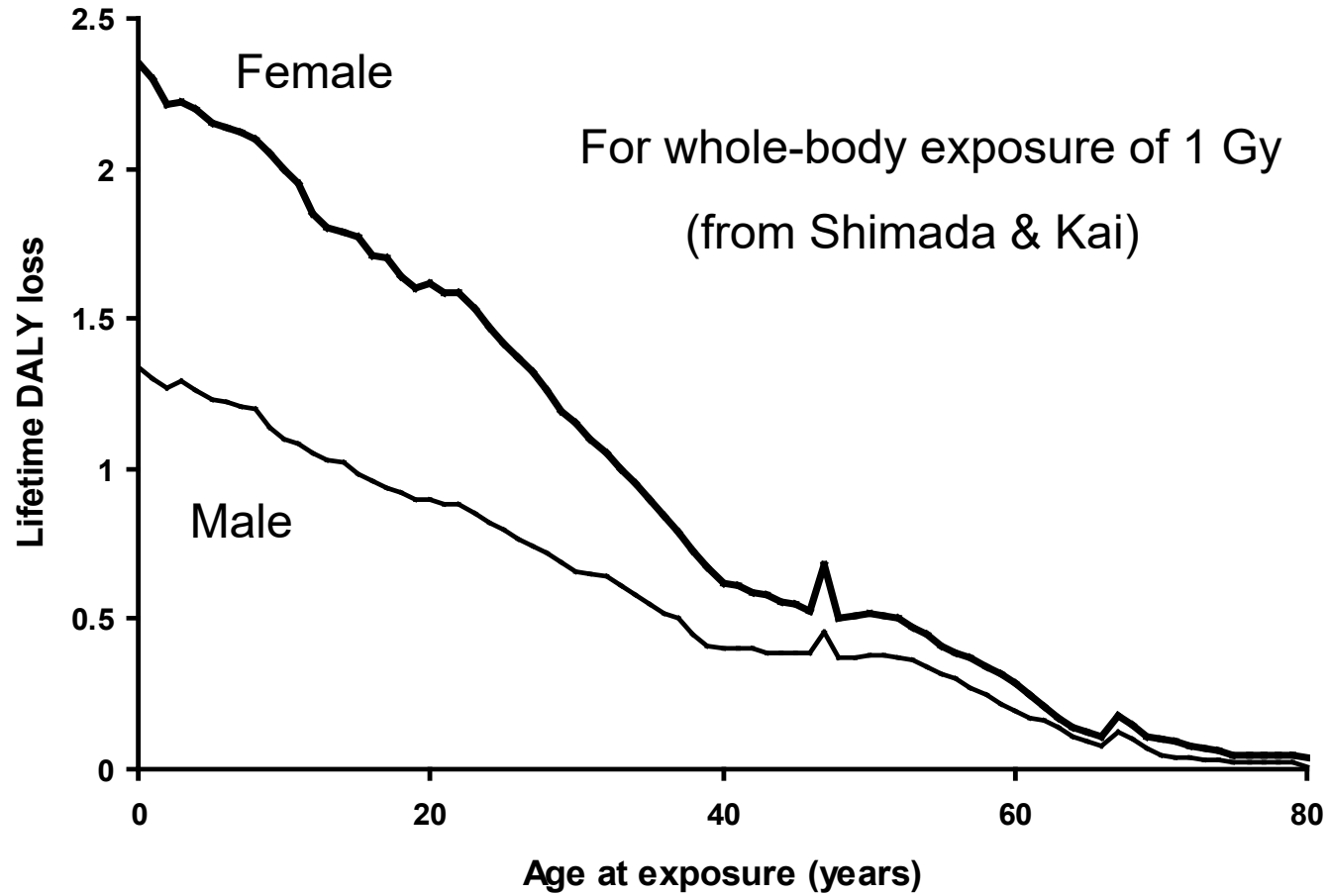
K Shimada and M Kai, 2015

“ICRP defined the detriment in Publication 60.....However, the detriment has the disadvantage that it can neither be appropriately interpreted nor used.”

In their paper *Calculating disability-adjusted life years (DALY) as a measure of excess cancer risk following radiation exposure*, Shimada and Kai calculate revised weighting factors for effective dose and give average lifetime detriment factors for the Japanese population of 0.84 DALY lost per 1 Gy whole-body exposure for males and 1.34 lost per 1 Gy for females.

Vaillant et al separately calculated a loss of 1 DALY per person per Sv for a combined male and female non-Japanese population.

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Life-tables and spreadsheets

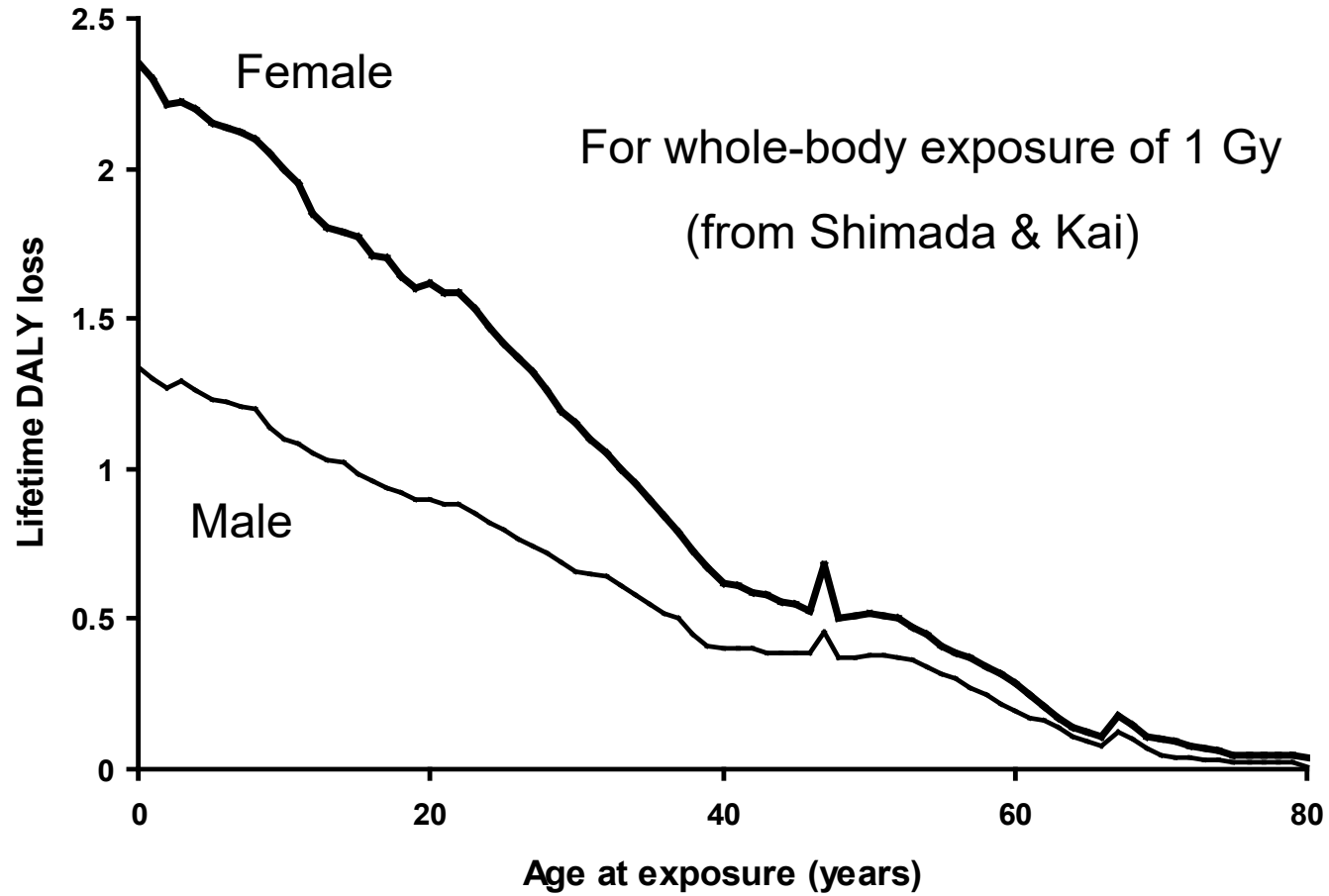
Using Japanese life-tables we can work out the net life-time DALY gain and loss using the constant 0.84 and 1.34 DALY loss per Sv.

Using the graphs of DALY loss at year of exposure we can perhaps get a better result. Need to know age at exposure in both methods.

The problem with these approaches is it all depends on population statistics not the outcome of the individual.

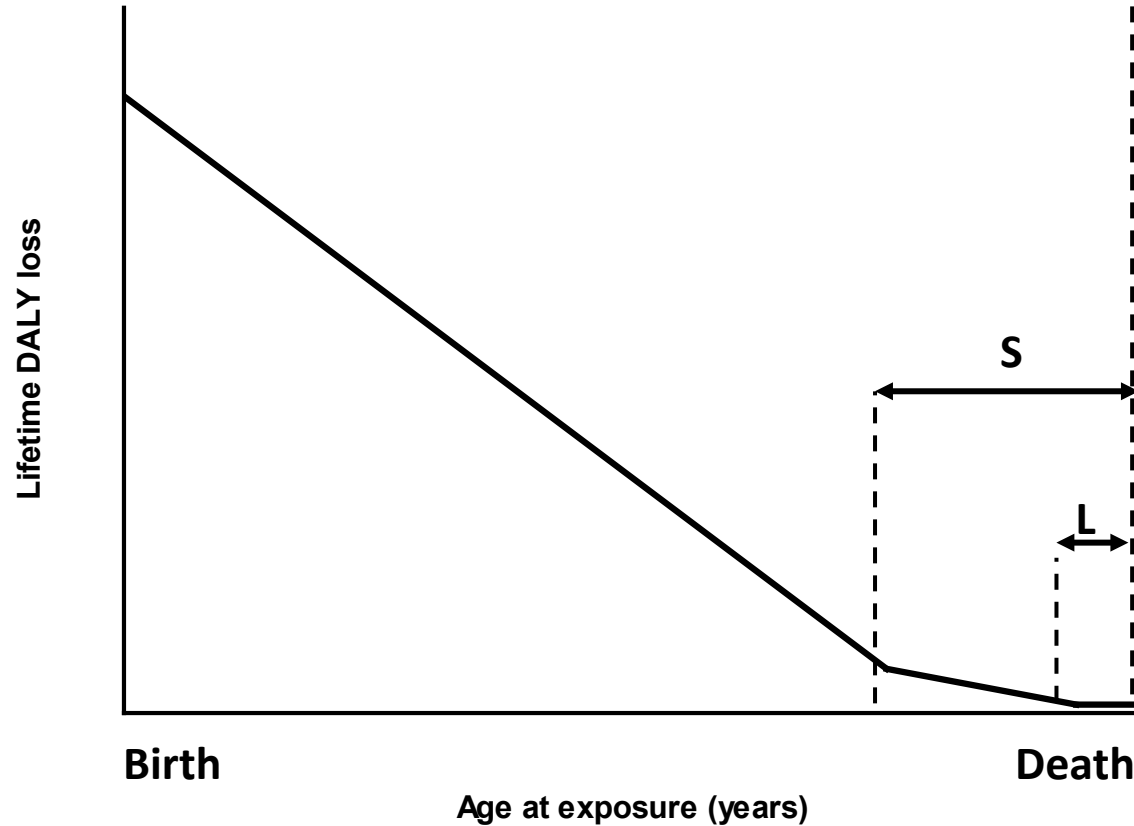
Let's take another look at those graphs.....

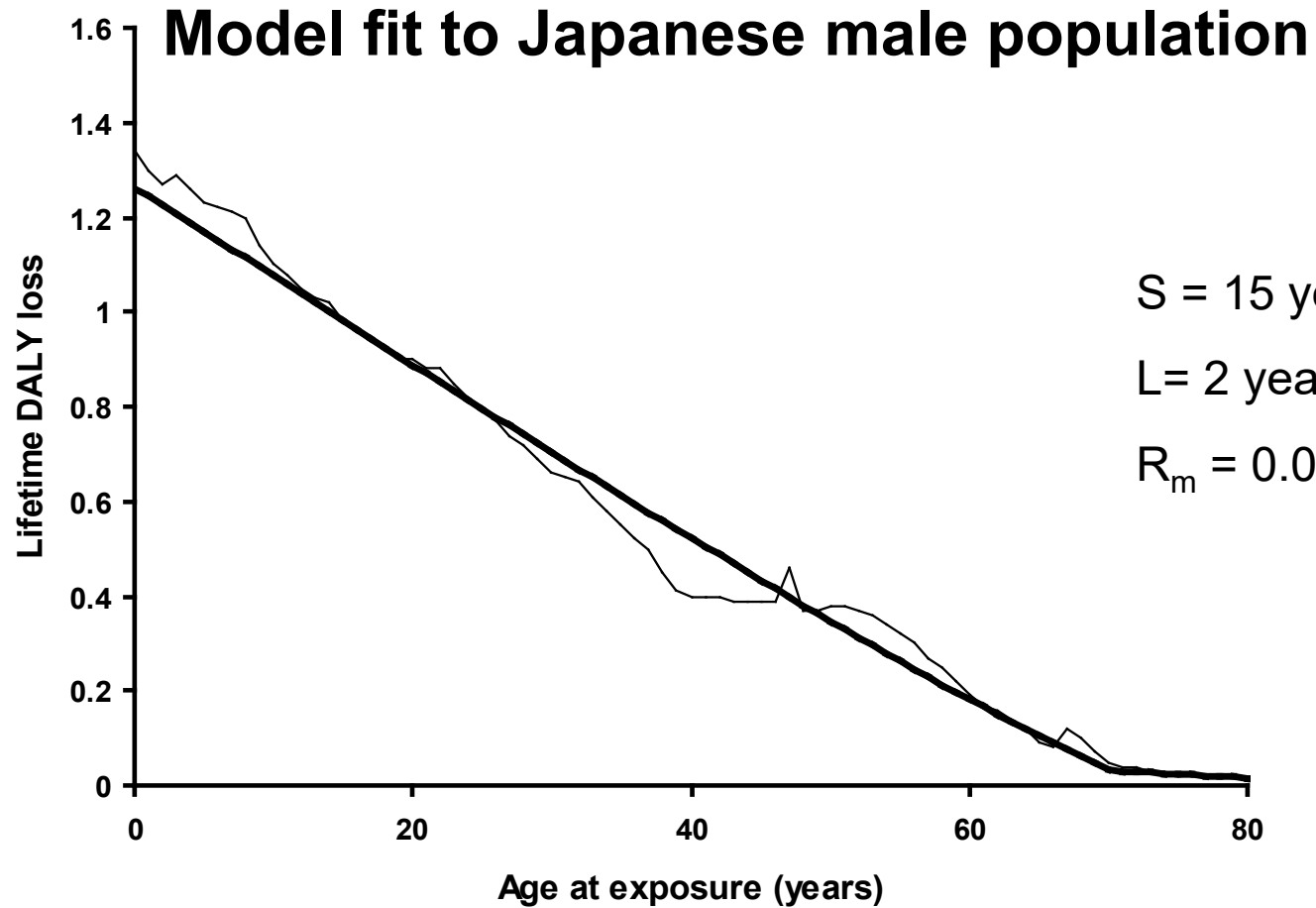
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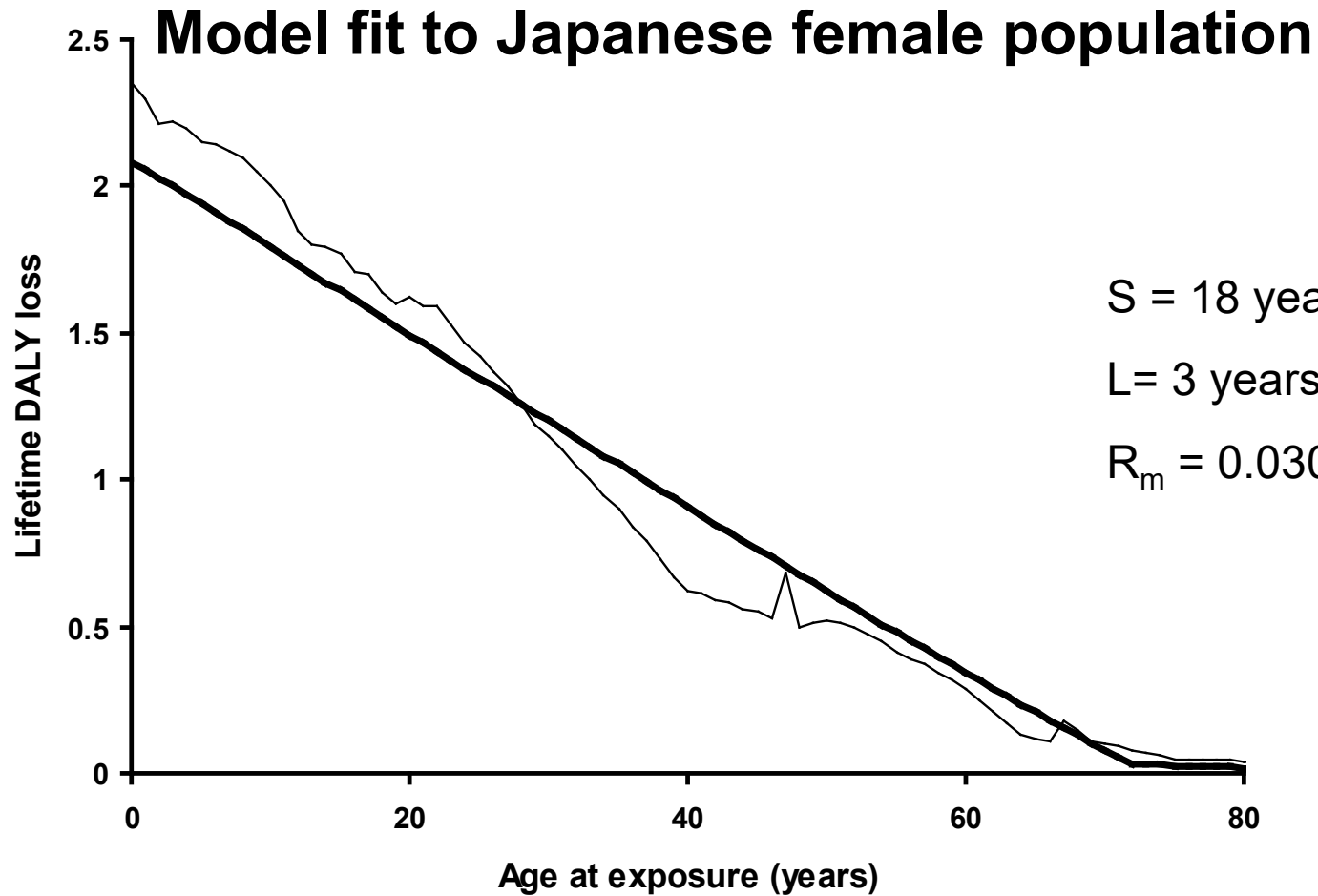




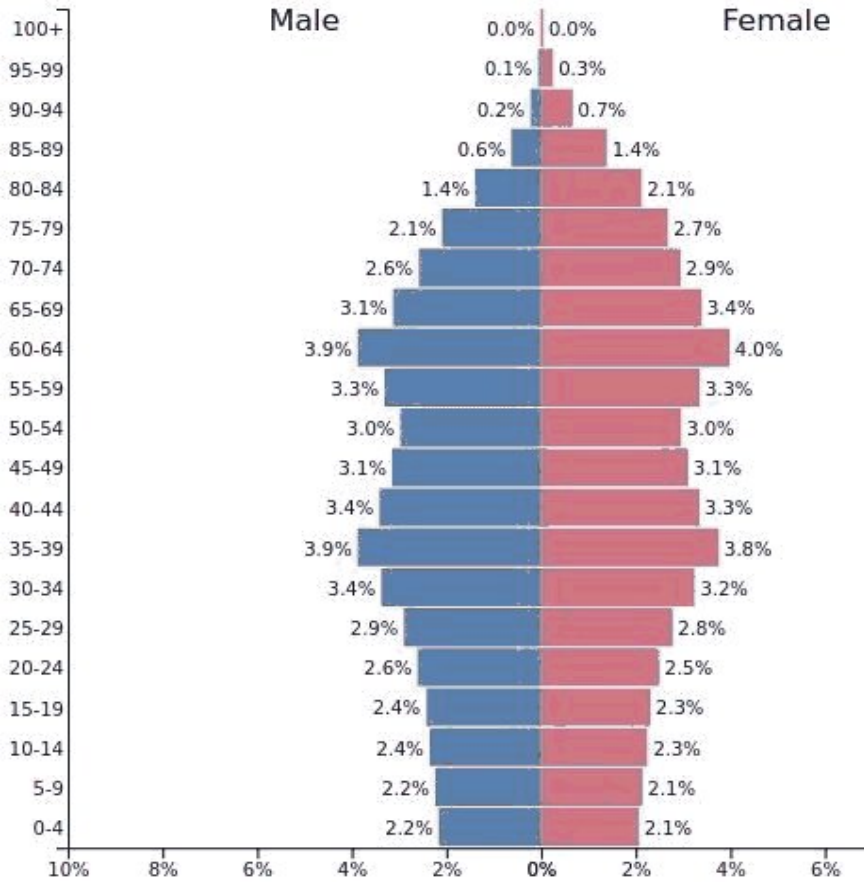
A Linear Model for the individual?



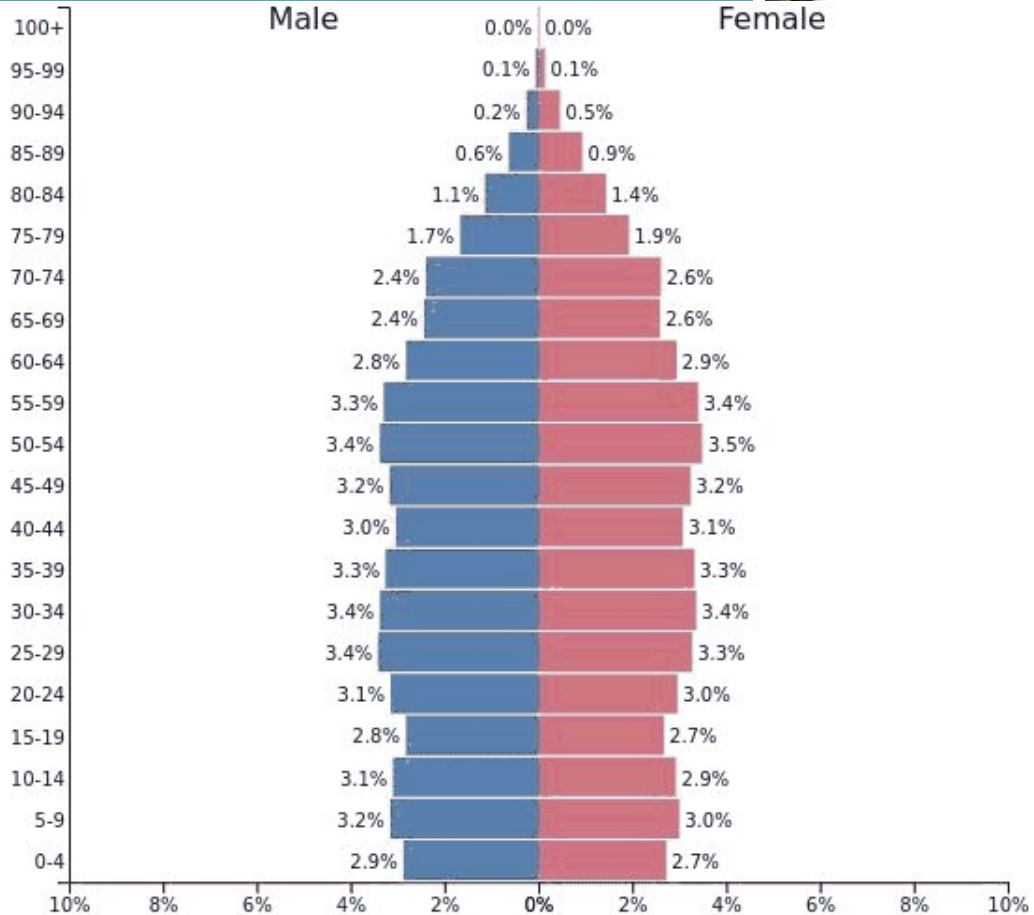




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Japanese 2010



UK 2020



A Disability Weight for Radiation Exposure

A disability weight due to exposure to ionising radiation, DW_R , can now be defined as:

$$DW_R = R_{m/f} \times E$$

DW_R	Disability Weight due to exposure from ionising radiation
$R_{m/f}$	DALY lost per year due to exposure to 1 Sv of ionising radiation (male or female)
E	Effective dose defined in terms of DALY detriment (Sv)

From the curve fits, $R_m = 0.019$ and $R_f = 0.030$ for Japanese population
Multiplying by E retains linear-no-threshold philosophy
Age > approximately 70, DW_R value too high. Does this matter?



Proposal for a Justification Factor, J

Instead of attempting to sum over a lifetime, consider a justification factor defined in terms of rates of change:

$$\text{Justification factor} = \frac{\text{Rate of change of benefit following diagnosis \& treatment}}{\text{Rate of change of radiation detriment from diagnosis (\& treatment)}}$$

These rates of change are all Disability Weights (DALY/year)

Dimensionless and independent of age and subsequent related or unrelated death

No consideration of missed diagnosis, failed treatment or self healing.



Proposal for a Justification Factor, J

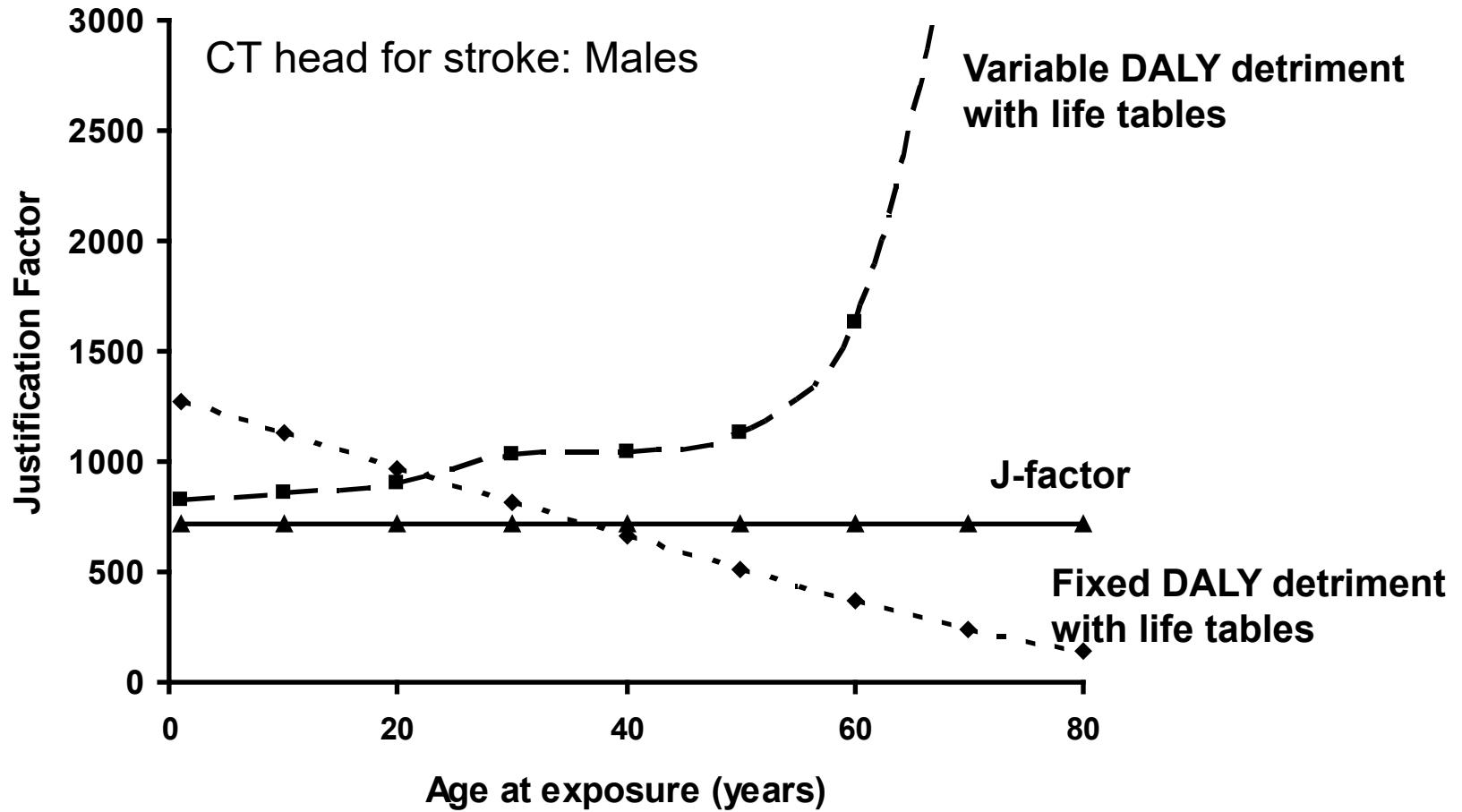
This justification factor, J, can be defined as:

$$J = (DW_B - DW_A) / DW_R$$

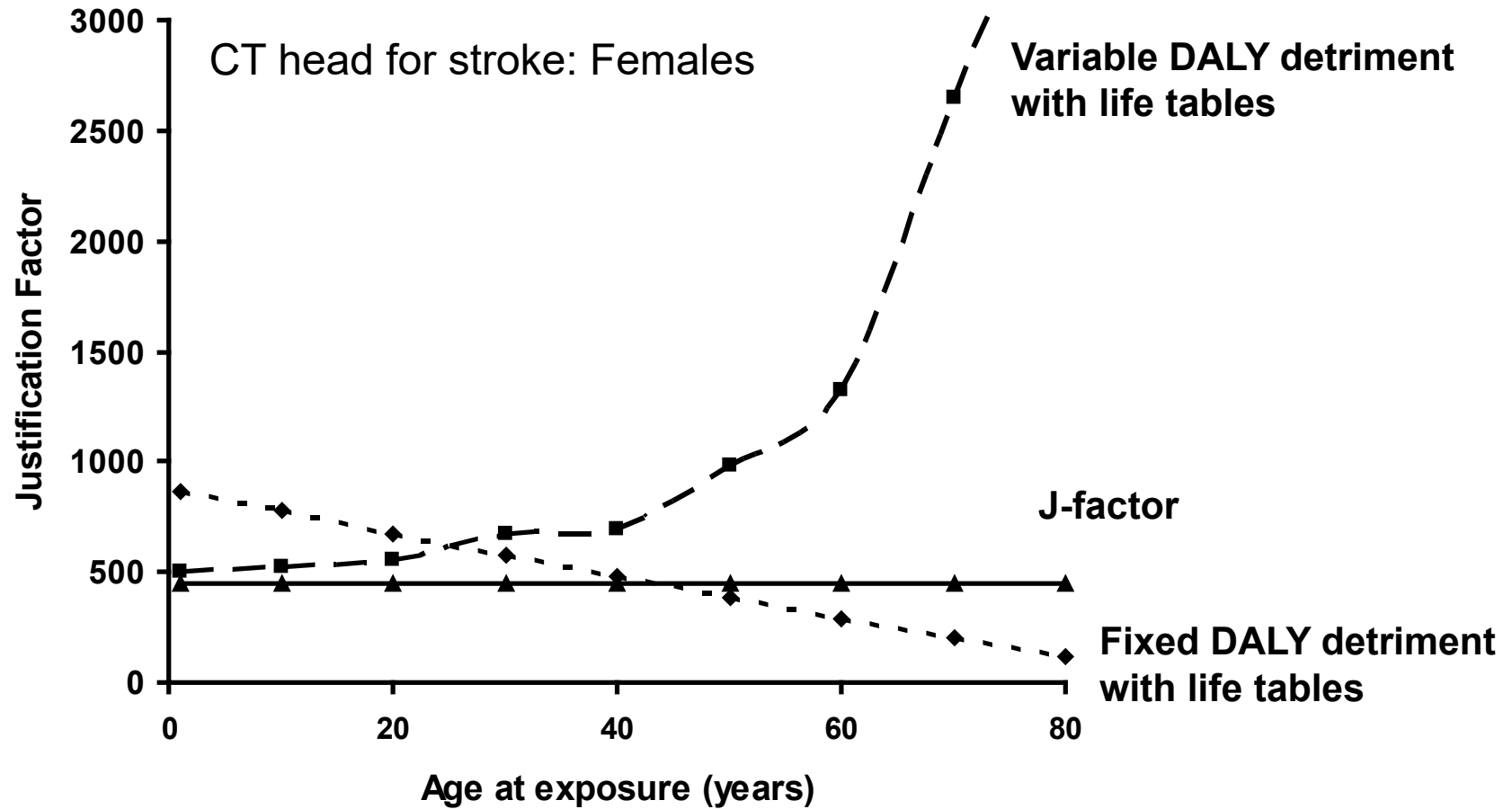
J	Justification factor
DW_B	Disability weight of disease being diagnosed before treatment
DW_A	Residual disability weight of disease after treatment
DW_R	Disability weight due to radiation exposure

The term $(DW_B - DW_A)$ quantifies the change in disability weight carried by the individual before and after treatment if the residual DW_A is known. For a successful treatment and restoration to full health DW_A will be zero and this is the assumption used in the results given below.

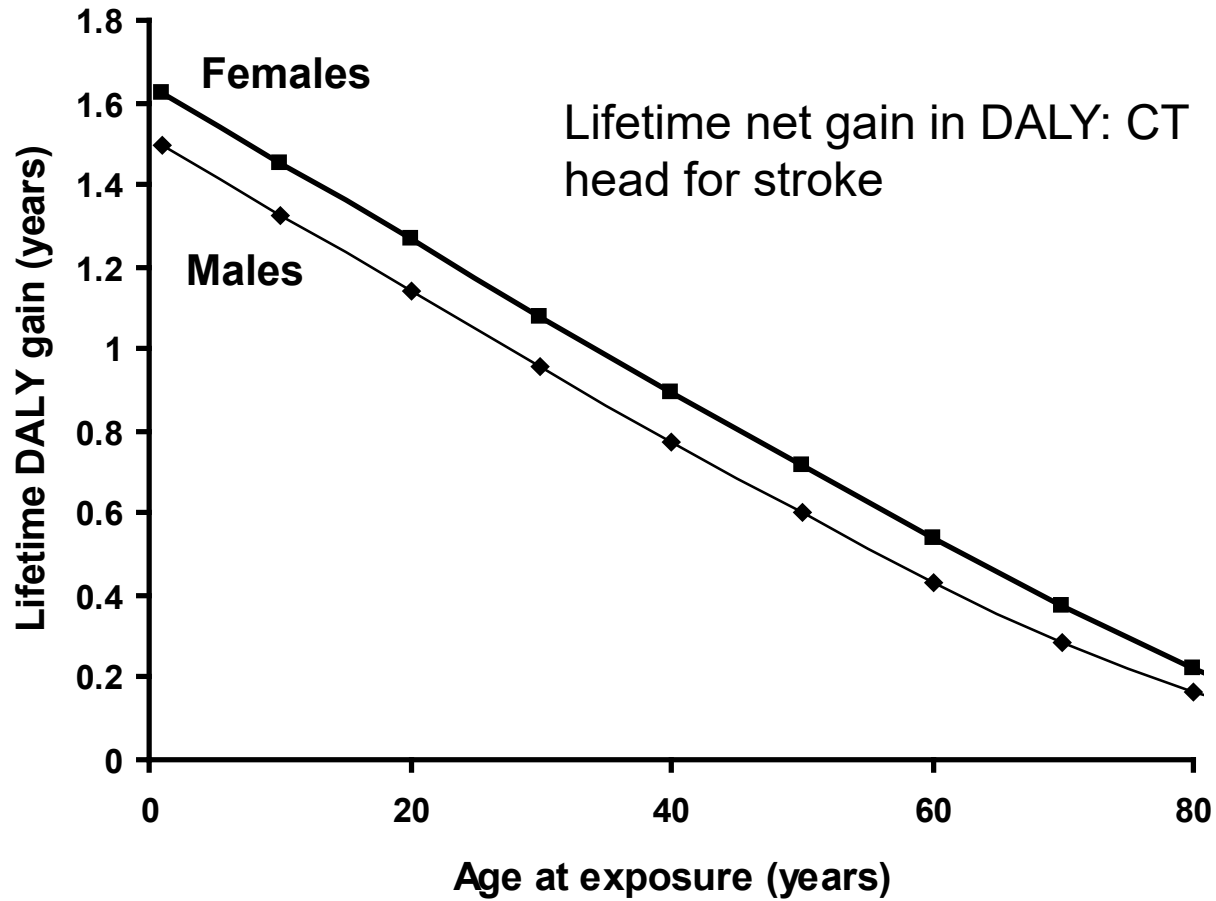
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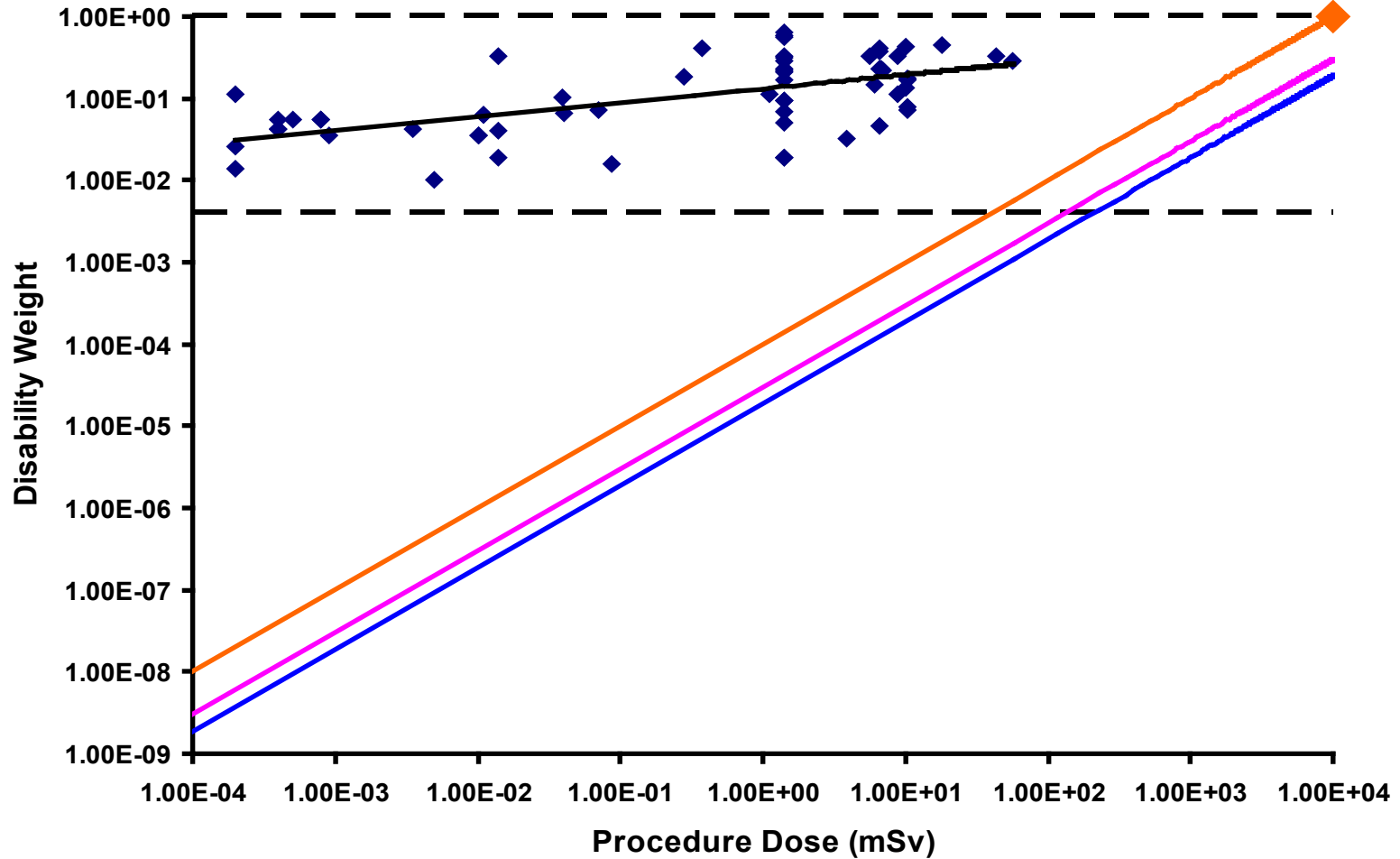


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WHO health state	Indicated examinations	Disability Weight	Typical Effective Dose (mSv)	Justification factor, J Male	Justification factor, J Female
Dental caries (symptomatic)	Intra-oral dental XR	0.01	0.005	105000	67000
Stroke: long term consequences, mild	CT head	0.019	1.4	714	452
Fractured foot	XR foot	0.026	0.0002	6840000	4330000
Fractured clavicle/scapula/humerus	XR orthogonal views	0.035	0.011	168000	106000
Dislocation of shoulder	XR orthogonal views	0.062	0.011	297000	188000
Face bone	XR facial bones	0.067	0.04	88100	55800
Stroke: long term consequences, moderate	CT head	0.070	1.4	2630	1670
Traumatic brain injury (minor)	CT head	0.094	1.4	3530	2240
Fractured sternum/ribs	CXR PA and lateral	0.103	0.039	139000	88000
Hearing loss: severe	CT head	0.167	1.4	6280	3980
Concussion	CT head	0.214	1.4	8050	5100
Cancer diagnosis and therapy	CXR and CT chest plus planning CT and 10 thorax cone-beam CT	0.288	57	266	168
Fractured neck of femur	XR pelvis and lateral hip	0.402	0.37	57200	36200
Acute MI days 1-2	CXR and Catheter coronary angiography & intervention	0.432	10	2270	1440
Cancer metastatic	CXR and possible CT chest, abdomen, pelvis plus possible PET-CT	0.451	18	1320	835

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Justification Factor – fag packet version

This justification factor, J, still defined as:

$$J = (DW_B - DW_A) / DW_R$$

- DW_B Disability weight of disease being diagnosed before treatment
- DW_A Residual disability weight of disease after treatment
- DW_R Disability weight due to radiation exposure

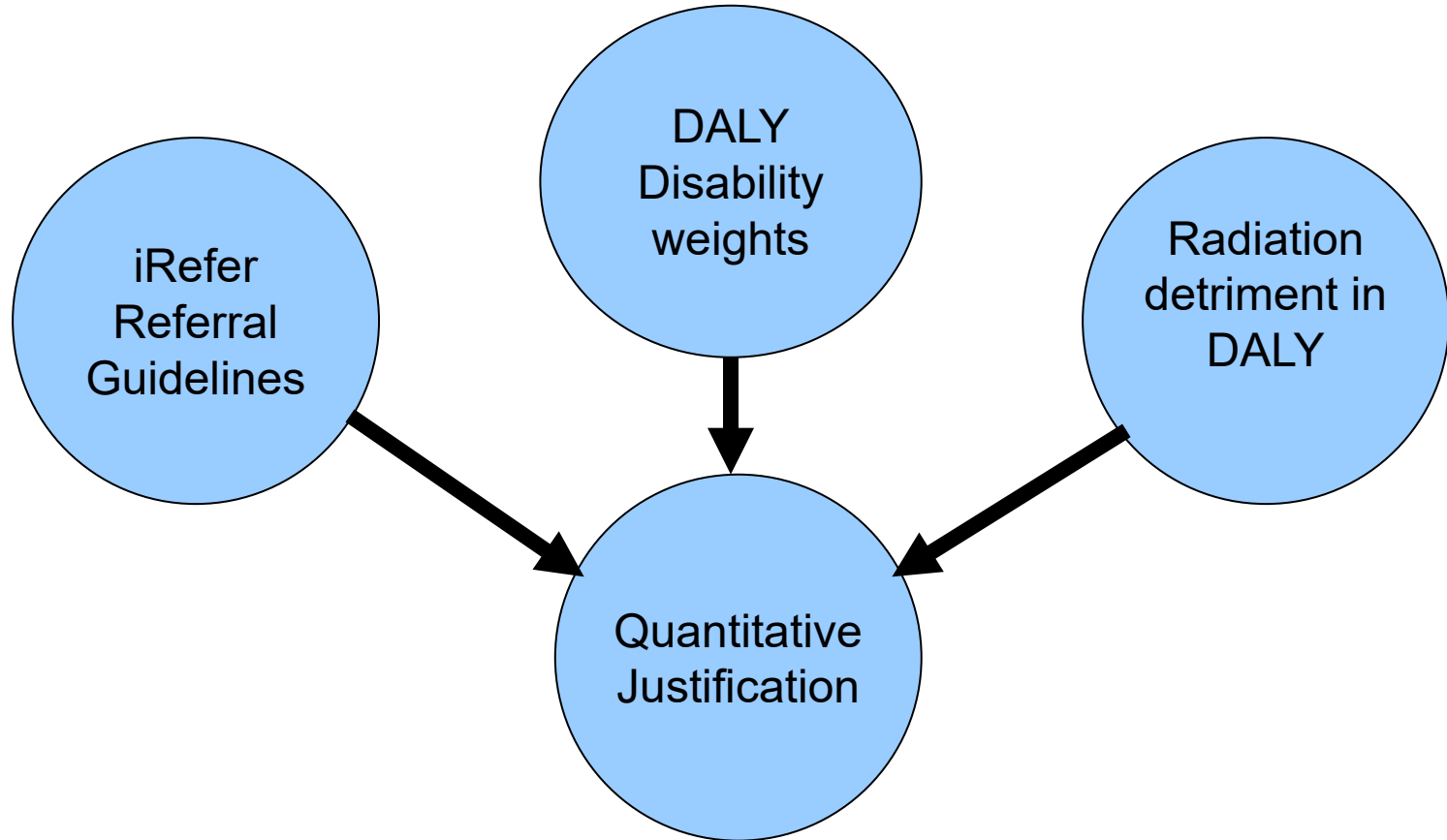
DW_R just based on LD₁₀₀ value (~10 Sv) at DW = 1 (death) and linear no threshold

$$DW_R = E / LD_{100}$$

- E Procedure effective dose (Sv)

Has advantage of using present (ICRP 103) definition of effective dose throughout and general population but depends on (limited) precision of LD₁₀₀ value. Gives J factors 4.3 times smaller than version based on DALY loss rates of change but still >>1.

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References

World Health Organization 2020. WHO estimates and data sources for global burden of disease estimates 2000-2019. Technical paper WHO/DDI/DNA/GHE/2020.3 https://cdn.who.int/media/docs/default-source/gho-documents/global-health-estimates/ghe2019_daly-methods.pdf

Shimada K and Kai M 2015. Calculating disability-adjusted life years (DALY) as a measure of excess cancer risk following radiation exposure. *J. Radiol. Prot.* **35** 763-775

Vaillant L, Kai M and Hauptmann M 2021. Radiation detriment methodology: review of current non-radiation-related parameters and perspectives. ICRP Future of Radiological Protection Digital Workshop <https://www.icrp.org/page.asp?id=549>