

Web supplement

An alternative model was tested. It should be noted that equation below without the *rain* terms ($rain_{hiro_yes}$, $rain_{naga_yes}$, $rain_{hiro_unk}$, $rain_{naga_unk}$) is identical to the excess relative risk (ERR) models that have been used in many analyses of the atomic bombing data.^{6, 7}

$$\lambda_0(c, s, b, a) [1 + \beta_1 d \cdot \exp(\alpha e + \nu \ln(a)) \cdot \sigma_s + \gamma rain_{hiro_yes} + \delta rain_{naga_yes} + \epsilon rain_{hiro_unk} + \zeta rain_{naga_unk}]$$

where $\lambda_0(\cdot)$ is baseline risks using stratification by city (c), sex (s), birth year (b), and attained age (a). The direct radiation effects (d) can be modified by age at exposure (e), sex and attained age, while rain effect is not assumed to vary with other factors.

Thus the difference between this model and the main model in the paper, is that this one allows effect modification for the direct exposure but not for the rain exposure, which is a less plausible assumption. We report the results of this model with no effect modification for rain for comparability to a previous unpublished, but publicized, report.

Tables for Web

Table S1. Parameter estimates for direct radiation, fallout rain exposure and modifying effects with 95% confidence intervals for all causes of death.

	Models		
	Direct exposure only model	Rain information included (No effect modification for rain term)	Common effect modification
1962-2005			
β_1 : Direct radiation (linear)	0.23 (0.18, 0.28)	0.23 (0.18, 0.28)	0.23 (0.18, 0.28)
γ : Hiroshima Rain (Yes vs No)	--	-0.02 (-0.05, 0.01)	-0.03 (-0.06, -0.01)
δ : Nagasaki Rain (Yes vs No)	--	0.12 (-0.01, 0.23)	0.08 (-0.008, 0.18)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.36 (0.20, 0.52)	0.36 (0.20, 0.52)	0.38 (0.22, 0.53)
ν : Attained age	0.57 (-0.21, 1.47)	0.56 (-0.21, 1.46)	0.42 (-0.32, 1.28)
τ : Age at exposure	-0.48 (-0.67, -0.32)	-0.48 (-0.66, -0.31)	-0.48 (-0.66, -0.31)
ϵ : Hiroshima Rain (Unknown vs No)	--	0.01 (-0.02, 0.03)	0.004 (-0.02, 0.03)
ζ : Nagasaki Rain (Unknown vs No)	--	0.02 (-0.04, 0.08)	0.02 (-0.04, 0.08)
Deviance	34,273	34,267	34,263
Parameters	179	183	183
AIC	34,631	34,633	34,629
LRT ^a	--	0.18	0.05
1950-2005			
β_1 : Direct radiation (linear)	0.23 (0.18, 0.27)	0.21 (0.16, 0.26)	0.21 (0.16, 0.25)
γ : Hiroshima Rain (Yes vs No)	--	-0.01 (-0.04, 0.02)	0.01 (-0.02, 0.04)
δ : Nagasaki Rain (Yes vs No)	--	0.06 (-0.05, 0.17)	0.08 (0.00006, 0.17)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.35 (0.20, 0.50)	0.38 (0.22, 0.54)	0.37 (0.20, 0.53)
ν : Attained age	0.20 (-0.33, 0.88)	0.53 (-0.12, 1.43)	0.72 (-0.07, 1.87)
τ : Age at exposure	-0.45 (-0.61, -0.31)	-0.55 (-0.73, -0.40)	-0.58 (-0.76, -0.42)
ϵ : Hiroshima Rain (Unknown vs No)	--	0.25 (0.22, 0.28)	0.26 (0.23, 0.29)
ζ : Nagasaki Rain (Unknown vs No)	--	0.42 (0.36, 0.49)	0.43 (0.36, 0.49)
Deviance	49,643	49,053	49,051
Parameters	179	183	183
AIC	50,001	49,419	49,417
LRT	--	$p < 0.001$	$p < 0.001$
1950-1961^b			
β_1 : Direct radiation (linear)	0.02 (-0.01*, 0.07)	0.004 (-0.008*, 0.03)	0.003 (-0.01*, 0.03)
γ : Hiroshima Rain (Yes vs No)	--	0.04 (-0.04, 0.12)	0.000 (-0.001*, 0.04)
δ : Nagasaki Rain (Yes vs No)	--	-0.23 (-0.44, 0.02)	0.0002 (-0.003*, 0.01)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.04 (-0.50, 0.52)	-0.06 (-0.68, 0.53)	-0.02 (-0.64, 0.56)
ν : Attained age	-2.73 (-4.24, -1.67)	-3.59 (-5.95, -2.34)	-3.72 (-6.49, -2.40)
τ : Age at exposure	--	--	--
ϵ : Hiroshima Rain (Unknown vs No)	--	1.84 (1.69, 1.99)	1.81 (1.68, 1.95)
ζ : Nagasaki Rain (Unknown vs No)	--	2.12 (1.89, 2.37)	2.14 (1.91, 2.39)
Deviance	15,235	12,836	12,840
Parameters	80	84	84
AIC	15,395	13,004	13,008
LRT	--	$p < 0.001$	$p < 0.001$

^a: Likelihood ratio test relative to the direct exposure only model, ^b: Model included effect modification by sex, attained age and age at exposure failed to converge. Effect modification by age at exposure was removed from the model. *: Likelihood-based estimation algorithm failed to identify an interval. A Wald-type confidence interval was calculated.

Table S2. Parameter estimates for direct radiation, fallout rain exposure and modifying effects with 95% confidence intervals for solid cancer death.

	Models		
	Direct exposure only model	Rain information included (No effect modification for rain term)	Common effect modification
1962–2005			
β_1 : Direct radiation (linear)	0.42 (0.32, 0.53)	0.43 (0.32, 0.53)	0.42 (0.32, 0.53)
γ : Hiroshima Rain (Yes vs No)	--	-0.003 (-0.07, 0.06)	-0.04 (-0.08, 0.01)
δ : Nagasaki Rain (Yes vs No)	--	0.25 (0.01, 0.53)	0.15 (-0.003, 0.36)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.35 (0.18, 0.52)	0.35 (0.18, 0.52)	0.36 (0.19, 0.52)
ν : Attained age	-0.73 (-1.57, 0.16)	-0.74 (-1.58, 0.15)	-0.77 (-1.64*, 0.11)
τ : Age at exposure	-0.35 (-0.54, -0.18)	-0.34 (-0.54, -0.17)	-0.35 (-0.54, -0.19)
ϵ : Hiroshima Rain (Unknown vs No)	--	0.000 (-0.06, 0.06)	-0.01 (-0.07, 0.05)
ζ : Nagasaki Rain (Unknown vs No)	--	-0.03 (-0.15, 0.09)	-0.03 (-0.15, 0.09)
Deviance	20,184	20,179	20,178
Parameters	159	163	163
AIC	20,502	20,505	20,504
LRT ^a	--	0.31	0.16
1950–2005			
β_1 : Direct radiation (linear)	0.43 (0.33, 0.53)	0.41 (0.31, 0.52)	0.41 (0.30, 0.52)
γ : Hiroshima Rain (Yes vs No)	--	-0.004 (-0.06, 0.06)	-0.02 (-0.06, 0.04)
δ : Nagasaki Rain (Yes vs No)	--	0.18 (-0.04, 0.43)	0.14 (-0.01, 0.33)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.36 (0.20, 0.53)	0.38 (0.20, 0.54)	0.37 (0.21, 0.54)
ν : Attained age	-0.38 (-1.09, 0.40)	-0.36 (-1.10, 0.44)	-0.37 (-1.20*, 0.47)
τ : Age at exposure	-0.37 (-0.55, -0.23)	-0.41 (-0.59, -0.25)	-0.42 (-0.60, -0.26)
ϵ : Hiroshima Rain (Unknown vs No)	--	0.19 (0.13, 0.26)	0.19 (0.13, 0.25)
ζ : Nagasaki Rain (Unknown vs No)	--	0.15 (0.03, 0.27)	0.15 (0.03, 0.27)
Deviance	25,069	25,014	25,013
Parameters	179	183	183
AIC	25,427	25,380	25,379
LRT	--	$p < 0.001$	$p < 0.001$
1950–1961^b			
β_1 : Direct radiation (linear)	0.46 (0.15, 0.84)	0.56 (0.14, 1.08)	0.46 (0.01*, 1.02)
γ : Hiroshima Rain (Yes vs No)	--	-0.05 (-0.22, 0.15)	0.14 (-0.02, 0.36)
δ : Nagasaki Rain (Yes vs No)	--	-0.59 (-0.91, 0.09)	-- ^c
Effect modification			
σ : Sex (Female=1; Male=-1)	1.11 (0.52, 1.74*)	0.99 (0.35, 1.70*)	1.17 (0.44*, 1.89*)
ν : Attained age	3.92 (-0.23, 10.03)	6.05 (0.93, 14.08)	6.29 (2.24, 11.87*)
τ : Age at exposure	--	--	--
ϵ : Hiroshima Rain (Unknown vs No)	--	1.87 (1.52, 2.28)	1.95 (1.61, 2.34)
ζ : Nagasaki Rain (Unknown vs No)	--	1.75 (1.17, 2.46)	1.78 (1.20, 2.50)
Deviance	4,777	4,418	4,419
Parameters	80	84	83
AIC	4,937	4,586	4,585
LRT	--	$p < 0.001$	NA

^a: Likelihood ratio test relative to the direct exposure only model, ^b: Model included effect modification by sex, attained age and age at exposure failed to converge. Effect modification by age at exposure was removed from the model. ^c: Parameter of Nagasaki "Yes" was fixed to 0 in the common effect modification model. *: Likelihood-based estimation algorithm failed to identify an interval. A Wald-type confidence interval was calculated.

Table S3. Parameter estimates for direct radiation, fallout rain exposure and modifying effects with 95% confidence intervals for leukemia death.

	Models		
	Direct exposure only model	Rain information included (No effect modification for rain term)	Common effect modification
1962–2005			
β_1 : Direct radiation (linear)	0.70 (-0.77, 2.54)	0.69 (-0.83, 2.55)	0.70 (-0.79, 2.54)
β_2 : Direct radiation (quadratic)	1.31 (0.23, 2.56)	1.29 (0.21, 2.60)	1.27 (0.19*, 2.57)
γ : Hiroshima Rain (Yes vs No)	--	0.06 (-0.35, 0.62)	0.05 (-0.36*, 0.56)
δ : Nagasaki Rain (Yes vs No)	--	-0.09 (-1.64*, 2.48)	-0.18 (-1.39*, 1.02*)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.25 (-0.14, 0.59)	0.26 (-0.14, 0.60)	0.25 (-0.14, 0.60)
ν : Attained age	-0.73 (-2.45, 1.04)	-0.74 (-2.47, 1.05)	-0.77 (-2.42*, 0.88*)
τ : Age at exposure	0.01 (-0.38, 0.40)	0.002 (-0.39, 0.40)	0.002 (-0.39, 0.36*)
ϵ : Hiroshima Rain (Unknown vs No)	--	-0.13 (-0.44, 0.30)	-0.13 (-0.44, 0.30)
ζ : Nagasaki Rain (Unknown vs No)	--	0.36 (-0.40, 1.64)	0.35 (-0.40, 1.63)
Deviance	2,209	2,207	2,207
Parameters	160	164	164
AIC	2,529	2,535	2,535
LRT ^a	--	0.86	0.86
1950–2005			
β_1 : Direct radiation (linear)	0.76 (-0.10, 1.96)	0.80 (-0.07, 2.00)	0.80 (-0.16*, 1.75*)
β_2 : Direct radiation (quadratic)	1.16 (0.49, 2.00)	1.13 (0.46, 2.00)	1.13 (0.42*, 1.96)
γ : Hiroshima Rain (Yes vs No)	--	0.07 (-0.30, 0.58)	0.06 (-0.15*, 0.32)
δ : Nagasaki Rain (Yes vs No)	--	-0.16 (-1.58*, 2.21)	-0.03 (-0.07*, 0.02*)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.01 (-0.31, 0.32)	0.01 (-0.31, 0.33)	0.02 (-0.31*, 0.35*)
ν : Attained age	-1.97 (-2.78, -1.22)	-1.98 (-2.81, -1.23)	-2.00 (-2.78*, -1.21*)
τ : Age at exposure	0.17 (-0.09, 0.44)	0.17 (-0.09, 0.44)	0.17 (-0.08*, 0.42*)
ϵ : Hiroshima Rain (Unknown vs No)	--	-0.14 (-0.42, 0.26)	-0.13 (-0.41, 0.24)
ζ : Nagasaki Rain (Unknown vs No)	--	0.73 (-0.11, 2.05)	0.74 (-0.10, 2.05)
Deviance	2,980	2,977	2,976
Parameters	180	184	184
AIC	3,340	3,345	3,344
LRT	--	0.44	0.38
1950–1961^b			
β_1 : Direct radiation (linear)	1.16 (-0.72*, 4.57)	1.53 (-0.16, 6.17)	1.57 (-0.79*, 3.92*)
β_2 : Direct radiation (quadratic)	1.50 (0.31, 4.08)	1.72 (0.32, 5.11)	1.63 (-0.27*, 3.53*)
γ : Hiroshima Rain (Yes vs No)	--	0.46 (-0.46, 2.49)	0.12 (-0.25*, 0.50*)
δ : Nagasaki Rain (Yes vs No)	--	-- ^c	-0.02 (-0.27*, 0.24*)
Effect modification			
σ : Sex (Female=1; Male=-1)	-0.51 (-0.87, 0.07)	-0.54 (-0.88, 0.04)	-0.51 (-1.02*, 0.004*)
ν : Attained age	-1.79 (-2.86, -0.84)	-1.81 (-2.88, -0.85)	-1.87 (-2.90*, -0.84*)
τ : Age at exposure	--	--	--
ϵ : Hiroshima Rain (Unknown vs No)	--	-0.06 (-0.70, 1.37)	-0.11 (-0.98*, 1.20)
ζ : Nagasaki Rain (Unknown vs No)	--	4.54 (0.46, 16.53)	4.63 (0.53, 16.12)
Deviance	722	716	716
Parameters	81	84	85
AIC	884	884	886
LRT	--	NA	0.16

^a: Likelihood ratio test relative to the direct exposure only model, ^b: Model included effect modification by sex, attained age and age at exposure failed to converge. Effect modification by age at exposure was removed from the model. ^c: Parameter of Nagasaki "Yes" was fixed to 0 in the common effect modification model. *: Likelihood-based estimation algorithm failed to identify

an interval. A Wald-type confidence interval was calculated.

Table S4. Parameter estimates for direct radiation, fallout rain exposure and modifying effects with 95% confidence intervals for solid cancer incidence.

	Models		
	Direct exposure only model	Rain information included (No effect modification for rain term)	Common effect modification
1962-2005			
β_1 : Direct radiation (linear)	0.50 (0.41, 0.59)	0.51 (0.42, 0.60)	0.49 (0.41, 0.58)
γ : Hiroshima Rain (Yes vs No)	--	-0.03 (-0.08, 0.02)	-0.06 (-0.10, -0.03)
δ : Nagasaki Rain (Yes vs No)	--	-0.17 (-0.33, 0.01)	-0.09 (-0.19*, 0.03)
Effect modification			
σ : Sex (Female=1; Male=-1)	0.34 (0.22, 0.46)	0.34 (0.22, 0.46)	0.34 (0.22, 0.46)
ν : Attained age	-0.82 (-1.40, -0.22)	-0.80 (-1.37, -0.21)	-0.96 (-1.52*, -0.38)
τ : Age at exposure	-0.26 (-0.39, -0.14)	-0.26 (-0.38, -0.14)	-0.26 (-0.38, -0.14)
ϵ : Hiroshima Rain (Unknown vs No)	--	-0.01 (-0.06, 0.04)	-0.02 (-0.07, 0.03)
ζ : Nagasaki Rain (Unknown vs No)	--	-0.19 (-0.28, -0.10)	-0.19 (-0.27, -0.10*)
Deviance	25,592	25,573	25,564
Parameters	144	148	148
AIC	25,880	25,869	25,860
LRT ^a	--	<i>p</i> <0.001	<i>p</i> <0.001
1958-2005			
β_1 : Direct radiation (linear)	0.49 (0.40, 0.57)	0.49 (0.41, 0.58)	0.47 (0.39*, 0.56)
γ : Hiroshima Rain (Yes vs No)	--	-0.03 (-0.08, 0.02)	0.06 (-0.09*, -0.03*)
δ : Nagasaki Rain (Yes vs No)	--	-0.21 (-0.36, -0.04)	-- ^c
Effect modification			
σ : Sex (Female=1; Male=-1)	0.33 (0.21, 0.45)	0.33 (0.21, 0.45)	0.33 (0.21*, 0.45*)
ν : Attained age	-0.94 (-1.45, -0.40)	-0.91 (-1.42, -0.38)	-1.06 (-1.56*, -0.56*)
τ : Age at exposure	-0.28 (-0.40, -0.16)	-0.27 (-0.39, -0.16)	-0.28 (-0.40, -0.17*)
ϵ : Hiroshima Rain (Unknown vs No)	--	-0.006 (-0.05, 0.04)	-0.02 (-0.06*, 0.03*)
ζ : Nagasaki Rain (Unknown vs No)	--	-0.19 (-0.27, -0.10)	-0.18 (-0.27*, -0.10*)
Deviance	28,420	28,398	28,394
Parameters	144	148	147
AIC	28,708	28,694	28,688
LRT	--	<i>p</i> <0.001	NA
1958-1961^b			
β_1 : Direct radiation (linear)	0.09 (0.008, 0.32)	0.09 (-0.06*, 0.23*)	0.10 (-0.06*, 0.25*)
γ : Hiroshima Rain (Yes vs No)	--	0.04 (-0.17*, 0.25*)	0.006 (-0.03*, 0.04*)
δ : Nagasaki Rain (Yes vs No)	--	-1.00 (-1.02*, -0.98*)	-0.002 (-0.01*, 0.01*)
Effect modification			
σ : Sex (Female=1; Male=-1)	-0.01 (-0.70, 0.65)	-0.02 (-0.82*, 0.77*)	-0.01 (-0.79*, 0.77*)
ν : Attained age	-3.94 (-6.44, -2.25)	-4.01 (-6.00*, -2.03*)	-3.89 (-5.82*, -1.97*)
τ : Age at exposure	--	--	--
ϵ : Hiroshima Rain (Unknown vs No)	--	0.05 (-0.15*, 0.25*)	0.05 (-0.15*, 0.24*)
ζ : Nagasaki Rain (Unknown vs No)	--	-0.23 (-0.65*, 0.18*)	-0.21 (-0.64*, 0.21*)
Deviance	2,715	2,704	2,714
Parameters	60	64	64
AIC	2,835	2,832	2,842
LRT	--	0.02	0.88

^a: Likelihood ratio test relative to the direct exposure only model, ^{*}: Likelihood-based estimation algorithm failed to identify an interval. A Wald-type confidence interval was calculated.

Table S5. Parameter estimates for direct radiation, fallout rain exposure and modifying effects with 95% confidence intervals for leukemia incidence in Hiroshima.

	Models		
	Direct exposure only model	Rain information included (No effect modification for rain term)	Common effect modification
1962-2005			
β_1 : Direct radiation (linear)	1.12 (-0.53, 3.14)	1.12 (-0.70, 2.89*)	0.98 (-0.73, 3.08)
β_2 : Direct radiation (quadratic)	0.82 (-0.29, 2.21)	0.86 (-0.31*, 2.40)	0.91 (-0.24, 2.38)
γ : Hiroshima Rain (Yes vs No)	--	0.26 (-0.21, 0.93)	0.31 (-0.16, 0.99)
δ : Nagasaki Rain (Yes vs No)	--	-0.79 (-1.71*, 2.03)	-- ^c
Effect modification			
σ : Sex (Female=1; Male=-1)	0.11 (-0.36, 0.54)	0.11 (-0.37, 0.57)	0.13 (-0.35, 0.56)
ν : Attained age	-0.49 (-2.73, 1.94)	-0.45 (-2.79, 2.02)	-0.25 (-2.57, 2.33)
τ : Age at exposure	-0.03 (-0.54, 0.46)	-0.02 (-0.53, 0.50)	-0.11 (-0.62, 0.40)
ϵ : Hiroshima Rain (Unknown vs No)	--	-0.03 (-0.39, 0.47)	-0.02 (-0.37, 0.49)
ζ : Nagasaki Rain (Unknown vs No)	--	0.48 (-0.44, 2.15)	0.52 (-0.42, 2.21)
Deviance	1,987	1,985	1,985
Parameters	145	149	148
AIC	2,277	2,283	2,281
LRT ^a	--	$p < 0.001$	NA
1958-2005			
β_1 : Direct radiation (linear)	1.35 (0.20, 3.02)	1.41 (0.21, 2.79*)	1.30 (-0.01*, 2.61*)
β_2 : Direct radiation (quadratic)	0.51 (-0.29, 1.49)	0.48 (-0.32*, 1.49)	0.49 (-0.28*, 1.25*)
γ : Hiroshima Rain (Yes vs No)	--	0.11 (-0.30, 0.70)	-0.03 (-0.27*, 0.21*)
δ : Nagasaki Rain (Yes vs No)	--	-0.90 (1.53*, 1.63)	-- ^c
Effect modification			
σ : Sex (Female=1; Male=-1)	0.03 (-0.38, 0.43)	0.02 (-0.40, 0.44)	0.05 (-0.37, 0.45)
ν : Attained age	-2.05 (-3.73, -0.59)	-2.02 (-3.79, -0.58*)	-2.16 (-3.63*, -0.70*)
τ : Age at exposure	0.19 (-0.21, 0.62)	0.18 (-0.18*, 0.54*)	0.22 (-0.22, 0.58*)
ϵ : Hiroshima Rain (Unknown vs No)	--	-0.10 (-0.42, 0.36)	-0.13 (-0.50*, 0.23*)
ζ : Nagasaki Rain (Unknown vs No)	--	0.35 (-0.49, 1.85)	0.40 (-0.72*, 1.53*)
Deviance	2,316	2,314	2,315
Parameters	145	149	148
AIC	2,606	2,612	2,611
LRT	--	0.72	NA
1958-1961^b			
β_1 : Direct radiation (linear)	2.64 (0.12, 16.65)	Not converged	Not converged
β_2 : Direct radiation (quadratic)	0.12 (-1.64*, 3.54)		
γ : Hiroshima Rain (Yes vs No)	--		
δ : Nagasaki Rain (Yes vs No)	--		
Effect modification			
σ : Sex (Female=1; Male=-1)	-0.51 (-0.98, 0.49)		
ν : Attained age	-2.09 (-5.23, -0.02)		
τ : Age at exposure	--		
ϵ : Hiroshima Rain (Unknown vs No)	--		
ζ : Nagasaki Rain (Unknown vs No)	--		
Deviance	286		
Parameters	61		
AIC	408		
LRT	--		

^a: Likelihood ratio test relative to the direct exposure only model, ^{*}: Likelihood-based estimation algorithm failed to identify an interval. A Wald-type confidence interval was calculated.