

Table 2.12. Cohort studies of exposure to Plutonium (Pu)

Reference, location, name of study	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/deaths	Relative risk (95% CI)*	Adjustment for potential confounders	Comments
Omar et al. (1999) Sellafield plant, UK	14319 workers, employed in 1947-1975. Follow-up through 1992 (mortality) or in 1971-1986 for cancer incidence. 3854 deaths	External doses: film badge dosimetry; Pu doses estimated by urinalysis and biokinetic model	Breast (ICD8: 174), mortality	Plutonium workers Other radiation workers	6 2	Pu workers / Other radiation workers rate ratio 7.66	Age, sex and calendar period	Also SMRs for cause-specific deaths were calculated using mortality rates in the population of England and Wales
			Liver and gall-bladder (ICD8: 155,156)	Plutonium workers Other radiation workers	1 1	Pu workers / Other radiation workers rate ratio 0.85		
			Lung (ICD8: 162)	Plutonium workers Other radiation workers	133 113	Pu workers / Other radiation workers rate ratio 1.12		
Gilbert et al. (2000) Ozyorsk, Russia, Mayak workers	Cohort of 11000 workers of Mayak PA initially employed in 1948-1958 at reactor, radiochemical, plutonium production plants, 60 liver cancer deaths	External (gamma and neutron) exposure doses individually measured by film badges, Pu exposure doses individually measured by urinalysis	Liver (ICD9 : 155)	Pu body burden, kBq	Males		Stratified by age, calendar year and sex, adjusted for external dose	10 of 60 liver cancer cases were angiosarcomas
				0-1.48	14	1.0		
				1.48-7.40	2	0.9 (0.1-3.2)		
				7.40+	7	9.2 (3.3-23)		
				Unknown:				
				Radiochemical workers	9	1.1 (0.5-2.6)		
				Plutonium workers	9	2.0 (0.8-4.8)		
				Females				
				0-1.48	2	1.0		
				1.48-7.40	2	7.1 (0.9-59)		
7.40+	9	66 (16-453)						
Unknown:								
Radiochemical workers	1	0.6 (0.03-6.1)						
Plutonium workers	5	13 (2.4-94)						

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Koshurnikova et al. (2000) Ozyorsk, Russia, Mayak workers	Cohort of 11000 workers of Mayak PA initially employed in 1948-1958 at reactor, radiochemical, plutonium production plants, 27 bone cancer cases	External (gamma and neutron) exposure doses individually measured by film badges, Pu exposure doses individually measured by urinalysis	Bone (ICD9 : 170,171)	Pu body burden, kBq	6	1.0	Stratified by age, calendar year and sex, adjusted for external dose	
				0-1.48	1	0.9 (0.05-5.5)		
				1.48-7.40	3	7.9 (1.6-32)		
				7.40+				
				Unknown:				
				Radiochemical workers	6	1.4 (0.4-4.7)		
				Plutonium workers	7	4.1 (1.2-14)		
Kreisheimer et al. (2000) Ozyorsk, Russia, Mayak workers	Cohort of 3841 male workers of Mayak PA hired in 1948-1958 at reactor, radiochemical or Pu production plants. Workers from the latter two plants included only if they had urinalysis data on Pu body burden and Pu lung dose, follow-up through 1995. 191 lung cancer deaths	External (gamma and neutron) exposure dose individually measured by film badges, Pu exposure doses individually measured by urinalysis	Lung	Pu lung dose	191 deaths; 74 among reactor workers with 0 Pu dose	12.1 ERR/Gy (SE 2.9)		
McGeoghegan et al. (2003) Sellafield plant, UK	6376 female workers of Sellafield, study period, 1946-1998	External doses: film badge dosimetry; Pu doses estimated by urinalysis and biokinetic model	All cancers, mortality	Plutonium workers Other radiation workers	15 19	Rate ratio Pu workers/Other radiation workers = 3.30	Rate ratios adjusted for age, sex, calendar year, industrial status and worker status	Also SMRs for cause-specific deaths were calculated using mortality rates in the female population of England and Wales
			Breast cancer mortality	Plutonium workers Other radiation workers	7 5	Rate ratio Pu workers/Other radiation workers = 3.77		
			Breast cancer incidence	Plutonium workers Other radiation workers	10 12	Rate ratio Pu workers/Other radiation workers = 3.34		

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Kreisheimer et al. (2003) Ozyorsk, Russia, Mayak workers	Cohort of 4212 male workers hired at Mayak in 1948-1958 at reactor, radiochemical or plutonium production plant. Workers of the latter two plants were included in analysis if they had Pu dose estimates. 1921 deaths. Follow-up through 1999.	External (gamma and neutron) exposure doses measured by film badges, Pu body burden and lung dose calculated using urinalysis data and Pu biokinetic model.	Lung	Pu dose, ERR/Gy	219 cases, 92 among reactor workers with 0 Pu lung dose	For α -particles the estimated excess relative risk for lung cancer was 4.50/Gy (95%CI: 3.15, 6.10)	Smoking, age attained, external dose	
Shilnikova et al. (2003) Ozyorsk, Russia, Mayak workers	Cohort of 21500 workers hired in 1948-1972 at auxiliary, reactor, radiochemical or Pu production plant. Follow-up through 1997. 668 deaths from lung, liver and bone cancer, 1062 deaths from other solid cancer, 77 leukemia deaths.	External (gamma and neutron) exposure dose individually measured by film badges, Pu exposure levels individually measured by urinalysis and characterized in terms of body burden	Solid cancer other than lung, liver, bone Lung, liver and skeletal cancers Leukaemia	Significant effect of Pu body burden Significant effect of Pu body burden	1062 deaths 668 deaths 77 deaths	P<0.001 P<0.001 The point estimate of the plutonium body burden dose response for monitored workers was negative but not statistically significant (P > 0.5)	Background modelled parametrically, effect estimated separately for external dose and internal dose as sum of contribution of Pu body burden and Pu surrogate index	Surrogate index of exposure to Pu depending on occupational history used to adjust for potential exposure to Pu among workers unmonitored for Pu

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Gilbert et al. (2004) Ozyorsk, Russia, Mayak workers	Cohort of 21790 workers of Mayak PA initially employed in 1948 – 1972 at reactor, radiochemical, plutonium production or auxiliary plants with mortality follow-up through 2000, vital status 90%, 8493 deaths, 97% known cause of death	Doses-2000 External exposure doses measured individually for 80% of workers, no or little potential for External (gamma and neutron) exposure for the rest. Pu exposure doses individually measured for 40% of radiochemical and Pu plant workers Radiation doses lagged for 5 years	Lung	Pu alpha particles dose to lung, Gy	Males		Age, gender, smoking, age at exposure	For internal dose, the excess relative risk (95% CI) per Gy at age 60 was 19 (9.5, 39) for females and 4.7 (3.3, 6.7) for males, while the excess absolute risk for females was less than half that for males.	
					0	176			1
					>0–0.2	91			1.4 (1.0–1.8)
					0.2–1.0	33			2.4 (1.5–3.6)
					1.0–3.0	26			10.1 (6.3–15)
					3.0–5.0	10			19 (9.5–35)
					5.0+	7			33 (14–67)
					Females				
					0	7			1
					>0–0.2	3			0.91 (<0.91, 3.1)
0.2–1.0	8	16 (6.1, 37)							
1.0–5.0	3	15 (3.0, 38)							
5.0+	10	250 (110, 660)							
Wing et al. (2004) Hanford, USA, Hanford plant workers	26389 workers hired between 1944 and 1978 with at least 180 days of employment. Follow-up through 1994. 8153 deaths, 98.9% of them with cause of death known, 0.7% of males and 4.4% lost to follow-up	Potential to Pu exposure defined as job-exposure matrix	Lung (ICD9: 162)	Years in routine Pu job:	0	607	-	Age, gender, race, birth cohort, SES, employment status, absence or presence of Pu monitoring data	Pu-related cancers included cancer of the lung (ICD9: 162), liver (ICD9: 155–156), bone and connective tissue (ICD9: 170, 171), and lymphatic tissue cancers (ICD9: 200–202).
					< 5	29	-26.7±19.9		
					5 – 10	10	-18.5±33.0		
					>10	20	20.4±26.2		
					Pu related cancers				
			0	783	-				
			< 5	34	-37.7±18.3				
			5 – 10	13	-14.0±29.9				
			>10	22	6.9±24.6				

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Jacob et al. (2005) Ozyorsk, Russia, Mayak workers	Cohort of 5058 male workers of Mayak PA hired in 1948-1972 at auxiliary, reactor, radiochemical or Pu production plant with known smoking status and, unless reactor worker, with Pu monitoring data. Follow-up through 1998. 2176 deaths.	External (gamma and neutron) exposure dose individually measured by film badges, Pu exposure doses individually measured by urinalysis	Lung	Pu dose, ERR/Sv: Ext. dose, ERR/Sv Smoking, ERR	244 deaths	0.11 (0.08–0.17) 0.03 (-0.04–0.13) 9.2 (4.3–21.4)	TSCE model with sub-multiplicative interaction between radiation and smoking	
Jacob et al. (2007), Ozyorsk, Russia, Mayak workers	Cohort of 6293 male workers of Mayak PA hired in 1948-1972 at auxiliary, reactor, radiochemical or Pu production plant with known smoking status and, unless reactor worker, with Pu monitoring data. Follow-up through 2002. 3039 deaths.	External (gamma and neutron) exposure dose individually measured by film badges, Pu exposure doses individually measured by urinalysis and calculated in terms of modified ICRP66 model and ICRP 67 model.	Lung	Pu dose, ERR/Sv: Ext. dose, ERR/Sv Smoking, ERR	301 deaths	0.20 (0.13–0.40) 0.25 (0.08–0.85) 13 (6–27)	TSCE model with sub-multiplicative interaction between radiation and smoking	No indication of bystander effect, either detriment or protective

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Sokolnikov et al. (2008) Ozyorsk, Russia, Mayak workers	Cohort of 17740 workers hired in 1948-1972 hired in 1948-1972 at auxiliary, reactor, radiochemical or Pu production plant and followed up for at least 5 years. Follow-up through 2003. 681 deaths from lung, 75 – from liver and 30 – from bone cancer	External (gamma and neutron) exposure dose individually measured by film badges, Pu exposure doses individually measured by urinalysis	Lung	Pu organ dose, Gy				Background modelled parametrically. Adjusted for external dose, gender, age at exposure, smoking. Surrogate index of exposure to plutonium used to estimate risk for the part of cohort experience when unmonitored for plutonium	With regard to lung cancer, the estimated ERR per Gy (95% CI) for Pu dose at attained age 60 was 7.1 (4.9–10.1) for males and 15 (7.6–29) for females
				0	139	1			
				>0–0.1	111	0.98 (<1–1.3)			
				0.1–0.2	16	1.4 (<1–2.4)			
				0.2–0.3	14	3.3 (1.7–5.8)			
				0.3–0.5	14	4.5 (2.4–7.7)			
				0.5–1.0	15	6.4 (3.5–11)			
				1.0–2.0	16	15 (8.1–25)			
				2.0–3.0	8	18 (8.3–35)			
				3.0–5.0	7	17 (7.1–35)			
				5.0–10.0	6	27 (10–58)			
				10.0+	8	186 (69–466)			
			Liver	0	14	1			
				>0–0.2	9	1.03 (<1–1.8)			
				0.2–1.0	2	1.5 (<1–3.2)			
				>1.0–3.0	3	4.0 (1.2–13)			
				3.0–5.0	3	16 (3.3–58)			
				5.0–10.0	7	43 (12–134)			
			Bone	10.0+	2	36 (4.5–196)			
				0	5	1			
				>0–1.0	3	0.9 (<1–4.3)			
>1–5.0	0	0 (0.0–8.7)							
>5–10.0	0	0 (0.0–61)							
10+	3	82 (17–338)							

ERR, excess relative risk; Ext., external; Mayak PA, Mayak Production Association