

Contents

Public Summary	1
Executive Summary	4
Introduction, 4	
The Mechanistic Basis of Radon-Induced Lung Cancer, 5	
The BEIR VI Risk Models, 7	
Risk Assessment, 8	
Lung Dosimetry of Radon Progeny, 9	
Extrapolation of Risks at Higher Exposures to Lower Exposures, 9	
Exposure Rate, 9	
Combined Effect of Smoking and Radon, 10	
Risks for Women, 10	
Risks Associated with Exposures in Childhood, 10	
Characterization of Radon Risks, 10	
Radon-Attributable Risks, 11	
Uncertainty Considerations, 16	
Effects of Radon Exposure Other Than Lung Cancer, 18	
Conclusions, 18	
1 Introduction	20
Radon and Lung Cancer: an Overview, 20	
Prior Reports on the Risk Associated With Radon, 24	
Population Exposure to Radon, 27	
The Committee's Approach, 28	
Critical Issues, 31	
Extrapolation from Higher to Lower Exposures, 31	

	Extrapolation from Higher to Lower Exposure Rates, 32	
	Interactions of Radon Progeny with Other Agents, 32	
	Susceptibility, 33	
	Links Between Biologic Evidence and Risk Models, 33	
	Signatures of Radon Effects, 33	
	Overview of Committee Risk Assessment, 34	
2	The Mechanistic Basis of Radon-Induced Lung Cancer	36
	Introduction, 36	
	Radiation and Oncogenes, 38	
	Tumor-Suppressor Genes, 39	
	Genomic Instability, 40	
	Individual and Genetic Susceptibility, 41	
	Cell-Cycle Effects, 44	
	Apoptosis, 45	
	Radiation-Induced Perturbations of Cellular Proliferation, 45	
	Cells at Risk, 46	
	Target Size, 48	
	The Special Nature of Biologic Damage Induced by Alpha Particles, 49	
	Biologic Effects of Low Exposure Levels to Alpha Particles, 56	
	Biologic Effects of Alpha Particles at Low Exposure Rates, 58	
	Interactions Between Lung Carcinogens, 62	
	The Dosimetric Approach to Radon Risk Estimation, 63	
	Mechanistic Considerations in Assessing Risks Associated with Radon, 64	
	Biologically-Based Risk Models, 64	
	Extrapolation From High to Low Radon-Progeny Exposures, 65	
	Effect of Changing Exposure Rate, 67	
	Interaction of Radon Progeny with Other Agents, 67	
	Biologic Signatures of Alpha-Particle Cancers, 68	
	Individual Susceptibility, 68	
3	Models and Risk Projections	69
	Introduction, 69	
	Risk-Estimation Approaches, 70	
	Dosimetric Approach, 70	
	Biologically Motivated Approach, 70	
	Empirical Approach, 71	
	Rationale for the Committee's Chosen Method for Radon Risk Estimation, 72	
	Previous Models, 74	
	BEIR VI Risk Model for Lung Cancer in Miners, 76	
	Introduction, 76	
	Sources of Data, 76	

Analysis of Pooled Data from Different Studies, 78	
Model Based on Full Data Set, 80	
Model Based on Exposure-Restricted Data, 81	
Coherence of Evidence from Miners and from the General Population, 84	
BEIR VI Risk Assessment for Lung Cancer in the General Population, 85	
Introduction, 85	
Measures of Risk, 91	
Relative-Risk Estimates, 92	
Population-Risk Estimates, 93	
Sources of Uncertainty, 100	
Uncertainties in Parameter Estimates Derived from Underground-Miner Data, 101	
Uncertainties in Specification of the Lung-Cancer Exposure-Response Model and Its Application to Residential Exposure of the General U.S. Population, 103	
Uncertainty Analysis, 104	
Comparisons with BEIR IV, 110	
BEIR IV and BEIR VI Risk Models, 110	
Summary and Conclusions, 113	
4 Health Effects of Radon Progeny on	
Non-Lung-Cancer Outcomes	117
Doses to Organs Other Than Lung, 118	
Nonmalignant Respiratory Diseases, 119	
Malignancies Other Than Lung Cancer, 120	
Studies of Underground Miners, 121	
Studies of the General Population, 124	
Reproductive Outcomes, 127	
Conclusions, 127	
Appendixes	
A Risk Modeling and Uncertainty Analysis	129
B Comparative Dosimetry	176
C Tobacco-Smoking and Its Interaction with Radon	224
D Miner Studies	254
E Exposures of Miners to Radon Progeny	291
Annex 1: Exposures to Miner Cohorts: Review of Estimates for the Studies	306
Annex 2: Workshop on Uncertainty in Estimating Exposures to Radon Progeny in Studies of Underground Miners	331

F	Exposures Other Than Radon in Underground Mines	344
G	Epidemiologic Studies in the Indoor Environment	356
	References	430
	Glossary	472
	Committee Biographies	482
	Index	487