# Contents

Preface ............................................................... iii

1. Executive Summary .............................................. 1

2. Introduction ..................................................... 8
   2.1 Background for Present Study ............................. 8
       2.1.1 Recommendations for Purposes of Radiation
            Protection .................................................. 9
       2.1.2 Assumptions for Purposes of Cancer Risk
            Assessment .................................................. 10
       2.1.3 Previous Reviews by NCRP ............................ 12
   2.2 Importance of Present Evaluation ....................... 13
   2.3 Term to Describe Modifying Factor to Represent
       Biological Effectiveness ................................... 15
   2.4 Specification of Reference Radiation .................. 17
   2.5 Use of Effectiveness Ratio in Cancer Risk Assessments . 19
   2.6 Approach to Evaluation of Biological Effectiveness .... 21

3. Spectral Characteristics of Representative Low
   Linear-Energy Transfer Radiations ......................... 25
   3.1 Production of Energetic Secondary Electrons by Photons 26
   3.2 Representative Spectra of Incident Photons ............ 29
   3.3 Spectra of First-Collision Electrons and Tritium Beta
       Particles ..................................................... 32
   3.4 Spectra of Lower-Energy Electrons Produced by First-
       Collision Electrons ....................................... 36

4. Line of Evidence: Microdosimetry ............................ 39
   4.1 Linear-Energy Distributions Produced by Photons ....... 43
   4.2 Prediction of $R_i$ Based on $f(y)$ ......................... 48
   4.3 Evaluation of the PDF of $R_i$ ............................. 59

5. Line of Evidence: Deoxyribonucleic Acid Damage ........ 64
   5.1 DNA Damage from Ionizing Radiation .................... 64
   5.2 Photon and Electron Damage to DNA .................... 67
   5.3 Experimental Data on Relative Biological Effectiveness
       for DNA Double-Strand Breaks ......................... 68
   5.4 Relative Biological Effectiveness of DNA Double-Strand
       Breaks from Theoretical Simulations ................... 79
5.5 Enhancement of Relative Biological Effectiveness for Slow-Rejoining Double-Strand Breaks
5.6 Enhancement of Relative Biological Effectiveness for Complex Double-Strand Breaks from Simulations
5.7 Role of DNA Base Damage
5.8 Estimation of Probability Density Functions for $R_i$ of Double-Strand Breaks and also with Enhancement for Biological Severity
  5.8.1 PDFs of $R_i$ for 15 to 30 keV Photons
  5.8.2 PDFs of $R_i$ for 1.5 keV Photons
  5.8.3 PDF of $R_i$ for 40 to 60 keV Photons
  5.8.4 PDF of $R_i$ for >60 to 150 keV Photons
  5.8.5 PDF of $R_i$ for Tritium Beta Particles
  5.8.6 Summary of Recommended PDFs
  5.8.7 Relevance of $R_i$ for Initial DSBs in DNA

6. Line of Evidence: Cellular Radiobiology and Animal Studies
  6.1 Introduction
  6.2 Structural Chromosome Aberrations
    6.2.1 Studies Using Conventional Giemsa Staining
    6.2.2 Difficulties with Studies Using Giemsa Staining
    6.2.3 Studies Using FISH and mFISH
  6.3 Micronuclei
  6.4 Cell Survival and Cell Killing
  6.5 Cell Mutation
  6.6 Cellular Transformation
  6.7 Effects in Cells (in vitro and in vivo) from Low-Energy Radionuclide Emissions
  6.8 Other Considerations of Cellular Effects
  6.9 Studies of Cancer and Other Organ Endpoints in Whole Animals
    6.9.1 Studies with External Radiation
    6.9.2 Studies with Radionuclides Incorporated in Animal Tissues
  6.10 Development of Probability Density Functions of $R_i$
    6.10.1 Photons of Energy 1.5 keV (AlK)
    6.10.2 Photons of Energy 15 to 30 keV
    6.10.3 Photons of Energy 40 to 60 keV or >60 to 150 keV
    6.10.4 Tritium Beta Particles
  6.11 Summary

7. Line of Evidence: Human Epidemiology
  7.1 Introduction
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Committee</td>
<td>264</td>
</tr>
<tr>
<td>The NCRP</td>
<td>270</td>
</tr>
<tr>
<td>NCRP Publications</td>
<td>281</td>
</tr>
</tbody>
</table>