

## 8. LEVELS OF SIGNIFICANT EXPOSURE TO RADIATION AND RADIOACTIVE MATERIAL

To help public health professionals and others address the needs of those who are exposed to radiation and radioactive material, the information in this section on ionizing radiation is organized first by route of exposure—inhalation, oral, dermal and external; and then by health effect—death, systemic, immunological, neurological, reproductive, developmental, genotoxic, and carcinogenic effects. The systemic effects are subdivided into respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, dermal, ocular, and body weight effects.

The data for the observed effects from radiation and radioactive material are presented in the following tables. These tables are not meant to be exhaustive reviews of all of the literature that reports biological effects resulting from exposure to ionizing radiation. It does, however, provide health care professionals, persons exposed (or potentially exposed) to radiation in their occupations, and the general public an overview of the types of effects observed in each category. The tables report no-observed-adverse-effect levels (NOAELs) or lowest-observed-adverse-effect levels (LOAELs), which reflect the actual radiation doses (or concentration of radioactive material) used in the studies. LOAELs have been further classified into "less serious" or "serious" effects. "Serious" effects are those that evoke failure in a biological system and can lead to morbidity or mortality (e.g., acute radiation sickness or death). "Less serious" effects are those that are not expected to cause significant dysfunction or death, or those whose significance to the organism is not entirely clear. ATSDR acknowledges that a considerable amount of judgment may be required in establishing whether an end point should be classified as a NOAEL, "less serious" LOAEL, or "serious" LOAEL, and that in some cases, there will be insufficient data to decide whether the effect is indicative of significant dysfunction. However, the Agency has established guidelines and policies that are used to classify these end points. ATSDR believes that there is sufficient merit in this approach to warrant an attempt at distinguishing between "less serious" and "serious" effects. The distinction between "less serious" effects and "serious" effects is considered to be important because it helps the users of the profiles to identify radiation doses at which major health effects may start to appear. LOAELs or NOAELs should also help in determining whether or not the effects vary with dose and/or duration, and place into perspective the possible significance of these effects to human health.

A range of radiological units were used in the studies and these are reported in Tables 8-1 to 8-4. In these studies, some authors reported units of absorbed dose (rad, Gy) or dose equivalent (rem, Sv), while other authors reported effects in terms of units of concentration, transformations (disintegrations) or activity

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( $\mu\text{Ci}/\text{kg}$  or  $\text{Bq}/\text{kg}$ , etc). Conversions between units is possible when given specific information about the exposed animal, organ weights, and the nuclide; however, the specific information required to perform those conversions was, in many cases, not complete or not reported at all. Many of the activities reported in Ci or Bq could not be converted into absorbed dose (rad, Gy) or dose equivalent (rem, Sv) to determine a dose-response relationship. Since these conversions were not practical, the unit information (rad, Gy, rem, Si) with the corresponding NOAEL or LOAEL are listed first under each heading (death, respiratory, gastrointestinal, etc). This information is then immediately followed by the studies that examined end points in terms of concentration or activity ( $\mu\text{Ci}/\text{kg}$  or  $\text{Bq}/\text{kg}$ ) for each organ system route of exposure. This provides the reader an opportunity to more clearly observe any dose-response effects resulting from exposure to ionizing radiation, both from an absorbed dose (rad, Gy) aspect as well as from a radionuclide activity (Ci, Bq) perspective.

The significance of the exposure levels shown in Tables 8-1 to 8-4 may differ depending on the user's perspective. Public health officials and others concerned with appropriate actions to take at hazardous waste sites may want information on levels of exposure associated with more subtle effects in humans or animals (LOAELs) or exposure levels below which no adverse effects (NOAELs) have been observed. Levels of exposure associated with carcinogenic effects (Cancer Effect Levels, CELs) of ionizing radiation are also indicated in Tables 8-1 through 8-4.

Estimates of exposure levels posing minimal risk to humans may be of interest to health professionals and citizens alike. Estimates of the acute radiation dose and chronic radiation dose rate that pose minimal risk to humans (Minimal Risk Levels or MRLs) have been made for ionizing radiation. An MRL is defined as an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse effects (noncarcinogenic) over a specified duration of exposure. MRLs are derived when reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration within a given route of exposure. MRLs are based on noncancerous health effects only and do not consider carcinogenic effects. MRLs can be derived for acute, intermediate, and chronic duration exposures for inhalation and oral routes as well as for external exposure. Appropriate methodology does not exist to develop chemical MRLs for dermal exposure.

Although methods have been established to derive these levels (Barnes and Dourson 1988; EPA 1990), uncertainties are always associated with these techniques. ATSDR acknowledges additional uncertainties inherent in the application of the procedures to derive less than lifetime MRLs. As an example, acute inhalation MRLs may not be protective for health effects that are delayed in development or are acquired

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following repeated acute insults, such as hypersensitivity reactions, asthma, or chronic bronchitis. As these kinds of health effects data become available and methods to assess levels of significant human exposure improve, these MRLs will be revised.

MRLs have been derived for radiation effects. During the evaluation process, ATSDR examined many factors, including (1) which specific studies would lend themselves to be most suitable for deriving an MRL, and (2) what health effect(s) an MRL should be based upon (cataract formation, reduction in IQ, etc.).

The tables showing Levels of Significant Exposure (LSE) to Radiation and Radioactive Material consist of the following information:

- (1) Route of Exposure One of the first considerations when reviewing the toxicity of ionizing radiation using these tables and figures should be the relevant and appropriate route of exposure. When sufficient data exist, four tables are presented in the document by the four principal routes of exposure, i.e., inhalation, oral, dermal, and external (Levels of Significant Exposure to Radiation and Radioactive Material tables 8-1, 8-2, 8-3 and 8-4, respectively). Not all studies will have data on each route of exposure.
- (2) Health Effect The major categories of health effects included in Levels of Significant Exposure to Radiation and Radioactive Material tables are death, systemic, immunological, neurological, developmental, reproductive, and cancer. NOAELs and LOAELs can be reported in the tables and figures for all effects but cancer. Systemic effects are further defined in the "System" column of the table.
- (3) Species The test species, whether animal or human, are identified in this column.
- (4) Duration/ Frequency of Administration The duration of the study and the weekly and daily exposure regimen are provided in this column. This permits comparison of NOAELs and LOAELs from different studies.
- (5) System This column further defines the systemic effects. These systems include: respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, and dermal/ocular. Other systems considered separately in these tables are immunological/lymphoreticular, neurological, reproductive, developmental, genotoxic, and cancer. "Other" refers to any systemic effect (e.g., a decrease in body weight) not covered in these systems.
- (6) NOAEL A No-Observed-Adverse-Effect Level (NOAEL) is the highest exposure level at which no harmful effects were seen in the organ system studied.
- (7) LOAEL A Lowest-Observed-Adverse-Effect Level (LOAEL) is the lowest dose used in the study that caused a harmful health effect. LOAELs have been arbitrarily classified into "Less Serious" and "Serious" effects. These distinctions help readers identify the levels of exposure at which adverse health effects first appear and the gradation of effects with increasing dose. A brief description of the specific endpoint used to quantify the adverse effect accompanies the LOAEL.

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- (8) CEL A Cancer Effect Level (CEL) is the lowest exposure level associated with the onset of carcinogenesis in experimental or epidemiologic studies. CELs are always considered serious effects.
- (9) Chemical Form The nuclide, the chemical form (chloride, oxide, etc.) and the type of emission (alpha or beta particle and gamma ray) is indicated in this column.
- (10) Reference The complete reference citation is given in chapter 10 of the profile.

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation

| Entry Number | Species (strain)      | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |   | Reference<br>Chemical Form                                    |
|--------------|-----------------------|--|--------|-------|--------------|---|---|
|              |                       |  |        |       | Less serious | Serious   |   |
| <b>Death</b> |                       |  |        |       |              |   |   |
| 1            | Rat<br>(Fischer- 344) | 20 min                                   |        |       |              | 71 radM (decr. median survival time in fibrotic vs non-fibrotic rats)                         | Lundgren et al. 1991<br>Alpha Particles [239]PuO <sub>2</sub> |
| 2            | Rat<br>(Fischer- 344) | 20 min                                   |        |       |              | 340 rad F (decr. median survival time in fibrotic vs non-fibrotic rats)                       | Lundgren et al. 1991<br>Alpha Particles [239]PuO <sub>2</sub> |
| 3            | Dog<br>(Beagle)       | 3-46 min                                 |        |       |              | 8,400 rad (21/33 dogs died-7.5 to 163 d post-exposure)  | Hobbs et al. 1972<br>Beta Particles [90]Y                     |
| 4            | Dog<br>(Beagle)       | once                                     |        |       |              | 8700 rad (3/4 died)   | Benjamin et al. 1976<br>Beta Particles [90]Y                  |
| 5            | Dog<br>(Beagle)       | once                                     |        |       |              | 10,000 rad (16/16 dogs died 12 to 163 d post exp)   | McClellan et al. 1970<br>Beta Particles [90]Y                 |
| 6            | Dog<br>(Beagle)       | <70 min                                  |        |       |              | 15,000 rad (40/96 died <3 yrs post exposure)  | Boecker et al. 1988<br>Beta Particles [91]Y                   |
| 7            | Dog<br>(Beagle)       | once                                     |        |       |              | 27,000 rad (14/16 died or were sacrificed due to severe condition within 5 yrs post exposure) | Benjamin et al. 1978<br>Beta-Gamma Particles [144]Ce          |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)         | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |  | Reference<br>Chemical Form   |
|--------------|--------------------------|--|--------|-------|--------------|--|--|
|              |                          |  |        |       | Less serious | Serious  |  |
| 8            | Dog<br>(Beagle)          | once                                     |        |       |              | 39,000 rad (1/4 died)  | Benjamin et al.<br>1976<br>Beta Particles<br>[90]Sr                  |
| 9            | Dog<br>(Beagle)          | once                                     |        |       |              | 42,000 rad (2/4 died)  | Benjamin et al.<br>1976<br>Beta Particles<br>[144]Ce                 |
| 10           | Dog<br>(Beagle)          | once                                     |        |       |              | 48,000 rad (9/9 dogs died 143- 410 d post exposure)              | McClellan et al.<br>1970<br>Beta Particles<br>[144]Ce                |
| 11           | Monkey<br>(Rhesus)       | once                                     |        |       |              | 270 nCiM (5/5 animals died 430-4334 d after exposure)            | Hahn et al.<br>1987<br>Alpha Particles<br>[239]PuO <sub>2</sub>      |
| 12           | Monkey<br>(Cynomol- gus) | once                                     |        |       |              | 1.08 uCiM (3/12 died)  | Brooks et al.<br>1992<br>Alpha Particles<br>[239]Pu                  |
| 13           | Mouse<br>(CFW)           | 10-20 min                                |        |       |              | 21 uCiM (survival 12% of controls, with median survival of 66 d) | Lundgren et al.<br>1981<br>Beta Particles<br>[90]Y                   |
| 14           | Rat<br>(Fischer- 344)    | 1x/2 mo<br>1 yr<br>(7x)                  |        |       |              | 32.4 uCi (29.3-31.9% shortened life span)                        | Hahn and<br>Lundgren 1992<br>Beta Particles<br>[144]CeO <sub>2</sub> |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain) | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |                | Reference<br>Chemical Form                                 |   |
|--------------|------------------|--|--------|-------|--------------|----------------|--|---|
|              |                  |  |        |       | Less serious | Serious        |  |   |
| 15           | Dog<br>(Beagle)  | once                                     |        |       |              | 320 uCi        | (5 dogs died, 93- 279 d post exposure)                     | McClellan et al.<br>1970<br>Beta Particles<br>[144]Ce               |
| 16           | Dog<br>(Beagle)  | once                                     |        |       |              | 320 uCi        | (5 dogs died, 93- 279 d post exposure)                     | McClellan et al.<br>1970<br>Beta Particles<br>[144]Ce               |
| 17           | Dog<br>(Beagle)  | once                                     |        |       |              | 0.26<br>uCi/kg | (death in 8/24 dogs over<br>1125- 2143 d<br>post-exposure) | Hahn et al.<br>1981<br>Alpha Particles<br>[238]PuO <sub>2</sub>     |
| 18           | Dog<br>(Beagle)  | once                                     |        |       |              | 0.97<br>uCi/kg | (51/72 died)   | Benjamin et al.<br>1979<br>Beta Particles<br>[90]SrCl <sub>2</sub>  |
| 19           | Dog<br>(Beagle)  | once                                     |        |       |              | 1.7<br>uCi/kg  | (27/72 died at 585+ d)                                     | McClellan et al.<br>1973<br>Beta Particles<br>[90]SrCl <sub>2</sub> |
| 20           | Dog<br>(Beagle)  | once                                     |        |       |              | 2.6<br>uCi/kg  | (43/55 died)   | Benjamin et al.<br>1979<br>Beta Particles<br>[144]CeCl <sub>3</sub> |
| 21           | Dog<br>(Beagle)  | once                                     |        |       |              | 14 uCi/kg      | (21/46 died)   | Benjamin et al.<br>1979<br>Beta Particles<br>[91]YCl <sub>3</sub>   |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number    | Species (strain)    | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |             | Reference<br>Chemical Form   |   |
|-----------------|---------------------|--|--------|-------|--------------|-------------|--|---|
|                 |                     |  |        |       | Less serious | Serious     |  |   |
| 22              | Dog<br>(Beagle)     | 2-22 min                                 |        |       |              | 45.9 uCi/kg | (death in 6/66 animals within 32 d)  | Gillett et al.<br>1987a<br>Beta Particles<br>[90]SrCl <sub>2</sub>  |
| 23              | Dog<br>(Beagle)     | once                                     |        |       |              | 74 uCi/kg   | (6/72 dogs died at 18-31 d)  | McClellan et al.<br>1973<br>Beta Particles<br>[90]SrCl <sub>2</sub> |
| 24              | Dog<br>(Beagle)     | <70 min                                  |        |       |              | NS          | (58/96 died >3 yrs post exposure)  | Boecker et al.<br>1988<br>Beta Particles<br>[91]Y                   |
| <b>Systemic</b> |                     |  |        |       |              |             |  |   |
| 25              | Hamster<br>(Syrian) | 1-45 min                                 | Resp   |       |              | 40 radM     | (radiation pneumonitis in 8%)  | Lundgren et al.<br>1983<br>Alpha Particles<br>[239]PuO <sub>2</sub> |
| 26              | Hamster<br>(Syrian) | 1 yr<br>7x/yr<br>1-45 min/x              | Resp   |       |              | 220 radM    | (radiation pneumonitis in 40% and bronchiolar epithelial hyperplasia in 35%) | Lundgren et al.<br>1983<br>Alpha Particles<br>[239]PuO <sub>2</sub> |
| 27              | Dog<br>(Beagle)     | once                                     | Resp   |       |              | 3700 rad    | (severe radiation pneumonitis and pulmonary fibrosis in 7/144)               | Hahn et al.<br>1981<br>Alpha Particles<br>[238]PuO <sub>2</sub>     |
| 28              | Dog<br>(Beagle)     | once                                     | Resp   |       |              | 8700 rad    | (pneumonitis, fibrosis, inflammation in 3/4 dogs)                            | Benjamin et al.<br>1976<br>Beta Particles<br>[90]Y                  |



Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)      | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |            | Reference<br>Chemical Form  |
|--------------|-----------------------|--|--------|-------|--------------|------------|---|
|              |                       |  |        |       | Less serious | Serious    |   |
| 29           | Dog<br>(Beagle)       | once                                     | Resp   |       |              | 27,000 rad | (pneumonitis and pulmonary fibrosis)<br>Benjamin et al. 1978<br>Beta-Gamma Particles<br>[144]Ce   |
| 30           | Dog<br>(Beagle)       | once                                     | Resp   |       |              | 39,000 rad | (dyspnea and cyanosis; pneumonitis and fibrosis in 1/4 dogs)<br>Benjamin et al. 1976<br>Beta Particles<br>[90]Sr  |
| 31           | Dog<br>(Beagle)       | once                                     | Resp   |       |              | 42,000 rad | (pneumonitis, fibrosis, inflammation in 2/4 dogs)<br>Benjamin et al. 1976<br>Beta Particles<br>[144]Ce  |
| 32           | Dog<br>(Beagle)       | once                                     | Resp   |       | 230 rad      |            | (decr. lung capacity & compliance, & incr. respiratory frequency & minute volume)<br>Muggenburg et al. 1988<br>Alpha Particles<br>[239]PuO <sub>2</sub>   |
| 33           | Rat<br>(Fischer- 344) | 20 min                                   | Resp   |       | 240 rad      |            | (decr. functional residual capacity and incr. percentage of forced vital capacity, mild septal fibrosis, small focal scars, decr. in lung volume, incr. in connective tissue)<br>Lundgren et al. 1991<br>Alpha Particles<br>[239]PuO <sub>2</sub> |
| 34           | Dog<br>(Beagle)       | 3-46 min                                 | Resp   |       | 8,400 rad    |            | (incr. resp. rate, pulmonary & pleural fibrosis, metaplastic and/or hyperplastic lesions in terminal bronchiolar and alveolar regions)<br>Hobbs et al. 1972<br>Beta Particles<br>[90]Y  |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)            | Duration/<br>Frequency of Administration | System | NOAEL     | LOAEL        |  | Reference<br>Chemical Form  |
|--------------|-----------------------------|--|--------|-----------|--------------|--|---|
|              |                             |  |        |           | Less serious | Serious  |   |
| 35           | Monkey<br>(Rhesus)          | once                                     | Resp   |           |              | 270 nCiM (pulmonary fibrosis)  | Hahn et al.<br>1987<br>Alpha Particles<br>[239]PuO <sub>2</sub>     |
| 36           | Monkey<br>(Rhesus)          | once                                     | Resp   |           |              | 1000 nCiM (radiation pneumonitis and pulmonary fibrosis)                               | LaBauve et al.<br>1980<br>Alpha Particles<br>[239]PuO <sub>2</sub>  |
| 37           | Monkey<br>(Rhesus)          | once                                     | Resp   | 210 nCi M |              |  | Hahn et al.<br>1987<br>Alpha Particles<br>[239]PuO <sub>2</sub>     |
| 38           | Monkey<br>(Cynomol-<br>gus) | once                                     | Resp   |           |              | 0.27 uCi M (2/2 fibrosis, 1/2 pneumonitis)   | Brooks et al.<br>1992<br>Alpha Particles<br>[239]Pu                 |
| 39           | Mouse<br>(C57BL/6J)         | once                                     | Resp   |           |              | 4.8 uCi F (92%, 34%, and 59% radiation pneumonitis in 70-, 260-, and 450-day old mice) | Lundgren et al.<br>1980a<br>Beta Particles<br>[144]CeO <sub>2</sub> |
| 40           | Mouse<br>(CFW)              | 10-20 min                                | Resp   |           |              | 21uCi M (radiation pneumonitis in 75-100% of mice)                                     | Lundgren et al.<br>1981<br>Beta Particles<br>[90]Y                  |
| 41           | Dog<br>(Beagle)             | 28-53 min                                | Resp   |           |              | 24,000 uCi (radiation pneumonitis in 6/7 dogs)   | Hahn et al.<br>1975<br>Beta Particles<br>[90]Y                      |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)            | Duration/<br>Frequency of Administration | System | NOAEL          | LOAEL        |               | Reference<br>Chemical Form  |
|--------------|-----------------------------|--|--------|----------------|--------------|---------------|---|
|              |                             |  |        |                | Less serious | Serious       |   |
| 42           | Monkey<br>(Cynomol-<br>gus) | once                                     | Resp   | 0.108 M<br>uCi |              |               | Brooks et al.<br>1992<br>Alpha Particles<br>[239]Pu   |
| 43           | Mouse<br>(C57BL/6J)         | once                                     | Resp   | 1.1 uCi F      |              |               | Lundgren et al.<br>1980a<br>Beta Particles<br>[144]CeO <sub>2</sub>   |
| 44           | Dog<br>(Beagle)             | once                                     | Resp   |                |              | 2.6<br>uCi/kg | (3/55 radiation<br>pneumonitis, pulmonary<br>fibrosis)<br>Benjamin et al.<br>1979<br>Beta Particles<br>[144]CeCl <sub>3</sub>   |
| 45           | Dog<br>(Beagle)             | <1 hr                                    | Resp   |                |              | 33 uCi/kg     | (radiation pneumonitis)<br>Hahn et al.<br>1976<br>Beta Particles<br>[144]Ce   |
| 46           | Dog<br>(Beagle)             | 3-46 min                                 | Cardio |                | 8,400 rad    |               | (ECG changes in 5/12<br>and hemorrhagic areas<br>near ventricular junction<br>in right atria of 7/12 dogs<br>dying 64-92 d post<br>exposure)<br>Hobbs et al.<br>1972<br>Beta Particles<br>[90]Y |
| 47           | Dog<br>(Beagle)             | once                                     | Cardio | 3200<br>rad    |              |               | Muggenburg et<br>al. 1988<br>Alpha Particles<br>[239]PuO <sub>2</sub>   |
| 48           | Dog<br>(Beagle)             | 28-53 min                                | Gastro |                |              | 3200<br>rads  | (colon lesion, ulcerative<br>and atrophic foci in 1/2<br>dogs)<br>Hahn et al.<br>1975<br>Beta Particles<br>[90]Y  |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)         | Duration/<br>Frequency of Administration | System | NOAEL      | LOAEL        |  | Reference<br>Chemical Form   |
|--------------|--------------------------|--|--------|------------|--------------|--|--|
|              |                          |  |        |            | Less serious | Serious  |  |
| 49           | Dog<br>(Beagle)          | 28-53 min                                | Gastro |            | 32,000 uCi   | (colitis in 2/7 dogs)  | Hahn et al.<br>1975<br>Beta Particles<br>[90]Y   |
| 50           | Dog<br>(Beagle)          | 2-22 min                                 | Gastro |            | 45.9 uCi/kg  | (diarrhea)   | Gillett et al.<br>1987a<br>Beta Particles<br>[90]SrCl <sub>2</sub>   |
| 51           | Dog<br>(Beagle)          | 3-46 min                                 | Hemato |            |              |  | 8,400 rad (lymphopenia)<br>Hobbs et al.<br>1972<br>Beta Particles<br>[90]Y                                       |
| 52           | Dog<br>(Beagle)          | 3-46 min                                 | Hemato |            | 8,400 rad    | (suppression of bone marrow in deaths up to 31d, repopulation of marrow in later deaths) | Hobbs et al.<br>1972<br>Beta Particles<br>[90]Y  |
| 53           | Monkey<br>(Cynomol- gus) | once                                     | Hemato | 1.08 uCi M |              |  | Brooks et al.<br>1992<br>Alpha Particles<br>[239]Pu  |
| 54           | Dog<br>(Beagle)          | once                                     | Hemato |            |              |  | 0.97 uCi/kg (bone marrow aplasia)<br>Benjamin et al.<br>1979<br>Beta Particles<br>[90]SrCl <sub>2</sub>          |
| 55           | Dog<br>(Beagle)          | once                                     | Hemato |            |              |  | 2.6-360 uCi/kg (9/55 bone marrow aplasia)<br>Benjamin et al.<br>1979<br>Beta Particles<br>[144]CeCl <sub>3</sub> |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)    | Duration/<br>Frequency of Administration | System  | NOAEL       | LOAEL   |  | Reference<br>Chemical Form                                    |
|--------------|---------------------|--|---------|-------------|---|--|---|
|              |                     |  |         |             | Less serious  | Serious  |   |
| 56           | Dog<br>(Beagle)     | once                                     | Hemato  |             |   | 14 uCi/kg (11/46 bone marrow aplasia)          | Benjamin et al. 1979<br>Beta Particles [91]YCl <sub>3</sub>   |
| 57           | Dog<br>(Beagle)     | 2-22 min                                 | Hemato  |             |   | 45.9 uCi/kg (bone marrow hypoplasia)           | Gillett et al. 1987a<br>Beta Particles [90]SrCl <sub>2</sub>  |
| 58           | Dog<br>(Beagle)     | 2-22 min                                 | Hemato  | 9.99 uCi/kg | (decreased platelet counts)   |  | Gillett et al. 1987a<br>Beta Particles [90]SrCl <sub>2</sub>  |
| 59           | Hamster<br>(Syrian) | 1 yr<br>7x/yr<br>1-45 min/x              | Hepatic |             |   | 3900 rad M (degenerative liver lesions in 40%) | Lundgren et al. 1983<br>Alpha Particles [239]PuO <sub>2</sub> |
| 60           | Dog<br>(Beagle)     | 3-46 min                                 | Hepatic | 8,400 rad   | (moderate or marked centrilobular hepatic congestion in deaths >38d, no necrosis) |  | Hobbs et al. 1972<br>Beta Particles [90]Y                     |
| 61           | Dog<br>(Beagle)     | once                                     | Hepatic |             |   | 2.6-360 uCi/kg (3/55 hepatic degeneration)     | Benjamin et al. 1979<br>Beta Particles [144]CeCl <sub>3</sub> |
| 62           | Dog<br>(Beagle)     | 3-46 min                                 | Dermal  | 8,400 rad   | (alopecia, atrophy and loss of hair follicles in 4/33 dogs)                       |  | Hobbs et al. 1972<br>Beta Particles [90]Y                     |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number                         | Species (strain) | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL   |  | Reference<br>Chemical Form   |
|--------------------------------------|------------------|--|--------|-------|---|--|--|
|                                      |                  |  |        |       | Less serious  | Serious  |  |
| 63                                   | Dog<br>(Beagle)  | 28-53 min                                | Dermal |       | ?<br>(nasal dermatitis in 4/7 dogs)                 |  | Hahn et al.<br>1975<br>Beta Particles<br>[90]Y                     |
| 64                                   | Dog<br>(Beagle)  | 3-46 min                                 | Bd Wt  |       | 8,400 rad<br>(anorexia and progressive weight loss) |  | Hobbs et al.<br>1972<br>Beta Particles<br>[90]Y                    |
| 65                                   | Dog<br>(Beagle)  | 2-22 min                                 | Metab  |       | 45.9 uCi/kg<br>(fever)                              |  | Gillett et al.<br>1987a<br>Beta Particles<br>[90]SrCl <sub>2</sub> |
| <b>Immunological/Lymphoreticular</b> |                  |  |        |       |   |  |  |
| 66                                   | Dog<br>(Beagle)  | once                                     |        |       |   | 1400 rad<br>(fibrosis, atrophy, or hyperplasia in lymph nodes) | Galvin et al.<br>1989<br>Alpha Particles<br>[239]PuO <sub>2</sub>  |
| 67                                   | Dog<br>(Beagle)  | once                                     |        |       |   | 27,000 rad<br>(60% decr. in lymphocyte count)                  | Benjamin et al.<br>1978<br>Beta-Gamma Particles<br>[144]Ce         |
| 68                                   | Dog<br>(Beagle)  | once                                     |        |       |   | 39,000 rad<br>(lymphopenia and decr. in lymphocyte function)   | Benjamin et al.<br>1976<br>Beta Particles<br>[90]Sr                |
| 69                                   | Dog<br>(Beagle)  | once                                     |        |       |   | 42,000 rad<br>(lymphopenia and decr. in lymphocyte function)   | Benjamin et al.<br>1976<br>Beta Particles<br>[144]Ce               |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain) | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |  | Reference<br>Chemical Form  |
|--------------|------------------|--|--------|-------|--------------|--|---|
|              |                  |  |        |       | Less serious | Serious  |   |
| 70           | Dog<br>(Beagle)  | once                                     |        |       | 520 rad      | (decr. response of lymphocytes to PHA in middle aged dogs)   | Davila et al.<br>1992<br>Alpha Particles<br>[239]PuO <sub>2</sub>   |
| 71           | Dog<br>(Beagle)  | once                                     |        |       | 740 rad      | (decr. response of lymphocytes to Con A and PHA in aged tumor bearing dogs)  | Davila et al.<br>1992<br>Alpha Particles<br>[239]PuO <sub>2</sub>   |
| 72           | Dog<br>(Beagle)  | once                                     |        |       | 1400 rad     | (incr. IgG in lung; neutrophils six-fold higher in lungs)  | Galvin et al.<br>1989<br>Alpha Particles<br>[239]PuO <sub>2</sub>   |
| 73           | Dog<br>(Beagle)  | 3-46 min                                 |        |       | 8,400 rad    | (<38 d, TBLN had marked lymphoid depletion; >38 d nodes were enlarged with hyperplastic repopulation of lymphocytes) | Hobbs et al.<br>1972<br>Beta Particles<br>[90]Y   |
| 74           | Mouse<br>(CFW)   | 10-20 min                                |        |       | 7 uCi M      | (incr. number vacuolated macrophages)  | Lundgren et al.<br>1976<br>Beta Particles<br>[90]Y  |
| 75           | Mouse<br>(CFW)   | 10-20 min                                |        |       | 8 uCi M      | (equivocal suppression of pulmonary bacterial clearance at 2 and 3 wk post-exposure)                                 | Lundgren et al.<br>1976<br>Beta Particles<br>[90]Y  |
| 76           | Dog<br>(Beagle)  | <1 hr                                    |        |       |              |  | 51<br>uCi/kg<br>(severe atrophy and fibrosis in both cortex and paracortex)<br>Hahn et al.<br>1976<br>Beta Particles<br>[144]Ce |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number  | Species (strain) | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL        |  | Reference<br>Chemical Form                                      |
|---------------|------------------|---|--------|-------|--------------|--|---|
|               |                  |   |        |       | Less serious | Serious  |   |
| <b>Cancer</b> |                  |   |        |       |              |  |   |
| 77            | Dog<br>(Beagle)  | once  |        |       |              | 180 rad (CEL: osteoblastic osteosarcomas in 4/15 dogs) | Gillett et al. 1985<br>Beta Particles [241]AmO <sub>2</sub>     |
| 78            | Dog<br>(Beagle)  | once  |        |       |              | 180 rad (CEL: osteoblastic osteosarcomas in 4/15 dogs) | Gillett et al. 1985<br>Beta Particles [241]AmO <sub>2</sub>     |
| 79            | Dog<br>(Beagle)  | once  |        |       |              | 190 radM (CEL: oral melanoma)                          | Muggenburg et al. 1988<br>Alpha Particles [239]PuO <sub>2</sub> |
| 80            | Dog<br>(Beagle)  | once  |        |       |              | 200 rad (CEL: 30 lung tumors observed, 1.2 expected)   | Hahn et al. 1988<br>Beta Particles [144]Ce                      |
| 81            | Dog<br>(Beagle)  | once  |        |       |              | 210 rad (CEL: osteosarcomas in 35/144 exposed dogs)    | Hahn et al. 1981<br>Alpha Particles [238]PuO <sub>2</sub>       |
| 82            | Dog<br>(Beagle)  | <70 min                                     |        |       |              | 310 rad (CEL: 28/36 lung cancer)                       | Boecker et al. 1988<br>Alpha Particles [239]PuO <sub>2</sub>    |
| 83            | Dog<br>(Beagle)  | once  |        |       |              | 800 rad (CEL: nasal squamous cell carcinomas in 5/55)  | Benjamin et al. 1979<br>Beta Particles [144]CeCl <sub>3</sub>   |



Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)   | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |            | Reference<br>Chemical Form                   |   |
|--------------|--------------------|--|--------|-------|--------------|------------|--|---|
|              |                    |  |        |       | Less serious | Serious    |  |   |
| 84           | Dog<br>(Beagle)    | once                                     |        |       |              | 860 rad    | (CEL: 3/46 nasal squamous cell carcinomas)   | Benjamin et al. 1979<br>Beta Particles [91]YCl3     |
| 85           | Dog<br>(Beagle)    | once                                     |        |       |              | 1000 rad   | (CEL: lung carcinoma)                        | Muggenburg et al. 1988<br>Alpha Particles [239]PuO2 |
| 86           | Dog<br>(Beagle)    | once                                     |        |       |              | 1400 rad   | (CEL: lung tumors in 3/4 dogs)               | Galvin et al. 1989<br>Alpha Particles [239]PuO2     |
| 87           | Monkey<br>(Rhesus) | once                                     |        |       |              | 1400 rad   | (CEL: pulmonary sarcoma in 1/12)             | Hahn et al. 1987<br>Alpha Particles [239]PuO2       |
| 88           | Dog<br>(Beagle)    | once                                     |        |       |              | 1900 rad   | (CEL: 8 lung tumors observed, 1.2 expected)  | Hahn et al. 1988<br>Beta Particles [90]Y            |
| 89           | Dog<br>(Beagle)    | once                                     |        |       |              | 2,800 rads | (CEL: 31 bone related sarcomas)              | Benjamin et al. 1979<br>Beta Particles [90]SrCl2    |
| 90           | Dog<br>(Beagle)    | once                                     |        |       |              | 3100 rad   | (CEL: 36 lung tumors observed, 1.2 expected) | Hahn et al. 1988<br>Beta Particles [91]Y            |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain) | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |  | Reference<br>Chemical Form  |
|--------------|------------------|--|--------|-------|--------------|--|---|
|              |                  |  |        |       | Less serious | Serious  |   |
| 91           | Dog<br>(Beagle)  | once                                     |        |       |              | 3200 rad (CEL: 2 heart tumors)                     | Hahn et al.<br>1988<br>Beta Particles<br>[144]Ce                          |
| 92           | Dog<br>(Beagle)  | once                                     |        |       |              | 3200 rad (CEL: 9 TBLN tumors)                      | Hahn et al.<br>1988<br>Beta Particles<br>[144]Ce                          |
| 93           | Dog<br>(Beagle)  | <70 min                                  |        |       |              | 3500 rad (CEL: lung cancer in 32/56)               | Boecker et al.<br>1988<br>Beta Particles<br>[91]Y                         |
| 94           | Dog<br>(Beagle)  | 10-15 min                                |        |       |              | 7,000 rad (CEL: pulmonary carcinomas and sarcomas) | Hahn et al.<br>1983<br>Beta Particles<br>[90]Y, [91]Y,<br>[144]Ce, [90]Sr |
| 95           | Dog<br>(Beagle)  | once                                     |        |       |              | 7100 rads (CEL: 2/72 other carcinomas of the head) | Benjamin et al.<br>1979<br>Beta Particles<br>[90]SrCl <sub>2</sub>        |
| 96           | Dog<br>(Beagle)  | once                                     |        |       |              | 7700 rad (CEL: 14 heart tumors)                    | Hahn et al.<br>1988<br>Beta Particles<br>[90]Sr                           |
| 97           | Dog<br>(Beagle)  | once                                     |        |       |              | 7700 rad (CEL: 8 TBLN tumors)                      | Hahn et al.<br>1988<br>Beta Particles<br>[90]Sr                           |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain) | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |            | Reference<br>Chemical Form   |   |
|--------------|------------------|--|--------|-------|--------------|------------|--|---|
|              |                  |  |        |       | Less serious | Serious    |  |   |
| 98           | Dog<br>(Beagle)  | once                                     |        |       |              | 8100 rad   | (CEL: 1/55 bone related sarcomas)                                    | Benjamin et al.<br>1979<br>Beta Particles<br>[144]CeCl <sub>3</sub>       |
| 99           | Dog<br>(Beagle)  | once                                     |        |       |              | 9600 rad   | (CEL: 1 heart tumor)   | Hahn et al.<br>1988<br>Beta Particles<br>[91]Y                            |
| 100          | Dog<br>(Beagle)  | once                                     |        |       |              | 9600 rad   | (CEL: 2 TBLN tumors)   | Hahn et al.<br>1988<br>Beta Particles<br>[91]Y                            |
| 101          | Dog<br>(Beagle)  | once                                     |        |       |              | 13000 rad  | (CEL: 1/72 nasal squamous cell carcinomas)                           | Benjamin et al.<br>1979<br>Beta Particles<br>[90]SrCl <sub>2</sub>        |
| 102          | Dog<br>(Beagle)  | 2-48 min                                 |        |       |              | 16,000 rad | (CEL: bronchiolo-alveolar carcinomas and pulmonary hemangiosarcomas) | Hahn et al.<br>1977<br>Beta Particles<br>[90]Y, [91]Y,<br>[144]Ce, [90]Sr |
| 103          | Dog<br>(Beagle)  | once                                     |        |       |              | 18,000 rad | (CEL: 28 lung tumors observed, 1.2 expected)                         | Hahn et al.<br>1988<br>Beta Particles<br>[90]Sr                           |
| 104          | Dog<br>(Beagle)  | once                                     |        |       |              | 27,000 rad | (CEL: pulmonary neoplasms in 5/16 dogs)                              | Benjamin et al.<br>1978<br>Beta-Gamma Particles<br>[144]Ce                |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain)         | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |             | Reference<br>Chemical Form  |
|--------------|--------------------------|--|--------|-------|--------------|-------------|---|
|              |                          |  |        |       | Less serious | Serious     |   |
| 105          | Rat<br>(Fischer- 344)    | once                                     |        |       |              | 0.06 uCi    | (CEL: pulmonary adenocarcinoma in 1/35)<br>Hahn and Lundgren 1992<br>Beta Particles [144]CeO <sub>2</sub>   |
| 106          | Rat<br>(Fischer- 344)    | 7x<br>1x/2 mo<br>1 yr                    |        |       |              | 0.35 uCi    | (CEL: pulmonary adenocarcinoma and adenoma in 2/36)<br>Hahn and Lundgren 1992<br>Beta Particles [144]CeO <sub>2</sub>   |
| 107          | Mouse<br>(CFW)           | 10-20 min                                |        |       |              | 1 uCiM      | (CEL: pulmonary adenomas)<br>Lundgren et al. 1981<br>Beta Particles [90]Y   |
| 108          | Monkey<br>(Cynomol- gus) | once                                     |        |       |              | 1.08 uCiM   | (CEL: lung cancer in 1/8)<br>Brooks et al. 1992<br>Alpha Particles [239]Pu  |
| 109          | Dog<br>(Beagle)          | 2-22 min                                 |        |       |              | 7.02 uCi/kg | (CEL: primary bone neoplasia in 30/66 dogs: osteosarcoma, hemangiosarcomas, fibrosarcomas, myxosarcoma)<br>Gillett et al. 1987b<br>Beta Particles [90]SrCl <sub>2</sub> |
| 110          | Dog<br>(Beagle)          | once                                     |        |       |              | NS          | (CEL: 100/144 osteosarcomas)<br>Gillett et al. 1988<br>Alpha Particles [238]PuO <sub>2</sub>  |
| 111          | Dog<br>(Beagle)          | once                                     |        |       |              | NS          | (CEL: 28/144 lung tumors)<br>Gillett et al. 1988<br>Alpha Particles [238]PuO <sub>2</sub>   |

Table 8-1. Levels of Significant Exposure to Radiation and Radioactive Material: Inhalation (continued)

| Entry Number | Species (strain) | Duration/<br>Frequency of Administration | System | NOAEL | LOAEL        |         | Reference<br>Chemical Form   |  |
|--------------|------------------|--|--------|-------|--------------|---------|--|--|
|              |                  |  |        |       | Less serious | Serious |  |  |
| 112          | Dog<br>(Beagle)  | once                                     |        |       |              | NS      | (CEL: lung tumors in 47/144 dogs; bronchioalveolar carcinomas & papillary adenocarcinomas) | Muggenburg et al. 1994<br>Alpha Particles<br>[238]PuO <sub>2</sub> |
| 113          | Dog<br>(Beagle)  | once                                     |        |       |              | NS      | (CEL: skeletal tumors in 92/144; osteosarcomas)  | Muggenburg et al. 1994<br>Alpha Particles<br>[238]PuO <sub>2</sub> |
| 114          | Dog<br>(Beagle)  | once                                     |        |       |              | NS      | (CEL: malignant liver tumors in 13/144)  | Muggenburg et al. 1994<br>Alpha Particles<br>[238]PuO <sub>2</sub> |

Bd Wt = body weight; Cardio = cardiovascular; CEL = cancer effect level; Con A = concanavalin A; d = day(s); decr = decrease; ECG = electrocardiograph; F = female; Gastro = gastrointestinal; Hemato = hematological; ILB = initial lung burden; incr = increase; LOAEL = lowest-observable-adverse-effect level; M = male; Metab = metabolism; min = minute(s); mo = month(s); NOAEL = no-observable-adverse-effect level; NS = not specified; PHA = phytohaemagglutinin; Resp = respiratory; skel = skeletal; TBLN = tracheobronchial lymph nodes; wk = week(s); yr = year(s); x = times

Table 8-2. Levels of Significant Exposure to Radiation and Radioactive Material: Oral

| Entry Number        | Species/ (Strain) | Duration/ Frequency of Administration (Specific Route) | System    | NOAEL                          | LOAEL                                |  | Reference Chemical Form                              |
|---------------------|-------------------|--|-----------|--------------------------------|--------------------------------------|--|--|
|                     |                   |  |           |                                | Less Serious                         | Serious  |  |
| <b>Systemic</b>     |                   |  |           |                                |                                      |  |  |
| 1                   | Human             | 4.7 yr   | Musc/skel | 1,851 F rad (17-19 yr of age)  |                                      |  | Polednak and Farnham 1980<br>Alpha Particles [226]Ra |
| 2                   | Human             | 4.7 yr   | Musc/skel | 10,110 F rad (13-16 yr of age) |                                      |  | Polednak and Farnham 1980<br>Alpha Particles [226]Ra |
| <b>Reproductive</b> |                   |  |           |                                |                                      |  |  |
| 3                   | Mouse (Hybrid)    | 2 wk 1x/d  |           |                                |                                      | 140 rad (incr. embryo mortality)                   | Ramaiya et al. 1994<br>Beta Particles [137]Cs        |
| 4                   | Mouse (Hybrid)    | once   |           |                                |                                      | 180 rad (incr. post-implantation embryo mortality) | Ramaiya et al. 1994<br>Beta Particles [137]Cs        |
| 5                   | Mouse (Hybrid)    | once   |           |                                | 190 rad M (decreased fertility)      |  | Ramaiya et al. 1994<br>Beta Particles [137]Cs        |
| 6                   | Mouse (Hybrid)    | 2 wk 1x/d  |           |                                | 350 rad M (reduced effective mating) |  | Ramaiya et al. 1994<br>Beta Particles [137]Cs        |

Table 8-2. Levels of Significant Exposure to Radiation and Radioactive Material: Oral (continued)

| Entry Number | Species/<br>(Strain) | Duration/<br>Frequency of<br>Administration<br>(Specific<br>Route) | System | NOAEL     | LOAEL        |         | Reference<br>Chemical Form                          |
|--------------|----------------------|--|--------|-----------|--------------|---------|---|
|              |                      |  |        |           | Less Serious | Serious |   |
| 7            | Mouse<br>(Hybrid)    | once   |        | 100 rad M |              |         | Ramaiya et al.<br>1994<br>Beta Particles<br>[137]Cs |

d = day(s); expos. = exposure; F = female; incr. = increase; LOAEL = lowest-observable-adverse-effect level; M = male; Musc/skel = musculoskeletal;  
NOAEL = no-observable-adverse-effect level; wk = week(s); yr = year(s)

**Table 8-3. Levels of Significant Exposure to Radiation and Radioactive Material: Dermal**

| Species/<br>(Strain)                  | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL        |  | Reference<br>Chemical Form                            |
|---------------------------------------|---|--------|-------|--------------|--|---|
|                                       |   |        |       | Less Serious | Serious  |   |
| <b>Systemic</b>                       |   |        |       |              |  |   |
| Hamster<br>(Syrian golden<br>& white) | once  | Dermal |       | 2000 rad     | (epilation)  | Garcia and<br>Shubik 1971<br>Beta Particles<br>[85]Kr |
| Gn Pig<br>(Albino)                    | once  | Dermal |       | 3000 rep M   | (incr. vascular<br>permeability)                                   | Song et al. 1968<br>Beta Particles<br>[90]Sr-[90]Y    |
| <b>Neurological</b>                   |   |        |       |              |  |   |
| Human                                 | once  |        |       | 38.2 rad M   | (tingling, pain, sensitive<br>to touch and<br>temperature changes) | Berger et al.<br>1996<br>X-ray<br>ionizing radiation  |

Cardio = cardiovascular; F = female; Gn pig = guinea pig; incr. = increase; LOAEL = lowest-observable-adverse-effect level; M = male; NOAEL = no-observable-adverse-effect level.



**Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External**

| Entry Number    | Species/ (strain)    | Duration/ Frequency of Administration | System | NOAEL | LOAEL   |  | Reference   |
|-----------------|----------------------|---------------------------------------|--------|-------|---|--|---|
|                 |                      |                                       |        |       | Less serious  | Serious  |   |
| <b>Death</b>    |                      |                                       |        |       |   |  |   |
| 1               | Rat (Sprague-Dawley) | once                                  |        |       |   | 10 rad M (1/9 died)                                  | Canfi et al. 1990<br>Gamma Ray [192]Ir                    |
| 2               | Mouse (ICR)          | 3x/wk <86 wk                          |        |       |   | 150 rad F (13/21 died)                               | Ootsuyama and Tanooka 1989<br>Beta Particles [90]Sr-[90]Y |
| 3               | Rat (Wistar)         | once                                  |        |       |   | 800 rad M (45% died through d 15)                    | Salovsky and Shopova 1992<br>Gamma Ray NS                 |
| 4               | Human                | once<br><br>(occup)                   |        |       |   | 2250 rad M (death 13 d after exposure)               | Stavem et al. 1985<br>Gamma Ray NS                        |
| <b>Systemic</b> |                      |                                       |        |       |   |  |   |
| 5               | Pig (Large white)    | once                                  | Resp   |       |   | 1280 rad F (severe thickening of interlobular septa) | Rezvani et al. 1989<br>Gamma Ray [60]Co                   |
| 6               | Rat (Wistar)         | once                                  | Resp   |       | 400 rad M (30% decr. in BALF LDH, 31% decr. in alkaline phosphatase, and 40% decr. in acid phosphatase) |  | Salovsky and Shopova 1992<br>Gamma Ray NS                 |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/ (strain) | Duration/ Frequency of Administration | System | NOAEL | LOAEL   |  | Reference                                    |
|--------------|-------------------|---------------------------------------|--------|-------|---|--|--|
|              |                   |                                       |        |       | Less serious  | Serious  |  |
| 7            | Human             | once<br><br>(occup)                   | Resp   |       | 2250 rad M (few mononuclear cells and no granulocytes in resp. tract)                     |  | Stavem et al. 1985<br>Gamma Ray<br>NS        |
| 8            | Monkey (Rhesus)   | 1.38 min                              | Cardio |       |   | 10,000 M (66% decr. blood pressure rad 20 min post-exposure) | Cockerham et al. 1986<br>Gamma Ray<br>[60]Co |
| 9            | Human             | once<br><br>(occup)                   | Cardio |       | 2250 rad M (hypertrophic ventricle)   |  | Stavem et al. 1985<br>Gamma Ray              |
| 10           | Dog (Beagle)      | once                                  | Cardio |       | 3000 rad M (focal area of pervasculitis, reduction in LVEF)                               |  | Durakovic 1986a<br>Gamma Ray<br>[60]Co       |
| 11           | Mouse (Hybrid)    | 3-24 hr                               | Gastro |       | 2.5 rad/hr M (cell death in the crypts of the small intestine and descending colon)       |  | Ijiri 1989<br>Gamma Ray<br>[137]Cs           |
| 12           | Mouse (BALB/c)    | once                                  | Gastro |       | 1500 rad M (changes in villous shape and reduction in height, tissue cell disintegration) |  | Indran et al. 1991<br>Gamma Ray<br>[60]Co    |
| 13           | Human             | once<br><br>(occup)                   | Gastro |       | 2250 rad M (atrophy of glands in stomach, small intestine, and large intestine; diarrhea) |  | Stavem et al. 1985<br>Gamma Ray              |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/<br>(strain) | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL        |   | Reference                                    |
|--------------|----------------------|---|--------|-------|--------------|---|--|
|              |                      |   |        |       | Less serious | Serious   |  |
| 14           | Monkey<br>(Rhesus)   | 1.38 min                                    | Hemato |       |              | 10,000 M rad (arterial plasma histamine level incr. 96.8- fold 2 min post-exposure)       | Cockerham et al. 1986<br>Gamma Ray<br>[60]Co |
| 15           | Dog<br>(NS)          | 20-1700 d<br>22 hr/d                        | Hemato |       | 1.88 rad/d   | (decreased lymphocytes, thrombocytes and neutrophilic granulocytes)                       | Nothdurft et al. 1995<br>Gamma Ray<br>[60]Co |
| 16           | Dog<br>(NS)          | 20-1700 d<br>22 hr/d                        | Hemato |       | 1.88 rad/d   | (decreased lymphocytes, thrombocytes and neutrophilic granulocytes)                       | Nothdurft et al. 1995<br>Gamma Ray<br>[60]Co |
| 17           | Mouse<br>(ICR)       | once  | Hemato |       | 5 rad M      | (significantly decreased leukocyte counts on day 1 post irradiation)                      | Lin et al. 1996<br>Gamma Ray<br>NS           |
|              |                      |   | Bd Wt  |       | 5 rad M      | (body weight significantly decreased 11.6% on day19 post irradiation)                     |  |
| 18           | Dog<br>(Beagle)      | 150 - 300 d<br>22 hr/d                      | Hemato |       | 7.5 rad/d M  | (suppression/recovery for granulocytes, monocytes, leukocytes, platelets, & erythrocytes) | Seed et al. 1989<br>Gamma Ray<br>[60]Co      |
| 19           | Dog<br>(Beagle)      | 150-300 d<br>22 hr/d                        | Hemato |       | 7.5 rad/d F  | (suppression/recovery for granulocytes, monocytes, leukocytes, platelets, & erythrocytes) | Seed et al. 1993<br>Gamma Ray<br>[60]Co      |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/ (strain)    | Duration/ Frequency of Administration | System | NOAEL        | LOAEL        |   | Reference                                   |
|--------------|----------------------|---------------------------------------|--------|--------------|--------------|---|---|
|              |                      |                                       |        |              | Less serious | Serious   |   |
| 20           | Human                | once                                  | Hemato |              | 38.2 rad M   | (decreased total white blood count)   | Berger et al. 1996<br>X-ray<br>NS           |
|              |                      |                                       | Dermal |              | 38.2 rad M   | (itching, swelling, blisters, discoloration and desquamation of the hand)             |   |
| 21           | Mouse (hybrid)       | once                                  | Hemato |              | 50 rad M     | (increase in proliferation of femoral CFU-S, oscillation in granulocytes and CFU-S)   | Gidali et al. 1985<br>Gamma Ray<br>[60]Co   |
| 22           | Human                | once                                  | Hemato |              | * 159 rad M  | (decr. leukocyte, neutrophil, and lymphocyte counts)                                  | Klener et al. 1986<br>Gamma Ray<br>[60]Co   |
|              |                      | (occup)                               |        |              |              |   |   |
| 23           | Rat (Sprague-Dawley) | once                                  | Hemato |              | 840 rad M    | (decrease in arachidonic acid incorporation into membrane phospholipids of platelets) | Lognonne et al. 1985<br>Gamma Ray<br>[60]Co |
| 24           | Human                | once                                  | Hemato |              | 2250 rad M   | (decr. leukocyte count, elevated serum creatinine, and hypocellular bone marrow)      | Stavem et al. 1985<br>Gamma Ray<br>NS       |
|              |                      | (occup)                               |        |              |              |   |   |
| 25           | Mouse (CBA/H)        | 0-177 min                             | Hemato | 12,000 F rad |              |   | Hulse 1966<br>Beta Particles<br>[204]TI     |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/<br>(strain)    | Duration/<br>Frequency of<br>Administration | System  | NOAEL     | LOAEL   |  | Reference                                  |
|--------------|-------------------------|---|---------|-----------|---|--|--|
|              |                         |   |         |           | Less serious  | Serious  |  |
| 26           | Dog<br>(Beagle)         | once  | Hepatic |           | 400 rad M (signif. decrease in SGOT)                                |  | Durakovic 1986b<br>Gamma Ray [60]Co        |
| 27           | Mouse<br>(Swiss)        | once  | Hepatic |           | 1000 rad M (incr. acid phosphatase activity, decr. protein content) |  | Mazur et al. 1991<br>Gamma Ray [60]Co      |
| 28           | Human                   | once<br><br>(occup)                         | Renal   |           | 2250 rad M (anuria, enlarged kidneys, and interstitial edema)       |  | Stavem et al. 1985<br>Gamma Ray NS         |
| 29           | Rat<br>(Sprague-Dawley) | once  | Endocr  |           | 1.0 rad M (decr. in hypophyseal and serum FSH)                      |  | Canfi et al. 1990<br>gamma ray [192]Ir     |
| 30           | Human                   | 2 mo-3 yr                                   | Endocr  |           | 200 rad M (decreased LH)  |  | Birioukov et al. 1993<br>Beta and Gamma NS |
| 31           | Rat<br>(Sprague-Dawley) | once  | Endocr  | 0.1 rad M |   |  | Canfi et al. 1990<br>gamma ray [192]Ir     |
| 32           | Human                   | once<br><br>(occup)                         | Dermal  |           |   | * 159 rad M (painful hard swelling of deep skin layers of hand resulting in amputation of fingers) | Klener et al. 1986<br>Gamma Ray [60]Co     |
| 33           | Human                   | 2 mo-3 yr                                   | Dermal  |           |   | 200 rad M (radiation dermatitis)   | Birioukov et al. 1993<br>Beta and Gamma NS |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/ (strain) | Duration/ Frequency of Administration | System | NOAEL   | LOAEL  |   | Reference                                       |
|--------------|-------------------|---------------------------------------|--------|---------|--|---|---|
|              |                   |                                       |        |         | Less serious   | Serious   |   |
| 34           | Gn Pig (Albino)   | once                                  | Dermal |         |  | 2200 rad M (hyperplastic epidermis)               | Etoh et al. 1977<br>Beta Particles [90]Sr-[90]Y |
| 35           | Mouse (CBA/H)     | 0-177 min                             | Dermal |         |  | 3000 rad F (radiation burns)                      | Hulse 1966<br>Beta Particles [204]TI            |
| 36           | Pig (Large white) | 1x or 6x                              | Dermal |         |  | 12,000 rad (skin and skeletal muscle ulcerations) | Lefaix et al. 1993<br>Gamma Ray [192]Ir         |
| 37           | Human             | once<br><br>(occup)                   | Dermal |         | * 159 rad M (reddening and inflammation of hand and epilation) |   | Klener et al. 1986<br>Gamma Ray [60]Co          |
| 38           | Mouse (CBA/H)     | 0-177 min                             | Dermal |         | 750 rad F (hair depigmentation and hyperkeratotic areas)       |   | Hulse 1966<br>Beta Particles [204]TI            |
| 39           | Mouse (Albino)    | 0-177 min                             | Dermal |         | 1500 rad (slight erythema)                                     |   | Hulse 1966<br>Beta Particles [204]TI            |
| 40           | Pig (Large white) | 1x or 6x                              | Dermal |         | 3200 rad (erythma)   |   | Lefaix et al. 1993<br>Gamma Ray [192]Ir         |
| 41           | Mouse (Albino)    | 0-177 min                             | Dermal | 750 rad |  |   | Hulse 1966<br>Beta Particles [204]TI            |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/ (strain) | Duration/ Frequency of Administration | System | NOAEL      | LOAEL        |   | Reference  |
|--------------|-------------------|---------------------------------------|--------|------------|--------------|---|--|
|              |                   |                                       |        |            | Less serious | Serious   |  |
| 42           | Gn Pig (Albino)   | once                                  | Dermal | 1000 rad M |              |   | Etoh et al. 1977<br>Beta Particles<br>[90]Sr-[90]Y |
| 43           | Pig (Large white) | 1x or 6x                              | Dermal | 1600 rad   |              |   | Lefaix et al. 1993<br>Gamma Ray<br>[192]Ir         |
| 44           | Human             | once                                  | Ocular |            |              | 200 rad (cataracts)   | Lipman et al. 1988<br>x-ray and beta<br>NS         |
| 45           | Dog (Beagle)      | pcd 2                                 | Ocular |            |              | 300 rad (severe bilateral degenerative retinal lesions in 99% of offspring)   | Schweitzer et al. 1987<br>Gamma Ray<br>[60]Co      |
| 46           | Rat (Wistar)      | once                                  | Ocular |            |              | 1500 rad (progressive inner retinal ischemia, cytoid bodies, capillary non-perfusion, general atrophy of inner retina in diabetic rats) | Stitt et al. 1994<br>X-ray<br>NS                   |
| 47           | Human             | once<br><br>(occup)                   | Ocular |            |              | * 159 rad M (deterioration of visual acuity)  | Klener et al. 1986<br>Gamma Ray<br>[60]Co          |
| 48           | Human             | 2 mo-3 yr                             | Ocular |            |              | 200 rad M (vision impairment)   | Birioukov et al. 1993<br>Beta and Gamma<br>NS      |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/<br>(strain)        | Duration/<br>Frequency of<br>Administration | System | NOAEL     | LOAEL  |                                      | Reference   |
|--------------|-----------------------------|---|--------|-----------|--|--------------------------------------|---|
|              |                             |   |        |           | Less serious                                       | Serious                              |   |
| 49           | Rat<br>(Sprague-<br>Dawley) | Gd 13, 15 or<br>17                          | Bd Wt  | 100 rad F |  |                                      | Norton and<br>Kilmer 1988<br>Gamma Ray<br>[137]Cs |
| 50           | Rat<br>(Sprague-<br>Dawley) | Gd 15                                       | Bd Wt  | 100 rad F |  |                                      | Norton and<br>Kimler 1990<br>Gamma Ray<br>[137]Cs |
| 51           | Rat<br>(Fischer- 344)       | Gd 20                                       | Bd Wt  | 150 rad F |  |                                      | Zaman et al.<br>1992<br>Gamma Ray<br>NS           |
| 52           | Rat<br>(Fischer- 344)       | Gd 20                                       | Bd Wt  | 150 rad F |  |                                      | Zaman et al.<br>1993<br>Gamma Ray<br>NS           |
| 53           | Human                       | once<br><br>(occup)                         | Metab  |           | * 159 rad M (irregular subfebrile<br>temperatures) |                                      | Klener et al.<br>1986<br>Gamma Ray<br>[60]Co      |
| 54           | Human                       | once<br><br>(occup)                         | Metab  |           | 2250 rad M (fever)                                 |                                      | Stavem et al.<br>1985<br>Gamma Ray<br>NS          |
| 55           | Human                       | 2 mo-3 yr                                   | Other  |           |  | 200 rad M (acute radiation sickness) | Birioukov et al.<br>1993<br>Beta and Gamma<br>NS  |



Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number                         | Species/<br>(strain) | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL        |  | Reference   |
|--------------------------------------|----------------------|---|--------|-------|--------------|--|---|
|                                      |                      |   |        |       | Less serious | Serious  |   |
| <b>Immunological/Lymphoreticular</b> |                      |   |        |       |              |  |   |
| 56                                   | Mouse<br>(NS)        | 1-30 d                                      |        |       | 0.6 rad M    | (moderate change in stem cell radiosensitivity)  | Rozhdestvensky & Fomicheva 1995<br>Gamma Ray  |
| 57                                   | Human                | once<br><br>(occup)                         |        |       |              |  | 2250 rad M (congestion and hemorrhage of spleen)<br>Stavem et al. 1985<br>Gamma Ray<br>NS |
| 58                                   | Dog<br>(NS)          | 20-1700 d<br>22 hr/d                        |        |       | 1.88 rad/d   | (decreased GM-CFC levels in bone marrow; increased CSA levels)   | Nothdurft et al. 1995<br>Gamma Ray<br>[60]Co  |
| 59                                   | Dog<br>(NS)          | 20-1700 d<br>22 hr/d                        |        |       | 1.88 rad/d   | (decreased GM-CFC levels in bone marrow; increased CSA levels)   | Nothdurft et al. 1995<br>Gamma Ray<br>[60]Co  |
| 60                                   | Mouse<br>(Swiss)     | once  |        |       | 1000 rad M   | (decr. spleen wt & levels of protein in spleen, incr. acid phosphatase activity & activity of beta- glucuronidase) | Mazur et al. 1991<br>Gamma Ray<br>[60]Co  |
| 61                                   | Human                | once<br><br>(occup)                         |        |       | 2250 rad M   | (decr. number of lymphocytes and hypocellular lymph nodes)   | Stavem et al. 1985<br>Gamma Ray<br>NS   |
| 62                                   | Mouse<br>(ICR)       | once  |        | 5 M   | 50 rad M     | (significantly decreased spleen weight on day 12 post irradiation)   | Lin et al. 1996<br>Gamma Ray<br>NS  |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number        | Species/<br>(strain)         | Duration/<br>Frequency of<br>Administration | System | NOAEL                   | LOAEL        |                 | Reference  |
|---------------------|------------------------------|---|--------|-------------------------|--------------|-----------------|--|
|                     |                              |   |        |                         | Less serious | Serious         |  |
| 63                  | Monkey<br>(Rhesus)           | >1 yr                                       |        | 12.5-10<br>0<br>rad/min |              |                 | Stone et al.<br>1994<br>High energy<br>protons<br>NS   |
| 64                  | Monkey<br>(Rhesus)           | once  |        | 10-100<br>rad/min       |              |                 | Stone et al.<br>1994<br>X-ray  |
| <b>Neurological</b> |                              |   |        |                         |              |                 |  |
| 65                  | Monkey<br>(Rhesus)           | 1.38 min                                    |        |                         |              | 10,000 M<br>rad | (51 and 63% decr. blood<br>flow to reticular formation<br>of pons & motor cortex,<br>resp.)<br>Cockerham et<br>al. 1986<br>Gamma Ray<br>[60]Co |
| 66                  | Rat<br>(Sprague-<br>Dawley)  | once  |        |                         | 200 rad      |                 | (increased brain<br>expression of<br>apoptosis-associated<br>protein c-jun)<br>Ferrer et al.<br>1996<br>Gamma Ray<br>[60]Co                    |
| 67                  | Rabbit<br>(Burgundy<br>fawn) | once  |        |                         | 450 rad M    |                 | (increased firing interval<br>in pyramidal cells)<br>Bassant and<br>Court 1978<br>Gamma Ray<br>[60]Co  |
| 68                  | Rat<br>(Wistar)              | once  |        |                         | 1435 rad M   |                 | (decreased<br>catecholamine levels)<br>Pastorova et<br>al. 1997<br>[60]Co<br>ionizing radiation  |
| <b>Reproductive</b> |                              |   |        |                         |              |                 |  |
| 69                  | Mouse<br>(B6C3F1)            | 10-50 wk<br>1x/wk<br>20 min/x               |        |                         |              |                 | 5 rad M (sperm abnormalities)<br>Grahn and<br>Carnes 1988<br>Gamma Ray<br>[60]Co   |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/<br>(strain)        | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL        |  | Reference  |
|--------------|-----------------------------|---|--------|-------|--------------|--|--|
|              |                             |   |        |       | Less serious | Serious  |  |
| 70           | Mouse<br>(B6C3F1)           | 60 wk<br>1x/wk<br>20 min/x                  |        |       |              | 5 rad M (sperm abnormalities)  | Grahn and<br>Carnes 1988<br>Gamma Ray<br>[60]Co        |
| 71           | Mouse<br>(NS)               | 22-25 d                                     |        |       |              | 80 rad (incr. post-implantation<br>mortality in progeny)   | Shevchenko et<br>al. 1992<br>Gamma and beta<br>NS      |
| 72           | Human                       | 2 mo-3 yr                                   |        |       |              | 200 rad M (impotency, abnormal<br>sperm, and decr. viability<br>of spermatozoa)                      | Birioukov et al.<br>1993<br>Beta and Gamma<br>NS       |
| 73           | Mouse<br>(Hybrid)           | once  |        |       |              | 300 rad M (sterility and decr. fertility)  | Ramaiya et al.<br>1994<br>Gamma Ray<br>[137]Cs         |
| 74           | Mouse<br>(Hybrid)           | once  |        |       |              | 300 rad (incr. total and<br>post-implantation embryo<br>mortality)                                   | Ramaiya et al.<br>1994<br>Gamma Ray<br>[137]Cs         |
| 75           | Mouse<br>(NS)               | 22-25 d<br><br>(environ)                    |        |       |              | 300 rad M (reversible sterility,<br>reduced testes mass)   | Shevchenko et<br>al. 1992<br>Gamma and beta<br>NS      |
| 76           | Rat<br>(Sprague-<br>Dawley) | once  |        |       |              | 900 rad M (decr. testis wt, epididymal<br>wt & epididymal content<br>ABP & damaged<br>spermatocytes) | Pinon-Lataillade<br>et al. 1991<br>Gamma Ray<br>[60]Co |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number         | Species/<br>(strain)    | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL                               |  | Reference                                       |
|----------------------|-------------------------|---|--------|-------|-------------------------------------|--|---|
|                      |                         |   |        |       | Less serious                        | Serious  |   |
| 77                   | Mouse<br>(Hybrid)       | 28 wk                                       |        |       |                                     | 1,128 M<br>rad (65% reduced testis mass)   | Searle et al.<br>1976<br>Gamma Ray<br>[60]Co    |
| 78                   | Mouse<br>(Hybrid)       | 28 wk                                       |        |       |                                     | 1,128 rad (incr. pre- and post-implantation loss)  | Searle et al.<br>1976<br>Gamma Ray<br>[60]Co    |
| 79                   | Mouse<br>(Hybrid)       | 28 wk                                       |        |       |                                     | 1,128 M rad (85% reduced epididymal sperm-count)   | Searle et al.<br>1976<br>Gamma Ray<br>[60]Co    |
| 80                   | Rat<br>(Sprague-Dawley) | once  |        |       | 1 rad M (25% decrease in fertility) |  | Canfi et al. 1990<br>gamma ray<br>[192]Ir       |
| <b>Developmental</b> |                         |   |        |       |                                     |  |   |
| 81                   | Rat<br>(Sprague-Dawley) | once  |        |       |                                     | 1 rad M (17% decr. pup weight at weaning)  | Canfi et al. 1990<br>gamma ray<br>[192]Ir       |
| 82                   | Mouse<br>(Swiss)        | Gd 11.5                                     |        |       |                                     | 25 rad (13.67% w/ microphthalmia; 2% decr. fetal head length and width; 5% decr. brain weight) | Devi et al. 1994<br>Gamma Ray<br>[60]Co         |
| 83                   | Rat<br>(Wistar)         | Gd 10<br>3 sec                              |        |       |                                     | 40 rad (32.2% fetal mortality, 53 resorption sites)  | Roux et al. 1986<br>Gamma Ray<br>[60]Co         |
| 84                   | Rat<br>(Sprague-Dawley) | 16.5 sec                                    |        |       |                                     | 50 rad (loss of granule cells, atrophied/reduced number of Purkinje cells in cerebellum)       | Ralcewicz et al.<br>1995<br>Gamma Ray<br>[60]Co |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/ (strain)    | Duration/ Frequency of Administration | System | NOAEL | LOAEL        |           | Reference   |   |
|--------------|----------------------|---------------------------------------|--------|-------|--------------|-----------|---|---|
|              |                      |                                       |        |       | Less serious | Serious   |   |   |
| 85           | Rat (Sprague-Dawley) | Gd 13, 15 or 17                       |        |       |              | 75 rad    | (decr. performance on functional tests; decr. motor activity PND 21; 11-23 % decr. thickness in 3 areas of cerebral cortex PND 21)      | Norton and Kilmer 1988<br>Gamma Ray [137]Cs   |
| 86           | Dog (Beagle)         | once                                  |        |       |              | 83 rad    | (premolar hypodontia)   | Lee et al. 1989<br>Gamma Ray [60]Co           |
| 87           | Rat (Sprague-Dawley) | Gd 11 or 17<br>2 min                  |        |       |              | 100 rad   | (24% decr. body weight; decr. performance on reflex suspension test; decr. thickness of sensorimotor cortex)                            | Norton and Kilmaer 1987<br>Gamma Ray [137]Cs  |
| 88           | Mouse (ICR)          | 7.5 min                               |        |       |              | 150 rad   | (exencephalia, cleft palate, open eyelid & paw malformations)   | Kusama and Hasegawa 1993<br>Gamma Ray [137]Cs |
| 89           | Rat (Wistar)         | Gd 20                                 |        |       |              | 210 rad   | (20% decr. body wt; 79% decr. testes, 72% ventral prostate, & 60% seminal vesicle wts; disrupted spermatogenesis & androgen production) | Suzuki et al. 1990<br>Gamma Ray [60]Co        |
| 90           | Rat (Wistar)         | Gd 13, 14, or 15                      |        |       |              | 400 rad   | (31-79% decr. fetal survival)   | Koshimoto et al. 1994<br>Gamma Ray [137]Cs    |
| 91           | Mouse (Swiss)        | Gd 12                                 |        |       |              | 400 rad F | (clefts of the secondary palate)  | Saad et al. 1991<br>Gamma Ray [137]Cs         |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/<br>(strain)    | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL  |   | Reference                                      |
|--------------|-------------------------|---|--------|-------|--|---|--|
|              |                         |   |        |       | Less serious   | Serious   |  |
| 92           | Mouse<br>(Swiss)        | Gd 12                                       |        |       |  | 400 rad F (reduced litter size, head measurements, & incr. in cleft palate) | Saad et al. 1994<br>Gamma Ray<br>[137]Cs       |
| 93           | Rat<br>(Fischer- 344)   | Gd 20                                       |        |       | 15 rad F (9-11 % decr. in pup relative cerebral cortex weight)   |   | Zaman et al. 1992<br>Gamma Ray<br>NS           |
| 94           | Mouse<br>(Swiss)        | Gd 11.5                                     |        |       | 50 rad (1% incr. incidence of microphthalmia)  |   | Devi et al. 1994<br>Gamma Ray<br>[60]Co        |
| 95           | Rat<br>(Sprague-Dawley) | Gd 15                                       |        |       | 50 rad (incr. total no. pyknotic cells and no. of macrophages in cortical mantle; decr. no. mitotic figures in ventricular zone) |   | Norton and Kimler 1990<br>Gamma Ray<br>[137]Cs |
| 96           | Rat<br>(Wistar)         | 4 or 6 d                                    |        |       | 56 rad F (13% decr. in brain weight)   |   | Reyners et al. 1991<br>Gamma Ray<br>[60]Co     |
| 97           | Rat<br>(Wistar)         | once<br>GD 13, 15,<br>17, or 19             |        |       | 100 rad (increase in reactive astrocyte proliferation)   |   | Janeczko et al. 1997<br>Gamma Ray<br>[60]Co    |
| 98           | Rat<br>(Wistar)         | Gd 13, 14,<br>or 15                         |        |       | 100 rad (incr. ratio of large hematocytes to small hematocytes)  |   | Koshimoto et al. 1994<br>Gamma Ray<br>[137]Cs  |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/<br>(strain)  | Duration/<br>Frequency of<br>Administration | System | NOAEL | LOAEL        |   | Reference                                      |
|--------------|-----------------------|---|--------|-------|--------------|---|--|
|              |                       |   |        |       | Less serious | Serious   |  |
| 99           | Mouse<br>(C57BL/6)    | Gd 14                                       |        |       | 100 rad      | (9% decr. brain weight, decr. area and length of cerebral hemispheres; incr. area of superior colliculi and its proportion to cerebral hemisphere length) | Minamisawa et al. 1990<br>Gamma Ray<br>[137]Cs |
| 100          | Mouse<br>(C57BL/6)    | Gd 14<br>4-8 min                            |        |       | 100 rad      | (incr. no. of instances of aggressive behavior in offspring; 16% decr. offspring body weight at 3 mo of age)  | Minamisawa et al. 1992<br>Gamma Ray<br>[137]Cs |
| 101          | Dog<br>(Beagle)       | Gd 28                                       |        |       | 100 rad      | (mild to moderate degenerative retinal lesions in offspring)  | Schweitzer et al. 1987<br>Gamma Ray<br>[60]Co  |
| 102          | Mouse<br>(CD-1)       | NS  |        |       | 100 rad M    | (inherited cell proliferation disadvantage by F1 & F2 embryos conceived at 6 & 7 wks; decr. body weight for rats conceived at week 6)                     | Wiley et al. 1997<br>Gamma Ray<br>[137]Cs      |
| 103          | Rat<br>(Fischer- 344) | Gd 20                                       |        |       | 150 rad      | (altered pivoting, cliff avoidance and upper jaw tooth eruption in offspring)   | Zaman et al. 1993<br>Gamma Ray<br>NS           |
| 104          | Dog<br>(Beagle)       | Gd 55                                       |        |       | 160 rad      | (moderate to severe bilateral degenerative retinal lesions in 75% of offspring)   | Schweitzer et al. 1987<br>Gamma Ray<br>[60]Co  |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number  | Species/ (strain)           | Duration/ Frequency of Administration | System | NOAEL     | LOAEL                                 |   | Reference                                |
|---------------|-----------------------------|---------------------------------------|--------|-----------|---------------------------------------|---|--|
|               |                             |                                       |        |           | Less serious                          | Serious   |  |
| 105           | Rat<br>(Fischer- 344)       | Gd 20                                 |        | 6.8 rad F |                                       |   | Zaman et al. 1992<br>Gamma Ray<br>NS     |
| 106           | Rat<br>(Fischer- 344)       | Gd 20                                 |        | 6.8 rad   |                                       |   | Zaman et al. 1993<br>Gamma Ray<br>NS     |
| 107           | Rat<br>(Sprague-<br>Dawley) | Gd 9.5<br>14-17 sec                   |        | 50 rad    |                                       |   | Bruni et al. 1994<br>Gamma Ray<br>[60]Co |
| 108           | Rat<br>(Wistar)             | Gd 20                                 |        |           | (decr. steroid hormone<br>production) |   | Inano et al. 1989<br>Gamma Ray<br>[60]Co |
| 109           | Rat<br>(Wistar)             | Gd 20                                 |        |           |                                       | (51-52% decr. body weight,<br>82% decr. testicular<br>weight, 66% decr. ovarian<br>weight)                | Inano et al. 1989<br>Gamma Ray<br>[60]Co |
| 110           | Human                       | NS                                    |        |           |                                       | >185<br>GBq<br>(incr. absolute 'null'<br>lymphocytes, decr.<br>absolute T lymphocytes,<br>decr. T4 cells) | Petrova et al. 1997<br>[137]Cs           |
| <b>Cancer</b> |                             |                                       |        |           |                                       |   |  |
| 111           | Human                       | NS                                    |        |           |                                       | 2.10 rad (CEL: lung cancer)   | Mancuso et al. 1977                      |
| 112           | Human                       | NS                                    |        |           |                                       | 2.10 rad (CEL: pancreatic cancers)  | Mancuso et al. 1977                      |
| 113           | Human                       | NS                                    |        |           |                                       | 2.10 rad (CEL: myelomas)  | Mancuso et al. 1977                      |



**Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)**

| Entry Number | Species/ (strain)       | Duration/ Frequency of Administration | System | NOAEL | LOAEL        |            | Reference  |
|--------------|-------------------------|---------------------------------------|--------|-------|--------------|------------|--|
|              |                         |                                       |        |       | Less serious | Serious    |  |
| 114          | Human                   | NS<br><br>(occup)                     |        |       |              | 15 rad     | (CEL: estimated doubling dose of cancers of radiosensitive tissues)<br>Kneale et al. 1981<br>Gamma Ray   |
| 115          | Dog<br>(Beagle)         | 10 min                                |        |       |              | 16 rad     | (CEL: cancers in 7 and neoplasms in 16 dogs out of 1,309; primarily squamous papilloma of eyelid)<br>Benjamin et al. 1986<br>Gamma Ray [60]Co  |
| 116          | Mouse<br>(ICR)          | 3x/wk<br><86 wk                       |        |       |              | 150 rad F  | (CEL: 23/96 osteosarcomas, optimum dose for induction was 250 to 350 cGy)<br>Ootsuyama and Tanooka 1989<br>Beta Particles [90]Sr-[90]Y   |
| 117          | Mouse<br>(CBA/H)        | 0-177 min                             |        |       |              | 1500 rad F | (CEL: signif. incr. in benign and malignant dermal tumors)<br>Hulse 1966<br>Beta Particles [204]Tl   |
| 118          | Mouse<br>(SAS/4 Albino) | 1 hr                                  |        |       |              | 2000 rad M | (CEL: 20% skin tumor incidence from 32 2-mm diameter source; 3% skin tumor incid. from 8 2-mm diam. source; 33% skin tumor incid. following uniform expos.)<br>Charles et al. 1988<br>Beta Particles [170]Th |
| 119          | Mouse<br>(SAS/4 Albino) | 1 hr                                  |        |       |              | 2000 rad   | (CEL: (20% increase in skin tumor incidence)<br>Charles et al. 1988<br>Beta Particles [170]Th  |
| 120          | Human                   | NS                                    |        |       |              | 0-10 mSv   | (CEL: childhood cancers associated with paternal exposure to radionuclides)<br>Sorahan and Roberts 1993<br>NS  |

Table 8-4. Levels of Significant Exposure to Radiation and Radioactive Material: External (continued)

| Entry Number | Species/ (strain) | Duration/ Frequency of Administration | System | NOAEL | LOAEL        |                                      | Reference                                      |
|--------------|-------------------|---------------------------------------|--------|-------|--------------|--------------------------------------|--|
|              |                   |                                       |        |       | Less serious | Serious                              |  |
| 121          | Human             | NS                                    |        |       |              | 0-10+ M (CEL: incr. lung cancer) rem | Checkoway et al. 1988<br>gamma and alpha [12]Y |

\* The reported dose at a distant location on the body, so the actual dose to the effected tissue was probably much higher.

BALF = bronchioalveolar lavage fluid; Bd Wt = body weight; Cardio = cardiovascular; CEL = cancer effect level; Con A = concanavalin A; d = day(s); decr = decrease; ECG = electrocardiograph; Endocr = endocrine; F = female; Gastro = gastrointestinal; GBq = GigaBecquerel; Gn pig = guinea pig; Hemato = hematological; hr = hour(s); incr = increase; ILB = initial lung burden; incr = increase; LOAEL = lowest-observable-adverse-effect level; LVEF = left ventricular ejection fraction; M = male; Metab = metabolism; min = minute(s); mo = month(s); no. = number; NOAEL = no-observable-adverse-effect level; NS = not specified; occup = occupational; pcd = days post coitus; PDN = post-natal day; Resp = respiratory; sec = second(s); SGOT = serum glutamic oxaloacetic transaminase; signif. = significant; wk = week(s); wt = weight; yr = year(s); x = times