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

(μCi/kg or Bq/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 (μCi/kg or Bq/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

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.

(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/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
	Death							
1	Rat (Fischer- 344)	20 min				71 rad M	(decr. median survival time in fibrotic vs non-fibrotic rats)	Lundgren et al. 1991 Alpha Particles [239]PuO2
2	Rat (Fischer- 344)	20 min				340 rad F	(decr. median survival time in fibrotic vs non-fibrotic rats)	Lundgren et al. 1991 Alpha Particles [239]PuO2
3	Dog (Beagle)	3-46 min				8,400 rad	(21/33 dogs died-7.5 to 163 d post-exposure)	Hobbs et al. 1972 Beta Particles [90]Y
4	Dog (Beagle)	once				8700 rad	(3/4 died)	Benjamin et al. 1976 Beta Particles [90]Y
5	Dog (Beagle)	once				10,000 rad	(16/16 dogs died 12 to 163 d post exp)	McClellan et al. 1970 Beta Particles [90]Y
6	Dog (Beagle)	<70 min				15,000 rad	(40/96 died <3 yrs post exposure)	Boecker et al. 1988 Beta Particles [91]Y
7	Dog (Beagle)	once				27,000 rad	(14/16 died or were sacrificed due to severe condition within 5 yrs post exposure)	Benjamin et al. 1978 Beta-Gamma Particles [144]Ce

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
8	Dog (Beagle)	once				39,000 rad	(1/4 died)	Benjamin et al. 1976 Beta Particles [90]Sr
9	Dog (Beagle)	once				42,000 rad	(2/4 died)	Benjamin et al. 1976 Beta Particles [144]Ce
10	Dog (Beagle)	once				48,000 rad	(9/9 dogs died 143- 410 d post exposure)	McClellan et al. 1970 Beta Particles [144]Ce
11	Monkey (Rhesus)	once				270 nCiM	(5/5 animals died 430- 4334 d after exposure)	Hahn et al. 1987 Alpha Particles [239]PuO2
12	Monkey (Cynomol- gus)	once				1.08 uCiM	(3/12 died)	Brooks et al. 1992 Alpha Particles [239]Pu
13	Mouse (CFW)	10-20 min				21 uCiM	(survival 12% of controls, with median survival of 66 d)	Lundgren et al. 1981 Beta Particles [90]Y
14	Rat (Fischer- 344)	1x/2 mo 1 yr (7x)				32.4 uCi	(29.3-31.9% shortened life span)	Hahn and Lundgren 1992 Beta Particles [144]CeO2

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
15	Dog (Beagle)	once				320 uCi	(5 dogs died, 93- 279 d post exposure)	McClellan et al. 1970 Beta Particles [144]Ce
16	Dog (Beagle)	once				320 uCi	(5 dogs died, 93- 279 d post exposure)	McClellan et al. 1970 Beta Particles [144]Ce
17	Dog (Beagle)	once				0.26 uCi/kg	(death in 8/24 dogs over 1125- 2143 d post-exposure)	Hahn et al. 1981 Alpha Particles [238]PuO2
18	Dog (Beagle)	once				0.97 uCi/kg	(51/72 died)	Benjamin et al. 1979 Beta Particles [90]SrCl2
19	Dog (Beagle)	once				1.7 uCi/kg	(27/72 died at 585+ d)	McClellan et al. 1973 Beta Particles [90]SrCl2
20	Dog (Beagle)	once				2.6 uCi/kg	(43/55 died)	Benjamin et al. 1979 Beta Particles [144]CeCl3
21	Dog (Beagle)	once				14 uCi/kg	(21/46 died)	Benjamin et al. 1979 Beta Particles [91]YCl3

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
22	Dog (Beagle)	2-22 min				45.9 uCi/kg	(death in 6/66 animals within 32 d)	Gillett et al. 1987a Beta Particles [90]SrCl2
23	Dog (Beagle)	once				74 uCi/kg	(6/72 dogs died at 18-31 d)	McClellan et al. 1973 Beta Particles [90]SrCl2
24	Dog (Beagle)	<70 min				NS	(58/96 died >3 yrs post exposure)	Boecker et al. 1988 Beta Particles [91]Y
	Systemic							
25	Hamster (Syrian)	1-45 min	Resp			40 radM	(radiation pneumonitis in 8%)	Lundgren et al. 1983 Alpha Particles [239]PuO2
26	Hamster (Syrian)	1 yr 7x/yr 1-45 min/x	Resp			220 radM	(radiation pneumonitis in 40% and bronchiolar epithelial hyperplasia in 35%)	Lundgren et al. 1983 Alpha Particles [239]PuO2
27	Dog (Beagle)	once	Resp			3700 rad	(severe radiation pneumonitis and pulmonary fibrosis in 7/144)	Hahn et al. 1981 Alpha Particles [238]PuO2
28	Dog (Beagle)	once	Resp			8700 rad	(pneumonitis, fibrosis, inflammation in 3/4 dogs)	Benjamin et al. 1976 Beta Particles [90]Y

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL				Reference Chemical Form
					Less serious		Serious		
29	Dog (Beagle)	once	Resp				27,000 rad	(pneumonitis and pulmonary fibrosis)	Benjamin et al. 1978 Beta-Gamma Particles [144]Ce
30	Dog (Beagle)	once	Resp				39,000 rad	(dyspnea and cyanosis; pneumonitis and fibrosis in 1/4 dogs)	Benjamin et al. 1976 Beta Particles [90]Sr
31	Dog (Beagle)	once	Resp				42,000 rad	(pneumonitis, fibrosis, inflammation in 2/4 dogs)	Benjamin et al. 1976 Beta Particles [144]Ce
32	Dog (Beagle)	once	Resp		230 rad	(decr. lung capacity & compliance, & incr. respiratory frequency & minute volume)			Muggenburg et al. 1988 Alpha Particles [239]PuO2
33	Rat (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)			Lundgren et al. 1991 Alpha Particles [239]PuO2
34	Dog (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)			Hobbs et al. 1972 Beta Particles [90]Y

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
35	Monkey (Rhesus)	once	Resp			270 nCi M	(pulmonary fibrosis)	Hahn et al. 1987 Alpha Particles [239]PuO2
36	Monkey (Rhesus)	once	Resp			1000 nCi M	(radiation pneumonitis and pulmonary fibrosis)	LaBauve et al. 1980 Alpha Particles [239]PuO2
37	Monkey (Rhesus)	once	Resp	210 nCi M				Hahn et al. 1987 Alpha Particles [239]PuO2
38	Monkey (Cynomol- gus)	once	Resp			0.27 uCi M	(2/2 fibrosis, 1/2 pneumonitis)	Brooks et al. 1992 Alpha Particles [239]Pu
39	Mouse (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. 1980a Beta Particles [144]CeO2
40	Mouse (CFW)	10-20 min	Resp			21uCi M	(radiation pneumonitis in 75-100% of mice)	Lundgren et al. 1981 Beta Particles [90]Y
41	Dog (Beagle)	28-53 min	Resp			24,000 uCi	(radiation pneumonitis in 6/7 dogs)	Hahn et al. 1975 Beta Particles [90]Y

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL				Reference Chemical Form
					Less serious		Serious		
42	Monkey (Cynomol- gus)	once	Resp	0.108 M uCi					Brooks et al. 1992 Alpha Particles [239]Pu
43	Mouse (C57BL/6J)	once	Resp	1.1 uCi F					Lundgren et al. 1980a Beta Particles [144]CeO2
44	Dog (Beagle)	once	Resp				2.6 uCi/kg	(3/55 radiation pneumonitis, pulmonary fibrosis)	Benjamin et al. 1979 Beta Particles [144]CeCl3
45	Dog (Beagle)	<1 hr	Resp				33 uCi/kg	(radiation pneumonitis)	Hahn et al. 1976 Beta Particles [144]Ce
46	Dog (Beagle)	3-46 min	Cardio		8,400 rad	(ECG changes in 5/12 and hemorrhagic areas near ventricular junction in right atria of 7/12 dogs dying 64-92 d post exposure)			Hobbs et al. 1972 Beta Particles [90]Y
47	Dog (Beagle)	once	Cardio	3200 rad					Muggenburg et al. 1988 Alpha Particles [239]PuO2
48	Dog (Beagle)	28-53 min	Gastro				3200 rads	(colon lesion, ulcerative and atrophic foci in 1/2 dogs)	Hahn et al. 1975 Beta Particles [90]Y

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL				Reference Chemical Form
					Less serious		Serious		
49	Dog (Beagle)	28-53 min	Gastro		32,000 uCi	(colitis in 2/7 dogs)			Hahn et al. 1975 Beta Particles [90]Y
50	Dog (Beagle)	2-22 min	Gastro		45.9 uCi/kg	(diarrhea)			Gillett et al. 1987a Beta Particles [90]SrCl2
51	Dog (Beagle)	3-46 min	Hemato				8,400 rad	(lymphopenia)	Hobbs et al. 1972 Beta Particles [90]Y
52	Dog (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. 1972 Beta Particles [90]Y
53	Monkey (Cynomol- gus)	once	Hemato	1.08 uCi M					Brooks et al. 1992 Alpha Particles [239]Pu
54	Dog (Beagle)	once	Hemato				0.97 uCi/kg	(bone marrow aplasia)	Benjamin et al. 1979 Beta Particles [90]SrCl2
55	Dog (Beagle)	once	Hemato				2.6-360 uCi/kg	(9/55 bone marrow aplasia)	Benjamin et al. 1979 Beta Particles [144]CeCl3

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL				Reference Chemical Form
					Less serious		Serious		
56	Dog (Beagle)	once	Hemato				14 uCi/kg	(11/46 bone marrow aplasia)	Benjamin et al. 1979 Beta Particles [91]YCl3
57	Dog (Beagle)	2-22 min	Hemato				45.9 uCi/kg	(bone marrow hypoplasia)	Gillett et al. 1987a Beta Particles [90]SrCl2
58	Dog (Beagle)	2-22 min	Hemato		9.99 uCi/kg	(decreased platelet counts)			Gillett et al. 1987a Beta Particles [90]SrCl2
59	Hamster (Syrian)	1 yr 7x/yr 1-45 min/x	Hepatic				3900 rad M	(degenerative liver lesions in 40%)	Lundgren et al. 1983 Alpha Particles [239]PuO2
60	Dog (Beagle)	3-46 min	Hepatic		8,400 rad	(moderate or marked centrilobular hepatic congestion in deaths >38d, no necrosis)			Hobbs et al. 1972 Beta Particles [90]Y
61	Dog (Beagle)	once	Hepatic				2.6-360 uCi/kg	(3/55 hepatic degeneration)	Benjamin et al. 1979 Beta Particles [144]CeCl3
62	Dog (Beagle)	3-46 min	Dermal		8,400 rad	(alopecia, atrophy and loss of hair follicles in 4/33 dogs)			Hobbs et al. 1972 Beta Particles [90]Y

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL				Reference Chemical Form
					Less serious		Serious		
63	Dog (Beagle)	28-53 min	Dermal		?	(nasal dermatitis in 4/7 dogs)			Hahn et al. 1975 Beta Particles [90]Y
64	Dog (Beagle)	3-46 min	Bd Wt		8,400 rad	(anorexia and progressive weight loss)			Hobbs et al. 1972 Beta Particles [90]Y
65	Dog (Beagle)	2-22 min	Metab		45.9 uCi/kg	(fever)			Gillett et al. 1987a Beta Particles [90]SrCl2
	Immunological/Lymphoreticular								
66	Dog (Beagle)	once					1400 rad	(fibrosis, atrophy, or hyperplasia in lymph nodes)	Galvin et al. 1989 Alpha Particles [239]PuO2
67	Dog (Beagle)	once					27,000 rad	(60% decr. in lymphocyte count)	Benjamin et al. 1978 Beta-Gamma Particles [144]Ce
68	Dog (Beagle)	once					39,000 rad	(lymphopenia and decr. in lymphocyte function)	Benjamin et al. 1976 Beta Particles [90]Sr
69	Dog (Beagle)	once					42,000 rad	(lymphopenia and decr. in lymphocyte function)	Benjamin et al. 1976 Beta Particles [144]Ce

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL				Reference Chemical Form
					Less serious		Serious		
70	Dog (Beagle)	once			520 rad	(decr. response of lymphocytes to PHA in middle aged dogs)			Davila et al. 1992 Alpha Particles [239]PuO2
71	Dog (Beagle)	once			740 rad	(decr. response of lymphocytes to Con A and PHA in aged tumor bearing dogs)			Davila et al. 1992 Alpha Particles [239]PuO2
72	Dog (Beagle)	once			1400 rad	(incr. IgG in lung; neutrophils six-fold higher in lungs)			Galvin et al. 1989 Alpha Particles [239]PuO2
73	Dog (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. 1972 Beta Particles [90]Y
74	Mouse (CFW)	10-20 min			7 uCi M	(incr. number vacuolated macrophages)			Lundgren et al. 1976 Beta Particles [90]Y
75	Mouse (CFW)	10-20 min			8 uCi M	(equivocal suppression of pulmonary bacterial clearance at 2 and 3 wk post-exposure)			Lundgren et al. 1976 Beta Particles [90]Y
76	Dog (Beagle)	<1 hr					51 uCi/kg	(severe atrophy and fibrosis in both cortex and paracortex)	Hahn et al. 1976 Beta Particles [144]Ce

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
	Cancer							
77	Dog (Beagle)	once				180 rad	(CEL: osteoblastic osteosarcomas in 4/15 dogs)	Gillett et al. 1985 Beta Particles [241]AmO2
78	Dog (Beagle)	once				180 rad	(CEL: osteoblastic osteosarcomas in 4/15 dogs)	Gillett et al. 1985 Beta Particles [241]AmO2
79	Dog (Beagle)	once				190 radM	(CEL: oral melanoma)	Muggenburg et al. 1988 Alpha Particles [239]PuO2
80	Dog (Beagle)	once				200 rad	(CEL: 30 lung tumors observed, 1.2 expected)	Hahn et al. 1988 Beta Particles [144]Ce
81	Dog (Beagle)	once				210 rad	(CEL: osteosarcomas in 35/144 exposed dogs)	Hahn et al. 1981 Alpha Particles [238]PuO2
82	Dog (Beagle)	<70 min				310 rad	(CEL: 28/36 lung cancer)	Boecker et al. 1988 Alpha Particles [239]PuO2
83	Dog (Beagle)	once				800 rad	(CEL: nasal squamous cell carcinomas in 5/55)	Benjamin et al. 1979 Beta Particles [144]CeCl3

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

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

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
91	Dog (Beagle)	once				3200 rad	(CEL: 2 heart tumors)	Hahn et al. 1988 Beta Particles [144]Ce
92	Dog (Beagle)	once				3200 rad	(CEL: 9 TBLN tumors)	Hahn et al. 1988 Beta Particles [144]Ce
93	Dog (Beagle)	<70 min				3500 rad	(CEL: lung cancer in 32/56)	Boecker et al. 1988 Beta Particles [91]Y
94	Dog (Beagle)	10-15 min				7,000 rad	(CEL: pulmonary carcinomas and sarcomas)	Hahn et al. 1983 Beta Particles [90]Y, [91]Y, [144]Ce, [90]Sr
95	Dog (Beagle)	once				7100 rads	(CEL: 2/72 other carcinomas of the head)	Benjamin et al. 1979 Beta Particles [90]SrCl2
96	Dog (Beagle)	once				7700 rad	(CEL: 14 heart tumors)	Hahn et al. 1988 Beta Particles [90]Sr
97	Dog (Beagle)	once				7700 rad	(CEL: 8 TBLN tumors)	Hahn et al. 1988 Beta Particles [90]Sr

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
98	Dog (Beagle)	once				8100 rad	(CEL: 1/55 bone related sarcomas)	Benjamin et al. 1979 Beta Particles [144]CeCl3
99	Dog (Beagle)	once				9600 rad	(CEL: 1 heart tumor)	Hahn et al. 1988 Beta Particles [91]Y
100	Dog (Beagle)	once				9600 rad	(CEL: 2 TBLN tumors)	Hahn et al. 1988 Beta Particles [91]Y
101	Dog (Beagle)	once				13000 rad	(CEL: 1/72 nasal squamous cell carcinomas)	Benjamin et al. 1979 Beta Particles [90]SrCl2
102	Dog (Beagle)	2-48 min				16,000 rad	(CEL: bronchiolo-alveolar carcinomas and pulmonary hemangiosarcomas)	Hahn et al. 1977 Beta Particles [90]Y, [91]Y, [144]Ce, [90]Sr
103	Dog (Beagle)	once				18,000 rad	(CEL: 28 lung tumors observed, 1.2 expected)	Hahn et al. 1988 Beta Particles [90]Sr
104	Dog (Beagle)	once				27,000 rad	(CEL: pulmonary neoplasms in 5/16 dogs)	Benjamin et al. 1978 Beta-Gamma Particles [144]Ce

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
105	Rat (Fischer- 344)	once				0.06 uCi	(CEL: pulmonary adenocarcinoma in 1/35)	Hahn and Lundgren 1992 Beta Particles [144]CeO2
106	Rat (Fischer- 344)	7x 1x/2 mo 1 yr				0.35 uCi	(CEL: pulmonary adenocarcinoma and adenoma in 2/36)	Hahn and Lundgren 1992 Beta Particles [144]CeO2
107	Mouse (CFW)	10-20 min				1 uCiM	(CEL: pulmonary adenomas)	Lundgren et al. 1981 Beta Particles [90]Y
108	Monkey (Cynomol- gus)	once				1.08 uCiM	(CEL: lung cancer in 1/8)	Brooks et al. 1992 Alpha Particles [239]Pu
109	Dog (Beagle)	2-22 min				7.02 uCi/kg	(CEL: primary bone neoplasa in 30/66 dogs: osteosarcoma, hemangiosarcomas, fibrosarcomas, myxosarcoma)	Gillett et al. 1987b Beta Particles [90]SrCl2
110	Dog (Beagle)	once				NS	(CEL: 100/144 osteosarcomas)	Gillett et al. 1988 Alpha Particles [238]PuO2
111	Dog (Beagle)	once				NS	(CEL: 28/144 lung tumors)	Gillett et al. 1988 Alpha Particles [238]PuO2

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

Entry Number	Species (strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
					Less serious	Serious		
112	Dog (Beagle)	once				NS	(CEL: lung tumors in 47/144 dogs; bronchioalveolar carcinomas & papillary adenocarcinomas)	Muggenburg et al. 1994 Alpha Particles [238]PuO2
113	Dog (Beagle)	once				NS	(CEL: skeletal tumors in 92/144; osteosarcomas)	Muggenburg et al. 1994 Alpha Particles [238]PuO2
114	Dog (Beagle)	once				NS	(CEL: malignant liver tumors in 13/144)	Muggenburg et al. 1994 Alpha Particles [238]PuO2

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		
	Systemic							
1	Human	4.7 yr	Musc/skel	1,851 F rad (17-19 yr of age)				Polednak and Farnham 1980 Alpha Particles [226]Ra
2	Human	4.7 yr	Musc/skel	10,110 F rad (13-16 yr of age)				Polednak and Farnham 1980 Alpha Particles [226]Ra
	Reproductive							
3	Mouse (Hybrid)	2 wk 1x/d				140 rad	(incr. embryo mortality)	Ramaiya et al. 1994 Beta Particles [137]Cs
4	Mouse (Hybrid)	once				180 rad	(incr. post-implantation embryo mortality)	Ramaiya et al. 1994 Beta Particles [137]Cs
5	Mouse (Hybrid)	once			190 rad M		(decreased fertility)	Ramaiya et al. 1994 Beta Particles [137]Cs
6	Mouse (Hybrid)	2 wk 1x/d			350 rad M		(reduced effective mating)	Ramaiya et al. 1994 Beta Particles [137]Cs

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

Entry Number	Species/ (Strain)	Duration/ Frequency of Administration (Specific Route)	System	NOAEL	LOAEL		Reference Chemical Form
					Less Serious	Serious	
7	Mouse (Hybrid)	once		100 rad M			Ramaiya et al. 1994 Beta Particles [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/ (Strain)	Duration/ Frequency of Administration	System	NOAEL	LOAEL			Reference Chemical Form
				Less Serious		Serious	
Systemic							
Hamster (Syrian golden & white)	once	Dermal		2000 rad	(epilation)		Garcia and Shubik 1971 Beta Particles [85]Kr
Gn Pig (Albino)	once	Dermal		3000 rep M	(incr. vascular permeability)		Song et al. 1968 Beta Particles [90]Sr-[90]Y
Neurological							
Human	once			38.2 rad M	(tingling, pain, sensitive to touch and temperature changes)		Berger et al. 1996 X-ray 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	
	Death						
1	Rat (Sprague-Dawley)	once				10 rad M (1/9 died)	Canfi et al. 1990 Gamma Ray [192]Ir
2	Mouse (ICR)	3x/wk <86 wk				150 rad F (13/21 died)	Ootsuyama and Tanooka 1989 Beta Particles [90]Sr-[90]Y
3	Rat (Wistar)	once				800 rad M (45% died through d 15)	Salovsky and Shopova 1992 Gamma Ray NS
4	Human	once (occup)				2250 rad M (death 13 d after exposure)	Stavem et al. 1985 Gamma Ray NS
	Systemic						
5	Pig (Large white)	once	Resp			1280 rad F (severe thickening of interlobular septa)	Rezvani et al. 1989 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 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 (occup)	Resp		2250 rad M (few mononuclear cells and no granulocytes in resp. tract)		Stavem et al. 1985 Gamma Ray NS
8	Monkey (Rhesus)	1.38 min	Cardio			10,000 M rad (66% decr. blood pressure 20 min post-exposure)	Cockerham et al. 1986 Gamma Ray [60]Co
9	Human	once (occup)	Cardio		2250 rad M (hypertrophic ventricle)		Stavem et al. 1985 Gamma Ray
10	Dog (Beagle)	once	Cardio		3000 rad M (focal area of pervasculitis, reduction in LVEF)		Durakovic 1986a Gamma Ray [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 Gamma Ray [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 Gamma Ray [60]Co
13	Human	once (occup)	Gastro		2250 rad M (atrophy of glands in stomach, small intestine, and large intestine; diarrhea)		Stavem et al. 1985 Gamma Ray

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		
14	Monkey (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 Gamma Ray [60]Co
15	Dog (NS)	20-1700 d 22 hr/d	Hemato		1.88 rad/d	(decreased lymphocytes, thrombocytes and neutrophilic granulocytes)			Nothdurft et al. 1995 Gamma Ray [60]Co
16	Dog (NS)	20-1700 d 22 hr/d	Hemato		1.88 rad/d	(decreased lymphocytes, thrombocytes and neutrophilic granulocytes)			Nothdurft et al. 1995 Gamma Ray [60]Co
17	Mouse (ICR)	once	Hemato		5 rad M	(significantly decreased leukocyte counts on day 1 post irradiation)			Lin et al. 1996 Gamma Ray NS
			Bd Wt		5 rad M	(body weight significantly decreased 11.6% on day19 post irradiation)			
18	Dog (Beagle)	150 - 300 d 22 hr/d	Hemato		7.5 rad/d M	(suppression/recovery for granulocytes, monocytes, leukocytes, platelets, & erythrocytes)			Seed et al. 1989 Gamma Ray [60]Co
19	Dog (Beagle)	150-300 d 22 hr/d	Hemato		7.5 rad/d F	(suppression/recovery for granulocytes, monocytes, leukocytes, platelets, & erythrocytes)			Seed et al. 1993 Gamma Ray [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 X-ray 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 Gamma Ray [60]Co
22	Human	once	Hemato		* 159 rad M (decr. leukocyte, neutrophil, and lymphocyte counts)		Klener et al. 1986 Gamma Ray [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 Gamma Ray [60]Co
24	Human	once	Hemato		2250 rad M (decr. leukocyte count, elevated serum creatinine, and hypocellular bone marrow)		Stavem et al. 1985 Gamma Ray NS
		(occup)					
25	Mouse (CBA/H)	0-177 min	Hemato	12,000 F rad			Hulse 1966 Beta Particles [204]Tl

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	
26	Dog (Beagle)	once	Hepatic		400 rad M (signif. decrease in SGOT)		Durakovic 1986b Gamma Ray [60]Co
27	Mouse (Swiss)	once	Hepatic		1000 rad M (incr. acid phosphatase activity, decr. protein content)		Mazur et al. 1991 Gamma Ray [60]Co
28	Human	once (occup)	Renal		2250 rad M (anuria, enlarged kidneys, and interstitial edema)		Stavem et al. 1985 Gamma Ray NS
29	Rat (Sprague-Dawley)	once	Endocr		1.0 rad M (decr. in hypophyseal and serum FSH)		Canfi et al. 1990 gamma ray [192]Ir
30	Human	2 mo-3 yr	Endocr		200 rad M (decreased LH)		Birioukov et al. 1993 Beta and Gamma NS
31	Rat (Sprague-Dawley)	once	Endocr	0.1 rad M			Canfi et al. 1990 gamma ray [192]Ir
32	Human	once (occup)	Dermal			* 159 rad M (painful hard swelling of deep skin layers of hand resulting in amputation of fingers)	Klener et al. 1986 Gamma Ray [60]Co
33	Human	2 mo-3 yr	Dermal			200 rad M (radiation dermatitis)	Birioukov et al. 1993 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 Beta Particles [90]Sr-[90]Y
35	Mouse (CBA/H)	0-177 min	Dermal				3000 rad F (radiation burns)	Hulse 1966 Beta Particles [204]Tl
36	Pig (Large white)	1x or 6x	Dermal				12,000 rad (skin and skeletal muscle ulcerations)	Lefaix et al. 1993 Gamma Ray [192]Ir
37	Human	once (occup)	Dermal		* 159 rad M	(reddening and inflammation of hand and epilation)		Klener et al. 1986 Gamma Ray [60]Co
38	Mouse (CBA/H)	0-177 min	Dermal		750 rad F	(hair depigmentation and hyperkeratotic areas)		Hulse 1966 Beta Particles [204]Tl
39	Mouse (Albino)	0-177 min	Dermal		1500 rad	(slight erythema)		Hulse 1966 Beta Particles [204]Tl
40	Pig (Large white)	1x or 6x	Dermal		3200 rad	(erythma)		Lefaix et al. 1993 Gamma Ray [192]Ir
41	Mouse (Albino)	0-177 min	Dermal	750 rad				Hulse 1966 Beta Particles [204]Tl

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 Beta Particles [90]Sr-[90]Y
43	Pig (Large white)	1x or 6x	Dermal	1600 rad					Lefaix et al. 1993 Gamma Ray [192]Ir
44	Human	once	Ocular				200 rad	(cataracts)	Lipman et al. 1988 x-ray and beta NS
45	Dog (Beagle)	pcd 2	Ocular				300 rad	(severe bilateral degenerative retinal lesions in 99% of offspring)	Schweitzer et al. 1987 Gamma Ray [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 X-ray NS
47	Human	once (occup)	Ocular		* 159 rad M	(deterioration of visual acuity)			Klener et al. 1986 Gamma Ray [60]Co
48	Human	2 mo-3 yr	Ocular		200 rad M	(vision impairment)			Birioukov et al. 1993 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	
49	Rat (Sprague-Dawley)	Gd 13, 15 or 17	Bd Wt	100 rad F			Norton and Kilmer 1988 Gamma Ray [137]Cs
50	Rat (Sprague-Dawley)	Gd 15	Bd Wt	100 rad F			Norton and Kimler 1990 Gamma Ray [137]Cs
51	Rat (Fischer- 344)	Gd 20	Bd Wt	150 rad F			Zaman et al. 1992 Gamma Ray NS
52	Rat (Fischer- 344)	Gd 20	Bd Wt	150 rad F			Zaman et al. 1993 Gamma Ray NS
53	Human	once (occup)	Metab		* 159 rad M (irregular subfebrile temperatures)		Klener et al. 1986 Gamma Ray [60]Co
54	Human	once (occup)	Metab		2250 rad M (fever)		Stavem et al. 1985 Gamma Ray NS
55	Human	2 mo-3 yr	Other			200 rad M (acute radiation sickness)	Birioukov et al. 1993 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		
	Immunological/Lymphoreticular								
56	Mouse (NS)	1-30 d			0.6 rad M	(moderate change in stem cell radiosensitivity)			Rozhdestvensky & Fomicheva 1995 Gamma Ray
57	Human	once					2250 rad M	(congestion and hemorrhage of spleen)	Stavem et al. 1985 Gamma Ray NS
		(occup)							
58	Dog (NS)	20-1700 d 22 hr/d			1.88 rad/d	(decreased GM-CFC levels in bone marrow; increased CSA levels)			Nothdurft et al. 1995 Gamma Ray [60]Co
59	Dog (NS)	20-1700 d 22 hr/d			1.88 rad/d	(decreased GM-CFC levels in bone marrow; increased CSA levels)			Nothdurft et al. 1995 Gamma Ray [60]Co
60	Mouse (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 Gamma Ray [60]Co
61	Human	once			2250 rad M	(decr. number of lymphocytes and hypocellular lymph nodes)			Stavem et al. 1985 Gamma Ray NS
		(occup)							
62	Mouse (ICR)	once		5 M	50 rad M	(significantly decreased spleen weight on day 12 post irradiation)			Lin et al. 1996 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		
63	Monkey (Rhesus)	>1 yr		12.5-10 0 rad/min					Stone et al. 1994 High energy protons NS
64	Monkey (Rhesus)	once		10-100 rad/min					Stone et al. 1994 X-ray
	Neurological								
65	Monkey (Rhesus)	1.38 min					10,000 M rad	(51 and 63% decr. blood flow to reticular formation of pons & motor cortex, resp.)	Cockerham et al. 1986 Gamma Ray [60]Co
66	Rat (Sprague-Dawley)	once			200 rad	(increased brain expression of apoptosis-associated protein c-jun)			Ferrer et al. 1996 Gamma Ray [60]Co
67	Rabbit (Burgundy fawn)	once			450 rad M	(increased firing interval in pyramidal cells)			Bassant and Court 1978 Gamma Ray [60]Co
68	Rat (Wistar)	once			1435 rad M	(decreased catecholamine levels)			Pastorova et al. 1997 [60]Co ionizing radiation
	Reproductive								
69	Mouse (B6C3F1)	10-50 wk 1x/wk 20 min/x					5 rad M	(sperm abnormalities)	Grahn and Carnes 1988 Gamma Ray [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		
70	Mouse (B6C3F1)	60 wk 1x/wk 20 min/x				5 rad M	(sperm abnormalities)	Grahn and Carnes 1988 Gamma Ray [60]Co
71	Mouse (NS)	22-25 d				80 rad	(incr. post-implantation mortality in progeny)	Shevchenko et al. 1992 Gamma and beta NS
72	Human	2 mo-3 yr				200 rad M	(impotency, abnormal sperm, and decr. viability of spermatozoa)	Birioukov et al. 1993 Beta and Gamma NS
73	Mouse (Hybrid)	once				300 rad M	(sterility and decr. fertility)	Ramaiya et al. 1994 Gamma Ray [137]Cs
74	Mouse (Hybrid)	once				300 rad	(incr. total and post-implantation embryo mortality)	Ramaiya et al. 1994 Gamma Ray [137]Cs
75	Mouse (NS)	22-25 d (environ)				300 rad M	(reversible sterility, reduced testes mass)	Shevchenko et al. 1992 Gamma and beta NS
76	Rat (Sprague-Dawley)	once				900 rad M	(decr. testis wt, epididymal wt & epididymal content ABP & damaged spermatocytes)	Pinon-Lataillade et al. 1991 Gamma Ray [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		
77	Mouse (Hybrid)	28 wk				1,128 rad M	(65% reduced testis mass)	Searle et al. 1976 Gamma Ray [60]Co
78	Mouse (Hybrid)	28 wk				1,128 rad	(incr. pre- and post-implantation loss)	Searle et al. 1976 Gamma Ray [60]Co
79	Mouse (Hybrid)	28 wk				1,128 rad M	(85% reduced epididymal sperm-count)	Searle et al. 1976 Gamma Ray [60]Co
80	Rat (Sprague-Dawley)	once			1 rad M	(25% decrease in fertility)		Canfi et al. 1990 gamma ray [192]Ir
	Developmental							
81	Rat (Sprague-Dawley)	once				1 rad M	(17% decr. pup weight at weaning)	Canfi et al. 1990 gamma ray [192]Ir
82	Mouse (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 Gamma Ray [60]Co
83	Rat (Wistar)	Gd 10 3 sec				40 rad	(32.2% fetal mortality, 53 resorption sites)	Roux et al. 1986 Gamma Ray [60]Co
84	Rat (Sprague-Dawley)	16.5 sec				50 rad	(loss of granule cells, atrophied/reduced number of Purkinje cells in cerebellum)	Ralcewicz et al. 1995 Gamma Ray [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 Gamma Ray [137]Cs
86	Dog (Beagle)	once				83 rad	(premolar hypodontia)	Lee et al. 1989 Gamma Ray [60]Co
87	Rat (Sprague-Dawley)	Gd 11 or 17 2 min				100 rad	(24% decr. body weight; decr. performance on reflex suspension test; decr. thickness of sensorimotor cortex)	Norton and Kilmaer 1987 Gamma Ray [137]Cs
88	Mouse (ICR)	7.5 min				150 rad	(exencephalia, cleft palate, open eyelid & paw malformations)	Kusama and Hasegawa 1993 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 Gamma Ray [60]Co
90	Rat (Wistar)	Gd 13, 14, or 15				400 rad	(31-79% decr. fetal survival)	Koshimoto et al. 1994 Gamma Ray [137]Cs
91	Mouse (Swiss)	Gd 12				400 rad F	(clefts of the secondary palate)	Saad et al. 1991 Gamma Ray [137]Cs

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		
92	Mouse (Swiss)	Gd 12					400 rad F	(reduced litter size, head measurements, & incr. in cleft palate)	Saad et al. 1994 Gamma Ray [137]Cs
93	Rat (Fischer- 344)	Gd 20			15 rad F	(9-11 % decr. in pup relative cerebral cortex weight)			Zaman et al. 1992 Gamma Ray NS
94	Mouse (Swiss)	Gd 11.5			50 rad	(1% incr. incidence of microphthalmia)			Devi et al. 1994 Gamma Ray [60]Co
95	Rat (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 Gamma Ray [137]Cs
96	Rat (Wistar)	4 or 6 d			56 rad F	(13% decr. in brain weight)			Reyners et al. 1991 Gamma Ray [60]Co
97	Rat (Wistar)	once GD 13, 15, 17, or 19			100 rad	(increase in reactive astrocyte proliferation)			Janeczko et al. 1997 Gamma Ray [60]Co
98	Rat (Wistar)	Gd 13, 14, or 15			100 rad	(incr. ratio of large hematocytes to small hematocytes)			Koshimoto et al. 1994 Gamma Ray [137]Cs

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	
99	Mouse (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 Gamma Ray [137]Cs
100	Mouse (C57BL/6)	Gd 14 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 Gamma Ray [137]Cs
101	Dog (Beagle)	Gd 28			100 rad	(mild to moderate degenerative retinal lesions in offspring)		Schweitzer et al. 1987 Gamma Ray [60]Co
102	Mouse (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 Gamma Ray [137]Cs
103	Rat (Fischer- 344)	Gd 20			150 rad	(altered pivoting, cliff avoidance and upper jaw tooth eruption in offspring)		Zaman et al. 1993 Gamma Ray NS
104	Dog (Beagle)	Gd 55			160 rad	(moderate to severe bilateral degenerative retinal lesions in 75% of offspring)		Schweitzer et al. 1987 Gamma Ray [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 (Fischer- 344)	Gd 20		6.8 rad F				Zaman et al. 1992 Gamma Ray NS
106	Rat (Fischer- 344)	Gd 20		6.8 rad				Zaman et al. 1993 Gamma Ray NS
107	Rat (Sprague-Dawley)	Gd 9.5 14-17 sec		50 rad				Bruni et al. 1994 Gamma Ray [60]Co
108	Rat (Wistar)	Gd 20			(decr. steroid hormone production)			Inano et al. 1989 Gamma Ray [60]Co
109	Rat (Wistar)	Gd 20					(51-52% decr. body weight, 82% decr. testicular weight, 66% decr. ovarian weight)	Inano et al. 1989 Gamma Ray [60]Co
110	Human	NS				>185 GBq	(incr. absolute 'null' lymphocytes, decr. absolute T lymphocytes, decr. T4 cells)	Petrova et al. 1997 [137]Cs
	Cancer							
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 (occup)				15 rad	(CEL: estimated doubling dose of cancers of radiosensitive tissues)	Kneale et al. 1981 Gamma Ray
115	Dog (Beagle)	10 min				16 rad	(CEL: cancers in 7 and neoplasms in 16 dogs out of 1,309; primarily squamous papilloma of eyelid)	Benjamin et al. 1986 Gamma Ray [60]Co
116	Mouse (ICR)	3x/wk <86 wk				150 rad F	(CEL: 23/96 osteosaracomas, optimum dose for induction was 250 to 350 cGy)	Ootsuyama and Tanooka 1989 Beta Particles [90]Sr-[90]Y
117	Mouse (CBA/H)	0-177 min				1500 rad F	(CEL: signif. incr. in benign and malignant dermal tumors)	Hulse 1966 Beta Particles [204]Tl
118	Mouse (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.)	Charles et al. 1988 Beta Particles [170]Th
119	Mouse (SAS/4 Albino)	1 hr				2000 rad	(CEL: (20% increase in skin tumor incidence)	Charles et al. 1988 Beta Particles [170]Th
120	Human	NS				0-10 mSv	(CEL: childhood cancers associated with paternal exposure to radionuclides)	Sorahan and Roberts 1993 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 rem (CEL: incr. lung cancer)	Checkoway et al. 1988 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 = bronchioalveiolar 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