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A COMPARISON OF DOSE-RESPONSE MODELS FOR DEATH FROM HEMATOLOGICAL DEPRESSION*

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ABSTRACT

Many radiation-induced lethality experiments have been published for various mammalian species. From those studies a subset of studies reflecting useful biological and physical variables has been compiled into a database suitable to study interspecific variability of radiosensitivity, dose-rate dependence of sensitivity, dose-response behavior within each experiment, etc.

The data compiled were restricted to continuous and nearly continuous exposures to photon radiations having source energies above 100 keV. Also, photon source energy, exposure geometry, and body weight considerations were used to select studies where the dose to hematopoietic marrow was nearly uniform, i.e. $\leq \pm 20\%$. The data base reflects 13 mammalian test species ranging from mouse to cattle.

Some 211 studies were compiled but only 105 were documented in adequate detail to be useful in development and evaluation of dose-response models of interest to practical human exposures. Of the 105 studies, 70 were for various rodent species, and 35 were for nonrodent groups ranging from standard laboratory primates (body weight ~5 kg) to cattle (body weight 375 kg).

This paper considers seven different dose-response models which are tested for validity against those 105 studies. The dose-response models included: a right-skewed extreme value, a left-skewed extreme value model, log-logistic, log-probit, logistic, probit, and Weibull models.

In general, the log transformed models did not improve model performance and the extreme value models did not seem consistent with the preponderance of the data. Overall, the probit and the logistic models seemed preferable over the Weibull model.

The shape of the dose-response function, the point of normalization, e.g., the LD_{50} value for man, and a statistical analysis of the effects from different biological and physical variables will help to assess the radiosensitivity of man in terms of the many published animal studies.

INTRODUCTION

When mammals are exposed to ionizing radiations, blood lymphocytes, stem cells of the hematopoietic bone marrow, and other reproductively viable cells of the human body are killed at rates that depend on the absorbed dose, the time- and dose-treatment protocol, and the degree of radiosensitivity of the target cells (Jones, et. al., 1986). Lymphocytes and hematopoietic stem cells are among the most sensitive in the human body (Langham, 1967; Lushbaugh, 1969). Thus, at doses and dose rates that cause severe depressions in these cell populations, mortality of the host mammal may result from infection and/or hemorrhage. Infection is associated with depressed neutrophils, and hemorrhage results from vascular leakage because of insufficient platelets.

The mechanisms of hematological death are widely accepted and are common to all mammals (Bond, et al., 1965). There are known species, strain, and even individual factors involved in the specific response to a metered dose. However, the shape of the dose-response relationship in any similar population is surprisingly consistent across these factors. For example, the minimum dose that causes 100 percent mortality in a specific population for specific conditions is generally about twice the greatest dose for which no mortality is observed (Jones, 1981; Baverstock, 1984).

Mortality from radiation exposures may result from damage to hematologic, gastrointestinal (GI), or central nervous (CN) tissues (Bond, 1969). Death from hematologic damage occurs at much lower doses but does not usually occur until the neutrophil and platelet counts in peripheral blood reach a nadir (Barabanova et al., 1986). When death

occurs due to damage to GI or CN tissue, the insult is assumed to be greater than that which would have been required to induce death by hematological depression. For most purposes, the specific cause of death at these dose levels is unimportant and, therefore, is not distinguished case-by-case in this work. In some instances, the exact sequela of response symptoms may be of great importance, e.g., when trained physicians and clinics are inadequate to handle massive exposures (Barabanova et al., 1986; NCRP, 1974).

BACKGROUND

Human populations have been exposed to radiation sources accidentally (Lushbaugh, 1969; Langham, 1967; Mole, 1984; Baverstock and Ash, 1983; Barabanova et al., 1986), therapeutically (Mathe', 1964; Lushbaugh, et al., 1967; Rider and Hasselback, 1968; Saenger et al., 1973), and through the experiences of Hiroshima and Nagasaki. However, reports of these episodes are based on small numbers of persons, and generally inaccurate dosimetry. Hence, there is no consensus among the leading experts on a "best" value for the human LD_{50} as a result of exposure to low LET radiations at any dose rate, and source geometries that result in nearly uniform dose to various hematopoietic tissues (Lushbaugh, et al., 1967; NRC, 1975; Mole, 1984; Rotblat, 1986; Jones, et al., 1986).

Extreme points of the human mortality response function (e.g., LD_{01} and LD_{99}) are even more uncertain than the LD_{50}. Mechanistically, it seems that mortality from hematological damage must have a dose-threshold below which death from this process does not occur (Jones, 1981; Baverstock, 1984). Few, if any, activities can claim zero-order

risk per individual, so this paper will not address the possibility of a dose-threshold for hematologic death. But reasonably accurate estimates of marrow doses that are likely to induce 1, 5, 50, 95, and 99 percent mortality are needed for a variety of practical considerations. Those applications include: manned space flight (Langham, 1967), irradiation as a tool of immunosuppression to prepare patients for allogenic marrow or organ transplants (Vriesendorp and van Bekkum, 1980); total body irradiation for metasticizing cancer cells, various blood dyscrasias, etc.; civil emergency preparedness (Adams, 1984; Messerschmidt, 1979; Feinendegen, 1983; NCRP, 1974); and reactor safety considerations (Scott and Hahn, 1985; NRC, 1975; Barabanova et al., 1986).

We have previously argued that the available human data from the accident data base or from individual therapeutic studies are inadequate to clarify any point of response versus dose--including the LD_{50} (Jones et al., 1986)--to an accuracy of better than a factor of two. Thus, we have compiled a comprehensive data base on mortality in test mammals (Jones, et al., 1987) to be used to model the expected radiosensitivity of man.

OBJECTIVE

Several different mathematical models are potentially suitable to describe the dose response behavior of death from hematological depression (Jones, 1981). Generally, only the probit (Baverstock, et al., 1985), the log-probit (NRC, 1975), and Weibull (Scott and Hahn, 1980) have been used widely. The functional form having the greatest utility for a wide range of dose-response studies has not been demonstrated previously. Jones (1981) considered the probit, log-probit,

Weibull, Gompertz, logistic, Gilbert's, and log-log functions in order to estimate LD_{01} and LD_{05} for man. Based on the data being examined in that study, Jones chose to use the log-log function and to define the mortality to be 100 percent at high doses where the fitted curve went above 100 percent (Jones, 1981).

Many dose-mortality studies have been published (Page, 1968; Jones, et al., 1987). In some of those studies, certain mathematical models fit the dose-response data quite well, and in other studies, the fits are statistically unacceptable. In this and other instances in which complex processes are empirically modeled, some degree of uncertainty almost always accompanies model selection.

The marrow cells of different species, strains, and individuals are thought to be quite similar in radiosensitivities (Bond and Robinson, 1967; Metcalf, 1979). Also, common mechanisms of death are described in different mammalian species. The sources of greatest variability are expected to be the number of hematopoietic stem cells per unit body weight, the proliferation and differentiation periods for the production of new cells to establish homeostatic equilibrium, the hardiness of the test population (i.e., the degree of resistance to infection or hemorrhage), and the environment/cage/hospital milieu during the post-treatment transition period.

In predicting human mortality, it is reasonable to use a model which does a relatively good job of fitting data from the animal studies conducted to date. In this paper, we will examine how well certain candidate dose-response models fit the data from a variety of animal experiments and will attempt to identify the two or three best models based on that composite experience.

MORTALITY DATA BASE

During the 1950s and 1960s, intensive scientific activity was concentrated in the area of mammalian radiobiology--including lethality due to hematologic depression. We have compiled the data from a total of 211 different mortality modeling studies according to a common format. Variables include: species, strain, body weight, investigator, exposure geometry, the total number of animals in the dose-response study, whether the dose was given continuously or intermittently, specification of the photon source, and data on each individual treatment group. Treatment-group data include: treatment dose, our calculation of the effective marrow dose, number of animals treated, number of deaths, mean survival time of the nonsurvivors, mean exposure rate over the treatment period, maximum exposure rate over the treatment period, exposure time (including down time), down time or length of nondosed period, and the dose/LD_{50} value (Jones, 1981) for that particular dosed group. Studies considered were restricted to continuous exposures and intermittent exposures where the effect of down time was thought to be unimportant.

Data included studies on 13 different species (body weights from about 10 grams to 375 kg) of various purebred, hybrid, mixed-bred, and wild-bred populations. Exposure rates ranged from about 10^{-2} to 10^{3} R/min--or five orders of magnitude. Those data are summarized in Jones, et al., 1987. (That report presents 100 pages of tabular data and is available from the authors upon request.) The biological experiments used to test the mathematical models are summarized briefly in Table I.

MATHEMATICAL MODELS FOR MORTALITY

The seven models included in this study are (1) the right-skewed extreme-value model, (2) the left-skewed extreme-value model, (3) the log-logistic model, (4) the log-probit model, (5) the logistic model, (6) the probit model, and (7) the Weibull model. The equations for these models are summarized in Table II. All models are cumulative probability models, that is, each is constrained to yield predicted mortality rates of between zero and 100 percent, and each is strictly nondecreasing across the range of dose values. Although some three-parameter models are occasionally used to fit data of this type, we have elected to examine only two-parameter models for three reasons. (We use the word "parameter" on reference to an unknown constant to be determined by statistical analysis rather than to reflect a biological or physical condition of the exposure of interest.) First, we deem it prudent to start with the simpler (and better understood) forms; three-parameter generalizations of the best-fitting two-parameter models can be further investigated later if necessary. Second, many experiments included in this data base contain so few dose levels that use of a three-parameter model could constitute "overfitting," resulting in other problems, e.g., imprecise estimates of parameters. Third, since all models in Table II have the same number of parameters, they can be compared on an approximately equal basis (e.g., none of the seven models is a special case of any other).

The specific models used were selected to include popular dose-response functions. Models one and two constitute two extreme cases--model one is also referred to as a Gompertz model and allows for a long right tail (e.g., relatively large differences between LD_{95} and LD_{50}), while model two is similar to the Weibull and allows for a longer left

tail. Models three and four are commonly used logistic and probit models based on dose transformed to a log scale, while models five and six are the same models in untransformed dose. The transformed logistic and probit models specify a "symmetric" dose-response relationship, in the sense that $LD_{50} - LD_{05}$ must equal $LD_{95} - LD_{50}$. Models three and four have this property in the log scale, but are skewed with a relatively long right tail in untransformed dose. Also, models three and four are tacitly constrained to predict zero percent mortality at zero dose because the dose in log units is negative infinity. Model seven has also been used for modeling studies of this type; it too is constrained to predict zero percent mortality for control groups and allows a relatively long left tail.

Of the 211 studies in our original data base, (Jones, et al., 1987) 105 studies included: (1) complete data on the numbers of animals treated and number of deaths for each group and (2) at least two different dosed groups displaying other than zero or 100 percent mortality. These are the minimum required characteristics for fitting (uniquely) any of our two-parameter models; hence, these studies serve as the basis of our model comparisons. The variety of species included in these studies is given in Table III. The subset of these studies which includes at least 100 animals and at least seven experimental groups is identified as "Large Studies" in this table. Certain analyses were repeated for this subset of relatively large experiments.

ANALYSIS

For each of the 105 experiments and each of the seven models, a goodness-of-fit test statistic was computed. This statistic is the

standard large-sample chi-square statistic (twice the difference of log-likelihood values for the fitted model and unconstrained saturated model), with degrees of freedom equal to the number of nonzero dose levels minus two. (Control groups were not included in this analysis, due to the log transformation used in models three and four.) In turn, these independent chi-square statistics were combined within species to give an index of fit for each model in each species. For each model, the chi-square statistic was highly significant ($p < 0.00001$) for mice and rats, indicating that any of our models can be technically rejected for these species. Statistics for other species were generally nonsignificant or marginally significant for most models—goat and guinea pig studies generally came closest to displaying model lack of fit for these remaining species.

A note concerning p-values: Death from hematopoietic depression results from infection and/or hemorrhage. The underlying biological chemical, and cellular mechanisms are obviously complex. We would assume that, given enough data, any fairly simple model can be shown to be inadequate in most complex systems. The quantity of data at hand for rats, and particularly for mice, would lead to rejection of almost any conceivable two-parameter model. Hence, we are using the chi-square statistics here more as descriptive measures of relative fit than as quantitative measures for formal statistical hypothesis testing. Our goal is to identify those relatively simple models that most accurately approximate the more complex (and unknown) dose-response relationship.

Summary chi-square statistics for each model are given in Table IV for experiment number 52, for mouse studies excluding experiment 52, and for all other species combined. [Experiment 52 (Cronkite et al. 1955) is

by far the largest experiment in our data base, as it includes nearly 5000 animals. It is also qualitatively different from most other mouse studies in that the dose was delivered in a flash (or pulse) during a bomb test in Operation Greenhouse and the animals experienced considerable stress due to transportation, heat, periods without food and water, and other environmental conditions. Hence, in order to keep this study from "swamping" the others in the summary statistic, it was kept separate.] In experiment 52, model two clearly provides the best fit (smallest chi-square), but even here the lack of fit is highly significant; the logistic and Weibull models also provide a relatively good fit to these data. The remaining mouse experiments are fit best by the log-logistic, logistic, and probit models. The pooled index for the remaining species is least significant for the logistic, probit, and Weibull models, although there is less difference between the best and worst fits in this case. Based on these statistics alone, it would appear that the two extreme value models are generally inferior to the others--except in the case of the unique experiment 52. Also, the log-probit model seems less competitive than the logistic, probit, and Weibull models.

Because there appears to be some inadequacy in each model for at least some species, a practical question is: Which models do the best job of "passing through the data," particularly at low and high doses? In order to examine this, each experiment was divided into low-dose (LD_0 but below LD_{25}), medium-dose (LD_{25} to LD_{75}), and high-dose (below LD_{100} but above LD_{75}) ranges. [The ranges were determined by a nonparametric method, isotonic nondecreasing regression on binary variates (see, for example, Bartholemew, et al., 1972), which essentially estimates

mortality at a given treatment dose as the actual proportion observed to die, except where a treated group displays a lower proportion of mortality than that observed in a group of lower dose, in which case a smoothing procedure is incorporated.] The percentage of positive residuals (experimental groups for which the observed mortality was greater than the predicted mortality) was calculated for each model in each of the three dose zones and is displayed for all species, and for mouse studies separately in Table V. If a model fits well in any zone, the proportion of positive residuals should be approximately 50 percent, indicating that the model is "above" the observed response about the same number of times it is "below" the observed value.

The logistic and probit models display between 45 and 55 percent positive residuals in each of the three zones, both for all species combined and for mouse studies separately. The proportion of positive residuals for the log-logistic model is between 40 and 60 percent in each zone. Each of the other models displays at least one case in which the percentage of positive residuals is either greater than 60 percent or less than 40 percent. In particular, the right-skewed extreme-value distribution tends to underestimate the mortality at high dose levels.

Finally, for each of the 105 experiments, the seven models were ranked from one (for best fit, as judged by the chi-square goodness of fit statistic) to seven (for worst fit). The number of experiments in which each model received a rank of one, two, and so forth, are presented in Table VI. The first two lines show that the two extreme-value models each were often best in particular experiments, but also often worst on others. In fact, in many instances where one extreme value model received a rank of one, the rank for the other extreme value

model was seven. This is not particularly surprising because both models are rather heavily skewed, but in opposite directions. The Weibull model is similar to the left-skewed extreme-value model and is most often ranked either next-to-best or next-to-worst. Of the log-logistic, log probit, logistic, and probit models, the average ranks are 4.41, 3.91, 3.96, and 3.41, respectively. The logistic and probit models have the additional appeal of never being worst and seldom being next-to-worst.

We repeated the above ranking procedure for mouse studies only, in order to see if the observed left- and right-skewness might be due to species. The results, given in Table VII, show that the pattern was substantially the same for this single species. Neither could left- and right-skewness be explained by strain of mouse (e.g., sensitive versus resistant strains). Also, the ranking was repeated for the 35 relatively large studies which included at least one hundred animals and seven dosed groups. The result is given in Table VIII; again, the pattern shown in Table VI was repeated. Hence, although there may be some indication that both left- and right-skewness are occasionally present in these studies, it is not clear that the distinction can be attributed (primarily) to strain or species differences.

CONCLUSIONS

Clearly, we cannot say that any one of these models is "right" and the others "wrong"; recall that all can be rejected based upon the large quantity of data available for mice and rats. However, we feel that a few general recommendations can be made. First, the log-transform on dose does not seem to be helpful. Overall, it appears that the logistic and probit models outperform their counterparts with log-transformed

dose in most comparisons made. Second, while some evidence of left- and right-skewness seems present, it is not consistent among or within the major species present in this data base. Hence, the extreme-value models do not seem desirable as general-purpose predictive models for extrapolations to man and untested combinations of experimental variables, because each fits poorly in a large proportion of cases. This leaves the logistic, probit, and Weibull models. Of these, preference might be given to the first two, based on the results presented in Tables V and VIII.

FUTURE STUDIES

Future studies will assume that man is a new species drawn at random from the same genetic pool as the 13 species considered in this study. Based on that assumption and the choice of model(s) from this study, estimates of the LD_{05}, LD_{10} ... LD_{50} ... will be made for humans exposed to photon radiations.

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EXP	SPECIES	STRAIN	WEIGHT	INVESTIGATOR	GEOMETRY	LD50(SE)	SLOPE(SE)	ANIM	GRPS	EXPOSURE	SOURCE	RATE
1	BURRO		189.00	STILL-69	BILATERAL	180(10.8)	1.7(0.32)	100	7	CONTINUOUS	1MVP-X	7.50
2	BURRO		139.50	RUST-54	WHOLE-BODY	282(10.9)	1.9(0.54)	50	5	CONTINUOUS	CO60	0.85
3	BURRO		146.00	RUST-53	MULTISOURCE	287(0.6)	54.7(30.20)	80	8	CONTINUOUS	TA182	0.37
4	BURRO		143.00	TRUM-59	MULTISOURCE	318(7.3)	3.8(1.34)	62	7	CONTINUOUS	ZR95/NB95	0.30
5	BURRO			STILL-68	BILATERAL				1	CONTINUOUS	1000KVP-X	7.00
6	CATTLE	HEREFORD	375.00	BROWN,D-61	MULTISOURCE	159(3.5)	6.9(1.54)	80	6	CONTINUOUS	CO60	0.92
7	CATTLE	HOLSTEIN	80.00	SHULTZE-59	MULTISOURCE			17	6	CONTINUOUS	CO60	6.60
8	CHINCHIL	LANIGER	0.43	STRIKE-69	UNILATERAL	494(29.7)	0.4(0.05)	430	17	CONTINUOUS	250KVP-X	20.00
9	DOG	BEAGLE	10.00	GEORGE-68	BILATERAL	207(3.6)	4.5(0.92)	112	9	CONTINUOUS	250KVP-X	16.80
10	DOG	MONGREL	11.00	ALPEN-58	BILATERAL	217(3.8)	4.1(1.07)	85	10	CONTINUOUS	250KVP-X	6.30
11	DOG	BEAGLE	10.00	MICHAELSON-68	BILATERAL	230(10.2)	1.9(0.55)	55	8	CONTINUOUS	1MVP-X	58.00
12	DOG	MONGREL	11.40	BOND-56	BILATERAL	239(7.5)	2.3(0.72)	65	8	CONTINUOUS	250KVP-X	15.00
13	DOG	FOX-H	17.00	GLEISER-53	BILATERAL	253(8.6)	1.7(0.30)	121	11	CONTINUOUS	2MVP-X	15.00
14	DOG	BEAGLE	10.60	NORRIS-68	BILATERAL	257(6.2)	4.2(1.30)	32	4	CONTINUOUS	CO60	15.00
15	DOG	BEAGLE	10.60	NORRIS-68	BILATERAL	262(2.4)	13.2(5.59)	29	4	CONTINUOUS	CO60	10.00
16	DOG	MONGREL	11.00	ALPEN-58	BILATERAL	280(7.6)	2.1(0.62)	73	7	CONTINUOUS	100KVP-X	6.20
17	DOG	MONGREL	9.60	AINSWORTH-65	BILATERAL	282(8.2)	1.4(0.30)	134	10	CONTINUOUS	1MVP-X	9.50
18	DOG	MONGREL	12.60	SHIVELY-58	BILATERAL	318(10.6)	2.5(0.70)	40	4	CONTINUOUS	CO60	6.00
19	DOG	MONGREL	12.00	SHIVELY-61	BILATERAL	336(18.2)	1.1(0.45)	46	4	CONTINUOUS	CO60	6.00
20	DOG	MONGREL	10.00	ALPEN-59	BILATERAL			40	1	CONTINUOUS	250KVP-X	11.80
21	DOG			MICHAELSON-68	BILATERAL				1	CONTINUOUS	CO60	57.50
22	DOG			HANSEN-61	BILATERAL				1	CONTINUOUS	1000KVP-X	55.00
23	DOG			BOND-56	BILATERAL				1	CONTINUOUS	1000KVP-X	15.00
24	DOG			BOND-56	BILATERAL				1	CONTINUOUS	2000KVP-X	15.00
25	G.PIG		0.25	HAGEN-56	WHOLE-BODY	96(35.9)	0.3(0.05)	342	10	CONTINUOUS	200KVP-X	15.00
26	G.PIG	HARTLEY	0.39	DACQUISTO-60	WHOLE-BODY	251(18.5)	1.0(0.19)	92	8	CONTINUOUS	250KVP-X	3.00
27	G.PIG	HARTLEY	0.39	DACQUISTO-60	WHOLE-BODY	253(17.8)	1.1(0.20)	91	8	CONTINUOUS	250KVP-X	30.00
28	G.PIG	HARTLEY		PHILLIPS-63	WHOLE-BODY	278(18.8)	0.6(0.14)	177	9	CONTINUOUS	250KVP-X	26.50
29	G.PIG		0.48	NEWTON-60	ROTATED	338(17.3)	0.8(0.39)	90	3	CONTINUOUS	CO60	18.50
30	GOAT	ANGORA	34.20	TAYLOR-71	BILATERAL	215(11.8)	1.4(0.18)	204	7	CONTINUOUS	1MVP-X	7.50
31	GOAT	BR.SAANEN	78.00	EDMONDSON-71	BILATERAL	232(13.4)	1.8(0.54)	42	7	CONTINUOUS	CO60	37.50
32	GOAT	ANGORA		LEONG-64	ROTATED			107	1	CONTINUOUS	1MEV-X	7.00
33	GOAT			EDMONSTON-66	BILATERAL				1	CONTINUOUS	2500KVP-X	32.00
34	HAMSTER	GOLDEN SYRIAN	0.11	KOHN-57	WHOLE-BODY	556(6.3)	1.3(0.12)	339	12	CONTINUOUS	250KVP-X	30.00
35	HAMSTER	CHINESE	0.28	CORBASCIO-62	WHOLE-BODY			234	1	CONTINUOUS	250KVP-X	44.00
36	MOUSE	ALBINO		FROLEN-61	WHOLE-BODY	384(5.0)	1.4(0.12)	490	7	CONTINUOUS	260KVP-X	84.00
37	MOUSE	C57		KAPLAN-52	WHOLE-BODY	393(7.6)	1.4(0.15)	1753	5	CONTINUOUS	120KVP-X	31.00
38	MOUSE	RF	0.02	UPTON-56	ROTATED	457(6.4)	2.2(0.33)	120	5	CONTINUOUS	250KVP-X	79.80
39	MOUSE	C57BL		KALLMAN-62	WHOLE-BODY	524(14.1)	1.5(0.31)	149	16	CONTINUOUS	120KVP-X	18.40
40	MOUSE	CF1		CARTER-56	WHOLE-BODY	573(11.7)	0.9(0.12)	238	12	CONTINUOUS	250KVP-X	25.00

Table I. Summary of experiments included in study

EXP	SPECIES	STRAIN	WEIGHT	INVESTIGATOR	GEOMETRY	LD50(SE)	SLOPE(SE)	ANIM	GRPS	EXPOSURE	SOURCE	RATE
41	MOUSE	C3H		FROLEN-61	WHOLE-BODY	580(7.3)	0.9(0.07)	560	7	CONTINUOUS	260KVP-X	84.00
42	MOUSE	F1-HYBRID		FROLEN-61	WHOLE-BODY	583(5.5)	1.2(0.08)	678	8	CONTINUOUS	260KVP-X	84.00
43	MOUSE	F2-HYBRID		FROLEN-61	WHOLE-BODY	590(5.6)	1.0(0.06)	1034	9	CONTINUOUS	260KVP-X	84.00
44	MOUSE	C57BL	0.02	STRIKE	WHOLE-BODY	600(7.7)	0.8(0.05)	728	15	CONTINUOUS	250KVP-X	23.00
45	MOUSE	WR-B	0.02	DACQUISTO-60	WHOLE-BODY	623(17.9)	0.8(0.10)	195	8	CONTINUOUS	250KVP-X	30.00
46	MOUSE	CF1	0.02	DELIHAS-58	ROTATED	628(8.0)	1.0(0.15)	287	10	CONTINUOUS	250KVP-X	195.00
47	MOUSE	C57BL		KALLMAN-62	WHOLE-BODY	630(11.5)	1.5(0.28)	153	16	CONTINUOUS	120KVP-X	4.84
48	MOUSE	F1-HYBRID		FROLEN-61	WHOLE-BODY	630(7.1)	0.9(0.07)	562	7	CONTINUOUS	260KVP-X	84.00
49	MOUSE	CBA		FROLEN-61	WHOLE-BODY	649(5.2)	1.3(0.09)	526	5	CONTINUOUS	260KVP-X	84.00
50	MOUSE	F2-HYBRID		FROLEN-61	WHOLE-BODY	651(7.2)	0.9(0.06)	674	9	CONTINUOUS	260KVP-X	84.00
51	MOUSE	RF	0.02	UPTON-56	ROTATED	651(15.9)	1.1(0.20)	136	8	CONTINUOUS	CO60	62.00
52	MOUSE	LAF1	0.02	CRONKITE-55	WHOLE-BODY	661(3.0)	0.9(0.03)	4713	28	CONTINUOUS	GAMMA	100000
53	MOUSE	C57BL		STRIKE	BILATERAL	683(9.0)	1.2(0.14)	260	6	CONTINUOUS	250KVP-X	23.00
54	MOUSE	M.MUSCULUS-W		GOLLEY-65	WHOLE-BODY	690(62.6)	0.4(0.13)	50	5	CONTINUOUS	CO60	25.00
55	MOUSE	C57BL		KALLMAN-62	WHOLE-BODY	693(37.6)	0.7(0.30)	84	6	CONTINUOUS	120KVP-X	2.19
56	MOUSE	C3H		STRIKE	BILATERAL	695(10.4)	0.9(0.08)	365	9	CONTINUOUS	250KVP-X	23.00
57	MOUSE	WR-B	0.02	DACQUISTO-60	WHOLE-BODY	734(24.4)	0.5(0.06)	195	6	CONTINUOUS	250KVP-X	3.00
58	MOUSE	R		BROWN-60	WHOLE-BODY	770(12.9)	1.3(0.24)	95	5	CONTINUOUS	250KVP-X	54.40
59	MOUSE	CBA		NEAL-60	WHOLE-BODY	788(11.4)	1.3(0.27)	130	4	CONTINUOUS	250KVP-X	786.00
60	MOUSE	R		BROWN-60	WHOLE-BODY	790(13.3)	1.7(0.35)	57	3	CONTINUOUS	250KVP-X	27.00
61	MOUSE	R		BROWN-60	WHOLE-BODY	806(13.3)	1.6(0.33)	76	4	CONTINUOUS	250KVP-X	54.40
62	MOUSE	CBA		CORP-59	UNILATERAL	814(11.2)	1.1(0.25)	120	4	CONTINUOUS	250KVP-X	70.40
63	MOUSE	CF1	0.02	VOGEL-57	WHOLE-BODY	827(4.1)	0.9(0.05)	3894	14		CO60	10.00
64	MOUSE	R		BROWN-60	WHOLE-BODY	829(12.5)	1.3(0.28)	76	4	INTERRUPTED	250KVP-X	13.70
65	MOUSE	CBA		NEAL-60	WHOLE-BODY	846(8.8)	1.4(0.24)	135	4	CONTINUOUS	250KVP-X	76.00
66	MOUSE	R		BROWN-60	WHOLE-BODY	886(14.4)	1.4(0.29)	76	4	CONTINUOUS	250KVP-X	6.10
67	MOUSE	R		BROWN-60	WHOLE-BODY	924(22.1)	0.7(0.12)	95	5	INTERRUPTED	250KVP-X	4.30
68	MOUSE	R		BROWN-60	WHOLE-BODY	941(21.1)	0.8(0.17)	76	4	INTERRUPTED	250KVP-X	3.80
69	MOUSE	CBA		NEAL-60	WHOLE-BODY	948(8.2)	1.9(0.33)	100	4	CONTINUOUS	250KVP-X	7.90
70	MOUSE	P.GOSSYPINUS-W		GOLLEY-65	WHOLE-BODY	996(97.3)	0.4(0.15)	25	5	CONTINUOUS	CO60	25.00
71	MOUSE	R		BROWN-60	WHOLE-BODY	1009(21.3)	1.2(0.36)	57	3	INTERRUPTED	250KVP-X	2.90
72	MOUSE	CBA		NEAL-60	WHOLE-BODY	1030(10.3)	2.1(0.40)	95	4	CONTINUOUS	250KVP-X	4.29
73	MOUSE	R		BROWN-60	WHOLE-BODY	1031(19.0)	1.0(0.19)	76	4	CONTINUOUS	250KVP-X	2.50
74	MOUSE	CBA		NEAL-60	WHOLE-BODY	1040(12.3)	1.8(0.37)	80	4	CONTINUOUS	250KVP-X	2.80
75	MOUSE	R		BROWN-60	WHOLE-BODY	1068(24.9)	0.7(0.12)	95	5	INTERRUPTED	250KVP-X	2.60
76	MOUSE	R		BROWN-60	WHOLE-BODY	1074(17.2)	1.1(0.22)	76	4	CONTINUOUS	250KVP-X	2.60
77	MOUSE	R		BROWN-60	WHOLE-BODY	1080(17.8)	1.1(0.22)	76	4	INTERRUPTED	250KVP-X	2.90
78	MOUSE	R		BROWN-60	WHOLE-BODY	1091(18.7)	0.9(0.15)	95	5	INTERRUPTED	250KVP-X	2.60
79	MOUSE	R		BROWN-60	WHOLE-BODY	1094(17.6)	1.2(0.23)	57	3	INTERRUPTED	250KVP-X	2.80
80	MOUSE	CBA		NEAL 60	WHOLE-BODY	1098(12.1)	1.3(0.20)	120	4	CONTINUOUS	250KVP-X	2.30
81	MOUSE	CF-NO.1	0.02	VOGEL-57	WHOLE-BODY	1160(7.1)	0.9(0.12)	426	9	CONTINUOUS	CO60	1.00
82	MOUSE	P.POLIONOTUS-W		GOLLEY-65	WHOLE-BODY	1168(56.7)	0.4(0.10)	55	5	CONTINUOUS	CO60	25.00
83	MOUSE	CBA		CORP-59	FREE-MOVING	1236(12.8)	1.0(0.11)	200	5	CONTINUOUS	250KVP-X	0.66
84	MOUSE	CBA		CORP-59	FREE-MOVING	1340(10.8)	1.1(0.16)	185	5	CONTINUOUS	250KVP-X	0.77
85	MOUSE	R		BROWN-60	WHOLE-BODY			38	2	CONTINUOUS	250KVP-X	17.90
86	MOUSE	CF-1	0.02	THOMSON-53	WHOLE-BODY			254	1	CONTINUOUS	CO60	42.00
87	MOUSE	CF-1	0.02	THOMSON-53	WHOLE-BODY			80	1	CONTINUOUS	CO60	15.00
88	MOUSE	CF-1	0.02	THOMSON-53	WHOLE-BODY			140	1	CONTINUOUS	CO60	4.00
89	MOUSE	CF-1	0.02	THOMSON-53	WHOLE-BODY			120	1	CONTINUOUS	CO60	1.45
90	MOUSE	CF-1	0.02	THOMSON-53	WHOLE-BODY			96	1	CONTINUOUS	TA182	0.62
91	MOUSE	CF-1	0.02	THOMSON-53	WHOLE-BODY			100	1	CONTINUOUS	CO60	0.10
92	MOUSE	CF-1	0.02	THOMSON-53	WHOLE-BODY			18	1	CONTINUOUS	CO60	0.08
93	MOUSE	BALB/C		KALLMAN-62	WHOLE-BODY			64	1	CONTINUOUS	120KVP-X	17.70
94	MOUSE	BALB/C		KALLMAN-62	WHOLE-BODY			32	1	CONTINUOUS	120KVP-X	4.73

Table I (continued)

EXP	SPECIES	STRAIN	WEIGHT	INVESTIGATOR	GEOMETRY	LD50(SE)	SLOPE(SE)	ANIM	GRPS	EXPOSURE	SOURCE	RATE
95	MOUSE	BALB/C		KALLMAN-62	WHOLE-BODY				1	CONTINUOUS	120KVP-X	2.22
96	MOUSE	CF-1		WALBURG-66	ROTATED			256	1	CONTINUOUS	300KVP-X	100.00
97	MOUSE	RFM/UN		WALBURG-66	ROTATED			146	1	CONTINUOUS	300KVP-X	100.00
98	MOUSE	ICR		WALBURG-66	ROTATED			300	1	CONTINUOUS	300KVP-X	100.00
99	MOUSE	CAF1		KOHN-56	WHOLE-BODY			556	1	CONTINUOUS	250KVP-X	35.00
100	MOUSE	BALB/C		KOHN-56	WHOLE-BODY			290	1	CONTINUOUS	250KVP-X	35.00
101	MOUSE	C57BL		KOHN-56	WHOLE-BODY			168	1	CONTINUOUS	250KVP-X	35.00
102	MOUSE	A/HE		KOHN-56	WHOLE-BODY			148	1	CONTINUOUS	250KVP-X	35.00
103	MOUSE	C3H		KOHN-56	WHOLE-BODY			307	1	CONTINUOUS	250KVP-X	35.00
104	MOUSE	ACF1		KOHN-56	WHOLE-BODY			118	1	CONTINUOUS	250KVP-X	35.00
105	MOUSE	RF-M		MELVILLE-57	UNILATERAL			96	1	CONTINUOUS	250KVP-X	100.00
106	MOUSE	RF-F		MELVILLE-57	UNILATERAL			96	1	CONTINUOUS	250KVP-X	100.00
107	MOUSE	CBA-F		MOLE-56	WHOLE-BODY			1836	1	CONTINUOUS	240KVP-X	43.00
108	MOUSE	CBA		MOLE-56	WHOLE-BODY			160	1	CONTINUOUS	240KVP-X	43.00
109	MOUSE	CBA		MOLE-56	WHOLE-BODY			2353	1	CONTINUOUS	240KVP-X	43.00
110	MOUSE	CBA		MOLE-56	WHOLE-BODY			318	1	CONTINUOUS	240KVP-X	43.00
111	MOUSE	C57BL		KALLMAN-62	WHOLE-BODY			30	1	CONTINUOUS	120KVP-X	9.51
112	MOUSE	LAF1		LEONG-64	WHOLE-BODY			544	1	CONTINUOUS	1MEV-X	7.00
113	MOUSE	BAF1	0.03	GRAHN-56	WHOLE-BODY			924	3	CONTINUOUS	250KVP-X	10.00
114	MOUSE	CF1		KREBS-68					1		CO60	27.00
115	MOUSE	A		PATERSON-52	WHOLE-BODY			44	1	CONTINUOUS	250KVP	45.00
116	MOUSE	A		PATERSON-52	WHOLE-BODY			44	1	CONTINUOUS	250KVP	45.00
117	MOUSE	A		PATERSON-52	WHOLE-BODY			880	1	CONTINUOUS	250KVP	45.00
118	MOUSE	A		PATERSON-52	WHOLE-BODY			88	1	CONTINUOUS	250KVP	45.00
119	MOUSE	A		PATERSON-52	WHOLE-BODY			88	1	CONTINUOUS	250KVP	45.00
120	MOUSE	C57BL		KOHN-57	WHOLE-BODY			368	1	CONTINUOUS	250KVP-X	35.00
121	MOUSE	C3H		KOHN-57	WHOLE-BODY			283	1	CONTINUOUS	250KVP-X	35.00
122	MOUSE	CAF1		KOHN-57	WHOLE-BODY			782	1	CONTINUOUS	250KVP-X	35.00
123	MOUSE	BALB/C		KOHN-57	WHOLE-BODY			869	1	CONTINUOUS	250KVP-X	35.00
124	MOUSE	A/HE		KOHN-57	WHOLE-BODY			358	1	CONTINUOUS	250KVP-X	35.00
125	MOUSE	BALB/C		GRAHN-57	WHOLE-BODY			40	1	CONTINUOUS	200KVP-X	22.00
126	MOUSE	A		GRAHN-57	WHOLE-BODY			34	1	CONTINUOUS	200KVP-X	22.00
127	MOUSE	A/HE		GRAHN-57	WHOLE-BODY			32	1	CONTINUOUS	200KVP-X	22.00
128	MOUSE	A/JAX		GRAHN-57	WHOLE-BODY			35	1	CONTINUOUS	200KVP-X	22.00
129	MOUSE	C3HF/HE		GRAHN-57	WHOLE-BODY			44	1	CONTINUOUS	200KVP-X	22.00
130	MOUSE	C57BL/6		GRAHN-57	WHOLE-BODY			43	1	CONTINUOUS	200KVP-X	22.00
131	MOUSE	P.POLIONOTUS-L		GOLLEY-65	WHOLE-BODY			45	3	CONTINUOUS	CO60	25.00
132	MOUSE	R.HUMULIS-W		GOLLEY-65	WHOLE-BODY			20	4	CONTINUOUS	CO60	25.00
133	MOUSE	M.MUSCULUS-L		GOLLEY-65	WHOLE-BODY			30	5	CONTINUOUS	CO60	25.00
134	MOUSE	P.LONGIMEMBRIS	0.01	GAMBINO-64	WHOLE-BODY			125	5	CONTINUOUS	250KVP-X	0.00
135	MOUSE	P.LONGIMEMBRIS	0.01	GAMBINO-64	WHOLE-BODY			200	8	CONTINUOUS	CO60	0.00
136	MOUSE	P.FORMOSUS	0.02	GAMBINO-64	WHOLE-BODY			38	4	CONTINUOUS	CO60	0.00
137	MOUSE	P.FORMOSUS	0.02	GAMBINO-64	WHOLE-BODY			71	3	CONTINUOUS	CO60	0.00
138	MOUSE	SWISS		ELLINGER-50	WHOLE-BODY			63	1	CONTINUOUS	200KVP-X	23.40
139	MOUSE	A/HE		KOHN-57	WHOLE-BODY			358	1	CONTINUOUS	250KVP-X	35.00
140	MOUSE	BALB/C		KOHN-57	WHOLE-BODY			869	1	CONTINUOUS	250KVP-X	35.00
141	MOUSE	LAF1		KOHN-57	WHOLE-BODY			782	1	CONTINUOUS	250KVP-X	35.00
142	MOUSE	C3H		KOHN-57	WHOLE-BODY			283	1	CONTINUOUS	250KVP-X	35.00
143	MOUSE	C57BL		KOHN-57	WHOLE-BODY			368	1	CONTINUOUS	250KVP-X	35.00
144	MOUSE	SWISS-WHITE		CRONKITE-50	WHOLE-BODY			100	1	CONTINUOUS	1000KVP-X	31.20
145	MOUSE	CBA		MOLE-56	WHOLE-BODY			153	1	CONTINUOUS	245KVP-X	45.90
146	MOUSE	CBA		MOLE-56	WHOLE-BODY			40	1	CONTINUOUS	245KVP-X	45.90
147	MOUSE	CBA		MOLE-56	WHOLE-BODY			53	1	CONTINUOUS	245KVP-X	45.90
148	MOUSE	LAF1		SWIFT-54	WHOLE-BODY			86	2	CONTINUOUS	230KVP-X	44.00

Table I (continued)

EXP	SPECIES	STRAIN	WEIGHT	INVESTIGATOR	GEOMETRY	LD50(SE)	SLOPE(SE)	ANIM	GRPS	EXPOSURE	SOURCE	RATE
149	PRIMATE	S.FUSCICOLLIS	0.32	GENGOZIAN	ROTATED	174(19.1)	1.4(0.40)	58	8	CONTINUOUS	CS137	4.10
150	PRIMATE	MACACA-M	3.20	ALLEN-60	4PI	366(59.8)	0.5(0.24)	35	6	CONTINUOUS	CO60	800.00
151	PRIMATE	RHESUS		SCHLUMBERGER-54	ROTATED	466(21.8)	0.8(0.14)	92	7	CONTINUOUS	250KVP-X	23.00
152	PRIMATE	RHESUS-M	5.00	HENSCHKE-57	ROTATED	474(18.8)	0.9(0.13)	110	7	CONTINUOUS	250KVP-X	22.00
153	PRIMATE	MACACA MULATTA	2.70	ELDRED-54	ROTATED	507(45.3)	0.6(0.20)	32	5	CONTINUOUS	250KVP-X	13.70
154	PRIMATE	RHESUS-M	3.60	HAIGH-56	MULTISOURCE	509(20.5)	1.1(0.47)	44	6	CONTINUOUS	250KVP-X	3.00
155	PRIMATE	MACACA-M	4.30	STANLEY-66	BILATERAL	518(22.1)	0.8(0.22)	80	7	CONTINUOUS	250KVP-X	20.00
156	PRIMATE	MACACA-M	3.50	DALRYMPLE-65	ROTATED	674(19.7)	1.0(0.19)	98	7	CONTINUOUS	2MVP-X	0.00
157	PRIMATE	RHESUS-M	3.60	PATERSON-56	MULTISOURCE			44	1	CONTINUOUS	250KVP-X	3.00
158	PRIMATE			ELTRINGHAM-68	ROTATED				1	CONTINUOUS	CO60	55.00
159	RABBIT	N.ZEALAND	3.10	PRYOR-67	WHOLE-BODY	838(15.6)	0.8(0.15)	160	8	CONTINUOUS	CO60	0.00
160	RABBIT	MIX		RUST-55	MULTISOURCE	907(30.2)	0.6(0.11)	100	10	CONTINUOUS	CO60	0.78
161	RABBIT	N.ZEALAND		LEONG-64	BILATERAL			106	1	CONTINUOUS	1MEV-X	7.00
162	RABBIT	NL1	2.88	GRAHN-56	WHOLE-BODY			126	3	CONTINUOUS	250KVP-X	10.00
163	RAT	WR-CF	0.18	DACQUISTO-60	WHOLE-BODY	426(24.3)	0.7(0.13)	90	6	CONTINUOUS	250KVP-X	30.00
164	RAT	WISTAR		HURSH-56	ROTATED	483(17.3)	0.8(0.15)	190	5	CONTINUOUS	250KVP-X	0.00
165	RAT	SPRAGUE	0.20	HAGEN-56	BILATERAL	485(4.5)	1.4(0.10)	711	8	CONTINUOUS	200KVP-X	12.00
166	RAT	SLONAKER ALBINO	0.12	CLARK-49	WHOLE-BODY	488(6.3)	1.4(0.23)	501	10	CONTINUOUS	200KVP-X	30.40
167	RAT	WR-CF	0.18	DACQUISTO-60	WHOLE-BODY	550(25.4)	0.6(0.12)	90	6	CONTINUOUS	250KVP-X	3.00
168	RAT	WISTAR		HURSH-56	ROTATED	571(12.3)	1.1(0.32)	152	3	CONTINUOUS	250KVP-X	0.00
169	RAT	SPRAGUE	0.51	JONES-69	WHOLE-BODY	589(13.1)	1.4(0.37)	86	4	CONTINUOUS	250KVP-X	29.00
170	RAT	SPRAGUE	0.52	JONES-69	WHOLE-BODY	629(14.7)	1.3(0.31)	95	5	CONTINUOUS	250KVP-X	29.00
171	RAT	SPRAGUE	0.54	JONES-69	WHOLE-BODY	648(11.0)	1.5(0.38)	72	4	CONTINUOUS	250KVP-X	29.00
172	RAT	SPRAGUE	0.38	JONES-69	WHOLE-BODY	695(6.7)	2.6(0.42)	100	5	CONTINUOUS	250KVP-X	29.00
173	RAT	SPRAGUE	0.48	JONES-69	WHOLE-BODY	731(11.7)	1.6(0.31)	102	6	CONTINUOUS	250KVP-X	29.00
174	RAT	SPRAGUE	0.30	STRIKE	WHOLE-BODY	745(5.4)	1.1(0.07)	911	19	CONTINUOUS	250KVP-X	23.00
175	RAT	SPRAGUE		BAUM		807(6.8)	1.2(0.11)	611	8	CONTINUOUS	CO60	
176	RAT	FAC(I)F1	0.21	KOHN-57	WHOLE-BODY			234	1	CONTINUOUS	250KVP-X	30.00
177	RAT	SPRAGUE	0.20	LOGIE-60	ROTATED			100	1	CONTINUOUS	CO60	474.00
178	RAT	SPRAGUE	0.20	LOGIE-60	ROTATED			100	1	CONTINUOUS	CO60	55.00
179	RAT	SPRAGUE	0.20	LOGIE-60	ROTATED			100	1	CONTINUOUS	CO60	3.41
180	RAT	SPRAGUE	0.20	LOGIE-60	ROTATED			100	1	CONTINUOUS	CO60	0.48
181	RAT	SPRAGUE	0.20	LOGIE-60	ROTATED			100	1	CONTINUOUS	CO60	0.18
182	RAT	WISTAR	0.18	CARSTEN-64	WHOLE-BODY			16	1	CONTINUOUS	250KVP-X	19.00
183	RAT	SPRAGUE-DAWLEY		SWIFT-54	WHOLE-BODY			40	4	CONTINUOUS	200KVP-X	12.50
184	SHEEP	COL.-RAM	43.00	HANKS-66	QUADRILATERAL	149(7.2)	2.2(0.37)	112	7	CONTINUOUS	CO60	10.10
185	SHEEP	COL.-RAM	41.00	HANKS-66	QUADRILATERAL	150(5.4)	4.1(0.69)	86	4	CONTINUOUS	1MVP-X	7.50
186	SHEEP	WELSH-MO	22.00	EDMONDSON-71	BILATERAL	183(24.0)	0.8(0.36)	60	6	CONTINUOUS	CO60	37.50
187	SHEEP	COL.-RAM	34.50	TAYLOR-69	BILATERAL	210(6.4)	2.5(0.37)	118	6	CONTINUOUS	1MVP-X	7.60
188	SHEEP	COL.-RAM.	43.00	PAGE-68	BILATERAL			96	1	CONTINUOUS	CO60	11.00
189	SHEEP	COL.-RAM.	43.00	PAGE-68	BILATERAL			72	1	CONTINUOUS	CO60	4.35
190	SHEEP	COL.-RAM.	43.00	PAGE-68	BILATERAL			60	1	CONTINUOUS	CO60	0.50
191	SHEEP	COL.-RAM.	43.00	PAGE-68	FREE-MOVING			80	1	CONTINUOUS	CO60	0.06
192	SHEEP	COL.-RAM	43.00	PAGE-68	FREE-MOVING			48	1	CONTINUOUS	CO60	0.03
193	SHEEP	COL.-RAM.		LEONG-64	ROTATED			67	1	CONTINUOUS	1MEV-X	7.00
194	SHEEP			TAYLOR-68	BILATERAL				1	CONTINUOUS	1MVP-X	7.50

Table I (continued)

EXP	SPECIES	STRAIN	WEIGHT	INVESTIGATOR	GEOMETRY	LD50(SE)	SLOPE(SE)	ANIM	GRPS	EXPOSURE	SOURCE	RATE
195	SHEEP			TAYLOR-68	BILATERAL				1	CONTINUOUS	CO60	0.06
196	SHEEP			TAYLOR-68	WHOLE-BODY				1	CONTINUOUS	CO60	0.06
197	SHEEP			MOBLEY-66	BILATERAL				1	CONTINUOUS	250KVP-X	7.50
198	SWINE	MIX-BRED	82.00	TULLIS-49	BILATERAL	177(16.0)	1.9(0.64)	32	4	CONTINUOUS	1MVP-X	30.00
199	SWINE	LANDRACE	61.70	TULLIS-52	BILATERAL	194(17.6)	1.3(0.33)	62	10	CONTINUOUS	2MVP-X	15.00
200	SWINE	DUROC	107.00	NACHTWEY-67	BILATERAL	277(8.0)	1.7(0.31)	113	11	CONTINUOUS	1MVP-X	9.50
201	SWINE	MIX-BRED	75.40	RUST-54	MULTISOURCE	379(21.6)	1.1(0.28)	49	5	CONTINUOUS	CO60	0.83
202	SWINE	DUROC	33.10	CHAMBERS-64	4PI			225	1	CONTINUOUS	CO60	21.30
203	SWINE	DUROC	67.60	CHAMBERS-64	4PI			225	1	CONTINUOUS	CO60	21.30
204	SWINE			BOND-51	BILATERAL				1	CONTINUOUS	1000KVP-X	27.00
205	SWINE			TULLIS-52	BILATERAL				1	CONTINUOUS	1000KVP-X	15.00
206	SWINE			PAGE-67	BILATERAL				1	CONTINUOUS	CO60	11.50
207	SWINE			BROWN-68	BILATERAL				1	CONTINUOUS	CO60	10.00
208	SWINE			BROWN-68	BILATERAL				1	CONTINUOUS	CO60	50.00
209	SWINE	DUROC	114.00	BROWN-68	MULTISOURCE				1	CONTINUOUS	CO60	1.00
210	SWINE	DUROC	114.00	BROWN-68	MULTISOURCE				1	CONTINUOUS	CO60	10.00
211	SWINE	DUROC	114.00	BROWN-68	MULTISOURCE				1	CONTINUOUS	CO60	50.00

Table I (continued)

Table II. Mathematical models for mortality

Number	Name	Functional Form
(1)	Extreme-value[a]	$\exp(-e^{-(\alpha+\beta d)})$
(2)	Extreme-value[b]	$1 - \exp(-e^{(\alpha+\beta d)})$
(3)	Log-logistic	$\frac{1}{1+e^{-(\alpha+\beta \ln(d))}}$
(4)	Log-probit	$\Phi(\alpha+\beta \ln(d))$
(5)	Logistic	$\frac{1}{1+e^{-(\alpha+\beta d)}}$
(6)	Probit	$\Phi(\alpha+\beta d)$
(7)	Weibull	$1 - e^{-(\frac{d}{\beta})^{\alpha}}$

Notes: d denotes dose in rads; Φ is the cumulative distribution function for the standard normal distribution.

[a]Right-skewed or Gompertz.
[b]Left-skewed.

Table III. Number of studies by species

Species	Studies	Large Studies
Burro	4	1
Cattle	1	0
Chinchilla	1	1
Dog	11	3
G. Pig	5	2
Goat	2	1
Hamster	1	1
Mouse	49	17
Primate	8	1
Rabbit	2	2
Rat	13	4
Sheep	4	1
Swine	4	1
Total	105	35

Table IV. Chi-square statistics for goodness-of-fit

Model	Exp. 52 (df=26)	Other Mouse Studies (df=203)	Other Species (df=309)
Extreme-value[a]	788.2	617.5	402.2
Extreme-value[b]	150.7	627.6	388.2
Log-logistic	491.7	507.4	375.6
Log-probit	592.6	533.9	375.2
Logistic	304.6	487.7	357.4
Probit	465.1	506.7	353.9
Weibull	286.4	541.4	359.9

[a]Right-skewed or Gompertz.

[b]Left-skewed.

Table V. Percentage of positive residuals by dose-zone

Model	All Species			Mouse Only		
	High	Low	Middle	High	Low	Middle
Extreme-value[a]	69	57	41	70	58	38
Extreme-value[b]	52	38	59	47	41	61
Log-logistic	57	55	47	55	56	48
Log-probit	61	55	48	58	56	50
Logistic	54	48	53	51	54	55
Probit	54	47	52	49	50	53
Weibull	51	41	56	47	42	60

[a]Right-skewed or Gompertz.

[b]Left-skewed.

Table VI. Numbers of experiments in each rank – all studies

	Rank						
Model	1	2	3	4	5	6	7
Extreme-value[a]	21	8	8	4	4	8	52
Extreme-value[b]	44	8	0	1	4	7	41
Log-logistic	7	8	19	12	26	26	7
Log-probit	11	23	5	21	18	24	3
Logistic	7	3	26	30	29	10	0
Probit	6	12	41	28	15	3	0
Weibull	9	43	6	9	9	27	2

Note: Rank of 1 is best; 7 is worst.

[a]Right-skewed or Gompertz.

[b]Left-skewed.

Table VII. Numbers of experiments in each rank – mouse studies only

	Rank						
Model	1	2	3	4	5	6	7
Extreme-value[a]	7	3	2	3	1	4	29
Extreme-value[b]	21	4	0	0	1	5	18
Log-logistic	4	6	5	8	10	14	2
Log-probit	6	8	1	13	10	11	0
Logistic	5	2	13	14	14	1	0
Probit	2	5	26	9	7	0	0
Weibull	4	21	2	2	6	14	0

Note: Rank of 1 is best; 7 is worst.

[a]Right-skewed or Gompertz.

[b]Left-skewed.

Table VIII. Numbers of experiments in each rank - large studies only

Model	Rank 1	2	3	4	5	6	7
Extreme-value[a]	7	3	2	2	2	2	16
Extreme-value[b]	14	1	0	1	2	2	14
Log-logistic	3	3	6	3	8	8	3
Log-probit	2	7	4	6	6	8	1
Logistic	2	1	10	11	6	4	0
Probit	2	6	10	9	7	0	0
Weibull	4	13	2	2	3	10	0

Note: Rank of 1 is best; 7 is worst.

[a]Right-skewed or Gompertz.

[b]Left-skewed.

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