

# Appendix A

## Helpful Information

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R. W. Hanf

The following information is provided to assist the reader in understanding this report. Included here is information on scientific notation, units of measures, radioactivity units, radiological dose units, chemical and elemental nomenclature, understanding data tables and data uncertainty, understanding graphs, and greater than or less than symbols. Definitions of technical terms can be found in Appendix B.

### Scientific Notation

Scientific notation is used to express very large or very small numbers. For example, the number 1 billion could be written as 1,000,000,000 or, by using scientific or “E” notation, written as  $1 \times 10^9$  or 1.0E+09. Translating from scientific notation to a more traditional number requires moving the decimal point either left or right from its current location. If the value given is  $2.0 \times 10^3$  (or 2.0E+03), the decimal point should be moved three places to the **right** so that the number would then read 2,000. If the value given is  $2.0 \times 10^{-5}$  (or 2.0E-05), the decimal point should be moved five places to the **left** so that the result would be 0.00002.

### Units of Measure

The primary units of measure used in this report follow the International System of Units (SI) and are metric. Table A.1 summarizes and defines the terms and corresponding symbols (metric and non-metric). A conversion table is also provided in Table A.2.

### Radioactivity Units

Much of this report deals with levels of activity (also known as radioactivity) in various environmental media.

Activity in this report is usually discussed in units of **curies (Ci)**, with conversions to **becquerels (Bq)**, the SI unit, provided (Table A.3). The curie is the basic unit used to describe the amount of activity present, and activities are generally expressed in terms of curies per mass or volume (e.g., picocuries per liter). One curie is equivalent to 37 billion disintegrations per second or is a quantity of any radionuclide that decays at the rate of 37 billion disintegrations per second. Conversely, one becquerel is equivalent to one disintegration per second. Nuclear disintegrations produce spontaneous emissions of alpha or beta particles, gamma radiation, or combinations of these. Table A.4 includes selected conversions from curies to becquerels.

### Radiological Dose Units

The amount of ionizing radiation energy absorbed by a living organism is expressed in terms of radiological dose. Radiological dose in this report is usually written in terms of effective dose equivalent and reported numerically in units of millirems (mrem), with the metric units millisieverts (mSv) following in parenthesis or footnoted.

Millirem (millisievert) is a term that relates radiological dose and biological effect or risk (to humans). For perspective, a dose of 0.01 millirem (1 millisievert) would have a biological effect roughly the same as received from 1 day’s exposure to natural background radiation. An acute (short-term) dose to the whole body of 100 rem (1 sievert) would likely cause temporary radiation sickness in some exposed individuals. An acute dose of over 500 rem (5 sieverts) would soon result in death in approximately 50% of those exposed. Exposure to lower amounts of radiation (10 mrem [100  $\mu$ Sv] or less) produces no immediate observable effects, but long-term (delayed) effects are possible. The average person in the

**Table A.1. Names and Symbols for Units of Measure**

<u>Symbol</u>	<u>Name</u>	<u>Symbol</u>	<u>Name</u>
<b>Temperature</b>		<b>Concentration</b>	
°C	degree Celsius	ppb	parts per billion
°F	degree Fahrenheit	ppm	parts per million
<b>Time</b>		ppmv	parts per million by volume
d	day	<b>Length</b>	
h	hour	cm	centimeter (1 x 10 <sup>-2</sup> m)
min	minute	ft	foot
s	second	in.	inch
yr	year	km	kilometer (1 x 10 <sup>3</sup> m)
<b>Rate</b>		m	meter
cfs (or ft <sup>3</sup> /s)	cubic foot per second	mi	mile
cpm	counts per minute	mm	millimeter (1 x 10 <sup>-3</sup> m)
gpm	gallon per minute	µm	micrometer (1 x 10 <sup>-6</sup> m)
mph	mile per hour	<b>Area</b>	
mR/hr	milliroentgen per hour	ha	hectare (1 x 10 <sup>4</sup> m <sup>2</sup> )
mrem/yr	millirem per year	km <sup>2</sup>	square kilometer
<b>Volume</b>		mi <sup>2</sup>	square mile
cm <sup>3</sup>	cubic centimeter	ft <sup>2</sup>	square foot
ft <sup>3</sup>	cubic foot	<b>Mass</b>	
gal	gallon	g	gram
L	liter	kg	kilogram (1 x 10 <sup>3</sup> g)
m <sup>3</sup>	cubic meter	mg	milligram (1 x 10 <sup>-3</sup> g)
mL	milliliter (1 x 10 <sup>-3</sup> L)	µg	microgram (1 x 10 <sup>-6</sup> g)
yd <sup>3</sup>	cubic yard	lb	pound

**Table A.2. Conversion Table**

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>	<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cm	0.394	in.	in.	2.54	cm
m	3.28	ft	ft	0.305	m
km	0.621	mi	mi	1.61	km
kg	2.205	lb	lb	0.454	kg
L	0.2642	gal	gal	3.785	L
m <sup>2</sup>	10.76	ft <sup>2</sup>	ft <sup>2</sup>	0.093	m <sup>2</sup>
ha	2.47	acres	acre	0.405	ha
km <sup>2</sup>	0.386	mi <sup>2</sup>	mi <sup>2</sup>	2.59	km <sup>2</sup>
m <sup>3</sup>	35.31	ft <sup>3</sup>	ft <sup>3</sup>	0.0283	m <sup>3</sup>
m <sup>3</sup>	1.308	yd <sup>3</sup>	yd <sup>3</sup>	0.7646	m <sup>3</sup>
pCi	1,000	nCi	nCi	0.001	pCi
µCi/mL	10 <sup>9</sup>	pCi/L	pCi/L	10 <sup>-9</sup>	µCi/mL
Ci/m <sup>3</sup>	10 <sup>12</sup>	pCi/m <sup>3</sup>	pCi/m <sup>3</sup>	10 <sup>-12</sup>	Ci/m <sup>3</sup>
mCi/cm <sup>3</sup>	10 <sup>15</sup>	pCi/m <sup>3</sup>	pCi/m <sup>3</sup>	10 <sup>-15</sup>	mCi/cm <sup>3</sup>
nCi/m <sup>2</sup>	1.0	mCi/km <sup>2</sup>	mCi/km <sup>2</sup>	1.0	nCi/m <sup>2</sup>
Ci	3.7 x 10 <sup>10</sup>	Bq	Bq	2.7 x 10 <sup>-11</sup>	Ci
pCi	0.037	Bq	Bq	27	pCi
rad	0.01	Gy	Gy	100	rad
rem	0.01	Sv	Sv	100	rem
ppm	1,000	ppb	ppb	0.001	ppm
°C	(°C x 9/5) + 32	°F	°F	(°F -32) ÷ 9/5	°C
oz	28.349	g	g	0.035	oz
ton	0.9078	tonne	tonne	1.1	ton

**Table A.3. Names and Symbols for Units of Radioactivity**

<u>Symbol</u>	<u>Name</u>	<u>Symbol</u>	<u>Name</u>
Ci	curie	Bq	becquerel ( $2.7 \times 10^{-11}$ Ci)
mCi	millicurie ( $1 \times 10^{-3}$ Ci)	kBq	kilobecquerel ( $1 \times 10^3$ Bq)
$\mu$ Ci	microcurie ( $1 \times 10^{-6}$ Ci)	MBq	megabecquerel ( $1 \times 10^6$ Bq)
nCi	nanocurie ( $1 \times 10^{-9}$ Ci)	mBq	millibecquerel ( $1 \times 10^3$ Bq)
pCi	picocurie ( $1 \times 10^{-12}$ Ci)	GBq	gigabecquerel ( $1 \times 10^9$ Bq)
fCi	femtocurie ( $1 \times 10^{-15}$ Ci)	TBq	terabecquerel ( $1 \times 10^{12}$ Bq)
aCi	attocurie ( $1 \times 10^{-18}$ Ci)		

**Table A.4. Conversions for Radioactivity Units**

aCi	fCi	fCi	pCi	pCi	nCi	nCi	$\mu$ Ci	$\mu$ Ci	mCi	mCi	Ci	Ci	kCi
27	1	27	1	27	1	27	1	27	1	27	1	27	1
1	37	1	37	1	37	1	37	1	37	1	37	1	37
$\mu$ Bq	$\mu$ Bq	mBq	mBq	Bq	Bq	kBq	kBq	MBq	MBq	GBq	GBq	TBq	TBq

New unit of quantity = Becquerel (Bq) (formerly curie [Ci]) ( $1 \text{ Ci} = 3.7 \times 10^{10}$  dps).  
 1 Becquerel = 1 disintegration/sec (dps).

United States receives an annual dose from exposure to naturally produced radiation of approximately 300 mrem (3 mSv). Medical and dental x-rays and air travel add to this total. Table A.5 includes selected conversions from rems to sieverts.

Also used in this report is the **rad**, with the corresponding unit **Gray (Gy)** in parenthesis or footnoted. The rad (Gray) is a measure of the energy absorbed by any material, whereas a rem relates to both the amount of radiation energy absorbed by humans and its consequence. The Gray can be converted to rad by multiplying by 100. The conversions in Table A.5 can also be used to convert Grays to rads.

A **roentgen (R)** is a measure of radiation exposure with no SI equivalent. One roentgen is equivalent to a charge release of 258 microcoulombs per kilogram of air.

The names and symbols for units of radiation dose used in this report are listed in Table A.6

Additional information on radiation and dose terminology can be found in Appendix B. A list of the radionuclides

**Table A.5. Conversions for Radiological Dose Units**

$\mu$ Sv	$\mu$ Sv	$\mu$ Sv	$\mu$ Sv	$\mu$ Sv	mSv	mSv	mSv	Sv
0.01	0.1	1	10	100	1	10	100	1
1	10	100	1	10	100	1	10	100
$\mu$ rem	$\mu$ rem	$\mu$ rem	mrem	mrem	mrem	rem	rem	rem

Unit of absorbed dose – Gray (Gy) (formerly rad).

Unit of dose equivalent – Sievert (Sv) (formerly rem).

Table also converts Gy to rad.

**Table A.6. Names and Symbols for Units of Radiation Dose or Exposure**

<u>Symbol</u>	<u>Name</u>
mrad	millirad ( $1 \times 10^{-3}$ rad)
mrrem	millirem ( $1 \times 10^{-3}$ rem)
$\mu$ rem	microrem ( $1 \times 10^{-6}$ rem)
Sv	sievert (100 rem)
mSv	millisievert ( $1 \times 10^{-3}$ Sv)
$\mu$ Sv	microsievert ( $1 \times 10^{-6}$ Sv)
R	roentgen
mR	milliroentgen ( $1 \times 10^{-3}$ R)
$\mu$ R	microroentgen ( $1 \times 10^{-6}$ R)
Gy	gray (100 rad)
mGy	milligray ( $1 \times 10^{-3}$ rad)

discussed in this report, their symbols, and their half-lives are included in Table A.7.

## Chemical and Elemental Nomenclature

Many of the chemical contaminants discussed in this report are listed in Table A.8 along with their chemical (or elemental) names and their corresponding symbols.

## Understanding the Data Tables

Some degree of variability, or uncertainty, is associated with all analytical measurements. This uncertainty is the consequence of random or systematic inaccuracies related to collecting, preparing, and analyzing the samples. These inaccuracies could include errors associated with reading

or recording the result, handling or processing the sample, calibrating the counting instrument, and numerical rounding. With radionuclides, inaccuracies can also result from the randomness of radioactive decay. In this report, the uncertainties used include standard deviation, total propagated analytical uncertainty, and standard error of the mean.

## Standard Deviation

The standard deviation (SD) of sample data relates to the variation around the mean of a set of individual sample results. If differences in analytical results occur among samples, then two times the standard deviation (or  $\pm 2$  SD) implies that 95% of the time, a re-count or re-analysis of the same sample would give a value somewhere between the mean result minus two times the standard deviation and the mean result plus two times the standard deviation.

**Table A.7. Radionuclides and Their Half-Lives<sup>(a)</sup>**

<b>Symbol</b>	<b>Radionuclide</b>	<b>Half-Life</b>	<b>Symbol</b>	<b>Radionuclide</b>	<b>Half-Life</b>
<sup>3</sup> H	tritium	12.35 yr	<sup>137m</sup> Ba	barium-137m	2.552 min
<sup>7</sup> Be	beryllium-7	53.44 d	<sup>152</sup> Eu	europium-152	13.3 yr
<sup>14</sup> C	carbon-14	5,730 yr	<sup>154</sup> Eu	europium-154	8.8 yr
<sup>40</sup> K	potassium-40	1.3 x 10 <sup>8</sup> yr	<sup>155</sup> Eu	europium-155	5 yr
<sup>51</sup> Cr	chromium-51	27.7 d	<sup>212</sup> Pb	lead-212	10.6 h
<sup>54</sup> Mn	manganese-54	312.7 d	<sup>220</sup> Rn	radon-220	56 s
<sup>55</sup> Fe	iron-55	2.7 yr	<sup>222</sup> Rn	radon-222	3.8 d
<sup>59</sup> Fe	iron-59	44.63 d	<sup>232</sup> Th	thorium-232	1.4 x 10 <sup>10</sup> yr
<sup>59</sup> Ni	nickel-59	75,000 yr	U or uranium	natural uranium	~(b)
<sup>60</sup> Co	cobalt-60	5.3 yr	<sup>233</sup> U	uranium-233	1.59 x 10 <sup>5</sup> yr
<sup>63</sup> Ni	nickel-63	100.1 yr	<sup>234</sup> U	uranium-234	2.4 x 10 <sup>5</sup> yr
<sup>65</sup> Zn	zinc-65	243.9 d	<sup>235</sup> U	uranium-235	7 x 10 <sup>8</sup> yr
<sup>85</sup> Kr	krypton-85	10.7 yr	<sup>237</sup> Np	neptunium-237	2.14 x 10 <sup>6</sup> yr
<sup>90</sup> Sr	strontium-90	29.1 yr	<sup>238</sup> U	uranium-238	4.5 x 10 <sup>9</sup> yr
<sup>90</sup> Y	yttrium-90	64.1 h	<sup>238</sup> Pu	plutonium-238	87.7 yr
<sup>95</sup> Zr	zirconium-95	63.98 d	<sup>239</sup> Pu	plutonium-239	2.4 x 10 <sup>4</sup> yr
<sup>99</sup> Tc	technetium-99	2.1 x 10 <sup>5</sup> yr	<sup>240</sup> Pu	plutonium-240	6.5 x 10 <sup>3</sup> yr
<sup>103</sup> Ru	ruthenium-103	39.3 d	<sup>241</sup> Pu	plutonium-241	14.4 yr
<sup>106</sup> Ru	ruthenium-106	368.2 d	<sup>242</sup> Pu	plutonium-242	3.76 x 10 <sup>5</sup> yr
<sup>113</sup> Sn	tin-113	115 d	<sup>241</sup> Am	americium-241	432.2 yr
<sup>125</sup> Sb	antimony-125	2.8 yr	<sup>243</sup> Am	americium-243	7,380 yr
<sup>129</sup> I	iodine-129	1.6 x 10 <sup>7</sup> yr	<sup>243</sup> Cm	curium-243	28.5 yr
<sup>131</sup> I	iodine-131	8 d	<sup>244</sup> Cm	curium-244	18.11 yr
<sup>134</sup> Cs	cesium-134	2.1 yr	<sup>245</sup> Cm	curium-245	8,500 yr
<sup>137</sup> Cs	cesium-137	30 yr			

(a) From Shleien (1992).

(b) Natural uranium is a mixture dominated by <sup>238</sup>U, thus the half-life is approximately 4.5 x 10<sup>9</sup> years.

Table A.8. Elemental and Chemical Constituent Nomenclature

<u>Symbol</u>	<u>Constituent</u>	<u>Symbol</u>	<u>Constituent</u>
Ag	silver	K	potassium
Al	aluminum	LiF	lithium fluoride
As	arsenic	Mg	magnesium
B	boron	Mn	manganese
Ba	barium	Mo	molybdenum
Be	beryllium	NH <sub>3</sub>	ammonia
Br	bromine	NH <sub>4</sub> <sup>+</sup>	ammonium
C	carbon	N	nitrogen
Ca	calcium	Na	sodium
CaF <sub>2</sub>	calcium fluoride	Ni	nickel
CCl <sub>4</sub>	carbon tetrachloride	NO <sub>2</sub> <sup>-</sup>	nitrite
Cd	cadmium	NO <sub>3</sub> <sup>-</sup>	nitrate
CHCl <sub>3</sub>	trichloromethane	Pb	lead
Cl <sup>-</sup>	chloride	PO <sub>4</sub> <sup>3-</sup>	phosphate
CN <sup>-</sup>	cyanide	P	phosphorus
Cr <sup>+6</sup>	chromium (hexavalent)	Sb	antimony
Cr	chromium (total)	Se	selenium
CO <sub>3</sub> <sup>2-</sup>	carbonate	Si	silicon
Co	cobalt	Sr	strontium
Cu	copper	SO <sub>4</sub> <sup>2-</sup>	sulfate
F <sup>-</sup>	fluoride	Ti	titanium
Fe	iron	Tl	thallium
HCO <sub>3</sub> <sup>-</sup>	bicarbonate	V	vanadium
Hg	mercury		

## Total Propagated Analytical Uncertainty

For samples that are prepared or manipulated in the laboratory prior to counting (counting the rate of radioactive emissions from a sample), the total propagated analytical uncertainty includes both the counting uncertainty and the uncertainty associated with sample preparation and chemical separations. For samples that are not manipulated (e.g., ashed, dried, chemically treated) in the laboratory before counting, the total propagated analytical uncertainty only accounts for the uncertainty associated with counting the sample. The uncertainty associated with samples that are analyzed but not counted includes only the analytical process uncertainty. In this situation, the total propagated analytical uncertainty is assumed to be the nominal detection limit.

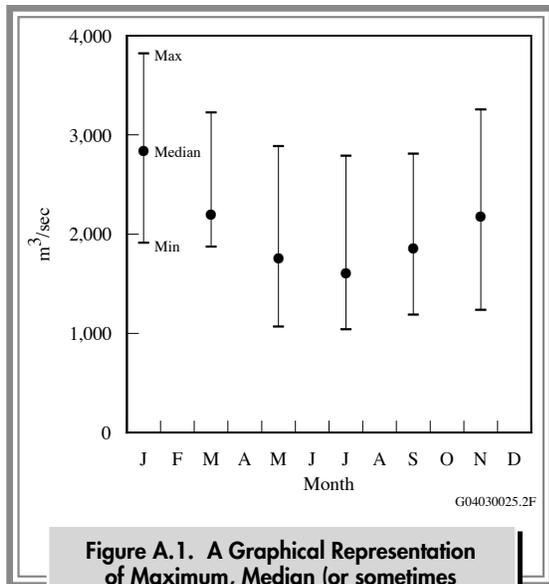
## Standard Error of the Mean

Just as individual values are accompanied by counting uncertainties, the mean of mean values (averages) is

accompanied by  $\pm 2$  times the standard error of the calculated mean (or  $\pm 2$  SEM). Two times the standard error of the mean implies that approximately 95% of the time the next calculated mean will fall somewhere between the reported value minus two times the standard error and the reported value plus two times the standard error.

## Median, Maximum, and Minimum Values

Median, maximum, and minimum values are reported in some sections of this report. A median value is the middle value of an odd numbered set and the average of the two central values in an even numbered set. For example, the median value in the odd numbered series of numbers — 1, 2, 3, 3, 4, 5, 5, 5, 6 is 4. The maximum value would be 6 and the minimum value would be 1. Median, maximum, and minimum values are reported when there are too few analytical results to accurately determine the average with a  $\pm$  statistical uncertainty or when the data do not follow a bell-shape (i.e., normal) distribution. Figure A.1 provides a graphical representation of median, maximum,



**Figure A.1. A Graphical Representation of Maximum, Median (or sometimes average), and Minimum Values**

and minimum values. The upper line is the maximum value, the center dot is the median value, and the lower line is the minimum value.

## Negative Concentrations

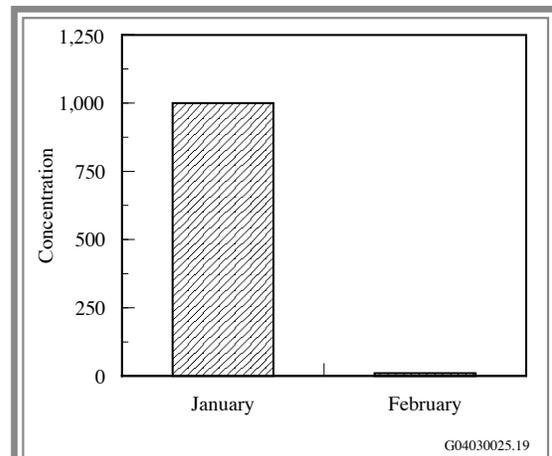
Instruments used in the laboratory to measure radioactivity in Hanford Site environmental samples are sensitive enough to measure natural, or background, radiation along with any contaminant radiation in a sample. To obtain a true measure of the contaminant level in a sample, the background radiation level must be subtracted from the total amount of radioactivity measured by an instrument. Because of the randomness of radioactive emissions, the very low activities of some contaminants, or the presence of undesirable materials, it is possible to obtain a background measurement that is larger than the actual contaminant measurement. When the larger background measurement is subtracted from the smaller contaminant measurement, a negative result is generated. The negative results are reported because they are essential when conducting statistical evaluations of the data.

## Understanding Graphs

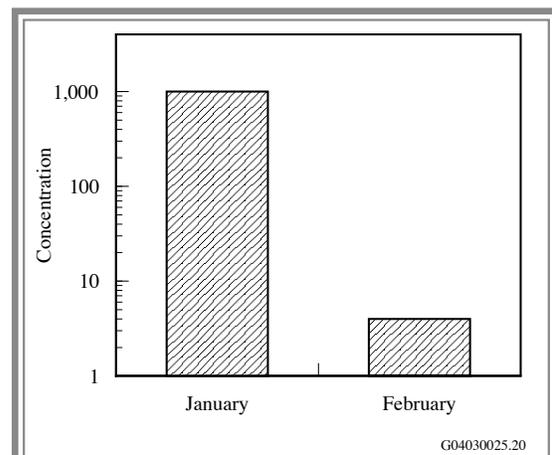
Graphs are useful when comparing numbers collected at several locations or at one location over time. Graphs

often make it easy to visualize differences in data where they exist. However, careful consideration should be given to the scale (linear or logarithmic) and concentration units.

Some of the data graphed in this report are plotted using logarithmic, or compressed, scales. Logarithmic scales are useful when plotting two or more numbers that differ greatly in size or are very close together. For example, a sample with a concentration of 5 grams per liter would get lost at the bottom of the graph if plotted on a linear scale with a sample having a concentration of 1,000 grams per liter (Figure A.2). A logarithmic plot of these same two numbers allows the reader to see both data points clearly (Figure A.3).

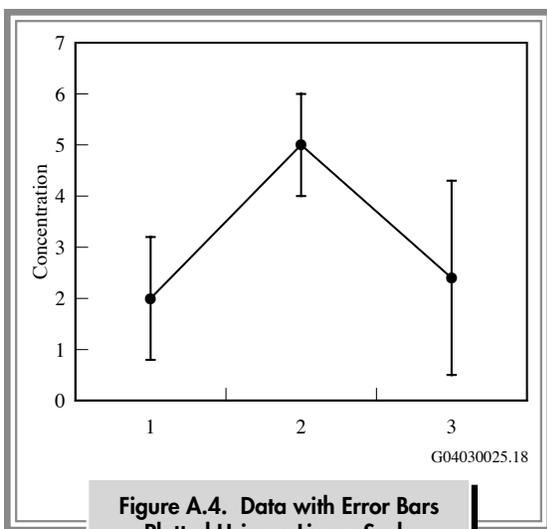


**Figure A.2. Data Plotted Using a Linear Scale**



**Figure A.3. Data Plotted Using a Logarithmic Scale**

The mean (average) and median (defined earlier) values graphed in this report have vertical lines extending above and below the data point. When used with a value, these lines (called error bars) indicate the amount of uncertainty (standard deviation, total propagated analytical uncertainty, or two standard error of the mean) in the reported value. The error bars in this report represent a 95% chance that the value is between the upper and lower ends of the error bar and a 5% chance that the true value is either lower or higher than the error bar.<sup>(a)</sup> For example, in Figure A.4, the first plotted value is  $2.0 \pm 1.1$ , so there is a 95% chance that the true value is between 0.9 and 3.1, a 2.5% chance that it is less than 0.9, and a 2.5% chance that it is greater than 3.1. Error bars are computed statistically, employing all of the information used to generate the value. These bars provide a quick, visual indication that one value may be statistically similar to or different from another value. If the error bars of two or more



**Figure A.4. Data with Error Bars Plotted Using a Linear Scale**

values overlap, as is the case with values 1 and 3 and values 2 and 3, the values may be statistically similar. If the error bars do not overlap (values 1 and 2), the values may be statistically different. Values that appear to be very different visually (values 2 and 3) may actually be quite similar when compared statistically.

When vertical lines are used with median values, the lower end of each bar represents the minimum concentration measured; the upper end of each bar represents the maximum concentration measured (Figure A.1).

## Greater Than (>) or Less Than (<) Symbols

Greater than (>) or less than (<) symbols are used to indicate that the actual value may either be larger than the number given or smaller than the number given. For example,  $>0.09$  would indicate that the actual value is greater than 0.09. A symbol pointed in the opposite direction ( $<0.09$ ) would indicate that the number is less than the value presented. A symbol used with an underscore ( $\leq$  or  $\geq$ ) indicates that the actual value is less than or equal to or greater than or equal to the number given, respectively.

## Reference

Shleien, B. 1992. *The Health Physics and Radiological Health Handbook, Revised Edition*. Scinta, Inc., Silver Spring, Maryland.

(a) Assuming the data are normally distributed.